

DEPARTMENT OF THE INTERIOR

CANADA

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Dominion Observatory

OTTAWA

Volume II

OTTAWA

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CANADA

HON. W. J. ROCHE, *Minister.*

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PUBLICATIONS

OF THE

Dominion Observatory

OTTAWA

W. F. KING, C.M.G., LL.D., *Director.*

Vol. II, No. 1

Precise Levelling

BY

F. B. REID, D.L.S.

OTTAWA
GOVERNMENT PRINTING BUREAU
1915

PRECISE LEVELLING.

BY F. B. REID, D.L.S.

Supervisor of Levelling.

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PRECISE LEVELLING.

This publication is the fifth one on the subject of precise levelling by the Geodetic Survey of Canada, the ones previously issued being Appendix No. 5 to the Chief Astronomer's report for 1910 and three "Publications of the Dominion Observatory", Vol. I, Nos. 2, 3 and 8. These are all by the writer with the exception of Vol. I, No. 2, which is by D. H. Nelles, D.L.S.; the levelling shown in it is in the Yukon territory—from White Pass to Dawson, etc. The present publication is arranged in the same general form as last year's, with the results of the levelling set forth in three tables. The index and map included herein are complete for all the work previously published, as well as that in the present publication; the index indicates in which publication descriptions and elevations of bench-marks published before this may be found.

Table I indicates the routes followed between terminal points and gives complete descriptions of all bench-marks established along these routes.

Table II shows in the first two columns the numbers of the bench-marks; in the third and fourth columns the approximate distance (in miles) between bench-marks, and from the initial bench-mark of the line; the fifth and sixth columns (headed "Discrepancy") give the difference (in feet) between the forward levelling and the backward levelling for each section between bench-marks and the accumulated difference from the initial bench-mark. The seventh column gives the elevations of the bench-marks shown in the second column; for convenience, these bench-marks are repeated (in the eighth column) in order that the number of any bench-mark and its elevation may be in adjoining columns. In this table are shown also the elevations determined by the Geodetic Survey for certain bench-marks established by other surveys and connected with our levelling.

Table III shows the elevations at railway stations and at crossings of intersecting railways; also on the bridges over rivers and lakes and the more important streams. Rail elevations were in all cases taken on top of the rail, in front of the telegraph office at telegraph stations and opposite the shelter or platform at flag stations.

The results are given for the following lines:—

1. Halifax, N.S., to Yarmouth, N.S.
2. Depot Harbour, Ont., to Renfrew, Ont.
3. Winnipeg, Man., to Kenora, Ont.
4. Saskatoon, Sask., to Wainwright, Alta.
5. Maple Creek, Sask., to Coutts, Alta.
6. Lethbridge, Alta., to Calgary, Alta.

Line 1—run by J. E. Ratz, 1913, and G. F. Dalton, 1914—was started at a bench-mark (a chiselled groove marked with a broad arrow) on No. 3 storehouse in the Naval Yard, Halifax. The elevation of this has been fixed by the Tidal and Current Survey, Department of the Naval Service, as 12.59 feet above mean sea level at Halifax, determined from the hourly ordinates of the tide, day and night, during nine complete years. Our elevations along line 1 are based upon the above mentioned figures and the line is terminated at Yarmouth upon another bench-mark of the same department (a broad arrow cut in the north wall of the post office); the elevation of this has been fixed by the Tidal Survey as 49.74 feet above mean sea level at Yarmouth, determined from the hourly ordinates of the tide, day and night, during one complete year. Our elevation for the above bench-mark—by precise levelling from Halifax—is 49.636, a difference of only 0.10 ft. The elevations along this line published in Table II are instrumental ones—no adjustment has been made to compensate for the small closing error at Yarmouth.

The elevations along line 2 (G. F. Dalton, 1913, and A. J. Rainboth, 1914) are based upon bench-mark No. 418 on the line from Bala to Sudbury,

which was published in 1914. By referring to the map it will be seen that, with the exception of the gap between Ottawa and Renfrew, a circuit of levels has been completed through Depot Harbour, Toronto, Kempton and Ottawa; utilizing the levelling by the Public Works Department to close up the circuit, the error of closure is found to be 0.25 ft., the distance being about 680 miles. Line 3 (N. H. Smith, 1913) was started at bench-mark MCCCCXCVII of the Public Works Department at Winnipeg. Bench-mark MCCCCLXXXIV at Emerson had already been connected with our levels from Stephen, Minn., and the difference of elevation between these two bench-marks, as ascertained by the Public Works Department—namely 19.146 feet—was used to give us a datum for line 3 or, in other words, an elevation of 767.738 was assigned to bench-mark MCCCCXCVII. Line 4 (N. H. Smith, 1914) commences at bench-mark 28-D on the Regina-Prince Albert line. Line 5 (D. McMillan, 1914) is a continuation of the line from Moosejaw to Maple Creek, published in 1914. It is terminated at Coutts upon bench-mark H-12 of the United States Coast and Geodetic Survey, and exhibits a closing error of 0.26 ft., the two lines being referred to the same datum at Stephen, Minn. Line 6 (G. S. Raley, 1914) was started from bench-mark 196-C on the above mentioned line 5.

All elevations given are instrumental and have had no adjustments applied to them, consequently changes may be made in the future; it should be noted, however, that in all cases where circuits have been closed, the closing errors are quite small.

The standard bench-mark adopted consists of a copper bolt, three-quarters of an inch in diameter and four inches long, stamped on the end with the letters "G.S.C.,B.M." (Geodetic Survey of Canada, Bench-mark). The bolt is sunk horizontally in rock or masonry so that only the circular end is visible; the number of the bench-mark is stamped on this end as well as the letters mentioned above, and a horizontal chisel line is cut, upon which the elevation is taken. At certain points concrete bench-mark piers have been built; these project from six inches to one foot above the ground and extend below the frost line; the copper bolt upon which the elevation is taken is placed horizontally as in other cases, and is about nine inches below the top of the pier.

TABLE I.

BENCH-MARKS BETWEEN HALIFAX AND YARMOUTH, NOVA SCOTIA,
VIA HALIFAX AND SOUTHWESTERN RAILWAY.

Note.—These descriptions are written with the assumption that the railway runs in a southwesterly direction from Halifax to Shag Harbour, thence northerly to Belleville and thence westerly to Yarmouth.

- 386-B In east face of stone footing of pilaster at southeast corner of Intercolonial station-house, corner of North and Lockman streets, Halifax.
- 387-B In fourth course of stonework below water-table course, in west end of north wall of clock tower of custom-house, Halifax.
- 388-B In north face of seat-stone of northerly girder—on east abutment—of subway by which main road from Halifax to Truro passes under Halifax and Southwestern railway at Fairview, 3 miles from Halifax.
- 389-B In northwest side of small rock cut on Halifax and Southwestern railway, 450 feet northeast of mile post 6 from Halifax.
- 390-B In exposed rock surface, 8 feet northwest of Halifax and Southwestern railway track and at seventh telegraph pole southwest of mile post 9 from Halifax.
- 391-B In southeast side of small rock cut on Halifax and Southwestern railway, at seventh telegraph pole northeast of mile post 13 from Halifax.
- 392-B In second course of stonework below bridge-seat, in south face of east retaining wall of Halifax and Southwestern railway bridge over East river, $1\frac{1}{2}$ miles northeast of French Village.
- 393-B In first course of stonework above bridge-seat, in northwest end of northeast face of retaining wall behind southwest abutment of plate-girder bridge on Halifax and Southwestern railway, $\frac{1}{2}$ mile southwest of French Village.
- 394-B In concrete bench-mark pier, 25 feet southeast of northwest line of Halifax and Southwestern railway right-of-way, 130 feet northeast of a private crossing and 0.3 mile northeast of St. Margaret station.
- 395-B In first course of stonework above bridge-seat, in northwest end of northeast face of retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Ingram river, 1 mile northeast of Ingraimport.
- 396-B In exposed rock surface in northwest side of shallow cut on Halifax and Southwestern railway, 160 feet southwest of mile post 32 from Halifax.
- 397-B In first course of stonework above bridge-seat, in northwest end of northeast face of retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Hubbards river, $\frac{1}{2}$ mile northeast of Hubbards.
- 398-B In exposed rock surface, 30 feet northwest of Halifax and Southwestern railway track, 60 feet southwest of a trestle bridge and 400 feet northeast of mile post 3 from Halifax.

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- 399-B In top course of stonework, in northwest end of northeast foundation wall of Halifax and Southwestern station-house at East River.
- 400-B In fourth course of stonework below bridge-seat, in northwest end of southwest abutment of plate-girder bridge on Halifax and Southwestern railway, 0.6 mile southwest of East River station.
- 401-B In first course of stonework above bridge-seat, in southeast end of southwest face of retaining wall behind northeast abutment of subway under Halifax and Southwestern railway, 350 feet southwest of Chester station.
- 402-B In first course of stonework above bridge-seat, in southeast end of northeast face of retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Middle river, 2 miles northeast of Chester Basin.
- 403-B In fourth course of stonework below bridge-seat, in southeast end of southwest abutment of bridge on Halifax and Southwestern railway, $\frac{1}{2}$ mile southwest of Western Shore station and at mile post 61 from Halifax.
- 404-B In first course of stonework above bridge-seat, in northwest end of northeast face of retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Martin river, 0.6 mile northeast of Martin River station.
- 405-B In southeast face of southwest abutment of stone and timber culvert under Halifax and Southwestern railway, $2\frac{1}{2}$ miles northeast of Mahone Junction and at fourth telegraph pole southwest of mile post 67 from Halifax.
- 406-B In concrete bench-mark pier, 3 feet northwest of southeast line of Halifax and Southwestern railway right-of-way and 340 feet northeast of mile post 71 from Halifax—immediately northeast of Blockhouse station.
- 407-B In southeast end of southwest stone abutment of open culvert under Halifax and Southwestern railway, 1 mile southwest of Maitland and at mileage 75.5 from Halifax.
- 408-B In north face of boulder in centre of shallow cut on Halifax and Southwestern railway—10 feet southeast of track—150 feet southwest of a small stone culvert and 1.2 miles northeast of Bridgewater station.
- 409-B In second course of stonework above bridge-seat, in south end of east face of west abutment of highway bridge over Lahave river at Bridgewater.
- 410-B In second course of stonework below brickwork, in north end of front (or east) wall of Bridgewater post office.
- 411-B In fourth course of stonework below bridge-seat, in northwest end of northeast face of southwest abutment of Halifax and Southwestern railway bridge over Lahave river, $1\frac{1}{4}$ miles from Bridgewater station—in the direction of Yarmouth.
- 412-B In first course of stonework above bridge-seat, in northwest end of southwest face of retaining wall behind northeast abutment of bridge on Halifax and Southwestern railway, $4\frac{1}{4}$ miles southwest of Bridgewater and at mileage 85.6 from Halifax.
- 413-B In northwest end of northeast stone abutment of open culvert under Halifax and Southwestern railway at mileage 90.6 from Halifax—midway between Conquerall and Italy Cross.
- 414-B In southeast face of large outcrop of rock—35 feet from southwest end of outcrop—12 feet northwest of northwest line of Halifax and Southwestern railway right-of-way, at sixteenth telegraph pole northeast of mile post 97 from Halifax and $2\frac{1}{4}$ miles northeast of County Line station.
- 415-B In fifth course of stonework below bridge-seat, in west face of north wing-wall of Halifax and Southwestern railway bridge over Port Medway river, 1,000 feet northeast of Medway.

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- 416-B In concrete bench-mark pier, 5 feet southeast of northwest line of Halifax and Southwestern railway right-of-way, 135 feet southwest of crossing of Liverpool-Bridgewater highway and 1 mile northeast of Brooklyn.
- 417-B In second course of stonework below bridge-seat, in west face of north wing-wall of bridge on Halifax and Southwestern railway, $\frac{1}{2}$ mile northeast of Brooklyn.
- 418-B In northwest end of southwest face—4 feet 6 inches below bridge-seat—of northeast concrete abutment of Halifax and Southwestern railway bridge over Liverpool river, $\frac{3}{4}$ mile southwest of Liverpool station.
- 419-B In second course of stonework below water-table course, in north end of west wall of Liverpool post office.
- 420-B In north end of west concrete foundation wall—18 inches below woodwork— of Liverpool town hall.
- 421-B In west face of large flat boulder, 6 feet southeast of northwest line of Halifax and Southwestern railway right-of-way, between fourth and fifth telegraph poles southwest of mile post 119 from Halifax and at northeast end of tangent at Hunt Point station.
- 422-B In northwest end of southwest face of northeast stone abutment of open culvert under Halifax and Southwestern railway, 1 mile southwest of Hunt Point station.
- 423-B In east face of large mass of rock, 22 feet northwest of northwest line of Halifax and Southwestern railway right-of-way, at thirteenth telegraph pole northeast of mile post 126 from Halifax and $1\frac{1}{2}$ miles southwest of Port Mouton.
- 424-B In southeast end of southwest face of northeast stone abutment of open culvert under Halifax and Southwestern railway, $\frac{1}{2}$ mile southwest of Wilkins.
- 425-B In south face of large mass of rock lying along southeast line of Halifax and Southwestern railway right-of-way, $1\frac{1}{2}$ miles southwest of Wilkins and between eighth and ninth telegraph poles northeast of mile post 135 from Halifax.
- 426-B In southeast end of southwest face of concrete retaining wall behind northeast abutment of Halifax and Southwestern railway bridge over Tom Tigney river, $1\frac{1}{4}$ miles northeast of Sable River station.
- 427-B In east face of south concrete wing-wall—1 foot below bridge-seat—of Halifax and Southwestern railway bridge over Sable river, $\frac{1}{4}$ mile northeast of Sable River station.
- 428-B In northwest end of southwest face of northeast stone abutment of open culvert under Halifax and Southwestern railway, $2\frac{3}{4}$ miles northeast of Lockeport and at mileage 144.4 from Halifax.
- 429-B In southeast face of north concrete wing-wall—2 feet above bridge-seat—of Halifax and Southwestern railway bridge over East river, $2\frac{1}{2}$ miles southwest of Lockeport.
- 430-B In northwest end of northeast face of concrete retaining wall behind southwest abutment of bridge on Halifax and Southwestern railway, 300 feet northeast of East Jordan.
- 431-B In second course of stone work above bridge-seat, in southeast end of northeast face of retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Jordan river, $\frac{1}{4}$ mile northeast of Jordan Falls station.
- 432-B In southeast end of northeast face—20 inches below bridge-seat—of southwest concrete abutment of bridge on Halifax and Southwestern railway, $1\frac{1}{2}$ miles southwest of Jordan Falls station.
- 433-B In second course of stonework below woodwork, in front (or west) wall of Shelburne academy, 18 feet from southwest corner.

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- 434-B In top course of stonework, in west end of south foundation wall of Shelburne court house.
- 435-B In third course of stonework below water-table course, in south wall of Shelburne post office, 5 feet 4 inches from wall of clock tower.
- 436-B In east face of south concrete wing-wall—at level of bridge-seat—of bridge on Halifax and Southwestern railway, $\frac{3}{4}$ mile southwest of Shelburne.
- 437-B In northwest end of northeast face—4 feet below bridge-seat—of southwest concrete abutment of Halifax and Southwestern railway bridge over Shelburne river, $1\frac{1}{2}$ miles southwest of Shelburne.
- 438-B In northwest end of northeast face—4 feet below bridge-seat—of southwest concrete abutment of Halifax and Southwestern railway bridge over Roseway river, 0.4 mile northeast of Birchtown.
- 439-B In concrete bench-mark pier, 3 feet southeast of northwest line of Halifax and Southwestern railway right-of-way, on top of small knoll 1,600 feet southwest of mile post 175 from Halifax and $1\frac{1}{4}$ miles southwest of Gunning Cove.
- 440-B In west face of north concrete wing-wall—8 inches below bridge-seat—of Halifax and Southwestern railway bridge over Round Bay brook, 2 miles southwest of Roseway.
- 441-B In second course of stonework below timber-seat, in southeast end of southwest face of northeast abutment of open culvert under Halifax and Southwestern railway, 800 feet northeast of Port Saxon.
- 442-B In north face of west concrete wing-wall—6 feet below bridge-seat—of Halifax and Southwestern railway bridge over Clyde river, 1,000 feet northeast of Port Clyde.
- 443-B In west face of granite boulder—about 20 feet square—on north side of Halifax and Southwestern railway, 700 feet northeast of a highway crossing, $2\frac{1}{2}$ miles southwest of Port Clyde and at eighth telegraph pole southwest of mile post 190 from Halifax.
- 444-B In northwest end of northeast face of concrete retaining wall behind southwest abutment of Halifax and Southwestern railway bridge over Barrington river, 1,200 feet northeast of Barrington.
- 445-B In north face of boulder, 35 feet southeast of southeast line of Halifax and Southwestern railway right-of-way, 2 miles southwest of Barrington and at mileage 196.8 from Halifax.
- 446-B In first course of stonework below water-table course, in west wall of Royal Bank at Barrington Passage, 26 feet from southwest corner of building.
- 447-B In second course of stonework below bridge-seat, in north face of west wing-wall of bridge on Halifax and Southwestern railway, 1 mile southwest of Barrington Passage.
- 448-B In southeast end of northeast face of southwest stone abutment of open culvert under Halifax and Southwestern railway, 1 mile southwest of Atwoods Brook station and at mileage 201.75 from Halifax.
- 449-B In third course of stonework below bridge-seat, in north face of west wing-wall of bridge on Halifax and Southwestern railway, $\frac{3}{4}$ mile northeast of Shag Harbour.
- 450-B In east end of north face of south stone abutment of open culvert under Halifax and Southwestern railway, $1\frac{1}{4}$ miles north of Woods Harbour.
- 451-B In west end of south face of north stone abutment of open culvert under Halifax and Southwestern railway, $\frac{3}{4}$ mile south of Upper Woods Harbour.
- 452-B In east face of small square stone culvert under Halifax and Southwestern railway, $\frac{3}{4}$ mile north of Lower East Pubnico.

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- 453-B In west face of concrete retaining wall behind south abutment of bridge on Halifax and Southwestern railway, $\frac{1}{2}$ mile north of East Pubnico.
- 454-B In first course of stonework below bridge-seat, in southwest face of southwest retaining wall of Halifax and Southwestern railway bridge over Pubnico river, 1,000 feet south of Pubnico.
- 455-B In south end of west face of small square stone culvert under Halifax and Southwestern railway, 1,500 feet north of Lower Argyle.
- 456-B In east end of north face of south concrete abutment of open culvert under Halifax and Southwestern railway, 1 mile north of Central Argyle and 800 feet north of mile post 227 from Halifax.
- 457-B In first course of stonework below bridge-seat, in southeast face of southeast wing-wall of Halifax and Southwestern railway bridge over Argyle river, $\frac{1}{2}$ mile north of Argyle.
- 458-B In east face of north concrete abutment of open culvert under Halifax and Southwestern railway, 2 miles south of Belleville.
- 459-B In northwest face of northeast wing-wall of open culvert under Halifax and Southwestern railway, $\frac{1}{2}$ mile west of Belleville.
- 460-B In second course of stonework above bridge-seat, in northeast face of northeast retaining wall of Halifax and Southwestern railway bridge over Tusket river, $\frac{1}{2}$ mile west of Tusket.
- 461-B In concrete bench-mark pier, 3 feet north of south line of Halifax and Southwestern railway right-of-way, 520 feet east of west fence line of Yarmouth-Barrington highway crossing, and $1\frac{1}{2}$ miles west of Tusket.
- 462-B In second altar-step below top, in northeast face of northeast concrete wing-wall of large open culvert under Halifax and Southwestern railway, 0.4 mile east of Arcadia.
- 463-B In second course of stonework below water-table course, in south end of west wall of Yarmouth post office.
- 464-B In eleventh course of stonework below woodwork, in south end of west wall of Yarmouth court house.
- 465-B In first course of stonework below water-table course, in south wall—9 feet from southeast corner—of Congregational church, Collins street, Yarmouth.

BENCH-MARKS BETWEEN DEPOT HARBOUR AND RENFREW, ONTARIO,
VIA GRAND TRUNK RAILWAY.

- 567 In rear (or westerly) concrete wall of Grand Trunk roundhouse at Depot Harbour, 18 inches below water-table and at foot of pilaster between engine stalls 11 and 12.
- 566 In concrete bench-mark pier, 8 feet south of north line of Grand Trunk railway right-of-way, 12 feet west of a private crossing, $\frac{1}{2}$ mile east of Depot Harbour and at sixth telegraph pole east of mile post 396 from Alburgh Junction.
- 565 In south end of east face of stone and concrete retaining wall behind east abutment of Grand Trunk railway swing-bridge, 400 feet west of Rose Point station. The copper bolt is 4 feet 4 inches below top and 2 feet 10 inches north of south face of retaining wall.
- 564 In south face—6 feet from southwest corner—of most southerly concrete pier of bridge by which Canadian Pacific railway passes over Grand Trunk railway, $2\frac{1}{2}$ miles east of Rose Point.
Note.—Bench-mark No. 418, on the Bolton-Sudbury line of levels, is in the north abutment of this bridge.

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- 563 In north face of exposed rock surface, 10 feet south of Grand Trunk railway track, 20 feet west of mile post 387 from Alburgh Junction, 1 mile east of Otter Lake station and at sixth telegraph pole east of point where Grand Trunk railway and Canadian Northern railway diverge from one another.
- 562 In south side of small rock cut on Grand Trunk railway, at fourth telegraph pole west of mile post 382 from Alburgh Junction.
- 561 In west end of south face—3 feet below top—of southwest concrete retaining wall of Grand Trunk railway bridge, $\frac{1}{2}$ mile east of Maple Lake station.
- 560 In south face of exposed rock surface, 10 feet south of north line of Grand Trunk railway right-of-way, 1.4 miles east of Edgington and 340 feet west of mile post 374 from Alburgh Junction.
- 559 In north face—3 feet 6 inches below top—of northwest concrete retaining wall of Grand Trunk railway bridge over Seguin river, $\frac{1}{2}$ mile west of Seguin Falls station.
- 558 In south face of exposed rock surface, 8 feet south of north line of Grand Trunk railway right-of-way, 180 feet east of a whistle post and between fourth and fifth telegraph poles west of mile post 366 from Alburgh Junction.
- 557 In north side of small rock cut on Grand Trunk railway—70 feet from west end of cut—300 feet east of mile post 362 from Alburgh Junction and $1\frac{1}{2}$ miles east of Bear Lake station.
- 556 In west concrete foundation wall—28 inches from northwest corner—of Wm. Morrison's general store at Sprucedale; this is a concrete block building at southeast corner of main road and first cross road east of the station.
- 555 In north face of exposed rock surface, 37 feet south of Grand Trunk railway track, 880 feet west of a private crossing and between fifth and sixth telegraph poles east of mile post 354 from Alburgh Junction.
- 554 In north face of concrete bench-mark pier, 4 feet south of north line of Grand Trunk railway right-of-way— at a private crossing between second and third telegraph poles east of mile post 350 from Alburgh Junction—and $3\frac{1}{2}$ miles west of Scotia Junction.
- 553 In south side of rock cut on Grand Trunk railway, 690 feet east of east line of a highway crossing and $\frac{1}{2}$ mile east of Scotia Junction.
- 552 In south end of west concrete foundation wall—3 feet below woodwork—of H. Braithwaite's hardware store at Kearney, opposite the Kearney house.
- 551 In north side of small rock cut on Grand Trunk railway at mile post 336 from Alburgh Junction.
- 550 In north side of rock cut on Grand Trunk railway, 1,500 feet east of section-house at east end of passing-track at Ravensworth and 160 feet east of mile post 333 from Alburgh Junction.
- 549 In south face of exposed rock surface, 25 feet north of Grand Trunk railway track, 280 feet east of a small timber culvert and at twentieth telegraph pole west of mile post 328 from Alburgh Junction.
- 548 In south face of exposed rock surface, 20 feet north of Grand Trunk railway track, 1 mile west of Rainy Lake station and 450 feet west of mile post 325 from Alburgh Junction.
- 547 In east end of north face—3 feet 3 inches below top—of northeast concrete retaining wall of Grand Trunk railway bridge, $3\frac{1}{2}$ miles west of Brulé Lake station.
- 546 In east face of exposed rock surface, 20 feet south of Grand Trunk railway track and 770 feet east of station-house at Brulé Lake.

- 545 In west face of exposed rock surface, 47 feet south and slightly below rail level of Grand Trunk railway track, 230 feet west of mile post 313 from Alburgh Junction—immediately east of a small lake.
- 544 In second course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge, 150 feet east of Canoe Lake station.
- 543 In third course of stonework below top, in south face of southwest retaining wall of Grand Trunk railway bridge over the narrows of Joe lake, 420 feet east of Joe Lake station.
- 542 In third course of stonework below top, in north face of northwest retaining wall of Grand Trunk railway bridge over Madawaska river, 2 miles west of Algonquin Park station.
- 541 In north face—3 feet 6 inches below top—of northeast concrete retaining wall of Grand Trunk railway bridge over Madawaska river, 1½ miles east of Algonquin Park station.
- 540 In third course of stonework below top, in south face of southeast retaining wall of Grand Trunk railway bridge over Madawaska river, 4½ miles east of Algonquin Park station.
- 539 In third course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge over Madawaska river, ½ mile west of Rock Lake station.
- 538 In south side of large rock cut on Grand Trunk railway—at rail level—300 feet west of “Men-Wah-Tay”, the summer residence of A. W. Fleck, 1½ miles east of Rock Lake station.
- 537 In south face—at rail level and near centre—of vertical rock surface about 500 feet long, situated 10 feet north of Grand Trunk railway track and 1,100 feet east of mile post 284 from Alburgh Junction, facing Long lake.
- 536 In fourth course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge over Madawaska river, 1½ miles east of Whitney.
- 535-A In concrete bench-mark pier, 36 feet north of Grand Trunk railway track, 350 feet east of mile post 276 from Alburgh Junction and 3 miles east of Whitney—on eastern slope of small depression in centre of a long clay cut.
- 535 In north face—at rail level and near centre—of vertical rock surface, 10 feet south of Grand Trunk railway track and 360 feet east of mile post 274 from Alburgh Junction.
- 534 In third course of stonework below top, in north face of northeast retaining wall of small plate-girder bridge on Grand Trunk railway, at mile post 271 from Alburgh Junction.
- 533 In northeast face of large boulder, 20 feet south of Grand Trunk railway track, 800 feet west of station-house at Egan Estate and between sixth and seventh telegraph poles east of mile post 267 from Alburgh Junction.
- 532 In concrete bench-mark pier, 8 feet south of north line of Grand Trunk railway right-of-way, 650 feet west of first rock cut west of Madawaska and 300 feet west of sign “Madawaska, 1 mile.”
- 531 In south concrete wall of Grand Trunk roundhouse at Madawaska, 2 feet above water-table and at foot of first plaster from southeast corner of engine stall number 1.
- 530 In second course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge over Madawaska river, 1,200 feet east of Madawaska station.
- 529 In northeast face of large flat boulder, 30 feet south of Grand Trunk railway track, 3 miles east of Madawaska and 175 feet east of mile post 260 from Alburgh Junction.

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- 528 In third course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge over Opeongo river, $6\frac{1}{4}$ miles east of Madawaska.
- 527 In north face of boulder, 35 feet south of Grand Trunk railway track and 200 feet east of mile post 253 from Alburgh Junction—at east end of a gravel cut.
- 526 In south face of boulder, 30 feet north of Grand Trunk railway track, between sixth and seventh telegraph poles west of mile post 250 from Alburgh Junction and 200 feet west of west end of cut at head of grade to the east of Aylen lake.
- 525 In third course of stonework below top, in south face of southwest retaining wall of Grand Trunk railway bridge, $5\frac{1}{2}$ miles west of Barrys Bay.
- 524 In south side of rock cut on Grand Trunk railway, 4 miles west of Barrys Bay and 915 feet east of mile post 246 from Alburgh Junction.
- 523 In east end of north face of coping on north end of concrete arch culvert under Grand Trunk railway, 1,700 feet east of Barrys Bay.
- 522 In third course of stonework below top, in north face of northeast retaining wall of open culvert under Grand Trunk railway, 270 feet west of Wilno.
- 521 In south side of rock cut on Grand Trunk railway, $1\frac{3}{4}$ miles east of Wilno and 960 feet east of first highway crossing east of mile post 234 from Alburgh Junction.
- 520 In south side of rock cut on Grand Trunk railway, 1,125 feet west of a highway crossing, 120 feet east of a farm crossing and $2\frac{1}{2}$ miles west of Killaloe.
- 519 In second course of stonework below top, in south face of southeast retaining wall of Grand Trunk railway bridge over Brennan creek, 360 feet west of Killaloe station.
- 518 In concrete bench-mark pier, 4 feet south of north line of Grand Trunk railway right-of-way, $\frac{1}{2}$ mile east of Killaloe and 2,130 feet east of mile post 227 from Alburgh Junction.
- 517 In south side of small rock cut on Grand Trunk railway, $3\frac{3}{4}$ miles east of Killaloe and between thirteenth and fourteenth telegraph poles west of mile post 223 from Alburgh Junction.
- 516 In south side of shallow rock cut on Grand Trunk railway, $1\frac{3}{4}$ miles west of Golden Lake station and 1,875 feet east of mile post 220 from Alburgh Junction.
- 515 In south side of shallow rock cut on Grand Trunk railway, $\frac{1}{2}$ mile east of Golden Lake station and 2,000 feet west of mile post 217 from Alburgh Junction.
- 514 In fourth course of stonework below top, in south face of southwest retaining wall of Grand Trunk railway bridge over Hurd brook, 0.6 mile west of Eganville.
- 513 In east face of large limestone boulder, 20 feet south of north line of Grand Trunk railway right-of-way and 95 feet west of mile post 208 from Alburgh Junction.
- 512 In north end of west stone foundation wall of residence owned by Moses Walsh at Caldwell; this is a brick building at southeast corner of main road and first cross road west of the station.
- 511 In west end of north face of small stone culvert under Grand Trunk railway, 1 mile east of Caldwell and 360 feet east of mile post 202 from Alburgh Junction.
- 510 In fourth course of stonework below top, in south face of southwest retaining wall of Grand Trunk railway bridge, $1\frac{3}{4}$ miles east of Douglas and at fourth telegraph pole west of mile post 198 from Alburgh Junction.

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- 509 In fourth course of stonework below top, in northeast face of northeast wing-wall of stone arch culvert under Grand Trunk railway, 800 feet east of Admaston.
- 508 In fifth course of stonework below top, in north face of northeast retaining wall of Grand Trunk railway bridge, $2\frac{1}{4}$ miles west of Renfrew and at fifth telegraph pole east of mile post 191 from Alburgh Junction.
- 507 In water-table course of stonework, in front (or east) wall of Renfrew high school, 20 feet south of south wall of tower.
- 506 In first course of stonework below water-table course, in front (or west) wall of Renfrew Presbyterian church, 5 feet south of south wall of entrance porch at northerly doorway.
- 505 In third course of stonework below water-table course, in front (or west) wall of Renfrew post office, 8 feet to the south of the letter drop.

BENCH-MARKS BETWEEN WINNIPEG, MANITOBA, AND KENORA,
ONTARIO, VIA CANADIAN PACIFIC RAILWAY, (direct line).

- 1-F In first course of stonework above concrete walk, in west end of north wall of Grand Trunk-Canadian Northern union station at Winnipeg.
- 2-F In first course of stonework below brickwork, in south end of east wall of rear section of Winnipeg post office—at northwest corner of lanes running north from Graham avenue and east from Garry street.
- 3-F In second course of stonework above concrete walk, in west wall of main (or southerly) section of Canadian Pacific station at Winnipeg, between third and fourth basement windows from southwest corner.
- 4-F In concrete bench-mark pier, 4 feet north of south line of Canadian Pacific railway right-of-way, 108 feet west of intersection of south line of right-of-way with west line of a highway crossing and $3\frac{1}{2}$ miles east of Winnipeg station.
- 5-F In west end of north face of square concrete culvert under Canadian Pacific railway, 3 miles east of North Transcona and at mileage 116.7 from Kenora.
- 6-F In south end of east face of concrete retaining wall behind west abutment—10 inches above bridge-seat—of plate-girder bridge on Canadian Pacific railway, at mileage 108.8 from Kenora.
- 7-F In concrete bench-mark pier, 10 feet north of south line of Canadian Pacific railway right-of-way, 86 feet west of mile post 102 from Kenora and about 900 feet west of a highway crossing.
- 8-F In southeast face of southwest concrete retaining wall—6 feet above bridge-seat—of Canadian Pacific railway bridge over Brokenhead river, 1 mile east of Lydiatt.
- 9-F In west face of concrete coping on south end of concrete arch culvert under Canadian Pacific railway, $1\frac{1}{4}$ miles east of Lydiatt and at mileage 93.4 from Kenora.
- 10-F In east face of southwest retaining wall of square concrete culvert under Canadian Pacific railway, 600 feet east of Molson.
- 11-F In west face of boulder, partly buried in muskeg, 25 feet south of centre line between tracks of Canadian Pacific railway, and at fourth telegraph pole east of mile post 84 from Kenora.
- 12-F In north face of concrete footing of Canadian Pacific railway semaphore, $\frac{1}{2}$ mile west of Shelley.
- 13-F In east face of southwest retaining wall of square concrete culvert under Canadian Pacific railway, $2\frac{1}{4}$ miles west of Whitemouth and at mileage 74.36 from Kenora.

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- 14-F In second course of stonework above bridge-seat, in south end of east face of retaining wall behind west abutment of Canadian Pacific railway bridge over Whitemouth river, $\frac{3}{4}$ mile east of Whitemouth.
- 15-F In south end of east face—4 feet below bridge-seat—of west concrete abutment of Canadian Pacific railway bridge over Bog river; $1\frac{1}{2}$ miles west of Darwin and at mileage 67.1 from Kenora.
- 16-F In south face of large mass of rock, 40 feet south of centre line between tracks of Canadian Pacific railway, $\frac{1}{4}$ mile west of mile post 64 from Kenora and 85 feet west of sign "Darwin, 1 mile"—east of station.
- 17-F In south side of shallow rock cut on Canadian Pacific railway—near east end of cut—at fourteenth telegraph pole west of mile post 60 from Kenora.
- 18-F In west face of south face-wall of square concrete culvert under Canadian Pacific railway, at mileage 57.5 from Kenora.
- 19-F In north end of east face of westerly concrete pier of bridge by which Grand Trunk Pacific railway crosses over Canadian Pacific railway, 2.7 miles west of Rennie. The bench-mark is near the level of the Canadian Pacific rails.
- 20-F In south end of east face of concrete retaining wall behind west abutment—16 inches above bridge-seat—of plate-girder bridge on Canadian Pacific railway, $\frac{1}{4}$ mile east of Rennie.
- 21-F In south face of west concrete abutment—16 inches below bridge-seat—of plate-girder bridge on Canadian Pacific railway, 2.4 miles east of Rennie and at mileage 49.7 from Kenora.
- 22-F In north face of exposed rock surface at south side of Canadian Pacific railway track, $1\frac{1}{2}$ miles west of Telford and 500 feet east of mile post 46 from Kenora.
- 23-F In west end of south face of square concrete culvert under Canadian Pacific railway, $2\frac{1}{2}$ miles east of Telford and at mileage 41.93 from Kenora.
- 24-F In southwest face of coping stone on southeast wing-wall of stone arch culvert under Canadian Pacific railway, at mileage 38.44 from Kenora.
- 25-F In concrete bench-mark pier, between seventh and eighth telegraph poles west of mile post 35 from Kenora and about 460 feet east of a divergence between the eastbound and westbound tracks of the Canadian Pacific railway; the pier is 62 feet north of the south track and 82 feet south of the north track.
- 26-F In south side of rock cut on Canadian Pacific railway, $\frac{3}{4}$ mile west of Ingolf and opposite mile post 32 from Kenora.
- 27-F In north side—25 feet from west end—of large rock cut on Canadian Pacific railway, $2\frac{1}{4}$ miles east of Ingolf and between fifth and sixth telegraph poles east of mile post 29 from Kenora.
- 28-F In north face of large boulder near southerly line of Canadian Pacific railway right-of-way, between fourth and fifth telegraph poles east of mile post 26 from Kenora.
- 29-F In exposed rock surface at south side of Canadian Pacific railway track, 100 feet west of mile post 21 from Kenora.
- 30-F In south side of shallow rock cut on Canadian Pacific railway—25 feet from west end—at mileage 17.6 from Kenora.
- 31-F In south side of long rock cut on Canadian Pacific railway—420 feet east of west end of cut—between sixth and seventh telegraph poles west of Busteed and directly opposite a railway bench-mark painted white.

- 32-F In south side of rock cut on Canadian Pacific railway, between second and third telegraph poles west of mile post 11 from Kenora.
- 33-F In concrete bench-mark pier, 46 feet south of centre line between tracks of Canadian Pacific railway, directly opposite an abandoned spur line leading to a ballast pit, and about 2,000 feet east of mile post 9 from Kenora.
- 34-F In east end of north face—1 foot below top—of northeast concrete retaining wall of bridge on Canadian Pacific railway, 450 feet west of Keewatin station.
- 35-F In north end of east face of concrete retaining wall behind west abutment—2 feet 8 inches above bridge-seat—of Canadian Pacific railway bridge over Winnipeg river, 1.17 miles west of Kenora.
- 36-F In second course of stonework below brickwork, in west end of north wall of Canadian Pacific station-house at Kenora.
- 37-F In fourth course of stonework below brickwork, in west wall of Kenora post office, 11 feet 6 inches north of north wall of tower.
- 38-F In third course of stonework below water-table course, in east face of corner stone at northeast corner of Kenora court house.

BENCH-MARKS BETWEEN SASKATOON, SASKATCHEWAN, AND
WAINWRIGHT, ALBERTA, VIA GRAND TRUNK PACIFIC
RAILWAY.

- 1-H In north end of west face of concrete retaining wall behind east abutment of Grand Trunk Pacific railway bridge over South Saskatchewan river, $2\frac{1}{4}$ miles west of South Saskatoon station.
- 2-H In north face of concrete pier supporting pulleys for interlocking plant—at north side of Grand Trunk Pacific railway track—and 120 feet east of diamond crossing of Canadian Northern railway, 5 miles west of South Saskatoon station.
- 3-H In west concrete foundation wall—7 inches below woodwork and 30 inches from northwest corner—of Grand Trunk Pacific railway section-house, at west end of Grandora passing-track and immediately east of a highway crossing.
- 4-H In concrete bench-mark pier, 5 feet south of north line of Grand Trunk Pacific railway right-of-way, 335 feet east of east line of a highway crossing, $1\frac{3}{4}$ miles west of Hawoods and at fifth telegraph pole east of mile post 488 from Winnipeg.
- 5-H In west concrete foundation wall—4 inches below woodwork and 7 feet from southwest corner—of Grand Trunk Pacific railway section-house, at east end of passing-track at Asquith.
- 6-H In south concrete foundation wall—1 foot below woodwork and 19 feet from southwest corner—of frame house owned by J. B. King, 100 yards north of Juniata station.
- 7-H In north end of east face of concrete retaining wall behind west abutment—4 feet above bridge-seat—of Grand Trunk Pacific railway bridge over Eaglehill creek, $2\frac{1}{4}$ miles east of Kinley.
- 8-H In west concrete foundation wall—8 inches below woodwork and 2 feet from southwest corner—of a frame school house, $\frac{1}{4}$ mile northeast of Leney station.
- 9-H In north concrete foundation wall—6 inches below galvanized iron sheeting and 6 inches from northeast corner—of engine house of Saskatchewan Co-operative Elevator company's elevator (local No. 11), $5\frac{1}{2}$ miles west of Leney.

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- 10-H In west concrete foundation wall—9 inches below woodwork and 7 feet from southwest corner—of Grand Trunk Pacific railway section-house, at east end of Neola passing-track.
- 11-H In concrete foundation—7 inches below woodwork and 40 inches to the right of the spout—of Grand Trunk Pacific water-tank, 3.3 miles east of Biggar.
- 12-H In east end of south concrete foundation wall—2 feet 10 inches below brickwork—of front (or southerly) section of Biggar public school.
- 13-H In concrete bench-mark pier, 9 feet south of north line of Grand Trunk Pacific railway right-of-way and immediately west of a jog in the right-of-way fence, 4.4 miles west of Biggar and 60 feet east of mile post 531 from Winnipeg.
- 14-H In south concrete foundation wall—4 inches below galvanized iron sheeting and 2 feet 6 inches from southwest corner—of Saskatchewan Co-operative Elevator company's elevator (local No. 38) at Oban.
- 15-H In west concrete foundation wall—4 inches below woodwork and 6 feet 6 inches from southwest corner—of Grand Trunk Pacific railway section-house at west end of Palo passing-track.
- 16-H In concrete foundation—8 inches below woodwork and 3 feet to the right of the spout—of Grand Trunk Pacific water-tank at Landis.
- 17-H In east concrete foundation wall—3 inches below woodwork and 7 feet 6 inches from northeast corner—of Grand Trunk Pacific station-house at Coblenz.
- 18-H In east end of north concrete foundation wall—10 inches below woodwork—of signal tower at diamond crossing of Grand Trunk Pacific and Canadian Pacific railways, 1 mile west of Reford.
- 19-H In east concrete foundation wall—4 inches below woodwork and 34 inches from southeast corner—of Grand Trunk Pacific railway station-house at Scott.
- 20-H In concrete foundation—4 inches below woodwork and 30 inches to the right of the spout—of Grand Trunk Pacific water-tank at Tako.
- 21-H In concrete bench-mark pier, 10 feet south of north line of Grand Trunk Pacific railway right-of-way, 3½ miles east of Unity and 10 feet west of mile post 581 from Winnipeg.
- 22-H In east concrete foundation wall—9 inches below woodwork and 25 inches from southeast corner—of Grand Trunk Pacific station-house at Unity.
- 23-H In north concrete foundation wall—6 inches below woodwork and 6 inches from northeast corner—of Grand Trunk Pacific railway section-house, at east end of Vera passing-track.
- 24-H In concrete foundation—6 inches below woodwork and 4 feet to the right of the spout—of Grand Trunk Pacific water-tank, 3¼ miles east of Winter.
- 25-H In south face, 5 inches below top, of block of concrete—about 3 feet by 7 feet—originally used as a foundation for a pumping engine—30 feet south of north line of Grand Trunk Pacific railway right-of-way and 460 feet west of Winter station.
- 26-H In concrete bench-mark pier, 8 feet south of north line of Grand Trunk Pacific railway right-of-way, 1¼ miles west of Yonker and 17 feet west of fourteenth telegraph pole west of mile post 612 from Winnipeg.
- 27-H In west concrete foundation wall—4 inches below woodwork and 6 feet 6 inches from southwest corner—of Grand Trunk Pacific railway section-house, at east end of Zumbro passing-track.
- 28-H In north concrete foundation wall—10 inches below top and 8 feet from northeast corner—of grain elevator on south side of Grand Trunk Pacific railway track, 1,000 feet east of Artland station.
- NOTE.—The superstructure of this elevator has been burned down and only the foundation remains.

- 29-H In west concrete foundation wall—3 inches below woodwork and 15 inches from northwest corner—of Grand Trunk Pacific railway section-house at Butze siding.
- 30-H In east concrete foundation wall—10 inches below woodwork and 25 inches from southeast corner—of Grand Trunk Pacific station-house at Chauvin.
- 31-H In concrete bench-mark pier, 7 feet south of north line of Grand Trunk Pacific railway right-of-way, 2,940 feet west of bridge over Ribstone creek and 410 feet east of mile post 640 from Winnipeg.
- 32-H In north concrete foundation wall—5 inches below woodwork and 19 inches from northwest corner—of Grand Trunk Pacific railway section-house, at east end of Dunn passing-track.
- 33-H In north face—7 inches below top—of concrete abutment along westerly wall of Alberta Co-operative Elevator company's elevator (local No. 86) at Edgerton.
- 34-H In south concrete foundation wall—4 inches below woodwork and 8 inches from southwest corner—of Grand Trunk Pacific railway section-house at Heath, $\frac{1}{4}$ mile east of station.
- 35-H In concrete bench-mark pier, 6 feet south of north line of Grand Trunk Pacific railway right-of-way, 1 mile east of Greenshields and 96 feet west of mile post 661 from Winnipeg.
- 36-H In south concrete foundation wall—23 inches below brickwork and 18 inches from southwest corner—of Wainwright public school.

BENCH-MARKS BETWEEN MAPLE CREEK, SASKATCHEWAN, AND
COUTTS, ALBERTA, VIA CANADIAN PACIFIC RAILWAY.

- 146-C In south face of concrete retaining wall behind west abutment—4 feet above bridge-seat—of plate-girder bridge on Canadian Pacific railway, 0.4 mile west of Maple Creek and at mileage 84.9 from Swift Current.
- 147-C In east end of south face of stone coping on southeast retaining wall of plate-girder bridge on Canadian Pacific railway, $3\frac{1}{2}$ miles west of Maple Creek and at mileage 88.1 from Swift Current.
- 148-C In south face of concrete retaining wall behind west abutment of small plate-girder bridge on Canadian Pacific railway, $5\frac{1}{2}$ miles west of Maple Creek and at mile post 90 from Swift Current.
- 149-C In concrete bench-mark pier, 5 feet north of south line of Canadian Pacific railway right-of-way, $1\frac{1}{4}$ miles east of Kincorth and 150 feet west of mile post 96 from Swift Current.
- 150-C In west face of south face-wall of concrete arch culvert under Canadian Pacific railway, $1\frac{3}{4}$ miles east of Hatton.
- 151-C In west concrete foundation wall—9 inches below woodwork and 9 inches from southwest corner—of Hotel Forres at Hatton, 220 feet north of the station.
- 152-C In south face of central supporting wall of double concrete culvert under Canadian Pacific railway, 1 mile east of Cummings and at mileage 108.4 from Swift Current.
- 153-C In south end of west face—6 inches below $\frac{1}{4}$ top—of concrete retaining wall behind west abutment of plate-girder bridge on Canadian Pacific railway, $2\frac{1}{2}$ miles west of Cummings and at mileage 111.9 from Swift Current.
- 154-C In south end of east face—6 inches below bridge-seat—of west concrete abutment of open culvert under Canadian Pacific railway, $2\frac{1}{4}$ miles east of Walsh and at mileage 112.8 from Swift Current.

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- 155-C In south end of east face of concrete retaining wall behind west abutment of Canadian Pacific railway bridge over Mackay creek, $\frac{3}{4}$ mile west of Walsh.
- 156-C In south end of east face of concrete retaining wall behind west abutment of open culvert under Canadian Pacific railway, $2\frac{3}{4}$ miles west of Walsh and at mileage 117.9 from Swift Current.
- 157-C In south end of east face of west concrete abutment of plate-girder bridge on Canadian Pacific railway, at mileage 120.4 from Swift Current.
- 158-C In south end of east face—7 inches below top—of concrete retaining wall behind west abutment of plate-girder bridge on Canadian Pacific railway, $3\frac{1}{2}$ miles east of Irvine and at mileage 122.2 from Swift Current.
- 159-C In south end of east stone foundation wall—6 inches below brickwork— of Kalmbach Block at Irvine, southwest of the station.
- 160-C In west end of south stone foundation wall—22 inches below concrete water-table course—of Irvine public school, a concrete block building northwest of the station
- 161-C In south end of east face of concrete retaining wall behind west abutment of plate-girder bridge on Canadian Pacific railway, 2 miles west of Irvine and at mileage 127.6 from Swift Current.
- 162-C In south end of west face—6 inches below top—of concrete retaining wall behind west abutment of plate-girder bridge on Canadian Pacific railway, 3 miles west of Irvine and at mileage 128.6 from Swift Current.
- 163-C In south face-wall, immediately above southwest wing-wall, of double concrete culvert under Canadian Pacific railway, at mileage 131.6 from Swift Current.
- 164-C In concrete bench-mark pier, 7 feet north of south line of Canadian Pacific railway right-of-way, 26 feet west of mile post 135 from Swift Current and about 5 miles east of Dunmore.
- 165-C In west concrete foundation wall of Canadian Pacific roundhouse at Dunmore, 32 inches below brickwork and 10 inches from southwest corner.
- 166-C In south end of west face—6 inches below top—of concrete retaining wall behind west abutment of Canadian Pacific railway bridge over Bullshead creek, 5 miles southeast of Medicine Hat.
- 167-C In second course of stonework below water-table course, in northwest end of southwest wall (facing Sixth avenue southeast) of Medicine Hat post office.
- 168-C In northwest face of concrete coping on south retaining wall—at rail level—of Canadian Pacific railway bridge over South Saskatchewan river, $\frac{1}{4}$ mile northwest of Medicine Hat station.
- 169-C In second course of stonework below water-table course, in southwest end of northwest wall of Canadian Pacific station-house at Medicine Hat.
- 170-C In east face of southwest wing-wall of square concrete culvert under Canadian Pacific railway, at mile post 6 from Dunmore.
- 171-C In south end of west wall—3 feet 6 inches below line of window sills—of Canada Cement company's office and machine shop, a large concrete building 400 feet north of Canadian Pacific railway at Dauntless.
- 172-C In east face of southwest wing-wall of double concrete culvert under Canadian Pacific railway, at mile post 14 from Dunmore.
- 173-C In south face—1 foot below top—of concrete retaining wall behind west abutment of Canadian Pacific railway bridge over Sevenpersons river, 1.9 miles east of Sevenpersons.

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- 174-C In west face of coping on south end of large concrete arch culvert under Canadian Pacific railway, 2.3 miles west of Sevenpersons and 1,000 feet east of mile post 20 from Dunmore.
- 175-C In west face of large boulder, 130 feet south of south line of Canadian Pacific railway right-of-way, 400 feet west of a highway crossing and 200 feet east of mile post 27 from Dunmore.
- 176-C In west concrete foundation wall—16 inches below woodwork and 6 feet from southwest corner—of Odd-fellows Hall at Winnifred, a frame building northwest of the station.
- 177-C In concrete bench-mark pier, 4 feet north of south line of Canadian Pacific railway right-of-way, 330 feet east of a farm crossing, 1½ miles west of Winnifred and 380 feet west of mile post 34 from Dunmore.
- 178-C In south face wall, immediately above southwest wing-wall of concrete arch culvert under Canadian Pacific railway, ¾ mile east of Bow Island and at mileage 40.3 from Dunmore.
- 179-C In north end of west concrete foundation wall—13 inches below woodwork—of Roman Catholic church at Bow Island.
- 180-C In north concrete foundation wall—1 foot 9 inches below woodwork and 4 feet 7 inches from northeast corner—of G. H. Johnston's general store and telephone office at Burdett.
- 181-C In west concrete foundation wall—8 inches below woodwork and 5 feet 5 inches from southwest corner—of Methodist church at Burdett.
- 182-C In west concrete foundation wall—15 inches below brickwork and 7 feet 6 inches from southwest corner—of hardware store of Larsen Bros. and Hinck, at Grassy Lake.
- 183-C In east end of north concrete foundation wall—5 feet 6 inches below brickwork—of Grassy Lake public school.
- 184-C In concrete bench-mark pier, 4 feet north of south line of Canadian Pacific railway right-of-way, 350 feet east of a highway crossing, 1 mile east of Purple Springs and 87 feet east of mile post 64 from Dunmore.
- 185-C In concrete bench-mark pier, 5 feet north of south line of Canadian Pacific railway right-of-way, 4½ miles east of Taber and 100 feet east of mile post 72 from Dunmore.
- 186-C In west concrete foundation wall—18 inches below brickwork and 4 feet from southwest corner—of Canadian Bank of Commerce at Taber.
- 187-C In west concrete foundation wall—9 inches below brickwork and 4 feet 8 inches from southwest corner—of Taber public school.
- 188-C In west end of south face of square concrete culvert under Canadian Pacific railway, 2 miles west of Taber.
- 189-C In centre of south face of square concrete culvert under Canadian Pacific railway, 360 feet east of a highway crossing and at mileage 85.7 from Dunmore.
- 190-C In south face-wall, immediately above southwest wing-wall, of square concrete culvert under Canadian Pacific railway, 600 feet west of westerly switch at Neidpath passing-track and at mileage 86.8 from Dunmore.
- 191-C In west concrete foundation wall—15 inches below woodwork and 4 feet 6 inches from southwest corner—of school house at Chin.
- 192-C In south face of concrete retaining wall behind west abutment of plate-girder bridge on Canadian Pacific railway, 1 mile west of Chin.

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- 193-C In west end of south face of square concrete culvert under Canadian Pacific railway, 700 feet west of mile post 94 from Dunmore.
- 194-C In west end of south face of square concrete culvert under Canadian Pacific railway, 600 feet east of Coal-dale.
- 195-C In south face-wall, immediately above southwest wing-wall, of double concrete culvert under Canadian Pacific railway, $3\frac{1}{4}$ miles east of Lethbridge and 400 feet west of mile post 105 from Dunmore.
- 196-C In second course of stonework below water-table course, in east end of south wall of Canadian Pacific station-house at Lethbridge.
- 197-C In fourth course of stonework below water-table course, in west wall of Lethbridge post office, 17 feet from northwest corner.
NOTE.—The copper bolt is below the surface of the concrete sidewalk on Seventh street; access to it may be had by a small chamber fitted with an iron cover.
- 198-C In east face of granite plinth course at foot of pilaster at southeast corner of Lethbridge court house.
- 199-C In second course of stonework below water-table course, in east wall—11 feet 6 inches from southeast corner—of Wesley Methodist church, Lethbridge.
- 200-C In north concrete foundation wall—7 inches below woodwork and 12 feet from northeast corner—of stock building "C," at Lethbridge exhibition grounds, immediately west of Canadian Pacific railway—Cutts subdivision.
- 201-C In concrete bench-mark pier, 5 feet east of west line of Canadian Pacific railway right-of-way, $\frac{3}{4}$ mile north of Wilson and 67 feet south of mile post 9 from Montana Junction.
- 202-C In north face of boulder, 10 feet east of west line of Canadian Pacific railway right-of-way and at sixteenth telegraph pole south of mile post 12 from Montana Junction.
- 203-C In south end of west concrete foundation wall—1 foot below woodwork—of Canadian Pacific station-house at Stirling.
- 204-C In east concrete foundation wall—8 inches below woodwork and 12 feet from southeast corner—of Stirling Presbyterian church, a small frame building about $\frac{1}{4}$ mile west of the station.
- 205-C In concrete bench-mark pier, 5 feet east of west line of Canadian Pacific railway right-of-way, 2 miles north of New Dayton and 468 feet north of mile post 25 from Montana Junction.
- 206-C In south end of east concrete foundation wall—14 inches below woodwork—of Canadian Bank of Commerce at New Dayton.
- 207-C In east concrete foundation wall—20 inches below woodwork and 11 feet from northeast corner—of New Dayton public school.
- 208-C In concrete bench-mark pier, 4 feet east of west line of Canadian Pacific railway right-of-way, 520 feet north of a bridge over a small brook and 85 feet north of mile post 35 from Montana Junction.
- 209-C In south concrete foundation wall—15 inches below woodwork and 9 feet 7 inches from southeast corner—of First Evangelical church at Warner.
- 210-C In south concrete foundation wall— $7\frac{1}{2}$ inches below brickwork and 15 feet 6 inches from southwest corner—of Warner public school.
- 211-C In north face of large flat boulder, 200 feet west of west line of Canadian Pacific railway right-of-way, 1,450 feet south of a highway crossing and 1,335 feet north of mile post 43 from Montana Junction.

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- 212-C In concrete bench-mark pier, 5 feet east of west line of Canadian Pacific railway right-of-way, 1 mile north of Milk River station and 215 feet north of mile post 51 from Montana Junction.
- 213-C In south end of east concrete foundation wall—18 inches below water-table—of Canadian Bank of Commerce at Milk River.
- 214-C In east face—8 feet 6 inches below bottom of coping—of northeast concrete retaining wall of highway bridge over Milk river, in the village of Milk River.
- 215-C In concrete bench-mark pier, 5 feet east of west line of Canadian Pacific railway right-of-way, 6 miles south of Milk River and 100 feet south of mile post 58 from Montana Junction.
- 216-C In north face of concrete pier (built originally for astronomical observations) 240 feet west of Canadian Pacific railway track, 1,050 feet north of international boundary and 150 feet south of Coutts post office.

BENCH-MARKS BETWEEN LETHBRIDGE AND CALGARY, ALBERTA,
VIA CANADIAN PACIFIC RAILWAY THROUGH KIPP,
CARMANGAY AND ALDERSYDE.

Note.—These descriptions are written with the assumption that the railway runs in a northwesterly direction from Kipp to Sandstone and thence northerly to Calgary.

- 83-D In south end of west face of concrete retaining wall behind east abutment of Canadian Pacific railway viaduct over Belly river at Lethbridge— $\frac{3}{4}$ mile west of station.
- 82-D In north end of east face of concrete retaining wall behind west abutment of Canadian Pacific railway viaduct over Belly river at Lethbridge— $1\frac{3}{4}$ miles west of station.
- 81-D In east end of north concrete foundation wall—10 inches below woodwork—of Canadian Pacific railway section-house, 500 feet west of Kipp station.
- 80-D In concrete bench-mark pier, 8 feet northeast of southwest line of Canadian Pacific railway right-of-way, 45 feet northwest of a farm crossing and 800 feet southeast of mile post 5 from Kipp.
- 79-D In northeast concrete foundation wall—7 inches below woodwork and 11 feet from north corner—of Canadian Pacific railway section-house, 600 feet northwest of Nobleford station.
- 78-D In concrete bench-mark pier, 7 feet northeast of southwest line of Canadian Pacific railway right-of-way, 820 feet southeast of mile post 12 from Kipp and about 1,900 feet northwest of a highway crossing.
- 77-D In west end of south concrete foundation wall—21 inches below brickwork—of westerly section of public school at Barons.
- 76-D In northeast concrete foundation wall—7 inches below woodwork and 10 feet from north corner—of Canadian Pacific railway section-house, 600 feet northwest of Barons station.
- 75-D In concrete bench-mark pier, 7 feet northeast of southwest line of Canadian Pacific railway right-of-way, 810 feet northwest of a highway crossing, $3\frac{3}{4}$ miles southeast of Carmangay and 1,025 feet southeast of mile post 24 from Kipp.
- 74-D In centre of north face of concrete parapet, on north side of stairway, at main entrance of Carmangay public school.
- 73-D In south end of rear (or east) concrete foundation wall—9 inches below woodwork—of Canadian Pacific station-house at Carmangay.

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- 72-D In concrete bench-mark pier, 6 feet northeast of southwest line of Canadian Pacific railway right-of-way, $4\frac{1}{4}$ miles northwest of Carmangay and 320 feet southeast of mile post 32 from Kipp.
- 71-D In northwest concrete foundation wall—2 feet below brickwork and 5 feet 6 inches from west corner—of public school at Champion.
- 70-D In southwest concrete foundation wall—8 inches below woodwork and 11 feet from south corner—of Canadian Pacific railway section-house at Kirkcaldy.
- 69-D In southwest concrete foundation wall—9 inches below woodwork and 4 feet from west corner—of Canadian Bank of Commerce at Vulcan.
- 68-D In southeast end of rear (or southwest) concrete foundation wall—22 inches below woodwork—of Canadian Pacific station-house at Vulcan.
- 67-D In concrete bench-mark pier, 6 feet northeast of southwest line of Canadian Pacific railway right-of-way, 230 feet northwest of a trestle bridge, 255 feet southeast of mile post 54 from Kipp and 5 miles northwest of Vulcan.
- 66-D In northeast concrete foundation wall—8 inches below woodwork and 10 feet from north corner—of Canadian Pacific railway section-house, 740 feet southeast of Ensign station.
- 65-D In southeast end of rear (or southwest) concrete foundation wall—7 inches below woodwork—of Canadian Pacific station-house at Brant.
- 64-D In concrete bench-mark pier, 8 feet northeast of southwest line of Canadian Pacific railway right-of-way, 10 feet northwest of a highway crossing and $2\frac{1}{4}$ miles northwest of Brant.
- 63-D In east end of north concrete foundation wall—15 inches below woodwork—of front (or east) section of public school at Blackie.
- 62-D In concrete bench-mark pier, 7 feet northeast of southwest line of Canadian Pacific railway right-of-way, 145 feet southeast of a highway crossing, 3 miles northwest of Blackie and 527 feet northwest of mile post 75 from Kipp.
- 61-D-2 In northeast concrete foundation wall—4 inches below woodwork and 30 inches from north corner—of Canadian Pacific railway section-house at Mazeppa.
- 61-D In concrete bench-mark pier, 7 feet northeast of southwest line of Canadian Pacific railway right-of-way, 187 feet southeast of southeast end of bridge over Highwood river and $1\frac{1}{2}$ miles southeast of Aldersyde.
- 60-D In south face of west concrete retaining wall—32 inches above bridge-seat and directly in line with southwesterly truss—of Canadian Pacific railway bridge over Sheep creek, 1 mile southeast of Okotoks.
- 59-D In southwest end of southeast face of concrete retaining wall behind northwest abutment of plate-girder bridge on Canadian Pacific railway, $1\frac{3}{4}$ miles northwest of Okotoks.
- 58-D In north end of west face of square concrete culvert under Canadian Pacific railway, 460 feet south of Sandstone station.
- 57-D In north face of east face-wall of concrete culvert under Canadian Pacific railway, 1 mile north of De Winton.
- 56-D In north face of east face-wall of concrete culvert under Canadian Pacific railway, 2 miles north of De Winton.
- 55-D In west face of exposed rock surface, 6 feet east of east line of Canadian Pacific railway right-of-way, 600 feet south of mile post 10 and $1\frac{1}{4}$ miles south of Midnapore.

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- 54-D In southeast face of northeast concrete retaining wall—2 feet above bridge-seat—of Canadian Pacific railway bridge over Fish creek, 0.6 mile north of Midnapore.
- 53-D In south face of west face-wall of concrete culvert under Canadian Pacific railway, $2\frac{3}{4}$ miles north of Midnapore.
- 52-D In west face—26 inches below top— of concrete footing of bridge by which Canadian Pacific railway (Macleod subdivision) passes under Canadian Northern railway, 2 miles southeast of Calgary station. The footing referred to is under a steel upright at south side of bridge and to the east of the Canadian Pacific railway track.
- 51-D In sixth course of stonework below water-table course, in south face of corner stone at southeast corner of Calgary city hall.
- 50-D In second course of stonework below water-table course, in west face of corner stone at northwest corner of Calgary court house.

TABLE II.

RESULTS OF PRECISE LEVELLING.

HALIFAX TO YARMOUTH, N.S.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 386-B.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
‡ 386-B	‡ 386-B 387-B	1.0	1.0	-.013	-.013	12.590 60.743 21.575	‡ 386-B 387-B
386-B	388-B	2.9	2.9	-.014	-.014	40.963	388-B
388-B	389-B	3.0	5.9	+.025	+.011	275.732	389-B
389-B	390-B	3.3	9.2	-.017	-.006	240.148	390-B
390-B	391-B	3.6	12.8	-.028	-.034	305.116	391-B
391-B	392-B	5.3	18.1	-.032	-.066	198.912	392-B
392-B	393-B	2.2	20.3	-.011	-.077	79.856	393-B
393-B	394-B	2.5	22.8	+.002	-.075	56.192	394-B
394-B	395-B	4.5	27.3	-.035	-.110	28.259	395-B
395-B	396-B	4.6	31.9	-.015	-.125	79.564	396-B
396-B	397-B	2.3	34.2	-.017	-.142	34.887	397-B
397-B	398-B	4.6	38.8	-.029	-.171	115.522	398-B
398-B	399-B	3.7	42.5	-.024	-.195	56.172	399-B
399-B	400-B	0.6	43.1	+.010	-.185	13.823	400-B
400-B	401-B	7.8	50.9	-.008	-.193	43.505	401-B
401-B	402-B	3.4	54.3	-.018	-.211	39.141	402-B
402-B	403-B	6.4	60.7	-.032	-.243	41.446	403-B
403-B	404-B	2.7	63.4	+.001	-.242	32.542	404-B
404-B	405-B	3.4	66.8	+.023	-.219	86.650	405-B
405-B	406-B	3.8	70.6	-.005	-.224	171.307	406-B
406-B	407-B	4.5	75.1	-.025	-.249	180.655	407-B
407-B	408-B	4.1	79.2	-.022	-.271	97.522	408-B
408-B	409-B	1.2	80.4	-.009	-.280	12.591	409-B
409-B	410-B	.....	80.4	.000	-.280	38.207	410-B
409-B	411-B	1.4	81.8	-.003	-.283	44.491	411-B
411-B	412-B	3.6	85.4	-.026	-.309	206.780	412-B
412-B	413-B	4.9	90.3	-.021	-.330	195.700	413-B
413-B	414-B	5.9	96.2	-.039	-.369	217.339	414-B
414-B	415-B	6.6	102.8	-.041	-.410	6.047	415-B
415-B	416-B	6.1	108.9	-.016	-.426	79.634	416-B

‡ Reference bench-mark, Department of the Naval Service.

RESULTS OF PRECISE LEVELLING.

HALIFAX TO YARMOUTH, N.S.—Continued.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 386-B	DISCREPANCY		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
416-B	417-B	0.6	109.5	+ .011	-.415	37.351	417-B
417-B	418-B	2.4	111.9	+ .002	-.413	5.868	418-B
418-B	419-B	1.1	113.0	-.013	-.426	20.064	419-B
419-B	420-B	.....	113.0	+ .009	-.417	23.340	420-B
418-B	421-B	6.5	118.4	+ .014	-.399	77.873	421-B
421-B	422-B	1.5	119.9	+ .004	-.395	33.595	422-B
422-B	423-B	5.0	124.9	+ .025	-.370	167.974	423-B
423-B	424-B	8.0	132.9	+ .008	-.362	197.982	424-B
424-B	425-B	1.1	134.0	+ .006	-.356	170.591	425-B
425-B	426-B	4.5	138.5	+ .021	-.335	70.115	426-B
426-B	427-B	1.0	139.5	+ .001	-.334	5.916	427-B
427-B	428-B	4.1	143.6	-.007	-.341	24.266	428-B
428-B	429-B	5.1	148.7	+ .034	-.307	25.956	429-B
429-B	430-B	5.1	153.8	+ .010	-.297	13.348	430-B
430-B	431-B	2.4	156.2	-.005	-.302	10.826	431-B
431-B	432-B	1.8	158.0	+ .011	-.291	47.511	432-B
432-B	433-B	3.9	161.9	-.019	-.310	60.967	433-B
433-B	434-B	0.2	162.1	+ .004	-.306	60.732	434-B
434-B	435-B	0.2	162.3	-.004	-.310	27.736	435-B
433-B	436-B	1.0	162.9	+ .007	-.303	32.950	436-B
436-B	437-B	0.9	163.8	+ .003	-.300	6.654	437-B
437-B	438-B	4.8	168.6	+ .032	-.268	4.389	438-B
438-B	439-B	6.4	175.0	+ .029	-.239	56.511	439-B
439-B	440-B	4.3	179.3	+ .030	-.209	15.637	440-B
440-B	441-B	5.4	184.7	-.005	-.214	22.044	441-B
441-B	442-B	2.2	186.9	+ .005	-.209	6.151	442-B
442-B	443-B	2.8	189.7	+ .010	-.199	75.036	443-B
443-B	444-B	4.2	193.9	-.003	-.202	8.349	444-B
444-B	445-B	2.2	196.1	+ .004	-.198	18.675	445-B
445-B	446-B	1.5	197.6	+ .017	-.181	21.675	446-B
446-B	447-B	1.2	198.8	+ .001	-.180	7.239	447-B
447-B	448-B	2.4	201.2	-.015	-.195	45.185	448-B
448-B	449-B	1.5	202.7	+ .004	-.191	7.071	449-B
449-B	450-B	4.5	207.2	-.019	-.210	37.064	450-B
450-B	451-B	1.7	208.9	-.006	-.216	43.593	451-B
451-B	452-B	4.5	213.4	-.011	-.227	11.728	452-B
452-B	453-B	3.8	217.2	-.035	-.262	11.296	453-B

RESULTS OF PRECISE LEVELLING.

HALIFAX TO YARMOUTH, N.S.—*Continued.*

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 386-B	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
453-B	454-B	2.1	219.3	+ .017	-.245	9.558	454-B
454-B	455-B	4.1	223.4	- .005	-.250	50.344	455-B
455-B	456-B	3.4	226.8	+ .007	-.243	31.522	456-B
456-B	457-B	2.3	229.1	- .001	-.244	8.896	457-B
457-B	458-B	2.9	232.0	- .011	-.255	39.942	458-B
458-B	459-B	2.7	234.7	+ .005	-.250	14.720	459-B
459-B	460-B	2.8	237.5	- .014	-.264	11.608	460-B
460-B	461-B	1.1	238.6	+ .004	-.260	22.191	461-B
461-B	462-B	3.7	242.3	- .028	-.288	20.061	462-B
462-B	463-B	5.5	247.8	- .031	-.319	48.212	463-B
463-B	464-B	0.2	248.0	+ .001	-.318	61.489	464-B
464-B	465-B	0.3	248.3	- .008	-.326	67.755	465-B

Connections at Halifax with Public Works Dept's. levels:—

B.M.—MXXIV—No. 3 storehouse, Elev. 9.966

B.M.—MXXVII—Drydock pump-house, Elev. 9.933

B.M.—MXXVIII—Boulder near mile post 3, Elev. 13.294.

For connection at Yarmouth with Tidal Survey B.M., see Introduction.

RESULTS OF PRECISE LEVELLING.
DEPOT HARBOUR TO RENFREW, ONT.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 418.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
	418					674.930	418
418	564	.....	.....	-.003	-.003	656.719	564
564	565	2.7	2.7	.000	-.003	596.598	565
565	566	2.0	4.7	-.010	-.013	603.974	566
566	567	0.9	5.6	+.002	-.011	604.136	567
	418					674.930	418
418	564	.....	.....	-.003	-.003	656.719	564
564	563	4.1	4.1	+.010	+.007	763.915	563
563	562	4.9	9.0	-.023	-.016	876.686	562
562	561	4.2	13.2	-.017	-.033	772.242	561
561	560	3.8	17.0	-.020	-.053	899.547	560
560	559	4.3	21.3	+.008	-.045	977.056	559
559	558	3.7	25.0	-.001	-.046	1018.716	558
558	557	4.0	29.0	-.019	-.065	1050.992	557
557	556	5.0	34.0	-.014	-.079	1082.741	556
556	555	3.2	37.2	-.001	-.080	1084.733	555
555	554	3.8	41.0	-.011	-.091	1133.032	554
554	553	4.3	45.3	+.001	-.090	1107.669	553
553	552	5.2	50.5	-.001	-.091	1115.299	552
552	551	4.5	55.0	+.010	-.081	1285.192	551
551	550	3.1	58.1	-.013	-.094	1438.433	550
550	549	4.4	62.5	-.006	-.100	1513.130	549
549	548	3.5	66.0	.000	-.100	1445.073	548
548	547	5.4	71.4	+.042	-.058	1542.919	547
547	546	3.6	75.0	+.015	-.043	1476.156	546
546	545	3.0	78.0	-.021	-.064	1433.632	545
545	544	3.4	81.4	+.034	-.030	1389.617	544
544	543	0.5	81.9	+.001	-.029	1392.434	543
543	542	5.4	87.3	+.043	+.014	1473.098	542
542	541	3.9	91.2	-.035	-.021	1378.840	541
541	540	2.4	93.6	-.017	-.038	1305.768	540
540	539	7.1	100.7	-.039	-.077	1288.014	539
539	538	2.0	102.7	-.027	-.104	1308.462	538
538	537	4.4	107.1	+.022	-.082	1287.267	537
537	536	6.1	113.2	+.033	-.049	1243.443	536
536	535-A	1.6	114.8	-.031	-.080	1264.648	535-A
535-A	535	2.1	116.9	+.024	-.056	1207.397	535
535	534	2.9	119.8	-.024	-.080	1130.619	534

RESULTS OF PRECISE LEVELLING.

DEPOT HARBOUR TO RENFREW, ONT—Continued.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 418.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet	Feet.	No.
534	533	4.2	124.0	--.013	--.093	1084.772	533
533	532	2.1	126.1	--.001	--.094	1072.195	532
532	531	1.7	127.8	+.005	--.089	1036.312	531
531	530	0.2	128.0	+.005	--.084	1025.970	530
530	529	2.9	130.9	--.004	--.088	1065.976	529
529	528	3.2	134.1	--.019	--.107	1074.151	528
528	527	3.5	137.6	--.002	--.109	1181.215	527
527	526	2.8	140.4	--.031	--.140	1179.797	526
526	525	2.8	143.2	+.010	--.130	1010.907	525
525	524	1.6	144.8	--.007	--.137	1021.980	524
524	523	4.1	148.9	--.031	--.168	952.841	523
523	522	6.1	155.0	+.032	--.136	951.348	522
522	521	1.8	156.8	+.016	--.120	881.362	521
521	520	4.3	161.1	+.026	--.094	664.407	520
520	519	2.3	163.4	+.012	--.082	594.072	519
519	518	0.5	163.9	--.002	--.084	567.497	518
518	517	3.2	167.1	--.014	--.098	576.581	517
517	516	3.7	170.8	+.025	--.073	565.927	516
516	515	2.3	173.1	+.015	--.058	582.652	515
515	514	6.5	179.6	--.007	--.065	574.743	514
514	513	2.8	182.4	--.013	--.078	531.263	513
513	512	5.0	187.4	--.021	--.099	496.990	512
512	511	0.9	188.3	+.013	--.086	460.280	511
511	510	3.9	192.2	--.020	--.106	439.415	510
510	509	4.0	196.2	--.006	--.112	390.979	509
509	508	3.2	199.4	--.008	--.120	388.475	508
508	507	3.0	202.4	--.008	--.128	417.090	507
507	505	0.3	202.7	--.005	--.133	425.628	505
505	506	0.1	202.8	+.003	--.130	449.162	506

Connections with Public Works Dept's levels:—

B.M.—DCCLXXI—Boulder at Scotia Jct., Elev. 1082.027

B.M.—CCCCLXXXIV—C.P.R. station, Renfrew, Elev. 417.090

B.M.—CCCCLXXXV—C.P.R. water-tank, Renfrew, Elev. 417.869.

RESULTS OF PRECISE LEVELLING.
WINNIPEG MAN., TO KENORA, ONT.

BENCH-MARK.		Distance between successive bench- marks.	Distance from bench- mark 1-F.	DISCREPANCY.		Elev. above mean sea level.	BENCH- MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
	1-F					764.684	1-F
1-F	2-F	0.5	0.5	+ .005	+ .005	763.856	2-F
2-F	3-F	1.3	1.8	- .022	- .017	765.484	3-F
3-F	4-F	3.5	5.3	+ .007	- .010	761.361	4-F
4-F	5-F	5.8	11.1	+ .016	+ .006	780.771	5-F
5-F	6-F	7.8	18.9	+ .044	+ .050	792.394	6-F
6-F	7-F	6.8	25.7	+ .018	+ .068	814.270	7-F
7-F	8-F	7.9	33.6	- .035	+ .033	813.454	8-F
8-F	9-F	0.8	34.4	- .008	+ .025	811.646	9-F
9-F	10-F	5.6	40.0	- .002	+ .023	878.794	10-F
10-F	11-F	3.8	43.8	+ .031	+ .054	915.601	11-F
11-F	12-F	5.3	49.1	- .010	+ .044	925.869	12-F
12-F	13-F	4.3	53.4	- .013	+ .031	903.605	13-F
13-F	14-F	3.0	56.4	+ .002	+ .033	898.019	14-F
14-F	15-F	4.3	60.7	+ .027	+ .060	932.099	15-F
15-F	16-F	3.0	63.7	- .001	+ .059	964.865	16-F
16-F	17-F	3.9	67.6	- .019	+ .040	995.920	17-F
17-F	18-F	2.9	70.5	+ .015	+ .055	1011.064	18-F
18-F	19-F	2.6	73.1	- .008	+ .047	1035.274	19-F
19-F	20-F	3.0	76.1	+ .004	+ .051	1051.124	20-F
20-F	21-F	2.1	78.2	+ .021	+ .072	1080.068	21-F
21-F	22-F	3.8	82.0	+ .019	+ .091	1113.841	22-F
22-F	23-F	4.0	86.0	+ .008	+ .099	1064.634	23-F
23-F	24-F	3.4	89.4	- .005	+ .094	1047.103	24-F
24-F	25-F	3.3	92.7	+ .013	+ .107	1125.015	25-F
25-F	26-F	3.2	95.9	+ .012	+ .119	1188.615	26-F
26-F	27-F	3.0	98.9	+ .030	+ .149	1223.854	27-F
27-F	28-F	3.1	102.0	+ .021	+ .170	1250.009	28-F
28-F	29-F	4.9	106.9	+ .025	+ .195	1226.108	29-F
29-F	30-F	3.4	110.3	- .005	+ .190	1182.367	30-F
30-F	31-F	3.5	113.8	- .021	+ .169	1183.081	31-F
31-F	32-F	3.0	116.8	+ .014	+ .183	1137.755	32-F
32-F	33-F	2.4	119.2	+ .003	+ .186	1118.948	33-F
33-F	34-F	5.4	124.6	+ .010	+ .196	1083.387	34-F
34-F	35-F	2.0	126.6	+ .001	+ .197	1084.013	35-F
35-F	36-F	1.2	127.8	- .022	+ .175	1093.051	36-F
36-F	37-F	0.2	128.0	- .002	+ .173	1090.832	37-F
37-F	38-F	0.3	128.3	+ .001	+ .174	1082.500	38-F

RESULTS OF PRECISE LEVELLING.

SASKATOON, SASK., TO WAINWRIGHT, ALTA.

BENCH-MARK.		Distance between successive bench- marks.	Distance from bench- mark 28-D.	DISCREPANCY.		Elev. above mean sea level.	BENCH- MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
	28-D					1651.349	28-D
28-D	1-H	1.7	1.7	--.008	--.008	1620.857	1-H
1-H	2-H	2.7	4.4	+.024	+.016	1653.142	2-H
2-H	3-H	10.8	15.2	--.048	--.032	1660.554	3-H
3-H	4-H	5.9	21.1	--.025	--.057	1642.618	4-H
4-H	5-H	3.2	24.3	--.015	--.072	1712.641	5-H
5-H	6-H	5.5	29.8	+.015	--.057	1789.459	6-H
6-H	7-H	2.4	32.2	--.017	--.074	1751.705	7-H
7-H	8-H	8.0	40.2	+.047	--.027	1813.974	8-H
8-H	9-H	5.3	45.5	--.017	--.044	1922.795	9-H
9-H	10-H	6.8	52.3	+.004	--.040	2046.107	10-H
10-H	11-H	4.0	56.3	--.036	--.076	2096.242	11-H
11-H	12-H	3.3	59.6	+.024	--.052	2193.804	12-H
12-H	13-H	4.4	64.0	--.007	--.059	2091.392	13-H
13-H	14-H	4.3	68.3	+.026	--.033	2121.095	14-H
14-H	15-H	7.7	76.0	+.052	+.019	2110.567	15-H
15-H	16-H	6.3	82.3	--.003	+.016	2134.549	16-H
16-H	17-H	7.3	89.6	+.001	+.017	2225.103	17-H
17-H	18-H	7.6	97.2	--.021	--.004	2142.559	18-H
18-H	19-H	5.0	102.2	--.012	--.016	2163.439	19-H
19-H	20-H	8.5	110.7	--.017	--.033	2106.474	20-H
20-H	21-H	3.2	113.9	--.012	--.045	2076.892	21-H
21-H	22-H	3.5	117.4	+.029	--.016	2092.363	22-H
22-H	23-H	10.3	127.7	--.013	--.029	1922.229	23-H
23-H	24-H	5.8	133.5	+.015	--.014	1958.406	24-H
24-H	25-H	3.3	136.8	--.003	--.017	1985.192	25-H
25-H	26-H	8.4	145.2	--.008	--.025	1993.118	26-H
26-H	27-H	5.0	150.2	--.006	--.031	2067.470	27-H
27-H	28-H	5.6	155.8	+.017	--.014	2009.657	28-H
28-H	29-H	7.3	163.1	--.011	--.025	2013.876	29-H
29-H	30-H	3.3	166.4	--.005	--.030	2059.784	30-H
30-H	31-H	6.4	172.8	--.001	--.031	2041.998	31-H
31-H	32-H	3.0	175.8	--.003	--.034	2108.791	32-H
32-H	33-H	4.6	180.4	--.005	--.039	2108.818	33-H
33-H	34-H	6.6	187.0	+.012	--.027	2185.465	34-H
34-H	35-H	6.8	193.8	+.037	+.010	2232.469	35-H
35-H	36-H	6.5	200.3	+.021	+.031	2236.888	36-H

RESULTS OF PRECISE LEVELLING.
MAPLE CREEK, SASK., TO COUTTS, ALTA.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 94-C.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
	146-C		198.8		+ .070	2505.817	146-C
146-C	147-C	3.2	202.0	- .001	+ .069	2506.670	147-C
147-C	148-C	1.9	203.9	- .007	+ .062	2531.642	148-C
148-C	149-C	5.9	209.8	+ .019	+ .081	2533.311	149-C
149-C	150-C	5.6	215.4	- .004	+ .077	2478.303	150-C
150-C	151-C	1.7	217.1	+ .001	+ .078	2469.640	151-C
151-C	152-C	5.0	222.1	+ .029	+ .107	2392.100	152-C
152-C	153-C	3.6	225.7	+ .017	+ .124	2420.192	153-C
153-C	154-C	0.9	226.6	+ .002	+ .126	2421.246	154-C
154-C	155-C	3.0	229.6	- .008	+ .118	2441.800	155-C
155-C	156-C	2.0	231.6	+ .004	+ .122	2432.266	156-C
156-C	157-C	2.5	234.1	- .005	+ .117	2461.658	157-C
157-C	158-C	1.8	235.9	+ .010	+ .127	2500.119	158-C
158-C	159-C	3.5	239.4	+ .023	+ .150	2503.461	159-C
159-C	160-C	0.2	239.6	+ .003	+ .153	2500.827	160-C
159-C	161-C	2.0	241.4	- .019	+ .131	2480.328	161-C
161-C	162-C	0.9	242.3	+ .004	+ .135	2466.074	162-C
162-C	163-C	3.0	245.3	+ .009	+ .144	2426.056	163-C
163-C	164-C	3.2	248.5	+ .014	+ .158	2419.033	164-C
164-C	165-C	5.4	253.9	- .003	+ .155	2413.604	165-C
165-C	166-C	2.3	256.2	- .009	+ .146	2317.593	166-C
166-C	169-C	5.0	261.2	+ .026	+ .172	2183.274	169-C
169-C	168-C	0.2	261.4	- .004	+ .168	2184.522	168-C
168-C	167-C	0.2	261.6	- .010	+ .158	2186.099	167-C
165-C	170-C	6.0	259.9	- .033	+ .122	2363.451	170-C
170-C	171-C	1.0	260.9	- .013	+ .109	2388.988	171-C
171-C	172-C	6.9	267.8	- .001	+ .108	2450.271	172-C
172-C	173-C	1.6	269.4	+ .004	+ .112	2460.625	173-C
173-C	174-C	4.2	273.6	+ .014	+ .126	2518.505	174-C
174-C	175-C	7.1	280.7	+ .003	+ .129	2763.200	175-C
175-C	176-C	5.8	286.5	- .010	+ .119	2724.517	176-C
176-C	177-C	1.4	287.9	+ .004	+ .123	2688.157	177-C
177-C	178-C	6.3	294.2	+ .019	+ .142	2597.864	178-C
178-C	179-C	0.5	294.7	.000	+ .142	2621.734	179-C
179-C	180-C	7.3	302.0	+ .019	+ .161	2574.426	180-C

RESULTS OF PRECISE LEVELLING.

MAPLE CREEK, SASK., TO COUTTS, ALTA—*Continued.*

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 94-C.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
180-C	181-C	.....	302.0	+ .004	+ .165	2576.419	181-C
180-C	182-C	7.9	309.9	+ .041	+ .202	2649.851	182-C
182-C	183-C	.....	309.9	- .005	+ .197	2658.048	183-C
182-C	184-C	8.0	317.9	+ .008	+ .210	2619.290	184-C
184-C	185-C	8.1	326.0	+ .048	+ .258	2641.552	185-C
185-C	186-C	4.6	330.6	- .011	+ .247	2668.310	186-C
186-C	187-C	0.5	331.1	.000	+ .247	2658.769	187-C
186-C	188-C	1.9	332.5	.000	+ .247	2677.669	188-C
188-C	189-C	7.1	339.6	+ .035	+ .282	2730.286	189-C
189-C	190-C	1.0	340.6	- .002	+ .280	2739.649	190-C
190-C	191-C	3.6	344.2	+ .023	+ .303	2780.475	191-C
191-C	192-C	0.8	345.0	- .003	+ .300	2773.720	192-C
192-C	193-C	3.0	348.0	+ .013	+ .313	2812.108	193-C
193-C	194-C	3.8	351.8	+ .004	+ .317	2825.793	194-C
194-C	195-C	7.1	358.9	- .009	+ .308	2991.190	195-C
195-C	196-C	3.3	362.2	- .028	+ .280	2984.862	196-C
196-C	197-C	0.3	362.5	- .010	+ .270	2976.338	197-C
197-C	198-C	.....	362.5	+ .001	+ .271	2978.588	198-C
198-C	199-C	0.3	362.8	- .009	+ .262	2994.353	199-C
196-C	200-C	2.6	364.8	+ .014	+ .294	2992.352	200-C
200-C	201-C	8.1	372.9	+ .053	+ .347	3046.760	201-C
201-C	202-C	3.4	376.3	+ .003	+ .350	3072.232	202-C
202-C	203-C	5.1	381.4	- .013	+ .337	3040.674	203-C
203-C	204-C	0.3	381.7	- .008	+ .329	3041.123	204-C
203-C	205-C	7.3	388.7	+ .015	+ .352	3187.573	205-C
205-C	206-C	2.1	390.8	+ .021	+ .373	3196.207	206-C
206-C	207-C	.....	390.8	- .005	+ .368	3210.503	207-C
206-C	208-C	8.1	398.9	- .016	+ .357	3205.644	208-C
208-C	209-C	5.7	404.6	+ .017	+ .374	3319.603	209-C

RESULTS OF PRECISE LEVELLING.
 MAPLE CREEK, SASK., TO COUTTS, ALTA.—Continued.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 94-C.	DISCREPANCY.		Elev. above mean sea level.	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
209-C	210-C	0.3	404.9	- .008	+ .366	3328.061	210-C
209-C	211-C	2.2	406.8	- .028	+ .346	3359.243	211-C
211-C	212-C	8.3	415.1	+ .015	+ .361	3467.163	212-C
212-C	213-C	1.0	416.1	+ .014	+ .375	3437.846	213-C
213-C	214-C	0.3	416.4	+ .002	+ .377	3409.719	214-C
214-C	215-C	5.8	422.2	- .006	+ .371	3425.941	215-C
215-C	216-C	6.6	428.8	+ .017	+ .388	3491.042	216-C
216-C	†	.....	428.8	- .006	+ .382	3466.647	†

†B.M. H-12 of the U.S. Coast and Geodetic Survey, in international boundary monument No. 354-B, at Coutts.

Connections with bench-marks of Irrigation Surveys Branch, Dept. of the Interior:—

- At N.W. corner of Dixon Bro's. store, town of Maple Creek (bench-mark No. 118), Elev. 2507.344
- At N.E. corner, tp. 11, rge. 1, W. 4th mer. (iron post), Elev. 2444.800
- On N.W. ¼ sec. 26, tp. 11, rge. 1, W. 4th mer. (iron post), Elev. 2443.733
- On N.W. ¼ sec. 31, tp. 11, rge. 2, W. 4th mer. (iron post), Elev. 2500.427
- On S.E. ¼ sec. 16, tp. 12, rge. 5, W. 4th mer. (iron post), Elev. 2305.530
- At N.E. corner of old court house, Lethbridge, Elev. 2993.430
- On N.E. ¼ sec. 21, tp. 2, rge. 16, W. 4th mer. (iron post on north bank of Milk river), Elev. 3412.420

RESULTS OF PRECISE LEVELLING.

LETHBRIDGE TO CALGARY, ALTA.

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 196-C.	DISCREPANCY.		Elev. above mean sea level	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
	196-C					2984.862	196-C
196-C	83-D	0.8	0.8	+ .011	+ .011	2980.806	83-D
83-D	82-D	1.0	1.8	+ .014	+ .025	3001.708	82-D
82-D	81-D	6.3	8.1	+ .013	+ .038	3058.150	81-D
81-D	80-D	5.3	13.4	- .037	+ .001	3108.756	80-D
80-D	79-D	5.1	18.5	+ .016	+ .017	3221.527	79-D
79-D	78-D	1.8	20.3	+ .002	+ .019	3203.418	78-D
78-D	76-D	6.4	26.7	- .018	+ .001	3152.806	76-D
76-D	77-D	.....	26.7	- .004	- .003	3157.521	77-D
76-D	75-D	5.7	32.4	- .012	- .011	3115.784	75-D
75-D	73-D	3.6	36.0	- .022	- .033	3081.951	73-D
73-D	74-D	.....	36.0	- .005	- .038	3081.244	74-D
73-D	72-D	4.4	40.4	+ .013	- .020	3161.474	72-D
72-D	71-D	4.3	44.7	+ .019	- .001	3148.759	71-D
71-D	70-D	8.3	53.0	- .017	- .018	3322.059	70-D
70-D	68-D	5.0	58.0	+ .004	- .014	3440.767	68-D
68-D	69-D	.....	58.0	+ .003	- .011	3452.532	69-D
68-D	67-D	5.1	63.1	- .010	- .024	3346.238	67-D
67-D	66-D	4.5	67.6	- .004	- .028	3266.004	66-D
66-D	65-D	4.5	72.1	- .019	- .047	3268.847	65-D
65-D	64-D	2.3	74.4	- .005	- .052	3301.664	64-D
64-D	63-D	6.7	81.1	- .025	- .077	3355.118	63-D
63-D	62-D	3.0	84.1	+ .005	- .072	3350.073	62-D
62-D	61-D-2	3.0	87.1	- .015	- .087	3361.071	61-D-2
61-D-2	61-D	5.5	92.6	+ .016	- .071	3391.775	61-D
61-D	60-D	6.2	98.8	- .015	- .086	3429.972	60-D
60-D	59-D	2.8	101.6	- .018	- .104	3487.295	59-D
59-D	58-D	2.3	103.9	+ .012	- .092	3522.166	58-D
58-D	57-D	6.1	110.0	+ .025	- .067	3601.013	57-D
57-D	56-D	1.1	111.1	+ .006	- .061	3540.931	56-D

RESULTS OF PRECISE LEVELLING.
LETHBRIDGE TO CALGARY, ALTA.—*Continued.*

BENCH-MARK.		Distance between successive bench-marks.	Distance from bench-mark 196-C.	DISCREPANCY.		Elev. above mean sea level	BENCH-MARK.
From	To			Partial.	Total.		
No.	No.	Miles.	Miles.	Feet.	Feet.	Feet.	No.
56-D	55-D	5.0	116.1	+ .039	- .022	3429.961	55-D
55-D	54-D	1.9	118.0	+ .003	- .019	3413.626	54-D
54-D	53-D	2.1	120.1	+ .001	- .018	3435.760	53-D
53-D	52-D	5.4	125.5	+ .002	- .016	3419.459	52-D
52-D	51-D	2.0	127.5	- .020	- .036	3428.199	51-D
51-D	50-D	1.1	128.6	- .003	- .039	3443.837	50-D

Connections at Calgary:—

Irrigation Surveys Branch, Dept. of the Interior—Bench-mark (iron post) on left bank of Elbow river, 870 feet up-stream from Twelfth Avenue bridge, Elev. 3423.851

Topographical Surveys Branch, Dept. of the Interior, B.M. H-3, N.E. corner of city hall, Elev. 3430.649.

TABLE III.

RAIL ELEVATIONS, HALIFAX TO YARMOUTH, N.S.

(Elevations taken in 1913).

	FEET
Intercolonial Railway—Halifax.....	59.9
“ Richmond.....	20.0
“ Southwestern Junction.....	28.0
Halifax & Southwestern Ry.—Beechville.....	282.9
“ Ninemile river; water, July 30, 1913, 211.7; rail.....	227.7
“ Bowser.....	244.1
“ Stream, mileage 14.1 from Halifax; water, July 30, 1913, 244.7; rail....	252.4
“ Stream, mileage 14.3 from Halifax; water, July 30, 1913, 242.7; rail....	249.9
“ Hubley.....	287.4
“ Stream, mileage 18.2 from Halifax; water, Aug. 5, 1913, 196.3; rail.....	204.5
“ French Village.....	79.1
“ Northeast river; water, Aug. 5, 1913, 70.4; rail.....	84.7
“ Indian river; rail.....	95.4
“ St. Margaret.....	57.2
“ Boutilier.....	30.8
“ Ingram river; water, Aug. 7, 1913, 21.4; rail.....	34.4
“ Ingramport.....	33.6
“ Hubbards river; water, Aug. 12, 1913, 21.3; rail.....	40.8
“ Hubbards.....	68.3
“ East River (station).....	56.1
“ East river; water, Aug. 16, 1913, 34.9; rail.....	44.1
“ East Chester.....	91.3
“ Chester.....	46.1
“ Stream, mileage 54.1 from Halifax; water, Aug. 19, 1913, 36.8; rail.....	63.8
“ Middle river; water, Aug. 19, 1913, 24.0; rail.....	43.4
“ Chester Basin.....	75.8
“ Western Shore.....	54.2
“ Martin River.....	56.5
“ Mahone Junction.....	84.9
“ Blockhouse.....	181.6
“ Maitland.....	206.7
“ Bridgewater.....	10.9
“ Conquerall.....	206.0
“ Italy Cross.....	201.3
“ County Line.....	120.0
“ Port Medway river, rail.....	19.3
“ Medway.....	24.6
“ Brooklyn.....	30.4
“ Liverpool (station).....	10.4
“ Hunt Point.....	73.0
“ Port Mouton.....	59.9
“ Mitchell brook; water, Oct. 2, 1913, 226.3; rail.....	236.6
“ Wilkins.....	215.3
“ Tom Tigney brook, mileage 137.1 from Halifax; water, Oct. 3, 1913, 94.9; rail.....	105.4
“ Tom Tigney brook, mileage 139.5 from Halifax; water, Oct. 3, 1913, 62.8; rail.....	74.3
“ Sable River (station).....	15.3
“ Lockeport.....	19.6
“ Stream, mileage 149.6 from Halifax; water, Oct. 7, 1913, 17.8; rail.....	30.3

RAIL ELEVATIONS, HALIFAX TO YARMOUTH, N.S.—*Continued.*

(Elevations taken in 1913).		FEET
Halifax & Southwestern Ry.—	East Jordan.....	15.3
"	Jordan Falls.....	16.0
"	Stream, mileage 158.4 from Halifax; water, Oct. 11, 1913, 44.1; rail.....	55.1
"	Shelburne.....	71.4
"	Birchtown.....	11.3
"	Gunning Cove.....	10.6
"	Roseway.....	37.4
"	Round Bay brook; water, Oct. 21, 1913, 11.4; rail.....	22.2
"	Greenwood.....	25.2
"	Port Saxon.....	25.9
"	Port Clyde.....	21.7
"	Barrington.....	10.9
"	Barrington Passage.....	10.3
"	Atwoods Brook.....	21.1
"	Shag Harbour.....	57.8
"	Woods Harbour.....	38.0
(Elevations taken in 1914).		
"	Upper Woods Harbour.....	14.0
"	Lower East Pubnico.....	14.5
"	D'Entremont.....	20.7
"	East Pubnico.....	15.9
"	Pubnico.....	12.2
"	Lower Argyle.....	69.7
"	Central Argyle.....	42.4
"	Argyle.....	12.2
"	Belleville.....	54.9
"	Tusket.....	34.9
"	Pleasant Lake.....	15.1
"	Arcadia.....	27.6
"	Yarmouth.....	19.7

RAIL ELEVATIONS, DEPOT HARBOUR TO RENFREW, ONTARIO.

(Elevations taken in 1914).		FEET
	Lake Huron; water, Aug. 25, 1914.....	579.4
Grand Trunk Railway—	Rose Point.....	600.2
"	Boyne river, 1.4 miles east of Rose Point; water, Aug. 22, 1914, 617.3; rail.....	630.5
"	Boyne river, 1.6 miles east of Rose Point; water, Aug. 22, 1914, 625.8; rail.....	634.5
"	Boyne river, 2.5 miles east of Rose Point; water, Aug. 22, 1914, 628.8; rail.....	652.4
"	James Bay Junction.....	686.3
"	Otter Lake (station).....	736.9
"	Beatty.....	901.2
"	Maple Lake (station).....	797.0
"	Edgington.....	891.3
"	Seguin river, 0.5 mile west of Seguin Falls; water, Aug. 7, 1914, 936.2; rail.....	979.7
"	Seguin Falls.....	962.8
"	Seguin river, 1.8 miles east of Seguin Falls; water, Aug. 7, 1914, 969.5; rail.....	978.3
"	Seguin river, 2 miles east of Seguin Falls; water, Aug. 7, 1914, 969.5; rail.....	980.6
"	Bear Lake (station).....	1038.3
"	Whitehall.....	1097.7
"	Sprucedale.....	1074.5
"	Scotia Junction (diamond crossing).....	1081.3

RAIL ELEVATIONS, DEPOT HARBOUR TO RENFREW, ONTARIO—*Continued.*

(Elevations taken in 1914).

	FEET
Grand Trunk Railway—Kearney.....	1109.8
“ Tonawanda creek; water, July 10, 1914, 1261.4; rail.....	1292.9
“ Ravensworth.....	1411.7
“ Rainy Lake (station).....	1452.2
“ Stream, 3.5 miles west of Brulé Lake; water, July 2, 1914, 1517.3; rail.....	1546.6
“ Summit, 2 miles west of Brulé Lake.....	1605.0
“ Brulé Lake (station).....	1470.7
“ Canoe Lake (station).....	1392.1
“ Joe Lake (station).....	1395.6
“ Joe lake; water, June 25, 1914.....	1381.4
“ Madawaska river, 2 miles west of Algonquin Park; water, June 24, 1914, 1461.4; rail.....	1476.7
“ Algonquin Park.....	1418.9
“ Madawaska river, 1 mile east of Algonquin Park; water, June 23, 1914, 1406.1; rail.....	1416.8
“ Madawaska river, 1.7 miles east of Algonquin Park; water, June 23, 1914, 1334.8; rail.....	1386.0
“ Madawaska river, 4.2 miles east of Algonquin Park; water, June 23, 1914, 1293.9; rail.....	1309.5
“ Rock Lake (station).....	1292.1
“ Whitney.....	1268.7
“ Egan Estate.....	1093.6
“ Madawaska.....	1035.0
“ Opeongo Forks.....	1125.9
“ Aylen Lake (station).....	1157.2

(Elevations taken in 1913).

“ Barrys Bay.....	983.4
“ Wilno.....	955.2
“ Brennan brook, immediately west of Killaloe; water, Sept. 16, 1913, 585.6; rail..	596.1
“ Killaloe.....	593.8
“ Golden lake; water, Sept. 19, 1913.....	553.0
“ Golden Lake (station).....	539.3
“ Hurd brook, 0.5 mile west of Eganville; water, Sept. 2, 1913, 549.7; rail.....	579.5
“ Eganville.....	569.6
“ Caldwell.....	494.7
“ Douglas.....	436.7
“ Admaston.....	412.2
“ Canadian Pacific railway, Kingston-Renfrew line, (diamond crossing).....	402.6
“ Renfrew.....	420.9
Canadian Pacific Railway—Renfrew.....	416.0

RAIL ELEVATIONS, WINNIPEG, MANITOBA, TO KENORA, ONTARIO.

(Elevations taken in 1913).

	FEET
Canadian Pacific Railway—Winnipeg.....	766.5
“ North Transcona.....	769.1
“ Canadian Northern railway (diamond crossing).....	772.7
“ Oakbank.....	811.7
“ Cook creek, 2.3 miles west of Hazelridge; water, June 12, 1913, 787.3; rail..	795.3

RAIL ELEVATIONS, WINNIPEG, MANITOBA, TO KENORA, ONTARIO—*Continue*

(Elevations taken in 1913).

	FEET
Canadian Pacific Railway—Cook creek, 1.6 miles west of Hazelridge; water, June 12, 1913, 782.2; rail..	793.2
“ Hazelridge.....	796.0
“ Cloverleaf.....	837.0
“ Lydiatt.....	825.0
“ Molson.....	883.4
“ Julius.....	932.1
“ Shelley.....	929.6
“ Whitemouth.....	911.2
“ Whitemouth river; water, June 20, 1913, 879.6; rail.....	904.9
“ Darwin.....	959.7
“ Grand Trunk Pacific railway (overhead crossing) rail 1062.7; C.P.R. rail....	1035.5
“ Rennie.....	1058.2
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“ Interprovincial boundary, Manitoba-Ontario.....	1164.3
“ Ingolf.....	1190.8
“ Lowther.....	1219.5
“ Busteed.....	1187.0
“ Lake of the Woods; water, July 16, 1913.....	1060.8
“ Keewatin.....	1085.7
“ Winnipeg river, 1.2 miles west of Kenora; water, July 16, 1913, 1060.1; rail..	1088.2
“ Winnipeg river, 0.7 mile west of Kenora; water, July 16, 1913, 1060.8; rail..	1089.4
“ Kenora.....	1091.0

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(Elevations taken in 1914).

	FEET
Grand Trunk Pacific Ry.—Canadian Northern railway, Regina-Prince Albert line (diamond crossing)....	1652.9
“ South Saskatchewan river; water, May 14, 1914, 1553; rail.....	1624.7
“ Canadian Northern railway, Saskatoon-Calgary line (diamond crossing).....	1654.4
“ Farley.....	1658.4
“ Grandora.....	1660.3
“ Hawoods.....	1645.1
“ Asquith.....	1710.8
“ Juniata.....	1791.1
“ Eaglehill creek; water, May 27, 1914, 1734.9; rail.....	1758.3
“ Kinley.....	1754.9
“ Leney.....	1823.4
“ Mead.....	1986.6
“ Neola.....	2044.3
“ Biggar.....	2154.0
“ Oban.....	2125.0
“ Palo.....	2107.4
“ Landis.....	2133.5
“ Coblenz.....	2225.1
“ Reford.....	2144.3
“ Canadian Pacific railway (diamond crossing).....	2143.2
“ Scott.....	2163.6
“ Tako.....	2106.0
“ Unity.....	2092.9
“ Canadian Pacific railway (overhead crossing) rail 2075.1; G. T. P. Ry. rail....	2046.4

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ALBERTA.—*Continued.*

(Elevations taken in 1914).

	FEET
Grand Trunk Pacific Ry.—Vera.....	1930.2
“ Yonker.....	1981.9
“ Zumbro.....	2055.7
“ Artland.....	2008.0
“ Interprovincial boundary, Saskatchewan-Alberta.....	1997.0
“ Butze.....	2017.8
“ Chauvin.....	2059.8
“ Ribstone.....	2032.5
“ Ribstone creek; water, July 30, 1914, 2006.6; rail.....	2028.6
“ Dunn.....	2107.2
“ Edgerton.....	2119.1
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“ Greenshields.....	2255.3
“ Wainwright.....	2222.1

RAIL ELEVATIONS, MAPLE CREEK, SASKATCHEWAN, TO MEDICINE HAT, ALBERTA.

(Elevations taken in 1914).

	FEET
Canadian Pacific Railway—Maple Creek.....	2507.0
“ Kincorth.....	2550.1
“ Hatton.....	2477.3
“ Cummings.....	2400.2
“ Walsh.....	2443.5
“ Mackay creek; water, May 7, 1914, 2428.8; rail.....	2442.6
“ Irvine.....	2504.7
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“ Pashley.....	2415.8
“ Dunmore.....	2411.0
“ Bullshead creek; water, May 21, 1914, 2285.0; rail.....	2319.6
“ Medicine Hat.....	2181.2

RAIL ELEVATIONS, DUNMORE TO COUTTS, ALBERTA.

(Elevations taken in 1914).

	FEET
Canadian Pacific Railway—Dunmore.....	2411.0
“ Dauntless.....	2397.5
“ Bulls Head.....	2411.8
“ Sevenpersons river; water, June 3, 1914, 2437.5; rail.....	2462.2
“ Sevenpersons.....	2480.0
“ Stornham.....	2591.4
“ Whitla.....	2747.8
“ Winnifred.....	2725.7
“ Bow Island.....	2621.4
“ Burdett.....	2576.9
“ Grassy Lake.....	2652.9
“ Purple Springs.....	2626.4

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(Elevations taken in 1914).

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Canadian Pacific Railway—Taber.....	2671.0
“ Barnwell.....	2734.2
“ Chin.....	2784.9
“ Coaldale.....	2828.1
“ Montana Junction.....	3013.5
“ Lethbridge.....	2983.3
“ Wilson.....	3045.1
“ Stirling.....	3041.6
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“ Warner.....	3313.2
“ Milk River.....	3424.2
“ Milk river; water, Aug. 27, 1914.....	3404.5
“ Coutts.....	3468.1

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(Elevations taken in 1914).

	FEET
Canadian Pacific Railway—Lethbridge.....	2983.3
“ Lenzie.....	3056.9
“ Kipp.....	3059.5
“ Nobleford.....	3225.7
“ Barons.....	3152.8
“ Carmangay.....	3082.2
“ Little Bow river; water, July 22, 1914, 2932.0; rail.....	3071.1
“ Champion.....	3152.0
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“ Vulcan.....	3442.0
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“ Okotoks.....	3447.8
“ Sandstone.....	3530.1
“ De Winton.....	3631.6
“ Academy.....	3495.9
“ Midnapore.....	3432.8
“ Fish creek; water, May 26, 1914, 3395.1; rail.....	3418.3
“ Turner.....	3443.7
“ Canadian Northern railway (overhead crossing) rail 3447.9; C.P.R. rail....	3420.8
“ Elbow river; water, May 22, 1914, 3406.2; rail.....	3425.0
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Note.—Under "Year of Publication,"

1910 refers to Appendix No. 5 to the Chief Astronomer's Report for 1910.

1913* refers to Vol. I, No. 2, on Precise Levelling.

1913 refers to Vol. I, No. 3, on Precise Levelling.

1914 refers to Vol. I, No. 8, on Precise Levelling.

1915 refers to the present publication.

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Madawaska, Ont.....	530, 531	1915	15	32
Magog, Que.....	40, 41, 41-A	1910	453	463

ALPHABETICAL LIST OF CITIES, TOWNS AND VILLAGES AT OR NEAR WHICH BENCH-MARKS
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			Page.	Page.
Maitland, Ont.....	121	1910	458	466
Malagash, N.S.....	144-B	1913	46	74
Mallorytown, Ont.....	128	1910	458	466
Manitou, Man.....	11-C, 12-C	1913	66	87
Maple Creek, Sask.....	145-C, 146-C	1914	231	241
Markdale, Ont.....	279	1913	59	82
Marysville, Ont.....	152	1910	459	467
Massawippi, Que.....	28-A	1913	48	75
Mather, Man.....	17-C	1913	67	87
McAdam Jct., N.B.....	11-B	1910	447	460
McGivney Jct., N.B.....	333-B	1914	215	233
Meadowville, N.S.....	153-B	1913	46	74
Medicine Hat, Alta.....	167-C, 168-C, 169-C	1915	22	35
Medora, Man.....	40-C	1913	68	88
Medway, N.S.....	415-B	1915	10	28
Megantic, Que.....	21-A-2, 22-A	1913	50	76
Melancthon, Ont.....	271-A, 272.	1913	59	82
Melita, Man.....	42-C, 43-C	1913	68	88
Merigomish, N.S.....	164-B	1913	47	74
Merritton, Ont.....	209	1913	63	85
Midale, Sask.....	71-C	1913	69	89
Midhurst, Ont.....	390	1913	65	86
Midnapore, Alta.....	54-D	1915	27	39
Milan, Que.....	18-A-2	1913	50	76
Milestone, Sask.....	85-C	1913	70	89
Milk River, Alta.....	213-C, 214-C	1915	25	37
Minto, Y.T.....	106	1913*	30	30
Molson, Man.....	10-F	1915	17	33
Monckland, Ont.....	102	1910	457	466
Moncton, N.B.....	132-B, 133-B, 134-B	1913	45	73
“ “.....	373-B, 374-B	1914	217	233
Montague, Y.T.....	69	1913*	28	28
Mooretown, Ont.....	362	1914	221	236
Moosejaw, Sask.....	94-C, 95-C, 96-C	1913	71	89
“ “.....	103-C	1914	229	241
Morden, Man.....	7-C, 8-C	1913	66	87
Morse, Sask.....	116-C, 117-C	1914	229	241
Mortlach, Sask.....	110-C	1914	229	241
Mountain, Ont.....	111	1910	457	466
Mulgrave, N.S.....	185-B	1913	48	75
Muniac, N.B.....	37-B	1910	448	461
Musquash, N.B.....	91-B, 92-B	1910	451	462
Mystic, Que.....	65	1910	453	464

ALPHABETICAL LIST OF CITIES, TOWNS AND VILLAGES AT OR NEAR WHICH BENCH-MARKS
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Napinka, Man.....	41-C	1913	68		88	
Nauwigewauk, N.B.....	107-B	1913	44		73	
Newbury, Ont.....	242	1913	56		81	
Newcastle, Ont.....	176	1913	53		79	
New Dayton, Alta.....	206-C, 207-C	1915	24		36	
New Glasgow, N.S.....	160-B	1913	47		74	
Ninga, Man.....	29-C	1913	67		87	
Nobleford, Alta.....	79-D	1915	25		38	
Nordenskiöld, Y. T.....	47	1913*	27		27	
Northfield, Ont.....	494	1914	219		235	
North Portal, Sask.....	†	1913	88		88	
Northwood, Ont.....	245	1913	57		81	
Norton, N.B.....	113-B	1913	44		73	
Norton Mills, Vermont.....	23, 24, 25	1910	455		465	
Notre-Dame-du-Lac, Que.....	64-B	1910	449		461	
O.						
Oak Bay, N.B.....	4-B	1910	446		460	
Oakville, Ont.....	193	1913	55		80	
Oban, Sask.....	14-H	1915	20		34	
Okotoks, Alta.....	60-D	1915	26		38	
Orangeville, Ont.....	267	1913	58		82	
Osgoode, Ont.....	117-A, 118-A	1913	52		78	
Oshawa, Ont.....	178-A, 179, 179-A	1913	54		79	
Osler, Sask.....	36-D	1914	228		240	
Ottawa, Ont.....	125-A	1913	53		78	
“ “.....	503, 504	1914	220		235	
Owen Sound, Ont.....	286, 287, 288	1913	60		82	
Oxbow, Sask.....	55-C	1913	69		88	
Oxford, Ont.....	114	1910	457		466	
Oxford, N.S.....	136-B	1913	46		74	
Oxford Jct., N.S.....	135-B	1913	45		74	
P.						
Palgrave, Ont.....	376	1913	64		86	
Palmerston, Ont.....	305	1913	61		83	
Paris, Ont.....	222	1913	55		80	
Parkbeg, Sask.....	111-C	1914	229		241	

†International Boundary Monument.

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Park Head Jct., Ont.....	291	1913	60	83
Parkhill, Ont.....	346	1914	221	236
Parry Sound, Ont.....	419, 420	1914	223	237
Pasqua, Sask.....	93-C	1913	71	89
Pelly, Y.T.....	118, 119	1913*	30	30
Pense, Sask.....	99-C	1913	71	89
Perth, N.B.....	39-B	1910	448	461
Petitcodiac, N.B.....	123-B	1913	45	73
Piapot, Sask.....	141-C	1914	231	241
Pickering, Ont.....	180-A-2	1913	54	79
Piedmont, N.S.....	165-B	1913	47	74
Pierson, Man.....	46-C	1913	68	88
Pike Creek, Ont.....	253	1913	57	81
Pilot Mound, Man.....	15-C	1913	67	87
Pinewood, Ont.....	20-E	1914	226	239
Pinto, Sask.....	67-C	1913	69	88
Plaster Rock, N.B.....	301-B, 302-B	1914	213	232
Pomquet, N.S.....	176-B	1913	48	74
Port Clyde, N.S.....	442-B	1915	12	29
Port Hope, Ont.....	172, 172-A, 173	1913	53	79
Port Robinson, Ont.....	212	1913	63	85
Port Saxon, N.S.....	441-B	1915	12	29
Port Union, Ont.....	182	1913	54	79
Prescott, Ont.....	119	1910	458	466
Prince Albert, Sask.....	47-D, 48-D, 49-D	1914	228	240
Princeton, Ont.....	224	1913	55	80
Pubnico, N.S.....	454-B	1915	13	30
R.				
Rainy River, Ont.....	17-E	1914	226	239
Reford, Sask.....	18-H	1915	20	34
Regina, Sask.....	1-D, 2-D, 3-D	1913	71	90
Renfrew, Ont.....	505, 506, 507	1915	17	32
River Glade, N.B.....	125-B	1913	45	73
Rivière-du-Loup, Que.....	76-B, 77-B, 78-B	1910	450	461
Roche-Percée, Sask.....	65-C	1913	69	88
Rock Island, Que.....	33-A	1913	49	75
Roosevelt, Minn.....	13-E	1914	226	239
Rose Point, Ont.....	565	1915	13	31
Rosthern, Sask.....	40-D	1914	*228	240
Rothesay, N.B.....	103-B, 104-B	1913	44	73
Rouleau, Sask.....	88-C, 89-C	1913	70	89
Rush Lake, Sask.....	120-C	1914	230	241
Russell, Ont.....	499	1914	220	235

ALPHABETICAL LIST OF CITIES, TOWNS AND VILLAGES AT OR NEAR WHICH BENCH-MARKS
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Ste. Henedine, Que.	212-B	1913	52	77
St. Henri, Que. (Lévis County).....	216-B	1913	52	77
St. Honoré, Que.....	70-B	1910	450	461
St. John, N.B.....	97-B, 98-B, 99-B, 100-B	1910	9 452	28 462
St. Johns, Que.....	75	1910	452	463
“ “	76	1910	455	463
St. Joseph-de-Lévis, Que.....	220-B	1913	52	77
St. Louis, Que. (Beauharnois County).....	88	1910	456	466
St. Margaret, N.S.....	394-B	1915	9	28
St. Mary, Que.....	209-B	1913	51	77
St. Polycarpe Jet., Que.....	92	1910	456	466
Ste. Rose, Que. (Temiscouata County)	62-B	1910	449	461
St. Stephen, N.B.....	2-B, 3-B	1910	446	460
T.				
Taber, Alta.....	186-C, 187-C	1915	23	36
Takhini, Y.T.....	20, 21	1913*	25	25
Tako, Sask.....	20-H	1915	20	34
Tara, Ont.....	293	1913	60	83
Tatamagouche, N.S.....	147-B	1913	46	74
Thamesville, Ont.....	243-A	1913	57	81
Thedford, Ont.....	349	1914	221	236
Thornhill, Man	9-C	1913	66	87
Thorold, Ont.....	210, 211	1913	63	85
Tompkins, Sask.....	138-C	1914	231	241
Toronto, Ont.....	185, 186, 187, 188, 188-A, 189	1913	54	79
Tottenham, Ont.....	377-A	1913	64	86
Trenton, Ont.....	161	1910	460	467
Tring Jet., Que.....	204-B	1913	51	77
Tupperville, Ont.....	369	1914	222	236
Tusket, N.S.....	460-B	1915	13	30
U.				
Unity, Sask.....	22-H	1915	20	34
Upper Woods Harbour, N.S.....	451-B	1915	12	20
Utopia, Ont.....	387	1913	65	86

ALPHABETICAL LIST OF CITIES, TOWNS AND VILLAGES AT OR NEAR WHICH BENCH-MARKS
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V.				
Valleyfield, Que.....	89	1910	456	466
Valley Jct., Que.....	207-B	1913	51	77
Vera, Sask.....	23-H	1915	20	34
Versailles, Que.....	72	1910	452	463
Vulcan, Alta.....	68-D, 69-D	1915	26	38
W.				
Wainwright, Alta.....	36-H	1915	21	34
Wakefield, Que.....	469, 470	1914	218	234
Wallaceburg, Ont.....	367	1914	222	236
Walsh, Alta.....	155-C	1915	22	35
Warman, Sask.....	35-D	1914	228	240
Warner, Alta.....	209-C, 210-C	1915	24	36, 37
Warroad, Minn.....	12-E	1914	226	239
Waterville, Que.....	9	1910	455	465
Webb, Sask.....	132-C	1914	230	241
Welland, Ont.....	213	1913	64	85
Welland Jct., Ont.....	214	1913	64	85
West Merigomish, N.S.....	163-B	1913	47	74
Weston, Ont.....	256-A	1913	58	82
Weyburn, Sask.....	80-C, 81-C	1913	70	89
Whitby, Ont.....	180-A	1913	54	79
Whitehorse, Y.T.....	1	1913*	25	25
Whitemouth, Man.....	14-F	1915	18	33
White Pass, Y.T.....	42-R, 43-R	1913*	23	23
Whitewater, Man.....	35-C	1913	68	88
Whitney, Ont.....	536	1915	15	31
Wilcox, Sask.....	86-C, 87-C	1913	70	89
Winchester, Ont.....	109	1910	457	466
Windsor, Ont.....	255	1913	57	81
Wingham, Ont.....	314	1913	61	83
Winnifred, Alta.....	176-C	1915	23	35
Winnipeg, Man.....	1-F, 2-F, 3-F	1915	17	33
Winona, Ont.....	202	1913	63	85
Winter, Sask.....	25-H	1915	20	34
Woodstock, Ont.....	226, 227	1913	55	80
Woodstock, N.B.....	25-B, 26-B, 27-B	1910	447	460
Wounded Moose, Y.T.....	179	1913*	33	33

ALPHABETICAL LIST OF CITIES, TOWNS AND VILLAGES AT OR NEAR WHICH BENCH-MARKS
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Place.	B. M. Number.	Year of Publication.	Description.	Elevation.
			Page.	Page.
	Y.			
Yarmouth, N.S.....	463-B, 464-B, 465-B	1915	13	30
Yellow Grass, Sask.....	83-C	1913	70	89
Yukon Crossing, Y.T.....	94	1913*	29	29
	Z.			
Zumbro, Sask.....	27-H	1915	20	34

Dominion Observatory,
Ottawa,
February, 1915.

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THE SPECTROSCOPIC BINARY θ^2 TAURI.

BY J. S. PLASKETT, D.Sc.

The star θ^2 Tauri (α 4^{h} $22^{\text{m}}.9$, $\delta+15^{\circ}$ $39'$, magnitude 3.6, spectral type A5) was announced as a spectroscopic binary by Moore in the Lick Observatory Bulletin, No. 62, and by Frost in the *Astrophysical Journal* XXIX, page 238. Their published velocities with the date, Julian day, phase and residual (the two latter being obtained from the elements finally accepted) are given at the beginning of the table of measures below.

The star was placed under observation here on December 11, 1909, and between that date and March, 1912, 66 plates were obtained. Of these plates, 52 were selected and measured. The measures of the plates were discussed and a preliminary orbit obtained and published in the *Journal of the Royal Astronomical Society of Canada* VI, page 231, July-August, 1912. A summary of this work will be given later but, as it was felt desirable to have further observations, 16 more plates were obtained and measured making a total of 68 plates on which the present determination is based.

The spectrum is of type A5 containing numerous metallic lines, but unfortunately all these lines are wide and diffuse making the measurements more or less uncertain. This is shown by the poor agreement often present between different lines on the same plate and by the comparatively high probable error ± 3.6 km. per second of a single plate derived from the plate residuals from the final orbit. Four different dispersions were tried in the hope of getting more satisfactory measures with this type of spectrum, but no one showed very marked advantages over the others. This will be discussed more fully later.

The principal lines measured—all those used in the measures—with their chosen wave-lengths and source are given in the accompanying list. The titanium lines seem in general to be the best defined and most reliable in this spectrum.

LINES MEASURED IN θ^2 TAURI.

Wave-length.	Element.	Wave-length.	Element.
4584.018	<i>Fe</i>	4455.116	<i>Blend</i>
4572.156	<i>Ti</i>	4415.293	<i>Fe</i>
4563.939	<i>Ti</i>	4404.927	<i>Fe</i>
4549.766	<i>Ti-Fe</i>	4399.935	<i>Ti-Cr</i>
4534.139	<i>Ti</i>	4395.201	<i>Ti</i>
4515.508	<i>Ti</i>	4374.520	<i>Blend</i>
4508.455	<i>Ti</i>	4351.930	<i>Cr</i>
4501.448	<i>Ti</i>	4340.634	<i>H</i>
4494.738	<i>Fe</i>	4325.939	<i>Fe</i>
4481.400	<i>Mg</i>	4315.138	<i>Fe</i>
4468.663	<i>Ti</i>	4290.377	<i>Ti</i>

The summary of the measures of the early plates at the Lick and Yerkes observatories, of the 52 plates used in the first determination, and of the 16 plates obtained subsequently, with other data are given in the accompanying table and this is followed by tables containing the measured values of the individual lines, with the corrections required to reduce the velocities to the sun.

SUMMARY OF MEASURES.

Plate No.	Date	Julian Date	Spectrograph	Phase	Velocity	Residual O-C.	Remarks
<i>Lick Plates—</i>	Dec. 1, 1903....	2,416,450.70	.....	139.10	+38	- 2.8	
	Jan. 3, 1905....	6,849.60	.....	115.90	+50	+13.9	
	Oct. 4, 1906....	7,488.65	.....	51.45	+74	- 7.8	
	Sept. 8, 1908....	8,193.90	.....	53.20	+80	+ 0.6	
	Oct. 21, 1908....	8,236.85	.....	96.15	+17	-14.8	
	Oct. 25, 1908....	8,240.85	.....	100.15	+23	- 9.7	
<i>Yerkes Plate.—</i>	Aug. 31, 1906....	7,454.88	.....	17.68	+42	- 5.9	
	Nov. 4, 1907....	884.77	.....	25.47	+29	-22.4	
	Aug. 25, 1908....	8,179.94	.....	39.24	+64	+ 2.6	
	Sept. 8, 1908....	193.95	.....	53.25	+88	+ 9.0	Secondary +40
	Sept. 18, 1908....	203.85	.....	63.15	+10	-18.7	
	Oct. 12, 1908....	227.85	.....	87.15	+39	+ 9.9	Secondary +8
	Nov. 8, 1908....	254.78	.....	114.08	+36	+ 0.3	
	Dec. 7, 1908....	283.63	.....	2.23	+38	- 6.0	
Dec. 11, 1908....	287.63	.....	6.23	+31	-13.0		

SUMMARY OF MEASURES—Continued.

Plate No.	Date	Julian Date	Spectrograph	Phase	Velocity	Residual O-C.	Remarks
<i>Ottawa Plates—</i>							
3030	Dec. 11, 1909....	2,418,652.73	III S	89.93	+28.2	- 2.3	
3041	Dec. 16, 1909....	657.74	III S	94.94	+30.9	- 0.6	
3044	Dec. 18, 1909....	659.66	III S	96.86	+34.7	+ 2.7	
3056	Dec. 28, 1909....	669.78	III S	106.98	+34.9	+ 0.8	
3068	Dec. 30, 1909....	671.51	III S	108.71	+22.8	-11.7	
3076	Dec. 30, 1909....	671.65	I	108.85	+22.1	-12.4	
3085	Jan. 7, 1910....	679.52	III S	116.72	+31.4	- 4.8	
3108	Jan. 14, 1910....	686.66	III S	123.86	+29.2	- 8.6	
3116	Jan. 15, 1910....	687.53	III S	124.73	+38.9	+ 0.8	
3133	Jan. 19, 1910....	691.56	III S	128.76	+37.4	- 1.6	
3169	Feb. 3, 1910....	706.70	III S	3.20	+46.0	+ 2.9	
3201	Feb. 21, 1910....	724.55	I	21.05	+42.6	- 5.6	
3208	Feb. 23, 1910....	726.55	I	23.05	+57.0	+ 6.8	
3222	Feb. 24, 1910....	727.56	III S	24.06	+46.7	- 4.0	
3255	Mar. 2, 1910....	733.63	I	30.13	+60.6	+ 6.5	
3268	Mar. 3, 1910....	734.59	III R	31.09	+54.0	- 0.7	
3308	Mar. 10, 1910....	741.61	III R	38.11	+58.6	- 1.6	
3334	Mar. 17, 1910....	748.55	III R	45.05	+71.8	+ 2.5	Pr. +107 Sec. + 43
3623	Sept. 7, 1910....	922.89	I	78.69	+31.9	+ 3.9	
3651	Sept. 14, 1910....	929.86	I	85.66	+37.3	+ 7.7	
3658	Sept. 15, 1910....	930.87	I	86.67	+42.5	+12.8	
3668	Sept. 16, 1910....	931.79	I	87.59	+27.3	- 2.7	
3687	Sept. 21, 1910....	936.88	I	92.68	+36.0	+ 5.0	
3730	Oct. 10, 1910....	955.90	I	111.70	+25.8	- 9.3	
3741	Oct. 12, 1910....	957.88	I	113.68	+37.6	+ 2.0	
3784	Oct. 31, 1910....	976.73	I	132.53	+38.7	- 1.3	
3793	Nov. 2, 1910....	978.82	I	134.62	+37.8	- 2.7	
3802	Nov. 8, 1910....	984.81	I	140.61	+44.3	+ 2.3	
3818	Dec. 5, 1910....	9,011.67	I	26.77	+56.7	+ 4.6	Pr. +112 Sec. + 11
3843	Dec. 9, 1910....	015.67	I	30.77	+56.2	+ 1.7	Pr. +66 Sec. - 37
3859	Dec. 12, 1910....	018.60	I	33.70	+61.2	+ 4.6	
3871	Dec. 15, 1910....	021.65	I	36.75	+55.1	- 3.9	
3888	Dec. 21, 1910....	027.66	I	42.76	+67.0	+ 1.4	
3916	Jan. 5, 1911....	042.57	I	57.67	+42.7	- 1.4	
3922	Jan. 9, 1911....	046.61	I	61.71	+27.0	- 3.4	
3930	Jan. 12, 1911....	049.61	I	64.71	+32.3	+ 4.6	
3938	Jan. 16, 1911....	053.67	I	68.77	+25.8	- 1.0	
3958	Jan. 18, 1911....	055.59	I	70.69	+28.0	+ 1.0	
3973	Jan. 30, 1911....	067.59	III L	82.69	+35.1	+ 6.1	
4627	Oct. 10, 1911....	320.79	I	54.49	+70.7	- 1.3	
4636	Oct. 12, 1911....	322.86	I	56.56	+62.1	+10.0	
4672	Oct. 28, 1911....	338.75	III L	72.45	+26.9	- 0.2	
4716	Dec. 6, 1911....	377.77	I	111.47	+34.2	- 0.9	
4733	Dec. 19, 1911....	390.82	III L	124.52	+26.7	-11.3	
4739	Dec. 25, 1911....	396.75	I	130.45	+35.4	- 4.1	
4746	Jan. 1, 1912....	403.71	III L	137.41	.....	.....	Pr. +54 Sec. +2
4760	Jan. 10, 1912....	412.63	III L	5.63	+41.4	- 2.4	
4780	Jan. 12, 1912....	414.67	I	7.67	+45.3	+ 0.9	
4788	Jan. 13, 1912....	415.50	III L	8.50	+39.1	- 5.6	
4792	Jan. 16, 1912....	418.60	I	11.60	+40.7	- 5.0	

SUMMARY OF MEASURES.—*Concluded.*

Plate No.	Date	Julian Date	Spectrograph	Phase	Velocity	Residual O-C.	Remarks
4832	Feb. 10, 1912....	2,419,443.66	I	36.66	+60.9	+ 2.0	
4835	Feb. 12, 1912....	445.65	I	38.65	+58.9	- 1.8	
4880	Mar. 11, 1912....	473.52	I	66.52	+25.8	- 1.4	
5218	Oct. 4, 1912....	680.78	I	133.08	+41.6	+ 1.5	
5236	Oct. 7, 1912....	683.79	I	136.09	+48.7	+ 7.8	
5243	Oct. 16, 1912....	692.80	I	4.40	+50.8	+ 7.3	
5244	Oct. 16, 1912....	692.85	I	4.45	+44.4	+ 0.9	
5250	Oct. 17, 1912....	693.82	I	5.42	+41.4	- 2.3	
5251	Oct. 17, 1912....	693.85	I	5.45	+48.0	+ 4.3	
5253	Oct. 20, 1912....	696.64	I	8.24	+45.5	+ 0.9	
5254	Oct. 20, 1912....	696.69	I	8.29	+46.9	+ 2.3	
5259	Oct. 25, 1912....	701.71	I	13.31	+56.7	+10.0	
5260	Oct. 25, 1912....	701.75	I	13.35	+43.9	- 2.8	
5892	Jan. 21, 1914....	20,154.56	I	44.06	+63.4	- 4.6	
5902	Jan. 25, 1914....	158.55	III L	48.05	+74.2	- 0.7	
5903	Jan. 30, 1914....	163.62	III L	53.12	+76.1	- 3.2	
5904	Feb. 2, 1914....	166.53	III L	56.03	+63.2	+ 6.2	
5905	Feb. 4, 1914....	168.50	III L	58.0	+37.6	- 4.4	
5914	Feb. 5, 1914....	169.60	I	59.10	+33.4	- 3.9	

MEASURES OF θ^2 TAURI.

λ	3030		3041		3044		3056		3068		3076		3085	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	+ 30.53	$\frac{1}{2}$	+ 31.73	$\frac{1}{2}$	.....	.....	+ 49.89	$\frac{1}{2}$	+ 37.42	1	+ 46.35	2	.....	.....
4572.156	+ 35.41	1	+ 32.72	1	+ 36.31	$\frac{1}{2}$	+ 49.71	1	.....	.....	.....	.....	+ 51.11	1
4563.939	.....	.....	+ 48.78	$\frac{1}{2}$	.....	.....	.....	.....	+ 44.85	1	.....	.....	.....	.....
4549.766	+ 43.01	$\frac{2}{3}$	+ 35.02	$1\frac{1}{2}$	+ 40.33	$1\frac{1}{2}$	+ 51.27	$\frac{1}{2}$	+ 37.45	$\frac{1}{2}$	.....	.....	+ 42.46	1
4534.139	.....	.....	+ 53.88	1	+ 43.58	1	.....	.....	+ 34.92	$\frac{1}{2}$	.....	.....	+ 47.01	$\frac{1}{2}$
4481.400	+ 32.94	1	+ 50.21	$1\frac{1}{2}$	+ 42.15	$1\frac{1}{2}$	.....	.....	+ 37.24	1	+ 40.56	2	+ 59.33	2
4468.663	.....	.....	+ 53.11	$\frac{1}{2}$	+ 54.83	2	.....	.....	.....	.....	+ 54.00	$\frac{1}{2}$	.....	.....
4395.201	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 26.70	1	+ 48.26	$\frac{1}{2}$
4374.520	.....	.....	+ 47.19	$\frac{1}{2}$	+ 48.36	$\frac{1}{2}$	+ 51.97	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4351.930	.....	.....	+ 24.80	1	+ 38.45	$\frac{1}{2}$	.....	.....	.....	.....	+ 30.80	1	.....	.....
4325.939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 29.11	$\frac{1}{2}$	.....	.....
4315.138	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 41.56	$\frac{1}{2}$
Weighted mean	+ 35.47		+ 38.35		+ 45.44		+ 50.51		+ 39.19		+ 38.43		+ 51.03	
V_a	- 6.87		- 9.50		- 10.48		- 15.06		- 15.97		- 16.03		- 19.38	
V_d	- 0.09		- 0.13		- 0.02		- 0.26		- 0.18		- 0.05		+ 0.08	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 28.2		+ 28.4		+ 34.7		+ 34.9		+ 22.8		+ 22.1		+ 31.4	

MEASURES OF θ TAURI—Continued.

λ	3108		3118		3133		3169		3201		3208		3222	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	+ 43.34	$\frac{1}{2}$	.....	.....	+ 35.76	$\frac{1}{2}$	+ 66.47	$\frac{1}{2}$	+ 61.36	1	.....	.....	+ 61.49	$\frac{1}{2}$
4572.156	+ 40.98	1	+ 49.55	$1\frac{1}{2}$	+ 52.67	1	+ 86.48	1	+ 96.96	$\frac{1}{2}$	+ 78.34	$\frac{1}{2}$	.....	.....
4563.939	.....	.....	.....	.....	+ 78.58	$\frac{1}{2}$	+ 73.18	$\frac{1}{2}$	+ 90.89	$\frac{1}{2}$	.....	.....	.....	.....
4549.766	+ 59.32	1	+ 61.98	1	+ 48.31	1	+ 75.29	$1\frac{1}{2}$	+ 60.65	1	+ 67.37	1	+ 88.19	1
4534.139	+ 51.04	1	+ 66.26	1	+ 66.41	$1\frac{1}{2}$	+ 72.31	1	+ 78.42	1	.....	.....	+ 73.43	$1\frac{1}{2}$
4508.455	.....	.....	.....	.....	.....	.....	.....	.....	+ 70.53	1	+ 97.17	$\frac{1}{2}$	.....	.....
4494.738	.....	.....	+ 55.07	$\frac{1}{2}$	.....	.....	.....	.....	+ 72.23	1	.....	.....	.....	.....
4481.400	+ 60.73	$1\frac{1}{2}$	+ 63.19	$1\frac{1}{2}$	+ 64.59	2	+ 73.01	$1\frac{1}{2}$	+ 57.16	$1\frac{1}{2}$	+ 92.25	2	+ 82.12	1
4468.663	.....	.....	+ 77.62	$\frac{1}{2}$	+ 68.65	$\frac{1}{2}$	.....	.....	+ 86.33	1	.....	.....	.....	.....
4395.201	+ 49.53	$\frac{1}{2}$	.....	.....	+ 52.68	$\frac{1}{2}$	.....	.....	+ 76.51	$\frac{1}{2}$	+ 82.41	1	+ 76.62	$\frac{1}{2}$
4340.634	.....	.....	.....	.....	+ 72.26	$\frac{1}{2}$	+ 62.51	$\frac{1}{2}$	+ 71.16	$1\frac{1}{2}$	+ 80.41	$\frac{1}{2}$	+ 77.57	$\frac{1}{2}$
4325.939	+ 44.21	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	+ 65.38	1	.....	.....	+ 74.10	$\frac{1}{2}$
4290.377	+ 49.00	1	+ 60.38	1	+ 76.78	$\frac{1}{2}$	.....	.....	+ 81.35	$1\frac{1}{2}$	+ 75.00	$\frac{1}{2}$	.....	.....
Weighted mean	+ 51.72		+ 60.58		+ 61.44		+ 74.40		+ 72.24		+ 87.60		+ 77.36	
V _a	- 22.09		- 22.40		- 23.74		- 27.70		- 29.89		- 29.87		- 29.88	
V _d	- 0.14		- 0.03		+ 0.01		- 0.27		- 0.14		- 0.14		- 0.14	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 29.2		+ 38.9		+ 37.4		+ 46.2		+ 42.9		+ 57.3		+ 47.0	

MEASURES OF θ^2 TAURI—Continued

λ	3255		3268		3308		3334		3623		3651		3658	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018					+ 87.86	$\frac{1}{2}$								
4572.156					+ 87.26	$\frac{1}{2}$	+109.32	$\frac{1}{2}$	+ 7.04	$\frac{1}{2}$	+ 1.62	$\frac{1}{2}$		
4563.939	+114.28	$\frac{1}{2}$	+105.18	1	+ 73.94	$\frac{1}{2}$	+ 92.34	$\frac{1}{2}$						
4549.766	+ 90.71	$\frac{1}{2}$	+ 66.55	$\frac{1}{2}$	+ 85.63	1	+ 96.19	$1\frac{1}{2}$	- 21.34	$\frac{1}{2}$	- 1.33	$\frac{1}{2}$	+ 25.35	$\frac{1}{2}$
4534.139	+ 98.28	$\frac{1}{2}$			+ 95.35	$\frac{1}{2}$								
4515.508			+ 60.55	$\frac{1}{2}$										
4481.400	+ 86.51	1	+ 71.46	$\frac{1}{2}$	+ 89.06	$1\frac{1}{2}$	+ 98.48	1	+ 18.88	1	+ 13.78	1	+ 9.70	1
4468.663			+ 95.03	$\frac{1}{2}$	+103.75	$\frac{1}{2}$					+ 13.68	1		
4395.201	+108.27	$\frac{1}{2}$			+ 95.21	1			+ 10.35	1	- 4.09	$\frac{1}{2}$	+ 20.47	$\frac{1}{2}$
4351.930	+ 85.66	$\frac{1}{2}$	+ 75.19	$\frac{1}{2}$	+ 92.86	$\frac{1}{2}$	+110.56	$\frac{1}{2}$						
4340.634	+ 84.46	1			+ 80.80	$\frac{1}{2}$			- 9.83	1	+ 21.98	$\frac{1}{2}$	+ 20.25	$\frac{1}{2}$
4325.939	+ 81.93	$\frac{1}{2}$	+ 94.50	$\frac{1}{2}$	+ 84.85	$\frac{1}{2}$								
4290.377	+ 79.04	$\frac{1}{2}$			+ 76.60	$\frac{1}{2}$	+105.91	1					+ 4.79	$\frac{1}{2}$
Weighted mean	+ 91.22		+ 84.50		+ 88.56		+100.70		+ 3.06		+ 9.14		+ 14.55	
V_a	- 29.78		- 29.73		- 29.13		- 28.12		+ 29.03		+ 28.33		+ 28.19	
V_d	- 0.28		- 0.21		- 0.28		- 0.21		+ 0.08		+ 0.08		+ 0.06	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		0.28		- 0.28	
Radial Velocity	+ 60.9		+ 55.3		+ 58.8		+ 72.1		+ 31.9		+ 37.3		+ 42.5	

MEASURES OF θ^2 TAURI—Continued.

λ	3668		3687		3730		3741		3784		3793		3802	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	- 0.68	$\frac{1}{2}$	- 17.44	$\frac{1}{2}$	- 7.90	1	- 7.22	$\frac{1}{2}$	+ 32.98	1	.....	.....	+ 19.35	$\frac{1}{2}$
4572.156	- 4.87	$\frac{1}{2}$	.....	.....	+ 11.91	1	.....	.....	+ 22.32	1	+ 20.57	$\frac{1}{2}$	+ 15.15	$\frac{1}{2}$
4563.939	.....	.....	+ 20.59	$\frac{1}{2}$	.....	.....	.....	.....	+ 29.48	$\frac{1}{2}$	+ 42.93	$\frac{1}{2}$	.....	.....
4549.766	+ 5.33	$\frac{1}{2}$	+ 10.68	1	+ 1.33	2	+ 26.68	1	+ 16.01	$1\frac{1}{2}$	+ 20.67	$1\frac{1}{2}$	+ 22.68	$1\frac{1}{2}$
4534.139	- 22.97	$\frac{1}{2}$	- 10.04	1	+ 8.45	1	.....	.....	+ 49.64	$\frac{1}{2}$	+ 30.90	$\frac{1}{2}$	+ 40.14	$\frac{1}{2}$
4515.508	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 30.26	$\frac{1}{2}$
4508.455	.....	.....	.....	.....	.....	.....	.....	.....	+ 10.01	1	.....	.....	+ 48.50	$\frac{1}{2}$
4501.448	.....	.....	.....	.....	.....	.....	.....	.....	+ 28.17	1	.....	.....	+ 33.34	1
4481.400	+ 13.47	1	+ 27.32	2	+ 1.03	2	+ 26.04	$1\frac{1}{2}$	+ 36.31	1	+ 24.76	2	+ 50.42	2
4468.663	.....	.....	.....	.....	+ 4.68	1	+ 19.86	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4404.927	+ 8.83	1	+ 2.78	$\frac{1}{2}$	.....	.....	.....	.....	+ 14.88	$\frac{1}{2}$	.....	.....	.....	.....
4399.935	- 18.48	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4395.201	.....	.....	+ 2.29	1	+ 5.52	$\frac{1}{2}$	+ 12.14	$\frac{1}{2}$	.....	.....	+ 24.78	$\frac{1}{2}$	+ 29.58	1
4374.520	.....	.....	+ 12.95	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4351.930	- 5.37	1	.....	.....	+ 2.81	1	+ 16.00	1	.....	.....	+ 30.20	$\frac{1}{2}$	+ 38.95	$\frac{1}{2}$
4340.634	+ 14.11	$1\frac{1}{2}$	+ 0.58	$\frac{1}{2}$	+ 24.87	$\frac{1}{2}$	+ 18.52	1	.....	.....	+ 28.93	$\frac{1}{2}$	+ 33.55	$\frac{1}{2}$
4325.939	- 12.48	1	.....	.....	.....	.....	- 12.15	$\frac{1}{2}$	.....	.....	+ 12.27	$\frac{1}{2}$	.....	.....
Weighted mean	- 0.72		+ 9.04		+ 3.99		+ 16.40		+ 25.10		+ 25.11		+ 34.52	
V _s	+ 28.06		+ 27.21		+ 22.24		+ 21.56		+ 13.97		+ 13.02		+ 10.17	
V _r	+ 0.20		+ 0.04		- 0.13		- 0.08		- 0.13		- 0.08		- 0.10	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 27.3		+ 36.0		+ 25.8		+ 37.6		+ 38.7		+ 37.8		+ 44.3	

MEASURES OF θ^2 TAURI—Continued.

λ	3818		3843		3859		3871		3888		3916		3922	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018			+ 71.83	1			+ 48.66	$\frac{1}{2}$	+ 52.06	$\frac{1}{2}$	+ 51.66	1	+ 34.35	$\frac{1}{2}$
4572.156			+ 67.24	1			+ 46.27	$\frac{1}{2}$	+ 69.27	$\frac{1}{2}$	+ 64.67	$1\frac{1}{2}$	+ 29.36	1
4563.939	+ 89.37	$\frac{1}{2}$	+ 38.90	$\frac{1}{2}$	+ 53.03	1	+ 79.95	$\frac{1}{2}$	- 72.55	$\frac{1}{2}$	+ 71.34	$\frac{1}{2}$		
4549.766	+ 50.69	1	+ 61.36	$1\frac{1}{2}$	+ 70.03	1	+ 67.37	$1\frac{1}{2}$	+ 69.37	1	+ 57.50	$1\frac{1}{2}$	+ 38.55	1
4534.139	+ 62.62	$\frac{1}{2}$	+ 69.88	1	+ 81.37	1			+ 100.92	$\frac{1}{2}$	+ 74.50	$\frac{1}{2}$	+ 48.08	$1\frac{1}{2}$
4501.448			+ 55.99	1							+ 55.08	1	+ 59.87	$\frac{1}{2}$
4481.400	+ 63.54	$1\frac{1}{2}$	+ 71.20	2	+ 69.92	$1\frac{1}{2}$	+ 67.37	$1\frac{1}{2}$	+ 90.34	1	+ 58.44	$1\frac{1}{2}$	+ 53.97	$1\frac{1}{2}$
4468.663					+ 84.38	$\frac{1}{2}$			+ 100.82	1	+ 80.58	1		
4404.927	+ 46.27	$\frac{1}{2}$	+ 64.55	1	+ 42.14	1	+ 61.82	1			+ 50.01	1	+ 52.44	$\frac{1}{2}$
4399.935													+ 33.80	$\frac{1}{2}$
4395.201			+ 53.65	1	+ 86.13	1	+ 57.38	1	+ 62.20	1	+ 62.28	1	+ 44.03	$\frac{1}{2}$
4351.930	+ 54.73	$\frac{1}{2}$					+ 67.22	1	+ 77.49	$\frac{1}{2}$			+ 55.90	$\frac{1}{2}$
4340.634			+ 56.11	1			+ 68.84	1	+ 83.88	1	+ 73.05	1	+ 63.63	$\frac{1}{2}$
Weighted mean	+ 60.55		+ 62.13		+ 68.54		+ 64.08		+ 79.03		+ 61.43		+ 47.41	
V_a	- 3.62		- 5.69		- 7.20		- 8.74		- 11.72		- 18.48		- 20.11	
V_s	+ 0.04		0.00		+ 0.14		0.00		- 0.04		+ 0.06		- 0.04	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 56.7		+ 56.2		+ 61.2		+ 55.1		+ 67.0		+ 42.7		+ 27.0	

MEASURES OF θ TAURI.—Continued.

λ	3930		3938		3958		3973		4627		4636		4672	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	+ 53.04	$\frac{1}{2}$	+ 50.02	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	- 7.73	$\frac{1}{2}$
4572.156	.....	.....	+ 42.21	$\frac{1}{2}$	+ 65.21	$\frac{1}{2}$	+ 61.27	$\frac{1}{2}$	+ 47.63	$\frac{1}{2}$	+ 39.89	1	+ 16.82	$\frac{1}{2}$
4563.939	+ 49.89	1	+ 38.23	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4549.766	.....	.....	+ 55.36	1	+ 49.36	$1\frac{1}{2}$	+ 58.88	1	+ 24.68	$\frac{1}{2}$	.....	.....	+ 7.03	$\frac{1}{2}$
4534.139	+ 49.41	1	+ 42.80	$\frac{1}{2}$	+ 49.41	$\frac{1}{2}$	.....	.....	+ 38.84	$\frac{1}{2}$	+ 49.41	$\frac{1}{2}$	+ 3.22	$\frac{1}{2}$
4501.448	+ 66.33	$\frac{1}{2}$	.....	.....	.....	.....	+ 48.18	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4481.400	+ 46.96	$1\frac{1}{2}$	+ 48.87	$1\frac{1}{2}$	+ 50.78	2	+ 73.25	1	+ 50.78	1	+ 48.23	1	+ 21.93	1
4468.663	+ 79.32	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	+ 21.19	$\frac{1}{2}$	.....	.....
4404.927	.....	.....	+ 57.28	$\frac{1}{2}$	+ 55.46	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4399.935	.....	.....	+ 33.80	$\frac{1}{2}$	+ 44.06	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4395.201	+ 46.07	$\frac{1}{2}$	+ 45.23	$\frac{1}{2}$	+ 59.67	1	.....	.....	.....	.....	+ 30.32	$\frac{1}{2}$	.....	.....
4351.930	+ 51.23	$\frac{1}{2}$	+ 63.48	$\frac{1}{2}$	+ 48.31	$\frac{1}{2}$	.....	.....	+ 52.98	$1\frac{1}{2}$	+ 48.31	$\frac{1}{2}$	.....	.....
4340.634	+ 55.53	$\frac{1}{2}$	+ 52.07	1	.....	.....	.....	.....	+ 57.27	2	+ 41.07	$1\frac{1}{2}$	.....	.....
Weighted mean	+ 53.92		+ 48.97		+ 52.35		+ 62.28		+ 48.48		+ 40.79		+ 11.73	
V_a	- 21.25		- 22.70		- 23.99		- 26.75		+ 22.36		+ 21.67		+ 15.42	
V_s	- 0.06		- 0.17		- 0.06		- 0.11		+ 0.10		- 0.03		+ 0.07	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 32.3		+ 25.8		+ 28.0		+ 35.1		+ 70.7		+ 62.1		+ 26.9	

MEASURES OF θ^2 TAURI.—Continued.

λ	4716		4733		4739		4760		4780		4788		4792	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	+ 8.45	$\frac{1}{2}$	.....	.....	+ 30.26	$\frac{1}{2}$	.....	.....	+ 44.98	$\frac{1}{2}$	.....	.....	+ 66.38	$\frac{1}{2}$
4572.156	+ 21.92	$\frac{1}{2}$	+ 32.92	$\frac{1}{2}$	.....	.....	+ 48.61	$\frac{1}{2}$	+ 78.07	$\frac{1}{2}$	.....	.....	.....	.....
4563.939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 50.48	$\frac{1}{2}$	+ 72.28	$\frac{1}{2}$
4549.766	+ 35.88	1	+ 40.28	1	+ 45.09	$\frac{1}{2}$	+ 57.20	$\frac{1}{2}$	+ 58.69	$\frac{1}{2}$	+ 56.31	$\frac{1}{2}$	+ 61.36	1
4534.139	.....	.....	+ 53.10	$\frac{1}{2}$	+ 41.48	$\frac{1}{2}$	+ 50.88	$\frac{1}{2}$	+ 71.86	$\frac{1}{2}$	+ 73.09	$\frac{1}{2}$	+ 73.05	$\frac{1}{2}$
4481.400	+ 53.34	$1\frac{1}{2}$	+ 46.51	1	+ 48.49	$1\frac{1}{2}$	+ 69.40	$\frac{1}{2}$	+ 65.46	$\frac{1}{2}$	+ 74.59	$\frac{1}{2}$	+ 76.94	1
4455.116	.....	.....	+ 35.84	$\frac{1}{2}$	.....	.....	.....	.....	+ 73.86	$\frac{1}{2}$	+ 58.60	$\frac{1}{2}$	.....	.....
4415.293	.....	.....	+ 26.48	1	+ 51.36	$\frac{1}{2}$	+ 77.91	$\frac{1}{2}$	.....	.....	+ 43.21	$\frac{1}{2}$	+ 41.96	$\frac{1}{2}$
4395.201	+ 32.12	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4351.930	+ 54.73	1	.....	.....	+ 59.98	1	.....	.....	+ 71.65	$\frac{1}{2}$	.....	.....	+ 56.48	1
4340.634	+ 37.83	1	.....	.....	+ 59.59	1	.....	.....	+ 69.42	1	.....	.....	+ 73.47	$\frac{1}{2}$
4325.939	+ 29.52	1	.....	.....	.....	.....	.....	.....	+ 56.45	$\frac{1}{2}$	.....	.....	+ 51.87	$\frac{1}{2}$
Weighted mean	+ 38.59		+ 37.99		+ 49.35		+ 62.15		+ 66.88		+ 60.71		+ 63.67	
V_a	- 4.03		- 10.70		- 13.54		- 20.41		- 21.18		- 21.49		- 22.60	
V_d	+ 0.07		- 0.27		- 0.17		- 0.07		- 0.14		+ 0.11		- 0.05	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 34.2		+ 26.7		+ 35.4		+ 41.4		+ 45.3		+ 39.1		+ 40.7	

MEASURES OF θ^2 TAURI.—Continued.

λ	4832		4835		4880		5218		5236		5243		5244	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584·018	.....	.....	.....	.....	.....	.....	.....	.....	+ 18·00	$\frac{1}{2}$	.....	.....	.....	.....
4572·156	.....	.....	+ 92·74	$\frac{1}{2}$	+ 44·92	$\frac{1}{2}$	.....	.....	+ 25·44	$\frac{1}{2}$	.....	.....	.....	.....
4549·766	+ 80·04	$\frac{1}{2}$	+ 83·24	$\frac{1}{2}$	+ 52·56	1	+ 5·87	1	+ 12·67	1	+ 26·14	1	+ 18·84	1
4534·139	+ 94·32	$\frac{2}{3}$	+ 86·39	$\frac{2}{3}$	+ 57·33	$\frac{1}{2}$	+ 17·04	$\frac{1}{2}$	+ 26·01	$\frac{2}{3}$	+ 37·50	$\frac{1}{2}$	+ 30·38	$\frac{1}{2}$
4481·400	+ 95·44	$\frac{1}{2}$	+ 91·69	1	+ 59·72	$\frac{1}{2}$	+ 35·49	1	+ 38·68	2	+ 33·45	$1\frac{1}{2}$	+ 29·11	2
4468·663	.....	.....	.....	.....	.....	.....	.....	.....	+ 39·59	1	.....	.....	.....	.....
4415·293	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 35·50	$\frac{1}{2}$	.....	.....
4395·201	+ 102·98	$\frac{1}{2}$	+ 78·07	$\frac{1}{2}$	+ 53·65	$\frac{1}{2}$	+ 23·23	$\frac{1}{2}$	.....	.....	.....	.....	+ 18·90	$\frac{2}{3}$
4351·930	+ 80·99	1	+ 92·08	1	+ 59·98	1	+ 8·29	$\frac{1}{2}$	+ 19·15	$\frac{2}{3}$	+ 27·80	$\frac{1}{2}$	+ 24·29	$\frac{2}{3}$
4340·634	+ 94·30	$\frac{1}{2}$	+ 89·67	$\frac{1}{2}$	+ 56·11	$\frac{1}{2}$	+ 19·10	1	+ 23·85	$\frac{1}{2}$	+ 27·79	1	+ 23·14	1
Weighted mean	+ 90·16		+ 88·50		+ 55·20		+ 17·72		+ 25·75		+ 30·90		+ 24·63	
V_s	- 28·79		- 29·05		- 28·96		+ 24·06		+ 23·16		+ 20·07		+ 20·06	
V_d	- 0·23		- 0·24		- 0·18		+ 0·12		+ 0·10		+ 0·12		+ 0·04	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	+ 60·9		+ 58·9		+ 25·8		+ 41·6		+ 48·7		+ 50·8		+ 44·4	

MEASURES OF θ^2 TAURI.—Continued.

λ	5250		5251		5253		5254		5259		5260		5892	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	+ 32.01	$\frac{1}{2}$	+ 24.93	$\frac{1}{2}$	+ 32.01	1	+ 20.69	1	+ 31.22	1	+ 19.34	1	+ 92.10	1
4534.939	.....	.....	+ 46.76	$\frac{1}{2}$	+ 34.34	1	+ 19.81	1	+ 39.70	$\frac{1}{2}$	+ 30.39	$\frac{1}{2}$	+ 111.00	$\frac{1}{2}$
4501.448	+ 8.70	$\frac{1}{2}$	+ 13.31	1	+ 20.81	$\frac{1}{2}$	+ 44.49	$\frac{1}{2}$	+ 41.76	$\frac{1}{2}$	.....	.....	+ 88.84	$\frac{1}{2}$
4481.400	+ 30.39	1	+ 43.78	1	+ 36.76	$1\frac{1}{2}$	+ 33.43	2	+ 45.69	1	+ 32.93	$1\frac{1}{2}$	+ 91.78	1
4404.927	+ 21.30	$\frac{1}{2}$	+ 27.13	1	+ 8.84	$\frac{1}{2}$	.....	.....	+ 39.38	$\frac{1}{2}$	+ 24.59	$\frac{1}{2}$	.....	.....
4395.201	.....	.....	.....	.....	+ 17.33	1	.....	.....	+ 46.70	1	+ 26.85	$\frac{1}{2}$	.....	.....
4351.930	+ 16.80	$\frac{1}{2}$	.....	.....	+ 32.69	$\frac{1}{2}$	.....	.....	+ 36.53	$\frac{1}{2}$	+ 20.90	$\frac{1}{2}$	.....	.....
4340.634	+ 35.30	$\frac{1}{2}$	+ 23.72	1	+ 20.25	$\frac{1}{2}$	+ 32.76	$\frac{1}{2}$	+ 38.79	$\frac{1}{2}$	+ 35.30	$\frac{1}{2}$	+ 85.38	2
4325.939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 79.75	1
Weighted mean	+ 22.13		+ 28.76		+ 27.72		+ 29.20		+ 40.31		+ 27.55		+ 88.20	
V_a	+ 19.68		+ 19.67		+ 17.75		+ 17.74		+ 16.51		+ 16.50		- 24.40	
V_d	- 0.10		- 0.15		+ 0.28		+ 0.21		+ 0.14		+ 0.07		- 0.08	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 41.4		+ 48.0		+ 45.5		+ 46.9		+ 56.7		+ 43.9		+ 63.4	

MEASURES OF θ^2 TAURI.—*Concluded.*

λ	5902		5903		5904		5905		5914					
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584.018	+ 82.38	$\frac{1}{2}$	.....		+ 83.95	$\frac{1}{2}$	+ 68.57	$\frac{1}{2}$	+ 49.38	$\frac{1}{2}$	.....		.....
4572.156	+ 82.70	$\frac{1}{2}$	.....		+ 62.84	$\frac{1}{2}$	+ 53.41	$\frac{1}{2}$	.....		.....		.....
4563.939	+102.95	$\frac{1}{2}$	+ 88.72	$\frac{1}{2}$	+104.82	$\frac{1}{2}$	+ 65.30	$\frac{1}{2}$	+ 67.00	$\frac{1}{2}$	.....		.....
4549.766	+104.55	1	+ 99.00	$\frac{1}{2}$	+ 98.66	$\frac{1}{2}$	+ 66.13	$\frac{1}{2}$	+ 73.42	$\frac{1}{2}$	.....		.....
4534.139	.....		+115.05	$\frac{1}{2}$	.....		+ 67.82	$\frac{1}{2}$	+ 51.45	$\frac{1}{2}$	.....		.....
4481.400	+105.90	1	+107.80	$\frac{1}{2}$	+ 94.38	$\frac{1}{2}$	+ 73.08	$\frac{1}{2}$	+ 64.60	1	.....		.....
4468.663	+113.83	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4340.634	.....		.....		.....		.....		+ 83.75	$\frac{1}{2}$	.....		.....
4325.939	+ 64.40	$\frac{1}{2}$	.....		.....		.....		+ 41.22	$\frac{1}{2}$	.....		.....
Weighted mean	+100.14		+103.67		+ 91.10		+ 65.77		+ 61.93		.....		.....
V_a	- 25.53		- 27.04		- 27.47		- 27.85		- 28.05		.....		.....
V_d	- 0.14		- 0.21		- 0.14		- 0.04		- 0.18		.....		.....
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		.....		.....
Radial Velocity	+ 74.2		+ 76.1		+ 63.2		+ 37.6		+ 33.4		.....		.....

A summary of the previous work on the orbit, which has considerable bearing on this later determination will now be given. It was found necessary to carry through three least-squares solutions of the orbit. In the first one of these, a correction for the period was introduced but when this correction was carried forward to the Lick and Yerkes observations it was found to be quite inapplicable. Consequently the period was determined as closely as possible from a comparison of the early with the Ottawa values and the coefficient for this correction omitted from the later solutions.

The second solution resulted in such a large increase of K and consequent rise of the positive maximum velocity above any observed values as again to be inadmissible. This was undoubtedly due to the absence of any Ottawa observations near the peak of the curve, which is of course very sharp when the eccentricity is 0.7. For the third solution,

therefore, one Lick observation of +80 km., and one Yerkes of +88 km., taken on the same day, Sept. 8, 1908, very near the maximum, were combined into an additional normal place and incorporated into the observation equations, and the resulting solution was satisfactory. These different solutions are given here:—

Element.	1st Preliminary.	1st Solution.	2nd Preliminary.	2nd Solution.	3rd Preliminary.	3rd Solution (without Lick and Yerkes Observations)	3rd Solution (with Lick and Yerkes Observations)
Period	141.0	141.487	140.50	140.50	140.50	140.50	140.50
e	0.65	0.699	0.65	0.758	0.70	0.772	0.694
K	25.0	26.59	27.0	33.76	32.0	37.99	29.128
ω	45°.0	47°.43	50°.0	39°.09	45°.0	38°.22	48°.57
T	51.0	51.075	56.33	54.876	55.74	55.207	56.12
γ	+41.51	+42.17	+42.72	+43.60	+43.16	+43.713	+42.90
Max. Vel.	+78.0	+81.34	+81.0	+97.22	+91.0	+104.7	+85.40
Min. Vel.	+28.0	+28.16	+27.0	+29.70	+27.0	+28.7	+27.14

The curious behaviour of these elements in the successive solutions is due to the preliminary elements in each case being not sufficiently close approximations to allow the second order differentials to be neglected, and also to the fact, and this also influenced the choice of the preliminary values, that there were no observations near the peak of the curve while the others were so situated as to abnormally influence the least-squares solutions. However it was not felt desirable, as was done in the 3rd solution, to combine the Ottawa measures with those from other observatories, especially in view of the high residuals given by some of the latter; and it was decided to secure further observations here, around the peak and on the descending branch of the curve, to enable a more accurate period and more consistent and homogeneous elements to be determined. Further, the question of a second spectrum shown by two of the Yerkes and also possibly on some Ottawa plates should, if possible, be settled.

The first series of additional plates in October, 1912, was, through an oversight, unfortunately taken at the wrong time, and it was not until January, 1914, that plates at the proper epoch were obtained. When these measures were combined with the earlier ones, it was at once seen

that the previous period of 140.50 days obtained from comparison of the Ottawa and earlier observations was not exact, but that it would have to be increased about 0.2 day. Observations 7 periods apart, at approximately the same place on the very steep descending branch, enabled the period to be determined quite accurately as 140.70 days. With this period all the observations were combined into 18 normal places, each plate being arbitrarily weighted according to its general quality and the number of lines measured. The weighted velocities and phases of these normal places are given in the accompanying table, the initial epoch T_0 being taken as Julian Day 2,418,000.

The number and position of these normal places were so chosen and, at the same time, the extreme range of phase in any one of them was relatively so small, that they satisfactorily represent all the observations. Their weights are submultiples of the sums of the weight of the plates therein, so taken for convenience of the least-squares solutions, that the maximum weight is unity. The residuals are those determined from the final elements.

NORMAL PLACES.

No.	Wt.	Phase	Velocity	Residual O-C.	No.	Wt.	Phase	Velocity	Residual O-C.
1	1	5.37	+ 44.84	+ 1.26	10	$\frac{1}{3}$	58.05	+ 37.87	- 4.00
2	$\frac{1}{4}$	12.75	47.10	+ 1.12	11	$\frac{1}{3}$	64.35	28.76	+ 0.88
3	$\frac{1}{2}$	23.24	50.15	- 0.07	12	$\frac{1}{3}$	70.12	26.90	+ 0.01
4	1	34.81	58.20	+ 0.93	13	$\frac{1}{3}$	80.69	33.50	+ 4.99
5	$\frac{1}{2}$	44.15	68.20	+ 0.57	14	$\frac{1}{3}$	87.20	35.04	+ 5.17
6	$\frac{1}{3}$	48.05	74.20	- 0.54	15	$\frac{1}{3}$	94.83	33.87	+ 2.36
7	$\frac{1}{3}$	53.12	76.10	- 3.33	16	$\frac{1}{3}$	111.28	29.98	- 5.04
8	$\frac{1}{3}$	54.49	70.70	- 1.07	17	$\frac{1}{3}$	125.55	33.63	- 4.58
9	$\frac{1}{4}$	56.26	62.70	+ 7.26	18	$\frac{1}{2}$	133.39	40.08	- 0.04

When the normal places were plotted on cross-section paper, preliminary elements suiting the velocity curve fairly well were, with the experience gained in the previous determination, soon obtained by the aid of Dr. King's graphical method.*

*Report of Chief Astronomer 1908, p. 329 and Astrophysical Journal XXVII p. 125.

The values adopted were:

- Period = 140.70 days
- $e = 0.7$
- $\omega = 55^\circ$
- $K = 26.25$ km.
- $T =$ J. D. 2,418,054.80
- $\gamma = +42.21$ km.

Observation equations for each of the 18 normal places were formed from these elements by Schlesinger's convenient method.* In these observation equations the numbering begins from the time of periastron instead of from T_0 as in the normal places, or No. 1 here is No. 9 in the normal places.

OBSERVATION EQUATIONS.

No.	Weight	Γ	κ	π	ϵ	τ	δV
1.....	$\frac{1}{4}$	1.000	+ .110	+ .994	+ .562	+ .895	+ 7.06
2.....	$\frac{1}{4}$	1.000	- .376	+ .927	+ .837	+ .611	- 4.88
3.....	$\frac{2}{5}$	1.000	- .948	+ .317	+ .248	+ .010	+ 1.01
4.....	$\frac{1}{4}$	1.000	- 1.000	- .010	- .006	- .001	+ 0.40
5.....	$\frac{1}{8}$	1.000	- .944	- .330	- .125	- .021	+ 5.62
6.....	$\frac{2}{5}$	1.000	- .893	- .451	- .133	- .023	+ 5.81
7.....	$\frac{2}{5}$	1.000	- .830	- .558	- .122	- .023	+ 3.01
8.....	$\frac{1}{4}$	1.000	- .694	- .720	- .066	- .024	- 4.49
9.....	$\frac{1}{2}$	1.000	- .570	- .822	+ .002	- .025	- 4.10
10.....	$\frac{1}{2}$	1.000	- .496	- .868	+ .045	- .023	+ 0.41
11.....	1	1.000	- .361	- .932	+ .139	- .034	+ 1.61
12.....	$\frac{1}{4}$	1.000	- .268	- .963	+ .195	- .039	+ 1.42
13.....	$\frac{1}{2}$	1.000	- .103	- .995	+ .303	- .052	+ 0.10
14.....	1	1.000	+ .168	- .986	+ .471	- .086	+ 1.03
15.....	$\frac{1}{2}$	1.000	+ .558	- .830	+ .612	- .160	+ 0.73
16.....	$\frac{1}{8}$	1.000	+ .810	- .586	+ .526	- .198	+ 0.13
17.....	$\frac{1}{8}$	1.000	+ .925	+ .379	- .240	+ .33	- 1.03
18.....	$\frac{1}{8}$	1.000	+ .659	+ .752	- .099	+ .747	+ 0.57

In these observation equations according to Schlesinger's notation,

$$\Gamma = \delta\gamma + e \cdot \cos \omega \cdot \delta K + K \cdot \cos \omega \cdot \delta e - K \cdot e \cdot \sin \omega \cdot \delta\omega$$

$$\kappa = \delta K$$

$$\pi = -K \cdot \delta\omega = -26.25 \delta\omega$$

$$\epsilon = -K \cdot \frac{2.21}{1-e^2} \delta e = -113.75 \delta e$$

$$\tau = K \cdot \mu \sqrt{\frac{1+e}{1-e}} \cdot \frac{1}{1-e} \cdot \delta T = 9.302 \delta T$$

*Publications Allegheny Observatory I, p. 33

The resulting normal equations are:

$$\begin{array}{rcl}
 7.759 \tau - 2.356 \kappa - 4.036 \pi + 1.659 \epsilon + .316 \tau & = & + 2.329 \\
 + 2.682 \kappa + 1.019 \pi + .094 \epsilon - .027 \tau & = & - .276 \\
 + 5.078 \pi - .480 \epsilon + .856 \tau & = & - 1.709 \\
 + 1.013 \epsilon + .245 \tau & = & - .227 \\
 + .481 \tau & = & - .127
 \end{array}$$

The solution of these equations gives the following values of the unknowns:

$\kappa = + .8711$	whence	$\delta K = + .87$
$\pi = + .3865$	“	$\delta \omega = - .844$
$\epsilon = - 1.927$	“	$\delta e = + .0169$
$\tau = - .7156$	“	$\delta T = - .0769$
$\gamma = + 1.207$	“	$\delta \gamma = + .381$

These corrections result in the following values for the elements with the derived values of the probable errors. Σpvv is reduced from 75.04 to 72.87, showing that the preliminary values were very close to the final ones. This is also indicated by the smallness of the differences between the values obtained by substituting in the observation equations and those obtained from the ephemeris from the corrected elements.

FINAL ELEMENTS

Period, $P = 140.70$ days

Eccentricity, $e = 0.717 \pm .022$

Longitude of Apse, $\omega = 54^\circ.16 \pm 4^\circ.35$

Semi-Amplitude, $K = 27.12$ km. ± 1.44 km.

Periastron Passage, $T = \text{J. D. } 2,418,054.723 \pm 0.520$ day

Velocity of System, $\gamma = + 42.59$ km.

Maximum Velocity = $+ 81.10$

Minimum Velocity = $+ 26.86$

Projected length semi-axis major, $a \sin i = 37,471,000$.

The comparatively high values of the probable error of the elements is due principally to the abnormal deviations between phases 70 and 134 from the velocity curve drawn from these elements and shown in full line

in the accompanying figure. These deviations, which will be more fully discussed later, make the probable error of a normal place of unit weight and consequently the probable errors of the elements nearly double what they would otherwise be.

From a carefully drawn curve on a large scale, the residuals from the observations were obtained and are given in the last column but one of the table of observations. From these residuals, the probable error of a single Ottawa plate comes out as ± 3.6 km. per second. It will be of interest to compare the probable errors for the different dispersions used and these are given herewith.

Spectrograph	\AA per mm. at H_{γ}	No. of Plates	Probable Error Single Plate
I.	33.4	45	3.7
III R.	20.2	3	3.2
III S.	17.6	11	
III L.	10.1	9	3.9

There is very little difference in the accuracy of measurement with the different dispersions, the advantage seeming to lie with the three-prism dispersion and short camera. The advantage of increased linear scale is offset evidently by increased diffuseness of the lines. Considering the character of the spectrum and the presence of some abnormal effect the accuracy may be considered satisfactory.

In the velocity curve drawn from these elements the normal places are represented by circles. It will be seen that, considering the diffuse character of the spectrum lines, the agreement is quite satisfactory excepting between phases 70 and 134 where there is a marked double hump. As the five normal places in this region have on the average four plates each it is evident that this deviation must be considered to have a probable objective existence. It is impossible to give a definite cause for this abnormal effect. As its period is approximately half the main period and

as there seems to be a continuance of this effect further along the velocity curve, one apparent explanation would be a secondary disturbance of half the period of the binary. Although such an effect does not admit of any probable physical explanation, it was thought worth while to determine the elements of the orbit on this supposition. Assuming suitable preliminary elements and carrying through a least-squares solution, adding terms for the amplitude and phase of a simple sine curve superposed on the velocity curve, the following elements were obtained.

Periods, 140.70 days and 70.35 days

Eccentricity, $e=0.711$

Longitude of Apse, $\omega=50^{\circ}.80$

Semi-Amplitude Primary, $K=29.03$ km.

Periastron Passage, $T=J. D. 2,418,054.641$

Velocity of System, $\gamma=+42.63$ km.

Semi-Amplitude Secondary, $K=3.57$ km.

Phase Ascending Node Secondary= $J. D. 2,418,067.42$

Maximum Velocity Primary 84.71 Combined 81.1

Minimum Velocity Primary 26.65 Combined 27.0.

The compound curve is shown in dotted lines in the figure, and it is quite evident that it does not represent the observations much, if any, more satisfactorily than the simple curve for, while the agreement is better between phases 80 and 130, it is poorer at other parts. The average plate residual is only reduced about 5 per cent. by the introduction of the secondary. One possible explanation of the deviations is the presence of the spectrum of the companion to the principal star and the displacement of the measured velocities towards the γ line by the blend effect of the two spectra. It is difficult to see how such a blend effect can cause deviations of the peculiar character shown here, as the curve goes through a complete cycle below the γ line and exhibits no evidence of blending above this line. Yet Harper's orbit of θ Aquilae*, a binary whose elements are quite similar to those of θ^2 Tauri, shows similar deviations below the γ line though not so strongly marked as here. In the case of θ Aquilae

*Journal R.A.S.C. III p. 87, Mar-Apr., 1909.

it was later shown that this was probably due to the presence of a second spectrum with the resultant blend effect. The inference is that the second spectrum is present in θ^2 Tauri, but as yet no reasonable evidence to that effect has been secured. On two of the early plates obtained at Yerkes, the second spectrum was measured, and on four obtained here some apparent doubling was observed. The results at Yerkes and the attempted measures here, given in the last column of the table of measures, all bring the secondary spectrum in impossible positions. For example, the secondary velocity in one plate and the primary velocity in the other plate at Yerkes fall within two or three kilometres of the γ line, while the velocities of primary and secondary in every suspected case here are in equally impossible relative positions. Furthermore, later trials on these suspected plates found me unable to repeat my measures and I strongly doubt the reality of the doubling. As previously stated, plates have been especially secured here, with three different dispersions, near the maximum positive velocity when the doubling should be most pronounced but in no case can doubled lines be definitely seen and while there is possibly a second spectrum present the lines are so broad, diffuse, and lacking in contrast, that I doubt whether positive evidence either way can be obtained.

Other reasons may be cited for suspecting abnormal conditions in this star. The large residuals from the orbit of some of the plates obtained at the Lick and Yerkes observatories, the average residual being 8.4 as compared with 4.1 km. at Ottawa, are much greater than can be explained by the poor character of the spectrum or by the choice of different lines with different wave-lengths for measurements. Another reason is to be found in the difference between the velocity of the system obtained here +42.6 km. per second and that obtained from its stream motion +39.2. θ^2 Tauri is of special interest as being one of the moving stream in Taurus described by Prof. Boss.* His computed radial velocity for θ^2 Tauri is 40.5 km. per second, 2.1 km. less than the Ottawa value. His velocity is based on Kustner's determination of the radial motion of three other stars of the group. In a later discussion of the Taurus stream by Wilson†,

* *Astronomical Journal* XXVI, p. 31.

† *Popular Astronomy* XX, p. 359.

in which the computed values are based on the radial velocities of 8 stars of the stream determined by Campbell and hence of much greater weight, the velocity of θ^2 Tauri comes out at 39.2 or 3.4 km. smaller than the Ottawa value.

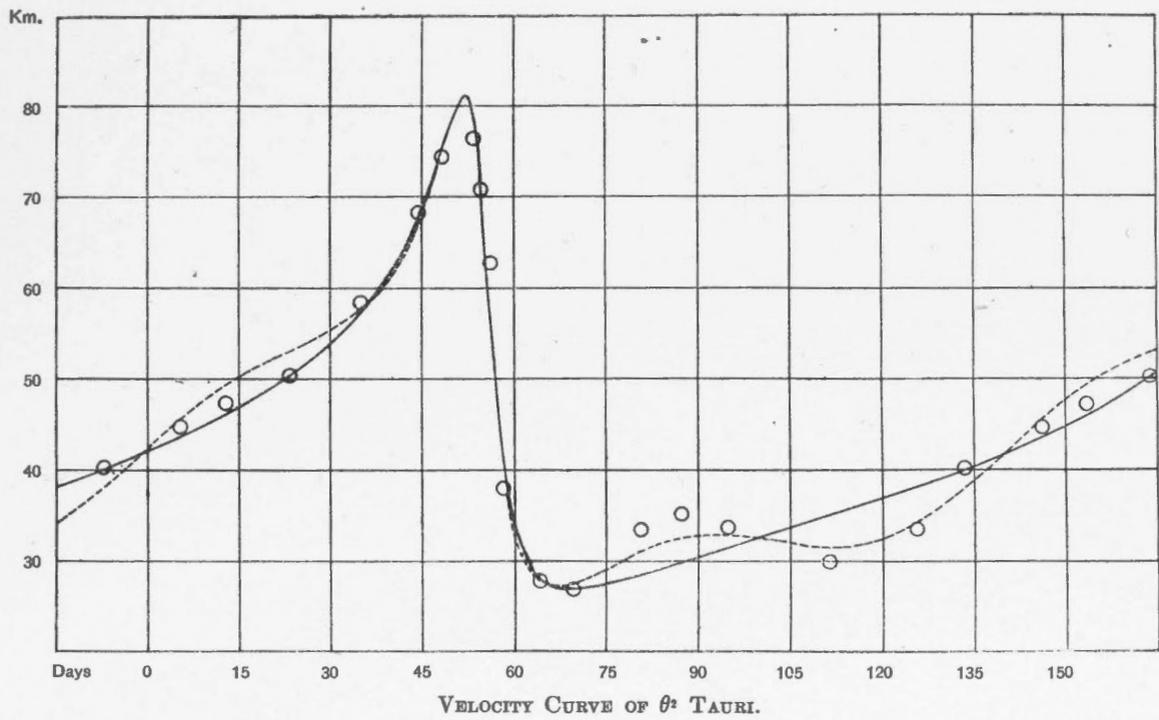
It seems to me probable, therefore, that the Ottawa value is over 3 km. too high and though it is possible to explain this systematic difference by incorrect identifications or wave-lengths it is more likely due to some cause which may be also operative in producing the curious humps in the curve and causing the early observations to have such unreasonably large residuals.

It is of interest to interpolate here that if Boss's value of the proper motion and of the distance of the convergent be accepted, the value of the parallax of θ^2 Tauri is $0''.023$ equivalent to a light journey of about 140 years.

The similarity between the velocity curve of θ^2 Tauri and that of the Cepheid variable W Sagittarii* is quite marked, the deviations from simple elliptic motion occurring in exactly the same relative positions in the orbits and being of approximately equal relative magnitudes. Moreover, except in the longer period and higher eccentricity, the elements are quite similar and it may be that the abnormal effects are produced by the same causes. Although the variation must be small it is possible that accurate photometric observations might show θ^2 Tauri to be a variable star and it would be of interest to have this tested. Although it is possible that a better orbit would be obtained if a considerable number of additional spectra were secured, the character of the spectrum lines is such as to render this additional work of doubtful value.

Dominion Observatory,
Ottawa,
February, 1915.

* Astrophysical Journal XX, p. 172.



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The binary character of ω Cassiopeiæ ($\alpha = 1^h 49^m \cdot 0$, $\delta = +68^\circ 15'$, 1910, mag. 5.2, type B9) was announced by Adams in 1912.* Fifty two spectrograms, taken at this observatory during 1913, 1914, 1915, have been used in determining the orbit.

The general features of the spectrum may be judged from Table I which contains in order the elements, the wave-lengths used, the residuals, and the number of times each line was measured. The residual for any line is the mean (algebraic or arithmetic) of all the residuals for that line. The separate residuals are found by subtracting the velocity as given by the plate from the velocity as given by the line.

*Astrophysical Journal, vol. 35, p. 172.

TABLE I.

Element	Wave-Length	Algebraic Residual	Arithmetic Residual	Number of times measured
Calcium.....	3933.869	- 0.1 km.	3.4 km.	44
Calcium.....	3968.625	+ 5.6 km.	7.2 km.	3
Helium.....	4026.352	+ 1.2 km.	7.1 km.	30
Hydrogen.....	4101.890	- 0.1 km.	5.5 km.	1
Silicon.....	4128.211	+ 1.6 km.	5.3 km.	24
Silicon.....	4131.047	0.0 km.	5.5 km.	21
Carbon.....	4267.3	- 5.8 km.	5.8 km.	2
Hydrogen.....	4340.634	0.0 km.	4.6 km.	47
Helium.....	4388.100	- 4.1 km.	7.6 km.	15
Helium.....	4471.676	- 1.0 km.	6.9 km.	30
Magnesium.....	4481.400	+ 0.6 km.	4.0 km.	46

TABLE II.
MT. WILSON AND YERKES OBSERVATIONS.

Observatory	Julian Date	Phase	Velocity	O-C.
Yerkes.....	2,418,570.78	32.60	- 35	+ 4.6
Mt. Wilson.....	9,023.65	65.95	+ 12	+ 1.8
Mt. Wilson.....	9,055.78	28.16	- 46	- 2.0
Mt. Wilson.....	9,056.77	29.15	- 44	- 0.7
Yerkes.....	9,267.84	30.46	- 28	+14.0
Yerkes.....	9,361.51	54.21	- 7	- 2.4
Yerkes.....	9,366.58	59.28	- 1	- 6.5
Mt. Wilson.....	9,410.71	33.49	- 41	- 2.5

TABLE III.
OTTAWA OBSERVATIONS OF ω CASSIOPEÆ.

Plate	Observer*	Date	Julian Date	Phase	Velocity	Weight	O-C.
1913							
5725	Y	Sept. 30.....	2,420,041.81	35.31	- 39.4	2½	- 1.4
5759	Y	Oct. 7.....	048.80	42.30	- 29.5	2½	- 0.9
5780	P ¹	Oct. 13.....	054.80	48.30	- 24.7	3½	- 6.2
5801	Y	Nov. 6.....	078.56	2.14	- 4.6	1½	+ 5.4
5811	C	Dec. 8.....	110.63	34.21	- 35.6	1	+ 3.4
5830	P	Dec. 17.....	119.63	43.21	- 42.2	1	-15.2
5845	P ¹	Dec. 22.....	124.69	48.27	- 24.8	¾	- 6.3
5863	P	Dec. 31.....	133.65	57.23	- 5.6	3	- 5.1
1914							
5869	Y	Jan. 1.....	134.54	58.12	- 2.7	2	- 4.0
5879	P ¹	Jan. 5.....	318.65	62.23	+ 8.5	1½	- 0.5
5913	Y	Feb. 5.....	169.56	23.21	- 47.0	2½	+ 1.0
5932	H	Feb. 12.....	176.66	30.32	- 38.4	1½	+ 4.7
5938	Y	Feb. 15.....	179.53	33.19	- 45.5	1½	- 5.4
5971	Y	Mar. 5.....	197.54	51.20	- 27.4	1½	-14.4
5972	Y	Mar. 11.....	203.52	57.17	- 5.5	2	- 4.9
5984	Y	Mar. 19.....	211.52	65.18	+ 6.0	3	- 4.3
6294	Y	Aug. 21.....	366.82	10.72	- 47.9	3	- 6.3
6303	C	Aug. 24.....	369.80	13.70	- 46.9	2½	- 1.0
6316	C	Aug. 26.....	371.87	15.77	- 49.4	1½	- 1.8
6321	Y	Aug. 27.....	372.85	16.75	- 54.3	2	- 6.2
6378	Y	Sept. 15.....	391.67	35.57	- 41.1	3½	- 3.4
6410	Y	Sept. 20.....	396.71	40.61	- 21.1	3	+10.0
6423	Y	Sept. 22.....	398.65	42.55	- 28.2	3½	0.0
6430	G	Sept. 25.....	401.86	45.76	- 26.7	2½	- 4.0
6434	Y	Sept. 27.....	403.83	47.63	- 13.6	4	+ 6.0
6448	G-C	Sept. 30.....	406.73	50.63	- 2.1	2	+11.9
6458	Y	Oct. 1.....	407.76	51.66	- 14.0	3½	- 1.9
6467	C	Oct. 2.....	408.69	52.59	- 11.8	3	- 1.5
6481	Y	Oct. 4.....	410.70	54.60	+ 3.5	2½	+ 9.3
6488	Y	Oct. 11.....	417.85	61.75	+ 11.9	3½	+ 3.7

TABLE III.
OTTAWA OBSERVATIONS OF ω CASSIOPEIÆ—Continued.

Plate	Observer*	Date	Julian Date	Phase	Velocity	Weight	O-C.
		1914					
6500	Y-H	Oct. 13.....	2,420,419.75	63.65	+ 9.9	1½	- 0.2
6506	Y	Oct. 20.....	426.67	0.65	- 0.5	3½	+ 2.5
6516	P ¹	Oct. 21.....	427.82	1.80	- 15.6	4	- 6.8
6536	C	Oct. 28.....	434.80	8.78	- 27.1	3½	+ 9.4
6539	Y	Oct. 31.....	437.84	11.81	- 44.9	2	- 1.4
6545	C	Nov. 2.....	439.78	13.76	- 43.7	3	+ 2.3
6552	H	Nov. 3.....	440.72	14.70	- 49.4	1½	- 2.5
6651	Y	Dec. 2.....	489.55	63.53	+ 12.2	3	+ 2.2
6656	P ¹ -C	Dec. 23.....	490.58	64.56	+ 15.9	2	+ 5.6
6660	H-Y	Dec. 25.....	492.62	66.60	+ 13.4	2	+ 4.3
6665	Y	Dec. 30.....	497.61	1.66	- 4.8	5	+ 3.2
6672	Y	Dec. 31.....	498.66	2.72	- 19.1	3½	- 6.1
		1915					
6678	P ¹	Jan. 4.....	502.63	6.69	- 25.1	2½	+ 4.9
6686	Y	Jan. 5.....	503.61	7.67	- 35.0	2	- 1.6
6700	Y	Jan. 10.....	508.50	12.56	- 46.7	3	- 2.1
6708	Y	Jan. 12.....	510.60	14.63	- 48.8	3	- 2.0
6717	Y	Jan. 16.....	514.46	18.52	- 45.0	2	+ 3.7
6718	Y	Jan. 19.....	517.66	21.72	- 50.9	2	- 2.4
6720	C	Jan. 20.....	518.61	22.67	- 55.7	1	- 7.5
6729	Y	Jan. 24.....	522.47	26.5	- 40.1	3	+ 6.7
6739	Y	Jan. 26.....	524.46	28.52	- 41.2	3½	+ 3.5
6741	P ¹	Jan. 27.....	525.53	29.59	- 43.1	3½	+ 0.7

*P=Plaskett; P¹=Parker; C=Cannon; H=Harper; G=Gibson; Y=Young.

MEASURES OF ω CASSIOPEIÆ.

λ	5725		5759		5780		5801		5811		5830		5845	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.869	- 51.0	$\frac{1}{2}$	- 37.9	$\frac{1}{2}$	- 52.2	$\frac{1}{2}$	.....	.....	- 29.3	$\frac{1}{2}$	- 26.4	$\frac{2}{3}$	- 16.7	$\frac{1}{2}$
4026.352	- 58.6	$\frac{1}{2}$	- 49.1	$\frac{1}{2}$	- 50.5	$\frac{1}{2}$	- 7.2	$\frac{1}{2}$	- 38.2	$\frac{1}{2}$	- 20.9	$\frac{1}{2}$	.....	.....
4101.890	.....	.....	.....	.....	- 22.1	$\frac{1}{2}$	- 1.9	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4128.211	- 42.7	$\frac{1}{2}$	- 29.4	$\frac{1}{2}$	- 33.4	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4131.047	- 49.0	$\frac{1}{2}$	- 47.4	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4267.3	.....	.....	.....	.....	- 39.4	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340.634	- 55.9	$\frac{1}{2}$	.....	.....	- 25.4	$\frac{1}{2}$	- 4.6	$\frac{1}{2}$	- 24.8	$\frac{1}{2}$	- 43.2	$\frac{1}{2}$	- 9.4	$\frac{1}{2}$
4388.100	.....	.....	.....	.....	- 49.8	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4471.676	- 52.8	$\frac{1}{2}$	- 41.3	$\frac{1}{2}$	- 11.4	$\frac{1}{2}$	.....	.....	.....	.....	- 34.5	$\frac{1}{2}$	.....	.....
4481.400	- 56.9	$\frac{1}{2}$	- 39.8	$\frac{2}{3}$	- 43.3	$\frac{1}{2}$	- 16.6	$\frac{1}{2}$	.....	.....	- 53.0	$\frac{1}{2}$	.....	.....
Weighted mean	- 53.1		- 41.7		- 35.4		- 8.6		- 29.2		- 33.1		- 14.2	
V_a	+ 14.02		+ 12.50		+ 11.06		+ 4.22		- 6.08		- 8.79		- 10.21	
V_s	- 0.03		- 0.04		- 0.07		+ 0.04		- 0.05		- 0.05		- 0.10	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 39.4		- 29.5		- 24.7		- 4.6		- 35.6		- 42.2		- 24.8	

MEASURES OF ω CASSIOPEIÆ—Continued.

λ	5863		5869		5879		5913		5932		5938		5971	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·869	- 3.3	$\frac{1}{2}$	+ 9.0	$\frac{1}{2}$	+ 18.9	$\frac{1}{2}$	.....	.....	- 9.9	$\frac{1}{2}$	.....	.....	+ 4.1	$\frac{1}{2}$
4026·352	.....	.....	.....	.....	.....	.....	- 45.7	$\frac{1}{2}$	- 14.1	$\frac{1}{2}$	- 7.4	$\frac{1}{2}$	- 7.9	$\frac{1}{2}$
4101·890	+ 12.2	$\frac{1}{2}$	.....	.....	.....	.....	- 29.1	$\frac{1}{2}$	- 16.3	$\frac{1}{2}$	.....	.....	- 5.6	$\frac{1}{2}$
4128·211	+ 7.7	$\frac{1}{2}$	+ 7.7	$\frac{1}{2}$	+ 24.0	$\frac{1}{2}$	- 17.3	$\frac{1}{2}$	- 12.6	$\frac{1}{2}$	.....	.....	.....	.....
4131·047	+ 10.6	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4340·634	+ 17.1	$\frac{1}{2}$	+ 3.4	$\frac{1}{2}$	+ 25.0	$\frac{1}{2}$	- 27.2	$\frac{1}{2}$	- 37.4	$\frac{1}{2}$	.....	.....	- 5.7	$\frac{1}{2}$
4388·100	.....	.....	.....	.....	.....	.....	- 34.0	$\frac{1}{2}$	.....	.....	- 45.5	$\frac{1}{2}$	.....	.....
4471·676	- 6.2	$\frac{1}{2}$	.....	.....	.....	.....	- 31.4	$\frac{1}{2}$	.....	.....	- 32.7	$\frac{1}{2}$	- 13.7	$\frac{1}{2}$
4481·400	+ 11.4	1	+ 20.2	$\frac{1}{2}$	+ 26.2	$\frac{1}{2}$	- 26.4	$\frac{1}{2}$	- 22.6	$\frac{1}{2}$	- 29.9	$\frac{1}{2}$	- 26.4	$\frac{1}{2}$
Weighted mean	+ 7.4		+ 10.40		+ 22.6		- 28.3		- 19.4		- 26.5		- 9.2	
V_a	- 12.57		- 12.77		- 13.73		- 18.31		- 18.62		- 18.68		- 17.89	
V_d	- 0.09		- 0.03		- 0.10		- 0.09		- 0.15		- 0.10		- 0.11	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 5.6		- 2.7		+ 8.5		- 47.0		- 38.4		- 45.5		- 27.5	

MEASURES OF ω CASSIOPEIÆ—Continued.

λ	5972		5984		6294		6303		6316		6321		6378	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.869	+ 13.1	$\frac{1}{2}$	+ 29.4	$\frac{1}{2}$	- 54.7	$\frac{1}{2}$	.....		- 62.0	$\frac{1}{2}$	- 81.2	$\frac{1}{2}$	- 57.3	$\frac{1}{2}$
4026.352	+ 12.1	$\frac{1}{2}$	+ 27.2	$\frac{1}{2}$	- 60.7	$\frac{1}{2}$	- 77.0	$\frac{1}{2}$	- 67.7	$\frac{1}{2}$	- 65.0	$\frac{1}{2}$	- 59.8	$\frac{1}{2}$
4101.890	.....		+ 16.0	$\frac{1}{2}$	- 62.1	$\frac{1}{2}$	.....		.....		.....		- 61.2	$\frac{1}{2}$
4128.211	.....		.....		- 56.9	$\frac{1}{2}$	- 63.6	$\frac{1}{2}$	.....		- 75.0	$\frac{1}{2}$	- 62.6	$\frac{1}{2}$
4131.047	+ 17.3	$\frac{1}{2}$	+ 24.0	$\frac{1}{2}$	- 74.1	$\frac{1}{2}$	- 69.4	$\frac{1}{2}$	.....		.....		.....
4340.634	.....		+ 6.8	$\frac{1}{2}$	- 76.5	$\frac{1}{2}$	- 70.9	$\frac{1}{2}$	.....		- 68.6	$\frac{1}{2}$	- 57.4	$\frac{1}{2}$
4471.676	+ 11.2	$\frac{1}{2}$	+ 35.0	$\frac{1}{2}$	.....		- 59.4	$\frac{1}{2}$	- 82.9	$\frac{1}{2}$	- 79.2	$\frac{1}{2}$	- 54.5	$\frac{1}{2}$
4481.400	+ 10.0	$\frac{1}{2}$	+ 18.9	$\frac{1}{2}$	- 66.0	1	- 57.4	$\frac{1}{2}$	- 64.9	$\frac{1}{2}$	.....		- 54.9	1
Weighted mean	+ 12.15		+ 22.5		- 66.0		- 64.9		- 67.3		- 72.7		- 57.2	
V_s	- 17.25		- 16.09		+ 18.25		+ 18.23		+ 18.18		+ 18.14		+ 16.43	
V_d	- 0.12		- 0.12		+ 0.12		0.00		- 0.02		0.00		+ 0.08	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 5.5		+ 6.0		- 47.9		- 46.9		- 49.4		- 54.8		- 41.0	

MEASURES OF ω CASSIOPELÆ—Continued.

λ	6410		6423		6430		6434		6448		6458		6467	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.869	- 32.7	$\frac{1}{2}$	- 43.8	$\frac{1}{2}$	- 33.5	$\frac{1}{2}$	- 23.9	1	- 14.7	$\frac{1}{2}$	- 33.6	1	- 25.5	1
4026.352	- 26.9	$\frac{1}{2}$	- 57.2	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 11.3	$\frac{1}{2}$	.....	.....
4101.890	- 34.4	$\frac{1}{2}$	- 35.3	$\frac{1}{2}$	- 43.6	$\frac{1}{2}$	- 38.0	$\frac{1}{2}$	- 25.0	$\frac{1}{2}$	- 29.4	$\frac{1}{2}$	.....	.....
4128.211	.....	.....	- 39.9	$\frac{1}{2}$	- 34.2	$\frac{1}{2}$	- 25.6	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4131.047	- 41.8	$\frac{1}{2}$	- 27.6	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4340.634	- 43.9	1	- 50.6	$\frac{1}{2}$	- 51.8	$\frac{1}{2}$	- 25.9	1	- 9.0	$\frac{1}{2}$	- 28.1	1	- 34.9	1
4388.100	.....	.....	.....	.....	- 36.1	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4471.676	.....	.....	- 44.6	$\frac{1}{2}$	- 52.0	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4481.400	- 27.4	$\frac{1}{2}$	- 48.6	$\frac{1}{2}$	- 38.7	$\frac{1}{2}$	- 30.0	1	- 15.0	$\frac{1}{2}$	.....	.....	- 21.2	1
Weighted mean	- 36.7		- 43.6		- 41.4		- 27.90		- 16.0		- 27.6		- 27.20	
V_s	+ 15.87		+ 15.56		+ 15.01		+ 14.65		+ 14.09		+ 13.88		+ 13.69	
V_s	+ 0.06		+ 0.09		- 0.05		- 0.05		+ 0.03		0.00		+ 0.04	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 21.1		- 28.2		- 26.7		- 13.6		- 2.2		- 14.0		- 13.8	

MEASURES OF ω CASSIOPELÆ—Continued.

λ	6481		6488		6500		6506		6516		6536		6539	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.869	- 11.2	$\frac{1}{2}$	+ 3.8	$\frac{1}{2}$	- 9.5	$\frac{1}{2}$	- 4.5	1	- 21.5	1	.....	.....	.....	.....
3968.625	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 36.2	$\frac{1}{2}$	.....	.....
4026.352	- 9.5	$\frac{1}{2}$	.....	.....	+ 13.9	$\frac{1}{2}$	.....	.....	- 17.3	$\frac{1}{2}$	- 44.2	$\frac{1}{2}$	.....	.....
4101.890	- 8.3	$\frac{1}{2}$	- 0.9	$\frac{1}{2}$	.....	.....	- 5.6	$\frac{1}{2}$	- 33.4	$\frac{1}{2}$	.....	.....	- 49.2	$\frac{1}{2}$
4128.211	- 9.5	$\frac{1}{2}$	- 6.6	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4131.047	- 5.7	$\frac{1}{2}$	- 9.5	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 39.6	$\frac{1}{2}$	.....	.....
4340.634	- 12.4	$\frac{1}{2}$	+ 4.5	1	- 1.1	$\frac{1}{2}$	- 19.1	1	- 22.5	1	- 29.3	1	- 50.7	$\frac{1}{2}$
4471.676	.....	.....	- 7.4	$\frac{1}{2}$	+ 28.5	$\frac{1}{2}$	- 21.0	$\frac{1}{2}$	.....	.....	- 30.9	$\frac{1}{2}$	.....	.....
4481.400	- 8.7	$\frac{1}{2}$	+ 7.5	$\frac{1}{2}$	+ 1.2	$\frac{1}{2}$	+ 7.4	$\frac{1}{2}$	- 27.4	1	- 34.9	1	- 51.1	1
Weighted mean	- 9.6		+ 0.7		+ 1.1		- 9.5		- 24.20		- 33.7		- 50.6	
V_a	+ 13.25		+ 11.60		+ 11.13		+ 9.31		+ 8.99		+ 6.98		+ 6.07	
V_d	+ 0.03		- 0.09		- 0.02		+ 0.03		- 0.09		- 0.09		- 0.11	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 3.5		+ 11.9		+ 9.9		- 0.5		- 15.6		- 27.1		- 44.9	

MEASURES OF ω CASSIOPEIÆ.—Continued.

λ	6545		6552		6651		6656		6660		6665		6672	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.869	- 47.0	$\frac{1}{2}$	- 50.9	$\frac{1}{2}$	+ 11.4	$\frac{1}{2}$	+ 19.1	$\frac{1}{2}$	+ 20.8	$\frac{1}{2}$	+ 3.1	1	- 5.7	1
3968.625	.....	.....	- 36.4	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	+ 9.1	$\frac{1}{2}$	.....	.....
4026.352	- 48.5	$\frac{1}{2}$	- 53.8	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	+ 11.3	$\frac{1}{2}$	- 14.8	$\frac{1}{2}$
4101.890	- 33.4	$\frac{1}{2}$	- 57.5	$\frac{1}{2}$	+ 28.0	$\frac{1}{2}$	+ 28.0	$\frac{1}{2}$	+ 25.2	$\frac{1}{2}$	- 0.9	$\frac{1}{2}$	- 5.6	$\frac{1}{2}$
4128.211	- 55.0	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	+ 5.7	$\frac{1}{2}$	.....	.....
4131.047	.....	.....	.....	.....	+ 7.7	$\frac{1}{2}$	.....	.....	+ 24.7	$\frac{1}{2}$	+ 1.9	$\frac{1}{2}$	.....	.....
4267.3	.....	.....	.....	.....	+ 13.9	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340.634	- 55.2	$\frac{1}{2}$	- 45.0	$\frac{1}{2}$	+ 20.4	$\frac{1}{2}$	+ 30.6	$\frac{1}{2}$	+ 28.3	$\frac{1}{2}$	+ 10.2	1	- 1.1	1
4471.676	- 48.3	$\frac{1}{2}$	- 69.3	$\frac{1}{2}$	+ 33.6	$\frac{1}{2}$	.....	.....	.....	.....	+ 6.2	$\frac{1}{2}$	.....	.....
4481.400	- 49.8	$\frac{1}{2}$	- 66.0	$\frac{1}{2}$	+ 25.7	$\frac{1}{2}$	+ 28.8	$\frac{1}{2}$	.....	.....	+ 16.3	1	- 10.0	1
Weighted mean	- 48.8		- 54.1		+ 21.6		+ 26.7		+ 24.7		+ 7.6		- 6.2	
V_a	+ 5.48		+ 5.19		- 10.11		- 10.40		- 10.99		- 12.20		- 12.49	
V_d	- 0.10		- 0.04		0.00		- 0.03		- 0.06		+ 0.04		- 0.10	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 43.7		- 49.4		+ 11.2		- 16.0		+ 13.4		- 4.8		- 19.1	

MEASURES OF ω CASSIOPELÆ.—Continued.

λ	6678		6686		6700		6708		6717		6718		6720	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·869	- 8.1	$\frac{1}{2}$	.....	.....	- 28.9	1	- 33.7	$\frac{1}{2}$	- 18.5	$\frac{1}{2}$	- 42.5	$\frac{1}{2}$	.....	.....
4026·352	.....	.....	.....	.....	.....	.....	- 19.0	$\frac{1}{2}$	- 36.6	$\frac{1}{2}$	- 32.3	$\frac{1}{2}$	.....	.....
4101·890	- 10.2	$\frac{1}{2}$	- 26.1	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4128·211	.....	.....	.....	.....	.....	.....	- 46.7	$\frac{1}{2}$	- 37.2	$\frac{1}{2}$	- 35.3	$\frac{1}{2}$	.....	.....
4131·047	- 3.8	$\frac{1}{2}$	- 11.5	$\frac{1}{2}$	.....	.....	- 29.6	$\frac{1}{2}$	.....	.....	- 35.4	$\frac{1}{2}$	.....	.....
4340·634	- 14.7	1	- 20.3	1	- 30.6	1	.....	.....	- 22.6	$\frac{1}{2}$	- 30.3	$\frac{1}{2}$	- 41.8	$\frac{1}{2}$
4471·676	- 16.7	$\frac{1}{2}$	.....	.....	- 39.8	$\frac{1}{2}$	- 44.8	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4481·400	.....	.....	- 25.0	$\frac{1}{2}$	- 31.3	$\frac{1}{2}$	- 28.8	1	- 27.5	$\frac{1}{2}$	- 25.0	$\frac{1}{2}$	- 36.3	$\frac{1}{2}$
Weighted mean	- 11.4		- 21.1		- 31.7		- 33.3		- 28.9		- 34.3		- 39.0	
V_s	- 13.32		- 13.55		- 14.72		- 15.13		- 15.84		- 16.36		- 16.52	
V_d	- 0.09		- 0.08		- 0.02		- 0.10		0.00		0.00		- 0.11	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 25.1		- 35.0		- 46.7		- 48.8		- 45.0		- 50.9		- 55.7	

A period was roughly determined from the Ottawa series of spectrograms and this approximate period adjusted more carefully from eight plates taken at the Mt. Wilson and Yerkes observatories (Table II). The interval separating the earliest and the most recent plates is thirty periods. With the period 69.92 days thus determined, the fifty-two plates taken here were combined into thirteen normal places.

NORMAL PLACES.

	Julian Day	Phase	Velocity	Weight	O-C Preliminary	O-C Final
1.....	2,420,427.82	1.42	- 9.3	1.5	- 2.2	- 1.3
2.....	433.73	7.33	- 28.4	0.8	+ 6.0	+ 5.1
3.....	438.52	12.12	- 46.1	1.3	0.0	- 1.6
4.....	441.49	15.09	- 50.4	0.8	- 1.2	- 2.8
5.....	447.55	21.15	- 48.7	0.7	+ 1.1	- 0.3
6.....	454.56	28.16	- 41.1	1.2	+ 4.2	+ 3.4
7.....	460.59	34.19	- 40.9	0.9	- 2.0	- 2.3
8.....	468.19	41.79	- 27.8	1.0	+ 0.4	+ 0.8
9.....	473.54	47.14	- 19.8	1.0	- 0.7	+ 0.1
10.....	477.54	51.14	- 13.0	1.0	- 2.0	- 0.9
11.....	482.80	56.40	- 2.4	1.0	- 2.6	- 1.3
12.....	488.81	62.41	+ 11.3	0.9	+ 0.4	+ 1.7
13.....	491.46	65.06	+ 10.9	0.7	- 0.8	+ 0.6

Preliminary elements were obtained graphically,

$$P = 69.92 \text{ days}$$

$$e = 0.3$$

$$\omega = 53^\circ$$

$$K = 31.1 \text{ km.}$$

$$\gamma = 24.82 \text{ km.}$$

$$T = 2,420,426.4 \text{ J. D.}$$

and a least-squares solution was carried through for all the elements save P .

OBSERVATION EQUATIONS.

	x	y	z	p	q	$-n$	Weight.
1.....	1	+ 0.569	+ 0.034	- 1.161	+ 1.536	+ 2.2	1.5
2.....	1	- 0.307	- 1.260	- 1.113	+ 1.097	- 6.0	0.8
3.....	1	- 0.685	- 0.471	- 0.740	+ 0.465	0.0	1.3
4.....	1	- 0.785	+ 0.104	- 0.498	+ 0.204	+ 1.2	0.8
5.....	1	- 0.805	+ 0.830	- 0.070	- 0.104	- 1.1	0.7
6.....	1	- 0.659	+ 0.954	+ 0.304	- 0.280	- 4.2	1.2
7.....	1	- 0.452	+ 0.658	+ 0.535	- 0.381	+ 2.0	0.9
8.....	1	- 0.108	- 0.022	+ 0.718	- 0.494	- 0.4	1.0
9.....	1	+ 0.183	- 0.566	+ 0.760	- 0.579	+ 0.7	1.0
10.....	1	+ 0.443	- 0.920	+ 0.725	- 0.643	+ 2.0	1.0
11.....	1	+ 0.805	- 0.999	+ 0.541	- 0.669	+ 2.6	1.0
12.....	1	+ 1.148	+ 0.063	+ 0.011	- 0.312	- 0.4	0.9
13.....	1	+ 1.174	+ 0.806	- 0.356	+ 0.170	+ 0.8	0.7

where $x = \delta\gamma$
 $y = \delta K$
 $z = K\delta e$
 $p = K\delta\omega$
 $q = \frac{K\mu}{(1-e^2)^{\frac{3}{2}}} \delta T$

NORMAL EQUATIONS.

$$\begin{aligned}
 12.800x + 0.506y - 1.054z - 0.689p + 0.648q + 0.550 &= 0 \\
 + 5.864y - 1.384z + 0.372p - 0.126q + 9.124 &= 0 \\
 + 6.157z + 0.024p - 0.225q - 2.400 &= 0 \\
 + 6.297p - 6.127q + 3.414 &= 0 \\
 + 6.595q - 2.211 &= 0
 \end{aligned}$$

whence $\delta\gamma = 0.00$ km.
 $\delta K = -1.46$ km.
 $\delta e = 0.00$
 $\delta\omega = -3^\circ.03$
 $\delta T = -0.38$ day

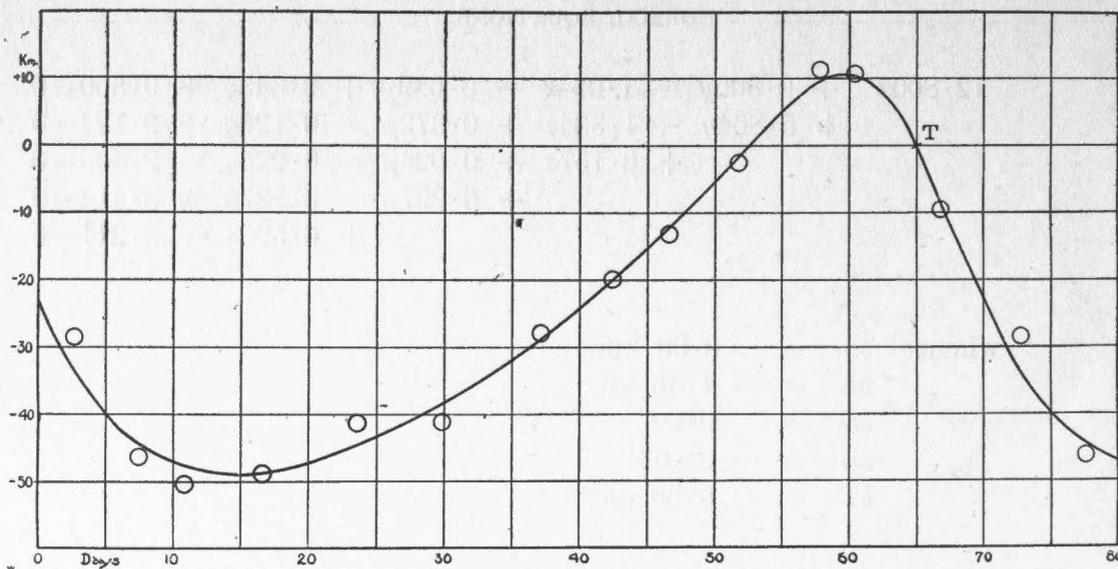
The above corrections lowered Σpv^2 from 75.0 to 51.5 and agreement between the residuals computed from the ephemeris and the observation equations showed that further solutions would leave the elements unaltered.

FINAL ELEMENTS.

$$\begin{aligned}
 P &= 69.92 \text{ days} \\
 e &= 0.30 \pm 0.024 \\
 \omega &= 49^\circ.97 \pm 4^\circ.08 \\
 K &= 29.64 \text{ km.} \pm 0.73 \\
 \gamma &= -24.82 \text{ km.} \pm 0.10 \\
 T &= 2,420,426.02 \text{ J. D.} \pm 0.67 \\
 a \sin i &= 27,190,000 \text{ km.} \\
 \frac{m_1^3 \sin^3 i}{(m + m_1)^2} &= 0.164 \odot
 \end{aligned}$$

The individual observations were represented graphically and the residuals are shown in Tables II and III. The probable error of a single plate, no attention being given to the weight, is 2.8 km.

Dominion Observatory,
Ottawa,
February, 1915.



Velocity Curve of ω Cassiopeiæ.

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ORBIT OF 136 TAURI.

BY J. B. CANNON, M.A.

The variable radial velocity of the star was discovered by Mr. Lows from the measurement of the second plate of a series of five, the results of which are published in L.O.B. 199. The orbit determination given below is based on 60 plates obtained here—the first on November 16, 1911, and the last on January 15, 1915. The spectrum is of A-type. Two spectra are visible, but so faintly on our plates that they were not considered worth measuring. On four out of the five Lick plates, however, the second component is measured, and on these alone is based the secondary curve seen in the figure—"Velocity curve of 136 Tauri."

The lines measured were as follows:—

TABLE I.

Element.	Wave-Length.	Element	Wave-Length
<i>H</i>	4861·527	<i>H</i>	4101·890
<i>Fe</i>	4549·766	<i>H</i>	3970·177
<i>Mg</i>	4481·400	<i>Ca</i>	3968·625
<i>H</i>	4340·634	<i>Ca</i>	3933·825

A summary of the measures is given in Tables II and III. Table II contains the Lick observations and Table III the Ottawa observations. In each case the phase is from periastron and the residual from the final curve. Measures in detail of the different plates follow Table III.

TABLE II.
LICK OBSERVATIONS.

Julian Date.	Phase.	V_1	R_1	V_2	R_2
2,418,402.64	1.149	-21.0	+ 2.8	.....	.....
739.66	3.889	+ 3.8	+ 1.0	-51.7	- 2.5
945.03	0.340	-60.8	- 1.3	+34.0	- 7.0
950.02	5.329	-60.6	+ 1.0	+49.3	+ 5.3
952.99	2.329	+27.8	+ 2.0	-84.4	- 3.0

TABLE III.
OTTAWA OBSERVATIONS.

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Wt.	O-C
		1911	m.					
4697	H	Nov. 16.....	75	2,419,357.820	1.269	-11.0	5	+ 7.0
4718	C	Dec. 6.....	65	377.807	3.347	+22.6	3	- 0.4
		1912						
4840	H	Feb. 13.....	70	446.589	0.508	-43.6	3	+10.4
4851	H	Feb. 20.....	103	453.670	1.619	+10.0	4	+10.0
4860	C	Feb. 28.....	70	461.642	3.621	+12.5	7	- 1.8
4871	H	Mar. 5.....	96	467.661	3.670	+10.4	5	- 1.6
4885	C	Mar. 13.....	75	475.554	5.593	-60.1	2	+ 6.0
		1913						
5314	P	Jan. 12.....	85	780.717	0.367	-47.8	6	+10.7
5368	C	Feb. 11.....	70	810.580	0.390	-45.8	6	+12.2
5361	P	Feb. 12.....	75	811.630	1.439	- 7.5	6	+ 1.5
5371	P ¹	Feb. 17.....	75	816.612	0.451	-47.6	4	+ 8.4
5384	H	Feb. 18.....	72	817.610	1.449	- 6.1	5	+ 2.4
5393	C	Feb. 24.....	75	823.640	1.509	- 6.2	5	+ 1.0
5408	P ¹	Feb. 28.....	75	827.592	5.461	-58.9	5	+ 5.0
5417	C	Mar. 7.....	75	834.623	0.552	-42.9	2	+ 8.7
5434	H	Mar. 12.....	109	839.603	5.532	-69.8	6	- 9.6
5438	P ¹	Mar. 17.....	100	844.597	4.556	-29.3	2	+ 1.0
5455	C	April 9.....	70	867.545	3.634	+14.5	3	+ 0.5
5468	P ¹	April 14.....	75	872.561	2.680	+42.3	6	+11.7
5488	H	April 17.....	75	875.548	5.667	-59.9	4	+ 6.9
5850	C	Dec. 22.....	35	20,124.814	4.233	-10.8	5	+ 3.2
		1914						
5936	P	Feb. 14.....	60	178.656	4.355	-14.5	5	+ 5.5
5987	C	Mar. 20.....	73	212.638	2.517	+17.2	5	-12.0
6007	C	April 3.....	75	226.525	4.474	-26.5	7	- 0.5
6014	C	April 5.....	73	228.540	0.519	-66.3	7	-12.8
6015	H	April 6.....	75	229.560	1.539	-17.2	5	-13.2
6024	C	April 10.....	82	233.538	5.511	-72.0	5	- 7.0
6030	H	April 13.....	76	236.569	2.578	+28.1	5	- 1.8
6032	C	April 14.....	75	237.533	3.542	+19.1	4	+ 2.1
6035	P ¹	April 17.....	80	240.552	0.591	-68.0	4	-17.5

TABLE III.
OTTAWA OBSERVATIONS—*Concluded.*

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Wt.	O-C
		1914	m.					
6040	P ¹	April 22.....	100	2,420,245.549	5.588	-64.4	5	+ 1.6
6046	H	April 23.....	66	246.540	0.609	-53.6	6	- 3.8
6053	C	May 1.....	70	254.559	2.658	+27.1	3	- 3.2
6396	Y	Sept. 17.....	72	393.841	4.653	-38.5	6	- 3.5
6404	P ¹	Sept. 18.....	75	394.894	5.706	-64.0	5	+ 3.0
6420	C	Sept. 21.....	75	397.894	2.727	+26.6	5	- 4.2
6431	G	Sept. 25.....	75	401.911	0.775	-42.2	4	0.0
6436	Y	Sept. 27.....	50	403.927	2.801	+34.9	6	+ 4.1
6444	C	Sept. 28.....	70	404.913	3.787	+ 6.7	6	- 1.3
6451	C	Sept. 30.....	15	406.890	5.764	-70.3	5	- 3.3
6461	Y	Oct. 1.....	45	407.875	0.780	-39.1	6	+ 2.0
6471	P ¹	Oct. 2.....	50	408.882	1.787	+15.4	5	+ 9.9
6484	H	Oct. 4.....	60	410.867	3.772	+13.1	3	+ 5.1
6490	Y	Oct. 11.....	55	417.929	4.788	-33.1	7	+ 8.0
6517	P ¹	Oct. 21.....	75	427.878	2.876	+34.7	6	+ 4.7
6538	C	Oct. 28.....	55	434.939	3.968	-12.4	6	-11.7
6548	C	Nov. 2.....	60	439.934	2.994	+26.8	5	- 2.9
6564	H	Nov. 17.....	60	454.924	0.077	-63.4	6	+ 2.8
6574	P ¹	Nov. 23.....	70	460.872	0.056	-72.1	6	- 6.1
6594	P	Dec. 4.....	130	471.840	5.055	-55.1	4	- 2.6
6600	Y	Dec. 5.....	60	472.806	0.052	-71.0	4	- 5.0
6607	H	Dec. 6.....	62	473.815	1.061	-30.4	3	- 2.0
6633	H	Dec. 15.....	66	482.939	4.216	-10.8	4	+ 1.7
6642	P ¹	Dec. 16.....	85	483.946	5.223	-50.8	3	+ 7.2
6653	Y	Dec. 22.....	40	489.625	4.933	-57.5	3	- 9.5
6670	Y	Dec. 30.....	45	497.717	1.087	-32.7	7	- 5.0
6674	Y	Dec. 31.....	40	498.767	2.137	+19.6	6	- 1.0
		1915						
6695	P ¹	Jan. 8.....	85	506.794	4.195	- 8.3	5	+ 3.7
6711	H	Jan. 12.....	60	510.786	2.218	+14.5	5	- 7.8
6715	P ¹	Jan. 15.....	95	513.862	5.194	-53.5	2	+ 3.8

*H=Harper; C=Cannon; P=Plaskett; P¹=Parker; Y=Young; G=Gibson.

MEASURES OF 136 TAURI.

λ	4697		4718		4840		4851		4860		4871		4885				
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.			
4861.527													+ 42.08	$\frac{1}{2}$	
4549.766	- 33.35	$\frac{1}{2}$														
4481.400	- 46.79	$\frac{1}{2}$	+ 28.82	$\frac{1}{2}$	+ 7.65	$\frac{1}{2}$	+ 62.73	$\frac{1}{2}$	+ 25.26	$\frac{1}{2}$	+ 42.20	$\frac{1}{2}$	.....			
4340.634	- 14.23	$\frac{1}{2}$	+ 11.92	$\frac{1}{2}$	- 9.37	1	+ 41.54	$\frac{1}{2}$	+ 46.16	1	+ 41.54	1	- 19.77	$\frac{1}{2}$			
4101.890	- 26.00	$\frac{1}{2}$	+ 23.11	$\frac{1}{2}$	- 22.34	$\frac{1}{2}$	.....		.....		+ 31.62	$\frac{1}{2}$	- 46.56	$\frac{1}{2}$
3933.825	- 23.63	$\frac{1}{2}$	+ 6.49	$\frac{1}{2}$	- 20.72	1	+ 31.53	$1\frac{1}{2}$	+ 42.52	1	+ 40.52	$\frac{1}{2}$	- 26.92	1			
Weighted mean	- 26.62		+ 16.45		- 17.49		+ 37.22		+ 40.67		+ 40.07		- 30.04				
V.	+ 16.13		+ 6.56		- 25.76		- 26.76		- 27.67		- 29.11		- 29.67				
V _z	- .18		- .11		- .06		- .20		- .19		- .23		- .13				
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28				
Radial Velocity	- 11.0		+ 22.6		- 43.6		+ 10.0		+ 12.5		+ 10.4		- 60.1				

MEASURES OF 136 TAURI.—Continued.

λ	5314		5368		5361		5371		5384		5384*		5393	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766									+ 38.55	$\frac{1}{2}$	+ 34.02	$\frac{1}{2}$	+ 29.96	$\frac{1}{2}$
4481.400	- 29.58	$\frac{1}{2}$	- 10.20	$\frac{1}{2}$	+ 20.14	$\frac{1}{2}$	- 3.44	$\frac{1}{2}$	+ 37.10	$\frac{1}{2}$	+ 23.97	$\frac{1}{2}$		
4340.634	- 37.48	$\frac{1}{2}$	- 22.56	$\frac{1}{2}$	+ 17.82	1	- 20.94	$\frac{1}{2}$	+ 22.44	1	+ 16.43	1	+ 28.81	$\frac{1}{2}$
4101.890	- 29.37	$\frac{1}{2}$			+ 24.27	$\frac{1}{2}$	- 15.21	$\frac{1}{2}$	+ 13.39	$\frac{1}{2}$	+ 12.23	$\frac{1}{2}$	+ 10.50	$\frac{1}{2}$
3970.177			- 20.36	$\frac{1}{2}$									+ 19.61	$\frac{1}{2}$
3968.625			- 14.45	$\frac{1}{2}$										
3933.825	- 36.94	1	- 29.29	$\frac{1}{2}$	+ 15.64	1	- 31.12	1	+ 16.56	$1\frac{1}{2}$	+ 24.87	2	+ 20.38	1
Weighted mean	- 34.58		- 20.93		+ 17.82		- 20.94		+ 21.90		+ 19.48		+ 20.97	
V_s	- 12.80		- 24.59		- 24.89		- 26.22		- 26.46		- 26.46		- 27.75	
V_d	- .11		- .04		- .14		- .13		- .09		- .09		- .14	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 47.8		- 45.8		- 7.5		- 47.6		- 4.9		- 7.3		- 6.2	

*Check measures.

MEASURES OF 136 TAURI.—*Continued.*

λ	5408		5417		5434		5438		5455		5468		5488	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4861.527	- 42.72	$\frac{1}{2}$	.....	.....	- 37.90	$\frac{1}{2}$	- 23.13	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4549.766	.....	.....	.....	.....	.....	.....	+ 1.47	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4481.400	- 21.29	$\frac{1}{2}$	.....	.....	- 40.83	$\frac{1}{2}$	+ 27.41	$\frac{1}{2}$	+ 18.10	$\frac{1}{2}$	+ 74.97	$\frac{1}{2}$	- 39.01	$\frac{1}{2}$
4340.634	- 35.64	$\frac{1}{2}$	- 10.87	1	- 52.76	$\frac{1}{2}$	- 0.23	$\frac{1}{2}$	+ 41.42	$\frac{1}{2}$	+ 65.60	$\frac{1}{2}$	- 18.16	$\frac{1}{2}$
4101.890	.....	.....	- 0.58	$\frac{1}{2}$	- 19.68	$\frac{1}{2}$	- 1.06	$\frac{1}{2}$	+ 19.16	$\frac{1}{2}$	.....	.....	- 30.91	$\frac{1}{2}$
3970.177	.....	.....	.....	.....	.....	.....	.....	.....	+ 57.96	$\frac{1}{2}$	.....	.....	.....	.....
3968.625	.....	.....	.....	.....	.....	.....	.....	.....	+ 32.04	$\frac{1}{2}$	.....	.....	.....	.....
3933.825	- 29.87	$\frac{1}{2}$	- 21.63	1	- 46.84	1	+ 1.83	$\frac{1}{2}$	+ 52.58	1	+ 65.56	$\frac{1}{2}$	- 40.19	$\frac{1}{2}$
Weighted mean	- 30.11		- 13.24		- 39.80		+ 0.89		+ 42.04		+ 68.71		- 33.70	
V_0	- 28.42		- 29.25		- 29.64		- 29.73		- 27.10		- 25.94		- 25.69	
V_2	- .10		- .14		- .14		- .19		- .20		- .23		- .23	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 58.9		- 42.9		- 69.8		- 29.3		+ 14.5		+ 42.3		- 59.9	

MEASURES OF 136 TAURI.—Continued.

λ	5850		5936		5987		6007		6014		6015		6024	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	.....	.....	- 1.19	$\frac{1}{2}$	.....	.....	- 13.44	$\frac{1}{2}$	- 28.20	$\frac{1}{2}$	- 2.24	$\frac{1}{2}$	.....	.....
4481.400	- 3.01	$\frac{1}{2}$	+ 11.08	$\frac{1}{2}$	+ 44.44	$\frac{1}{2}$	- 3.15	$\frac{1}{2}$	- 35.88	$\frac{1}{2}$	+ 21.15	$\frac{1}{2}$	- 37.52	$\frac{1}{2}$
4340.634	- 17.27	$\frac{1}{2}$	+ 11.14	1	+ 43.43	$\frac{1}{2}$	+ 3.07	$\frac{1}{2}$	- 43.32	$\frac{1}{2}$	+ 4.66	$\frac{1}{2}$	- 44.80	$\frac{1}{2}$
4101.890	- 6.01	1	+ 31.52	$\frac{1}{2}$	+ 28.04	$\frac{1}{2}$	+ 6.77	$\frac{1}{2}$	- 40.93	$\frac{1}{2}$	+ 8.09	$\frac{1}{2}$	- 47.05	$\frac{1}{2}$
3970.177	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 13.99	$\frac{1}{2}$	.....	.....
3968.625	.....	.....	.....	.....	.....	.....	+ 6.00	$\frac{1}{2}$	.....	.....	+ 22.05	$\frac{1}{2}$	.....	.....
3933.825	- 9.96	$\frac{1}{2}$	+ 6.83	$\frac{1}{2}$	+ 54.56	1	+ 7.00	1	- 35.72	1	+ 10.70	1	- 44.94	1
Weighted mean	- 8.28		+ 11.07		+ 47.20		+ 2.47		- 37.54		+ 11.41		- 43.94	
V_a	- 2.08		- 25.15		- 29.48		- 28.56		- 28.25		- 28.08		- 27.55	
V_s	- .17		- .16		- .25		- .16		- .19		- .22		- .20	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 10.8		- 14.5		+ 17.2		- 26.5		- 66.3		- 17.2		- 72.0	

MEASURES OF 136 TAURI.—Continued.

λ	6030		6032		6035		6040		6046		6053		6396	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4481.400	+ 23.72	$\frac{1}{2}$	+ 36.64	$\frac{1}{2}$	- 41.17	$\frac{1}{2}$	.....		- 28.45	$\frac{1}{2}$	.....		- 50.25	$\frac{1}{2}$
4340.634	+ 60.15	$\frac{1}{2}$	+ 54.69	$\frac{1}{2}$	- 45.37	$\frac{1}{2}$	- 35.75	1	- 22.85	$\frac{1}{2}$	+ 58.79	$\frac{1}{2}$	- 75.67	$\frac{1}{2}$
4101.890	+ 53.30	$\frac{1}{2}$	+ 38.20	$\frac{1}{2}$	.....		- 50.34	$\frac{1}{2}$	- 50.91	$\frac{1}{2}$	+ 61.14	$\frac{1}{2}$	- 69.88	$\frac{1}{2}$
3970.177	.....		.....		.....		.....		.....		+ 46.20	$\frac{1}{2}$	.....
3933.825	+ 61.89	1	+ 49.38	1	- 38.76	$\frac{1}{2}$	- 37.86	1	- 26.75	1	+ 21.89	$\frac{1}{2}$	- 67.26	$\frac{1}{2}$
Weighted mean	+ 55.37		+ 45.46		- 41.76		- 39.51		- 29.00		+ 49.23		- 67.67	
V_s	- 26.71		- 26.00		- 25.76		- 24.40		- 24.10		- 21.54		+ 29.48	
V_d	- .23		- .22		- .24		- .24		- .24		- .27		+ .17	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 28.1		+ 19.1		- 68.0		- 64.4		- 53.6		+ 27.1		- 38.5	

MEASURES OF 136 TAURI.—Continued.

λ	6404		6420		6431		6436		6444		6451		6461	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766									- 38.95	$\frac{1}{2}$				
4481.400	-118.59	$\frac{1}{2}$	+ 13.22	$\frac{1}{2}$			+ 1.87	$\frac{1}{2}$	- 26.56	$\frac{1}{2}$	-118.96	$\frac{1}{2}$	- 46.89	$\frac{1}{2}$
4340.634	- 92.78	$\frac{1}{2}$	- 0.11	$\frac{1}{2}$	- 61.25	$\frac{1}{2}$	+ 9.35	$\frac{1}{2}$	- 14.53	$\frac{1}{2}$	- 80.17	$\frac{1}{2}$	- 70.83	$\frac{1}{2}$
4101.890	- 78.32	$\frac{1}{2}$	+ 9.28	$\frac{1}{2}$	- 81.20	$\frac{1}{2}$	+ 3.80	$\frac{1}{2}$	- 24.31	$\frac{1}{2}$	-103.01	$\frac{1}{2}$	- 72.01	$\frac{1}{2}$
3970.177							+ 7.49	$\frac{1}{2}$						
3968.625							+ 0.49	$\frac{1}{2}$						
3933.825	- 88.64	$\frac{1}{2}$	- 1.67	1	- 71.79	$\frac{1}{2}$	+ 8.51	$\frac{1}{2}$	- 18.44	$\frac{1}{2}$	- 94.60	$\frac{1}{2}$	- 70.52	1
Weighted mean	- 93.29		- 2.76		- 71.41		+ 5.91		- 22.25		- 99.18		- 67.83	
V_s	+ 29.48		+ 29.50		+ 29.38		+ 29.26		+ 29.21		+ 29.04		+ 28.93	
V_s	+ .11		+ .11		+ .08		+ .01		+ .04		+ .07		+ .08	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 64.0		+ 26.6		- 42.2		+ 34.9		+ 6.7		- 70.3		- 39.1	

MEASURES OF 136 TAURI.—Continued.

λ	6471		6484		6490		6517		6538		6548		6564	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4481.400	- 7.86	$\frac{1}{2}$	- 4.86	$\frac{1}{2}$	- 59.11	$\frac{1}{2}$	+ 8.35	$\frac{1}{2}$	- 46.89	$\frac{1}{2}$	- 3.62	$\frac{1}{2}$	- 60.11	$\frac{1}{2}$
4340.634	- 26.91	$\frac{1}{2}$	- 25.56	$\frac{1}{2}$	- 55.40	$\frac{1}{2}$	+ 11.37	$\frac{1}{2}$	- 26.80	$\frac{1}{2}$	- 3.94	$\frac{1}{2}$	- 73.42	$\frac{1}{2}$
4101.890	- 6.03	$\frac{1}{2}$	- 2.78	$\frac{1}{2}$	- 64.31	$\frac{1}{2}$	+ 1.39	$\frac{1}{2}$	- 23.85	$\frac{1}{2}$	+ 3.53	$\frac{1}{2}$	- 94.93	$\frac{1}{2}$
3970.177	.....												
3968.625	.....												
3933.825	- 11.37	1	- 16.54	$\frac{1}{2}$	- 53.90	$\frac{1}{2}$	+ 14.87	$\frac{1}{2}$	- 39.35	1	+ 15.50	1	- 78.31	1
Weighted mean	- 13.25		- 15.30		- 60.25		+ 9.70		- 35.21		+ 5.60		- 78.89	
V _s	+ 28.84		+ 28.61		+ 27.51		+ 25.27		+ 23.20		+ 21.64		+ 15.52	
V _d	+ .07		+ .08		- .06		- .02		- .15		- .18		- .21	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 15.4		+ 13.1		- 33.1		+ 34.7		- 12.4		+ 26.8		- 63.4	

MEASURES OF 136 TAURI.—Continued.

λ	6574		6594		6600		6607		6633		6642		6653	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4481·400	- 99·66	$\frac{1}{2}$	- 76·75	$\frac{1}{2}$	- 94·65	$\frac{1}{2}$	- 18·78	$\frac{1}{2}$	- 9·89	$\frac{1}{2}$	- 27·17	$\frac{1}{2}$	- 61·35	$\frac{1}{2}$
4340·634	- 79·17	$\frac{1}{2}$	- 67·07	$\frac{1}{2}$	- 67·52	$\frac{1}{2}$	- 54·55	$\frac{1}{2}$	- 11·76	$\frac{1}{2}$	- 57·68	$\frac{1}{2}$	- 48·86	$\frac{1}{2}$
4101·890	- 91·90	$\frac{1}{2}$	- 50·57	$\frac{1}{2}$	- 71·84	$\frac{1}{2}$	- 27·88	$\frac{1}{2}$	.....	.....	.....	.....	- 50·10	$\frac{1}{2}$
3970·177	- 69·14	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3968·625	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 38·90	$\frac{1}{2}$
3933·825	- 83·97	1	- 61·76	1	- 84·37	$\frac{1}{2}$	- 31·24	$\frac{1}{2}$	- 14·22	$\frac{1}{2}$	- 63·05	$\frac{1}{2}$	- 62·96	$\frac{1}{2}$
Weighted mean	- 84·46		- 62·12		- 77·44		- 36·37		- 11·95		- 51·39		- 55·22	
V _a	+ 12·80		+ 7·42		+ 6·83		+ 6·41		+ 1·67		+ 1·14		- 1·85	
V _d	- .18		- .16		- .11		- .12		- .28		- .29		- .14	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 72·1		- 55·1		- 71·0		- 30·4		- 10·8		- 50·8		- 57·5	

MEASURES OF 136 TAURI.—*Concluded.*

λ	6670		6674		6695		6711		6715		Vel.	Wt.	Vel.	Wt.
	Vel.	Wt.												
4549.766	- 27.95	$\frac{1}{2}$	+ 23.04	$\frac{1}{2}$	.....	.....	.....	.....	- 42.51	$\frac{1}{2}$	.....	.....	.....	.....
4481.400	- 21.41	$\frac{1}{2}$	+ 23.41	$\frac{1}{2}$	+ 8.76	$\frac{1}{2}$	+ 17.53	$\frac{1}{2}$	- 50.08	$\frac{1}{2}$	.....	.....	.....	.....
4340.634	- 37.32	$\frac{1}{2}$	+ 45.53	$\frac{1}{2}$	+ 1.36	$\frac{1}{2}$	+ 25.22	$\frac{1}{2}$	- 11.99	$\frac{1}{2}$	.....	.....	.....	.....
4101.890	- 27.43	$\frac{1}{2}$	.....	.....	- 10.54	$\frac{1}{2}$	+ 13.06	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
3933.825	- 22.61	1	+ 25.33	1	+ 8.47	1	+ 36.91	1	- 51.15	$\frac{1}{2}$	.....	.....	.....	.....
Weighted mean	- 26.33		+ 26.64		+ 2.82		+ 27.62		- 38.93		.....	.....	.....	.....
V_a	- 6.07		- 6.61		- 10.66		- 12.60		- 14.05		.....	.....	.....	.....
V_d	- .07		- .17		- .22		- .22		- .28		.....	.....	.....	.....
Curv.	- .28		- .28		- .28		- .28		- .28		.....	.....	.....	.....
Radial Velocity	- 32.7		+ 19.6		- 8.3		+ 14.5		- 53.5		.....	.....	.....	.....

The sixty observations were grouped into twelve normal places. The normal places are given below in Table IV together with the mean Julian day, mean phase from periastron, mean velocity, weight and residual from final curve.

TABLE IV.
NORMAL PLACES.

No.	Julian Day.	Phase.	Velocity.	Weight.	Residual.
1	2,419,970.118	0.490	-53.3	3.0	+1.0
2	2,420,448.018	0.929	-36.2	1.5	-1.0
3	2,419,808.190	1.441	- 9.5	2.0	-0.5
4	2,420,267.281	1.966	+15.4	1.5	+0.8
5	2,420,118.162	2.607	+29.6	1.5	-0.3
6	2,420,417.271	2.848	+31.1	2.0	+0.5
7	2,419,868.535	3.640	+13.1	2.5	-0.5
8	2,420,343.708	4.183	-11.4	2.0	-0.6
9	2,420,298.792	4.630	-32.1	2.0	+1.3
10	2,420,486.316	5.090	-54.4	1.0	-0.8
11	2,419,963.863	5.550	-65.0	2.0	+0.4
12	2,420,438.266	5.918	-68.0	2.0	-1.4

The preliminary elements obtained from these by Dr. King's graphic method were as follows:—

$$\begin{aligned}
 P &= 5.969 \text{ days} \\
 e &= .02 \\
 \omega &= 190^\circ \\
 K &= 49.5 \text{ km.} \\
 \gamma &= -17.5 \text{ km.} \\
 T &= 2,419,362.52 \text{ J. D.}
 \end{aligned}$$

A closer approximation to the curve was attempted by applying a least-squares solution. The period of oscillation was taken as fixed, being obtained by using both Lick and Ottawa observations, which being far apart, cover a great many cycles. On account of e being very small, T was also taken as fixed and e , ω , K , and γ used in the solution.

Observation equations were formed as in Table V.

TABLE V.
OBSERVATION EQUATIONS.

x	y	z	u	$-n$	Weight.
1	-.778	-.313	+.666	-2.7	.3
1	-.395	+.595	+.930	-0.9	1.5
1	+.140	+.991	+.991	-1.1	2.0
1	+.630	+.317	+.763	-1.7	1.5
1	+.959	-.832	+.210	+0.3	1.5
1	+.980	-.995	-.032	-0.1	2.0
1	+.647	-.073	-.741	+1.4	2.5
1	+.152	+.863	-.982	+1.4	2.0
1	-.309	+.917	-.953	-0.7	2.0
1	-.728	+.176	-.702	+0.8	1.0
1	-.980	-.734	-.277	-1.0	2.0
1	-1.013	-.851	+.122	+0.3	2.0

$$\begin{aligned}
 \text{when } x &= \delta\gamma \\
 y &= \delta K \\
 z &= K\delta e \\
 u &= K\delta\omega
 \end{aligned}$$

Normal equations resulting from these observation equations were as follows:—

$$\begin{aligned} 23x - 1.713y - 0.444z + 0.037u - 9.650 &= 0 \\ 11.711y + 0.421z - 0.970u + 9.050 &= 0 \\ 11.700z - 0.900u + 0.545 &= 0 \\ 11.327u - 14.621 &= 0 \end{aligned}$$

Solving these gave,

$$\begin{aligned} x &= + .37 \\ y &= - .62 \\ z &= + .085 \\ u &= + 1.244 \end{aligned}$$

from which,

$$\begin{aligned} \delta\gamma &= + .37 \text{ km.} \\ \delta K &= - .62 \text{ km.} \\ \delta e &= + .0017 \\ \delta\omega &= + 1^\circ.44 \end{aligned}$$

and hence the new values of the elements,

$$\begin{aligned} P &= 5.969 \text{ days} \\ e &= .0217 \\ \omega &= 191^\circ.44 \\ \gamma &= -17.13 \text{ km.} \\ K &= 48.88 \text{ km.} \\ T &= 2,419,362.52 \text{ J. D.} \end{aligned}$$

The value of Σpv was reduced from 25 to 16 — a very substantial reduction. Excellent agreement between computed and observation equation residuals showed that any further solution would be useless, and these elements were accepted as final.

The following table (Table VI) contains a summary of preliminary and final values together with the probable errors of each element.

TABLE VI.

Element.	Preliminary.	Final.	Probable Error.
P	5.969 days	5.969 days	
e	.02	.0217	$\pm .014$
ω	190°	$191^\circ.44$	$\pm 0^\circ.88$
K	49.5 km.	48.9 km.	$\pm .73$ km.
γ	-17.5 km.	-17.1 km.	$\pm .52$ km.
T	2,419,362.52 J. D.	2,419,362.52 J. D.	.....
$a \sin i$	.....	4,011,000 km.	.....

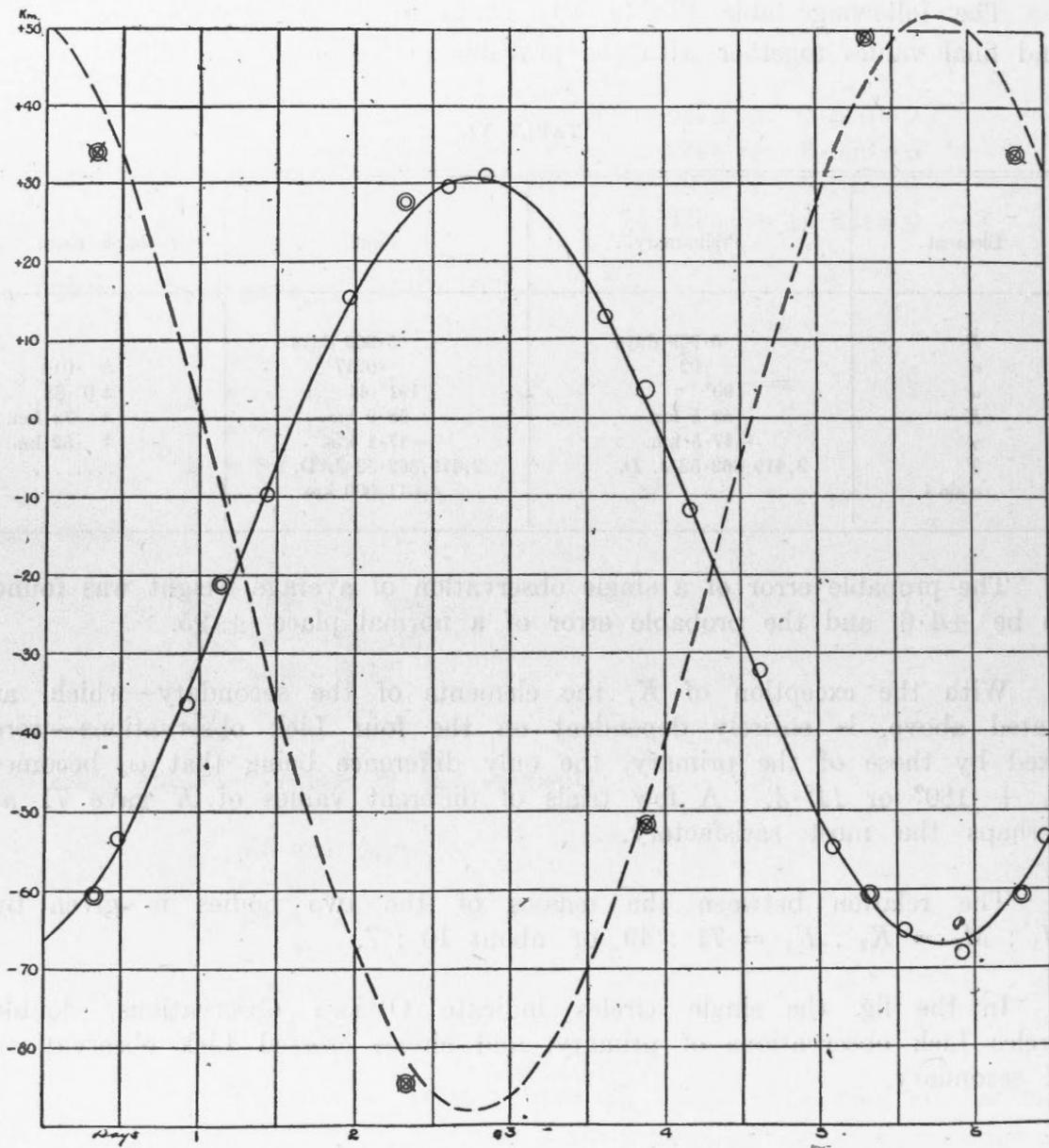
The probable error of a single observation of average weight was found to be ± 4.6 , and the probable error of a normal place $\pm .95$.

With the exception of K , the elements of the secondary—which, as stated above, is entirely dependent on the four Lick observations—were fixed by those of the primary, the only difference being that ω_2 becomes $\omega_1 + 180^\circ$ or $11^\circ.4$. A few trials of different values of K gave 71 as perhaps the most satisfactory.

The relation between the masses of the two bodies is given by $M_1 : M_2 = K_2 : K_1 = 71 : 49$ or about 10 : 7.

In the fig. the single circles indicate Ottawa observations, double circles Lick observations of primary, and circles crossed Lick observations of secondary.

Dominion Observatory,
Ottawa,
February, 1915.



Velocity Curve of 136 Tauri.

DEPARTMENT OF THE INTERIOR
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HON. W. J. ROCHE, *Minister.*

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ORBITS OF THE SPECTROSCOPIC COMPONENTS OF 50 DRACONIS.

BY W. E. HARPER, M.A.

This star ($\alpha=18^{\text{h}} 49^{\text{m}}.6$, $\delta=+75^{\circ} 19'$, photographic magnitude 5.4) was announced as a spectroscopic binary by Frost at the Evanston meeting of the American Astronomical Society. The velocities of the ten measurable plates secured at Yerkes in June and July, 1914, were made available to the writer who undertook the determination of the star's orbit. Professor Frost said that the period seemed to be about 4.2 days as the lines were double on alternate days.

The weather during September and October was very favourable and 34 spectrograms of the star, each averaging about 70 minutes exposure, were obtained before the end of the year. Of these, two have been rejected; one, for temperature changes in the prism during exposure, and the other, for the general uncertain character of the lines. The remaining 32—the measures of which are given in detail—form the basis of this publication. Seed 27 plates and the single-prism were used throughout, the dispersion at $\lambda 4325$ being 32.1\AA per millimetre.

The spectrum of both components is of the A-type the intensities being nearly, though not quite, equal. When the spectra are superposed a great many lines can be seen which are not recorded when the spectra are resolved. These lines are probably too weak when standing alone to appear, but when superposed they show sufficient contrast to be measurable. The following table gives the wave-lengths of the lines and the elements to which they are due.

LINES IN 50 DRACONIS.

Element.	Wave-Length.	Element.	Wave-Length.	Element.	Wave-Length.
<i>Fe</i>	4584.018	<i>Cr Mg</i>	4352.006	<i>Si</i>	4128.211
<i>Fe-Ti</i>	4549.766	<i>Hγ</i>	4340.634	<i>Hδ</i>	4101.890
<i>Ti</i>	4534.139	<i>Fe</i>	4325.939	<i>Sr</i>	4077.885
<i>Fe-Ti</i>	4522.871	<i>Fe</i>	4308.081	<i>Fe</i>	4071.901
<i>Ti</i>	4515.508	<i>Fe</i>	4294.301	<i>Fe</i>	4063.756
<i>Ti</i>	4508.455	<i>Fe-Fe</i>	4271.760	<i>Fe</i>	4045.975
<i>Mg</i>	4481.400	<i>Fe</i>	4260.640	<i>Fe</i>	4005.355
<i>Ti</i>	4468.663	<i>Fe</i>	4233.328	<i>He</i>	3970.177
<i>Fe</i>	4466.734	<i>Fe-Ca</i>	4227.010	<i>Ca</i>	3968.625
<i>Fe</i>	4404.927	<i>Sr-Cr</i>	4215.668	<i>Ca</i>	3933.825
<i>Ti</i>	4395.286	<i>Fe</i>	4143.928		

It is customary to deduce corrections to the assumed wave-lengths by equating to zero the sum of the residuals of each line from the mean of the plate. Such residuals were formed in the case of 29 plates whose lines were considered free from any error due to the blending of the components but in only two cases did there seem to be a systematic error in the wave-length employed. Improvement would be effected in the agreement of the individual lines by decreasing the wave-length of the $H\gamma$ line 0.058\AA and by increasing the K line 0.089\AA but, as the lines are poor in this star and as no appreciable change would result in the velocity of the plate, the assumed wave-lengths were allowed to stand.

MEASURES OF 50 DRACONIS.

λ	6354				6375				6382					
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549					+57.9	$\frac{1}{2}$	-69.9	$\frac{1}{2}$						
4481					52.7	$\frac{3}{4}$	85.3	$\frac{1}{2}$	+48.7	$\frac{1}{2}$	-59.7	$\frac{1}{2}$		
4340					38.0	$\frac{1}{2}$	80.7	$\frac{1}{2}$			80.7	$\frac{1}{4}$		
4300							109.9	$\frac{1}{2}$						
4294					48.5	$\frac{1}{2}$								
4233											45.9	$\frac{1}{4}$		
4143					65.4	$\frac{1}{2}$	84.5	$\frac{1}{2}$			66.8	$\frac{1}{2}$		
4101					47.6	$\frac{1}{2}$	125.0	$\frac{1}{4}$			44.4	$\frac{1}{4}$		
4077					56.3	$\frac{1}{2}$								
4045					39.3	$\frac{1}{2}$	84.3	$\frac{1}{2}$	28.8	$\frac{3}{4}$	66.9	$\frac{3}{4}$		
4005									+36.4	$\frac{3}{4}$	61.1	$\frac{1}{4}$		
3933	+39.8	$\frac{3}{4}$	-69.8	$\frac{3}{4}$	+70.2	$\frac{1}{2}$	-66.3	$\frac{1}{4}$			-55.0	$\frac{1}{2}$		
Weighted mean	+ 39.80		- 69.80		+ 52.17		- 87.56		+ 36.62		- 61.22			
V _a	+ 4.89		+ 4.89		+ 4.80		+ 4.80		+ 4.77		+ 4.77			
V _d	- .05		- .05		- .01		- .01		- .02		- .02			
Curv.	- .28		- .28		- .28		- .28		- .28		- .28			
Radial Velocity	+ 44.4		- 65.2		+ 56.7		- 83.0		+ 41.1		- 56.8			

MEASURES OF 50 DRACONIS—*Continued.*

λ	6390				6398				6405				6408	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549														
4481					+ 26.6	$\frac{2}{4}$	- 59.4	$\frac{1}{2}$	+ 62.6	$\frac{1}{2}$			- 7.2	$\frac{1}{2}$
4340			- 91.4	$\frac{1}{2}$					54.2	1	- 90.3	$\frac{1}{2}$	- 23.6	$\frac{1}{2}$
4233									66.5	$\frac{1}{4}$			- 21.6	$\frac{1}{2}$
4101	+ 50.2	$\frac{1}{2}$	85.6	$\frac{1}{2}$	38.0	$\frac{1}{2}$	77.0	$\frac{1}{4}$			80.0	$\frac{1}{2}$	- 19.7	$\frac{1}{4}$
4071							63.8	$\frac{1}{4}$						
4063					35.1	$\frac{1}{4}$	60.0	$\frac{1}{4}$	49.9	$\frac{1}{4}$	83.8	$\frac{1}{4}$	+ 20.4	$\frac{1}{2}$
4045					24.9	$\frac{1}{4}$	65.3	$\frac{1}{4}$			84.1	$\frac{1}{2}$	+ 29.9	$\frac{1}{2}$
4005													+ 24.6	$\frac{1}{2}$
3933	+ 62.0	$\frac{1}{4}$	- 76.6	1	+ 35.4	$\frac{1}{2}$	- 65.1	$\frac{2}{4}$	+ 55.1	$\frac{2}{4}$	- 85.8	$\frac{2}{4}$	- 26.8	$\frac{1}{2}$
Weighted mean	+ 54.13		- 82.55		+ 31.84		- 64.46		+ 56.70		- 85.56		- 4.15	
V_a	+ 4.73		+ 4.73		+ 4.70		+ 4.70		+ 4.68		+ 4.68		+ 4.65	
V_d	- .02		- .02		- .04		- .04		- .02		- .02		- .04	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 58.6		- 78.1		+ 36.2		- 60.1		+ 61.1		- 81.2		+ 0.2	

MEASURES OF 50 DRACONIS.—Continued.

λ	6414		6421		6424		6437		6445					
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.				
4563										8.0	$\frac{1}{2}$			
4549					9.2	$\frac{1}{2}$			21.6	$\frac{3}{4}$	41.0	$\frac{3}{4}$		
4508											23.2	$\frac{1}{2}$		
4501											27.9	$\frac{1}{2}$		
4481	+ 68.3	$\frac{1}{2}$	- 80.0	$\frac{1}{2}$	- 8.5	$\frac{1}{2}$	+ 68.7	$\frac{1}{2}$	- 84.0	$\frac{1}{2}$	- 15.1	1	20.4	1
4468							52.5	$\frac{1}{2}$	105.6	$\frac{1}{2}$	+ 1.7	$\frac{1}{2}$		
4466											- 4.8	$\frac{1}{2}$		
4404											+ 2.0	1		
4395											- 4.0	$\frac{1}{2}$		
4383					+ 19.9	$\frac{1}{2}$					- 24.8	$\frac{1}{2}$		
4352														
4340	68.5	$\frac{1}{2}$	82.9	$\frac{1}{2}$	- 8.7	$\frac{1}{2}$	78.0	$\frac{1}{2}$	80.7	$\frac{1}{2}$	- 15.9	$\frac{3}{4}$	30.9	$\frac{1}{2}$
4308							82.7	$\frac{1}{2}$					30.8	$\frac{1}{2}$
4271											- 31.4	$\frac{1}{2}$		
4260											- 14.2	$\frac{1}{2}$		
4233	88.0	$\frac{1}{2}$					93.3	$\frac{1}{2}$			- 11.9	$\frac{3}{4}$	21.5	$\frac{1}{2}$
4227														
4215											- 26.3	$\frac{1}{2}$	18.2	$\frac{3}{4}$
4143											- 19.0	$\frac{3}{4}$		
4128													15.3	1
4101					- 37.0	$\frac{1}{2}$	52.1	$\frac{1}{2}$	67.0	$\frac{1}{2}$				
4077							64.5	$\frac{1}{2}$	78.5	$\frac{1}{2}$	- 20.7	1	33.1	$\frac{1}{2}$
4071							62.1	$\frac{1}{2}$			- 5.9	$\frac{1}{2}$	27.3	$\frac{1}{2}$
4063	53.7	$\frac{1}{2}$	75.7	$\frac{1}{2}$					90.2	$\frac{1}{2}$			24.2	$\frac{3}{4}$
4045									100.1	$\frac{1}{2}$	- 10.9	1	26.1	1
3933	+ 68.7	$\frac{1}{2}$	- 94.3	$\frac{1}{2}$	+ 11.2	$\frac{1}{2}$	+ 86.8	$\frac{3}{4}$	- 85.3	$\frac{3}{4}$	- 6.8	$\frac{3}{4}$	- 14.6	$\frac{3}{4}$
Weighted mean	+ 72.53		- 83.22		- 2.70		+ 73.05		- 84.56		- 13.29		- 23.68	
V _a	+ 4.71		+ 4.71		+ 4.58		+ 4.50		+ 4.50		+ 4.40		+ 4.33	
V _d	- .04		- .04		- .03		- .04		- .04		- .04		- .05	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 76.9		- 78.8		+ 1.6		+ 77.2		- 80.4		- 9.2		- 19.7	

MEASURES OF 50 DRACONIS.—Continued.

λ	6452		6463		6473		6476		6491					
	Vel.	Wt.												
4584					- 32.1	$\frac{1}{4}$					- 47.6	$\frac{1}{2}$		
4549					- 14.8	$\frac{1}{4}$			-105.9	$\frac{3}{4}$	15.6	$\frac{3}{4}$	- 29.8	$\frac{1}{4}$
4522									87.5	$\frac{1}{2}$				
4481					- 7.1	$\frac{1}{2}$	+ 41.4	$\frac{3}{4}$	95.1	$\frac{3}{4}$	13.8	$\frac{3}{4}$	15.7	$\frac{1}{2}$
4352					+ 2.7	$\frac{1}{4}$								
4340	+ 60.0	$\frac{1}{4}$	- 98.0	$\frac{1}{4}$	- 13.5	1	61.4	$\frac{1}{2}$	122.3	$\frac{1}{2}$	17.7	$\frac{3}{4}$		
4325					- 21.2	$\frac{1}{2}$					14.4	$\frac{1}{2}$		
4308											8.5	$\frac{1}{2}$		
4271					- 30.9	$\frac{1}{2}$								
4260					- 12.2	$\frac{1}{2}$								
4233	60.8	$\frac{3}{4}$			- 3.2	$\frac{3}{4}$							1.9	$\frac{1}{2}$
4215											15.1	$\frac{1}{2}$		
4143	60.9	$\frac{1}{2}$			- 19.9	$\frac{1}{2}$	69.2	$\frac{1}{2}$						
4101	48.0	$\frac{1}{2}$	106.1	$\frac{1}{2}$	- 15.6	$\frac{3}{4}$	83.0	$\frac{1}{2}$	68.0	$\frac{1}{4}$	23.9	$\frac{1}{2}$	34.1	$\frac{1}{4}$
4077					- 12.2	$\frac{1}{2}$					15.0	$\frac{1}{2}$		
4071					- 24.0	$\frac{3}{4}$								
4063	70.7	$\frac{3}{4}$			- 14.0	$\frac{3}{4}$								
4045			91.4	$\frac{3}{4}$	- 18.5	1			86.1	$\frac{1}{2}$				
3933	+ 71.9	$\frac{1}{2}$	- 78.6	$\frac{1}{2}$	- 10.4	$\frac{3}{4}$	+ 67.6	$\frac{3}{4}$	- 96.5	$\frac{3}{4}$	- 8.1	$\frac{1}{2}$	- 34.2	$\frac{1}{2}$
Weighted mean	+ 62.80		- 92.70		- 15.26		+ 62.85		- 97.02		- 17.67		- 22.71	
V_a	+ 4.30		+ 4.30		+ 4.27		+ 4.23		+ 4.23		+ 4.20		+ 3.90	
V_d	- .02		- .02		- .03		- .03		- .03		- .02		- .10	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 66.8		- 88.7		- 11.3		+ 66.8		- 93.1		- 13.8		- 19.2	

MEASURES OF 50 DRACONIS.—Continued.

λ	6495				6502				6519					
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549	+ 44.6	$\frac{1}{2}$	- 86.1	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4481	76.6	$\frac{1}{4}$	53.1	$\frac{1}{8}$	.....	.....	.....	.....	+ 48.1	$\frac{1}{4}$	- 95.3	$\frac{1}{4}$	.....	.....
4340	25.6	$\frac{1}{2}$	97.3	$\frac{1}{4}$	.....	.....	.....	.....	60.3	1	93.2	1	.....	.....
4315	53.3	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4308	58.6	1	93.7	$\frac{1}{8}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4271	.....	.....	84.5	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4233	.....	.....	.....	.....	+ 25.4	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4101	.....	.....	.....	.....	29.2	$\frac{1}{2}$	- 54.8	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....
4063	46.5	$\frac{1}{4}$	60.0	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4045	.....	.....	86.2	$\frac{1}{4}$	.....	.....	.....	.....	54.5	$\frac{1}{4}$	85.0	$\frac{1}{4}$	.....	.....
3968	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	75.2	$\frac{1}{4}$	.....	.....
3933	+ 45.6	$\frac{1}{4}$	- 63.7	$\frac{1}{4}$	+ 31.6	$\frac{1}{2}$	- 62.5	$\frac{1}{2}$	+ 54.8	1	- 77.0	1	.....	.....
Weighted mean	+ 50.42		- 78.73		+ 28.73		- 59.93		+ 56.31		- 85.12		.....	.....
V_a	+ 3.84		+ 3.84		+ 3.78		+ 3.78		+ 3.27		+ 3.27		.....	.....
V_d	- .05		- .05		- .05		- .05		- .04		- .04		.....	.....
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		.....	.....
Radial Velocity	+ 53.9		- 75.2		+ 32.2		- 56.5		+ 59.3		- 82.2			

MEASURES OF 50 DRACONIS.—Continued.

λ	6528		6540		6554		6567				6577			
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584														
4549			- 15.9	$\frac{1}{2}$	- 41.0	$\frac{1}{2}$	+ 32.2	$\frac{1}{2}$						
4534					- 14.3	$\frac{1}{2}$								
4481			- 18.1	$\frac{2}{4}$	- 31.3	$\frac{1}{2}$					+ 55.5	$\frac{1}{2}$	- 54.5	$\frac{1}{2}$
4415											56.8	$\frac{1}{4}$		
4340			- 14.2	$\frac{1}{2}$	- 8.1	$\frac{1}{2}$					97.4	$\frac{1}{4}$	77.4	$\frac{1}{4}$
4308			- 5.5	$\frac{1}{2}$							40.6	$\frac{1}{2}$	119.0	$\frac{1}{4}$
4271					+ 13.3	$\frac{1}{2}$								
4233			- 11.4	$\frac{1}{2}$										
4215			+ 2.0	$\frac{1}{2}$										
4101			+ 1.8	$\frac{1}{2}$						- 23.0	$\frac{1}{4}$			
4077											+ 62.9	$\frac{1}{2}$	- 62.4	$\frac{1}{2}$
4063					- 29.1	$\frac{1}{2}$				44.7	$\frac{1}{4}$			
4045	- 47.2	$\frac{1}{4}$	- 11.6	$\frac{3}{4}$	- 16.6	$\frac{1}{4}$				46.8	$\frac{1}{4}$			
3970			- 0.8	$\frac{1}{2}$										
3968			- 3.5	$\frac{1}{2}$										
3933	- 40.9	$\frac{1}{2}$	- 15.0	$1\frac{1}{4}$			+ 41.0	$\frac{2}{4}$	- 53.6	$\frac{1}{4}$				
Weighted mean	- 43.03		- 9.61		- 19.53		+ 37.50		- 42.02		+ 58.50		- 71.60	
V_a	+ 3.20		+ 2.55		+ 1.62		+ .85		+ .85		+ .60		+ .60	
V_d	- .07		- .08		- .10		- .10		- .10		- .11		- .11	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 40.2		- 7.4		- 18.3		+ 38.0		- 41.5		+ 58.7		- 71.4	

MEASURES OF 50 DRACONIS.—Continued.

λ	6578		6589				6602				6622			
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4584	.....	.....	.....	.....	.....	.....	+ 31.8	$\frac{1}{4}$	-127.9	$\frac{1}{4}$	.....	.....	.....	.....
4549	.....	.....	+ 86.2	1	- 76.1	1	54.3	$\frac{3}{4}$	94.1	$\frac{1}{2}$	.....	.....	.....	.....
4481	- 1.0	$\frac{1}{2}$	.....	.....	93.9	$\frac{1}{2}$	53.8	$\frac{1}{4}$	90.8	$\frac{1}{2}$	+ 59.2	1	- 86.3	1
4340	13.1	$\frac{1}{2}$	94.2	$\frac{1}{4}$	88.1	$\frac{1}{4}$	52.7	$\frac{1}{4}$	94.1	$\frac{1}{4}$	48.6	$\frac{1}{2}$	92.8	$\frac{1}{4}$
4308	.....	.....	65.1	$\frac{1}{4}$	101.2	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	89.8	$\frac{3}{4}$
4271	.....	.....	95.7	$\frac{1}{2}$	.....	.....	63.7	$\frac{1}{4}$	98.8	$\frac{1}{2}$	.....	.....	.....	.....
4260	.....	.....	74.0	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	94.4	$\frac{1}{2}$
4101	25.6	$\frac{1}{4}$	.....	.....	.....	.....	68.7	$\frac{1}{4}$	88.5	$\frac{1}{4}$	60.3	$\frac{1}{2}$	.....	.....
4077	.....	.....	65.1	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4071	26.3	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4063	.....	.....	69.3	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4045	8.2	$\frac{1}{4}$	+ 70.9	$\frac{1}{4}$	- 81.6	$\frac{1}{4}$	.....	.....	100.0	$\frac{1}{2}$	.....	.....	.....	.....
3933	- 7.2	$\frac{1}{2}$	.....	.....	.....	.....	+ 80.0	$\frac{1}{4}$	- 87.7	$\frac{1}{2}$	+ 70.2	$\frac{1}{2}$	- 94.8	$\frac{1}{4}$
Weighted mean	- 11.33		+ 78.64		- 84.80		+ 57.07		- 96.37		+ 59.48		- 90.73	
V _a	+ .52		- .11		- .11		- .27		- .27		- .99		- .99	
V _d	- .10		- .11		- .11		- .10		- .10		- .10		- .10	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 11.2		+ 78.1		- 85.3		+ 56.4		- 97.0		+ 58.1		- 92.1	

MEASURES OF 50 DRACONIS.—*Concluded.*

λ	6624		6634				6659							
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549	- 7.5	$\frac{1}{2}$					- 74.2	$\frac{1}{2}$						
4481	+ 8.5	$\frac{3}{4}$	+ 66.6	1										
4415							59.0	$\frac{1}{2}$						
4340	- 5.4	$\frac{1}{2}$	72.7	$\frac{1}{2}$	- 97.0	$\frac{1}{2}$								
4233							43.9	$\frac{1}{4}$						
4101	- 20.2	$\frac{1}{4}$	39.7	$\frac{1}{2}$	91.4	$\frac{1}{2}$								
4045			39.6	$\frac{1}{4}$	73.6	$\frac{1}{4}$	47.0	$\frac{1}{2}$						
4005							40.4	$\frac{1}{2}$						
3968			45.4	$\frac{1}{2}$	79.8	$\frac{1}{2}$								
3933	- 6.5	$\frac{3}{4}$	+ 70.4	$\frac{3}{4}$	- 77.0	$\frac{3}{4}$	- 47.0	$\frac{1}{2}$						
Weighted mean	- 3.64		+ 59.44		- 84.12		- 54.68							
V_a	- 1.10		- 1.16		- 1.16		- 1.92							
V_d	- .11		- .11		- .11		- .10							
Curv.	- .28		- .28		- .28		- .28							
Radial Velocity	- 5.1		+ 57.9		- 85.7		- 57.0							

The following table contains all the data of the measures. The phases are reckoned from the periastron finally adopted J. D. 2420293.930 using the period 4.120 days. The number of lines measured and the weight assigned each plate follow. The residuals O-C are scaled from the curve representing the adopted elements. They are given only for those plates whose lines are fully resolved. Corresponding data is given for the Yerkes' observations.

TABLE OF MEASURES OF 50 DRACONIS.

Plate.	Ob-server*	Date.	Julian Date.	Phase.	COMPONENT I.				COMPONENT II.				
					n	Wt.	Vel.	O-C.	n	Wt.	Vel.	O-C.	
		1914											
6354	P	Sept. 11.....	2420387.607	3.037	1	1	+ 44.4	+9.0	1	1	- 65.2	- 7.2	
6375	Y	Sept. 15.....	391.523	2.833	9	6	+ 56.7	+9.7	8	5	- 83.0	-10.0	
6382	G	Sept. 16.....	392.535	3.845	8	5.5	- 56.8	-1.8	3	2.5	+ 41.1	+1.1	
6390	H	Sept. 17.....	393.522	.712	3	2.5	- 78.1	-5.3	2	1.5	+ 58.6	- 1.4	
6398	C	Sept. 18.....	394.577	1.767	6	4	+ 36.2	+2.0	5	3.5	- 60.1	- 1.1	
6405	H	Sept. 19.....	395.523	2.713	5	4	+ 61.1	+2.6	5	3.5	- 81.2	+ 2.0	
6408	Y	Sept. 20.....	396.563	3.753	8	5.5	+ 0.2	.....	.....	.....	.....	.....
6414	H	Sept. 21.....	397.564	.634	5	3	- 78.8	-0.8	4	2	+ 76.9	-11.9	
6421	Y	Sept. 22.....	398.542	1.612	6	4	+ 1.6	.....	.....	.....	.....	.....
6424	P ¹	Sept. 25.....	401.542	.492	8	5.5	- 80.4	+4.6	9	6	+ 77.2	+ 5.0	
6437	P ¹	Sept. 28.....	404.531	3.481	17	12	- 9.2	.....	.....	.....	.....	.....
6445	G	Sept. 30.....	406.570	1.400	16	11	- 19.7	.....	.....	.....	.....	.....
6452	H	Oct. 1.....	407.504	2.334	6	4.5	+ 66.8	+3.4	4	3	- 88.7	+ 2.7	
6463	C	Oct. 2.....	408.514	3.344	16	11	- 11.3	.....	.....	.....	.....	.....
6473	P	Oct. 3.....	409.510	.220	7	5.5	- 93.1	-6.7	5	4	+ 66.8	- 6.8	
6476	Y	Oct. 4.....	410.490	1.200	10	7	- 13.8	.....	.....	.....	.....	.....
6491	G	Oct. 12.....	418.539	1.009	5	3.5	- 19.2	.....	.....	.....	.....	.....
6495	Y	Oct. 13.....	419.503	1.973	7	5	+ 53.9	+4.3	8	4	- 75.2	+ 0.2	
6502	P ¹	Oct. 14.....	420.516	2.986	3	2	+ 32.2	-5.0	2	1.5	- 56.5	+ 6.0	
6519	H	Oct. 22.....	428.478	2.708	4	3	+ 59.3	+1.3	5	4	- 82.2	+ 1.2	
6528	C	Oct. 23.....	429.510	3.740	2	1.5	- 40.2	.....	.....	.....	.....	.....
6540	P	Nov. 2.....	439.517	1.387	11	8	- 7.4	.....	.....	.....	.....	.....
6554	P	Nov. 14.....	451.513	1.023	7	5	- 18.3	.....	.....	.....	.....	.....
6567	C	Nov. 23.....	460.483	1.753	1	1	+ 38.0	+5.0	1	0.5	- 41.5	+15.7	
6577	H	Nov. 26.....	463.550	.700	4	2.5	- 71.4	+2.0	5	3.5	+ 58.7	- 2.0	
6578	C	Nov. 27.....	464.485	1.635	6	4	- 11.2	.....	.....	.....	.....	.....
6589	C	Dec. 4.....	471.497	.407	5	3.5	- 85.3	+1.3	8	5	+ 78.1	+ 3.7	
6602	Y	Dec. 6.....	473.451	2.361	7	4	+ 56.4	-7.4	8	5	- 97.0	- 5.0	
6622	P ¹	Dec. 14.....	481.517	2.187	4	3	+ 58.1	-1.5	5	3.5	- 92.1	- 4.7	
6624	Y	Dec. 15.....	482.500	3.170	5	3.5	- 5.1	.....	.....	.....	.....	.....
6634	H	Dec. 16.....	483.520	.070	5	3.5	- 85.7	-4.3	6	4.5	+ 57.9	-10.8	
6659	H	Dec. 25.....	492.562	.872	6	3	- 57.0	+2.6	.....	.....	.....	.....

*P=Plaskett; Y=Young; G=Gibson; H=Harper; P¹=Parker; C=Cannon.

YERKES' OBSERVATIONS, 50 DRACONIS.

Date.	Julian Date.	Phase.	COMPONENT I.			COMPONENT II.		
			<i>n</i>	Vel.	O-C.	<i>n</i>	Vel.	O-C.
1914.								
June 9.....	2420293.930	3.95	5	- 71	- 4	5	+ 48	- 3
June 15.....	299.693	1.64	3	- 28	.....	.....	.....	.....
June 16.....	300.654	2.60	4	+ 84	+23	4	- 92	- 4
June 17.....	301.677	3.62	5	- 5	.....	.....	.....	.....
June 22.....	306.725	0.43	2	- 80	+ 6	2	+ 78	+ 4
June 29.....	313.807	3.40	4	- 6	.....	.....	.....	.....
July 2.....	316.637	2.11	4	+ 73	+17	3	- 82	+ 2
July 3.....	317.680	3.15	3	+ 29	.....	.....	.....	.....
July 20.....	334.661	3.65	6	+ 4	.....	.....	.....	.....
July 21.....	335.626	0.50	1	- 68	+17	2	+ 95	+23

Comparison of Yerkes' observations with our own indicated a period of 4.120 days. No attempt was made to improve this value by least-squares.* The Ottawa plates were grouped on the basis of phases into the following normal places. Nos. 1-10 refer to Component I, Nos. 11-20 to Component II.

*Further observations will be made to improve the value.

NORMAL PLACES.

No.	Mean Phase.	Mean Vel.	Wt.	O-C	Eq.-Eph.
1.....	3.45	- 7.9	1.5	+ 3.8	- .1
2.....	3.85	- 53.2	.7	+ 3.3	.0
3.....	.31	- 86.2	1.8	+ 1.3	.0
4.....	.74	- 70.2	1.0	+ 1.1	+ .1
5.....	1.33	- 13.4	2.0	- 1.2	+ .1
6.....	1.77	+ 36.8	.5	+ 2.9	- .1
7.....	1.97	+ 54.0	.5	+ 4.9	+ .2
8.....	2.30	+ 60.9	1.2	- 2.2	+ .1
9.....	2.77	+ 58.3	1.3	+ 4.8	+ .1
10.....	3.00	+ 36.3	.3	- 0.3	+ .1
11.....	3.45	- 7.9	1.5	+ 0.3	+ .1
12.....	3.85	+ 40.7	.3	- 0.1	+ .1
13.....	.32	+ 70.9	2.0	- 4.0	.0
14.....	.67	+ 67.9	1.0	+ 5.6	.0
15.....	1.33	- 13.4	2.0	- 5.6	- .1
16.....	1.77	- 58.0	.5	+ 0.3	.0
17.....	1.97	- 75.2	.4	+ 0.1	.0
18.....	2.30	- 93.3	1.2	- 2.7	.0
19.....	2.75	- 82.3	1.2	- 1.0	.0
20.....	3.00	- 60.0	.3	+ 1.4	- .1

The plates, where the lines were not fully resolved, were grouped into two groups about the crossing points, care having previously been taken to have the plates balanced in phase on either side of these points. The two groups thus formed were each subdivided into two, (Nos. 1 and 11, 5 and 15), half the weight being assigned to each, and the residuals from each curve taken in the solution. No great objection can be taken to this as the grouped observations refer equally to both components and for all practical purposes the intensities of the component spectra are the same.

It was seen that the eccentricity was very small, though from a few preliminary trials there was no doubt of there being a slight eccentricity. The value of ω could be stated as lying somewhere between 120° and 240° , but it was hard to state from graphical methods just what value in this interval suited best. Recourse was had to the method of least-squares, and the resulting value of Σpvv was lowest for $\omega_1 = 151^\circ$, though $\omega_1 = 203^\circ$ was a good second. A least-squares solution was also carried through for $e=0$. The results were:—

$$\begin{aligned} \text{For } e &= 0 & \Sigma pvv &= 271 \\ \text{For } \omega_1 &= 203^\circ & \Sigma pvv &= 230 \\ \text{For } \omega_1 &= 151^\circ & \Sigma pvv &= 226 \end{aligned}$$

The observation and normal equations for the latter only will be given. In this case T had to be fixed, otherwise the solution became indeterminate. The preliminary values adopted were:—

$$\begin{aligned} P &= 4.120 \text{ days} \\ e &= .03 \\ \omega_1 &= 150^\circ \\ \omega_2 &= 330^\circ \\ K_1 &= 75 \text{ km.} \\ K_2 &= 82.1 \text{ km.} \\ \gamma &= -11.0 \text{ km.} \\ A_1 &= 73 \\ B_1 &= 77 \\ A_2 &= 84.3 \\ B_2 &= 79.9 \\ T &= \text{J. D. } 2420293.93 \end{aligned}$$

The following substitutions were made and the equations resulting from both components were combined* into one set of normals:—

$$\begin{aligned} x &= \delta\gamma \\ y &= \delta K_1 \\ z &= \delta K_2 \\ u &= 100 \delta e \\ v &= 100 \delta \omega \end{aligned}$$

*Publications of the Dominion Observatory, Vol. I, No. 11, p. 327.

OBSERVATION EQUATIONS 50 DRACONIS.

—	<i>x</i>	<i>y</i>	<i>z</i>	<i>u</i>	<i>v</i>	<i>-n</i>	Wt.
1.....	1.000	.....	.....	+ .678	- .739	- 3.1=0	1.5
2.....	1.000	- .600	.....	- .123	- .603	- 2.8	0.7
3.....	1.000	-1.026	.....	- .667	- .006	- 1.8	1.8
4.....	1.000	- .827	.....	+ .181	+ .460	- 2.0	1.0
5.....	1.000	- .040	.....	+ .651	+ .761	- 0.6	2.0
6.....	1.000	+ .563	.....	- .165	+ .617	- 5.6	0.5
7.....	1.000	+ .768	.....	- .536	+ .466	- 7.4	0.5
8.....	1.000	+ .958	.....	- .739	+ .144	- 0.1	1.2
9.....	1.000	+ .849	.....	- .030	- .352	- 5.7	1.3
10.....	1.000	+ .634	.....	+ .452	- .552	+ 0.2	0.3
11.....	1.000	.....	.....	- .742	+ .809	- 3.1	1.5
12.....	1.000	.....	+ .600	+ .135	+ .660	- 2.5	0.3
13.....	1.000	.....	+1.026	+ .715	- .008	+ 2.3	2.0
14.....	1.000	.....	+ .879	- .048	- .441	- 6.8	1.0
15.....	1.000	.....	+ .040	- .712	- .833	+ 5.6	2.0
16.....	1.000	.....	- .563	+ .181	- .676	+ 0.7	0.5
17.....	1.000	.....	- .768	+ .587	- .511	+ 1.1	0.4
18.....	1.000	.....	- .958	+ .808	- .158	+ 3.6	1.2
19.....	1.000	.....	- .862	+ .079	+ .365	+ 0.5	1.2
20.....	1.000	.....	- .634	- .495	+ .604	- 3.1	0.3

NORMAL EQUATIONS.

$$\begin{aligned}
 21.200x - .065y + .229z + .199u - .295v - 19.540 &= 0 \\
 5.446y \dots\dots\dots + .033u - .151v - 3.839 &= 0 \\
 5.496z + .244u - .314v - 5.862 &= 0 \\
 7.144u - .050v + 4.038 &= 0 \\
 6.346v - 10.610 &= 0
 \end{aligned}$$

From these equations resulted the corrections,

$$\begin{aligned}
 x &= +0.94 \\
 y &= +0.77 \\
 z &= +1.16 \\
 u &= -0.622 \\
 v &= +1.786
 \end{aligned}$$

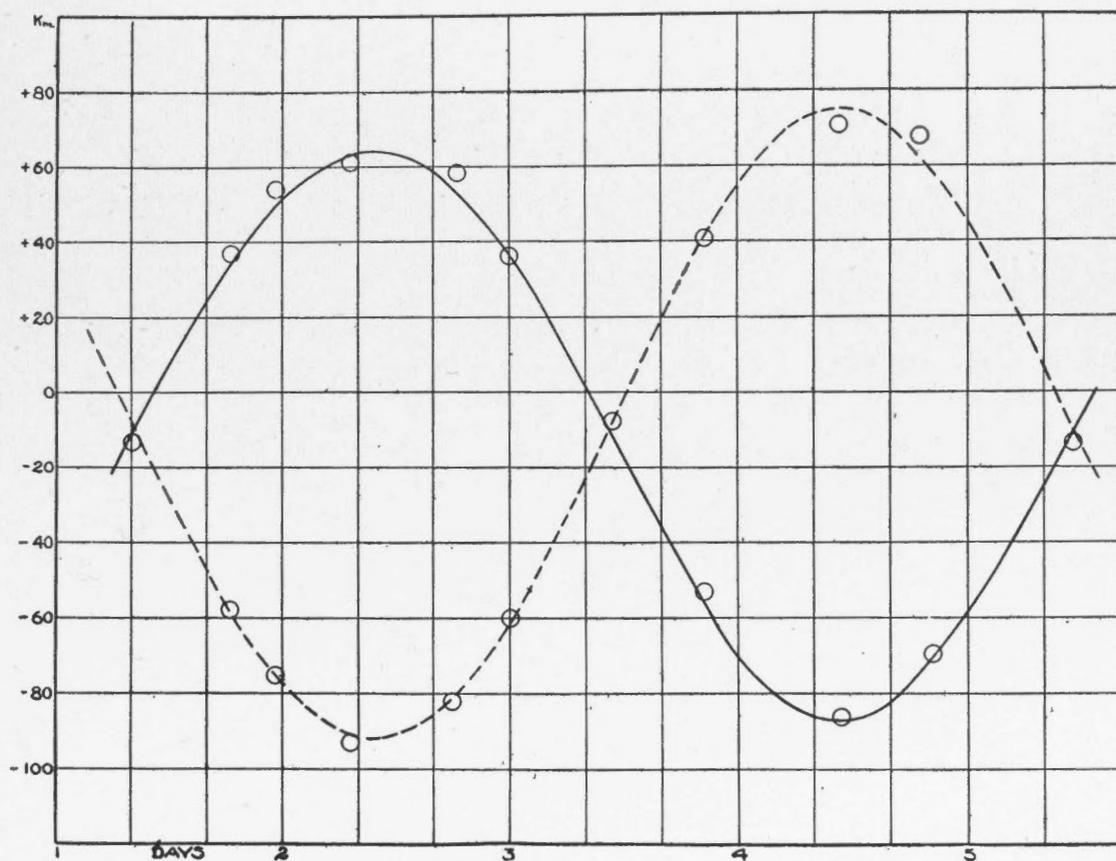
One solution was seen to be sufficient, as the differences between equation and ephemeris residuals were very small.

The final values of the elements with their probable errors are, then, as follows:—

P	$= 4.120$ days	A_1	$= 74.18$ km.
e	$= .024 \pm .001$	B_1	$= 77.36$ km.
K_1	$= 75.77$ km. ± 1.57 km.	A_2	$= 85.01$ km.
K_2	$= 83.26$ km. ± 1.56 km.	B_2	$= 81.51$ km.
γ	$= -10.1$ km ± 0.8 km.	$a_1 \sin i$	$= 4291000$ km.
ω_1	$= 151^\circ.0 \pm 0^\circ.8$	$a_2 \sin i$	$= 4716000$ km.
ω_2	$= 331^\circ.0 \pm 0^\circ.8$	$m_1 \sin^3 i$	$= 0.90 \odot$
T	$=$ J. D. 2420293.930	$m_2 \sin^3 i$	$= 0.82 \odot$

The graph accompanying represents the final elements and the observations as grouped. The probable error of a plate is ± 3.7 km. per second.

Dominion Observatory,
Ottawa,
February, 1915.



VELOCITY CURVE OF 50 DRACONIS.

DEPARTMENT OF THE INTERIOR

CANADA

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Dominion Observatory

OTTAWA

W. F. KING, C.M.G., LL.D., *Director.*

Vol. II, No. 6

Orbit of ζ Andromedæ

BY

J. B. CANNON, M.A.

OTTAWA
GOVERNMENT PRINTING BUREAU
1915

DEPARTMENT OF THE INTERIOR

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PUBLICATIONS

OF THE

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Four measures of the velocity of this star are given in L.O.B. 199, the range of the four being 35 km. The spectral type is K, but the lines are not so good as is usually the case with stars of this type. The note added to the list of measures in L.O.B. 199 says that "the lines are rather broad, possibly due to the effect of a second spectrum." This may be the cause of the broadness of the lines, although no indication of doubling has been observed here in any case. Fifty-eight plates were used in the work of determining the orbit, dating from Sept. 1st, 1913, to Feb. 12th, 1915. On the average, about 12 lines were measured on each plate and, generally speaking, the agreement was very fair. A list of the lines used and the element to which each is due follows in Table I.

TABLE I.

Wave-Length.	Element.	Wave-Length.	Element.
4571.958	<i>Ti</i>	4260.640	<i>Fe</i>
4549.721	<i>Fe</i>	4227.066	<i>Fe</i>
4534.139	<i>Ti</i>	4216.028	<i>Fe</i>
4501.814	<i>Ti</i>	4215.849	<i>Fe</i>
4415.271	<i>Fe</i>	4202.161	<i>Fe</i>
4404.962	<i>Fe</i>	4143.928	<i>Fe</i>
4395.505	<i>Ti-V</i>	4130.950	<i>Si</i>
4352.006	<i>Cr-Mg</i>	4128.031	<i>Si</i>
4340.798	<i>H</i>	4101.820	<i>H</i>
4325.939	<i>Fe</i>	4077.885	<i>Sr</i>
4314.945	<i>Fe-Ti</i>	4071.927	<i>Fe</i>
4294.528	<i>Ti-Fe</i>	4063.849	<i>Fe</i>
4289.857	<i>Cr</i>	4045.975	<i>Fe</i>
4271.874	<i>Fe</i>	4005.422	<i>Fe</i>

A summary of the measures is given in Tables II and III. Table II contains the Lick measures. The four above mentioned are here, and also another taken in 1911 and communicated by Dr. Campbell. Table III contains the Ottawa observations. In these tables, the phase is from periastron and the residual from the final curve.

TABLE II.
LICK OBSERVATIONS.

Julian Day.	Phase.	Velocity.	Residual.
2,414,582.751	12.431	- 21.4	+ 1.0
2,416,820.764	11.764	- 15.7	+ 1.0
2,417,501.757	17.600	- 51.3	+ 5.1
2,418,206.893	12.044	- 18.2	+ 1.0
2,419,335.679	3.723	- 28.0	+ 6.5

TABLE III.
OTTAWA OBSERVATIONS.

Plate	Observer*	Date	Exposure	Julian Day	Phase	Vel.	Wt.	Residual
		1913	m.					
5657	Y	Sept. 1.....	68	2,420,012.782	5.606	- 19.4	7	- 1.0
5681	P ¹	Sept. 19.....	40	030.760	5.879	- 17.8	4	- 2.2
5689	C	Sept. 22.....	80	033.853	8.972	- 6.1	4	- 0.9
5715	C	Sept. 29.....	75	040.825	15.944	- 45.3	8	+ 5.7
5737	C-P ¹	Oct. 3.....	75	044.750	2.102	- 43.3	8	+ 5.0
5754	C	Oct. 6.....	75	047.783	5.143	- 27.3	4	- 4.8
5777	C	Oct. 13.....	75	054.690	12.041	- 20.8	5	- 1.6
5856	P	Dec. 27.....	35	129.533	15.815	- 57.7	3	- 7.7
5860	P	Dec. 31.....	50	133.552	2.066	- 47.1	4	+ 1.2
		1914						
5875	P ¹	Jan. 5.....	60	138.538	7.053	- 3.8	6	+ 5.4
5882	P ¹	Jan. 12.....	60	145.576	14.091	- 45.9	3	- 9.1
6246	C	Aug. 3.....	75	348.859	4.167	- 38.2	6	- 7.2
6269	C	Aug. 5.....	75	350.862	6.169	- 22.5	4	- 8.1
6302	Y-C	Aug. 24.....	79	369.747	7.287	- 7.3	8	+ 0.8
6315	C	Aug. 26.....	90	371.809	9.349	- 7.3	3	- 1.6
6338	P ¹	Sept. 4.....	75	380.817	0.590	- 60.4	8	- 5.0
6372	C	Sept. 14.....	75	390.792	10.565	- 10.8	8	- 1.2
6385	G	Sept. 16.....	85	392.692	12.465	- 19.4	6	+ 3.0
6401	C-P ¹	Sept. 18.....	75	394.724	14.497	- 35.3	8	+ 4.7

OTTAWA OBSERVATIONS—Continued.

Plate	Observer*	Date	Exposure	Julian Day	Phase	Vel.	Wt.	Residual
		1914.	m.					
6411	P ¹	Sept. 20.....	90	2,420,896.778	16.551	- 47.4	8	+ 6.6
6417	H-C	Sept. 21.....	79	397.729	17.502	- 59.0	7	- 2.5
6429	G	Sept. 25.....	70	401.806	3.812	- 33.8	8	+ 0.7
6441	C	Sept. 28.....	75	404.751	6.756	- 16.5	7	- 5.7
6446	G	Sept. 30.....	80	406.625	8.630	- 11.3	6	- 5.1
6457	H-Y	Oct. 1.....	55	407.726	9.731	- 1.4	4	+ 5.0
6466	C	Oct. 2.....	65	408.641	10.646	- 2.3	7	+ 7.6
6478	Y	Oct. 4.....	64	410.583	12.588	- 23.4	8	+ 0.1
6494	C	Oct. 12.....	77	418.789	3.027	- 47.5	4	- 6.7
6498	Y	Oct. 13.....	70	419.653	3.891	- 29.4	5	+ 4.1
6505	P ¹	Oct. 14.....	65	420.665	4.903	- 32.7	5	- 8.5
6507	Y-H	Oct. 20.....	90	426.729	10.967	- 10.5	6	+ 1.3
6515	P ¹	Oct. 21.....	90	427.757	11.995	- 25.5	7	- 6.9
6523	Y	Oct. 22.....	60	428.792	13.030	- 25.9	7	+ 1.6
6530	C	Oct. 23.....	75	429.592	13.830	- 38.4	8	- 4.2
6544	P ¹ -C	Nov. 2.....	70	439.729	6.200	- 14.5	5	- 0.5
6551	C	Nov. 4.....	75	441.634	8.105	- 3.5	6	+ 2.2
6558	P ¹	Nov. 16.....	105	453.675	2.379	- 46.4	8	- 0.4
6560	Y	Nov. 17.....	83	454.638	3.342	- 35.5	8	+ 3.3
6570	C	Nov. 23.....	70	460.625	9.329	- 4.3	7	+ 1.4
6581	C	Nov. 27.....	75	464.636	13.340	- 33.4	6	- 4.1
6585	P ¹	Nov. 28.....	65	465.529	14.233	- 38.5	6	- 0.5
6590	C	Dec. 4.....	85	471.564	2.505	- 40.9	8	+ 4.1
6614	C	Dec. 11.....	75	478.567	9.503	- 9.4	7	- 3.4
6637	H	Dec. 16.....	96	483.665	14.601	- 40.4	8	+ 0.4
6647	Y	Dec. 20.....	70	487.536	0.705	- 58.2	8	- 3.2
6648	P ¹	Dec. 21.....	80	488.684	1.853	- 52.5	7	- 2.5
6649	Y	Dec. 22.....	60	489.469	2.638	- 40.5	7	+ 3.5
6662	H	Dec. 26.....	60	493.433	6.664	- 5.5	7	+ 5.6
		1915						
6675	Y	Jan. 3.....	60	501.540	14.709	- 41.0	8	+ 0.5
6676	P ¹	Jan. 4.....	75	502.522	15.691	- 47.6	7	+ 1.9
6684	Y	Jan. 5.....	60	503.483	16.642	- 57.7	8	- 2.9
6690	C	Jan. 8.....	70	506.538	1.940	- 43.4	6	+ 6.0
6724	H	Jan. 21.....	45	519.460	14.862	- 44.2	5	- 1.3
6728	Y	Jan. 24.....	70	522.472	0.107	- 55.0	6	+ 1.2
6772	H	Feb. 4.....	60	533.492	11.126	- 6.6	5	+ 5.9
6775	Y	Feb. 9.....	60	538.490	16.124	- 55.2	8	- 3.2
6779	H	Feb. 10.....	83	539.522	17.156	- 60.1	6	- 4.1
6780	C	Feb. 12.....	63	541.495	1.362	- 54.4	8	- 1.8

*Y=Young,

P¹=Parker,

C=Cannon,

P=Plaskett,

G=Gibson,

H=Harper.

The detailed measures of the plates are now given.

MEASURES OF ζ ANDROMEDÆ.

λ	5657		5681		5689		5715		5737		5754		5777	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 6.71	$\frac{1}{2}$	- 28.17	$\frac{1}{2}$	- 26.79	$\frac{1}{2}$	- 63.27	$\frac{1}{2}$	- 52.61	$\frac{1}{2}$	- 28.17	$\frac{1}{2}$	- 12.40	$\frac{1}{2}$
4549.721	- 25.60	$\frac{1}{2}$	.....	.....	- 13.50	$\frac{1}{2}$	- 43.88	$\frac{1}{2}$	.....	.....	.....	.....	- 20.18	$\frac{1}{2}$
4501.814	.....	.....	.....	.....	.....	.....	- 63.18	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4415.271	.....	.....	.....	.....	.....	.....	.....	.....	- 50.04	$\frac{1}{2}$	- 40.80	$\frac{1}{2}$	- 2.99	$\frac{1}{2}$
4404.962	- 40.32	$\frac{1}{2}$	.....	.....	- 15.91	$\frac{1}{2}$	- 57.39	$\frac{1}{2}$	- 46.63	$\frac{1}{2}$	- 28.98	$\frac{1}{2}$	- 17.49	$\frac{1}{2}$
4395.505	- 48.77	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4352.006	.....	.....	.....	.....	- 13.27	$\frac{1}{2}$	- 23.96	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4340.798	- 37.58	$\frac{1}{2}$	- 27.54	$\frac{1}{2}$	- 8.79	$\frac{1}{2}$	- 51.96	$\frac{1}{2}$	- 48.77	$\frac{1}{2}$	- 34.93	$\frac{1}{2}$	- 10.92	$\frac{1}{2}$
4325.939	- 45.56	$\frac{1}{2}$	- 20.78	$\frac{1}{2}$	- 1.37	$\frac{1}{2}$	- 51.76	$\frac{1}{2}$	- 45.11	$\frac{1}{2}$	- 29.92	$\frac{1}{2}$	- 29.51	$\frac{1}{2}$
4314.945	.....	.....	.....	.....	- 26.79	$\frac{1}{2}$	.....	.....	- 52.89	$\frac{1}{2}$	- 15.10	$\frac{1}{2}$	- 19.98	$\frac{1}{2}$
4289.857	- 29.95	$\frac{1}{2}$	.....	.....	- 14.95	$\frac{1}{2}$	- 57.88	$\frac{1}{2}$	- 44.86	$\frac{1}{2}$	.....	.....	- 15.51	$\frac{1}{2}$
4260.640	.....	.....	.....	.....	.....	.....	- 60.00	$\frac{1}{2}$	- 53.31	$\frac{1}{2}$	- 26.32	$\frac{1}{2}$	- 13.60	$\frac{1}{2}$
4227.066	- 34.77	$\frac{1}{2}$	- 31.23	$\frac{1}{2}$	.....	.....	- 45.44	$\frac{1}{2}$	- 32.18	$\frac{1}{2}$	.....	.....	- 16.54	$\frac{1}{2}$
4216.028	- 46.64	$\frac{1}{2}$	.....	.....	.....	.....	- 42.06	$\frac{1}{2}$	- 47.18	$\frac{1}{2}$	.....	.....	.....	.....
4215.849	.....	.....	.....	.....	.....	.....	.....	.....	- 38.08	$\frac{1}{2}$	.....	.....	.....	.....
4143.928	- 40.89	$\frac{1}{2}$	.....	.....	.....	.....	- 57.54	$\frac{1}{2}$	- 39.80	$\frac{1}{2}$	.....	.....	.....	.....
4130.950	- 45.48	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 48.01	$\frac{1}{2}$	.....	.....	- 21.43	$\frac{1}{2}$
4128.031	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4101.820	- 45.59	$\frac{1}{2}$	.....	.....	.....	.....	- 56.25	$\frac{1}{2}$	- 40.50	$\frac{1}{2}$	.....	.....	- 9.81	$\frac{1}{2}$
4077.885	.....	.....	.....	.....	.....	.....	.....	.....	- 45.72	$\frac{1}{2}$	.....	.....	.....	.....
4071.927	- 18.71	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	- 36.88		- 28.23		- 14.68		- 50.65		- 46.73		- 29.25		- 14.83	
V_a	+ 17.75		+ 10.39		+ 8.99		+ 5.74		+ 3.86		+ 2.39		- 5.69	
V_d	- .06		- .04		- .18		- .18		- .09		- .14		- .02	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 19.4		- 17.8		- 6.1		- 45.3		- 43.2		- 27.3		- 20.8	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	5856		5860		5875		5882		6246		6269		6302	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 23.12	$\frac{1}{2}$	- 21.52	$\frac{1}{2}$	+ 26.52	$\frac{1}{2}$	.....	.....	- 84.07	$\frac{1}{2}$	- 51.18	$\frac{1}{2}$	- 35.93	$\frac{1}{2}$
4549.721	- 31.04	$\frac{1}{4}$	- 8.86	$\frac{1}{4}$	+ 32.26	$\frac{1}{2}$	- 22.87	$\frac{1}{4}$	- 68.62	$\frac{1}{4}$	.....	.....	- 31.16	$\frac{1}{4}$
4415.271	.....	.....	.....	.....	+ 29.40	$\frac{1}{2}$	- 10.25	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4404.962	.....	.....	.....	.....	+ 29.68	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4395.505	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 35.39	$\frac{1}{4}$
4352.006	.....	.....	.....	.....	.....	.....	- 5.05	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....
4340.798	- 39.91	$\frac{1}{4}$	- 17.87	$\frac{1}{2}$	+ 16.78	$\frac{1}{2}$	- 18.78	$\frac{1}{2}$	- 62.16	$\frac{1}{4}$	- 40.20	$\frac{1}{4}$	- 17.59	$\frac{1}{2}$
4325.939	.....	.....	- 9.79	$\frac{1}{4}$	+ 34.30	$\frac{1}{4}$	- 32.17	$\frac{1}{4}$	- 51.86	$\frac{1}{4}$	- 29.38	$\frac{1}{4}$	- 18.70	$\frac{1}{2}$
4314.945	.....	.....	- 20.04	$\frac{1}{2}$	+ 17.88	$\frac{1}{2}$	- 19.49	$\frac{1}{2}$	- 65.69	$\frac{1}{4}$	- 38.97	$\frac{1}{4}$	- 28.46	$\frac{1}{2}$
4294.528	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 28.83	$\frac{1}{2}$
4289.857	.....	.....	.....	.....	+ 34.32	$\frac{1}{4}$	.....	.....	- 50.13	$\frac{1}{4}$	- 66.39	$\frac{1}{2}$	- 39.26	$\frac{1}{4}$
4260.640	.....	.....	- 20.58	$\frac{1}{2}$	+ 33.40	$\frac{1}{4}$	.....	.....	.....	.....	- 53.92	$\frac{1}{4}$	- 24.59	$\frac{1}{4}$
4227.066	.....	.....	.....	.....	+ 15.50	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 31.17	$\frac{1}{2}$
4202.161	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 20.00	$\frac{1}{4}$
4101.820	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 22.00	$\frac{1}{2}$
4077.885	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 35.81	$\frac{1}{2}$
4063.849	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 23.68	$\frac{1}{4}$
Weighted mean	- 29.30		- 18.27		+ 25.36		- 16.97		- 63.75		- 49.70		- 27.74	
V_a	- 28.06		- 28.47		- 28.76		- 28.42		+ 25.85		+ 25.48		+ 20.61	
V_d	- .11		- .10		- .18		- .23		+ .02		+ .01		+ .11	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 57.7		- 47.1		- 3.8		- 45.9		- 38.2		- 24.5		- 7.3	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	6315		6338		6372		6385		6401		6411		6417	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 40.84	$\frac{1}{2}$	- 82.21	$\frac{1}{4}$	- 23.74	$\frac{1}{4}$	- 29.30	$\frac{1}{4}$	- 35.14	$\frac{1}{2}$	- 37.92	$\frac{1}{2}$	- 77.84	$\frac{1}{4}$
4549.721	- 37.36	$\frac{1}{2}$	- 88.35	$\frac{1}{2}$	- 20.26	$\frac{1}{2}$	.....	.....	- 38.03	$\frac{1}{2}$	- 43.00	$\frac{1}{4}$	- 87.83	$\frac{1}{4}$
4501.814	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 54.95	$\frac{1}{2}$	.....	.....
4415.271	.....	.....	- 79.14	$\frac{1}{4}$	- 24.92	$\frac{1}{2}$	.....	.....	- 52.12	$\frac{1}{4}$	- 42.36	$\frac{1}{4}$	- 60.10	$\frac{1}{2}$
4404.962	.....	.....	- 71.57	$\frac{1}{2}$	.....	.....	.....	.....	- 48.66	$\frac{1}{2}$	- 59.40	$\frac{1}{2}$	- 54.09	$\frac{1}{2}$
4395.505	.....	.....	- 64.93	$\frac{1}{2}$	.....	.....	- 40.67	$\frac{1}{4}$	- 40.06	$\frac{1}{4}$	.....	.....	.....	.....
4340.798	- 29.95	$\frac{1}{4}$	- 66.10	$\frac{1}{4}$	- 30.06	$\frac{1}{2}$	- 37.50	$\frac{1}{2}$	- 52.47	1	- 66.88	$\frac{1}{4}$	- 75.33	$\frac{1}{2}$
4325.939	.....	.....	- 75.68	$\frac{1}{2}$	- 32.28	$\frac{1}{2}$	- 21.48	$\frac{1}{2}$	- 50.75	$\frac{1}{4}$	- 69.01	$\frac{1}{2}$	- 67.67	$\frac{1}{2}$
4314.945	- 9.36	$\frac{1}{2}$	- 79.38	$\frac{1}{2}$	- 34.00	$\frac{1}{2}$	- 25.83	$\frac{1}{2}$	- 49.35	$\frac{1}{2}$	- 60.17	$\frac{1}{2}$	- 53.87	$\frac{1}{4}$
4294.528	.....	.....	- 72.31	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4289.857	.....	.....	.....	.....	- 13.87	$\frac{1}{2}$	.....	.....	- 34.23	$\frac{1}{2}$	- 60.33	$\frac{1}{2}$	- 81.23	$\frac{1}{2}$
4271.874	.....	.....	.....	.....	- 24.13	$\frac{1}{2}$	- 32.67	$\frac{1}{4}$	- 43.14	$\frac{1}{2}$	- 58.84	$\frac{1}{2}$	- 73.58	$\frac{1}{2}$
4260.640	.....	.....	- 78.59	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4216.028	- 15.02	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4215.849	.....	.....	- 81.27	$\frac{1}{4}$	- 19.74	$\frac{1}{2}$	- 35.46	$\frac{1}{2}$	- 44.24	$\frac{1}{2}$	- 63.64	$\frac{1}{2}$	- 64.56	$\frac{1}{2}$
4128.031	.....	.....	.....	.....	- 20.97	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4101.820	.....	.....	.....	.....	- 13.28	$\frac{1}{2}$	.....	.....	- 67.38	$\frac{1}{4}$	- 60.42	$\frac{1}{4}$	.....	.....
4063.849	.....	.....	.....	.....	- 24.04	$\frac{1}{4}$	- 31.58	$\frac{1}{2}$	.....	.....	.....	.....	- 63.15	$\frac{1}{2}$
4045.975	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 62.96	$\frac{1}{2}$	.....	.....
Weighted mean	- 26.91		- 76.74		- 23.23		- 32.08		- 46.08		- 57.05		- 68.36	
V_s	+ 19.94		+ 16.72		+ 12.67		+ 11.85		+ 10.96		+ 10.04		+ 9.61	
V_d	- .02		- .08		- .08		+ .10		+ .04		- .09		+ .02	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 7.3		- 60.4		- 10.9		- 19.4		- 35.3		- 47.4		- 59.0	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	6429		6441		6446		6457		6466		6478		6494	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 51.32	$\frac{1}{2}$	- 8.09	$\frac{1}{2}$	- 18.30	$\frac{1}{2}$	+ 8.09	$\frac{1}{2}$	+ 4.11	$\frac{1}{2}$	- 39.78	$\frac{1}{2}$	- 35.93	$\frac{1}{2}$
4549.721	.....	.....	- 20.91	$\frac{1}{2}$	.....	.....	- 13.33	$\frac{1}{2}$	+ 3.92	$\frac{1}{2}$	- 43.26	$\frac{1}{2}$	- 43.78	$\frac{1}{2}$
4415.271	- 44.39	$\frac{1}{2}$	- 21.78	$\frac{1}{2}$	- 20.71	$\frac{1}{2}$	- 5.36	$\frac{1}{2}$	- 4.52	$\frac{1}{2}$	- 21.54	$\frac{1}{2}$	.....	.....
4404.962	- 48.30	$\frac{1}{2}$	- 36.35	$\frac{1}{2}$	- 14.76	$\frac{1}{2}$	- 13.70	$\frac{1}{2}$	- 12.72	$\frac{1}{2}$	- 19.60	$\frac{1}{2}$	- 44.76	$\frac{1}{2}$
4340.798	- 36.03	$\frac{1}{2}$	- 11.94	$\frac{1}{2}$	- 13.74	$\frac{1}{2}$	- 8.90	$\frac{1}{2}$	- 9.57	$\frac{1}{2}$	- 31.64	$\frac{1}{2}$	- 64.41	$\frac{1}{2}$
4325.939	- 18.70	$\frac{1}{2}$	- 29.38	$\frac{1}{2}$	- 16.81	$\frac{1}{2}$	- 18.70	$\frac{1}{2}$	- 10.57	$\frac{1}{2}$	- 32.50	$\frac{1}{2}$	.....	.....
4314.945	- 47.91	$\frac{1}{2}$	- 27.47	$\frac{1}{2}$	- 13.25	$\frac{1}{2}$	- 10.82	$\frac{1}{2}$	- 7.95	$\frac{1}{2}$	- 27.38	$\frac{1}{2}$	.....	.....
4289.857	- 43.33	$\frac{1}{2}$	- 12.79	$\frac{1}{2}$	- 14.24	$\frac{1}{2}$	- 2.71	$\frac{1}{2}$	- 10.19	$\frac{1}{2}$	- 23.29	$\frac{1}{2}$	.....	.....
4271.874	- 50.19	$\frac{1}{2}$	- 9.28	$\frac{1}{2}$	- 17.18	$\frac{1}{2}$	- 5.22	$\frac{1}{2}$	- 4.26	$\frac{1}{2}$	- 26.48	$\frac{1}{2}$	.....	.....
4260.640	.....	.....	- 22.85	$\frac{1}{2}$	- 22.85	$\frac{1}{2}$	- 15.02	$\frac{1}{2}$	- 12.24	$\frac{1}{2}$	- 22.75	$\frac{1}{2}$	.....	.....
4215.849	- 40.16	$\frac{1}{2}$	- 29.54	1	- 11.57	$\frac{1}{2}$	+ 0.17	$\frac{1}{2}$	+ 3.54	$\frac{1}{2}$	- 22.25	$\frac{1}{2}$	.....	.....
4128.031	- 41.38	$\frac{1}{2}$	.....	.....	.....	.....	- 5.12	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4101.820	- 36.02	$\frac{1}{2}$	- 31.93	$\frac{1}{2}$	- 7.06	$\frac{1}{2}$	+ 0.38	$\frac{1}{2}$	.....	.....	- 22.19	$\frac{1}{2}$	.....	.....
4071.927	.....	.....	.....	.....	- 11.31	$\frac{1}{2}$	.....	.....	- 7.33	$\frac{1}{2}$	.....	.....	.....	.....
4063.849	- 34.81	$\frac{1}{2}$	.....	.....	- 25.93	$\frac{1}{2}$	.....	.....	.....	.....	- 29.84	$\frac{1}{2}$	.....	.....
4045.975	.....	.....	.....	.....	- 21.81	$\frac{1}{2}$	.....	.....	- 13.77	$\frac{1}{2}$	.....	.....	.....	.....
Weighted mean	- 42.20		- 22.54		- 16.68		- 6.08		- 6.63		- 26.87		- 46.53	
V_a	+ 8.21		+ 6.36		+ 5.47		+ 4.94		+ 4.50		+ 3.57		- 0.43	
V_d	- .14		- .04		+ .15		- .02		+ .11		+ .21		- .18	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 33.8		- 16.5		- 11.3		- 1.4		- 2.3		- 23.4		- 47.4	

MEASURES OF ζ ANDROMEDÆ.—*Continued.*

λ	6498		6505		6507		6515		6523		6530		6544	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	.....		- 37.26	$\frac{1}{2}$	- 8.49	$\frac{1}{2}$	- 33.02	$\frac{1}{2}$	- 18.56	$\frac{1}{2}$	- 35.01	$\frac{1}{2}$	- 2.76	$\frac{1}{2}$
4549.721	- 17.08	$\frac{1}{2}$	- 26.14	$\frac{1}{2}$	- 13.20	$\frac{1}{2}$	.....		- 7.19	$\frac{1}{2}$	- 30.32	$\frac{1}{2}$	- 18.56	$\frac{1}{2}$
4415.271	- 33.40	$\frac{1}{2}$	.....		+ 3.93	$\frac{1}{2}$	- 21.18	$\frac{1}{2}$	- 25.70	$\frac{1}{2}$	- 37.37	$\frac{1}{2}$	- 6.19	$\frac{1}{2}$
4404.962	- 32.04	$\frac{1}{2}$	.....		+ 1.42	$\frac{1}{2}$	- 12.05	$\frac{1}{2}$	- 19.25	$\frac{1}{2}$	- 24.68	$\frac{1}{2}$	- 0.94	$\frac{1}{2}$
4352.006	- 36.60	$\frac{1}{2}$	- 27.60	$\frac{1}{2}$	- 17.90	$\frac{1}{2}$	.....		.....		.....		.....
4340.798	- 33.00	$\frac{1}{2}$	- 27.70	$\frac{1}{2}$	.....		- 16.64	$\frac{1}{2}$	- 12.50	$\frac{1}{2}$	- 40.09	$\frac{1}{2}$	- 4.17	$\frac{1}{2}$
4325.939	- 28.39	$\frac{1}{2}$	.....		- 1.78	$\frac{1}{2}$	- 22.37	$\frac{1}{2}$	- 23.48	$\frac{1}{2}$	- 43.85	$\frac{1}{2}$	.....
4314.945	.....		- 31.68	$\frac{1}{2}$	.....		- 27.38	$\frac{1}{2}$	.....		- 26.28	$\frac{1}{2}$	- 8.83	$\frac{1}{2}$
4294.528	.....		- 36.30	$\frac{1}{2}$	- 4.64	$\frac{1}{2}$	.....		.....		.....		.....
4289.857	- 25.23	$\frac{1}{2}$	.....		+ 1.08	$\frac{1}{2}$	- 16.13	$\frac{1}{2}$	- 21.34	$\frac{1}{2}$	- 38.45	$\frac{1}{2}$	+ 0.10	$\frac{1}{2}$
4271.874	.....		.....		- 6.50	$\frac{1}{2}$	- 23.91	$\frac{1}{2}$	- 34.81	$\frac{1}{2}$	- 34.59	$\frac{1}{2}$	- 6.03	$\frac{1}{2}$
4227.066	.....		.....		.....		.....		.....		- 33.66	$\frac{1}{2}$	.....
4215.849	- 20.60	$\frac{1}{2}$	.....		- 11.67	$\frac{1}{2}$	- 26.27	$\frac{1}{2}$	- 22.80	$\frac{1}{2}$	- 33.01	1	- 0.12	$\frac{1}{2}$
4128.031	.....		.....		- 7.49	$\frac{1}{2}$	.....		.....		.....		.....
4101.820	.....		.....		.....		- 20.43	$\frac{1}{2}$	- 20.52	$\frac{1}{2}$	- 27.94	$\frac{1}{2}$	+ 5.46	$\frac{1}{2}$
4063.849	.....		.....		- 5.92	$\frac{1}{2}$	.....		.....		- 18.03	$\frac{1}{2}$	.....
4045.975	.....		.....		+ 6.26	$\frac{1}{2}$	.....		.....		.....		.....
4005.422	.....		.....		.....		.....		.....		- 31.72	$\frac{1}{2}$	.....
Weighted mean	- 28.30		- 31.11		- 5.83		- 20.26		- 20.09		- 32.56		- 3.50	
V_s	- 0.87		- 1.35		- 4.32		- 4.83		- 5.33		- 5.72		- 10.54	
V_d	+ 0.04		+ 0.02		- 0.04		- 0.16		- 0.22		+ 0.11		- 0.17	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 29.4		- 32.7		- 10.5		- 25.5		- 23.0		- 38.4		- 14.5	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	6551		6558		6560		6570		6581		6585		6590	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571·958	+ 9·81	$\frac{1}{2}$	- 27·45	$\frac{1}{2}$	- 24·93	$\frac{1}{2}$	+ 9·14	$\frac{1}{2}$	- 3·38	$\frac{1}{2}$	.....	.....	- 15·37	$\frac{1}{2}$
4549·721	- 4·18	$\frac{1}{2}$	- 36·46	$\frac{1}{2}$	- 9·41	$\frac{1}{2}$	+ 5·76	$\frac{1}{2}$	.....	.....	.....	.....	- 14·06	$\frac{1}{2}$
4415·271	+ 10·23	$\frac{1}{2}$	- 31·30	$\frac{1}{2}$	- 24·39	$\frac{1}{2}$	+ 10·60	$\frac{1}{2}$	.....	.....	- 6·96	$\frac{1}{2}$	- 8·87	$\frac{1}{2}$
4404·962	- 8·50	$\frac{1}{2}$	- 28·11	$\frac{1}{2}$	- 21·97	$\frac{1}{2}$	+ 13·27	$\frac{1}{2}$	+ 0·27	$\frac{1}{2}$	- 16·00	$\frac{1}{2}$	- 12·82	$\frac{1}{2}$
4395·505	.....	.....	- 30·12	$\frac{1}{2}$	- 14·65	$\frac{1}{2}$	+ 17·74	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4352·006	.....	.....	- 29·76	$\frac{1}{2}$	- 19·25	$\frac{1}{2}$	.....	.....	- 6·85	$\frac{1}{2}$	- 6·50	$\frac{1}{2}$	- 9·24	$\frac{1}{2}$
4340·798	+ 18·47	$\frac{1}{2}$	- 30·63	$\frac{1}{2}$	- 11·02	$\frac{1}{2}$	+ 12·82	1	- 14·10	$\frac{1}{2}$	- 22·24	$\frac{1}{2}$	- 22·47	$\frac{1}{2}$
4325·939	+ 7·79	$\frac{1}{2}$	- 27·71	$\frac{1}{2}$	- 15·01	$\frac{1}{2}$	+ 7·60	$\frac{1}{2}$	- 7·16	$\frac{1}{2}$	- 24·04	$\frac{1}{2}$	- 22·56	$\frac{1}{2}$
4314·945	+ 13·80	$\frac{1}{2}$	- 30·91	$\frac{1}{2}$	.....	.....	+ 10·23	$\frac{1}{2}$	- 11·72	$\frac{1}{2}$	.....	.....	- 15·50	$\frac{1}{2}$
4294·528	.....	.....	.....	.....	- 12·61	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4289·857	+ 4·32	$\frac{1}{2}$	- 24·15	$\frac{1}{2}$	.....	.....	+ 15·21	$\frac{1}{2}$	- 15·26	$\frac{1}{2}$	.....	.....	- 17·11	$\frac{1}{2}$
4271·874	+ 15·06	$\frac{1}{2}$	- 32·68	$\frac{1}{2}$	- 19·76	$\frac{1}{2}$	+ 5·09	$\frac{1}{2}$	- 11·00	$\frac{1}{2}$	- 18·73	$\frac{1}{2}$	- 21·72	$\frac{1}{2}$
4260·640	.....	.....	.....	.....	.....	.....	.....	.....	- 20·56	$\frac{1}{2}$	.....	.....	.....	.....
4227·066	+ 5·58	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	- 13·42	$\frac{1}{2}$	- 22·94	$\frac{1}{2}$
4215·849	+ 9·05	$\frac{1}{2}$	- 22·77	$\frac{1}{2}$	- 17·97	$\frac{1}{2}$	+ 11·09	$\frac{1}{2}$	- 13·92	$\frac{1}{2}$	- 20·80	$\frac{1}{2}$	- 10·85	$\frac{1}{2}$
4101·820	+ 5·18	$\frac{1}{2}$	- 36·66	$\frac{1}{2}$	- 21·06	$\frac{1}{2}$	+ 23·47	$\frac{1}{2}$	- 26·91	$\frac{1}{2}$	- 14·99	$\frac{1}{2}$	- 32·51	$\frac{1}{2}$
4071·927	+ 13·11	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 9·62	$\frac{1}{2}$	- 15·66	$\frac{1}{2}$	- 23·61	$\frac{1}{2}$
4063·849	+ 7·35	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 10·16	$\frac{1}{2}$	- 11·00	$\frac{1}{2}$	.....	.....
4045·975	+ 14·04	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 13·33	$\frac{1}{2}$
Weighted mean	+ 8·31		- 29·27		- 18·05		+ 11·52		- 12·10		- 15·71		- 17·50	
V_s	- 11·43		- 16·66		- 17·05		- 15·43		- 20·84		- 22·54		- 23·10	
V_d	- 0·11		- 0·15		- 0·09		- 0·11		- 0·14		+ 0·04		- 0·06	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	- 3·5		- 46·4		- 35·5		- 4·3		- 33·4		- 38·5		- 40·9	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	6614		6637		6647		6648		6649		6662		6675	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	+ 15.26	$\frac{1}{4}$	- 16.41	$\frac{1}{4}$	- 33.89	$\frac{1}{2}$	- 30.42	$\frac{1}{2}$	- 2.85	$\frac{1}{2}$	+ 32.98	$\frac{1}{4}$	- 15.90	$\frac{1}{2}$
4549.721	+ 27.14	$\frac{1}{4}$	- 11.95	$\frac{1}{4}$	- 32.42	$\frac{1}{2}$	- 20.62	$\frac{1}{2}$	- 16.68	$\frac{1}{4}$	+ 19.92	$\frac{1}{4}$	- 9.33	$\frac{1}{4}$
4415.271	+ 16.70	$\frac{1}{2}$	- 12.94	$\frac{1}{2}$	- 24.05	$\frac{1}{2}$	- 15.93	$\frac{1}{2}$	- 10.38	$\frac{1}{2}$	+ 22.43	$\frac{1}{4}$	- 6.72	$\frac{1}{2}$
4404.962	+ 17.07	$\frac{1}{2}$	- 7.60	$\frac{1}{2}$	- 24.56	$\frac{1}{2}$	- 25.98	$\frac{1}{2}$	- 11.39	$\frac{1}{2}$	+ 29.81	$\frac{1}{4}$	- 13.17	$\frac{1}{2}$
4395.505	.....	.....	- 18.53	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4352.006	+ 19.63	$\frac{1}{4}$	- 11.76	$\frac{1}{4}$	- 28.53	$\frac{1}{4}$	- 17.69	$\frac{1}{4}$	.....	.....	+ 28.75	$\frac{1}{2}$	- 19.97	$\frac{1}{4}$
4340.798	+ 13.61	$\frac{1}{2}$	- 10.37	$\frac{1}{2}$	- 35.25	$\frac{1}{2}$	- 29.32	$\frac{1}{2}$	- 16.59	$\frac{1}{2}$	+ 7.73	$\frac{1}{2}$	- 8.99	$\frac{1}{2}$
4325.939	+ 7.38	$\frac{1}{4}$	- 16.32	$\frac{1}{4}$	- 33.76	$\frac{1}{4}$	- 28.96	$\frac{1}{4}$	- 25.59	$\frac{1}{4}$	+ 26.16	$\frac{1}{4}$	- 7.83	$\frac{1}{2}$
4314.945	+ 24.43	$\frac{1}{4}$	- 14.18	$\frac{1}{2}$	- 39.89	$\frac{1}{2}$	- 35.24	$\frac{1}{4}$	- 17.13	$\frac{1}{2}$	+ 22.10	$\frac{1}{4}$	- 7.17	$\frac{1}{4}$
4294.528	.....	.....	.....	.....	- 24.95	$\frac{1}{2}$	- 32.27	$\frac{1}{4}$	.....	.....	+ 27.57	$\frac{1}{4}$	- 10.10	$\frac{1}{4}$
4289.857	+ 6.50	$\frac{1}{2}$	- 17.31	$\frac{1}{2}$	- 22.66	$\frac{1}{2}$	- 27.99	$\frac{1}{4}$	- 18.19	$\frac{1}{2}$	+ 24.24	$\frac{1}{2}$	- 8.62	$\frac{1}{2}$
4271.874	+ 11.85	$\frac{1}{2}$	- 13.04	$\frac{1}{2}$	- 38.90	$\frac{1}{2}$	- 33.43	$\frac{1}{2}$	- 13.04	$\frac{1}{2}$	+ 20.43	$\frac{1}{2}$	- 20.34	$\frac{1}{2}$
4227.066	+ 12.14	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4215.849	.....	.....	- 15.46	$\frac{1}{2}$	- 32.80	$\frac{1}{4}$	- 13.92	$\frac{1}{4}$	- 8.18	$\frac{1}{2}$	+ 20.86	$\frac{1}{2}$	- 17.00	$\frac{1}{4}$
4101.820	+ 18.81	$\frac{1}{4}$	- 15.43	$\frac{1}{4}$	.....	.....	- 37.17	$\frac{1}{4}$	- 8.55	$\frac{1}{4}$	.....	.....	.....	.....
4071.927	+ 13.44	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4063.849	+ 20.24	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4045.975	+ 24.30	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 15.99		- 13.61		- 30.87		- 24.80		- 12.93		+ 22.64		- 11.93	
V ₀	- 25.05		- 26.23		- 26.99		- 27.19		- 27.32		- 27.90		- 28.65	
V ₂	- 0.10		- 0.27		- 0.09		- 0.25		+ 0.04		+ 0.08		- 0.14	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 9.4		- 40.4		- 58.2		- 52.5		- 40.5		- 5.5		- 41.0	

MEASURES OF ζ ANDROMEDÆ.—Continued.

λ	6676		6684		6690		6724		6728		6772		6775	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 13.77	$\frac{1}{2}$	- 18.70	$\frac{1}{2}$	- 12.71	$\frac{1}{2}$	- 0.19	$\frac{1}{2}$	- 22.96	$\frac{1}{2}$	+ 24.45	$\frac{1}{2}$	- 35.61	$\frac{1}{2}$
4549.721	- 14.45	$\frac{1}{2}$	- 25.34	$\frac{1}{2}$	- 17.49	$\frac{1}{2}$	- 3.95	$\frac{1}{2}$	- 17.60	$\frac{1}{2}$	+ 27.86	$\frac{1}{2}$	- 15.73	$\frac{1}{2}$
4415.271	- 17.24	$\frac{1}{2}$	- 21.66	$\frac{1}{2}$	- 15.56	$\frac{1}{2}$	- 9.50	$\frac{1}{2}$	.....	.....	+ 32.65	$\frac{1}{2}$	- 25.60	$\frac{1}{2}$
4404.962	- 17.21	$\frac{1}{2}$	- 29.90	$\frac{1}{2}$	- 8.19	$\frac{1}{2}$	- 27.52	$\frac{1}{2}$	- 35.47	$\frac{1}{2}$	+ 26.80	$\frac{1}{2}$	- 25.28	$\frac{1}{2}$
4352.006	- 25.67	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 28.87	$\frac{1}{2}$	+ 34.00	$\frac{1}{2}$	- 32.30	$\frac{1}{2}$
4340.798	- 25.64	$\frac{1}{2}$	- 34.12	$\frac{1}{2}$	- 25.07	$\frac{1}{2}$	- 24.51	$\frac{1}{2}$	- 31.07	$\frac{1}{2}$	+ 8.86	$\frac{1}{2}$	- 34.70	$\frac{1}{2}$
4325.939	- 32.09	$\frac{1}{2}$	- 22.02	$\frac{1}{2}$	- 8.84	$\frac{1}{2}$	- 13.19	$\frac{1}{2}$	- 38.68	$\frac{1}{2}$	+ 18.66	$\frac{1}{2}$	- 27.40	$\frac{1}{2}$
4314.945	- 14.94	$\frac{1}{2}$	- 28.58	$\frac{1}{2}$	- 5.75	$\frac{1}{2}$	- 21.15	$\frac{1}{2}$	- 23.26	$\frac{1}{2}$	+ 19.66	$\frac{1}{2}$	- 36.23	$\frac{1}{2}$
4294.528	- 18.62	$\frac{1}{2}$	- 34.56	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4289.857	- 16.13	$\frac{1}{2}$	- 31.25	$\frac{1}{2}$	- 18.98	$\frac{1}{2}$	- 25.81	$\frac{1}{2}$	- 20.04	$\frac{1}{2}$	+ 8.46	$\frac{1}{2}$	- 33.31	$\frac{1}{2}$
4271.874	- 11.11	$\frac{1}{2}$	- 34.29	1	- 12.83	$\frac{1}{2}$	- 10.47	$\frac{1}{2}$	- 25.27	$\frac{1}{2}$	.....	.....	- 36.32	$\frac{1}{2}$
4215.849	- 15.46	$\frac{1}{2}$	- 26.44	$\frac{1}{2}$	- 11.67	$\frac{1}{2}$	- 15.05	$\frac{1}{2}$	- 27.16	$\frac{1}{2}$	+ 17.52	$\frac{1}{2}$	- 26.96	$\frac{1}{2}$
4101.820	- 15.43	$\frac{1}{2}$	- 27.38	$\frac{1}{2}$	- 19.29	$\frac{1}{2}$	.....	.....	- 23.64	$\frac{1}{2}$	.....	.....	.....	.....
4071.927	.....	.....	- 27.88	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4063.849	.....	.....	- 33.88	$\frac{1}{2}$	- 16.11	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	- 18.54		- 28.59		- 14.15		- 15.49		- 26.72		+ 20.01		- 29.96	
V _a	- 28.71		- 28.75		- 28.84		- 28.26		- 27.91		- 26.07		- 24.79	
V _d	- 0.12		- 0.06		- 0.15		- 0.17		- 0.13		- 0.21		- 0.22	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 47.6		- 57.7		- 43.4		- 44.2		- 55.0		- 6.6		- 55.2	

MEASURES OF ζ ANDROMEDÆ.—*Concluded.*

λ	6779		6780											
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4571.958	- 44.85	$\frac{1}{2}$	- 46.62	$\frac{1}{2}$	.....		.....		.....		.....		.....
4549.721	.....		- 31.20	$\frac{1}{2}$	.....		.....		.....		.....		.....
4415.271	- 33.40	$\frac{1}{2}$	- 24.16	$\frac{1}{2}$	.....		.....		.....		.....		.....
4404.962	- 26.10	$\frac{1}{2}$	- 31.66	$\frac{1}{2}$	.....		.....		.....		.....		.....
4340.798	- 41.01	$\frac{1}{2}$	- 28.14	$\frac{1}{2}$	.....		.....		.....		.....		.....
4325.939	- 37.90	$\frac{1}{2}$	- 30.50	$\frac{1}{2}$	.....		.....		.....		.....		.....
4314.945	- 27.38	$\frac{1}{2}$	- 21.90	$\frac{1}{2}$	.....		.....		.....		.....		.....
4289.857	.....		- 32.58	$\frac{1}{2}$	.....		.....		.....		.....		.....
4271.874	- 26.34	$\frac{1}{2}$	- 28.70	$\frac{1}{2}$	.....		.....		.....		.....		.....
4215.849	.....		- 29.01	$\frac{1}{2}$	.....		.....		.....		.....		.....
4101.820	.....		- 22.70	$\frac{1}{2}$	.....		.....		.....		.....		.....
Weighted mean	- 35.02		- 29.92		.....		.....		.....		.....		.....
V_a	- 24.52		- 23.98		.....		.....		.....		.....		.....
V_s	- 0.26		- 0.23		.....		.....		.....		.....		.....
Curv.	- 0.28		- 0.28		.....		.....		.....		.....		.....
Radial Velocity	- 60.1		- 54.4		.....		.....		.....		.....		.....

The fifty-eight observations were grouped into twelve normal places. These are given in Table IV with the mean Julian day, mean phase, mean velocity, weight and residual from final elements.

TABLE IV.
NORMAL PLACES.

	Julian Day.	Phase.	Velocity.	Weight.	Residual.
1	2,420,190.230	5.922	-18.5	2	- 2.7
2	359.875	6.912	- 8.4	3	+ 1.2
3	350.183	8.833	- 6.4	3	- 1.3
4	433.369	10.173	- 6.6	3	+ 1.1
5	475.258	11.039	- 8.7	1	+ 3.3
6	360.912	12.451	-22.8	3.5	- 0.6
7	447.072	14.278	-39.0	5.5	- 0.5
8	374.830	16.175	-51.2	4.5	+ 1.3
9	460.083	0.158	-58.6	4	- 2.3
10	354.066	1.836	-48.4	3.5	+ 1.4
11	463.087	2.578	-43.4	3	+ 1.0
12	408.999	3.767	-34.5	3	- 0.5

Preliminary elements of the orbit were obtained by the application of Dr. King's graphical method. These were,

$$\begin{aligned}
 P &= 17.7673 \text{ days} \\
 e &= .05 \\
 \omega &= 180^\circ \\
 K &= 26 \text{ km.} \\
 \gamma &= -29.70 \text{ km.} \\
 T &= 2,420,024.881 \text{ J. D.}
 \end{aligned}$$

A least-squares solution was carried through to improve, if possible, the elements obtained graphically. The period, obtained by using Lick observations in connection with our own, covering an epoch of 334 cycles was considered as fixed. In the solution, T was also left out on account of the eccentricity being so small, and e , ω , K and γ used.

The following observation equations were formed:—

TABLE V.
OBSERVATION EQUATIONS.

<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>-n</i>	Weight.
1	+ .521	+ .333	+ .821	+ 2.3	2
1	+ .754	- .306	+ .594	- 1.7	3
1	+ .950	-1.000	+ .016	+ 1.4	3
1	+ .866	- .683	- .412	- 0.5	3
1	+ .717	- .191	- .641	- 2.3	1
1	+ .342	+ .680	- .920	+ 2.0	3.5
1	- .285	+ .902	- .971	+ 1.9	5.5
1	- .864	- .311	- .580	- 1.0	4.5
1	-1.048	- .992	+ .062	+ 1.6	4
1	- .806	- .126	+ .654	- 2.3	3.5
1	- .595	+ .428	+ .838	- 1.8	3
1	- .190	+ .973	+ .990	- 0.1	3

From these, the following normal equations were derived:—

$$\begin{aligned}
 39.000x - 4.158y + 0.243z - 1.554u + 5.500 &= 0 \\
 19.772y - 1.303z - 0.773u + 5.948 &= 0 \\
 18.848z - 1.843u + 8.004 &= 0 \\
 19.547u - 20.759 &= 0
 \end{aligned}$$

The solutions of the normal equations gave,

$$\begin{aligned}
 x &= - .132 \\
 y &= - .312 \\
 z &= - .346 \\
 u &= +1.006
 \end{aligned}$$

from which,

$$\begin{aligned}
 \delta\gamma &= - .13 \text{ km.} \\
 \delta K &= - .31 \text{ km.} \\
 \delta e &= - .013 \\
 \delta\omega &= +2^\circ.22
 \end{aligned}$$

Hence the new values of the elements:—

$$\begin{aligned}\gamma &= -29.83 \\ K &= 25.69 \\ e &= .037 \\ \omega &= 182^\circ.22 \\ T &= 2,420,024.881 \text{ J. D., as before.}\end{aligned}$$

These new values of the elements gave a reduction of Σpvv from 107 to 81 or about 25 per cent. The residuals computed from the orbital elements and those from the observation equations were very nearly identical and no further corrections were attempted.

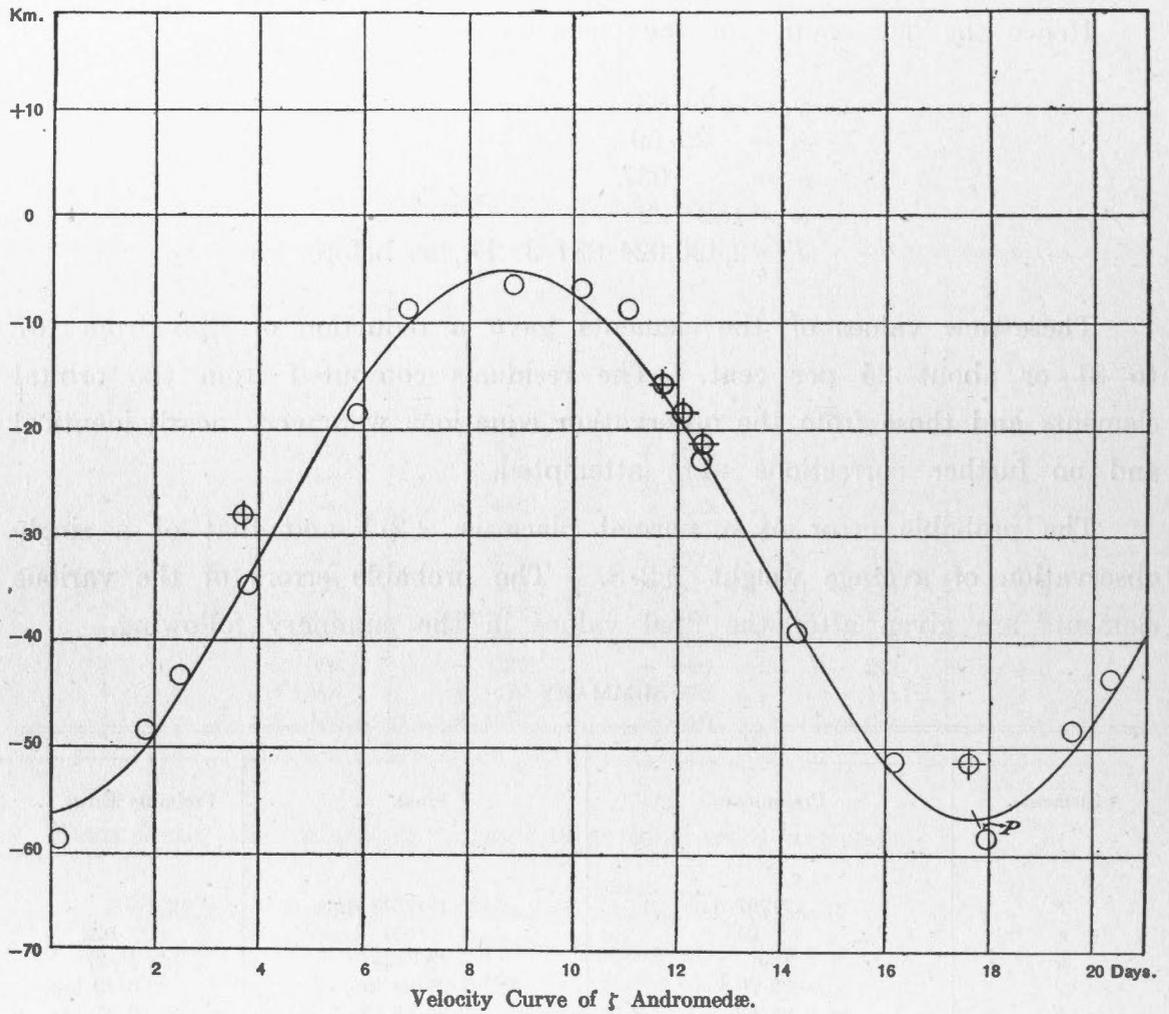
The probable error of a normal place is ± 2.1 and that of a single observation of average weight ± 2.8 . The probable errors of the various elements are given after the final values in the summary following.

SUMMARY.

Element.	Preliminary.	Final.	Probable Error.
P	17.767 days	17.7673 days	
e	.05	.037	$\pm .022$
ω	180°	$182^\circ.22$	$\pm 1^\circ.27$
γ	-29.70 km.	-29.83 km.	± 0.40 km.
K	26 km.	25.69 km.	± 0.57 km.
T	2,420,024.881 J. D.	2,420,024.881 J. D.	
$a \sin i$		6,272.000 km.	

In the figure the circles are Ottawa normal places and the circles crossed are Lick observations. It will be seen that if the whole curve were raised about 3 km. the Lick observations would be better satisfied. This is probably due to different wave-lengths being used, or perhaps, to some extent, to the fact that no doubt in the work here many of the lines measured are blends. Any change in the period does not seem to bring the Lick observations closer to the curve given by our own observations.

Dominion Observatory,
Ottawa,
February, 1915.



DEPARTMENT OF THE INTERIOR
CANADA

HON. W. J. ROCHE, *Minister.*

W. W. CORY, C.M.G., *Deputy Minister.*

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OTTAWA

W. F. KING, C.M.G., LL.D., *Director.*

Vol. II, No. 7

A Meteor Star Atlas

BY

REYNOLD K. YOUNG, Ph.D.

OTTAWA
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A METEOR STAR ATLAS

BY REYNOLD K. YOUNG, Ph. D.

The following set of twenty maps is intended to facilitate the observation of meteors and the plotting of their paths. As is well known, the observed track of a meteor is nearly an arc of a great circle and is therefore conveniently plotted on a map where great circles are represented by straight lines. The accompanying charts are constructed on the gnomonic or central projection which gives this desired property.

It is not easy to calculate what amount of error will be introduced by using a map constructed by other projections, because it will depend on several factors; the fraction of the sky covered by one chart, the distance of the meteor track from the radiant and also the particular projection used. It is safe to say, however, that in many cases the error will be more than five degrees, that is to say that a path which has been correctly observed, if produced backward on a map with unsuitable projection, may not pass within five degrees of the radiant. Of course the difficulty arising from projection may be eliminated by using a celestial globe but in general a globe is awkward to handle. Also a record of observations would be hard to preserve if plotted on such a globe.

The epoch is taken at 1900. All stars given in the Revised Harvard Photometry, volume fifty, as brighter than 5.0 have been plotted. Variables whose maxima are brighter than 5.0 have been entered. The size of the circles indicates the brightness of the stars. The smallest marked five indicates magnitudes as faint or fainter than 4.6. Those marked four indicate magnitudes lying between 4.5.....4.1 and 4.0.....3.6 and so on. Those marked zero indicate magnitudes brighter than 0.6. In choosing a scale for the representation of magnitudes, one has to bear in mind that the relative apparent brightness of the stars varies from night to night. The bright stars stand out relatively strong on a clear moonlight night, while on a moonless night the immense number of faint stars

visible, renders the bright stars less conspicuous. The clearness of the atmosphere also affects the appearance of the stars. The best one can do is to strike an average. A normal appearance of the maps is more nearly approached, if all constellation boundaries and star names are omitted. It has become so general however to think of the stars by name and constellation, that it would seriously detract from the usefulness of the maps to omit these features. Nevertheless nothing has been plotted which was deemed unnecessary and which might confuse the maps. The right ascension circles for every hour and the declination circles for every ten degrees have been drawn. In order to make the readings of positions from the maps easier, the intermediate positions of the right ascension circles for every twenty minutes and the declination circles for every five degrees have been indicated. This procedure avoids the confusion which results if all the circles are drawn in full.

It is hoped that the positions will in general be found correct to within one-tenth of one degree. In reading of positions more accuracy can be obtained by measuring rectangular co-ordinates and then computing the right ascension and declination than by estimating the distances from the neighbouring hour and declination circles. For those who may desire to compute the positions, the method of construction of the maps and the constants used in the projection are outlined.

For the circumpolar map, the celestial sphere is imagined cut by a plane which includes a segment of the sphere sixty degrees in diameter. Any point in this segment is projected on the plane by joining it to the centre of the sphere. The north celestial pole may be called the axis of projection. The right ascension circles are straight lines uniformly distributed around the pole and the declination circles remain circles, the distances from the pole being given by the formula

$$r = 5.33 \cot \delta,$$

where r is the radius of the circle in inches and δ is the declination of the circle under consideration.

For the next six maps, the axis of projection lies at plus forty-five degrees declination and right ascension successively zero hours, four hourstwenty hours. If we call the axis of projection of any map the

point (0, 0,) in cartesian co-ordinates, x being the abscissa and y the ordinate, δ the declination of a star and (a) the angle between the hour circle passing through the axis of projection and that one passing through the star, the following relations hold:—

$$x = 5.33\sqrt{2} \frac{\tan (a) \cot \delta}{\sec (a) + \cot \delta} \quad (1)$$

$$y = 5.33 \frac{\sec (a) - \cot \delta}{\sec (a) + \cot \delta} \quad (2)$$

The equation to the right ascension circles is

$$x = \frac{\tan (a)}{\sqrt{2}} [5.33 - y] \quad (3)$$

and to the declination circles

$$[5.33 - y]^2 - [5.33 + y]^2 \cot^2 \delta + 2x^2 = 0 \quad (4)$$

The axis of projection for the next set of six maps lies on the equator and at right ascensions, zero hours, four hours,.....as before. With the same notation,

$$x = 5.33 \tan (a) \quad (5)$$

$$y = 5.33 \sec (a) \tan \delta. \quad (6)$$

The equation to the right ascension circles is

$$x = 5.33 \tan (a) \quad (7)$$

and to the declination circles

$$y^2 \cot^2 \delta - x^2 = (5.33)^2 \quad (8)$$

In the next set of six maps the axis of projection lies at minus forty-five degrees of declination and the relations are the same as for plus forty-five. The southern circumpolar map is similar to the northern circumpolar one. The co-ordinates are measured in inches. The method of computing the position of a point on the chart by means of the foregoing relations will now be illustrated by an example.

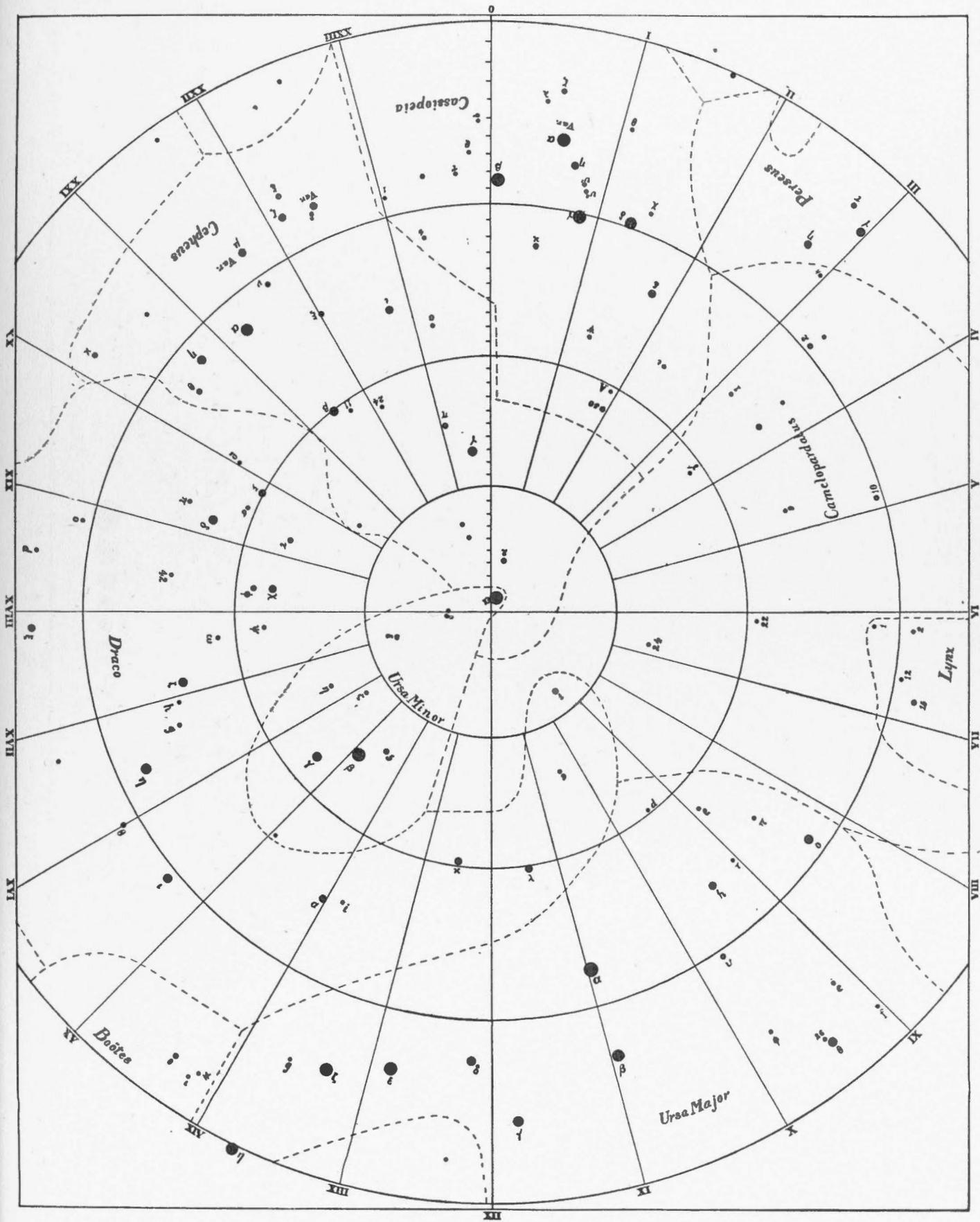
Let it be required to find the position of α Arietis from the first chart of the set whose axis of projection lies at plus forty-five degrees declination. By measurement $x = 2.94$ inches. $y = -1.81$ inches. Substituting these values in equation (3)

$$(a) = 30^{\circ} 30'$$

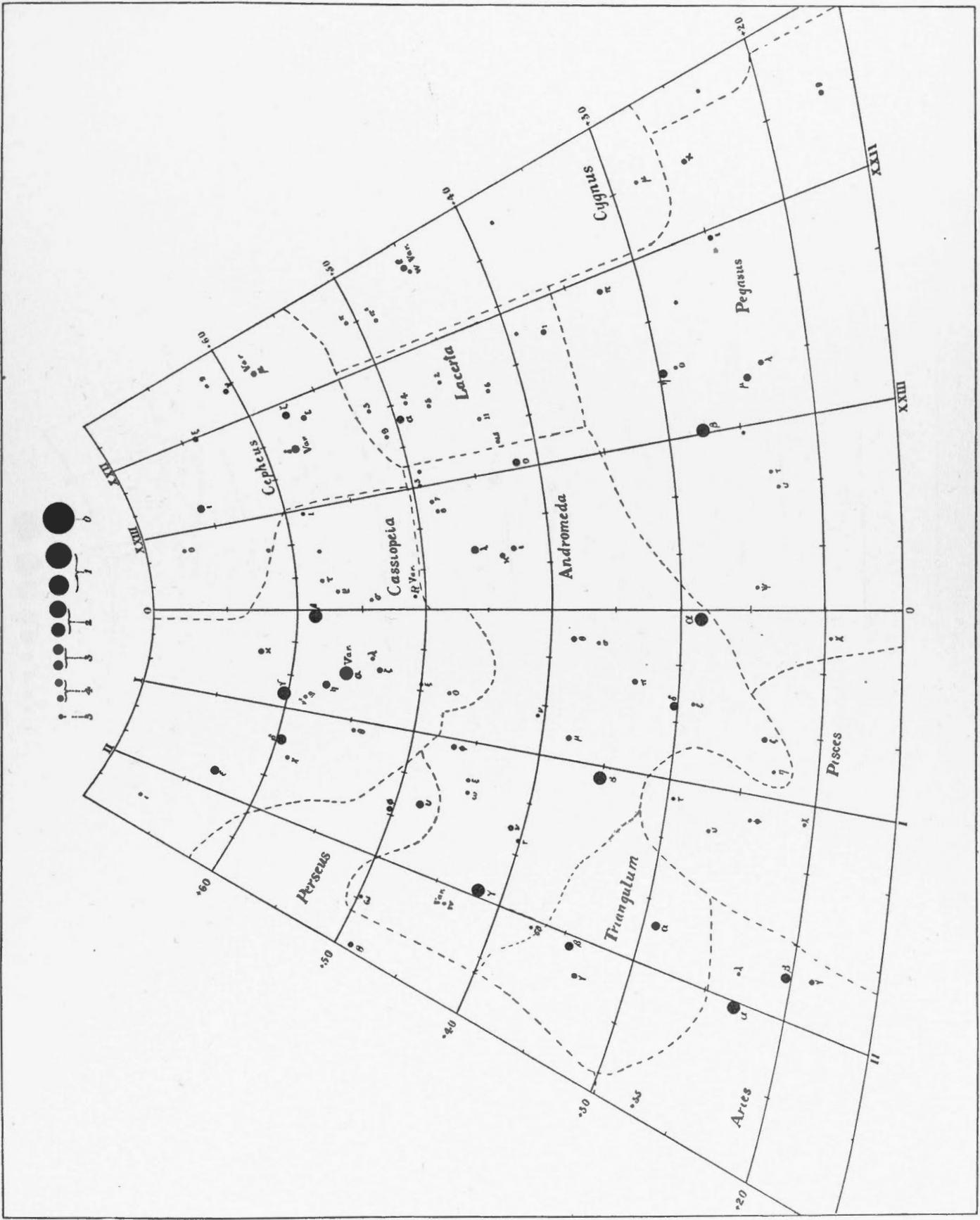
α of center of map equals zero, therefore right ascension of α Arietis is $2^{\text{h}} 1^{\text{m}} 2$. Either equation (1) or (2) will now serve to determine δ . Substituting in (1) we obtain $\delta = +22^{\circ} 59'$.

The numerical coefficients in the preceding equations and also the measurements in the example were computed on the basis of the width of the maps being nine inches. The maps vary in size to some extent, and many of them have become slightly distorted in the process of reproduction. Probably the best method to pursue in attempting to compute a position, is to first measure the rectangular co-ordinates of the nearest intersection of right ascension and declination circles. This computation will give the correction, if any, that should be applied to that portion of the map to eliminate any error arising from distortion or shrinkage of the paper.

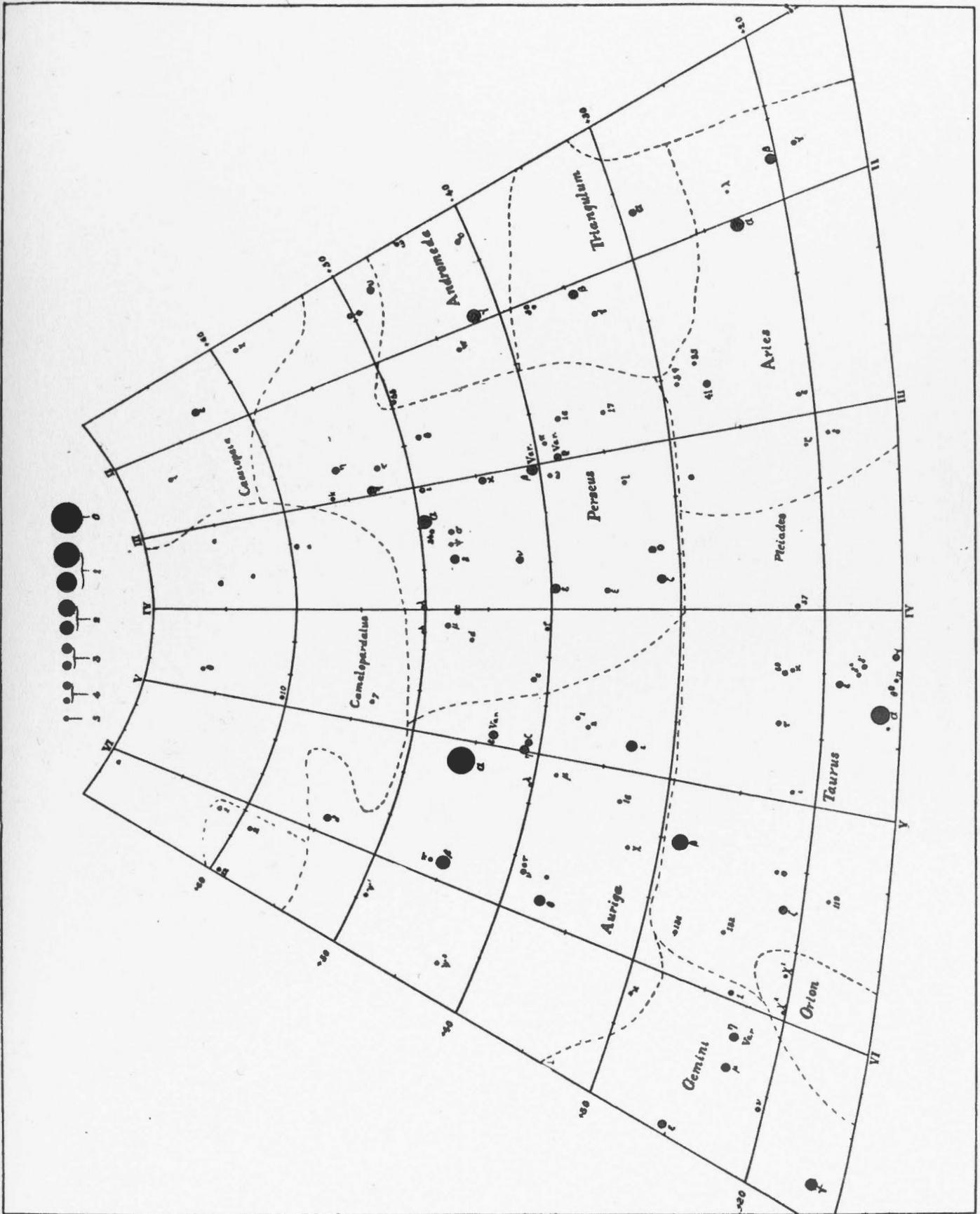
Dominion Observatory,
Ottawa,
March, 1915.



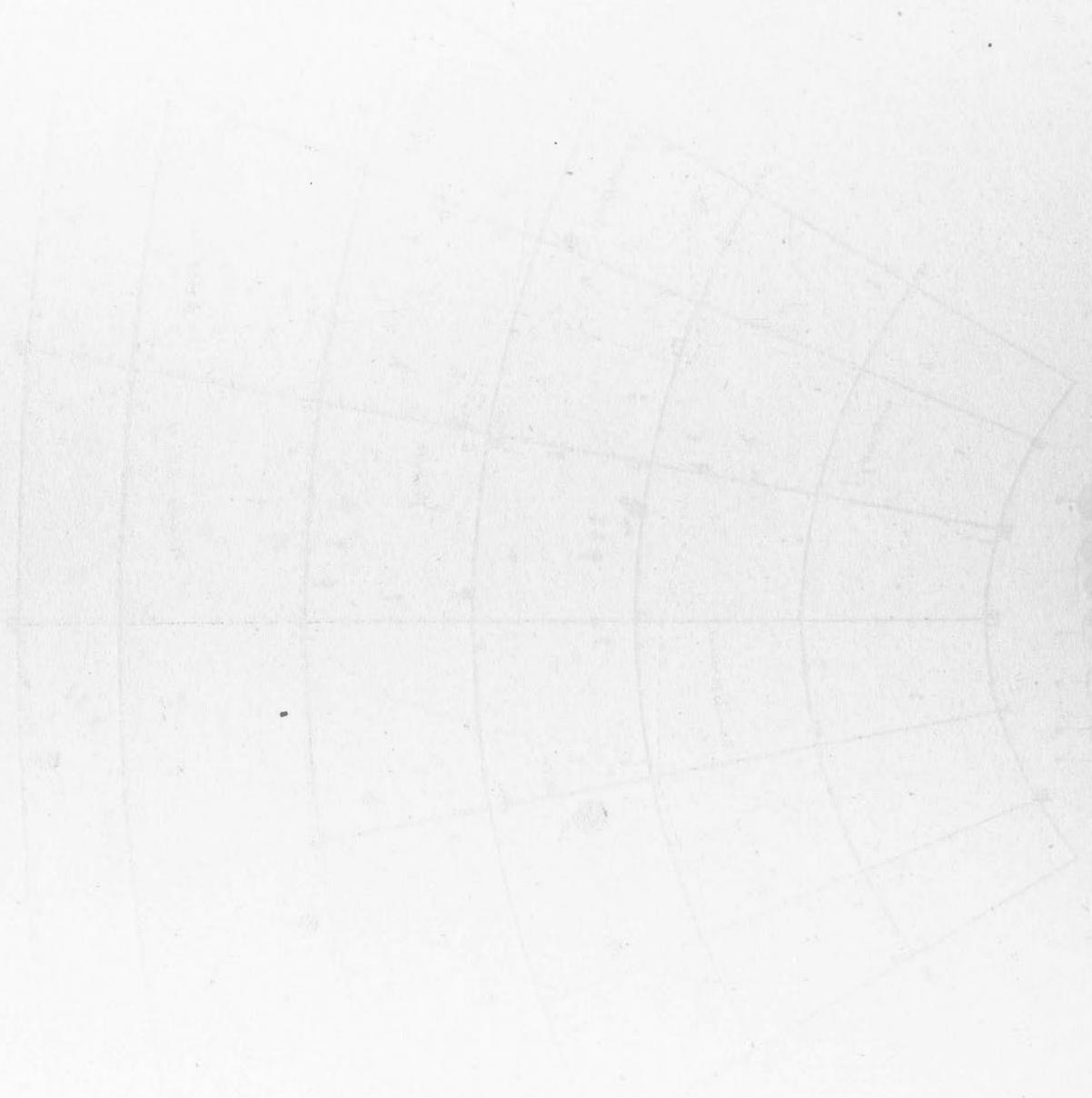
MAP I.

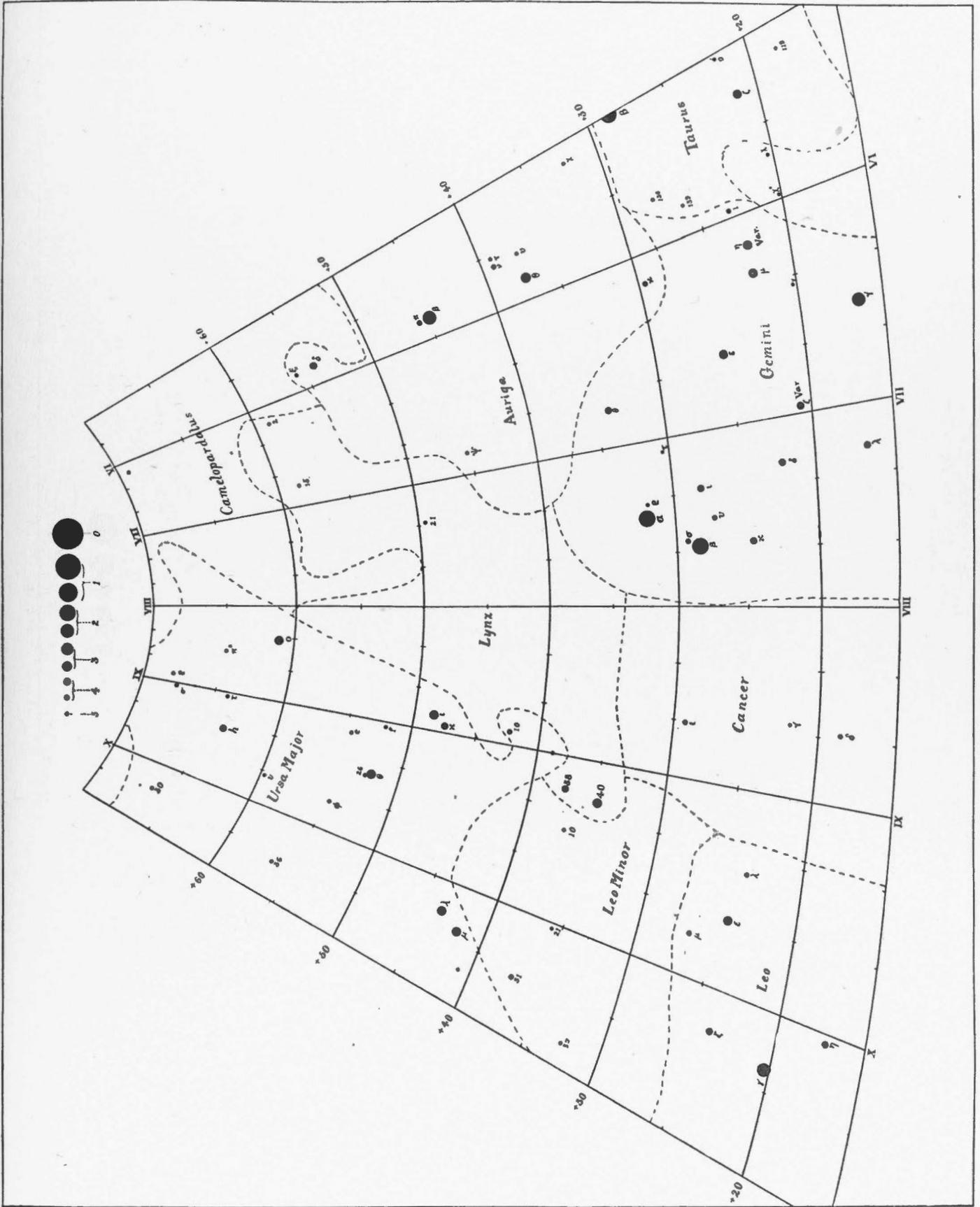


MAP II.

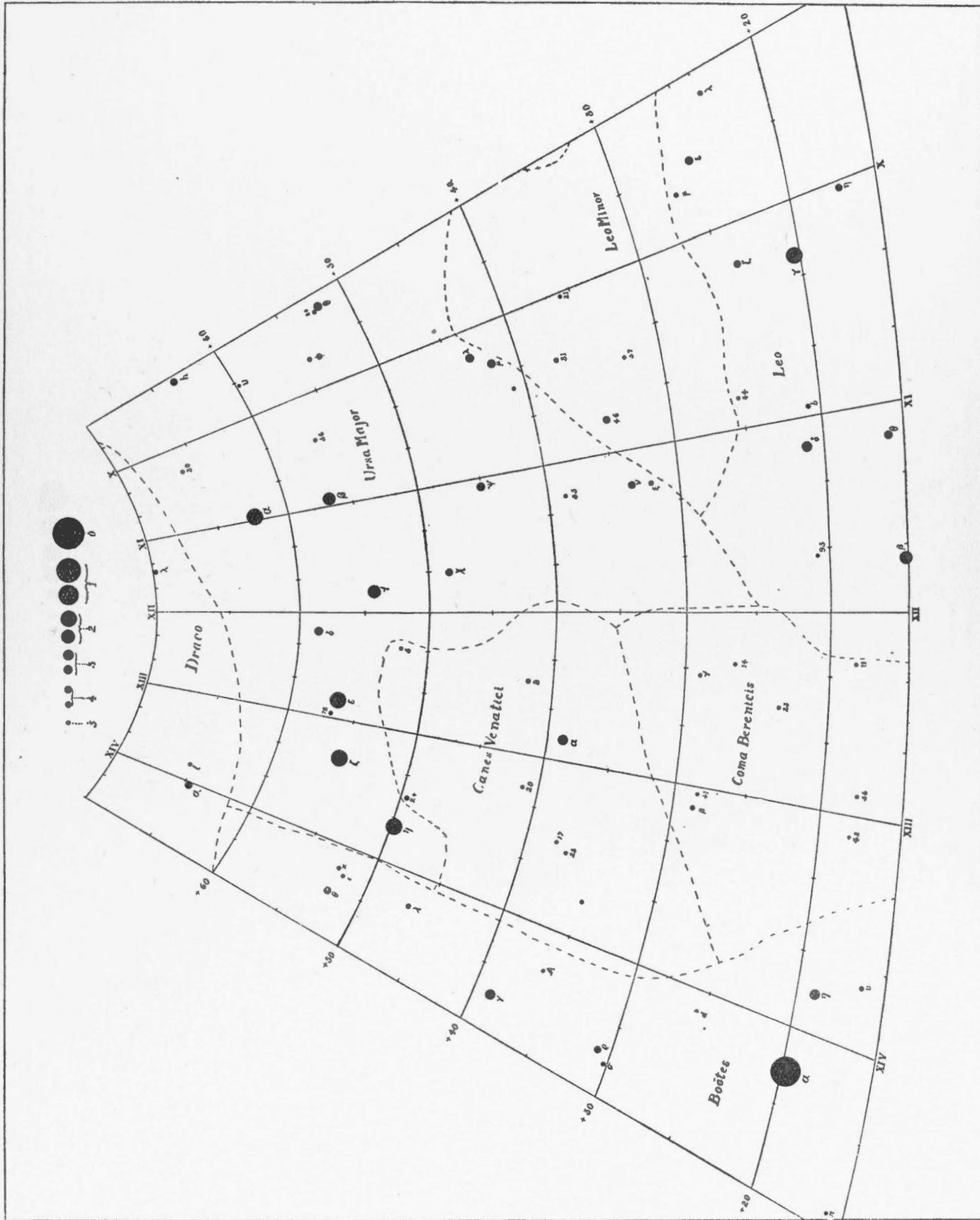


MAP III.

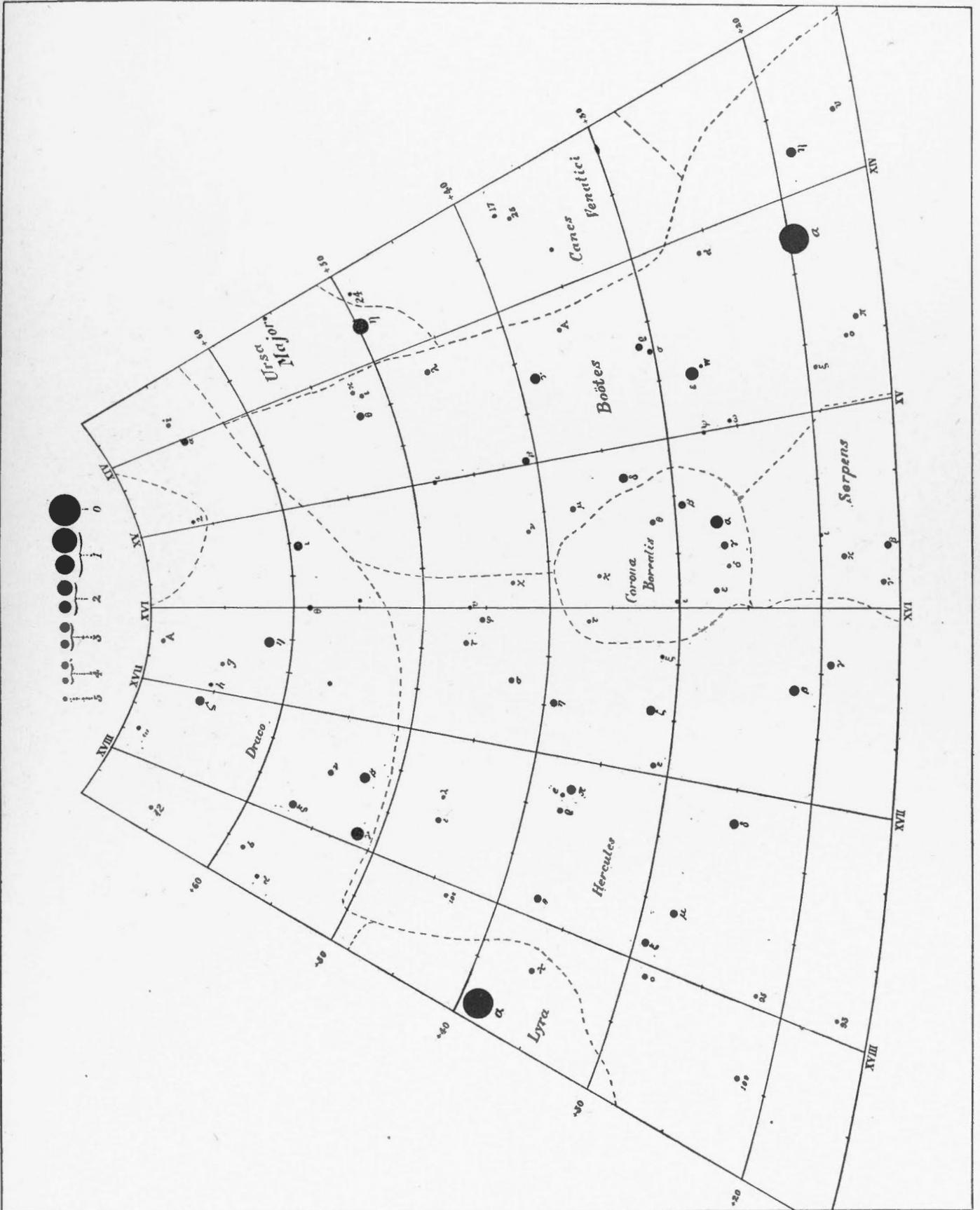




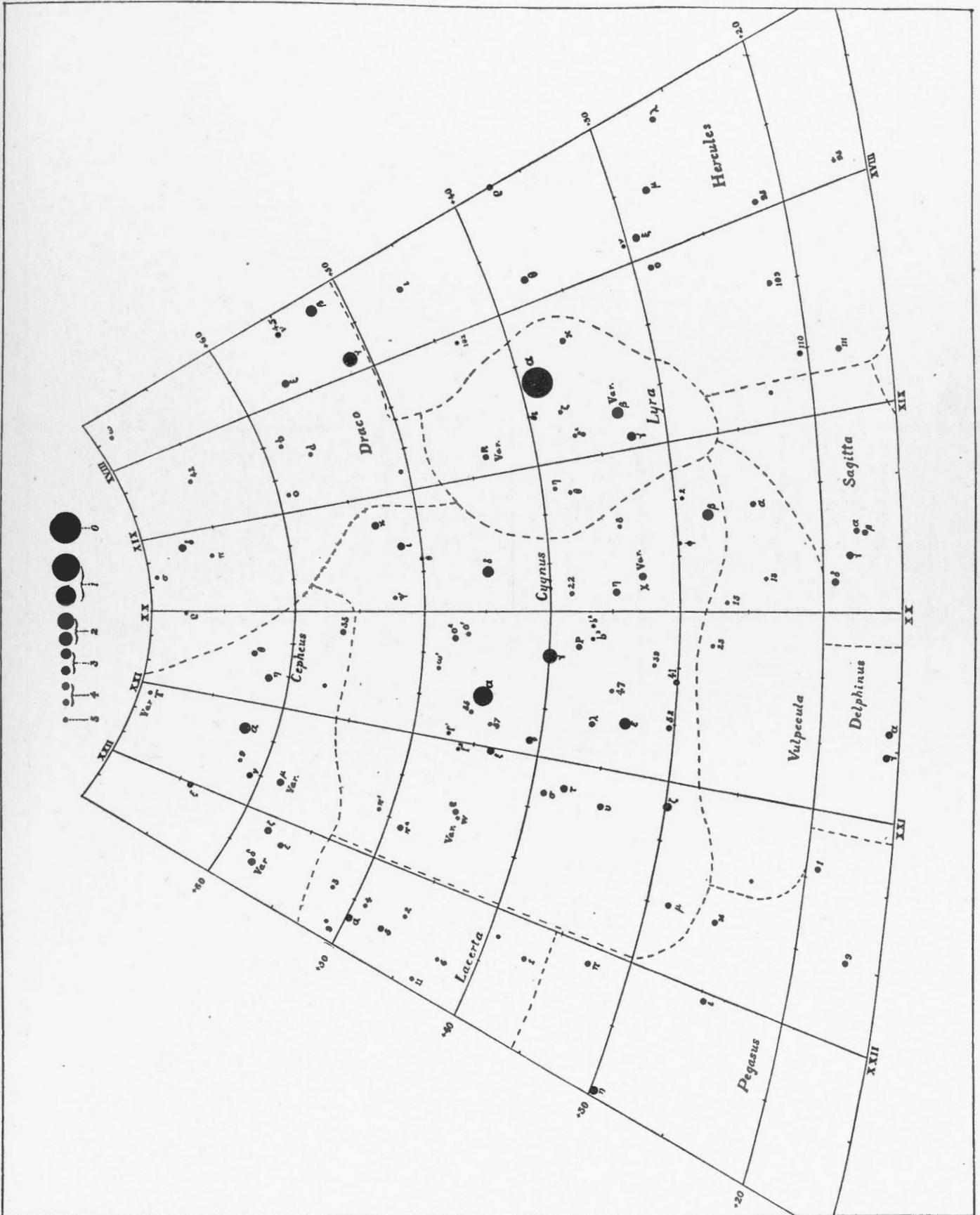
MAP IV.



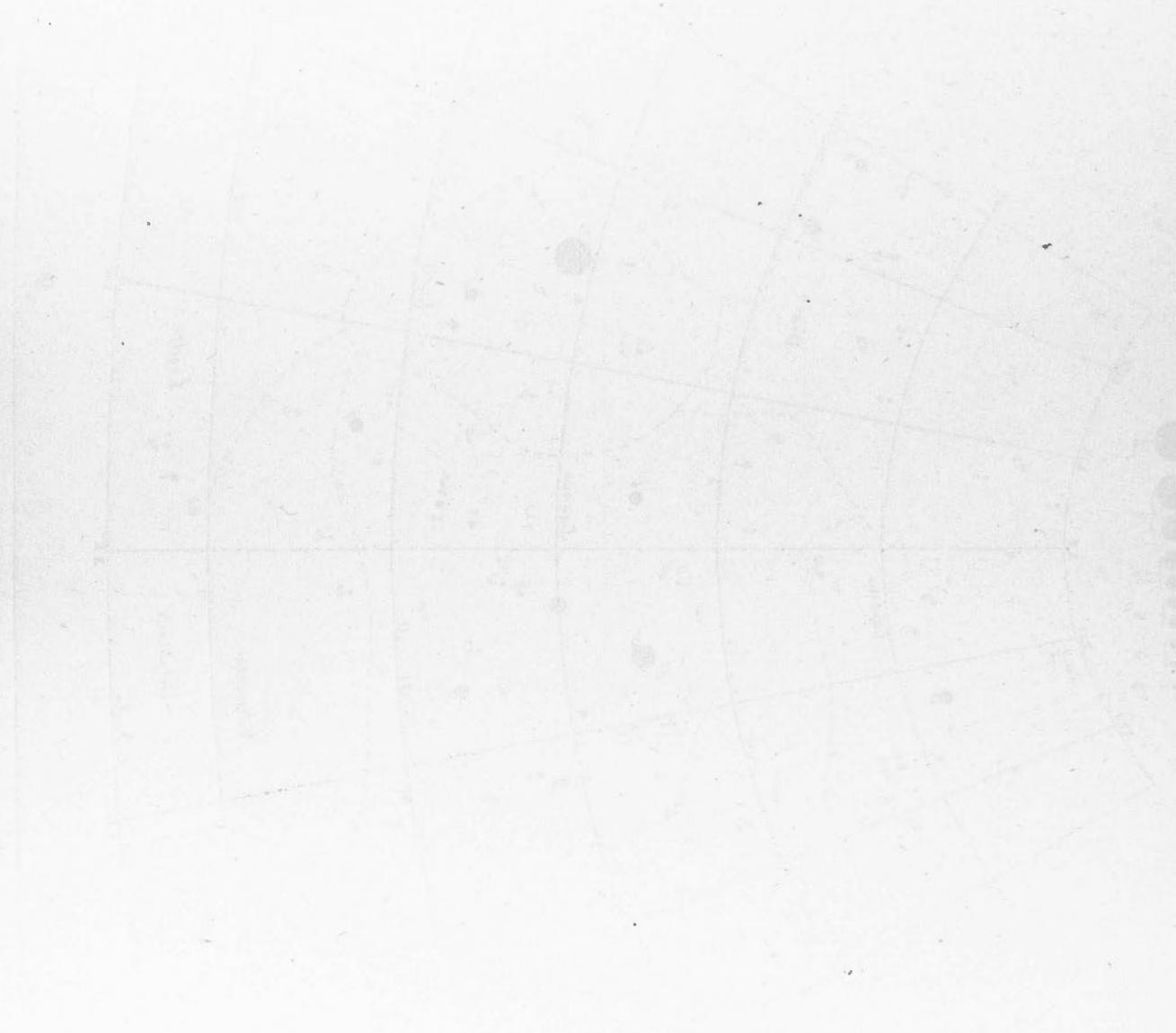
MAP V.

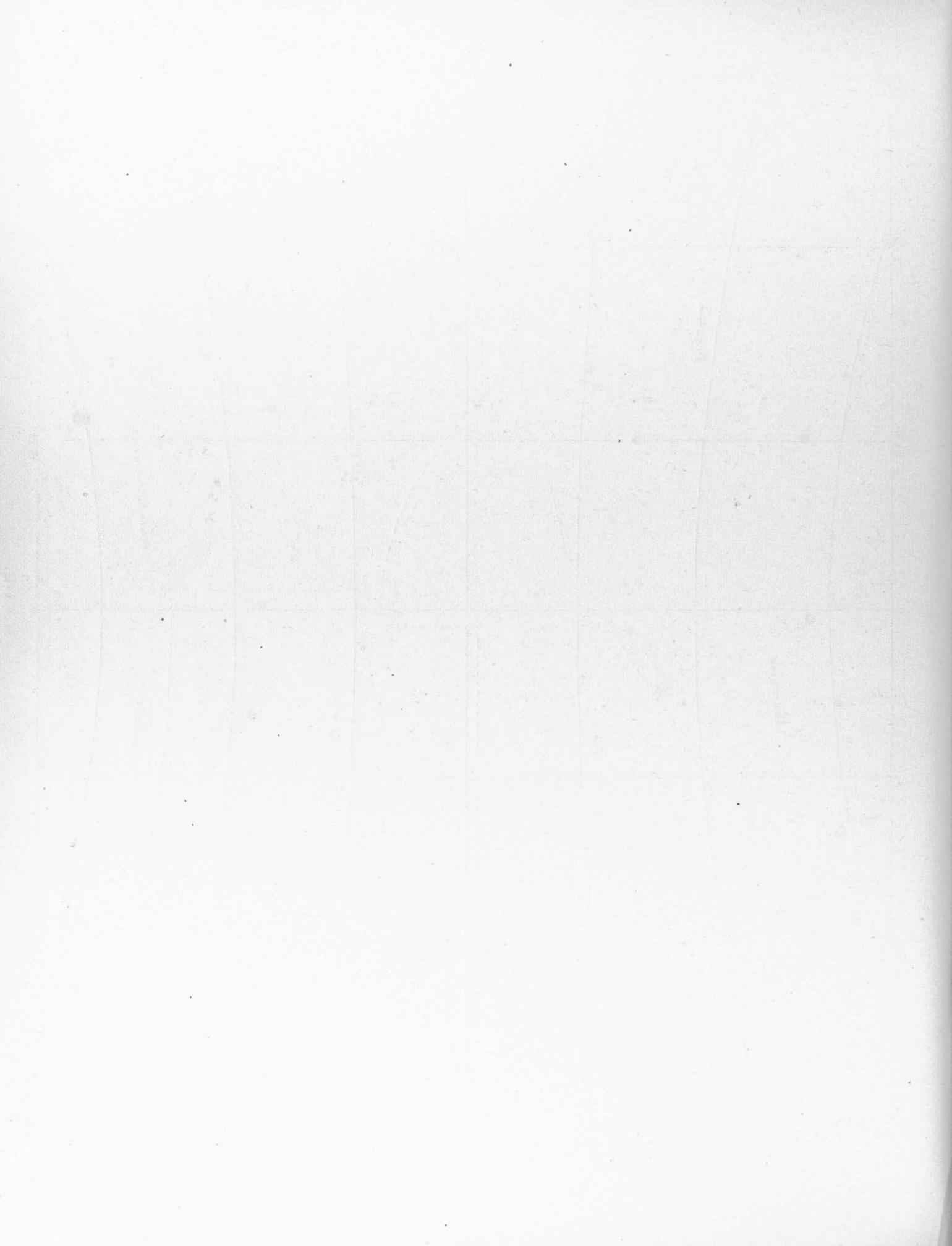


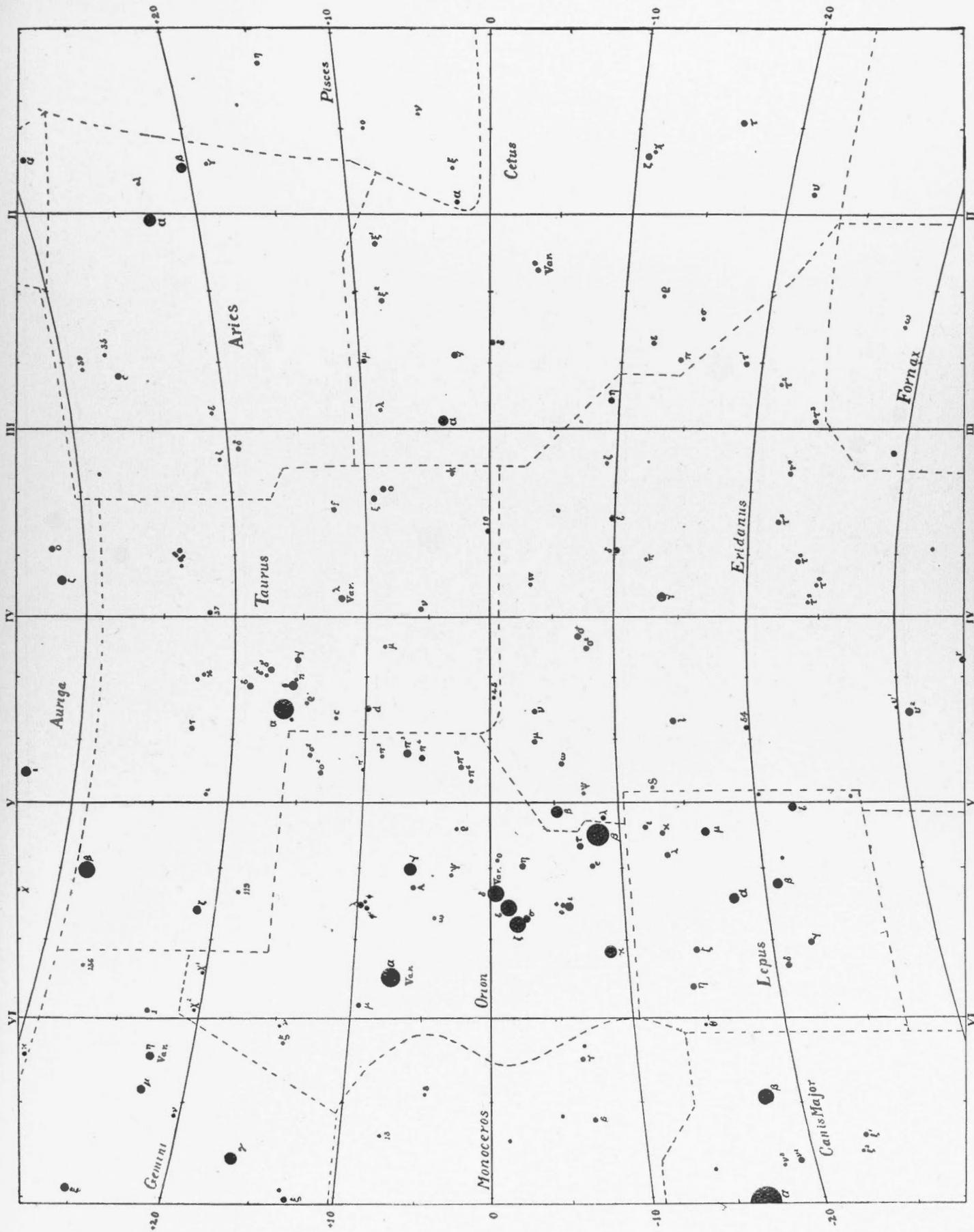
MAP VI.



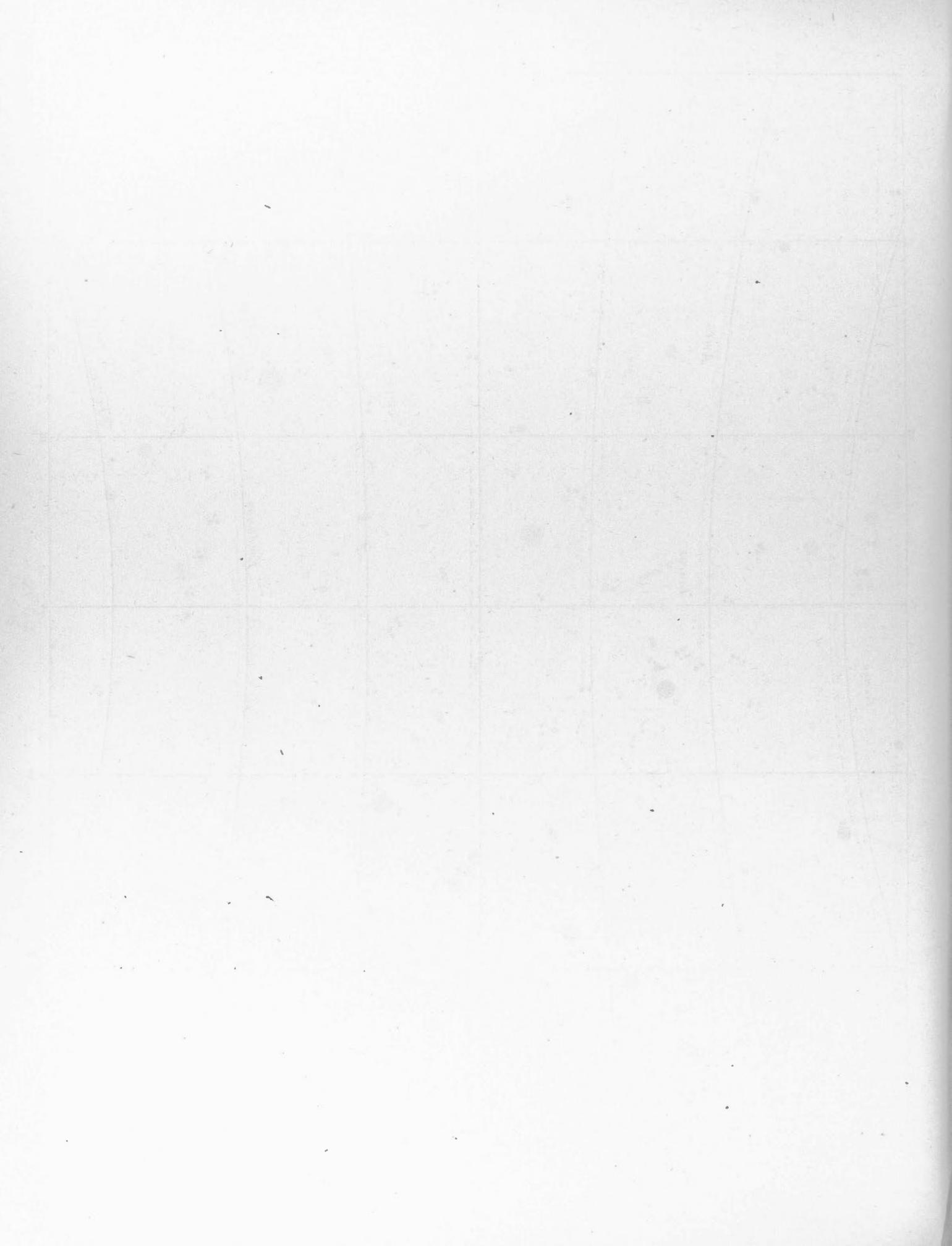
MAP VII.

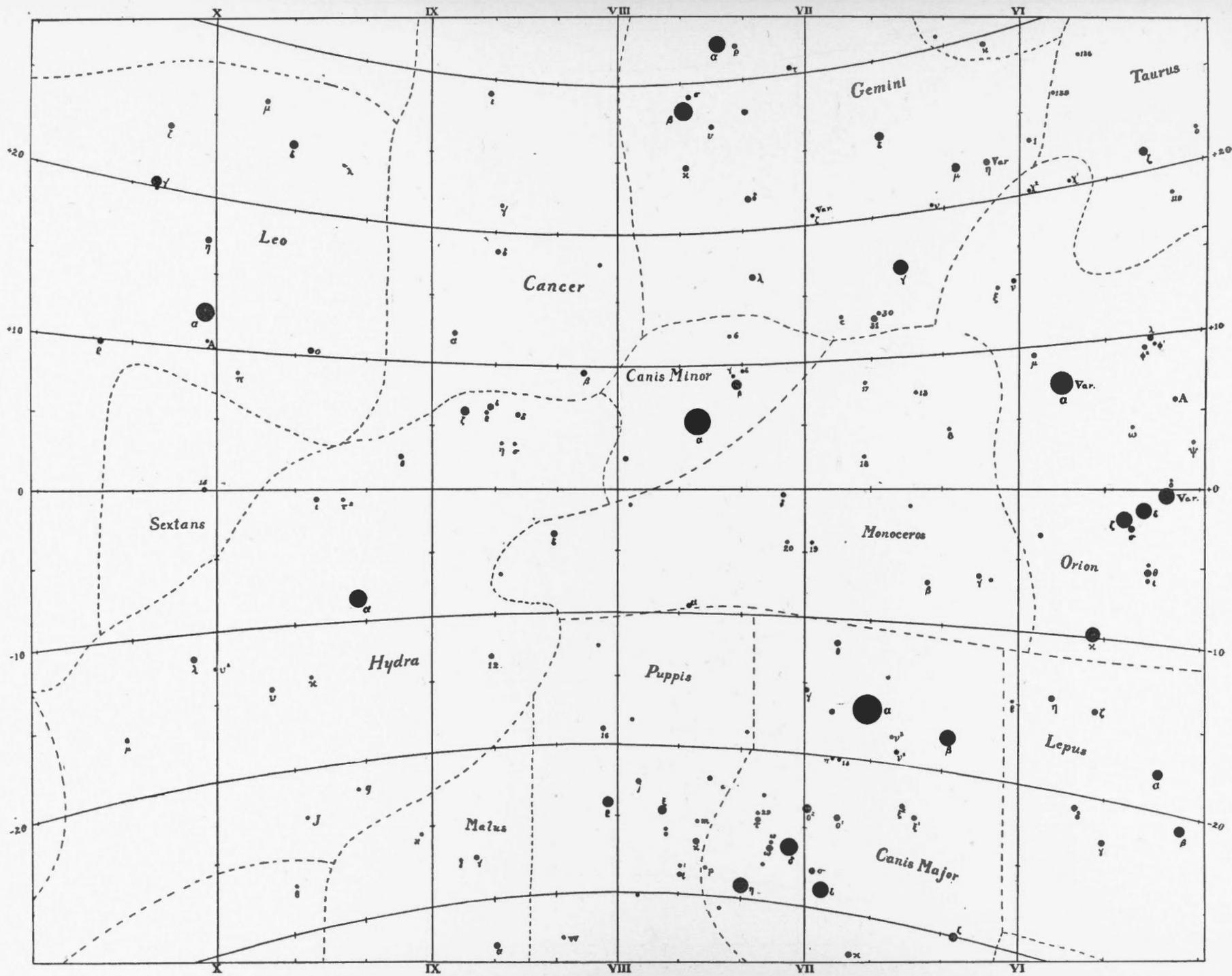




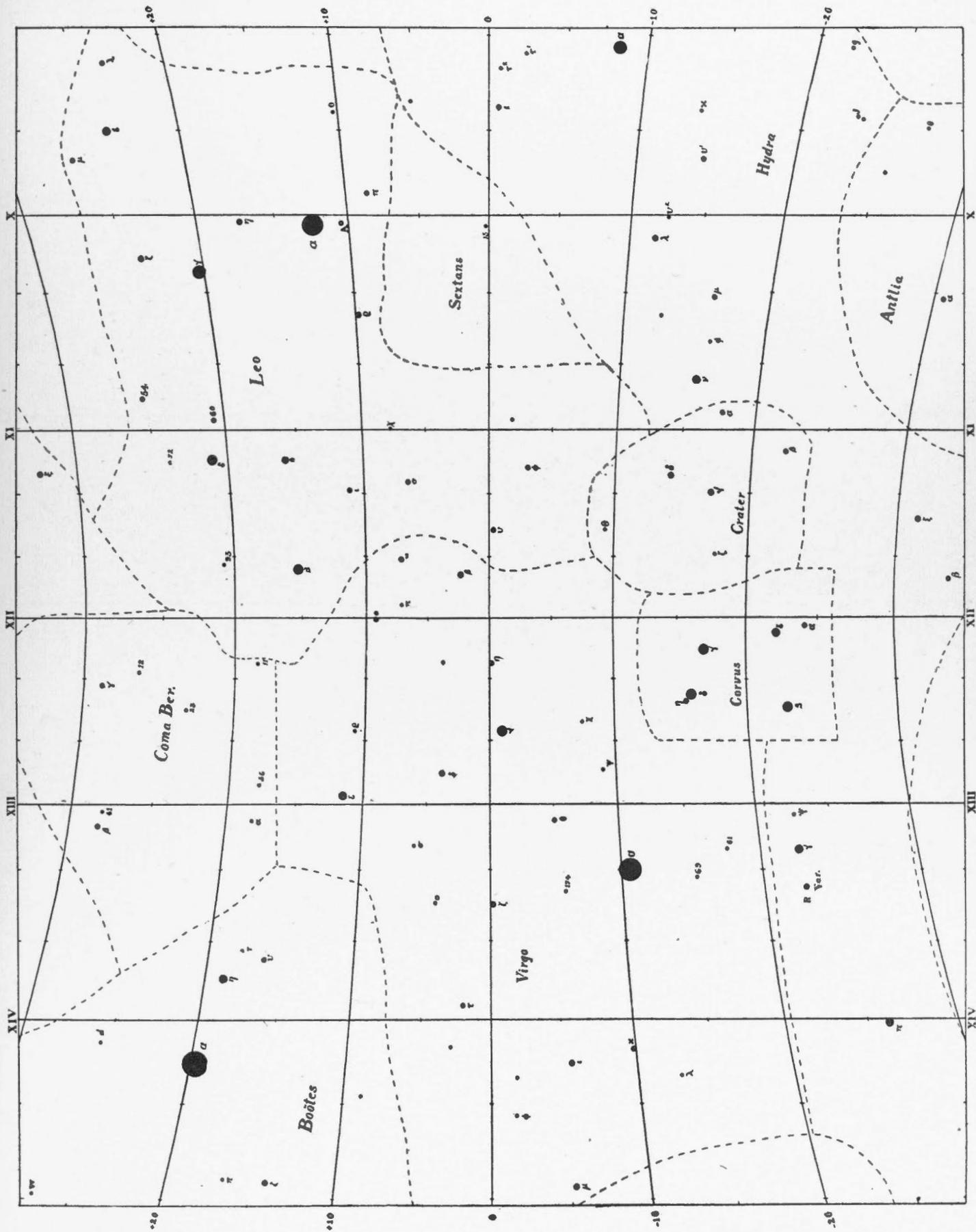


MAP IX.

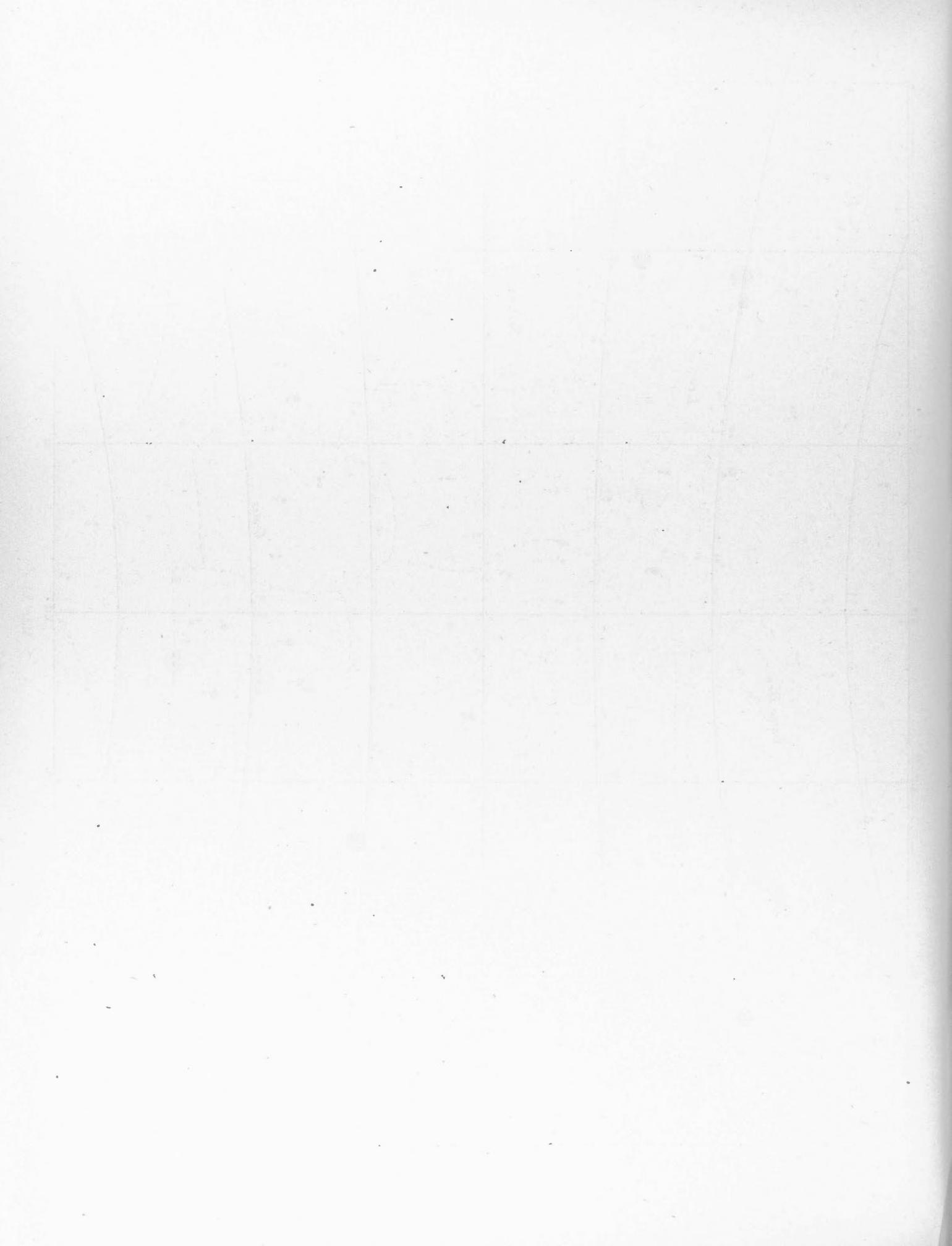


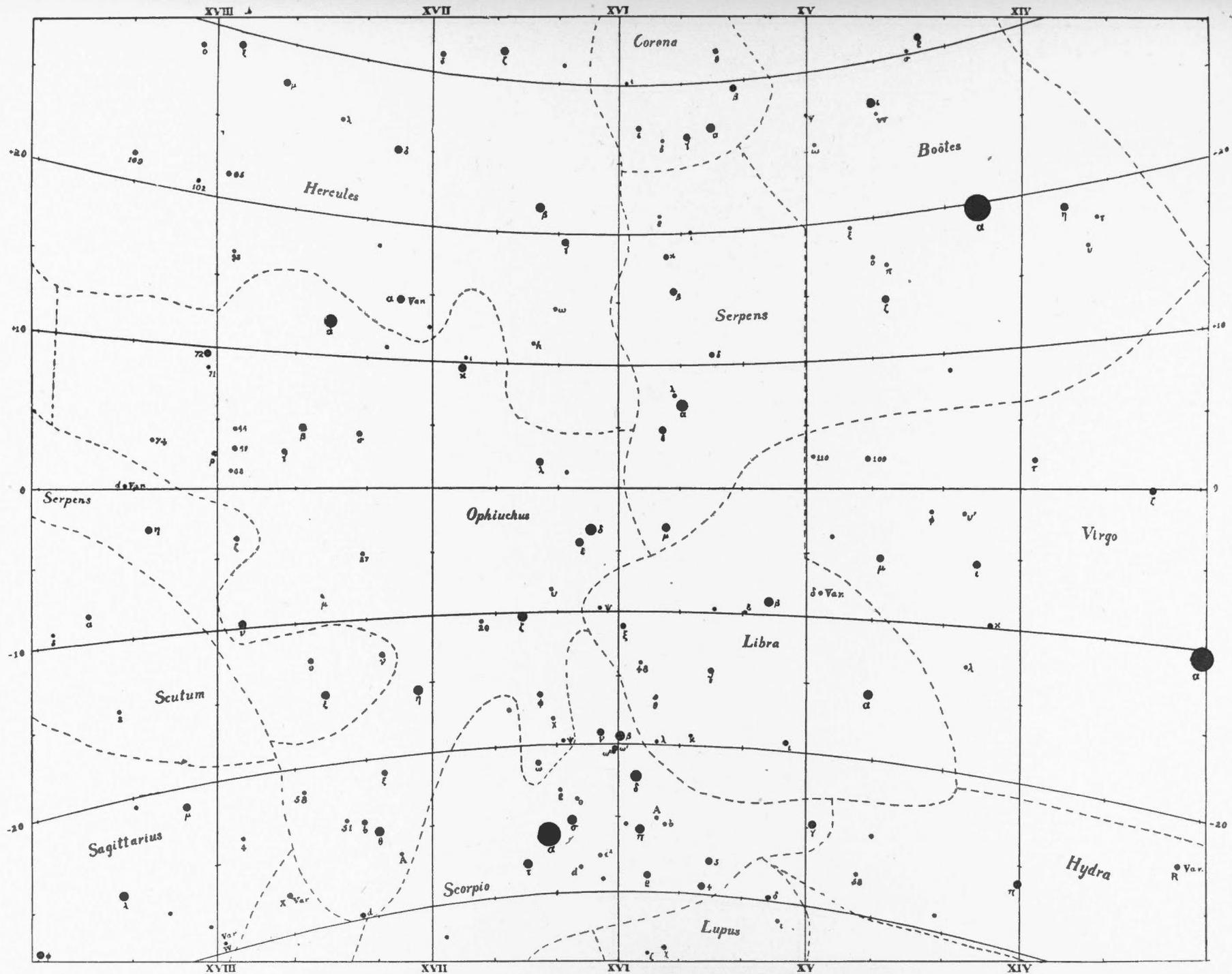


MAP X.

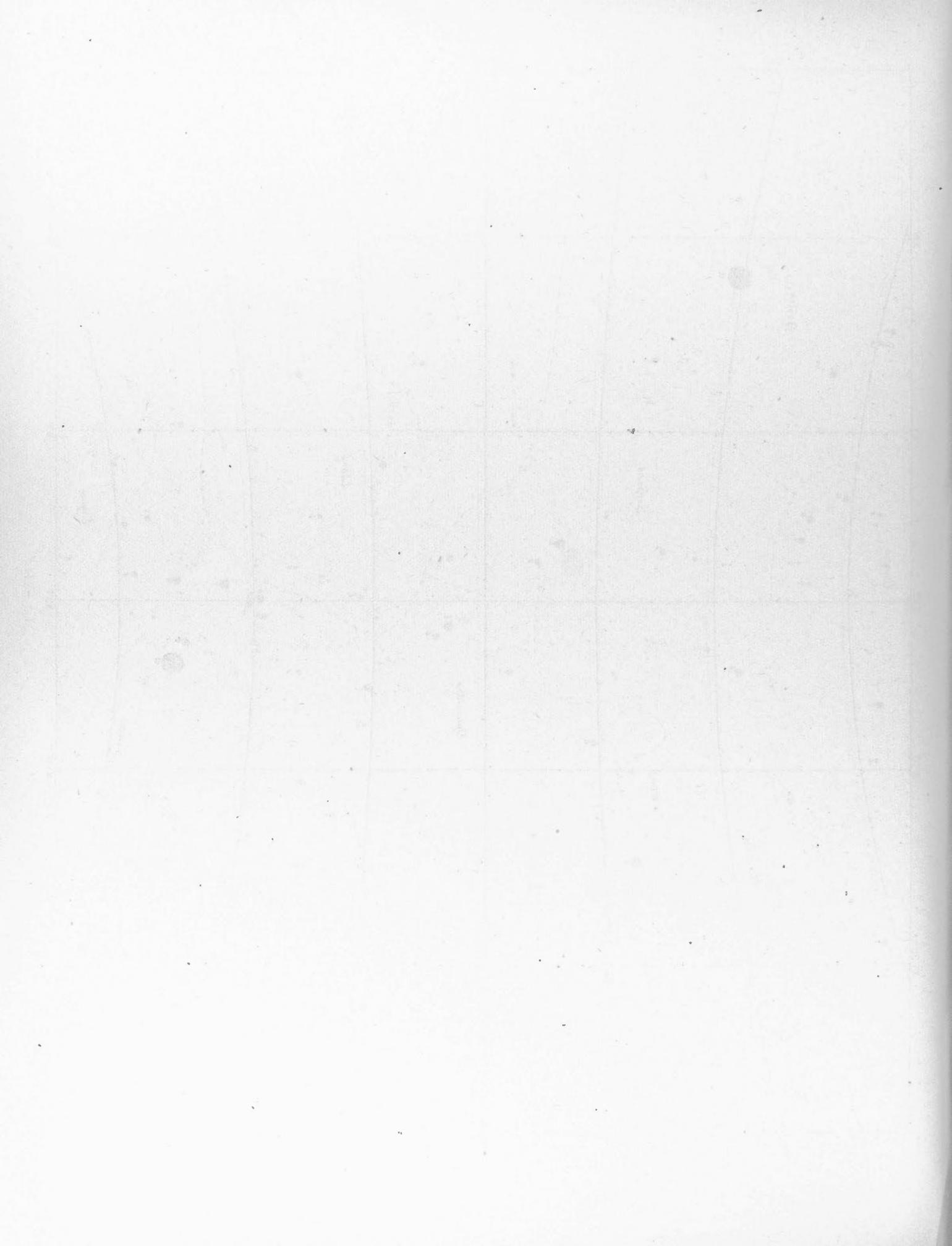


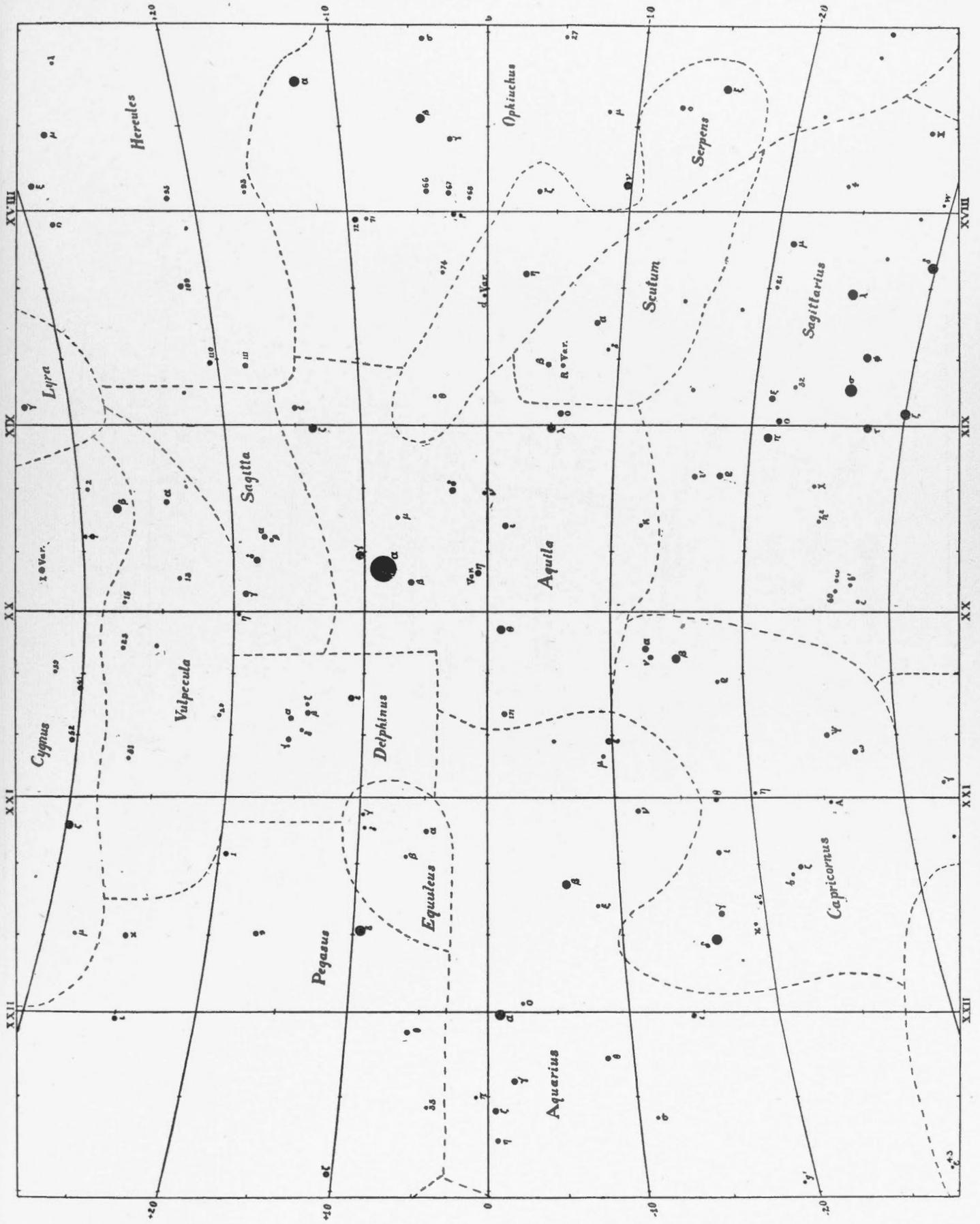
MAP XI.



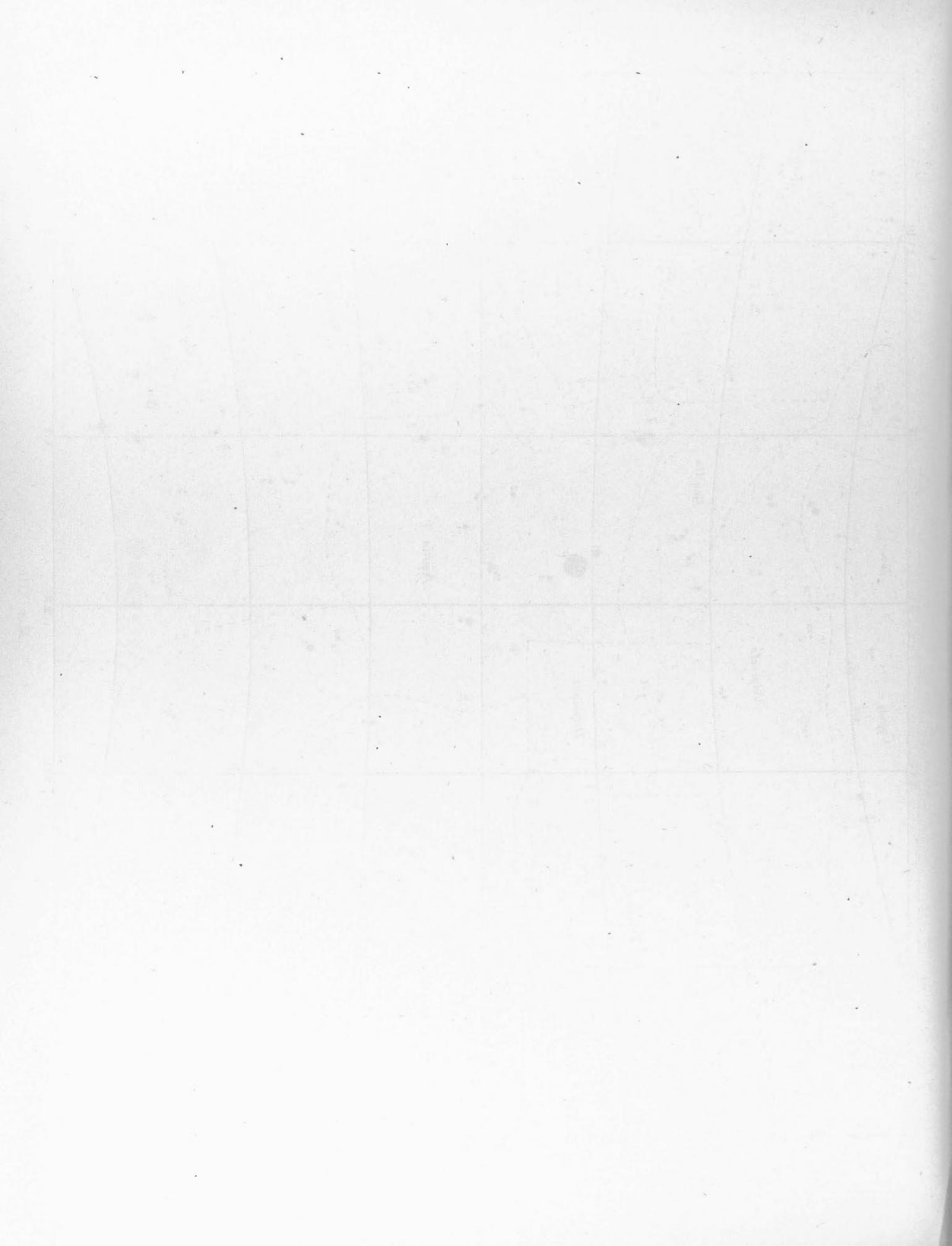


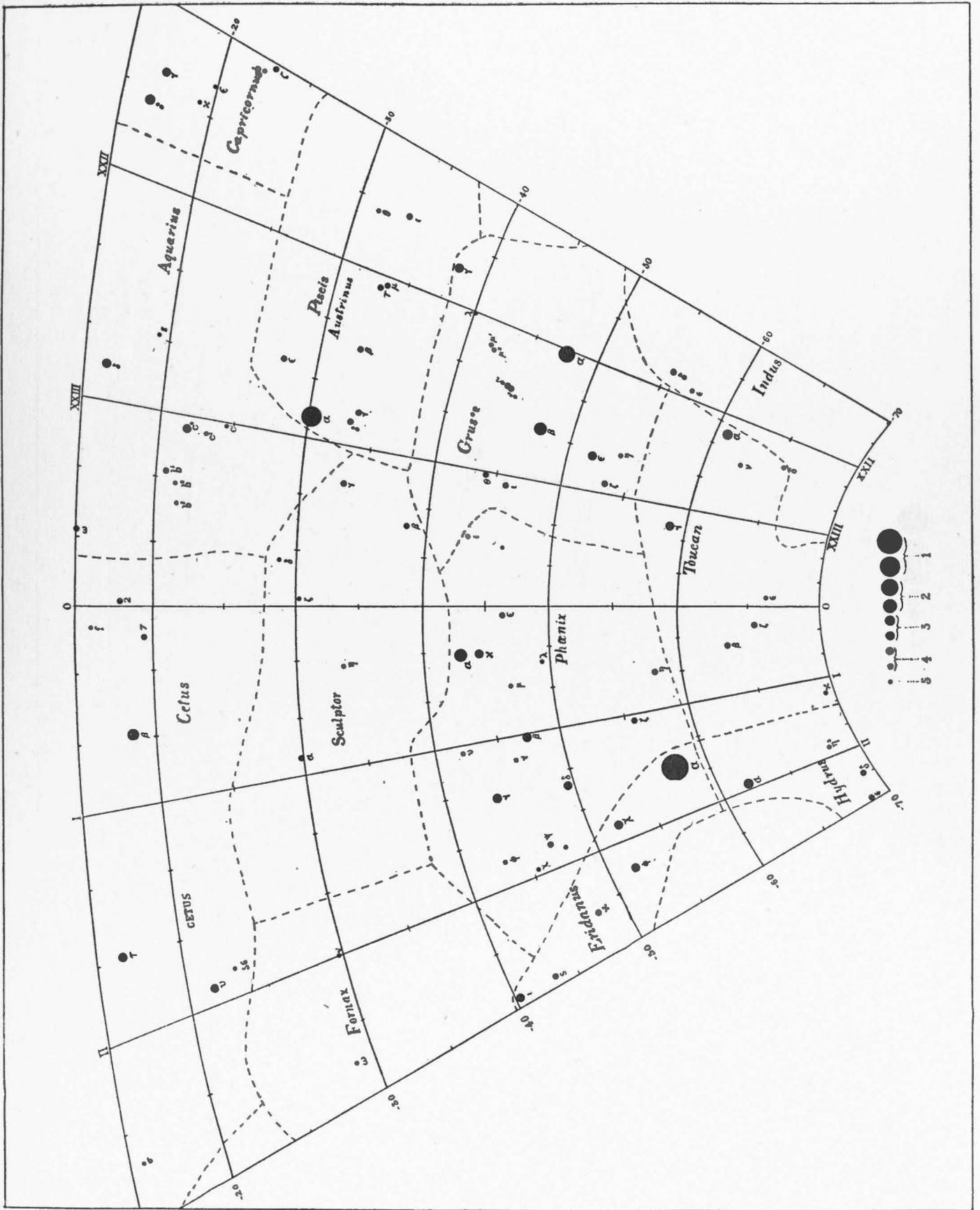
MAP. XII.





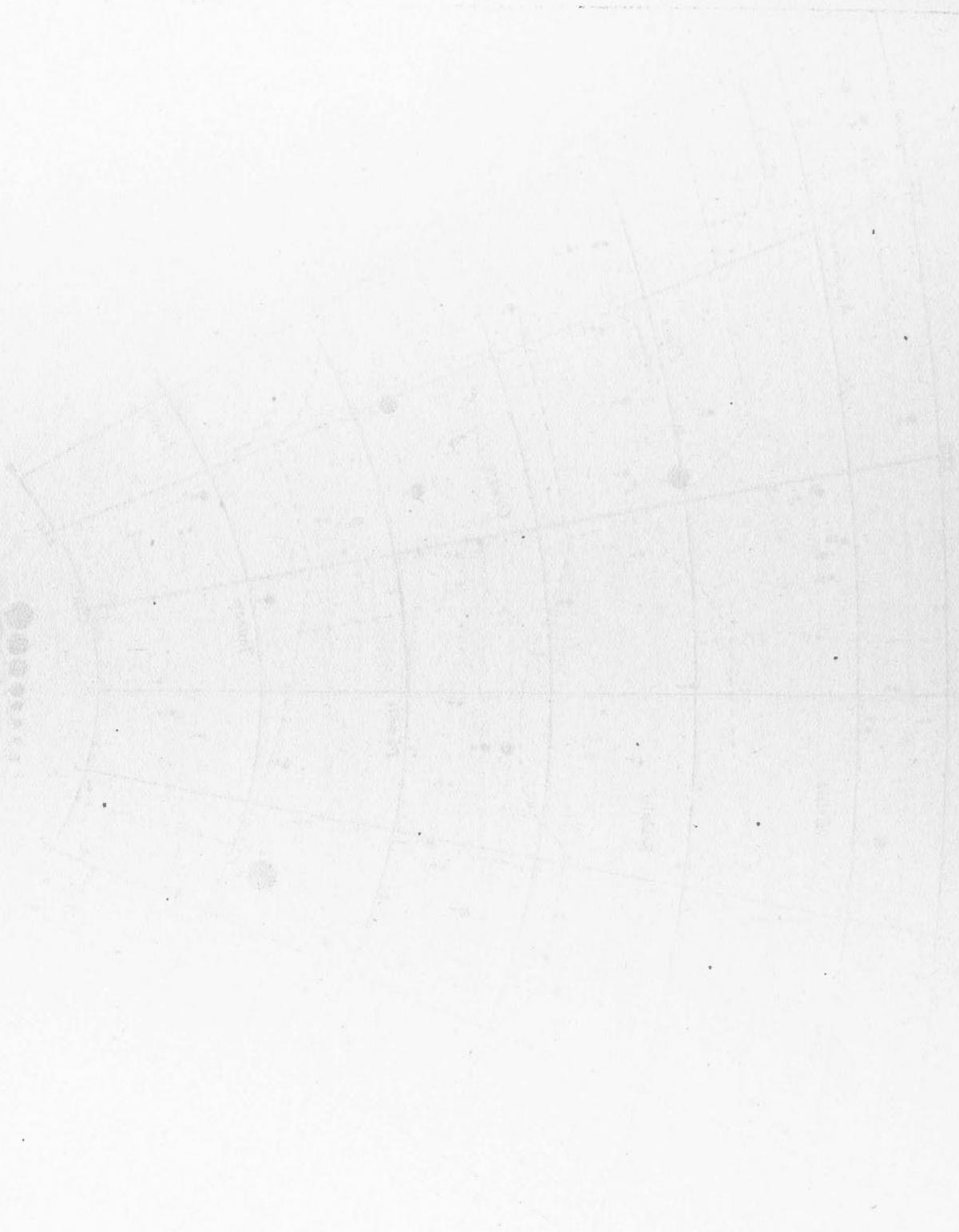
MAP XIII.

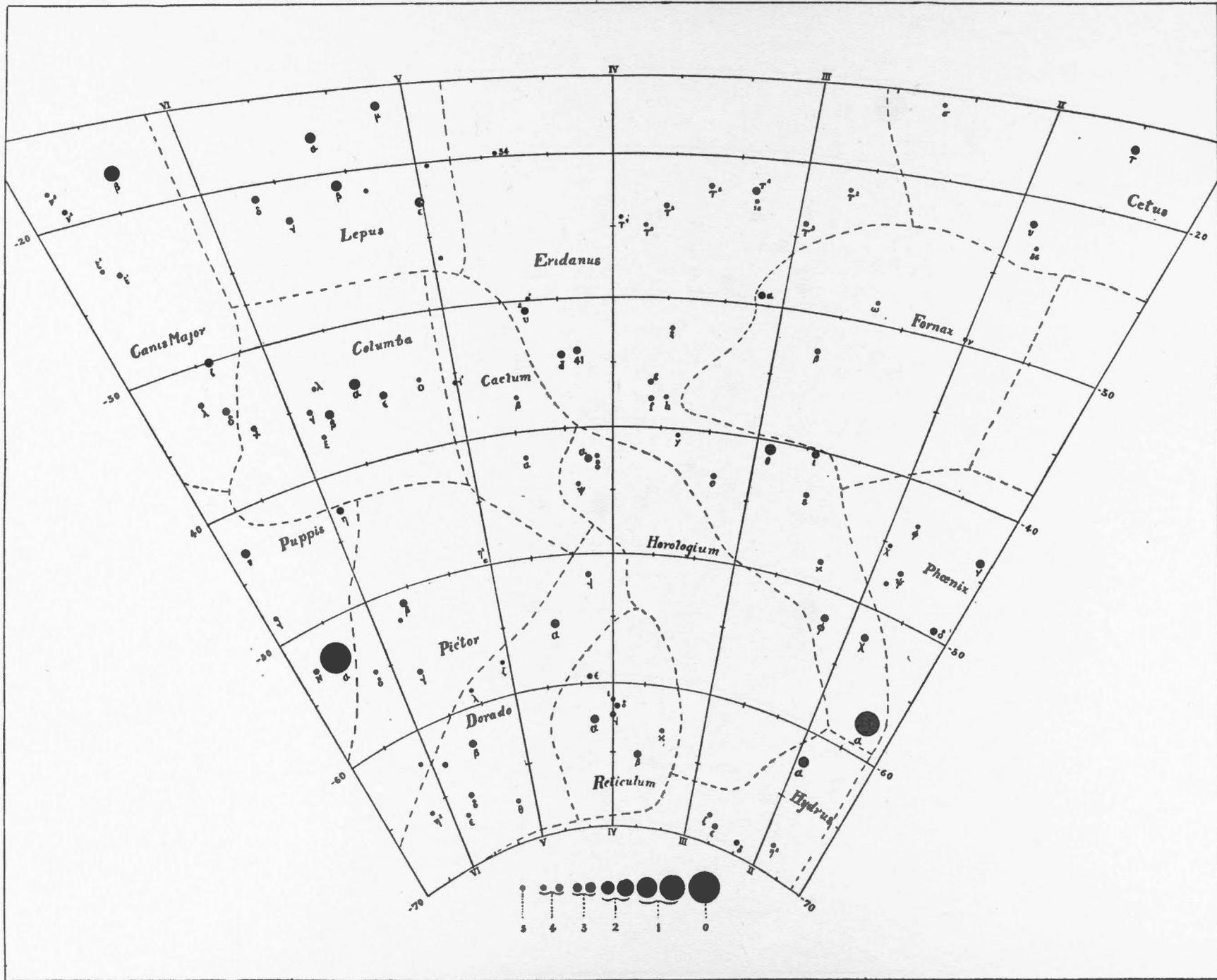




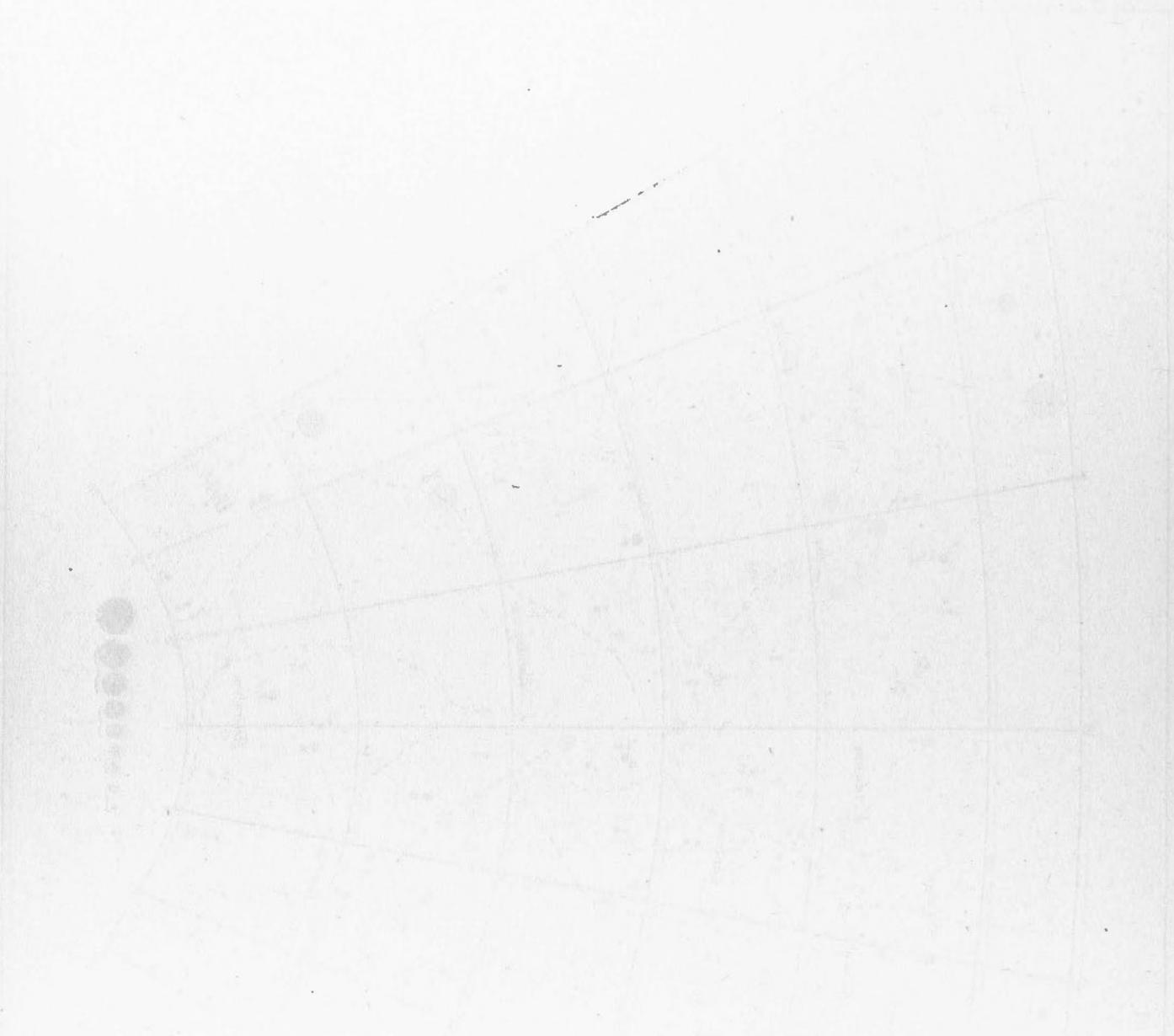
MAP XIV.

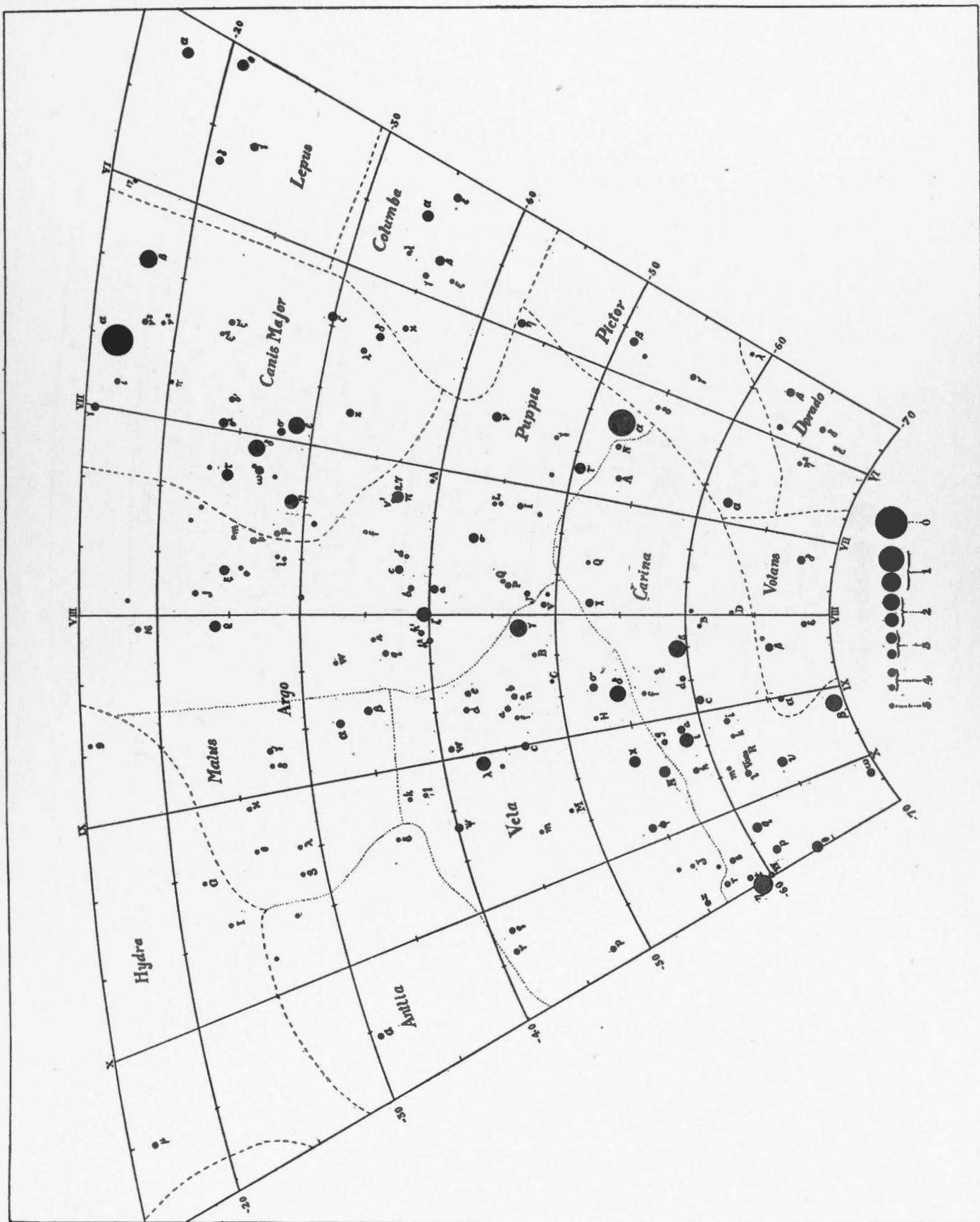
EXHIBIT



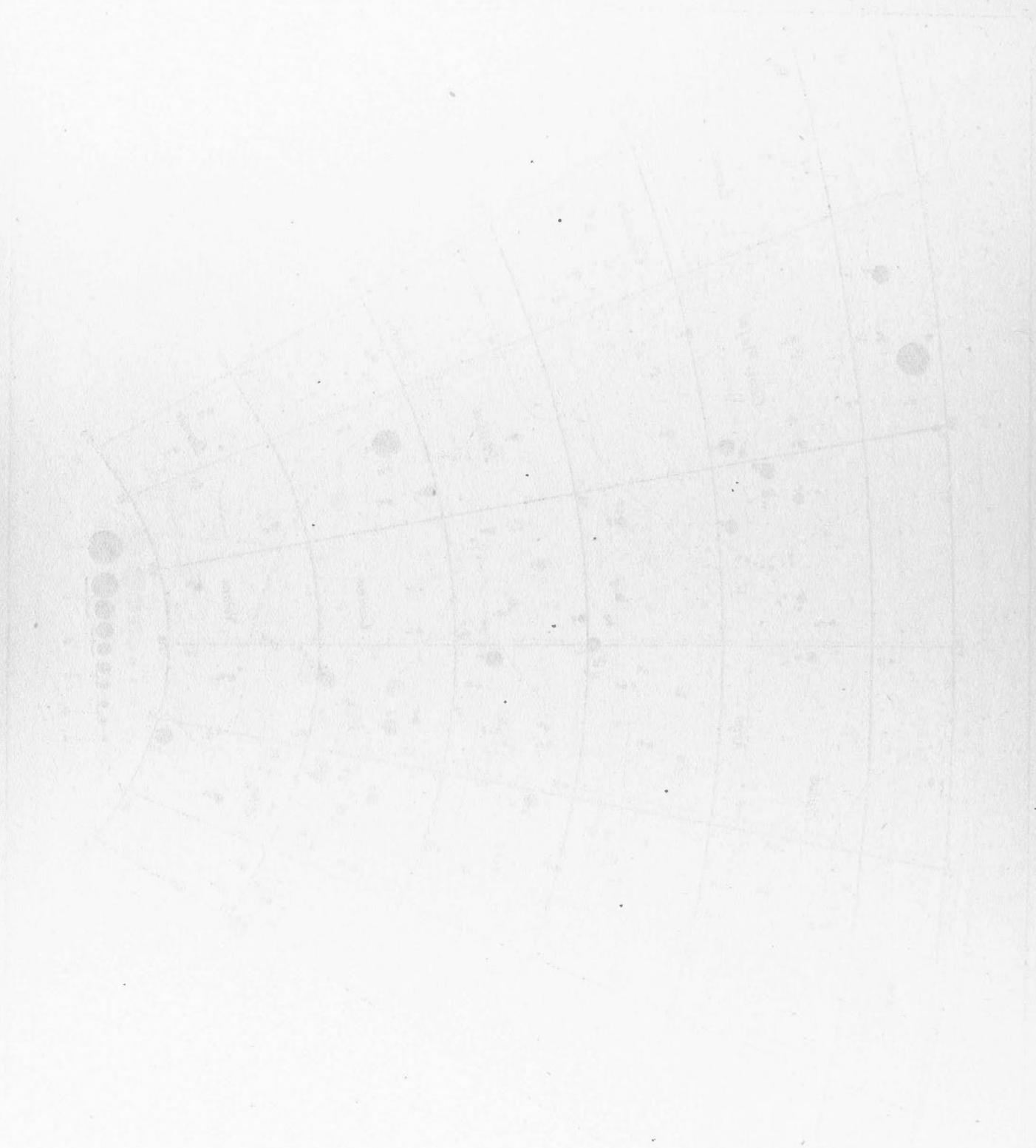


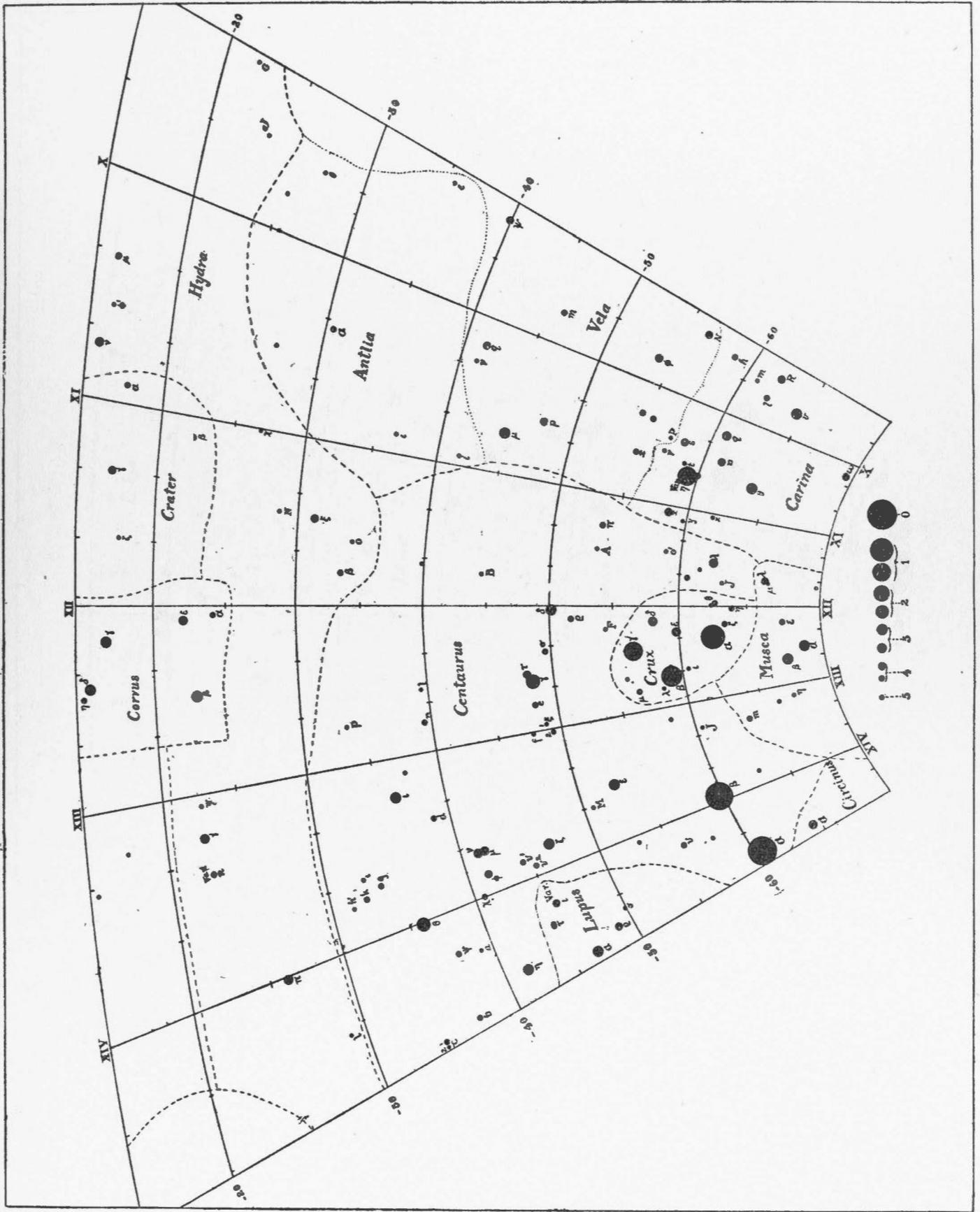
MAP XV.



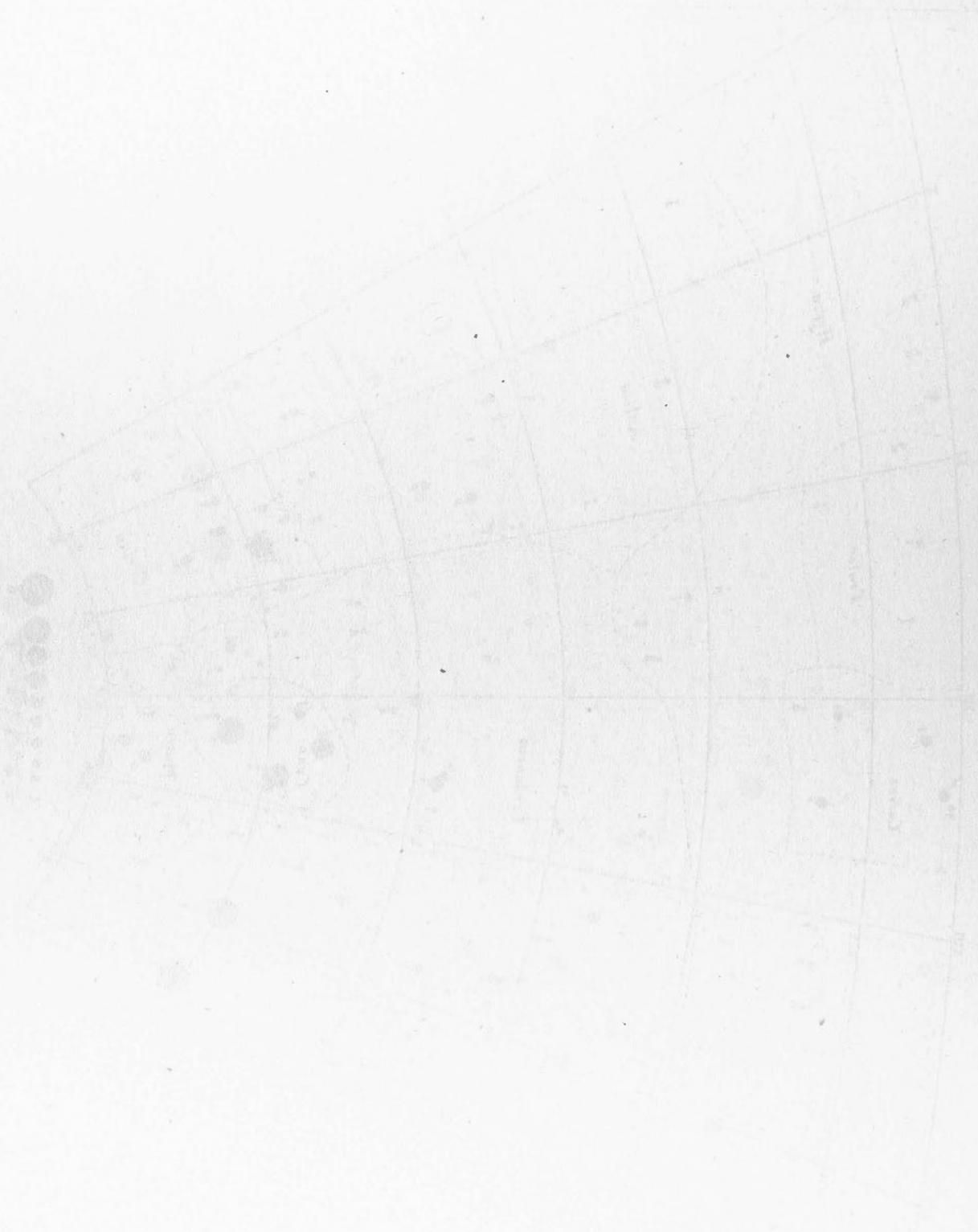


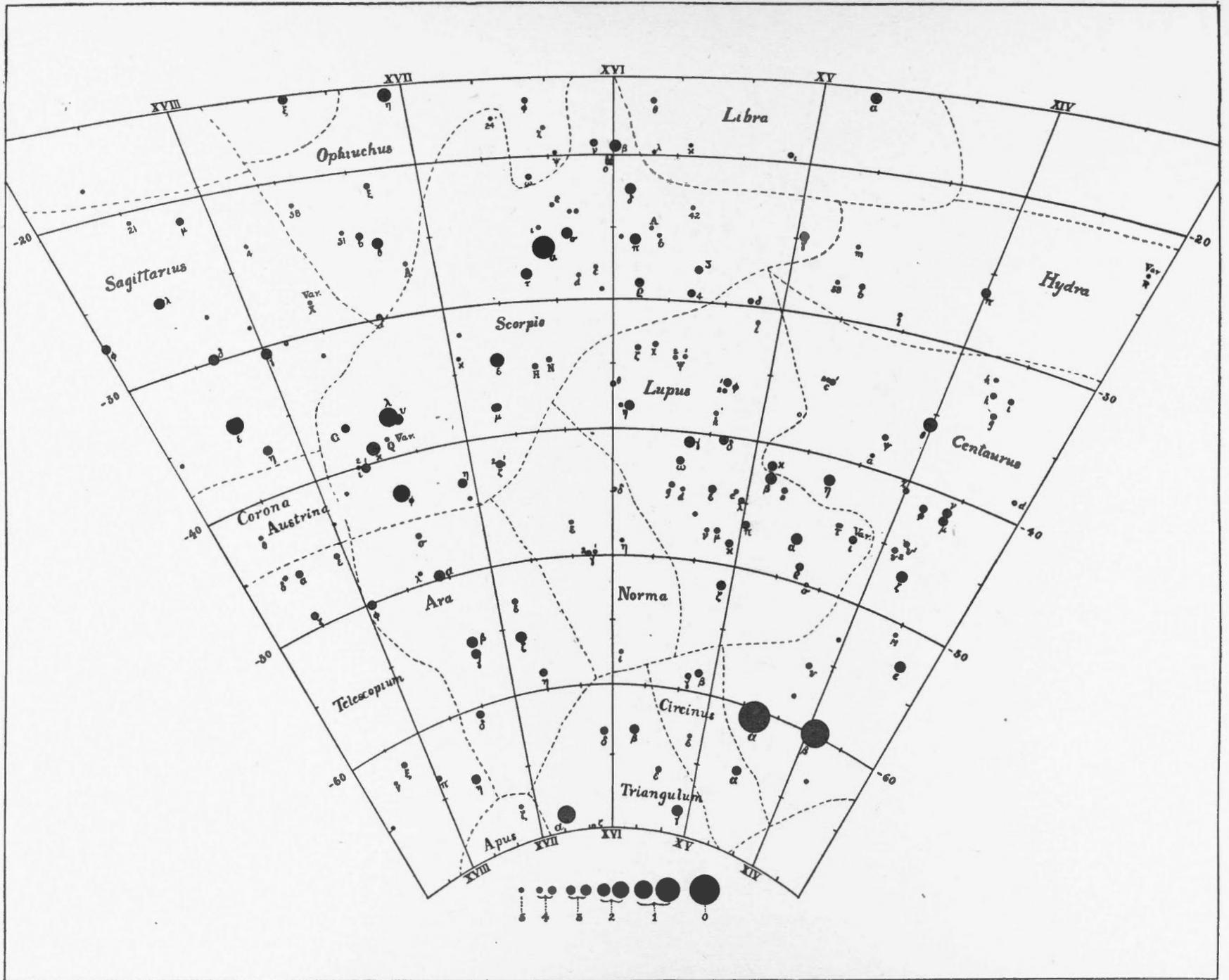
MAP XVI.



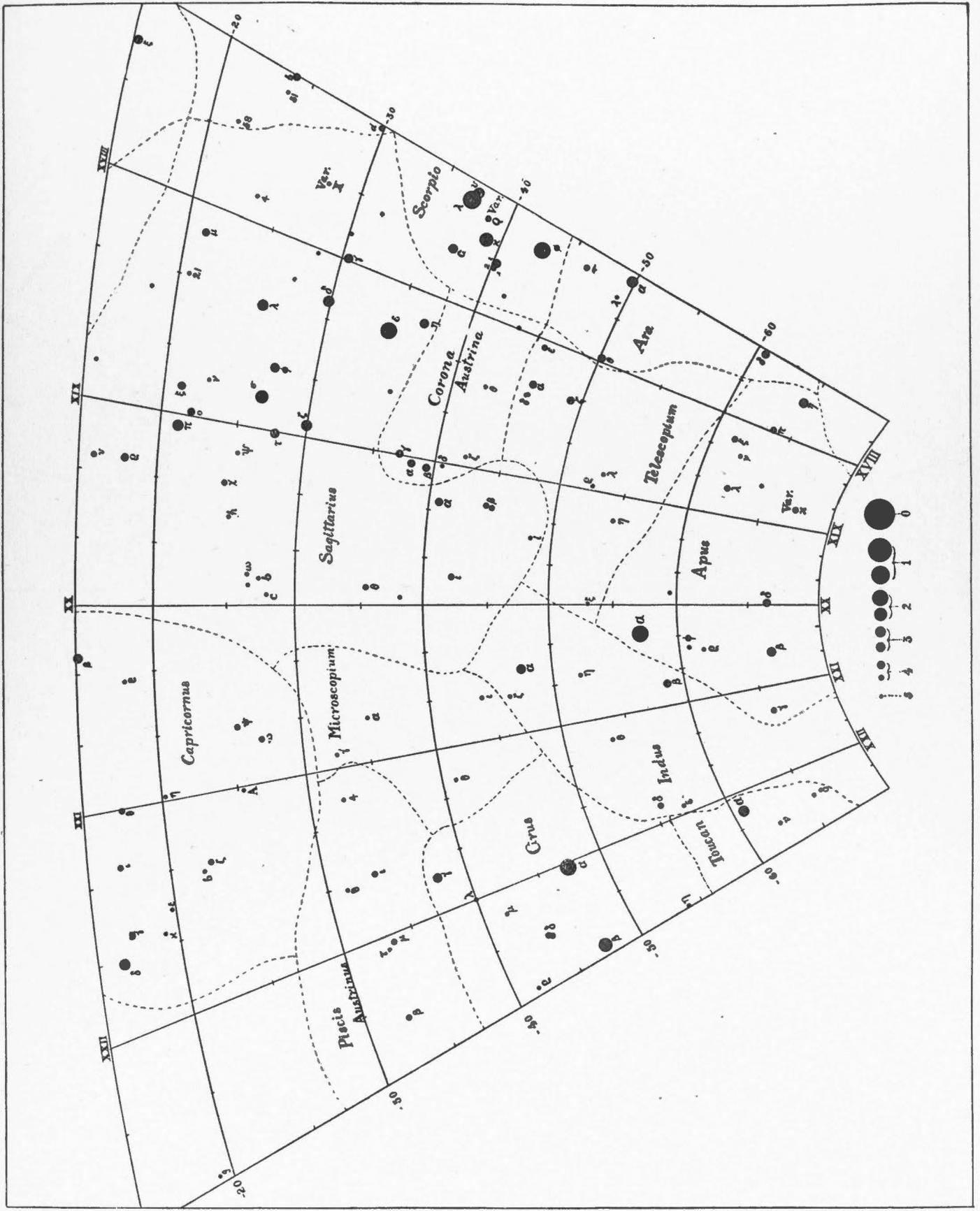


MAP XVII.

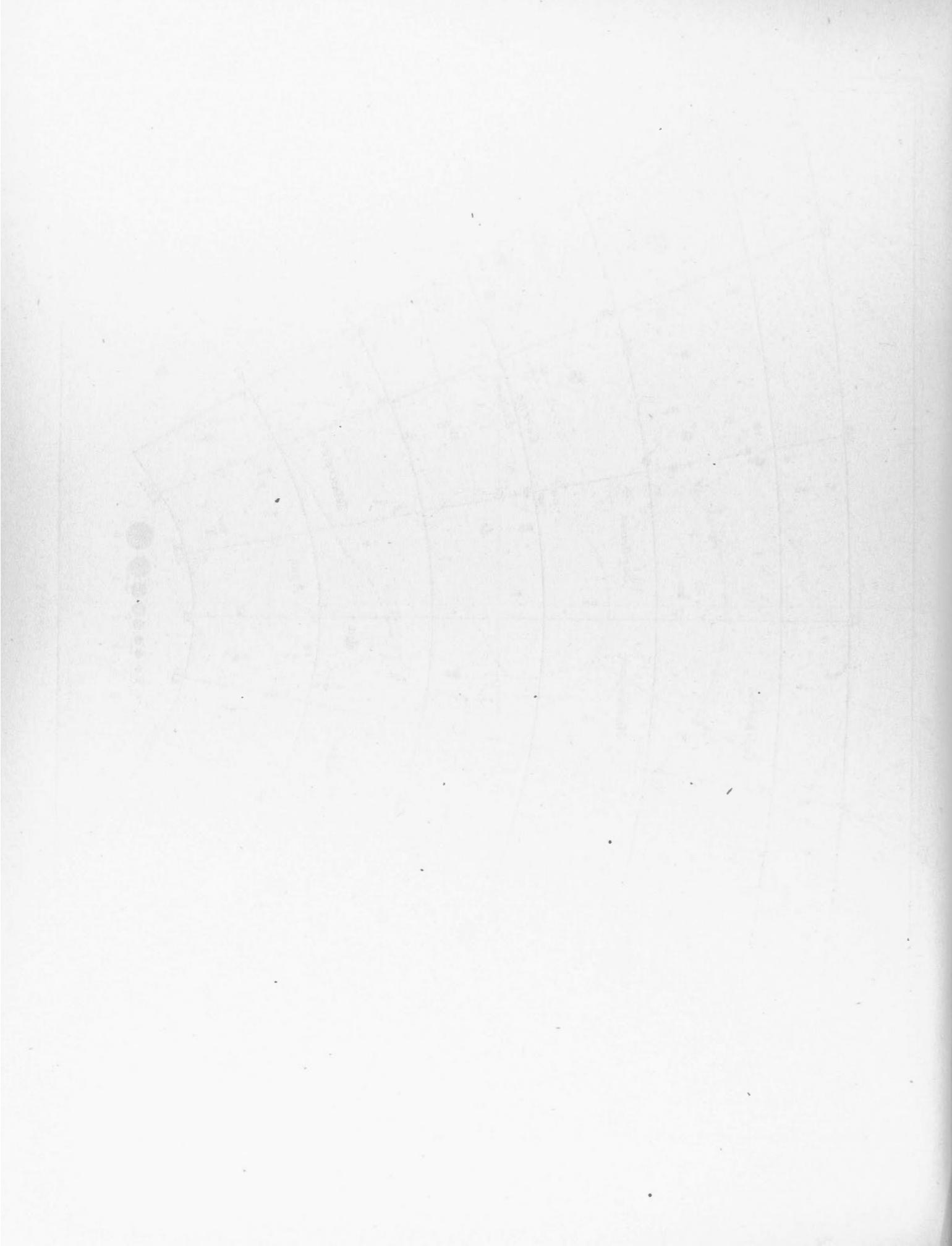


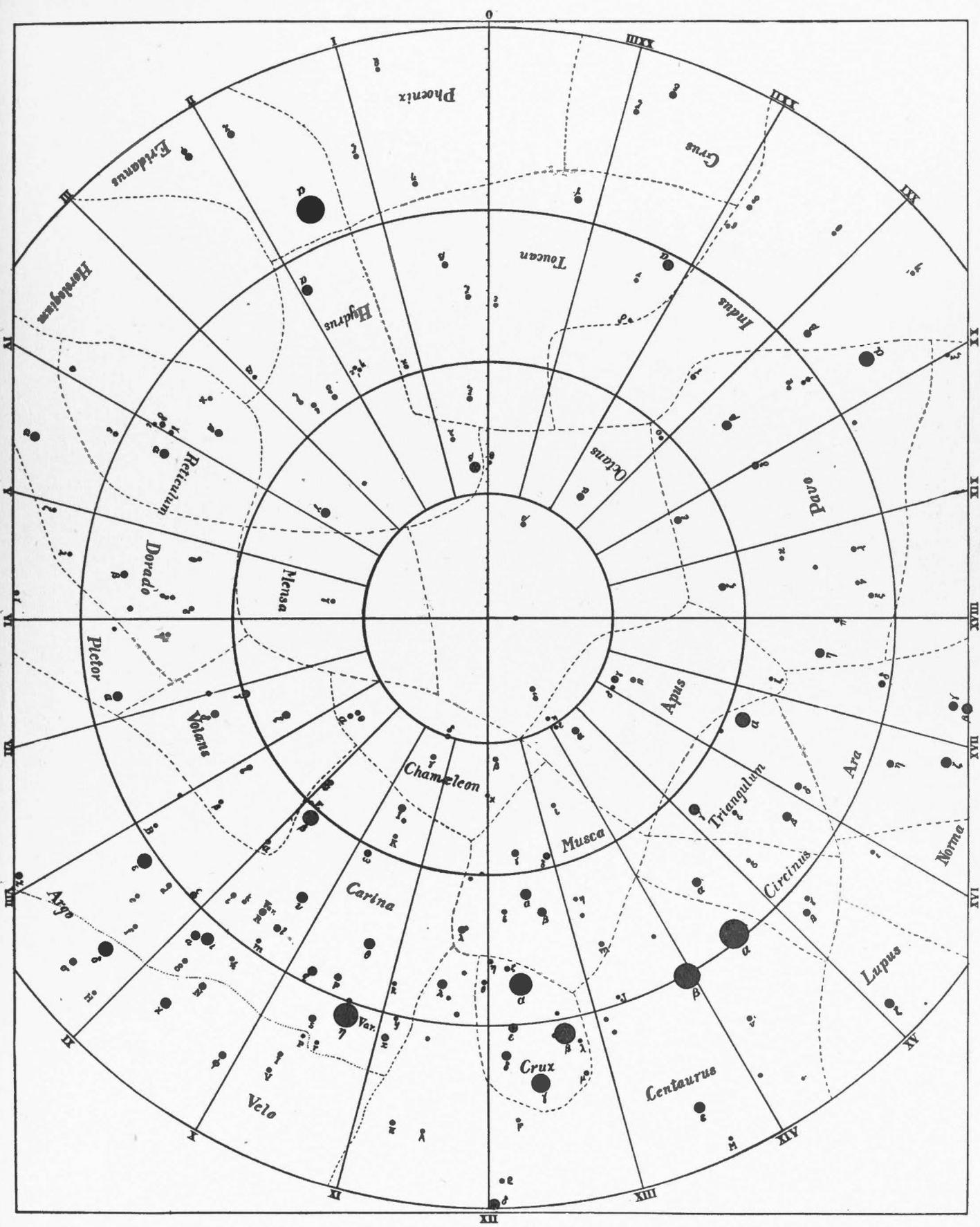


MAP XVIII.



MAP XIX.





MAP XX.

DEPARTMENT OF THE INTERIOR
CANADA

HON. W. J. ROOME, *Minister*. W. W. COBT, C.M.G., *Deputy Minister*.

PUBLICATIONS

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Dominion Observatory

OTTAWA

W. F. KING, C.M.G., LL.D., *Director*.

Vol. II, No. 8

Orbit of the Spectroscopic Binary
1149 Groombridge

BY

W. E. HARPER, M.A.

OTTAWA
GOVERNMENT PRINTING BUREAU
1915

DEPARTMENT OF THE INTERIOR
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OTTAWA
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1915

RESEARCH

Domination Observatory

OTTAWA

1980

Vol. 1, No. 1

Chart of the Spectroscopic Shift

AND

ORBIT OF THE SPECTROSCOPIC BINARY 1149 GROOMBRIDGE.

BY W. E. HARPER, M.A.

This star ($\alpha=6^{\text{h}} 18^{\text{m}}$, $\delta=+56^{\circ} 20'$, photographic magnitude 5.7) was announced by Adams as a spectroscopic binary from the measures* of three plates taken in the autumn of 1911. These three measures have served very materially in the accurate determination of the period.

Thirty spectrograms of the star have been secured here between February 20, 1914, and March 16, 1915. The single-prism spectrograph with a dispersion of 32.1 Å at $\lambda 4325$ was used throughout. The exposure times varied between 30 and 110 minutes, the average for the 30 plates being 78 minutes. In fair seeing, with the Seed 27 plates used, 70 minutes or even less should be sufficient to give a measurable spectrum of this star which is of the A5 type.

The period was discovered from the first half dozen measures taken in conjunction with Adams' early measures and the aim was kept in view to obtain the curve with the least amount of observational data compatible with accuracy. The gaps in the curve were filled up rather slowly as cloudy weather was usually the rule at the particular phase desired. There are three or four plates which have abnormal residuals but further observations at the same phases show that they are purely accidental, as the residuals are both positive and negative, and as no valid reason can be given for rejecting the plates they have all been retained.

Rowland's values of the wave-lengths were used as preliminary, and corrections to these were obtained by the customary method of equating to zero the residuals given by each line from the mean of the plate. Twenty-five plates were used in this connection.

*Astrophysical Journal Vol. 25, page 175.

WAVE-LENGTHS OF LINES USED.

4572.144	4468.870	4290.120	4198.719
4558.799	4415.217	4282.583	4143.788
4549.746	4404.927	4271.645	4101.890
4534.139	4395.286	4260.579	4077.862
4522.907	4351.991	4250.698	4071.861
4520.430	4340.667	4235.991	4063.706
4508.455	4325.907	4233.421	4045.929
4501.503	4307.980	4215.745	4005.402
4481.464	4294.269	4202.118	

MEASURES OF 1149 GROOMBRIDGE.

λ	5948		6008		6016		6016*		6031		6041		6051	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572	+ 39.1	1	- 50.6	1	- 27.3	1	- 25.4	1						
4558													+ 51.1	$\frac{1}{2}$
4549	30.2	1	61.3	1	19.0	1	9.5	1	- 69.6	$\frac{3}{4}$	- 5.6	1	57.4	1
4534					26.1	1	26.0	1	51.5	$\frac{1}{2}$				
4522											- 19.2	1		
4508													60.1	$\frac{3}{4}$
4501									66.7	$\frac{1}{2}$				
4481	35.4	1	77.3	1	11.8	1	12.6	1	43.6	$\frac{1}{2}$	+ 2.6	1		
4415	33.9	1	70.9	1	4.1	1	4.3	1			- 11.8	1		
4404									72.8	$\frac{1}{2}$	- 20.0	1		
4395					13.9	1	14.1	1	48.2	$\frac{3}{4}$	- 11.2	$\frac{1}{2}$		
4352	35.6	1			17.1	1	9.3	$\frac{3}{4}$	62.9	$\frac{1}{4}$	- 2.4	$\frac{1}{2}$	71.8	$\frac{3}{4}$
4340			50.2	1	11.8	$\frac{1}{2}$	20.9	$\frac{1}{2}$			0.0	$\frac{1}{2}$		
4325	43.5	1							61.5	$\frac{3}{4}$	- 4.5	1	51.1	$\frac{1}{2}$
4308	38.6	1	59.7	1	0.0	1			67.6	$\frac{1}{2}$	- 6.9	1	39.6	$\frac{1}{2}$
4294			57.4	1	7.7	1	10.4	1						
4290	36.2	1	53.0	1	7.1	1	8.8	1	51.5	1	- 11.3	1		
4282			66.5	1										
4271	36.0	1	63.2	1	8.1	1	6.7	1	43.5	1	- 15.7	1		
4260							13.1	1						
4250	33.7	1	57.9	1	10.1	1							37.3	$\frac{1}{2}$
4236							9.1	1	63.2	1				
4233	33.9	1	49.5	1	8.7	1	6.1	1	47.3	$\frac{3}{4}$	- 11.3	1		
4215	36.8	1	56.5	1	1.1	1	5.5	1	54.9	$\frac{1}{2}$	- 3.3	1		
4202			47.5	1					77.5	$\frac{1}{2}$				
4143	34.0	1	60.5	1	10.6	1	9.8	$\frac{1}{2}$			+ 0.4	1		
4077			52.9	1	11.5	$1\frac{1}{2}$	9.4	1			- 7.5	$\frac{1}{2}$		
4071			62.2	1										
4063			47.1	1	17.5	$1\frac{1}{2}$	13.8	1	50.9	$\frac{1}{2}$	- 12.5	1	45.4	1
4045	+ 21.3	1	50.6	1	3.2	$1\frac{1}{2}$	0.5	$1\frac{1}{4}$	59.5	1	- 6.1	1	+ 41.6	$\frac{3}{4}$
4005			- 56.6	1	- 7.3	1	- 9.3	1	- 71.7	$\frac{1}{2}$				
Weighted mean	+ 34.87		- 57.57		- 11.15		- 10.89		- 58.02		- 8.48		+ 51.57	
V_a	- 21.38		- 24.64		- 24.38		- 24.38		- 23.52		- 21.92		- 20.09	
V_d	- .11		- .12		- .17		- .17		- .15		- .15		- .16	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 13.1		- 80.6		- 36.0		- 35.7		- 82.0		- 30.8		+ 31.0	

*Checked by Harper.

MEASURES OF 1149 GROOMBRIDGE—Continued.

λ	6066		6462		6472		6485		6509		6524		6524*	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572			- 70.1	1			+ 35.0	$\frac{1}{2}$						
4549	+ 61.1	$1\frac{1}{2}$	78.4	1	- 55.4	$\frac{1}{2}$	26.0	1	-112.0	$\frac{1}{2}$	- 33.6	1	- 31.1	1
4534			69.7	1	45.8	$\frac{3}{4}$								
4522			79.1	1	47.3	1			94.3	$\frac{1}{2}$				
4501									102.2	$\frac{1}{2}$	24.3	1	28.6	$\frac{1}{2}$
4481	54.2	$\frac{1}{2}$			31.6	$\frac{1}{2}$	21.3	$\frac{1}{2}$	94.5	1	26.5	$\frac{1}{2}$	17.0	$\frac{1}{2}$
4468							22.2	$\frac{1}{2}$						
4415											26.4	1		
4404			71.4	1	39.5	1	40.4	1	97.6	$\frac{1}{2}$				
4340											17.5	$\frac{1}{2}$	31.5	$\frac{1}{2}$
4325			69.6	1			35.9	1			40.0	$\frac{1}{2}$	33.8	$\frac{1}{2}$
4308			79.5	1			26.4	1	102.4	1	23.7	1	26.4	$\frac{1}{2}$
4290			77.4	1	41.8	1	23.7	1	104.9	1	26.4	1	30.0	1
4282							32.9	$\frac{1}{2}$	97.7	$\frac{1}{2}$				
4271			79.0	1			25.7	$\frac{3}{4}$			25.7	$\frac{1}{2}$	26.3	$\frac{1}{2}$
4260							25.8	1			30.3	$\frac{1}{2}$	30.5	1
4250	57.9	$\frac{1}{2}$			30.0	$\frac{1}{2}$			88.3	$\frac{1}{2}$				
4236					29.3	1	39.1	$\frac{1}{2}$	102.2	$\frac{1}{2}$				
4233			82.2	1	56.9	$\frac{3}{4}$	38.9	$\frac{3}{4}$	110.9	$\frac{1}{2}$	19.0	1	19.6	1
4215	47.1	$\frac{3}{4}$	81.7	1	32.1	$\frac{1}{2}$	24.6	$\frac{3}{4}$	99.2	1	28.3	1	29.2	1
4198									94.9	$\frac{1}{2}$	22.1	1	25.1	$\frac{1}{2}$
4143	64.7	$\frac{1}{2}$			39.4	$\frac{3}{4}$	31.7	$\frac{1}{2}$			36.3	1	25.9	1
4101											25.5	$\frac{1}{2}$		
4077			72.3	1			23.7	1			28.8	1	24.8	$\frac{1}{2}$
4071			74.8	1			33.8	$\frac{1}{2}$	-109.0	$\frac{1}{2}$	29.5	$\frac{1}{2}$	28.6	$\frac{1}{2}$
4063			68.6	1	42.0	1	29.1	$\frac{1}{2}$			32.3	1	23.9	1
4045	52.7	1	66.8	1	39.0	$1\frac{1}{2}$	+ 23.4	1			28.8	1	- 21.9	$\frac{1}{2}$
4005	+ 48.4	$\frac{1}{2}$	- 74.9	1	- 36.6	$\frac{1}{2}$					- 29.1	$\frac{1}{2}$		
Weighted mean	+ 55.66		- 74.72		- 40.69		+ 29.08		-100.59		- 27.00		- 26.84	
V_d	- 17.90		+ 24.90		+ 24.78		+ 24.67		+ 22.78		+ 22.41		+ 22.41	
V_d	- .15		+ .03		+ .03		+ .03		+ .09		+ .06		+ .06	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 37.3		- 50.1		- 16.2		+ 53.5		- 78.1		- 4.8		- 4.6	

*Checked by Young.

MEASURES OF 1149 GROOMBRIDGE—Continued.

λ	6547		6563		6575		6605		6621		6632		6658	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572	+ 7.4	1					- 20.5	$\frac{1}{2}$					+ 56.5	1
4549	+ 2.8	1	-51.9	$\frac{1}{2}$			14.4	$1\frac{1}{2}$	- 8.1	1	+ 18.8	$\frac{1}{2}$	49.5	$\frac{1}{2}$
4534	+ 13.2	1					20.3	$\frac{1}{2}$	20.3	1				
4522	+ 10.2	1												
4508	+ 1.4	1												
4501									5.2	1				
4481	- 11.8	1	60.0	$\frac{3}{4}$	+ 41.1	$\frac{1}{2}$	25.1	1	17.9	1	12.9	1	42.6	$\frac{3}{4}$
4468													54.5	$\frac{3}{4}$
4415									12.3	1				
4404	+ 4.9	1	66.1	$\frac{3}{4}$					1.2	1	25.8	1	46.4	1
4395							15.8	1						
4352	+ 15.3	1	74.9	$\frac{1}{2}$										
4340	+ 4.2	1			54.9	$\frac{3}{4}$	6.1	$\frac{1}{2}$	37.5	$\frac{1}{2}$	5.1	$\frac{1}{2}$	42.1	$\frac{1}{2}$
4325	+ 13.4	1											58.7	$\frac{3}{4}$
4308	+ 15.0	1			27.5	$\frac{1}{2}$	14.0	1	11.6	1				
4294							17.6	1	14.9	1	7.7	1		
4290	+ 3.3	1			44.0	$\frac{1}{4}$	15.6	1	12.5	1	16.1	1	55.5	1
4271	+ 11.4	1	65.5	$\frac{1}{2}$					14.9	1	0.0	1		
4260	+ 15.1	1			41.4	$\frac{1}{2}$			9.9	1			46.6	$\frac{1}{2}$
4250							24.7	1						
4236											2.7	$\frac{3}{4}$	48.6	1
4233	+ 12.8	1	66.8	$\frac{3}{4}$	38.2	$\frac{1}{2}$	15.0	1	10.6	1	8.1	$\frac{3}{4}$	48.7	1
4215	+ 9.8	1	78.3	$\frac{1}{2}$			27.2	1	17.9	1	7.7	1	47.2	1
4202			63.1	$\frac{1}{2}$					4.3	1	0.8	$\frac{3}{4}$	50.5	1
4143					27.7	$\frac{1}{2}$	16.0	1	17.6	1	15.3	1		
4077	+ 8.3	1	69.5	$\frac{3}{4}$	33.9	1	11.3	$1\frac{1}{2}$			10.9	1	54.7	1
4071	+ 5.6	1	54.9	$\frac{1}{2}$			15.2	1	13.3	1			60.3	1
4063	+ 2.2	1	64.9	$1\frac{1}{2}$	26.8	$\frac{3}{4}$	16.9	1	16.3	$1\frac{1}{2}$	19.9	$1\frac{1}{2}$	42.1	1
4045	+ 6.4	1	- 68.8	$\frac{3}{4}$	+ 31.2	1	17.6	$1\frac{1}{2}$	1.3	1	20.7	$1\frac{1}{2}$		
4005	+ 9.9	1					- 17.3	1	- 13.5	1	+ 17.2	1	+ 42.0	1
Weighted mean	+ 7.56		- 65.44		+ 35.62		- 17.14		- 12.52		+ 12.80		+ 50.08	
V_a	+ 19.91		+ 15.31		+ 13.13		+ 8.05		+ 5.81		+ 4.10		+ 0.01	
V_d	- .02		- .05		- .11		+ .09		- .15		- .11		+ .04	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 27.2		- 50.5		+ 48.4		- 9.3		- 7.1		+ 16.5		+ 49.8	

MEASURES OF 1149 GROOMBRIDGE—Continued.

λ	6671		6696		6710		6726		6740		6763		6835	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572	- 26.8	$\frac{1}{2}$	- 59.4	1										
4558			64.3	1										
4549	39.4	$\frac{1}{2}$	70.5	1	+ 70.8	1	+ 66.6	$\frac{1}{2}$	- 59.7	$\frac{3}{4}$			+ 67.5	$\frac{1}{2}$
4534					50.4	1	33.5	$\frac{1}{2}$	57.8	1				
4522					51.7	1	52.6	$\frac{1}{2}$	69.4	1				
4520					56.6	1	49.8	$\frac{1}{2}$	70.4	1				
4508	31.7	$\frac{1}{2}$												
4501	25.7	$\frac{1}{2}$												
4481	18.7	$\frac{1}{2}$	60.6	1	73.7	1			71.3	$\frac{1}{2}$	+ 4.2	$\frac{1}{2}$	67.6	$\frac{1}{2}$
4468			59.9	1										
4415			67.3	1	49.4	1	60.4	1			21.4	1	62.0	$\frac{1}{2}$
4404					49.7	1								
4395	30.7	$\frac{1}{2}$	62.6	1			54.1	$\frac{1}{2}$	70.2	1	24.6	$\frac{1}{2}$		
4352	20.9	$\frac{1}{2}$												
4340	37.8	$\frac{1}{2}$	63.0	1	59.5	1	39.9	$\frac{1}{2}$	66.1	$\frac{3}{4}$	13.3	$\frac{1}{2}$	75.9	$\frac{1}{2}$
4325	28.2	1	71.8	1	47.5	1			73.5	1			71.5	$\frac{1}{2}$
4308			60.1	1	45.7	1	55.2	$\frac{1}{2}$						
4294					56.8	1					8.9	$\frac{3}{4}$		
4290	35.4	$\frac{3}{4}$	62.2	1	42.9	1			66.2	1			70.5	1
4271	30.4	$\frac{3}{4}$	56.9	1	50.5	1	61.6	1	67.7	1	23.5	$\frac{3}{4}$	72.3	1
4260			58.2	1	44.6	1	47.0	1					59.0	$\frac{3}{4}$
4236	32.9	$\frac{1}{2}$	63.9	$1\frac{1}{2}$	57.2	1	58.4	$\frac{3}{4}$	74.5	1	22.5	$\frac{1}{2}$		
4233	28.4	$\frac{1}{2}$	56.8	$1\frac{1}{2}$	47.5	1	50.3	$\frac{3}{4}$	71.9	$1\frac{1}{2}$	30.1	$\frac{1}{2}$	76.4	1
4215	21.8	$\frac{3}{4}$	64.6	$1\frac{1}{2}$	53.8	1			63.6	$\frac{3}{4}$			69.6	1
4202	26.2	$\frac{3}{4}$			60.8	1					26.6	$\frac{3}{4}$	70.8	$\frac{3}{4}$
4198					50.7	1								
4143			53.8	$1\frac{1}{2}$	42.1	1								
4101							54.2	$\frac{1}{2}$			21.4	$\frac{1}{2}$	53.6	1
4077			55.2	$1\frac{1}{2}$	61.5	1	56.3	$\frac{3}{4}$	71.5	$\frac{3}{4}$	16.6	$\frac{3}{4}$	74.7	$\frac{1}{2}$
4071					57.2	1	39.5	$\frac{1}{2}$			15.0	$\frac{1}{2}$		
4063	24.0	$\frac{1}{2}$	64.4	$1\frac{1}{2}$	57.6	1	50.0	$\frac{3}{4}$	62.0	$1\frac{1}{2}$				
4045	- 26.6	1	65.3	$1\frac{1}{2}$	49.5	1	44.6	1	62.5	$1\frac{1}{2}$	28.4	1	61.6	1
4005			- 61.3	1	+ 52.4	1	+ 45.8	1	- 62.9	1	+ 20.5	$\frac{3}{4}$	+ 63.1	$\frac{1}{2}$
Weighted mean	- 28.42		- 61.80		+ 53.60		+ 51.46		- 66.98		+ 20.22		+ 67.50	
V_a	- 2.48		- 6.46		- 8.10		- 12.55		- 13.96		- 15.02		- 23.60	
V_d	- .07		- .15		- .07		- .10		+ .12		- .11		- .03	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 31.2		- 68.7		+ 45.2		+ 38.5		- 81.1		+ 4.8		+ 43.6	

MEASURES OF 1149 GROOMBRIDGE—*Concluded.*

λ	6845		6847		6848		6872		Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.						
4572	- 47.6	$\frac{3}{4}$												
4549	60.0	$\frac{3}{4}$	- 69.8	1			- 8.2	1						
4534							- 3.6	1						
4481	43.9	$\frac{3}{4}$	66.1	1	- 72.9	$\frac{1}{2}$	+ 13.2	$\frac{1}{2}$						
4415	49.5	$\frac{1}{2}$					- 5.5	$\frac{1}{2}$						
4404			68.3	$\frac{1}{2}$	53.2	1	+ 0.7	$\frac{1}{2}$						
4395	43.9	$\frac{1}{2}$					- 9.9	$\frac{1}{2}$						
4352							+ 1.1	$\frac{1}{2}$						
4340	50.6	$\frac{1}{2}$	63.8	$\frac{1}{2}$	65.7	1	+ 9.7	$\frac{1}{2}$						
4325			69.6	1			- 8.8	$\frac{1}{2}$						
4308			71.7	1										
4294							+ 3.2	$\frac{1}{2}$						
4290	59.6	1	59.0	1	62.1	1	- 4.7	$\frac{1}{2}$						
4271	49.4	1	64.4	$\frac{1}{2}$			- 8.6	1						
4260	62.8	$\frac{3}{4}$	61.9	1	70.0	$\frac{3}{4}$								
4250			74.0	1	65.6	$\frac{3}{4}$								
4236			65.2	1	56.7	1	- 5.9	$\frac{1}{2}$						
4233	50.6	$\frac{3}{4}$	56.7	1	54.2	1	- 9.4	$\frac{3}{4}$						
4215	54.2	1	66.6	1	58.7	1	- 6.1	$\frac{1}{2}$						
4202			61.7	1			+ 12.7	$\frac{1}{2}$						
4198			76.5	$\frac{1}{2}$	64.5	$\frac{3}{4}$	+ 1.7	$\frac{1}{2}$						
4143			60.2	1			- 3.8	1						
4101			68.9	1	65.2	1								
4077	43.1	$\frac{1}{2}$	67.0	1	68.1	1	- 12.6	$\frac{3}{4}$						
4071	53.6	$\frac{1}{2}$	64.9	$\frac{1}{2}$	71.0	1								
4063	43.8	$\frac{1}{2}$	65.5	1	62.3	$\frac{1}{2}$	- 9.0	$\frac{1}{2}$						
4045	49.8	$\frac{3}{4}$	- 57.8	$1\frac{1}{2}$	56.0	1	- 3.0	1						
4005	- 56.1	$\frac{3}{4}$			- 53.7	$\frac{3}{4}$	+ 2.2	$\frac{1}{2}$						
Weighted mean	- 51.82		- 65.23		- 62.05		- 3.32							
V_s	- 23.99		- 24.12		- 24.12		- 24.82							
V_d	- .10		- .06		- .14		- .20							
Curv.	- .28		- .28		- .28		- .28							
Radial Velocity	- 76.2		- 89.7		- 86.6		- 28.6							

The following table contains all the data of the measures. The phases are reckoned from the periastron finally adopted using the period 9.944 days which was determined from a comparison of Mt. Wilson observations with our own. The residuals, O-C, are scaled from the curve representing the adopted elements.

TABLE OF MEASURES OF 1149 GROOMBRIDGE.

Plate No.	Observer.*	Date.	Julian Date.	Phase.	Lines.	Weight.	Vel.	O-C.
1914								
5948	P ¹	Feb. 20.....	2,420,184.693	7.621	14	7	+ 13.1	- 2.5
6008	C	April 3.....	226.590	9.742	20	10	- 80.6	- 7.4
6016	H	April 6.....	229.623	2.831	20	7	- 35.8	-11.0
6031	H	April 13.....	236.609	9.817	18	7.5	- 82.0	- 7.0
6041	P ¹	April 22.....	245.628	8.892	18	8.5	- 30.8	+ 8.8
6051	H	April 30.....	253.612	6.932	9	4	+ 31.0	- 5.0
6066	C	May 8.....	261.570	4.946	7	3	+ 37.3	- 3.6
6462	Y	Oct. 1.....	407.917	2.133	16	8	- 50.1	+ 2.8
6472	H	Oct. 2.....	408.921	3.137	14	6	- 16.2	- 3.4
6485	H	Oct. 4.....	410.916	5.132	19	8	+ 53.5	+ 9.5
6509	H	Oct. 20.....	426.839	1.167	14	6	- 78.1	+ 2.6
6524	Y	Oct. 22.....	428.843	3.171	20	9	- 4.7	+ 6.5
6547	H	Nov. 2.....	439.882	4.266	21	10	+ 27.2	+ 1.4
6563	H	Nov. 17.....	454.875	9.315	12	5	- 50.5	+ 8.0
6575	P ¹	Nov. 23.....	460.926	5.422	10	4	+ 48.4	+ 1.5
6605	H	Dec. 6.....	473.675	8.227	18	9	- 9.3	+ 0.1
6621	P ¹	Dec. 11.....	478.948	3.556	20	9	- 7.1	- 9.8
6632	H	Dec. 15.....	482.888	7.496	16	8	+ 16.5	- 3.3
6658	C	Dec. 23.....	490.687	5.351	17	8	+ 49.8	+ 3.4
6671	P ¹	Dec. 30.....	497.764	2.484	17	7	- 31.2	+ 8.2
1915								
6696	P	Jan. 8.....	506.859	1.635	21	11	- 68.7	+ 1.0
6710	Y	Jan. 12.....	510.725	5.501	25	12	+ 45.2	- 2.3
6726	Y	Jan. 23.....	521.743	6.575	18	7.5	+ 38.5	- 4.5
6740	H	Jan. 27.....	525.475	0.363	17	8.5	- 81.1	+ 3.5
6763	P	Jan. 30.....	528.739	3.627	14	6	+ 4.8	- 0.3
6835	H	Mar. 4.....	561.544	6.600	15	7	+ 43.6	+ 0.8
6845	Y	Mar. 7.....	565.625	9.681	16	6	- 76.2	- 4.5
6847	H	Mar. 8.....	565.568	0.680	21	9.5	- 89.7	- 3.9
6848	H	Mar. 8.....	565.675	0.787	16	8	- 86.6	- 1.4
6872	Y	Mar. 16.....	573.687	8.799	22	6.5	- 28.6	+ 7.4

*P=Plaskett, P¹=Parker, C=Cannon, Y=Young, H=Harper.

MT. WILSON OBSERVATIONS.

Date	Julian Date	Phase	Velocity	O-C.
1911				
Oct. 30.....	2,419,340.959	9.127	-55.8	- 5.2
Nov. 4.....	345.923	4.147	+21.2	- 0.8
Dec. 11.....	382.978	1.426	-75.8	+ 0.1

NORMAL PLACES.

	Mean Phase from Final <i>T</i>	Mean Vel.	Weight	O-C.		Mean Phase from Final <i>T</i>	Mean Vel.	Weight	O-C.
1	0.609	-85.9	.9	- 0.1	7	6.662	+38.8	.6	- 3.7
2	1.470	-72.0	.6	+ 4.2	8	7.554	+14.9	.5	- 3.6
3	2.465	-39.5	.7	+ 2.7	9	8.227	- 9.3	.3	- 0.8
4	3.307	- 8.5	.8	- 0.9	10	8.852	-29.9	.5	+ 6.9
5	4.172	+21.7	.6	- 1.5	11	9.674	-74.7	.9	- 5.1
6	5.361	+48.8	1.1	+ 1.1					

Our own observations were grouped on the basis of phase into eleven normal places as above, and, after a few trials, preliminary elements were adopted as follows:—

$$\begin{aligned}
 P &= 9.944 \text{ days} \\
 e &= .07 \\
 \omega &= 160^\circ \\
 K &= 68 \text{ km.} \\
 \gamma &= -13.53 \text{ km.} \\
 T &= \text{J. D. } 2419342.0
 \end{aligned}$$

using these elements and making the transformations,

$$\begin{aligned}
 x &= \delta\gamma \\
 y &= \delta K \\
 z &= K\delta e \\
 u &= K\delta\omega \\
 v &= [1.63633]\delta T
 \end{aligned}$$

we get the following observation equations according to the differential formula of Lehmann-Filhés:—

OBSERVATION EQUATIONS 1149 GROOMBRIDGE.

	Weight.	x	y	z	u	v	$-n$
1	.9	1.000	- 1.064	- .980	- .094	+ .079	+ 0.1=0
2	.6	1.000	- .922	- .115	+ .492	- .563	- 4.2
3	.7	1.000	- .423	+ .938	+ .910	- .936	- 2.7
4	.8	1.000	+ .087	+ .771	+ .964	- .922	+ 0.9
5	.6	1.000	+ .541	- .105	+ .770	- .703	+ 1.5
6	1.1	1.000	+ .901	- .985	+ .231	- .221	- 1.1
7	.6	1.000	+ .825	- .829	- .478	+ .411	+ 3.7
8	.5	1.000	+ .471	+ .702	- .867	+ .818	+ 3.6
9	.3	1.000	+ .075	+ 1.022	- 1.014	+ 1.020	+ 0.8
10	.5	1.000	- .343	+ .652	- .985	+ 1.041	- 6.9
11	.9	1.000	- .825	- .468	- .675	+ .738	+ 5.1

From these were obtained the normal equations:

$$\begin{aligned}
 7.500x - .582y - .433z + .211u - .177v + 1.490 &= 0 \\
 3.919y + .048z + .302u - .308v + 2.577 &= 0 \\
 4.056z + .374u - .375v - 3.454 &= 0 \\
 3.604u - 3.602v - 4.420 &= 0 \\
 3.618v + 4.587 &= 0
 \end{aligned}$$

which resulted in the corrections,

$$\begin{aligned}
 \delta\gamma &= -0.21 \text{ km.} \\
 \delta K &= -0.81 \text{ km.} \\
 \delta e &= +.011 \\
 \delta\omega &= -7^\circ.14 \\
 \delta T &= 0.224 \text{ day}
 \end{aligned}$$

It was feared that owing to the small value of e and consequent similarity of columns for u and v in the observation equations that either ω or T would have to be taken as fixed, but such was not the case and one solution was sufficient, as the difference between the residuals obtained by computing directly and by substituting in the observation equations were all less than 0.2 km. The value of Σpvv for the normal places was reduced from 81.0 to 67.8.

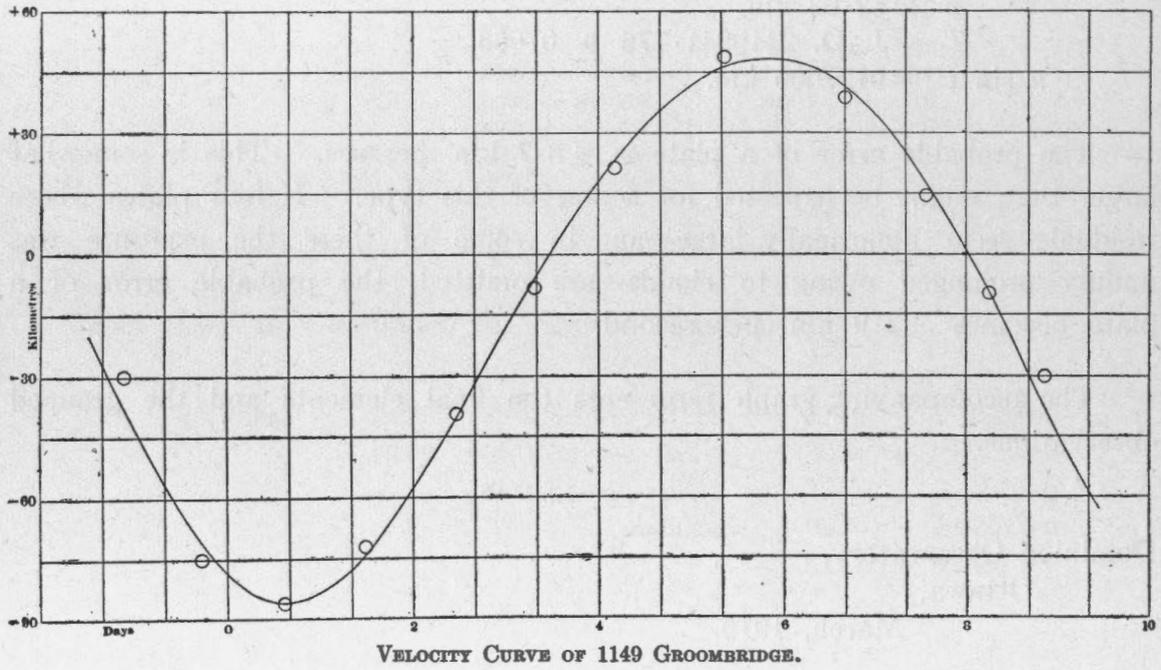
The final values then of the elements with their probable errors are the following:—

$$\begin{aligned}P &= 9.944 \text{ days} \\e &= .081 \pm .027 \\\omega &= 152^{\circ}.9 \pm 24^{\circ}.2 \\K &= 67.19 \text{ km.} \pm 1.19 \\\gamma &= -13.74 \text{ km.} \pm 1.39 \\A &= 62.35 \text{ km.} \\B &= 72.03 \text{ km.} \\T &= \text{J. D. } 2419341.776 \pm 0.663 \\a \sin i &= 9127000 \text{ km.}\end{aligned}$$

The probable error of a plate is ± 3.7 km. per sec. This is somewhat larger than might be expected for a star of this type. If four plates whose residuals seem abnormally large—and in some of these the exposure was unduly prolonged owing to clouds—are omitted, the probable error of a plate becomes ± 2.9 km. per second.

The accompanying graph represents the final elements and the grouped observations.

Dominion Observatory,
Ottawa,
March, 1915.



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OTTAWA

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ORBIT OF THE SPECTROSCOPIC BINARY 23 CASSIOPEIÆ.

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The binary character of 23 Cassiopeiæ ($\alpha=0^h 41^m 1$, $\delta=+74^\circ 18'$, 1900, mag. 5.39, type B8) was announced by Adams in 1912.* Sixty-one spectrograms, taken with a one-prism spectrograph at this observatory during 1914 and 1915, have been used in determining an orbit.

The principal lines showing in the spectrum are given in Table I which gives in order:—The wave-lengths used, the elements to which the wave-lengths are assigned, the residuals, and the number of times each line was measured. The residual for any line is the mean (algebraic or arithmetic) of all the residuals for that line. The separate residuals are found by subtracting the velocity as given by the plate from the velocity as given by the line.

TABLE I.

Wave- Length.	Element.	Algebraic Residual	Arithmetic Residual.	Number of times measur'd	Wave- Length.	Element.	Algebraic Residual.	Arithmetic Residual.	Number of times measur'd
3933.825	Calcium	0.0	3.6	50	4340.634	Hydrogen	- 0.8	5.1	59
4101.890	Hydrogen	- 1.2	4.4	44	4481.400	Magnesi'm	+ 1.2	6.6	44
4128.211	Silicon	0.0	7.1	39	4549.766	Iron	+ 5.9	8.7	7
4131.047	Silicon	+ 0.5	5.9	39					

*Ap. J. vol. 35, 172.

TABLE II.
MT. WILSON OBSERVATIONS.

Julian Date.	Phase.	Velocity.	O-C.	Julian Date.	Phase.	Velocity.	O-C.
2,419,026.713	29.21	+18.0	+10.5	2,419,340.839	5.84	+ 3.0	- 1.6
027.736	.....	.....	.....	380.761	12.01	+ 5.0	+11.0
055.640	24.39	-16.0	+ 3.6	407.635	5.13	+11.0	+ 7.4

TABLE III.
OTTAWA OBSERVATIONS OF 23 CASSIOPELÆ.

Plate Number.	Observer*	Date.	Julian Date.	Phase from 2420550.0	Velocity.	Weight.	O-C.
		1914.					
6185	H	July 14.....	2,420,328.843	15.09	-17.8	2.0	- 7.3
6218	H	July 21.....	335.854	22.10	-16.6	2.7	+ 3.4
6239	Y	July 30.....	344.833	31.08	+ 4.8	2.5	- 7.2
6245	C	Aug. 3.....	348.804	1.30	+ 7.5	2.0	- 1.8
6267	C	Aug. 5.....	350.782	3.28	+12.1	1.7	+ 5.6
6293	C-Y	Aug. 21.....	366.746	19.25	-29.2	2.0	-12.7
6301	Y	Aug. 24.....	369.687	22.19	-27.6	1.7	- 7.6
6307	Y	Aug. 25.....	370.646	23.14	-19.7	2.5	+ 0.7
6337	H-Pa	Sept. 4.....	380.755	33.25	+14.7	3.2	+ 3.2
6344	H	Sept. 8.....	384.643	3.39	+12.0	1.0	+ 5.7
6358	H	Sept. 11.....	387.798	6.55	+ 0.5	2.2	- 1.2
6371	Pa-C	Sept. 14.....	390.743	9.49	+ 2.2	1.7	+ 4.7
6376	Y	Sept. 15.....	391.586	10.34	- 3.5	2.5	+ 0.3
6392	H	Sept. 17.....	393.612	12.36	- 7.6	2.0	- 1.1
6400	C	Sept. 18.....	394.663	13.41	+ 0.8	1.5	+ 8.9
6407	P	Sept. 19.....	395.722	14.47	- 5.7	1.5	+ 4.4
6422	Y	Sept. 22.....	398.598	17.35	-15.8	2.5	- 2.2
6428	Pa-G	Sept. 25.....	401.748	20.50	-11.0	1.7	+ 7.3
6432	Y	Sept. 27.....	403.769	22.52	-20.9	2.5	- 0.7
6456	H	Oct. 1.....	407.679	26.43	- 2.0	1.5	+ 9.5
6465	C	Oct. 2.....	408.592	27.34	+ 4.3	1.7	+ 9.3
6475	P	Oct. 3.....	409.760	28.51	- 2.6	2.2	- 6.1

TABLE III.

OTTAWA OBSERVATIONS OF 23 CASSIOPELÆ—*Concluded.*

Plate Number.	Observer*	Date.	Julian Date.	Phase from 2420550.0	Velocity.	Weight.	O-C.
		1914.					
6477	Y	Oct. 4.....	2,420,410.535	29.28	+19.7	1.2	+11.7
6487	Y	Oct. 11.....	417.802	2.80	+4.9	4.0	-3.3
6496	Y	Oct. 13.....	419.557	4.56	+3.4	4.0	-1.2
6514	C	Oct. 21.....	427.694	12.69	+0.4	2.7	+7.4
6522	H-Y	Oct. 22.....	428.746	13.75	-11.1	4.0	-2.5
6556	P	Nov. 14.....	451.716	2.97	+5.2	2.0	-1.7
6569	C	Nov. 23.....	460.570	11.82	-2.2	2.5	+3.6
6580	C	Nov. 27.....	464.583	15.83	-12.1	0.7	-0.6
6586	P	Nov. 28.....	465.691	16.94	-21.4	1.5	-8.1
6588	Y	Nov. 28.....	465.802	17.05	-1.0	0.7	+12.9
6591	C	Dec. 4.....	471.627	22.88	-21.8	1.7	-1.4
6598	H	Dec. 5.....	472.696	23.95	-17.3	3.0	+2.7
6603	Y	Dec. 6.....	473.517	24.77	-18.9	2.0	+0.1
6615	C	Dec. 11.....	478.622	29.87	+11.9	3.7	+1.9
6625	Y	Dec. 15.....	482.549	0.05	+10.6	2.2	0.0
6638	H-Pa	Dec. 16.....	483.726	1.23	+20.3	3.0	+11.1
		1915.					
6677	Pa	Jan. 4.....	502.576	20.08	-25.5	2.0	-7.8
6685	Y	Jan. 5.....	503.556	21.06	-17.5	1.2	+1.4
6698	H	Jan. 9.....	507.429	24.93	-24.7	1.5	-6.1
6699	Y	Jan. 10.....	508.458	25.96	-16.0	2.7	-2.0
6707	Y	Jan. 12.....	510.551	28.05	-3.1	2.5	-3.1
6764	C	Feb. 3.....	532.493	16.24	-5.8	1.5	+6.2
6774	H	Feb. 4.....	533.583	17.33	-7.7	2.0	+5.9
6776	Y	Feb. 9.....	538.538	22.29	-24.2	2.5	-4.1
6781	C	Feb. 12.....	541.548	25.30	-18.0	3.0	-0.8
6785	H	Feb. 17.....	546.495	30.24	+11.2	3.0	+0.2
6796	H	Feb. 18.....	547.525	31.27	+12.5	2.0	+0.4
6805	C	Feb. 19.....	548.509	32.26	+9.8	1.5	-2.2
6810	P	Feb. 20.....	549.522	33.27	+11.6	4.0	+0.1
6812	Y	Feb. 21.....	550.497	0.50	+4.1	3.5	-6.1
6817	Y	Feb. 28.....	557.509	7.51	-3.6	3.5	-3.8
6826	H	Mar. 3.....	560.517	10.52	-9.2	2.0	-5.2
6850	Y	Mar. 9.....	566.519	16.52	-12.8	0.7	+1.7
6854	H	Mar. 11.....	568.517	18.52	-8.9	2.7	+6.6
6859	P	Mar. 13.....	570.524	20.52	-14.8	3.0	+2.4
6862	Y	Mar. 14.....	571.517	21.52	-24.6	3.0	-5.2
6867	H	Mar. 15.....	572.517	22.52	-20.4	2.7	-0.1
6873	H	Mar. 18.....	575.510	25.52	-12.1	1.0	+4.4
6878	Y	Mar. 19.....	576.510	26.51	-10.2	3.0	+1.0

*P=Plaskett. Pa=Parker. C=Cannon. Y=Young. H=Harper. G=Gibson.

MEASURES OF 23 CASSIOPEÆ

λ	6185		6218		6239		6245		6267		6293		6301	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·825	.....		- 33·4	$\frac{1}{2}$	+ 3·1	$\frac{1}{2}$	+ 0·8	$\frac{1}{2}$	- 7·1	$\frac{1}{2}$	- 42·9	$\frac{1}{2}$	.....
4101·890	.....		- 29·7	$\frac{1}{4}$	- 16·7	$\frac{1}{4}$	- 3·7	$\frac{1}{2}$	- 10·2	$\frac{1}{4}$	.....		.....
4128·211	- 19·9	$\frac{1}{4}$	- 27·5	$\frac{1}{4}$	- 17·0	$\frac{1}{4}$	.....	.....	.....	.....	- 36·0	$\frac{1}{4}$	- 36·0	$\frac{1}{2}$
4131·047	- 39·0	$\frac{1}{2}$	- 30·4	$\frac{1}{4}$	- 14·3	$\frac{1}{4}$	+ 1·9	$\frac{1}{4}$	- 2·9	$\frac{1}{4}$	- 54·2	$\frac{1}{4}$	- 42·8	$\frac{1}{2}$
4340·634	- 22·5	1	- 29·3	1	- 11·3	1	- 19·1	$\frac{1}{2}$	- 13·5	$\frac{1}{2}$	- 45·0	$\frac{1}{2}$	- 38·3	$\frac{1}{2}$
4481·400	- 43·6	$\frac{1}{2}$	- 24·9	$\frac{1}{2}$	+ 1·2	$\frac{1}{2}$	- 8·7	$\frac{1}{2}$	+ 13·7	$\frac{1}{2}$	- 42·3	$\frac{1}{2}$	+ 49·9	$\frac{1}{2}$
Weighted mean	- 29·50		- 29·20		- 8·76		- 6·40		- 1·99		- 43·85		- 42·29	
V_a	+ 11·91		+ 12·86		+ 13·82		+ 14·15		+ 14·29		+ 14·83		+ 14·83	
V_d	+ 0·04		+ 0·03		+ 0·02		+ 0·02		+ 0·06		+ 0·06		+ 0·09	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	- 17·8		- 16·6		+ 4·8		+ 7·5		+ 12·1		- 29·2		- 27·6	

MEASURES OF 23 CASSIOPEIÆ—Continued.

λ	6307		6337		6344		6358		6371		6376		6392	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·825	- 27·8	1	- 7·9	$\frac{1}{2}$	- 7·2	$\frac{1}{2}$	- 9·5	$\frac{1}{2}$	- 8·7	$\frac{1}{2}$	- 14·3	$\frac{1}{2}$	- 19·1	$\frac{1}{2}$
4101·890	- 39·0	$\frac{1}{2}$	- 2·0	$\frac{1}{2}$	- 2·8	$\frac{1}{2}$	- 20·4	$\frac{1}{2}$	- 14·8	$\frac{1}{2}$	- 27·8	$\frac{1}{2}$	- 23·2	$\frac{1}{2}$
4128·211	.....	+	3·8	$\frac{1}{2}$	.....	.....	- 24·7	$\frac{1}{2}$	.....	.....	- 21·8	$\frac{1}{2}$	- 15·2	$\frac{1}{2}$
4131·047	- 31·4	$\frac{1}{2}$	.....	.....	.....	.....	- 9·5	$\frac{1}{2}$	- 13·3	$\frac{1}{2}$	- 8·6	$\frac{1}{2}$	- 9·5	$\frac{1}{2}$
4340·634	- 38·3	$\frac{1}{2}$	+ 2·3	1	0·0	$\frac{1}{2}$	- 16·9	$\frac{1}{2}$	- 9·0	$\frac{1}{2}$	- 7·9	$\frac{1}{2}$	- 24·7	$\frac{1}{2}$
4481·400	- 46·1	$\frac{1}{2}$	+ 3·7	1	+ 2·5	$\frac{1}{2}$	- 5·0	$\frac{1}{2}$	.....	.....	- 18·7	$\frac{1}{2}$	- 29·9	$\frac{1}{2}$
Weighted mean	- 34·32		+ 0·61		- 1·87		- 13·04		- 11·17		- 16·78		- 20·70	
V_a	+ 14·82		+ 14·40		+ 14·14		+ 13·88		+ 13·60		+ 13·52		+ 13·28	
V_d	+ 0·08		+ 0·02		+ 0·06		- 0·04		+ 0·01		+ 0·06		+ 0·06	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	- 19·7		+ 14·7		+ 12·0		+ 0·5		+ 2·2		- 3·5		- 7·6	

MEASURES OF 23 CASSIOPELÆ—Continued.

λ	6400		6407		6422		6428		6432		6456		6465	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·825	.....	.....	.....	.....	- 40·5	$\frac{1}{2}$	- 21·5	$\frac{1}{2}$	- 20·7	$\frac{1}{2}$	- 11·1	$\frac{1}{2}$	- 8·8	$\frac{1}{2}$
4101·890	- 13·9	$\frac{1}{2}$	.....	.....	- 28·8	$\frac{1}{2}$	.....	.....	- 29·7	$\frac{1}{2}$	- 15·8	$\frac{1}{2}$	- 7·4	$\frac{1}{2}$
4128·211	.....	.....	- 16·1	$\frac{1}{2}$	- 39·9	$\frac{1}{2}$	- 18·0	$\frac{1}{2}$	.....	.....	.....	.....	- 9·5	$\frac{1}{2}$
4131·047	.....	.....	- 15·2	$\frac{1}{2}$	- 44·7	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340·634	- 11·3	1	- 22·5	$\frac{1}{2}$	- 19·1	$\frac{1}{2}$	- 31·5	$\frac{1}{2}$	- 35·0	1	- 12·3	$\frac{1}{2}$	- 2·2	$\frac{1}{2}$
4481·400	.....	.....	- 16·2	$\frac{1}{2}$	- 21·1	$\frac{1}{2}$	- 5·0	$\frac{1}{2}$	- 42·4	$\frac{1}{2}$	.....	.....	.....	.....
Weighted mean	- 12·17		- 18·50		- 28·24		- 23·00		- 32·56		- 13·06		- 6·61	
V_a	+ 13·18		+ 13·05		+ 12·69		+ 12·26		+ 11·96		+ 11·34		+ 11·19	
V_d	+ 0·04		+ 0·02		+ 0·07		+ 0·04		- 0·02		+ 0·02		+ 0·02	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	+ 0·8		- 5·7		- 15·8		- 11·0		- 20·9		- 2·0		+ 4·3	

MEASURES OF 23 CASSIOPELÆ—Continued.

λ	6475		6477		6487		6496		6514		6522		6556	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.825	- 17.5	$\frac{1}{2}$	.....	.....	- 9.5	1	- 5.6	1	.....	.....	- 13.1	1	.....	.....
4101.890	- 15.8	$\frac{1}{2}$	.....	.....	- 9.3	1	+ 2.8	$\frac{1}{2}$	- 13.9	$\frac{1}{2}$	- 19.5	$\frac{1}{2}$	.....	.....
4128.211	.....	.....	+ 18.0	$\frac{1}{2}$	+ 0.9	1	- 13.3	$\frac{1}{2}$	- 19.9	$\frac{1}{2}$	- 8.5	$\frac{1}{2}$	- 0.9	$\frac{1}{2}$
4131.047	- 13.3	$\frac{1}{2}$	.....	.....	.....	.....	- 7.6	$\frac{1}{2}$	- 1.9	$\frac{1}{2}$	- 30.4	$\frac{1}{2}$	+ 9.6	$\frac{1}{2}$
4340.634	- 5.6	$\frac{1}{2}$	+ 11.3	$\frac{1}{2}$	- 3.4	1	- 2.5	1	- 4.9	$\frac{1}{2}$	- 11.3	1	+ 13.9	$\frac{1}{2}$
4481.400	- 13.7	$\frac{1}{2}$	+ 2.5	$\frac{1}{2}$	0.0	1	- 8.7	$\frac{1}{2}$	- 4.2	$\frac{1}{2}$	- 36.2	$\frac{1}{2}$	0.0	$\frac{1}{2}$
4549.766	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 5.2	$\frac{1}{2}$
Weighted mean	- 13.28		+ 9.10		- 4.26		- 5.50		- 6.71		- 17.95		+ 3.27	
V_a	+ 10.99		+ 10.85		+ 9.50		+ 9.15		+ 7.41		+ 7.16		+ 2.33	
V_d	- 0.03		0.0		- 0.07		+ 0.07		+ 0.02		- 0.03		- 0.09	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 2.6		+ 19.7		+ 4.9		+ 3.4		+ 0.4		- 11.1		+ 5.2	

MEASURES OF 23 CASSIOPELÆ—Continued.

λ	6569		6580		6586		6588		6591		6598		6603	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.825	+ 4.0	$\frac{1}{2}$	0.0	$\frac{1}{2}$	- 17.6	1	- 3.2	$\frac{1}{2}$	- 18.4	$\frac{1}{2}$	- 10.4	1	- 17.6	$\frac{1}{2}$
4101.890	+ 3.7	$\frac{1}{2}$	.....	.....	- 25.1	$\frac{1}{2}$	- 6.5	$\frac{1}{2}$	- 10.2	$\frac{1}{2}$	- 31.6	$\frac{1}{2}$	- 19.6	$\frac{1}{2}$
4128.211	0.0	$\frac{1}{2}$	.....	.....	- 18.1	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4131.047	+ 6.7	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 18.2	$\frac{1}{2}$
4340.634	- 19.0	$\frac{1}{2}$	- 14.7	$\frac{1}{2}$	.....	.....	+ 13.6	$\frac{1}{2}$	- 21.5	$\frac{1}{2}$	- 24.8	$\frac{1}{2}$	- 14.7	$\frac{1}{2}$
4481.400	0.0	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 23.8	$\frac{1}{2}$	+ 6.2	$\frac{1}{2}$	- 3.8	$\frac{1}{2}$
4549.766	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 6.6	$\frac{1}{2}$	.....	.....
Weighted mean	- 0.92		- 9.80		- 18.90		+ 1.4		- 17.72		- 12.93		- 14.35	
V_a	- 0.96		- 2.00		- 2.20		- 2.23		- 3.75		- 4.03		- 4.25	
V_d	0.00		- 0.01		+ 0.01		+ 0.01		- 0.03		- 0.09		+ 0.02	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 2.2		- 12.1		- 21.4		- 1.0		- 21.8		- 17.3		- 18.9	

MEASURES OF 23 CASSIOPEIÆ—Continued.

λ	6615		6625		6638		6677		6685		6698		6699	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933.825	+ 12.0	1	+ 8.8	$\frac{1}{4}$	+ 34.4	$\frac{1}{2}$	- 6.4	$\frac{1}{2}$	+ 4.0	$\frac{1}{2}$	.....	.....	- 2.4	1
4101.890	+ 19.6	$\frac{1}{2}$	.....	.....	+ 27.9	$\frac{1}{2}$	- 18.7	$\frac{1}{4}$	.....	.....	.....	.....	- 3.7	$\frac{1}{4}$
4128.211	+ 36.1	$\frac{1}{4}$	+ 22.4	$\frac{1}{4}$	+ 27.7	$\frac{1}{2}$	- 21.0	$\frac{1}{2}$	- 8.7	$\frac{1}{4}$	- 29.5	$\frac{1}{4}$	- 4.8	$\frac{1}{4}$
4131.047	+ 15.3	$\frac{1}{2}$	+ 15.3	$\frac{1}{4}$	+ 18.2	$\frac{1}{2}$	- 6.7	$\frac{1}{4}$	- 7.7	$\frac{1}{4}$	- 17.2	$\frac{1}{4}$	- 3.8	$\frac{1}{4}$
4340.634	+ 29.4	$\frac{1}{2}$	+ 14.3	$\frac{1}{2}$	+ 28.2	1	- 17.0	$\frac{1}{2}$	- 12.4	$\frac{1}{4}$	- 7.9	$\frac{1}{2}$	- 13.5	$\frac{1}{2}$
4481.400	+ 13.8	$\frac{1}{2}$	+ 20.4	1	.....	.....	.....	.....	- 6.0	$\frac{1}{4}$	- 6.9	$\frac{1}{2}$	+ 3.7	$\frac{1}{2}$
4549.766	+ 13.1	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 17.76		+ 17.42		+ 27.43		- 14.30		- 6.16		- 12.70		- 3.78	
V_a	- 5.53		- 6.49		- 6.74		- 10.83		- 11.02		- 11.70		- 11.88	
V_d	- 0.06		- 0.03		- 0.08		- 0.09		- 0.05		0.00		- 0.01	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	+ 11.9		+ 10.6		+ 20.3		- 25.5		- 17.5		- 24.7		- 16.0	

MEASURES OF 23 CASSIOPEIÆ—Continued.

λ	6707		6764		6774		6776		6781		6785		6796	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933-825	+ 5.6	$\frac{1}{2}$	+ 4.8	$\frac{1}{2}$	- 0.8	1	- 4.0	$\frac{1}{2}$	- 1.6	1	+ 27.2	1	+ 22.4	1
4101-890	.....	.....	+ 16.0	$\frac{1}{2}$	.....	.....	- 5.6	$\frac{1}{2}$	+ 2.8	$\frac{1}{2}$	+ 30.8	$\frac{1}{2}$	+ 19.6	$\frac{1}{2}$
4128-211	+ 13.3	$\frac{1}{2}$	.....	.....	+ 15.3	$\frac{1}{2}$	- 2.9	$\frac{1}{2}$	+ 5.7	$\frac{1}{2}$	+ 21.9	$\frac{1}{2}$	.....	.....
4131-047	+ 11.5	$\frac{1}{2}$	.....	.....	.....	.....	- 9.6	$\frac{1}{2}$	0.0	$\frac{1}{2}$	+ 19.1	$\frac{1}{2}$	.....	.....
4340-634	+ 11.3	$\frac{1}{2}$	+ 6.8	$\frac{1}{2}$	+ 15.8	$\frac{1}{2}$	- 13.6	$\frac{1}{2}$	- 10.2	1	+ 27.1	1	+ 47.5	$\frac{1}{2}$
4481-400	+ 5.0	$\frac{1}{2}$	.....	.....	.....	.....	- 15.0	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
Weighted mean	+ 9.34		+ 9.20		+ 7.37		- 8.88		- 2.53		+ 26.67		+ 28.00	
V_a	- 12.22		- 14.70		- 14.77		- 15.01		- 15.10		- 15.16		- 15.15	
V_d	- 0.07		- 0.07		.....		- 0.08		- 0.08		- 0.07		- 0.07	
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		- 0.28	
Radial Velocity	- 3.1		- 5.8		- 7.7		- 24.2		- 18.0		+ 11.2		+ 12.5	

MEASURES OF 23 CASSIOPELÆ—Continued.

λ	6805		6810		6812		6817		6826		6850		6854	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
3933·825	.....	.....	+ 27·2	1	+ 26·4	1	+ 12·0	$\frac{1}{2}$	+ 4·8	1	.....	.....	- 1·6	1
4101·890	+ 29·9	$\frac{1}{2}$	+ 29·8	$\frac{1}{2}$	+ 22·4	$\frac{1}{2}$	+ 17·7	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4128·211	.....	.....	+ 14·3	$\frac{1}{2}$	+ 37·2	$\frac{1}{2}$	- 2·8	$\frac{1}{2}$	.....	.....	.....	.....	- 0·9	$\frac{1}{2}$
4131·047	+ 38·2	$\frac{1}{2}$	+ 33·5	$\frac{1}{2}$	.....	.....	+ 16·3	$\frac{1}{2}$	.....	.....	.....	.....	+ 19·1	$\frac{1}{2}$
4340·634	.....	.....	+ 9·0	$\frac{1}{2}$	+ 7·9	$\frac{1}{2}$	+ 15·8	$\frac{1}{2}$	+ 10·2	$\frac{1}{2}$	+ 7·9	$\frac{1}{2}$	+ 6·2	1
4481·400	+ 7·9	$\frac{1}{2}$	+ 31·3	$\frac{1}{2}$	+ 16·3	$\frac{1}{2}$	+ 8·1	$\frac{1}{2}$	+ 3·7	$\frac{1}{2}$	.....	.....	+ 16·2	$\frac{1}{2}$
4549·766	.....	.....	+ 26·2	$\frac{1}{2}$	0·0	$\frac{1}{2}$	+ 14·4	$\frac{1}{2}$	.....	.....	- 10·4	$\frac{1}{2}$	.....	.....
Weighted mean	+ 25·33		+ 27·06		+ 19·54		+ 11·64		+ 5·87		+ 2·13		+ 6·00	
V _a	- 15·15		- 15·15		- 15·12		- 14·88		- 14·71		- 14·58		- 14·55	
V _d	- 0·07		- 0·07		- 0·06		- 0·08		- 0·08		- 0·08		- 0·08	
Curv.	- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28		- 0·28	
Radial Velocity	+ 9·8		+ 11·6		+ 4·1		- 3·6		- 9·2		- 12·8		- 8·9	

MEASURES OF 23 CASSIOPELÆ—*Concluded.*

λ	6859		6862		6867		6873		6878		Vel.	Wt.	Vel.	Wt.
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.				
3933.825	- 1.6	1	- 11.2	1	- 6.4	1	.....	.....	- 1.6	1	.....	.....	.....	.....
4101.890	- 4.7	$\frac{1}{2}$	- 12.1	$\frac{1}{2}$	- 6.5	$\frac{1}{2}$	.....	.....	+ 3.7	$\frac{1}{2}$	.....	.....	.....	.....
4128.211	+ 2.9	$\frac{1}{2}$	- 10.5	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4131.047	- 15.3	$\frac{1}{2}$	- 2.9	$\frac{1}{2}$	- 7.6	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340.634	- 5.7	$\frac{1}{2}$	- 17.0	$\frac{1}{2}$	- 6.2	1	+ 1.5	1	+ 8.4	1	.....	.....	.....	.....
4481.400	+ 16.3	$\frac{1}{2}$	- 5.0	$\frac{1}{2}$	.....	.....	.....	.....	+ 2.5	$\frac{1}{2}$	.....	.....	.....	.....
Weighted mean	- 0.60		- 10.52		- 6.46		+ 1.50		+ 3.30		.....	.....	.....	.....
V_s	- 13.85		- 13.73		- 13.63		- 13.28		- 13.14		.....	.....	.....	.....
V_d	- 0.08		- 0.08		- 0.08		- 0.08		- 0.08		.....	.....	.....	.....
Curv.	- 0.28		- 0.28		- 0.28		- 0.28		- 0.28		.....	.....	.....	.....
Radial Velocity	- 14.8		- 24.6		- 20.4		- 12.1		- 10.2		.....	.....	.....	.....

A period was determined from the Ottawa series of spectrograms and then adjusted from five plates taken from the Mt. Wilson observatory (Table II). The time covered by the observations is about forty periods. The final period adopted was 33.75 days. With this element fixed, the sixty-one velocities were grouped into thirteen normal places and approximate elements derived.

$$T = \text{Julian Day } 2,420,577.34$$

$$K = 17.0 \text{ km.}$$

$$\omega = 270^\circ$$

$$e = 0.40$$

$$\gamma = -4.08$$

$$P = 33.75 \text{ days.}$$

NORMAL PLACES.

	Julian Day.	Phase.	Velocity.	Weight.	O-C Preliminary.	O-C Final.
1	2,420,550.77	7.18	+10.3	1.1	- 0.1	+ 0.4
2	553.40	9.81	+ 6.0	1.3	- 0.5	- 0.2
3	557.85	14.26	- 1.1	0.7	- 0.9	- 0.9
4	561.26	17.67	- 5.3	0.9	0.0	- 0.3
5	563.58	19.99	- 5.2	1.0	+ 3.5	+ 3.1
6	566.54	22.95	-12.9	1.2	+ 0.3	- 0.3
7	569.77	26.18	-17.2	1.1	+ 0.8	0.0
8	572.13	28.54	-21.8	1.8	- 1.1	- 1.9
9	574.20	30.61	-19.6	0.9	+ 0.7	+ 0.3
10	575.94	32.35	-12.8	1.1	+ 1.5	+ 1.6
11	578.30	0.96	+ 2.3	0.8	- 1.0	- 0.2
12	580.61	3.27	+10.2	1.1	- 2.1	- 1.4
13	582.93	5.59	+12.4	0.9	+ 0.2	+ 0.8

OBSERVATION EQUATIONS.

	<i>x</i>	<i>y</i>	<i>z</i>	<i>p</i>	<i>q</i>	- <i>n</i>	Weight.
1.....	1	+ 0.851	+ 0.954	- 0.126	+ 0.328	+ 0.10	1.1
2.....	1	+ 0.624	+ 0.979	- 0.381	+ 0.369	+ 0.50	1.3
3.....	1	+ 0.229	+ 0.428	- 0.574	+ 0.362	+ 0.90	0.7
4.....	1	- 0.069	- 0.132	- 0.598	+ 0.360	0.00	0.9
5.....	1	- 0.272	- 0.504	- 0.562	+ 0.364	- 3.50	1.0
6.....	1	- 0.535	- 0.895	- 0.445	+ 0.370	- 0.30	1.2
7.....	1	- 0.819	- 0.991	- 0.174	+ 0.340	- 0.80	1.1
8.....	1	- 0.978	+ 0.509	+ 0.610	- 0.247	+ 1.10	1.8
9.....	1	- 0.955	+ 0.713	+ 0.696	- 0.370	- 0.70	0.9
10.....	1	- 0.602	+ 1.328	+ 1.199	- 1.392	- 1.50	1.1
11.....	1	+ 0.432	- 1.096	+ 1.302	- 1.670	+ 1.00	0.8
12.....	1	+ 0.965	- 0.631	- 0.661	- 0.318	+ 2.10	1.1
13.....	1	+ 0.960	+ 0.607	+ 0.119	+ 0.222	- 0.20	0.9

where

$$x = d\gamma$$

$$y = dK$$

$$z = Kde$$

$$p = Kd\omega$$

$$q = \frac{K\mu}{(1-e^2)^{\frac{3}{2}}} dT$$

NORMAL EQUATIONS.

$$\begin{aligned}
 13.900x - 0.981y + 1.828z + 0.604p - 1.197q - 0.720 &= 0 \\
 + 7.442y + 0.454z - 2.501p + 0.951q + 4.569 &= 0 \\
 + 9.278z + 2.373p - 0.760q - 0.113 &= 0 \\
 + 5.890p - 4.861q - 0.047 &= 0 \\
 + 5.668q - 1.276 &= 0
 \end{aligned}$$

whence, $d\gamma = +0.02$ km.
 $dK = -0.68$ km.
 $de = +0.005$
 $d\omega = -0^\circ.29$
 $dT = +0.07$ day.

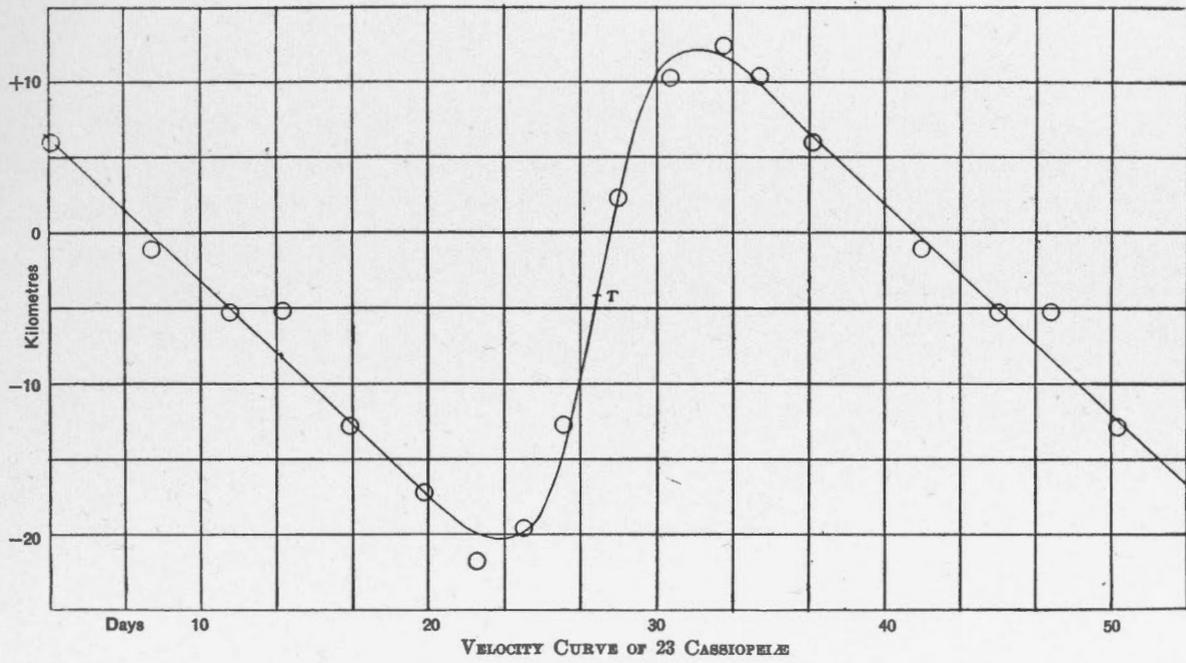
The above corrections lowered Σpv^2 from 24.7 to 22.7. While this is not a very great reduction, the fact that about two-fifths of this quantity arises from the residual 3.5 km. and also considering the fact that residuals computed from the observation equation and ephemeris agree to within 0.2 km., a second least-squares solution would not improve the orbit to a very great extent, if at all.

The final elements are:—

$$\begin{aligned}
 T &= \text{Julian Day } 2,420,577.41 \pm 0.27 \\
 K &= 16.32 \text{ km. } \pm 0.50 \\
 \omega &= 269^\circ.71 \pm 4^\circ.10 \\
 e &= 0.405 \pm 0.026 \\
 \gamma &= -4.06 \pm 0.34 \\
 P &= 33.75 \\
 a \sin i &= 7,020,000 \text{ km.} \\
 \frac{m_1^3 \sin^3 i}{(m+m_1)^2} &= 0.0121 \odot
 \end{aligned}$$

The individual observations were represented graphically, and the residuals are shown in Tables II and III. The probable error of a single plate as computed from the formula $r = 0.6745 \sqrt{\frac{\Sigma pv^2}{n-1} \cdot \frac{n}{\Sigma p}}$ is 3.4 kilometres.

Dominion Observatory,
 Ottawa,
 April, 1915.



DEPARTMENT OF THE INTERIOR

CANADA

HON. W. J. ROCHE, *Minister.*

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F. A. McDIARMID, B.A.

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GRAVITY.

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GRAVITY.

BY F. A. McDIARMID, B.A.

INTRODUCTION.

Canada is largely a new field for gravity observations; of the immense country from the Atlantic to the Pacific, and from the southern boundary to the Arctic ocean, there have been gravity determinations made at only four points. Dr. Otto Klotz, under whose supervision the work is at present carried on, made observations at Ottawa, Toronto and Montreal in 1902; and Professor L. B. Stewart observed at Northwest River, Labrador, in 1905. Reasons for the prosecution of a gravity campaign covering the whole country will be given later in this report, and also a comparison of the results obtained for Ottawa by Dr. Klotz with those obtained last season will be shown.

The following report of the gravity observations made at eighteen stations during the past season is considered under the following heads:—

- Position and description of stations.
- Instruments and apparatus.
- Use of apparatus.
- Method of observation.
- Determination of coefficients.
- Rating of chronometers.
- Reduction of observations.
- Changes in lengths of pendulums.
- Periods of pendulums.
- Deduction of absolute gravity.
- Computation of the intensity of gravity at any selected station.
- Corrections for elevation, topography, and isostatic compensation.
- Reasons for the prosecution of pendulum work.
- Conclusion.

POSITION AND DESCRIPTION OF STATIONS.

The gravity stations occupied during the summer of 1914 are in the provinces of Ontario and Quebec; in Ontario—Ottawa, Kingston, Mattawa, Liskeard, Cochrane, Sault Ste. Marie, Chapleau, Port Arthur, Rose Point, Whitby, Woodstock and Windsor; in Quebec—Maniwaki, Roberval, Tadoussac, Portneuf, St. Jérôme and Ste. Anne-de-Bellevue.

For the purpose of standardizing the pendulums, observations were made at Washington. The pendulum pier in the basement of the Coast and Geodetic Survey building is the base of all the gravity observations in the United States. The observed value of gravity at Washington (C. & G. S.) is 980.112 dynes. This value depends upon the absolute determination of the value of gravity at Potsdam, Germany, and upon the relative values at Potsdam and Washington, as determined by Mr. G. R. Putman in 1900.

Ottawa will be used as the base for all the Canadian work, and as the gravity at Ottawa has been determined differentially from Washington, all the gravity determinations on the North American continent will depend on the value at Washington, and as Washington was determined from Europe, there is a common base for all gravity results.

Early in March of the year 1914, the writer was directed to proceed to Washington with the pendulum outfit. The apparatus had not been used for a number of years, and needed a complete overhauling. The pendulums were constructed some years ago under the supervision of Mr. E. G. Fischer, Chief of the Instrument Division of the Coast and Geodetic Survey; and Mr. Fischer very kindly placed the whole outfit in good order. The writer, here, wishes to express his gratitude to Mr. Tittmann, Superintendent of the Coast and Geodetic Survey, for giving every facility for the furtherance of the work. Mr. William Bowie, Chief of the Computing Division and Inspector of Geodetic Work, gave much valuable information concerning gravity observations, and also on other lines of geodetic work. In the observing, Mr. C. H. Swick of the Computing Division assisted; Mr. Swick has had considerable field experience, and was most painstaking in giving every aid possible.

After determining the periods of the three pendulums 1, 2 and 3 in Washington the instruments were shipped to Ottawa, and the periods determined. The trip Ottawa to Washington to Ottawa was repeated, and second sets of observations were made both at Washington and Ottawa. These four sets, two at Washington and two at Ottawa, give two independent determinations of the gravity at Ottawa, and establish Ottawa as a base point for all Canadian work.

The pendulum stations established during the summer of 1914 were all located near astronomical stations, and are described as follows:—

Ottawa.—The pendulum pier was in the southwest corner of the basement of the Dominion Observatory.

Maniwaki.—The pendulum pier was in the cellar of the Larentier hotel, 4 feet below the level of the rail in front of the C.P.R. station, and 120 feet due west of the astronomical station (1906), distance to astronomical station measured.

Kingston.—The pendulum pier was in the furnace room of the city hall, 10 feet below the G.S.C. bench-mark in the Kingston post office, and 2700 feet west and 950 feet south of the astronomical station (1905) on the Royal Military College grounds, distance to astronomical station scaled from map of the city of Kingston.

Roberval.—The pendulum pier was in the cellar of Mr. Legault's residence, 2 feet below the level of the rail in front of the Quebec and Lake St. John railway station, and 935 feet south and 570 feet east of the astronomical station (1907), distance to astronomical station measured.

Tadoussac.—The pendulum pier was in the cellar of the Tadoussac hotel, 40 feet above mean tide water, and 190 feet south and 60 feet west of the astronomical station (1905), distance to astronomical station measured.

Portneuf.—The pendulum pier was in the foundry near the C.P.R. station, the same elevation as the rail in front of the station, and 135 feet south and 570 feet west of astronomical station (1903), distance to astronomical station measured.

St. Jérôme.—The pendulum pier was in the cellar of the Chateau Larose, 7 feet below the level of the rail in front of the C.P.R. station, and 42 feet north and 472 feet west of astronomical station (1908), distance to astronomical station measured.

Ste. Anne-de-Bellevue.—The pendulum pier was in the basement of the Physics building, Macdonald college, 10 feet below the level of the rail in front of the G.T.R. station, and 1949 feet east and 122 feet north of the astronomical station (1905), distance to astronomical station scaled from map of the town of Ste. Anne-de-Bellevue.

Mattawa.—The pendulum pier was in the cellar of the Victoria hotel, 10 feet below the level of rail in front of the C. P. R. station, and 210 feet north and 300 feet east of astronomical station (1907), distance to astronomical station measured.

Liskeard.—The pendulum pier was in the basement of the public library, 7 feet below the level of rail in front of the T. & N. O. railway station, and 4090 feet east of astronomical station (1906), distance to astronomical station scaled from plan of Liskeard.

Cochrane.—The pendulum pier was in the cellar of the King George hotel, on level with rail in front of the T. & N. O. railway station, and 1700 feet east and 20 feet north of astronomical station (1909), distance to the astronomical station scaled from map of the town of Cochrane.

Sault Ste. Marie.—The pendulum pier was in the furnace room of the city hall, 22 feet below the level of rail in front of the C. P. R. station, and 508 feet south and 700 feet east of astronomical station (1910), distance to astronomical station scaled from map of the town of Sault Ste. Marie.

Chapleau.—The pendulum pier was in the cellar of V. J. Perpeté's store near the C. P. R. station, 6 feet below the level of the rail in front of the C. P. R. station, and 860 feet east and 510 feet south of astronomical station (1907), distance to astronomical station scaled from map of town of Chapleau.

Port Arthur.—The pendulum pier was in the cellar under the Masonic building, Arthur street, 12 feet above the level of the rail in front of the C. P. R. station, and 1148 feet west and 546 feet north of astronomical station (1887), distance to astronomical station scaled from map of the city of Port Arthur.

Rose Point.—The pendulum pier was in the cellar of the Rose Point hotel, 2 feet below the level of rail in front of the G. T. R. station, 150 feet west and

100 feet north of astronomical station (1900), distance to astronomical station measured.

Whitby.—The pendulum pier was in the cellar of E. R. Blow's store, 8 feet above the level of rail in front of G. T. R. station, 50 feet south and 300 feet west of astronomical station (1905), distance to astronomical station measured.

Woodstock.—The pendulum pier was in the basement of the market building, 10 feet below the G. S. C. bench-mark in the Woodstock post office, 3800 feet west and 2500 feet north of the astronomical station (1903), distance to astronomical station scaled from map of the city of Woodstock.

Windsor.—The pendulum pier was in the cellar under the C. P. R. telegraph office, 14 feet below the G. S. C. bench-mark in the Windsor post office, 780 feet north and 1490 feet east of the astronomical station (1910), distance to astronomical station scaled from map of the city of Windsor.

These stations were previously occupied for longitude and latitude, so their geographical positions are accurately known. The figures for elevation were obtained from the best information available. Whenever possible the bench-marks of the Geodetic Survey of Canada were tied to, and for all other stations the figures for altitude as given by White's "Altitudes in Canada" were used.

In the following table are given brief descriptions of the pendulum piers, the longitude, the latitude, and the altitude of each station. At every station with the exception of Portneuf a dry cellar with a good concrete floor was found, and a pier constructed by cementing three cubical stones of equal height to the concrete floor with plaster of Paris. The pendulum case (receiver) was then placed on the pier. This method of mounting proved very satisfactory. At Portneuf a concrete floor in a foundry was used as the observing station, and on account of the frequent changes of temperature it was necessary to take thermometer readings every few hours. With the exception of Portneuf, at no station was there a larger range of temperature than three degrees Centigrade during the two days of observing.

Station.	Longitude.			Latitude.			Altitude.	Description of Station.
	h.	m.	s.	°	'	"			metres.
Washington.....	5	08	00	38	53	13	.....	Pendulum pier in basement of C. & G. S. building.
Ottawa.....	5	02	52	45	23	39	83	Pendulum room in basement of Dominion Observatory.
Maniwaki.....	5	03	55	46	22	28	169	Concrete floor in cellar of Larentier hotel.
Kingston.....	5	05	52	44	13	37	79	Concrete floor in furnace room of city hall.
Roberval.....	4	48	54	48	30	54	107	Concrete floor in cellar of residence of Mr. Legault.
Tadoussac.....	4	38	52	48	08	25	12	Concrete wall around furnace in cellar of Tadoussac hotel.
Portneuf.....	4	47	35	46	42	32	59	Concrete floor in foundry near C.P.R. station.
St. Jérôme.....	4	52	28	45	46	34	107	Concrete floor in basement of Chateau Larose.
Ste. Anne-de-Bellevue...	4	55	48	45	24	27	34	Concrete floor in basement of Physics building, Macdonald College.
Mattawa.....	5	14	47	46	18	43	170	Concrete floor in basement of Victoria hotel.
Liskeard.....	5	18	50	47	30	34	194	Concrete floor in basement of public library.
Cochrane.....	5	24	05	49	03	44	277	Concrete floor in basement of King George hotel.
Sault Ste. Marie.....	5	37	18	46	30	26	186	Concrete floor in basement of city hall.
Chapleau.....	5	33	36	47	50	27	430	Concrete floor in cellar of V. J. Perpeté's store.
Port Arthur.....	5	56	52	48	26	08	189	Concrete floor in basement of Masonic building.
Rose Point.....	5	20	10	45	19	02	183	Concrete floor in basement of Rose Point hotel.
Whitby.....	5	15	46	43	52	43	84	Concrete floor in cellar of E. R. Blow's store.
Woodstock.....	5	23	07	43	08	33	288	Concrete floor in basement of market building.
Windsor.....	5	32	10	42	19	06	178	Concrete floor in basement of C.P.R. telegraph office.

INSTRUMENTS AND APPARATUS.

The outfit used in all the work consisted of half-seconds pendulums 1, 2 and 3 with the accompanying air-tight receiver, flash apparatus, wherein an electro-magnet in the circuit of a chronometer moves a shutter and throws a flash of light every two seconds, a telescope for observing, mounted above the flash apparatus, dummy or temperature pendulum, sidereal break-circuit chronometers Bond 519 and Dent 52866, thermometers, air pump, dry cells, chronograph, switchboard and flash lamp. When necessary to determine time by star observations a transit telescope must be added, but this year time signals were sent from the standard sidereal clocks at the Dominion Observatory, and a transit was not needed.

The receiver and pendulums are described in the "Report of the Chief Astronomer, 1905, Appendix 2"; the flash apparatus is also described in that report, but in order to explain the mechanism of the shutter the whole flash apparatus will be briefly described.

*Flash apparatus**.—The flash apparatus consists of a light metal box, mounted on a brass stand having both vertical and azimuthal movements and clamps, and carries with it an ordinary observing telescope, *e*, which may be focussed for objects within a few feet. The object of the flash apparatus is to observe coincidences between the swinging pendulum and the chronometer used for determining the period or time of an oscillation of the pendulum, which in turn depends upon the time determination made by means of the chronometer, *i.e.*, the time determination made by observing transits of stars with the chronometer as a scale with which to measure the period of the pendulum. This box contains an electro-magnet, whose coils are connected with the chronometer circuit, and whose armature carries an arm which moves two shutters, and by an ingenious device a flash of light is emitted from the box when the circuit is broken, but not when it is closed.

The apparatus is shown in the accompanying diagram (Fig. 1), and with one side of the box removed. This box contains an electro-magnet, *a*, whose coils are connected to the chronometer circuit through the binding posts, *f*, projecting through an opening in the end of the box. This arm carries two shutters, *t* and *v*, by means of which a flash of light is emitted from the box when the circuit is opened, but not when closed. In the front of the box are placed two pieces of metal, *z*, leaving a narrow horizontal slit between them, and behind them move the two shutters, *t* and *v*. The arm, *d*, passes through the upper end of these two shutters; *t* has no play on the arm, but moves directly with it; the opening in *v*, however, is somewhat longer than the thickness of the arm, so that it does not move until the arm is near the middle of its stroke. A stop prevents the slit in *v* from descending below that in *z*, and a friction spring, *h*, holds *v* so that it moves only with the arm. When the circuit is closed the arm, *d*, is down and the slit, *t*, is below the line of slits, *v* and *z*. As soon as the circuit is broken the spring, *h*, causes the arm to rise and the slit, *t*, passes the line of slits, *v* and *z*, emitting a flash of light. Before the end of the stroke, the arm also lifts the shutter, *v*, so that its slit is no longer in line with the slit in *z*. When the circuit is again closed the arm, *d*, is pulled down, but the slit in *t* is opposite that in *v* when *v* just commences to move, so that the three slits are not in line, and no flash

* United States C. & G. S. Report, 1891, Appendix 15.

is emitted. It is thus seen that the three slits are only in line immediately after the breaking of the circuit. A small oil lamp attached to one side of the box furnishes the light for the flash, the light being concentrated by a lens on the slit after being reflected by a mirror in the interior of the box set at an angle of 45° . The tension on the friction spring must not be changed during a set of pendulum readings, otherwise the slits would not have the same relative motion to one another.

When the pendulum is swinging, the image as reflected from the pendulum mirror will change its position relatively to that of the fixed mirror as seen in the field of the telescope, because of the fact that the pendulum makes a double oscillation in a little more than a sidereal second, and will be found a little behind its former position at the end of each break when the flash is thrown. The moving image will, therefore, appear to travel up and down the field of the telescope by successive jumps, wholly disappearing from the field to return again with apparent retrograde motion. Coincidences are observed by noting the time when the two images are in the same horizontal line. It is evident that in the interval between two occurrences of this phenomenon, the pendulum has made one less than twice as many oscillations as the chronometer has beat seconds, and that in the mean interval of time between the first and last of a number of coincidences, the number of oscillations of the pendulum will be twice the number of seconds (s) less the number of coincidence intervals (n), so that the time of a single oscillation is readily derived from the relation $P = \frac{s}{2s-n}$. The beauty of the coincidence method lies in the fact that a small error in noting the time of a coincidence has little effect on P .

Chronometers.—Two chronometers are used in the observation of coincidences. One serves as a check on the other, and seldom does the period of an oscillation, as determined from the two, differ by more than one or two in the seventh decimal place of the period of the pendulum. The chronometers used during the season of 1914 are Bond No. 519 and Dent No. 52866. During a part of the observations at Ottawa the Negus chronometer No. 2088 was also used.

Thermometers.—The thermometers in the pendulum outfit are Green Nos. 116, 118 and 121. No. 118 was used at Washington, Ottawa, Maniwaki and

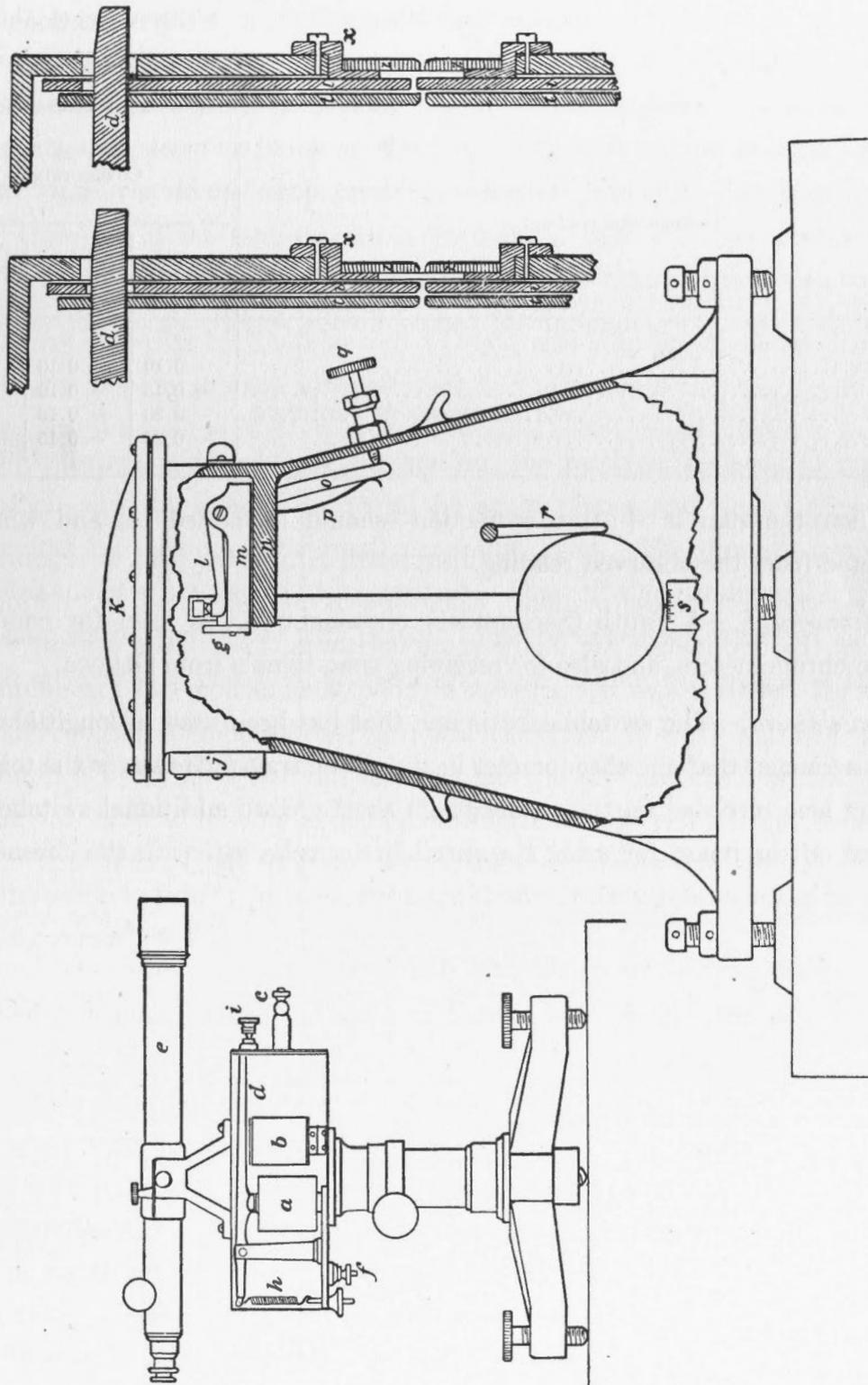


FIG. 1.—SIDE ELEVATION OF RECEIVER AND FLASH APPARATUS AND SECTION THROUGH SHUTTERS.

Kingston, and No. 121 at all the other stations. The thermometers were standardized at the Bureau of Standards in Washington, and the corrections are in the following table:—

Thermometer reading.	CORRECTION.		
	No. 116.	No. 118.	No. 121.
0° C.....	— 0.10	— 0.10	— 0.10
10 C.....	— 0.15	— 0.10	— 0.00
20 C.....	— 0.20	— 0.15	— 0.05
30 C.....	— 0.25	— 0.15	— 0.05

When the sign is + the correction should be added to, and when — subtracted from the observed reading.

Chronograph.—A Fauth (Saegmüller) chronograph was used for comparing the two chronometers, and also for receiving time signals from Ottawa.

Switchboard.—The switchboard is one that has been used in longitude work. It is so arranged that the chronometer beats can be transmitted over the telegraph line, and also recorded on the chronograph sheet. Two additional switches were mounted on the board for using the chronometer relay either in the chronograph circuit, or in the circuit with the flash apparatus.

USE OF APPARATUS.

Very little preparation was needed at a station before mounting the instrument. A cellar with a concrete floor was generally easily found, and as stated above, three cubical stones of equal thickness were secured, and made fast to the floor with plaster of Paris. The stones were needed to raise the receiver to a sufficient height to enable the flash apparatus to be mounted in a position suitable for observing. In some places the floor was so constructed that the receiver could be mounted on the floor directly. The different boxes in which the outfit was packed were used as tables, etc. The chronometers were always kept in their padded carrying boxes, so as to preserve as nearly as possible the same temperature. As pointed out above, the change of temperature rarely

exceeded two degrees Centigrade during the two days spent at a station. Before commencing observations, the pendulum case and the pendulum should be mounted in the observing room for several hours, in order that the pendulum and case will both be at the temperature of the room. If the temperature of the room is constant, thermometer readings at the beginning and end of a swing will be sufficient; and even if the temperature is changing gradually, two readings will suffice. However, if the temperature is fluctuating, then the thermometer must be read frequently. In order to keep the temperature constant it is well to close all windows and doors. Black cotton is used for darkening windows and cutting off extraneous light.

METHOD OF OBSERVATION.

After selecting and preparing the station, the receiver is placed in position and levelled, and the relation between the agate planes and the exterior level is determined by means of the small pendulum level. The dummy pendulum and the manometer are then put in position. One of the pendulums is placed in the chamber on the lifter, that it may come to the temperature of the air. The flash apparatus is placed in position and after finding the images of the slit on the mirrors, the stationary mirror is adjusted so as to make the two images lie in the same straight line and slightly overlap. The surfaces of the top of the receiver and the cap having been thoroughly cleaned, a little lard or soft tallow is rubbed evenly over them, and the cap is placed in position. By moving the cap from side to side under considerable pressure from the hands, good contact is generally secured without difficulty.

The air-pump is then attached and the air exhausted to about 50 millimetres. After exhausting the chamber some time should elapse before commencing observations, in order to insure that the pendulum reaches the temperature of the receiver.

After having obtained the errors of the sidereal chronometers, either by comparison with some standard clock or from star observations, the pendulum is gently lowered to the knife-edge, and set swinging with an arc of about 5 millimetres amplitude. The pendulum must always be placed in the same position on the knife-edge. Of the two knife-edges Nos. I and II, only No. I was used.

The pendulum having been set swinging, the observer by means of a switch turns either of the chronometers on the flash apparatus and notes the coincidences. In timing coincidences a hack chronometer, placed on the table near the observer, is used. A complete set of coincidences consists of three, two up and one down, or two down and one up. Readings are taken with both chronometers on the flash apparatus. The hack chronometer is always compared with the observing chronometers at each set of coincidences. Readings of arc, thermometer, and manometer are made and recorded. After approximately eight hours the readings are again repeated. This constitutes a swing of the pendulum which is then stopped, and restarted, and the readings again repeated. This is done a third time, and at the end of twenty-four hours a second pendulum is installed, and three sets of readings are similarly taken on it. At the end of the first twenty-four hours a second comparison between the chronometers and the standard clock is made, or a second set of time observations (if possible) is taken. When a standard clock is available for comparison, such a comparison may be made once, twice, or three times a day. When the rates of the two chronometers are determined from star observations, such observations are generally taken at the beginning of the first swing of the first pendulum, and at the end of the third swing of the third pendulum. When on account of cloudy weather, it is impossible to get star observations at the end of complete sets of the three pendulums, then the pendulum observation must be continued until such time as the sky clears. It is believed that by swinging the pendulums continuously between time determinations, the effect of diurnal irregularities of rate are entirely eliminated, as it will not be by any other method, and this is strikingly shown by computing the mean periods of the three pendulums as determined from the two chronometers. The average difference at the different stations is less than $0^{\circ}.0000001$, and the maximum difference is $0^{\circ}.0000004$.

Below follows a set of observations:—

Station:—Cochrane.

Date:—31st July, 1914.

Pendulum 1. Swing 1.

Bond No. 519.

Dent No. 52866.

"19"			"26"		
D	13h	48m 13s	D	13h	50m 07s
		3m 17s			3m 17s
U	13	51 30	U	13	53 24
		3 13			3 16
D	13	54 43	D	13	56 40
		Mean 3 15			Mean 3 16.5

Arc mm.	Pressure mm.	Temperature °
2.6	23.0	17.15
3.0	25.0	
—	—	
5.6	48.0	

"38"			"45"		
D	21h	11m 06s	D	21h	11m 55s
		3m 14s			3m 16s
U	21	14 20	U	21	15 11
		3 15			3 12
D	21	17 35	D	21	18 23
		Mean 3 14.5			Mean 3 14

Arc mm.	Pressure mm.	Temperature °
1.2	29.0	17.25
0.7	27.0	
—	—	
1.9	56.0	

NOTE.—The figures in quotation marks, as "19" above, are the seconds of the hack chronometer at the even minutes of the observing chronometers.

DETERMINATION OF COEFFICIENTS.

As the Canadian pendulums were made at Washington under the supervision of the Coast and Geodetic Survey, and as a replica of the Washington apparatus, the results of the experiments with the latter for the determination of the coefficients relating to temperature, atmospheric density and flexibility of support were utilized for the Canadian pendulums. The results of the Washington observations will be given. For the purpose, pendulum B4 was used as a standard to eliminate the rate of the chronometer, being swung in an adjoining room under uniform conditions, while A4, A5, A6 were successively swung under the various conditions desired to be investigated. Simultaneous swings were made with the pendulums, using the same chronometer to operate both flash apparatuses by means of suitable electrical connections. The true period of B4 being known, the difference between this and the observed period must be due to rate of chronometer, which may therefore be computed for each swing, and the resulting rate correction applied to the observations with A. This splendid method of determining pendulum coefficients was first used by Airy, and has more recently been employed by Von Sterneck.

TEMPERATURE COEFFICIENT.*

Pendulum.	At Low TEMPERATURE.		At High TEMPERATURE.		DIFFERENCES.		Increase of period for 1° increase of temperature.
	Temp. C.	Period (corrected except for temperature).	Temp. C.	Period (corrected except for temperature).	Temp. C.	Period.	
	o.	s.	o.	s.	o.	s.	s.
A4D.....	7.58	.5008466	29.41	.5009366	21.83	.0000900	.00000412
A4R.....	7.93	.5008474	29.41	.5009377	21.48	.0000903	.00000420
A5D.....	8.27	.5006758	29.33	.5007644	21.06	.0000886	.00000421
A5R.....	8.57	.5006768	29.19	.5007630	20.62	.0000862	.00000418
A6D.....	8.92	.5006425	27.27	.5007192	18.35	.0000767	.00000418
A6R.....	9.17	.5006428	26.94	.5007187	17.77	.0000759	.00000427
					Mean.....		.00000419

The mean of the values, $0^s.00000419$, is adopted as the temperature coefficient for the three pendulums.

* United States Coast and Geodetic Survey report, 1894, Appendix 1.

PRESSURE COEFFICIENT.*

Pendulum	At Low Pressure.		At High Pressure.		DIFFERENCES.		Increase of period for 1 mm. increase of pressure at 0° C.
	Pressure reduced to 0° C.	Period corrected except for pressure.	Pressure reduced to 0° C.	Period corrected except for pressure.	Pressure.	Period.	
	mm.	s.	mm.	s.	mm.	s.	s.
A4.....	6.0	.5008350	94.5	.5008441	88.5	.0000091	.000000103
A5.....	6.1	.5006619	96.1	.5006708	90.0	.0000089	.000000099
						Mean.....	.000000101

The pressure correction in the neighbourhood of 60 millimetres pressure, the adopted standard, is therefore $+.000000101 \left(60 - \frac{Pr}{1 + .00367 T}\right)$, where Pr is the pressure reading and T is the temperature.

Flexure coefficient.—The horizontal component of the force acting on the knife-edge through the swinging pendulum causes the support to move in unison with the pendulum, and therefore affects the period of the oscillation. This movement is called the flexure of the pendulum support.

The movement or displacement is an exceedingly minute quantity. Several methods have been devised to measure it, such as using an auxiliary pendulum which is set in motion by the oscillation of the support under the influence of the standard pendulum; and by the static method which has been used until recently. In the static method a horizontal pull of 15 kilogrammes was applied at the height of the knife-edge, and the resulting displacement measured by means of a scale and microscope. But in none of these methods was the actual displacement of the support due to the swinging pendulum measured. There were certain very doubtful assumptions made in the static method, and to avoid these Mr. John F. Hayford, formerly of the United States Coast and Geodetic Survey, proposed the plan of using the interferometer to measure the absolute displacement of the support due to the oscillating pendulum, and to determine the effect of the

*United States Coast and Geodetic Survey report, 1894, Appendix 1.

displacement upon the period of the pendulum. Mr. W. H. Burger of the Coast and Geodetic Survey staff made the observations for flexure with the interferometer, and the method he employed will be given, as described by Mr. Burger in his report.*

“In determining the coefficient of flexure of the support in terms of the period of the pendulum, simultaneous swings of two different pendulums were observed, the period of each being determined by using the same two chronometers to operate both flash apparatuses. The pendulums were swung on separate piers, and under nearly identical conditions except for flexure. One pendulum was kept swinging as a standard with no change of condition, while the other was swung under constant conditions except for the varying flexibility of the support. The work was divided into “runs”, each run being independent as far as observations were concerned. The pendulums were swung in nominally eight-hour periods, with no renewal of pendulums, each run beginning and ending with a time set. When all corrections had been applied to the period of the standard pendulum, the flexure being constant throughout the run, the variation from the mean period of the run shown by the individual swings was assumed to be due to the variation of the chronometer for the periods covered by the individual swings and to whatever small observational errors might be present. As the period of the other pendulum was approximately the period of the standard pendulum, it was assumed that its individual periods had the same corrections due to rate as the corresponding periods of the standard pendulum.

“When these corrections had been applied to the swings of the pendulums having varying flexure, it was found that the periods obtained for the various swings differed. It was assumed that this variation was caused by the variation in flexure conditions, and that the change in period was proportional to the displacement of the support, and therefore proportional to the flexure as expressed in terms of fringe width.

“The following programme was used:—

“Run A: Pendulum A4 under standard conditions, and B4 under standard conditions except for changes of flexure conditions, as follows:—swings 1 and 2 small flexure; 3 and 4 large flexure; 5 and 6 medium flexure.

*United States Coast and Geodetic Survey report, 1910, Appendix 6.

“Run B: Same as run A, except B4 under standard conditions and A4 under varying conditions of flexure.

“Run C: Like run A, with A5 in place of A4 and B5 in place of B4.

“The following are the results obtained:—

PENDULUM.	SMALL FLEXURE.		LARGE FLEXURE.		DIFFERENCE.		RESULTS.
	Flexure.	Period corrected except for flexure.	Flexure.	Period corrected except for flexure.	Flexure.	Period.	
	Fringe.	s.	Fringe.	s.	Fringe.	s.	
B4.....	0.10 0.08 0.07	.5008099 .5008177 .5008099	0.370	.5008166			.01 F = 2.13 in 7th place of period.
	0.083	.5008105	0.370	.5008166	0.287	.0000061	
A4.....	0.06 0.12 0.06	.5008409 .5008400 .5008411	0.322	.5008438			.01 F = 1.32 in 7th place of period.
	0.080	.5008406	0.322	.5008438	0.242	.0000032	
A5.....	0.09	.5006635	0.26 0.28	.5006649 .5006674			.01 F = 1.50 in 7th place of period.
	0.090	.5006635	0.27	.5006662	0.180	.0000027	

“Results weighted according to the difference in flexure give for a final mean 0.01 F = 1.70 in the seventh place of the period.”

This was adopted as the flexure coefficient for the two sets of pendulums, and as the Canadian pendulums are nearly identical in construction and mounting, it is assumed 1.70 in seventh place of the period is the flexure coefficient.

RATING OF CHRONOMETERS.

To all the stations except Washington, clock signals were sent from the standard clock at the Dominion Observatory, and recorded on a chronograph sheet for comparison with the chronometers used in the pendulum observations. Signals were sent once a day to Maniwaki, Kingston and Roberval, and twice a day to all the other stations. When observing in Ottawa the Riefler sidereal clock was used in all the observations; and in Washington, in March, time observations were made to determine the rates of the chronometers. In Washington, each pendulum was swung between time sets, hence the values of the periods of the different pendulums are entirely independent of one another. The noon signals from the United States Naval Observatory were also used to rate the chronometers. For the May observations in Washington, the noon signals alone were used. The Naval Observatory issues at the end of each month a table of corrections to the time of the noon signals for each day.

Below follow tables of chronometer comparisons, the deduced daily rates, and the corrections to the periods of the pendulums due to clock rates. When a standard sidereal clock (such as the Riefler or the Howard of the Dominion Observatory), whose rate is accurately known from observation, is used for comparison or for sending time signals, the accuracy of pendulum determinations is greater than when star observations are taken. Any errors in the observation for rate of the standard clock largely disappear when the rate for a period of time is deduced, whereas in field observations any error in the time observations must enter directly into the pendulum period. An error of $\pm 0^s.05$ in a time determination is not uncommon, and that gives an error of $\pm 0^s.0000003$ in the pendulum period.

CHRONOMETER RATES FROM OBSERVATIONS AND DEDUCED CORRECTIONS TO
PENDULUM PERIOD.

Station.	Date.	CHRONOMETER 1823.			CHRONOMETER COMPARISON.		Rel. rate per day.	Daily rate 1841.	CORRECTIONS TO 7TH PLACE OF PERIOD.	
		T	ΔT	Daily rate.	1823.	1841.			1823.	1841.
	1914.	h. m.	s.	s.	h. m. s.	h. m. s.	s.	s.		
Washington.....	Mar. 26	7 59	51.991		8 43 49.77	8 44 00.00				
	" 30	12 12	57.756	3.775	12 47 52.90	12 48 00.00	0.751	4.526	219	263
	Apr. 1	15 04	66.466	4.110	15 36 54.22	15 37 00.00	0.623	4.733	238	274
	" 3	8 00	73.367	4.046	8 43 54.92	8 44 00.00	0.407	4.453	235	258

CHRONOMETER RATES FROM NOON SIGNALS AND DEDUCED CORRECTIONS TO
PENDULUM PERIOD.

Station.	Date.	Noon signals on chronometer 1823.	Difference for one standard day.	Diff. of sidereal time between noons.	Daily rate 1823.	CHRONOMETER COMPARISON.		Rel. daily rate.	Daily rate 1841.	CORRECTIONS TO 7TH PLACE OF PERIOD.	
						1823.	1841.			1823.	1841.
	1914.	h. m. s.	m. s.	m. s.	s.	h. m. s.	h. m. s.	s.	s.		
Washington	Mar. 27	12 07 20.41				12 09 50.39	12 10 00				
	" 28	12 11 13.36	3 52.95	3 56.56	3.600	12 12 51.20	12 13 00	0.808	4.408	209	256
	" 30	12 18 58.92	3 52.78	3 56.56	3.770	12 09 52.54	12 10 00	0.671	4.441	219	258
	" 31	12 22 51.31	3 52.39	3 56.55	4.149	12 24 53.13	12 25 00	0.584	4.733	241	275
	Apr. 1	12 26 43.76	3 52.45	3 56.55	4.089	12 28 53.88	12 29 00	0.748	4.837	238	281
	" 2	12 30 36.31	3 52.55	3 56.56	4.000	12 31 54.27	12 32 00	0.389	4.389	232	255
	" 3	12 34 28.71	3 52.40	3 56.55	4.139	12 34 54.56	12 35 00	0.289	4.428	240	257

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM PERIOD.

Station	Date.	CHRONOMETER COMPARISONS			RELATIVE RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Negus	Riefler	B to R	N to R	Riefler	Bond	Negus	Bond	Negus
	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Ottawa..	Apr. 15	.....	23 44 00	23 43 29.66							
	" 15	23 47 00	.....	23 46 52.96	-2.093	-0.949	-0.218	-2.311	-1.167	-134	- 68
	" 15	.....	7 19 00	7 19 29.36							
	" 15	7 21 00	.....	7 21 52.30	-3.289	-2.072	-0.218	-3.507	-2.290	-203	-133
	" 16	.....	14 16 00	14 15 28.41							
	" 16	14 18 00	.....	14 17 51.70	-2.983	-2.649	-0.218	-3.201	-2.867	-186	-166
	" 16	.....	23 04 00	23 03 27.33							
	" 16	23 05 00	.....	23 04 50.73	-2.862	-2.715	-0.218	-3.080	-2.933	-179	-170
	" 16	.....	6 57 00	6 56 26.39							
	" 16	6 57 00	.....	6 56 49.84	-2.465	-2.281	-0.218	-2.683	-2.499	-156	-145
	" 17	.....	13 40 00	13 39 25.70							
	" 17	13 41 00	.....	13 40 49.20	-2.712	-2.239	-0.218	-2.930	-2.457	-170	-143
	" 17	.....	22 59 00	22 58 24.68							
	" 17	22 59 00	.....	22 58 48.32	-2.364	-1.934	-0.218	-2.582	-2.152	-150	-125
	" 17	.....	6 48 00	6 47 24.05							
	" 17	6 48 00	.....	6 47 47.55	-2.324	-1.966	-0.218	-2.542	-2.184	-147	-127
	" 18	.....	14 44 00	14 43 23.40							
	" 18	14 45 00	.....	14 44 46.78	-1.735	-2.061	-0.218	-1.953	-2.279	-113	-132
	" 18	.....	23 28 00	23 27 22.65							
	" 18	23 28 00	.....	23 27 46.15	-2.394	-1.382	-0.218	-2.612	-1.600	-151	- 93
	" 18	.....	7 17 00	7 16 22.20							
	" 18	7 17 00	.....	7 16 45.39	-2.411	-1.312	-0.218	-2.629	-1.530	-152	- 89
	" 19	.....	14 14 00	14 13 21.82							
	" 19	14 15 00	.....	14 14 44.69	-1.735	-2.776	-0.218	-1.953	-2.994	-113	-174
	" 19	.....	22 06 00	22 05 20.91							
	" 19	22 08 00	.....	22 07 44.12	-2.045	-2.477	-0.218	-2.263	-2.695	-131	-156
	" 19	.....	6 55 00	6 54 20.00							
	" 19	6 56 00	.....	6 55 45.37	-2.142	-2.427	-0.218	-2.360	-2.645	-137	-153
	" 19	.....	14 20 00	14 19 19.25							
	" 19	14 20 00	.....	14 19 42.71	-1.968	-3.428	-0.218	-2.186	-3.646	-127	-211

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	CHRONOMETER COMPARISONS			RELATIVE RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Negus	Riefler	B to R	N to R	Riefler	Bond	Negus	Bond	Negus
	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Ottawa..	Apr. 20	23 43 00	23 43 00	23 42 17.91							
"	" 20	23 44 00	23 44 00	23 43 41.94							
"	" 20	6 36 00	6 36 00	6 35 17.19	-2.957	-2.510	-0.218	-3.175	-2.728	-184	-158
"	" 20	6 38 00	6 38 00	6 37 41.09							
"	" 20	14 39 00	14 39 00	14 38 16.56	-2.395	-1.936	-0.218	-2.613	-2.154	-152	-125
"	" 20	14 39 00	14 39 00	14 38 40.29							
"	" 21	23 20 00	23 20 00	23 19 15.31	-1.628	-3.455	-0.218	-1.846	-3.673	-107	-213
"	" 21	23 21 00	23 21 00	23 20 39.70							
"	" 24	6 28 00	6 28 00	6 27 45.23							
"	" 24	6 30 00	6 30 00	6 29 12.62	-1.640	-1.488	-0.218	-1.858	-1.706	-108	-99
"	" 24	14 32 00	14 32 00	14 31 44.73							
"	" 24	14 33 00	14 33 00	14 32 12.07	-1.786	-0.948	-0.218	-2.004	-1.166	-116	-68
"	" 25	23 24 00	23 24 00	23 23 44.38							
"	" 25	23 25 00	23 25 00	23 24 11.41	-1.397	-0.570	-0.218	-1.615	-0.788	-94	-46
"	" 25	7 49 00	7 49 00	7 48 44.18							
"	" 25	7 50 00	7 50 00	7 49 10.92							
"	" 27	1 21 00	1 21 00	1 20 41.80							
"	" 27	1 22 00	1 22 00	1 21 09.72	-1.957	-2.110	-0.218	-2.175	-2.328	-126	-135
"	" 27	7 50 00	7 50 00	7 49 41.23							
"	" 27	7 52 00	7 52 00	7 51 09.19	-2.638	-1.608	-0.218	-2.856	-1.826	-166	-106
"	" 27	14 24 00	14 24 00	14 23 40.79							
"	" 27	14 25 00	14 25 00	14 24 08.47	-2.790	-1.501	-0.218	-3.008	-1.719	-174	-100
"	" 28	23 31 00	23 31 00	23 30 40.22							
"	" 28	23 32 00	23 32 00	23 31 07.41							
"	" 28	2 22 00	2 22 00	2 21 40.04							
"	" 28	2 21 00	2 21 00	2 20 07.12	-2.424	-1.100	-0.218	-2.642	-1.318	-153	-76
"	" 28	7 23 00	7 23 00	7 22 39.81							
"	" 28	7 24 00	7 24 00	7 23 06.61	-2.635	-1.078	-0.218	-2.853	-1.296	-165	-75
"	" 28	15 24 00	15 24 00	15 23 39.45							
"	" 28	15 25 00	15 25 00	15 24 05.73	-2.571	-0.948	-0.218	-2.789	-1.166	-162	-68

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—*Concluded.*

Station	Date	CHRONOMETER COMPARISONS			RELATIVE RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Negus	Riefler	B to R	N to R	Riefler	Bond	Negus	Bond	Negus
1914		h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Ottawa..	Apr. 29	.....	24 16 00	24 15 39.10							
	" 29	24 17 00	.....	24 16 04.78							
	" 29	.....	1 06 00	1 05 39.08							
	" 29	1 07 00	.....	1 06 04.79							
					-1.400	-4.704	-0.218	-1.618	-4.922	-94	-286
	" 29	.....	6 47 00	6 46 37.77							
	" 29	6 48 00	.....	6 47 04.40							
					-1.941	-4.493	-0.218	-2.159	-4.711	-125	-274
	" 29	.....	13 34 00	13 33 36.50							
	" 29	13 36 00	.....	13 35 03.85							
					-1.979	-4.594	-0.218	-2.197	-4.812	-127	-279
	" 30	.....	23 39 00	23 38 34.57							
	" 30	23 40 00	.....	23 39 03.02							
	" 30	.....	0 20 00	0 19 34.50							
	" 30	0 21 00	.....	0 20 03.00							
					-2.235	-1.498	-0.218	-2.453	-1.716	-142	-100
	" 30	.....	6 54 00	6 53 34.09							
	" 30	6 54 00	.....	6 53 02.39							
	" 30	.....	7 48 00	7 47 34.06							
	" 30	7 46 00	.....	7 45 02.29							
					-2.489	-1.174	-0.218	-2.707	-1.392	-157	-81
	" 30	.....	15 22 00	15 21 33.69							
	" 30	15 23 00	.....	15 22 01.50							
					-2.446	-1.058	-0.218	-2.664	-1.276	-155	-74
	May 1	.....	23 59 00	23 58 33.31							
	" 1	24 01 00	.....	24 00 00.62							

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM PERIOD.

Station	Date	CHRONOMETER COMPARISONS		Relative daily rate	DAILY RATES		CORRECTIONS TO 7TH PLACE OF PERIOD	
		1841	1823		1823	1841	1823	1841
	1914	h. m. s.	h. m. s.	s.	s.	s.		
Washington.....	May 6	2 43 00.00	2 43 17.713	0.588	3.271	3.859	190	224
	" 7	2 47 00.00	2 47 18.303	1.097	3.241	4.338	188	252
	" 8	2 51 00.00	2 51 19.403	0.316	3.237	3.553	188	206
	" 9	2 55 00.00	2 55 19.720	0.299	3.522	3.821	204	222
	" 10	2 59 00.00	2 59 20.020	0.050	3.766	3.816	218	221
	" 11	3 03 00.00	3 03 20.070	1.017	3.402	4.419	197	256
	" 12	3 07 00.00	3 07 21.090					

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM PERIOD
—Continued.

Station.	Date	CHRONOMETER COMPARISONS		Rela- tive daily rate B to R	DAILY RATES.		CORRECTIONS TO 7TH PLACE OF PERIOD	
		Riefler	Bond		Riefler	Bond	Riefler	Bond
	1914	h. m. s.	h. m. s.	s.	s.	s.		
Ottawa, Ont.	May 18	6 47 13.58	6 47 00.00	-1.868	-0.285	-2.153	-17	-125
"	18	13 51 13.03	13 51 00.00	-1.984	-0.285	-2.269	-17	-132
"	19	22 48 12.29	22 48 00.00	-1.891	-0.285	-2.176	-17	-126
"	19	6 25 11.69	6 25 00.00					
"	19	7 10 15.63	7 10 00.00	-1.955	-0.285	-2.240	-17	-130
"	19	14 32 15.03	14 32 00.00	-2.405	-0.285	-2.690	-17	-156
"	20	22 25 14.24	22 25 00.00					
"	20	23 06 14.20	23 06 00.00	-2.213	-0.285	-2.498	-17	-145
"	20	6 35 15.51	6 35 00.00					
"	20	7 46 15.41	7 46 00.00	-1.974	-0.285	-2.259	-17	-131
"	20	14 20 14.87	14 20 00.00	-2.109	-0.285	-2.394	-17	-139
"	21	23 40 14.05	23 40 00.00	-2.148	-0.285	-2.433	-17	-141
"	21	6 49 13.41	6 49 00.00					
"	21	7 30 13.33	7 30 00.00	-2.416	-0.285	-2.701	-17	-157
"	21	14 51 12.59	14 51 00.00	-3.010	-0.285	-3.295	-17	-191
"	22	23 42 11.48	23 42 00.00	-2.984	-0.285	-3.269	-17	-190
"	22	6 37 10.62	6 37 00.00					
"	22	8 00 16.49	8 00 00.00	-2.449	-0.285	-2.734	-17	-159
"	22	14 34 15.82	14 34 00.00	-2.697	-0.285	-2.982	-17	-173
"	23	23 44 14.79	23 44 00.00					
"	23	3 08 14.35	3 08 00.00	-2.212	-0.285	-2.497	-17	-145
"	23	9 19 13.78	9 19 00.00	-1.939	-0.285	-2.224	-17	-130
"	23	15 08 13.31	15 08 00.00	-2.113	-0.285	-2.398	-17	-139
"	24	0 20 12.50	0 20 00.00					
"	24	1 16 12.40	1 16 00.00	-2.114	-0.285	-2.399	-17	-139
"	24	9 06 11.71	9 06 00.00	-2.156	-0.285	-2.441	-17	-142

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM PERIOD.
—Continued.

Station.	Date.	CHRONOMETER COMPARISONS		Relative daily rate B to R	DAILY RATES.		CORRECTIONS TO 7TH PLACE OF PERIOD.	
		Riefler	Bond		Riefler	Bond	Riefler	Bond
	1914	h. m. s.	h. m. s.	s.	s.	s.		
Ottawa, Ont.....	May 24	15 00 11.18	15 00 00.00	-1.453	-0.285	-1.738	-17	-101
	" 25	0 15 10.62	0 15 00.00					
	" 25	1 18 10.56	1 18 00.00	-2.521	-0.285	-2.806	-17	-162
	" 25	10 32 09.59	10 32 00.00	-2.900	-0.285	-3.185	-17	-185
	" 25	17 44 08.72	17 44 00.00	-2.596	-0.285	-2.881	-17	-168
	" 26	1 41 07.86	1 41 00.00	-2.148	-0.285	-2.433	-17	-141
	" 26	7 43 07.32	7 43 00.00	-2.933	-0.285	-3.218	-17	-187
	" 26	14 55 06.44	14 55 00.00	-3.154	-0.285	-3.439	-17	-199
	" 27	23 52 05.25	23 52 00.00	-2.978	-0.285	-3.263	-17	-189
	" 27	6 43 04.40	6 43 00.00					
	" 27	7 56 16.29	6 56 00.00	-2.652	-0.285	-2.937	-17	-170
	" 27	14 54 15.52	14 54 00.00	-2.112	-0.285	-2.397	-17	-139
	" 28	0 20 14.69	0 20 00.00	-2.101	-0.285	-2.386	-17	-138
	" 28	8 13 14.00	8 13 00.00					
	" 28	8 58 13.95	8 58 00.00	-2.677	-0.285	-2.962	-17	-172
	" 28	16 03 13.16	16 03 00.00	-2.443	-0.285	-2.728	-17	-158
	" 29	0 30 12.30	0 30 00.00	-1.989	-0.285	-2.274	-17	-132
	" 29	3 31 12.05	3 31 00.00					
	" 29	7 40 11.72	7 40 00.00	-2.575	-0.285	-2.860	-17	-166
	" 29	15 13 10.91	15 13 00.00	-2.716	-0.285	-3.001	-17	-174
	" 30	0 35 09.85	0 35 00.00					

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
		h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Maniwaki Que.	1914										
	June 1	5 15 02.62	5 15 00	.....						
	" 1	5 33 28.12	.....	5 33 00							
	" 2	5 08 02.58	5 08 00	.....	-1.574	-0.040	-0.334	-1.908	-1.948	-111	-113
	" 2	5 29 29.69	.....	5 29 00							
	" 3	23 55 02.16	23 55 00	.....						
	" 3	23 52 24.81	.....	23 52 00	-1.484	-2.105	-0.334	-1.818	-3.923	-105	-228
	" 4	0 05 00.04	0 05 00	.....						
" 4	0 08 26.31	0 08 00	0 08 00								
Kings-ton, Ont.	June 9	4 46 02.12	4 46 00	.....						
	" 9	5 13 45.20	.....	5 13 00	-2.858	-1.846	-0.334	-3.192	-5.038	-185	-292
	" 10	4 41 00.28	4 41 00	.....						
	" 10	4 44 48.00	.....	4 44 00	-2.536	-2.027	-0.334	-2.870	-4.897	-166	-284
	" 11	4 43 58.25	4 44 00	.....						
	" 11	4 46 50.54	.....	4 46 00							
Roberval Que.	June 16	12 20 05.68	12 20 00	.....						
	" 16	11 07 21.80	.....	11 07 00	+1.084	-4.267	-0.334	+0.750	-3.517	+44	-204
	" 17	10 33 01.71	10 33 00	.....						
	" 17	10 48 20.73	.....	10 48 00	-0.805	-2.368	-0.334	-1.139	-3.507	-66	-203
	" 18	10 10 59.38	10 11 00	.....						
	" 18	10 04 21.51	.....	10 04 00							
Tadous-sac, Que.	June 22	6 55 55.41	6 55 00	.....						
	" 22	6 49 54.61	.....	6 49 00	0.000	-0.735	-0.334	-0.334	-1.069	-19	-62
	" 22	14 45 55.17	14 45 00	.....						
	" 22	14 42 54.61	.....	14 42 00	0.000	-0.810	-0.334	-0.334	-1.144	-19	-66
	" 23	3 47 54.73	3 47 00	.....						
	" 23	3 21 54.61	.....	3 21 00	+0.237	-0.600	-0.334	-0.097	-0.697	-6	-40
	" 23	12 35 54.51	12 35 00	.....						
	" 23	12 28 54.52	.....	12 28 00	-1.212	+0.743	-0.334	-1.546	-0.803	-90	-47
	" 24	2 48 54.95	2 48 00	.....						
	" 24	2 55 55.25	.....	2 55 00							

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
		h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Portneuf Que.	1914										
	June 25	8 55 15.90	8 55 00	.....						
	" 25	8 47 59.80	.....	8 48 00	-2.057	-2.281	-0.334	-2.391	-4.672	-139	-271
	" 26	1 26 14.33	1 26 00	.....						
	" 26	1 21 01.22	.....	1 21 00	-2.109	-1.700	-0.334	-2.443	-4.143	-142	-240
	" 26	7 56 13.87	7 56 00	.....						
	" 26	7 57 01.80	.....	7 57 00	-1.544	-0.728	-0.334	-1.878	-2.606	-109	-151
	" 26	14 12 13.68	14 12 00	.....						
	" 26	14 10 02.20	.....	14 10 00	-2.092	-1.977	-0.334	-2.426	-4.403	-141	-255
	" 27	3 04 12.62	3 04 00	.....						
" 27	3 01 03.32	.....	3 01 00								
Ste. Jérôme, Que.	July 1	8 59 44.03	8 59 00	.....						
	" 1	8 52 27.73	.....	8 52 00	-2.509	+0.331	-0.334	-2.843	-2.512	-165	-146
	" 2	22 03 44.21	22 03 00	.....						
	" 2	21 58 29.10	.....	21 58 00	-2.447	+0.513	-0.334	-2.781	-2.268	-161	-131
	" 2	4 36 44.35	4 36 00	.....						
	" 2	4 50 29.80	.....	4 50 00	-2.533	+2.183	-0.334	-2.867	-0.684	-168	-40
	" 3	21 59 31.61	.....	21 59 00							
	" 3	21 45 45.91	21 45 00	.....	-2.618	+3.160	-0.334	-2.952	+0.208	-171	+13
" 3	3 45 46.70	3 45 00	.....							
" 3	3 51 32.25	.....	3 51 00								
Ste. Anne de Belle- vue, Que.	July 8	3 08 09.88	3 08 00	.....						
	" 8	3 01 15.09	.....	3 01 00	-2.659	-1.228	-0.334	-2.993	-4.221	-174	-245
	" 8	10 11 09.52	10 11 00	.....						
	" 8	10 16 15.90	.....	10 16 00	-2.614	-1.331	-0.334	-2.948	-4.279	-171	-248
	" 9	3 51 08.54	3 51 00	.....						
	" 9	3 48 17.81	.....	3 48 00	-2.088	-2.202	-0.334	-2.422	-4.624	-140	-268
	" 9	10 43 07.91	10 43 00	.....						
	" 9	10 40 18.42	.....	10 40 00	-0.738	-3.792	-0.334	-1.072	-4.864	-62	-282
	" 10	2 02 05.49	2 02 00	.....						
	" 10	2 00 18.89	.....	2 00 00							

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD		
		Bond	Dent	Howard	B to H	D to B	Howard	Bond	Dent	Bond	Dent	
	1914	h. m. . s.	h. m. s.	h. m. s	s.	s.	s.	s.	s.			
Mattawa, Ont.	July 14	6 38 45.61	6 38 00	.....							
	" 14	6 26 23.92	.....	6 36 00	-1.945	-1.350	-1.014	-2.959	-4.309	-172	-250
	" 15	23 10 44.68	23 10 00	.....							
	" 15	23 37 25.30	.....	23 37 00	-1.948	-0.910	-1.014	-2.962	-3.872	-172	-225
	" 15	6 33 44.40	6 33 00	.....							
	" 15	6 31 25.86	.....	6 31 00	-1.392	-2.161	-1.014	-2.406	-4.567	-140	-265
	" 16	23 19 42.89	23 19 00	.....							
	" 16	23 25 26.84	.....	23 25 00	-1.543	-0.763	-1.014	-2.557	-3.320	-148	-193
	" 16	6 14 42.67	6 14 00	.....							
	" 16	6 33 27.30	.....	6 33 00							
	Liskeard, Ont.	July 17	11 21 52.18	11 21 00							
		" 17	11 16 48.10	11 16 00	-3.256	+0.136	-1.014	-4.270	-4.134	-248	-240
" 18		3 14 52.27	3 14 00	.....							
" 18		3 11 50.26	.....	3 11 00	-2.538	-0.373	-1.014	-3.552	-3.925	-206	-228
" 18		10 57 52.15	10 57 00	.....							
" 18		11.19 51.12	.....	11 19 00	-2.420	+1.239	-1.014	-3.434	-2.195	-199	-127
" 19		3 25 53.00	3 25 00	.....							
" 19		3 23 52.74	.....	3 23 00	-2.506	+1.800	-1.014	-3.520	-1.720	-204	-100
Cochrane Ont.	July 19	11 01 53.57	11 01 00	.....							
	" 19	11 20 53.57	.....	11 20 00							
	July 20	14 29 06.88	14 29 00	.....							
	" 20	14 27 59.90	.....	14 28 00	-1.667	+0.321	-1.014	-2.681	-2.360	-155	-136
	" 21	5 25 07.08	5 25 00	.....							
	" 21	6 10 00.95	.....	6 10 00	-1.576	+0.705	-1.014	-2.590	-1.885	-150	-109
	" 21	13 15 07.31	13 15 00	.....							
	" 21	13 37 01.44	.....	13 37 00	-1.628	-0.148	-1.014	-2.642	-2.790	-153	-162
	" 22	5 30 07.21	5 30 00	.....							
	" 22	5 41 02.53	.....	5 41 00	-2.035	+0.623	-1.014	-3.049	-2.426	-177	-141
" 22	13 12 07.41	13 12 00	.....								
" 22	13 35 03.20	.....	13 35 00								

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—*Continued.*

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES.			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Sault Ste. Marie, Ont.	July 24	17 10 49.01	17 10 00	.....						
	" 24	17 21 14.29	.....	17 21 00	-2.753	-0.090	-0.207	-2.960	-3.050	-172	-177
	" 25	9 11 48.95	9 11 00	.....						
	" 25	9 20 16.12	.....	9 20 00	-3.147	+1.796	-0.207	-3.354	-1.558	-195	- 90
	" 25	16 56 49.53	16 56 00	.....						
	" 25	17 25 17.18	.....	17 25 00	-2.625	+0.684	-0.207	-2.832	-2.148	-165	-125
	" 26	9 26 50.00	9 26 00	.....						
	" 26	9 25 18.93	.....	9 25 00	-3.055	+1.898	-0.207	-3.262	-1.364	-189	- 79
	" 26	17 24 50.63	17 24 00	.....						
	" 26	17 21 19.94	.....	17 21 00							

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Chapleau Ont.	July 28	20 48 16.34	20 48 00	.....						
	" 28	20 36 10.62	.....	20 36 00	-3.854	+0.494	-0.207	-4.061	-3.567	-236	-207
	" 28	3 07 16.97	3 07 00	.....						
	" 28	3 27 11.72	.....	3 27 00	-3.895	+2.233	-0.207	-4.102	-1.869	-238	-108
	" 29	18 16 18.38	18 16 00	.....						
	" 29	18 29 14.16	.....	18 29 00							
	" 29	2 14 18.84	2 14 00	.....						
	" 29	2 30 15.07	.....	2 30 00	-3.188	+1.738	-0.207	-3.395	-1.657	-197	-96
	" 30	18 15 20.00	18 15 00	.....						
	" 30	18 41 17.22	.....	18 41 00	-3.409	+2.284	-0.207	-3.616	-1.332	-210	-77
	" 30	1 11 20.66	1 11 00	.....						
	" 30	1 26 20.73	1 26 00	.....						
	" 30	1 35 18.20	.....	1 35 00	-0.566	-1.021	-0.207	-0.773	-1.794	-45	-104
	" 31	15 32 20.13	15 32 00	.....						
	" 31	15 34 18.53	.....	15 34 00	-0.235	-1.230	-0.207	-0.442	-1.672	-26	-97
	" 31	22 32 19.77	22 32 00	.....						
	" 31	22 43 18.60	.....	22 43 00							
	Port Arthur, Ont.	Aug. 3	10 11 40.33	10 11 00						
" 3		10 09 30.06	.....	10 09 00	-1.609	+2.204	-0.207	-1.816	+0.388	-105	+23
" 4		1 56 41.78	1 56 00	.....						
" 4		1 49 31.11	.....	1 49 00	-1.330	+2.956	-0.207	-1.537	+1.419	-89	+82
" 4		10 08 42.79	10 08 00	.....						
" 4		10 07 31.57	.....	10 07 00	-1.310	+2.484	-0.207	-1.517	+0.967	-90	+56
" 5		1 47 44.41	1 47 00	.....						
" 5		1 52 32.43	.....	1 52 00	-1.390	+2.365	-0.207	-1.597	+0.768	-93	+45
" 5		9 48 45.20	9 48 00	.....						
" 5		9 59 32.90	.....	9 59 00							

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station.	Date	CHRONOMETER COMPARISONS		RELATIVE DAILY RATE	DAILY RATES		CORRECTIONS TO 7TH PLACE OF PERIOD	
		Riefler	Bond	B to R	Riefler	Bond	Riefler	Bond
Ottawa, Ont.	1914	h. m. s.	h. m. s.	s.	s.	s.		
	Aug. 12	11 12 42.13	11 13 00.00	-3.764	-0.207	-3.971	-12	-230
	" 12	16 41 41.27	16 41 00.00	-3.846	-0.207	-4.053	-12	-235
	" 13	1 14 39.90	1 14 00.00	-2.675	-0.207	-2.882	-12	-167
	" 13	9 40 38.96	9 40 00.00	-2.488	-0.207	-2.695	-12	-156
	" 13	17 00 38.20	17 00 00.00	-3.325	-0.207	-3.532	-12	-205
	" 14	1 44 36.99	1 44 00.00	-3.671	-0.207	-3.878	-12	-225
	" 14	9 23 35.82	9 23 00.00					
	" 14	10 25 35.71	10 25 00.00	-3.503	-0.207	-3.710	-12	-215
	" 14	16 35 34.81	16 35 00.00					
	Sept. 8	20 48 20.72	20 48 00.00	-1.875	-0.099	-1.974	- 6	-115
	" 8	3 58 20.16	3 58 00.00	-2.019	-0.099	-2.118	- 6	-123
	" 9	12 03 19.48	12 03 00.00	-1.517	-0.099	-1.616	- 6	- 94
	" 9	20 07 18.97	20 07 00.00					
	" 9	20 37 18.93	20 37 00.00	-0.777	-0.099	-0.876	- 6	- 51
	" 9	3 43 18.70	3 43 00.00	-0.972	-0.099	-1.071	- 6	- 62
	" 10	11 52 18.37	11 52 00.00	-0.576	-0.099	-0.675	- 6	- 39
	" 10	19 47 18.18	19 47 00.00					

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—Continued.

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
Rose Point, Ont.	Aug. 18	15 14 24.42	15 14 00	.....						
	" 18	15 12 29.50	.....	15 12 00	-1.685	-0.220	-0.099	-1.784	-2.004	-104	-116
	" 19	4 20 24.30	4 20 00	.....						
	" 19	4 18 30.42	.....	4 18 00	-0.790	-0.463	-0.099	-0.889	-1.352	-52	-78
	" 19	10 33 24.18	10 33 00	.....						
	" 19	10 41 30.63	.....	10 41 00	-0.812	-0.668	-0.099	-0.911	-1.579	-53	-91
	" 19	15 10 24.05	15 10 00	.....						
	" 19	15 07 30.78	.....	15 07 00							
Whitby, Ont.	Aug. 20	18 03 55.39	18 03 00	.....						
	" 20	18 01 22.43	.....	18 01 00	-2.198	+0.616	-0.099	-2.297	-1.681	-133	-98
	" 21	6 54 55.72	6 54 00	.....						
	" 21	7 07 23.63	.....	7 07 00	-2.005	+0.313	-0.099	-2.104	-1.791	-122	-104
	" 21	13 02 55.80	13 02 00	.....						
	" 21	12 59 24.12	.....	12 59 00	-1.813	+0.692	-0.099	-1.912	-1.220	-111	-71
	" 21	19 58 56.00	19 58 00	.....						
	" 21	20 00 24.65	.....	20 00 00	-2.511	+1.672	-0.099	-2.610	-0.938	-151	-54
" 22	8 53 56.90	8 53 00	.....							
" 22	9 00 26.01	.....	9 00 00								
Woodstock, Ont.	Aug. 24	17 28 04.35	17 28 00	.....						
	" 24	17 30 26.38	.....	17 30 00	-1.060	+0.211	-0.099	-1.159	-0.948	-67	-55
	" 25	7 07 04.47	7 07 00	.....						
	" 25	7 05 26.98	.....	7 05 00	-0.806	+0.242	-0.099	-0.905	-0.663	-52	-34
	" 25	13 59 04.61	13 59 00	.....						
	" 25	13 56 27.21	.....	13 56 00	-0.717	+0.358	-0.099	-0.816	-0.458	-47	-27
	" 25	20 01 04.72	20 01 00	.....						
	" 25	19 58 27.42	.....	19 58 00	-1.684	+0.892	-0.099	-1.783	-0.891	-103	-52
" 26	10 17 05.23	10 17 00	.....							
" 26	10 25 28.42	.....	10 25 00								

CHRONOMETER COMPARISONS AND DEDUCED CORRECTIONS TO PENDULUM
PERIOD—*Concluded.*

Station	Date	COMPARISON OF CHRONOMETERS			RELATIVE DAILY RATES		DAILY RATES			CORRECTIONS TO 7TH PLACE OF PERIOD	
		Bond	Dent	Riefler	B to R	D to B	Riefler	Bond	Dent	Bond	Dent
Windsor, Ont.	1914	h. m. s.	h. m. s.	h. m. s.	s.	s.	s.	s.	s.		
	Aug. 27	12 41 44.60	12 41 00	.....						
	" 27	12 48 29.12	.....	12 48 00							
	" 27	20 46 45.30	20 46 00	.....	-3.160	+2.078	-0.099	-3.259	-1.181	-189	- 69
	" 27	20 42 30.16	.....	20 42 00							
	" 28	12 39 46.91	12 39 00	.....	-3.041	+2.433	-0.099	-3.140	-0.707	-182	- 41
	" 28	12 45 32.18	.....	12 45 00							
	" 28	20 58 47.90	20 58 00	.....	-2.862	+2.857	-0.099	-2.961	-0.104	-172	- 6
	" 28	20 53 33.15	.....	20 53 00							
	" 29	12 20 50.25	12 20 00	.....	-3.434	+3.670	-0.099	-3.533	+0.137	-205	+ 8
	" 29	12 24 35.37	.....	12 24 00							

REDUCTION OF OBSERVATIONS.

The periodic time as determined from the coincidence period must be corrected for arc, temperature, pressure, rate and flexure. The reduction must be made to infinitely small arc; the standard temperature is 15° Centigrade; the standard density of air in the chamber is 60 millimetres at 0° Centigrade, and this standard was closely realized in each experiment. The correction for flexure was determined experimentally at the different stations.

Arc correction.—The initial and final semi-arcs of oscillation for each swing are given on the scale near the point of the pendulum. The correction to reduce the time of oscillation to what it would be were the pendulum swinging in an infinitely small arc was computed by means of Borda's formula:—

$$b = \frac{Mn \cdot \sin(\varphi + \varphi^1) \cdot \sin(\varphi - \varphi^1)}{32 (\log \sin \varphi - \log \sin \varphi^1)},$$

where M is the modulus of the common logarithmic system, n the number of oscillations actually made, φ the initial semi-arc, φ^1 the final semi-arc,

and b the quantity to be added to n oscillations in order to obtain the number that would have been made in the same interval had the arc been infinitely small.

Transforming this expression into a correction to the period, it becomes with a sufficient degree of accuracy when the arc is small,

$$A = \frac{PM}{32} \cdot \frac{\sin(\varphi + \varphi^1) \cdot \sin(\varphi - \varphi^1)}{\log \sin \varphi - \log \sin \varphi^1},$$

where P is the period of the pendulum in seconds, and A is the amount to be subtracted from the period to reduce to infinitely small arc.

Temperature correction.—Each period is corrected for the difference between the mean temperature of the swing and 15° Centigrade, adopted as a standard. The temperature coefficient as determined above is $0^s \cdot 00000419$ for each degree Centigrade. The correction to the period is, therefore, $(15^\circ - T)(0^s \cdot 00000419)$, where T is the observed temperature in degrees Centigrade.

Pressure correction.—An atmospheric density represented by air at a temperature of 0° Centigrade, and under a pressure of 60 millimetres of mercury, is taken as the standard, and periods are corrected for the difference between the conditions under which observations are made and this standard. The receiver is always exhausted to a point where the density therein nearly approaches the standard, so that this correction takes the form of

$$C = k \left(60 - \frac{Pr}{1 + .00367 T} \right),$$

where C is the correction in seconds (to be subtracted if observed density is above the standard and added if below the standard), k is the pressure coefficient, or variation in period for change of 1 millimetre in pressure (at 0° Centigrade), Pr is the observed pressure in millimetres of mercury, and T is the mean temperature of swing in degrees Centigrade. The determination of k was described under determination of pressure coefficient. Its value as determined is $0^s \cdot 000000101$.

Rate correction.—The periods are reduced to sidereal time by correcting for the rate of the chronometer. This may be applied conveniently by the formula, $D = 0^s \cdot 00001157 R.P$, where D is the correction to period (to be subtracted if chronometer is gaining, and added if losing), R is the rate of the chronometer, and P is the period of the pendulum in seconds.

Flexure correction.—In observing flexure by means of the interferometer, there is presented the problem of finding the shift, or displacement of the fringe due to the oscillation of the pendulum, in terms of the width of one fringe.

The principle of the interferometer is shown in Fig. 2.

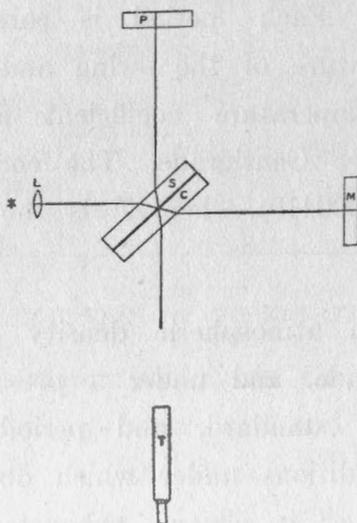


FIG. 2.

The beam from the source of light (*) with its rays made parallel by a lens, L , strikes the rear or second surface of the plate, s , and separates, part of it being reflected to the plane mirror, P , returns exactly on its own path through s , and then through c to T where it is examined by a telescope, T . The other part goes through the plate, s , passes through the plate, c , and is reflected by the mirror, M , returns on its path through c to the plate, s , where it is reflected so as to unite with the first ray as to produce interference. The result is a series of bands in the form of a grating, as shown in Fig. 3, the dark band being produced when the two wave-trains differ by one-half a wave-length of light, and the light bands when they are in the same phase.

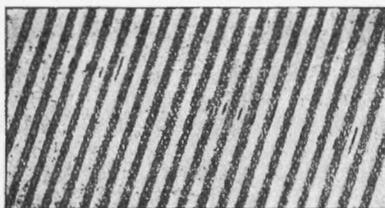


FIG. 3.—FRINGES AND SCALE.

As one mirror is attached to the pendulum receiver and the remainder of the interferometer is mounted on a support entirely independent of the pendulum receiver, it is easily seen that any movement in the pendulum case will cause a shift or displacement of the fringes in the interferometer. Owing to the two parts of the interferometer being mounted on separate and independent supports, and the consequent instability in relative position of its parts, vibrations from sources other than the oscillating pendulum cause shifting of fringes, but they are erratic and are seldom mistaken for the shift due to the pendulum. Since the pendulum makes one complete swing in one-half a second, the shift of fringes will occur as a half-second shift across the field. It is the magnitude of this half-second movement which it is desired to measure. This movement is a measure of the amount of flexure in the pendulum case caused by the oscillation of the pendulum.

The method employed to determine the flexure at the pendulum stations was to observe the width of a fringe in terms of the divisions of the scale in the telescope, and then observe the amount of the shift or displacement of the fringe-band in terms of the scale divisions. The second quantity divided by the first will give the shift of the fringes in terms of their width.

In the use of the interferometer it is essential that a monochromatic light be used, as it is necessary to know the wave-length. In selecting a monochromatic light to use with the interferometer the sodium light was chosen, as it could very easily be obtained by the use of sodium chloride and an alcohol flame.

If the fringes shift, or are displaced one fringe-width due to the motion of the pendulum, it is easily seen that the pendulum case has moved

through a distance equal to one-half the wave-length of the light used, for a change of distance between the thinly silvered plate and the mirror on the pendulum case causes a change in the total path of the ray to and from that mirror by double that amount, so that if the length of the ray of light used is known we have a means of computing the movement of the case.

The wave-length of sodium light is practically 0.58 microns, and therefore a shift or displacement of the fringe by an amount equal to one fringe-width means a displacement of the pendulum case of 0.29 microns.

The following is a specimen of record and computation in the measurement of flexure in the field (Liskeard, Ont., 19th July, 1914).

SEMI-ARCS		Total Arcs	WIDTH OF FRINGE			MOVEMENT OF FRINGE			F = Displacement per 5 mm. of Arc.	
C	D		A	B	Diff.	A	A	Diff.		
mm.	mm.	mm.								
6.8	7.6	14.4	4.0	7.0	3.0	4.0	4.5	0.5	$\frac{0.44 \times 5}{2.80 \times 13.9}$ $= 0.056.$	
			3.0	5.6	2.6	3.0	3.5	0.5		
			5.0	8.0	3.0	5.0	5.4	0.4		
6.3	7.1	13.4	4.0	6.4	2.4	4.0	4.3	0.3		
			3.0	6.0	3.0	3.0	3.5	0.5		
			Mean...		2.80			0.44		
6.3	7.1	13.4	4.0	7.5	3.5	4.0	4.6	0.6		
			6.0	9.0	3.0	6.0	6.5	0.5		
			3.2	6.4	3.2	3.2	3.7	0.5		
6.1	6.9	13.0	6.0	9.0	3.0	6.0	6.5	0.5		$\frac{0.54 \times 5}{3.14 \times 13.20}$ $= 0.064.$
			4.0	7.0	3.0	4.0	4.6	0.6		
			Mean...		3.14			0.54		
10.0	10.8	20.8	4.0	7.0	3.0	4.0	5.0	1.0		
			2.0	5.2	3.2	2.0	2.9	0.9		
			2.0	5.6	3.6	2.0	2.8	0.8		
9.6	10.4	20.0	4.0	7.2	3.2	4.0	4.8	0.8	$\frac{0.86 \times 5}{3.20 \times 20.20}$ $= 0.066$	
			5.0	8.0	3.0	5.0	5.8	0.8		
			Mean...		3.20			0.86		
9.6	10.4	20.0	2.5	6.0	3.5	2.5	3.5	1.0		
			5.0	8.0	3.0	5.0	5.9	0.9		
			5.0	9.0	4.0	5.0	6.0	1.0		
8.9	9.7	18.6	5.0	9.0	4.0	5.0	6.1	1.1		$\frac{1.00 \times 5}{3.54 \times 19.30}$ $= 0.074$
			5.0	9.0	4.0	5.0	6.1	1.1		
			6.0	9.2	3.2	6.0	7.0	1.0		
Mean...		3.54			1.00					

The correction for flexure is the mean of 0.056, 0.064, 0.066 and 0.074, or, 0.065 fringe per 5 millimetres of arc. Correction = 6.5×1.70 , or 11 in seventh place of period of half-seconds pendulum.

VARIATION IN LENGTHS OF PENDULUMS.

Pendulums 1, 2 and 3 were swung twice, both at Washington and at Ottawa. It was found that the results from pendulums 1 and 3 agreed, while those from pendulum 2 seemed to be in error. Also, between the first and second observations at Ottawa, pendulum 2 changed its period from 0.5014643 second to 0.5014306 second. No apparent reason for this large change can be given, unless the pendulum had been injured in shipment. A careful examination of the pendulum and the support failed to show any traces of injury, and it was decided to commence the field work. At the first station, Maniwaki, pendulum 2 instead of swinging the full eight-hour period, only swung about three hours. Another careful examination of the pendulum and the agate edges was made, but nothing was found to account for the very peculiar and unsatisfactory behaviour of this pendulum. It was then decided to continue observing, but to use only the two pendulums 1 and 3.

During the season neither of these pendulums kept the same length. At all the stations from Ottawa to Ste. Anne-de-Bellevue there was agreement between the two pendulums, but on taking observations at Mattawa it was immediately noticed that the periods had changed relatively to one another. Observations were continued at all the stations in northern Ontario, and after finishing at Port Arthur the pendulums were brought to Ottawa and re-standardized. It was found that the period of pendulum 1 for Ottawa had changed from 0.5012993 to 0.5013267 second, and the period of pendulum 3 had changed from 0.5014157 to 0.5014101 second. The pendulums were then taken to Rose Point, where the periods agreed with the new values at Ottawa. However, on the journey from Rose Point to Whitby there was another change. The stations, Whitby, Woodstock and Windsor, were observed and the pendulums were returned to Ottawa and again standardized. Pendulum 3 was found still to have the period 0.5014101

second, while pendulum 1 had changed from 0.5013267 to 0.5013208 second. These changes in the lengths of pendulums are very disconcerting, and if it had not been possible to have returned to the base point and re-standardized them, the season's work would have been seriously impaired. However, all the stations have a tie to the base point at Ottawa.

What happened to the pendulums is, of course, a matter of which there is no certainty. The only thing that could change the period of a pendulum other than a blow, would be a looseness in some part of the system. For instance, there might be looseness in one of the following:—

The bob on the stem.

The head on the stem.

The agate plane in the brass box.

Between the brass box holding the agate plane and the head of the pendulum.

Of either one of the two mirrors attached to the pendulum, or a tilting of the plane endwise so that the pendulum rests on one end of the knife-edge.

With regard to pendulum 2, there must have been a rubbing of the parts of the pendulum, on either the prongs of the lifting device, the scale for reading the arc, or some part of the apparatus that holds the knife-edge. A careful examination failed to discover any cause for the behaviour of this pendulum.

It may be of interest to state that one of the pendulums of the United States Coast and Geodetic Survey changed its length in 1909 by a very appreciable amount. During the past season it changed back to nearly its original length; a careful examination of all parts of this pendulum failed to show any defects, and the only remedy is to rebuild the pendulum in a most substantial manner. The whole value of pendulum observations depends on the invariability of the pendulum, therefore every care must be taken to insure that property. Only a change of very few microns in the length is necessary to affect the period materially.

Little difficulty was experienced in obtaining the right degree of pressure. The air pump worked satisfactorily and the receiver held well, except at two stations, Sault Ste. Marie and Chapleau. During the last swing at Sault Ste. Marie, the air started to leak into the case. It was thought that the leak was around the cap, but at Chapleau it still continued, and a careful examination revealed a wearing of one of the stop-cocks on the base of the receiver. The foreman in the C.P.R. shops at Chapleau was good enough to grind the defective part. The result was that the leak was very much reduced, and the observations were allowed to proceed.

PERIODS OF THE PENDULUMS, OBSERVATIONS AND REDUCTIONS.

In the following tables are the reductions of the periods of the three pendulums 1, 2 and 3, for Washington and Ottawa; and of the two pendulums 1 and 3 for all] the field stations.

Mar. 27.....	3	1	D	I	178.64	179.55	5.7	2.1	13.86	51.20	.5014034	.5013962	-12	+43	+11	+209	+256	-11	.5014279	.5014254		
" 27.....	4	1	D	I	178.64	179.17	5.6	2.2	14.23	53.70	.5014034	.5013993	-13	+32	+09	+209	+256	-11	.5014260	.5014266		
" 28.....	5	1	D	I	178.53	178.88	5.6	2.0	14.56	56.85	.5014042	.5014015	-12	+18	+06	+209	+256	-11	.5014252	.5014272		
																			Mean.....	.5014264	.5014264	.5014264
" 28.....	6	1	D	I	177.90	178.86	6.3	2.2	14.92	59.05	.5014090	.5014016	-14	+03	+04	+219	+258	-11	.5014291	.5014256		
" 28.....	7	1	D	I	178.37	178.85	4.5	1.4	15.07	61.75	.5014056	.5014018	-07	-03	+01	+219	+258	-11	.5014255	.5014256		
" 29.....	8	1	D	I	178.69	178.96	4.5	1.9	14.80	52.65	.5014030	.5014008	-09	+08	+10	+219	+258	-11	.5014247	.5014264		
" 29.....	9	1	D	I	178.51	179.24	4.8	1.7	14.38	54.75	.5014044	.5013986	-09	+26	+08	+219	+258	-11	.5014277	.5014258		
" 29.....	10	1	D	I	179.14	179.35	4.9	1.4	14.03	57.80	.5013995	.5013978	-08	+46	+05	+219	+258	-11	.5014246	.5014268		
" 30.....	11	1	D	I	179.16	179.46	5.4	2.0	13.65	60.75	.5013991	.5013969	-11	+56	+02	+219	+258	-11	.5014246	.5014263		
																			Mean.....	.50142603	.50142608	.5014261
																				Mean.....		.5014262

Rate determined from noon signals.

Mar. 31.....	1	2	D	I	160.14	160.40	6.3	2.0	13.31	53.20	.5015660	.5015635	-14	+57	+09	+238	+274	-11	.5015939	.5015950		
" 31.....	2	2	D	I	159.91	160.50	5.0	1.6	13.28	60.00	.5015677	.5015626	-08	+72	+03	+238	+274	-11	.5015971	.5015956		
" 31.....	3	2	D	I	160.05	160.47	5.2	1.3	13.31	66.30	.5015666	.5015625	-08	+71	-03	+238	+274	-11	.5015953	.5015949		
Apr. 1.....	4	2	D	I	160.10	160.42	5.5	2.1	13.18	57.15	.5015664	.5015633	-12	+76	+05	+238	+274	-11	.5015960	.5015965		
" 1.....	5	2	D	I	159.88	160.35	5.2	1.9	13.11	64.35	.5015666	.5015640	-11	+79	-01	+238	+274	-11	.5015980	.5015970		
" 1.....	6	2	D	I	160.09	160.30	5.5	1.9	13.19	55.70	.5015665	.5015644	-12	+76	+07	+238	+274	-11	.5015963	.5015978		
																			Mean.....	.5015961	.5015961	.5015961

Rate determined from star observations.

Mar. 31.....	2	2	D	I	159.91	160.50	5.0	1.6	13.28	60.00	.5015677	.5015626	-08	+72	+03	+238	+281	-11	.5015971	.5015963		
Apr. 1.....	3	2	D	I	160.05	160.47	5.2	1.3	13.31	66.30	.5015666	.5015625	-08	+71	-03	+238	+281	-11	.5015953	.5015955		
" 1.....	4	2	D	I	160.10	160.42	5.3	2.1	13.18	57.15	.5015664	.5015633	-12	+76	+05	+238	+291	-11	.5015958	.5015972		
																			Mean.....	.5015966	.5015963	.5015962

Rate determined from noon signals.

PENDULUM OBSERVATIONS AND REDUCTIONS—Continued.

Station—WASHINGTON, D.C.—Continued.

Observer—F. A. McDIARMID.

DATE.	Swing number.	Pendulum.	Position.	Knife-edge.	COINCIDENCE INTERVAL.		ARC.		Temperature.	Pressure.	PERIOD UNCORRECTED.		CORRECTIONS (7TH DECIMAL PLACE).					PERIOD CORRECTED.			
					CHRONOMETER.		Initial.	Final.			No. 1823	No. 1841	Arc.	Temp.	Pressure.	RATE.		Flexure.	CHRONOMETER.		MEAN.
					No. 1823	No. 1841										1823	1841		No. 1823	No. 1841	
1914					s.	s.	mm.	mm.	°	mm.	s.	s.						s.	s.	s.	
Apr. 2.....	1	3	D	I	165-47	165-56	5.4	1.8	13-38	55-80	.5015152	.5015146	-10	+68	+07	+235	+258	-11	.5015441	.5015458	
" 2.....	2	3	D	I	165-19	165-52	5.4	1.5	13-43	64-50	.5015180	.5015150	-09	+66	-02	+235	+258	-11	.5015459	.5015452	
" 2.....	3	3	D	I	165-50	165-67	5.2	1.7	13-63	58-35	.5015151	.5015136	-11	+57	+05	+235	+258	-11	.5015426	.5015434	
" 3.....	4	3	D	I	165-31	165-26	5.2	1.4	13-61	66-80	.5015169	.5015174	-09	+58	-04	+235	+258	-11	.5015438	.5015466	
" 3.....	5	3	D	I	164-47	165-24	5.6	1.7	14-53	66-75	.5015247	.5015175	-12	+20	+02	+235	+258	-11	.5015481	.5015432	
																Mean.5015449	.5015448	.5015449

Rate determined from star observations.

Apr. 2.....	2	3	D	I	165-19	165-52	5.4	1.5	13-43	64-50	.5015180	.5015150	-09	+66	-02	+240	+257	-11	.5015464	.5015451	
" 2.....	2	3	D	I	165-50	165-67	5.2	1.7	13-63	58-35	.5015151	.5015136	-10	+57	+05	+240	+257	-11	.5015432	.5015434	
" 3.....	4	3	D	I	165-31	165-26	5.2	1.4	13-61	66-80	.5015169	.5015174	-09	+58	-03	+240	+257	-11	.5015444	.5015466	
																Mean.5015447	.5015450	.5015449

Rate determined from noon signals.

81097-4

PENDULUM OBSERVATIONS AND REDUCTIONS—Continued.

Station—OTTAWA, ONT.

Observer—F. A. McDIARMID.

DATE.	Swing number.	Pendulum.	Position.	Knife-edge.	COINCIDENCE INTERVAL.		ARC.		Temperature.	Pressure.	PERIOD UNCORRECTED.		CORRECTIONS (7TH DECIMAL PLACE).					PERIOD CORRECTED.			
					CHRONOMETER.		Initial.	Final.			CHRONOMETER.		Arc.	Temp.	Pressure.	RATE.		Flexure.	CHRONOMETER.		MEAN.
					Bond.	Negus.					Bond.	Negus.				B.	N.		Bond.	Negus.	
1914.					s.	s.	mm.	mm.	°	mm.	s.	s.						s.	s.	s.	
Apr. 15.....	1	1	D	I	189.54	190.46	5.0	1.9	17.91	43.50	.5013225	.5013161	-10	-122	+19	-134	-68	-11	.5012967	.5012969	.5012968
" 15.....	2	1	D	I	188.81	187.89	5.0	2.0	18.93	45.85	.5013276	.5013341	-10	-165	+17	-133	-203	-11	.5012974	.5012969	.5012971
" 16.....	3	1	D	I	188.43	188.16	4.8	1.8	18.95	48.60	.5013303	.5013322	-09	-166	+14	-166	-186	-11	.5012965	.5012964	.5012965
" 16.....	4	1	D	I	188.58	188.46	5.4	1.9	18.51	50.00	.5013292	.5013301	-11	-147	+13	-170	-179	-11	.5012966	.5012966	.5012966
" 16.....	5	1	D	I	189.05	188.90	5.6	2.0	18.11	51.50	.5013259	.5013270	-12	-130	+12	-145	-156	-11	.5012973	.5012973	.5012973
" 17.....	6	1	D	I	189.51	189.05	5.0	1.6	17.71	53.45	.5013227	.5013259	-08	-114	+10	-143	-170	-11	.5012961	.5012966	.5012964
															Mean.....				.5012968	.5012968	.5012968
Apr. 27.....	1	1	D	I	190.16	190.03	4.7	2.0	16.96	46.60	.5013182	.5013191	-09	-82	+16	-126	-135	-11	.5012970	.5012970	.5012970
" 30.....	2	1	D	I	188.04	189.12	5.4	1.6	19.75	52.20	.5013331	.5013254	-09	-199	+11	-157	-81	-11	.5012966	.5012966	.5012966
" 30.....	3	1	D	I	187.87	189.06	5.3	1.5	19.83	55.00	.5013341	.5013258	-09	-202	+09	-155	-74	-11	.5012973	.5012971	.5012972
															Mean.....				.5012970	.5012969	.5012969
																		Mean.....			.5012969
Apr. 17.....	1	3	D	I	173.79	174.04	5.5	1.8	17.84	48.50	.5014427	.5014406	-10	-119	+15	-150	-125	-11	.5014152	.5014156	.5014154
" 17.....	2	3	D	I	173.42	173.73	6.1	1.9	18.28	50.70	.5014458	.5014432	-14	-137	+14	-147	-127	-11	.5014163	.5014157	.5014160
" 17.....	3	3	D	I	173.96	173.77	5.8	1.6	18.16	52.65	.5014413	.5014428	-10	-132	+10	-113	-132	-11	.5014157	.5014153	.5014155
" 18.....	4	3	D	I	173.42	174.12	5.9	1.7	18.26	54.50	.5014458	.5014399	-10	-136	+08	-151	-93	-11	.5014158	.5014157	.5014158
" 18.....	5	3	D	I	173.10	173.83	5.5	1.9	18.78	56.60	.5014484	.5014415	-11	-154	+07	-152	-89	-11	.5014163	.5014157	.5014160
" 18.....	6	3	D	I	173.64	172.87	5.3	1.5	18.71	57.55	.5014439	.5014503	-09	-155	+06	-113	-174	-11	.5014157	.5014160	.5014158
															Mean.....				.5014158	.5014157	.5014158

GRAVITY.

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Station—PORTNEUF, QUE.

Observer—F. A. McDIARMID.

June 25.....	1	1	D	I	191.71	189.88	6.0	2.2	22.36	47.05	.5013075	.5013236	-14	-308	+17	-139	-271	-11	.5012626	.5012649		
" 25.....	2	1	D	I	194.06	193.17	5.8	1.5	17.07	52.90	.5012876	.5012975	-10	-87	+10	-139	-271	-11	.5012639	.5012606		
" 26.....	3	1	D	I	195.37	193.83	5.2	2.5	16.05	59.50	.5012832	.5012931	-13	-44	+03	-142	-240	-11	.5012625	.5012626		
																			Mean.....	.5012628	.5012627	.5012627
June 26.....	1	3	D	I	178.31	177.81	5.4	2.0	18.51	56.00	.5014060	.5014100	-11	-147	+08	-109	-151	-11	.5013790	.5013788		
" 26.....	2	3	D	I	178.40	176.83	5.2	2.2	17.64	59.15	.5014050	.5014178	-12	-111	+05	-141	-255	-11	.5013780	.5013794		
" 27.....	3	3	D	I	179.47	178.21	5.4	2.0	15.53	61.25	.5013999	.5014070	-11	-22	+02	-141	-255	-11	.5013786	.5013773		
																			Mean.....	.5013785	.5013785	.5013785

Station—St. JÉRÔME, QUE.

Observer—F. A. McDIARMID.

July 1.....	1	3	D	I	177.53	177.60	5.0	1.8	14.03	50.00	.5014122	.5014116	-09	+41	+12	-165	-146	-11	.5013990	.5014003		
" 2.....	2	3	D	I	177.47	177.86	5.0	1.6	13.88	52.40	.5014127	.5014096	-08	+47	+10	-165	-146	-11	.5014000	.5013988		
" 2.....	3	3	D	I	177.68	178.05	4.7	1.6	13.73	54.00	.5014110	.5014081	-08	+53	+09	-161	-131	-11	.5013992	.5013993		
																			Mean.....	.5013994	.5013995	.5013994
July 2.....	1	1	D	I	193.62	194.68	6.1	2.0	13.58	48.75	.5012845	.5012875	-14	+59	+13	-166	-40	-11	.5012826	.5012882		
" 3.....	2	1	D	I	193.69	196.51	6.4	1.9	13.06	51.30	.5012941	.5012755	-15	+81	+11	-166	-40	-11	.5012841	.5012781		
" 3.....	3	1	D	I	193.55	196.28	5.5	2.5	13.15	54.50	.5012950	.5012769	-14	+77	+07	-172	+12	-11	.5012837	.5012840		
																			Mean.....	.5012835	.5012834	.5012834

Station—StE. ANNE-DE-BELLEVUE, QUE.

Observer—F. A. McDIARMID.

July 8.....	1	1	D	I	188.75	187.74	5.5	2.3	20.13	46.25	.5013280	.5013352	-13	-215	+16	-174	-245	-11	.5012883	.5012884		
" 8.....	2	1	D	I	188.95	187.24	5.5	2.0	20.17	48.50	.5013268	.5013388	-12	-217	+14	-171	-248	-11	.5012871	.5012914		
" 9.....	3	1	D	I	188.59	188.07	5.4	1.6	20.20	52.65	.5013291	.5013328	-09	-218	+11	-171	-248	-11	.5012893	.5012853		
																			Mean.....	.5012882	.5012884	.5012883
July 9.....	1	1	D	I	173.84	172.36	6.1	2.1	20.35	52.00	.5014428	.5014547	-14	-224	+11	-140	-268	-11	.5014045	.5014041		
" 9.....	2	1	D	I	175.09	172.04	5.5	1.9	20.38	54.00	.5014319	.5014574	-12	-225	+10	-62	-282	-11	.5014019	.5014054		
" 10.....	3	1	D	I	174.81	172.56	5.0	1.7	20.37	57.0	.5014342	.5014530	-10	-228	+07	-62	-282	-11	.5014041	.5014009		
																			Mean.....	.5014035	.5014035	.5014035

PENDULUM OBSERVATIONS AND REDUCTIONS—Continued.

Station—MATTAWA, ONT.

Observer—F. A. McDIARMID.

DATE.	Swing number.	Pendulum.	Position.	Knife-edge.	COINCIDENCE INTERVAL.		ARC.		Temperature.	Pressure.	PERIOD UNCORRECTED.		CORRECTIONS (7TH DECIMAL PLACE).						PERIOD CORRECTED.		
					CHRONOMETER.		Initial.	Final.			CHRONOMETER.		Arc.	Temp.	Pressure.	RATE.		Flexure.	CHRONOMETER.		MEAN.
					Bond.	Dent.					Bond.	Dent.				B.	D.		Bond.	Dent.	
					s.	s.	mm.	mm.			°	mm.	s.	s.	s.	s.					
July 14.....	1	3	D	I	175.26	174.00	5.4	1.8	17.47	49.85	.5014305	.5014360	-10	-103	+13	-172	-250	-11	.5014022	.5013999	
" 14.....	2	3	D	I	175.55	174.38	6.0	1.7	16.69	52.00	.5014282	.5014378	-13	-71	+11	-172	-250	-11	.5014026	.5014044	
" 15.....	3	3	D	I	175.68	175.02	5.4	1.6	16.57	54.00	.5014271	.5014325	-09	-66	+09	-172	-225	-11	.5014022	.5014023	
															Mean.....				.5014023	.5014022	.5014022
July 15.....	1a	1	D	I	186.70	.....	5.6	4.5	16.87	48.25	.5013426	.....	-23	-78	+15	-140	.....	-11	.5013189		
" 15.....	1	1	D	I	186.76	185.35	5.9	2.6	16.97	49.75	.5013422	.5013525	-16	-82	+13	-140	-265	-11	.5013186	.5013164	
" 15.....	2	1	D	I	186.92	185.01	5.6	1.3	16.96	52.25	.5013411	.5013549	-09	-82	+11	-140	-265	-11	.5013180	.5013193	
" 16.....	3	1	D	I	186.74	186.10	5.0	1.8	16.96	55.40	.5013424	.5013470	-09	-82	+08	-148	-193	-11	.5013182	.5013183	
															Mean.....				.5013183	.5013180	.5013182

Station—LESKARD, ONT.

Observer—F. A. McDIARMID.

July 17.....	1	1	D	I	186.65	186.62	5.0	1.7	23.25	47.75	.5013430	.5013432	-09	-346	+16	-248	-240	-11	.5012832	.5012842	
" 18.....	2	1	D	I	187.75	187.96	5.4	1.6	21.40	54.00	.5013351	.5013336	-09	-268	+10	-248	-240	-11	.5012826	.5012818	
" 18.....	3	1	D	I	189.80	189.54	5.4	1.8	20.27	53.85	.5013274	.5013295	-10	-221	+10	-206	-228	-11	.5012836	.5012835	
															Mean.....				.5012831	.5012832	.5012831
July 18.....	1	3	D	I	178.52	178.79	5.6	1.8	19.35	48.50	.5014043	.5014022	-11	-182	+14	-199	-127	-11	.5013664	.5013705	
" 19.....	2	3	D	I	178.63	180.15	5.2	1.8	18.65	51.50	.5014036	.5013916	-19	-153	+12	-199	-127	-11	.5013675	.5013627	
" 19.....	3	3	D	I	178.65	180.00	5.8	2.0	18.43	55.75	.5014032	.5013923	-13	-144	+07	-204	-100	-11	.5013667	.5013667	
															Mean.....				.5013665	.5013666	.5013666

Station—COCHRANE, ONT.

Observer—F. A. McDIARMID.

July 20.....	1	3	D	I	183.03	182.67	5.6	1.8	17.74	46.83	.5013696	.5013723	-11	-115	+16	-155	-136	-11	.5013420	.5013466	
" 21.....	2	3	D	I	183.11	184.03	5.4	1.9	17.24	51.75	.5013690	.5013622	-11	-94	+11	-155	-136	-11	.5013430	.5013381	
" 21.....	3	3	D	I	183.25	183.85	5.9	1.8	17.14	55.40	.5013680	.5013655	-12	-90	+08	-150	-109	-11	.5013425	.5013421	
																		Mean. ....	.5013425	.5013423	.5013424
July 21.....	1	1	D	I	195.24	194.76	5.6	1.9	17.17	52.00	.5012838	.5012869	-12	-91	+11	-153	-162	-11	.5012582	.5012604	
" 22.....	2	1	D	I	194.85	195.08	6.0	1.8	17.34	61.00	.5012863	.5012848	-13	-98	+03	-153	-162	-11	.5012591	.5012567	
" 23.....	3	1	D	I	194.16	194.67	4.9	1.6	18.05	55.00	.5012908	.5012875	-08	-128	+08	-177	-141	-11	.5012593	.5012595	
																		Mean. ....	.5012589	.5012589	.5012589

Station—SAULT STE. MARIE, ONT.

Observer—F. A. McDIARMID.

July 24.....	1	1	D	I	185.78	186.07	5.7	1.8	19.70	55.30	.5013493	.5013472	-11	-197	+09	-172	-177	-11	.5013111	.5013087	
" 25.....	2	1	D	I	186.42	185.99	6.1	1.9	18.66	55.40	.5013447	.5013478	-14	-153	+09	-172	-177	-11	.5013106	.5013132	
" 25.....	3	1	D	I	186.31	187.76	5.9	2.0	18.29	58.75	.5013455	.5013350	-13	-138	+05	-195	-90	-11	.5013103	.5013103	
																		Mean. ....	.5013107	.5013107	.5013107
" 25.....	1	3	D	I	175.88	175.88	5.8	2.0	18.21	59.60	.5014255	.5014255	-13	-134	+04	-165	-125	-11	.5013936	.5013976	
" 26.....	2	3	D	I	175.84	176.93	5.7	1.5	18.06	63.09	.5014258	.5014170	-09	-128	00	-165	-125	-11	.5013945	.5013897	
" 26.....	3	3	D	I	175.54	176.58	5.2	3.3	17.96	53.70	.5014282	.5014198	-16	-124	+09	-189	-79	-11	.5013951	.5013977	
" 26.....	4	3	D	I	175.61	177.12	2.8	1.6	18.19	74.38	.5014277	.5014155	-04	-133	-09	-189	-79	-11	.5013931	.5013919	
																		Mean. ....	.5013941	.5013942	.5013942

GRAVITY.

PENDULUM OBSERVATIONS AND REDUCTIONS—Continued.

Station—CHAPLEAU, ONT.

Observer—F. A. McDIARMID.

DATE.	Swing number.	Pendulum.	Position.	Knife-edge.	COINCIDENCE INTERVAL.		ARC.		Temperature.	Pressure.	PERIOD UNCORRECTED		CORRECTIONS (7TH DECIMAL PLACE).					PERIOD CORRECTED.					
					CHRONOMETER.		Initial.	Final.			Bond.	Dent.	CHRONOMETER.		Arc.	Temp.	Pressure.	RATE.		Flexure.	CHRONOMETER.		MEAN.
					Bond.	Dent.							Bond.	Dent.				B.	D.		Bond.	Dent.	
					s.	s.	mm.	mm.			°	mm.	s.	s.				mm.	mm.		mm.	mm.	
1914.																							
July 28.....	1	3	D	I	178.79	178.99	4.7	3.9	16.20	58.50	.5014022	.5014006	-16	-50	+04	-236	-207	-11	.5013713	.5013726			
" 28.....	1a	3	D	I	178.80	179.22	3.6	1.8	15.90	63.82	.5014021	.5013988	-06	-38	-01	-236	-207	-11	.5013729	.5013725			
" 28.....	2	3	D	I	178.86	180.51	5.5	1.6	15.22	68.25	.5014027	.5013888	-09	-09	-04	-238	-108	-11	.5013746	.5013747			
" 29.....	3	3	D	I	179.68	181.46	5.6	2.3	14.53	60.25	.5013952	.5013815	-13	+20	+03	-238	-108	-11	.5013713	.5013706			
															Mean.....	.....	.....	.....	.5013725	.5013726	.5013726
July 29.....	1	1	D	I	191.00	192.07	5.5	1.5	15.75	59.85	.5013124	.5013048	-09	-31	+03	-197	-96	-11	.5012879	.5012904			
" 30.....	2	1	D	I	191.40	193.23	6.1	1.7	14.69	60.40	.5013096	.5012972	-12	+13	+03	-197	-96	-11	.5012892	.5012869			
" 30.....	3	1	D	I	191.37	193.33	5.3	1.9	14.78	56.65	.5013098	.5012965	-11	+09	+05	-210	-77	-11	.5012880	.5012880			
															Mean.....	.....	.....	.....	.5012884	.5012884	.5012884
July 30.....	1	3	D	I	181.74	181.07	5.6	2.1	15.12	45.70	.5013794	.5013848	-12	-05	+17	-45	-104	-11	.5013738	.5013733			
" 31.....	2	3	D	I	181.86	180.95	5.2	1.8	15.12	57.25	.5013785	.5013854	-10	-05	+06	-45	-104	-11	.5013720	.5013730			
" 31.....	3*	3	D	I	182.00	181.09	5.8	1.9	15.03	59.25	.5013774	.5013844	-13	-01	+04	-26	-97	-11	.5013727	.5013726			
															Mean.....	.....	.....	.....	.5013728	.5013730	.5013729

Station—PORT ARTHUR, ONT.

Observer—F. A. McDIARMID.

Aug. 3.....	1	3	D	I	182.77	183.99	6.0	2.1	15.36	49.40	.5013716	.5013625	-14	-15	+14	-105	+23	-11	.5013585	.5013622		
" 4.....	2	3	D	I	182.58	184.78	6.5	1.9	15.15	67.65	.5013730	.5013566	-17	-06	-04	-105	+23	-11	.5013587	.5013551		
" 4.....	3	3	D	I	183.02	185.22	6.4	2.0	15.05	53.35	.5013697	.5013534	-15	-02	+05	- 89	+82	-11	.5013585	.5013593		
																			Mean.....	.5013586	.5013589	.5013587
" 4.....	1	1	D	I	195.48	197.70	5.3	1.6	15.08	45.50	.5012827	.5012677	-09	-03	+18	- 90	+56	-11	.5012732	.5012728		
" 5.....	2	1	D	I	194.68	196.77	5.9	1.8	15.05	62.65	.5012875	.5012738	-13	-02	00	- 90	+56	-11	.5012759	.5012768		
" 5.....	3	1	D	I	194.73	196.70	5.2	1.4	15.12	65.25	.5012871	.5012727	-09	-05	-02	- 93	+45	-11	.5012751	.5012745		
																			Mean.....	.5012747	.5012745	.5012746

PENDULUM OBSERVATIONS AND REDUCTIONS.—Continued.

Station—OTTAWA, ONT.

Observer—F. A. McDIARMID.

DATE.	Swing number.	Pendulum.	Position.	Knife-edge.	COINCIDENCE INTERVAL.		ARC.		Temperature.	Pressure.	PERIOD UNCORRECTED.		CORRECTIONS (7TH DECIMAL PLACE).					PERIOD CORRECTED.			
					CHRONOMETER.		Initial.	Final.			CHRONOMETER.		Arc.	Temp.	Pressure.	RATE.			CHRONOMETER.		MEAN.
					Riefler.	Bond.					Riefler.	Bond.				R.	B.	Flexure.	Riefler.	Bond.	
					s.	s.	mm.	mm.			°	mm.				s.	s.	s.	s.		
1914.																					
Aug. 12.....	1	1	D	I	183.96	181.12	5.5	2.8	23.10	46.10	.5013624	.5013841	-15	-339	+18	-12	-230	-11	.5013265	.5013264	.5013265
" 12.....	2	1	D	I	184.08	181.12	5.4	1.5	22.95	51.95	.5013618	.5013841	-09	-333	+12	-12	-235	-11	.5013265	.5013265	.5013265
" 13.....	3	1	D	I	184.23	182.15	5.9	1.5	22.25	64.40	.5013607	.5013763	-10	-304	00	-12	-167	-11	.5013270	.5013271	.5013270
																Mean.....	.....	.....	.5013267	.5013267	.5013267
Aug. 13.....	1	3	D	I	173.96	172.22	5.2	1.9	22.20	48.65	.5014413	.5014559	-11	-302	+15	-12	-156	-11	.5014092	.5014094	.5014093
" 13.....	2	3	D	I	173.66	171.38	5.6	1.3	22.28	61.65	.5014438	.5014630	-08	-305	+02	-12	-205	-11	.5014104	.5014103	.5014103
" 14.....	3	3	D	I	173.61	171.15	5.3	1.7	22.15	69.65	.5014442	.5014650	-10	-300	-05	-12	-225	-11	.5014104	.5014099	.5014102
" 14.....	4	3	D	I	173.51	171.14	4.9	2.1	22.35	62.25	.5014447	.5014651	-10	-308	+02	-12	-216	-11	.5014108	.5014108	.5014108
																Mean.....	.....	.....	.5014102	.5014101	.5014101

DEDUCTION OF ABSOLUTE GRAVITY.

The ratio of gravity at two places is readily obtained from fundamental formula of the simple pendulum, $P = \pi \sqrt{\frac{l}{g}}$, where P is the period and l is the length of the corresponding pendulum, and g is the force of gravity. We have then the relation, $P^2 : P_x^2 = g_x : g$, or $g = \frac{P_x^2}{P^2} \times g_x$, where P_x and g_x are the period and gravity at the base station and P is the period at the field station.

The observed value of gravity at Washington is taken as 980.112 dynes. Adopting this value, and using the values of the periods of pendulums 1 and 3 for Washington and Ottawa, the values of gravity for Ottawa are 980.618, 980.613, 980.616 and 980.615 dynes, or the mean value of gravity at Ottawa is 980.615 dynes which has been adopted as the observed value for Ottawa.

All the field stations have been referred to Ottawa. In deducing the gravity for the different stations three different sets of values for the pendulums at Ottawa were used. The change in periods has already been referred to in the discussion of "Variation in lengths of pendulums." For the stations, Maniwaki, Kingston, Roberval, Tadoussac, Portneuf, St. Jérôme, and Ste. Anne-de-Bellevue, the periods of the pendulums obtained at Ottawa in May were used; for the stations, Mattawa, Liskeard, Cochrane, Sault Ste. Marie, Chapleau, Port Arthur and Rose Point, the periods obtained in August were used; and for Whitby, Woodstock and Windsor, the periods obtained in September were used.

COMPUTATION OF THE INTENSITY OF GRAVITY AT ANY SELECTED STATION.

The intensity of gravity may be computed on an ideal earth having the same size and shape as an ellipsoid of revolution which most nearly coincides with the sea-level surface of the real earth, and having no topography and no variations in density at any depth. To convert the real earth into this ideal earth all material on the real earth above sea-level must be removed, the water of the ocean must be replaced by material of density equal to the mean surface density of the real earth, and all

variations in density at any given depth in the real earth must then be removed by taking out or rejecting enough material in each part to make the density conform accurately to the mean density in the real earth at that point. In this ideal earth the density will increase with increase of depth in the same manner as it does upon an average in the real earth, but in the ideal earth all masses lying at the same depth will have the same density, whereas in the real earth such masses have densities which are known to differ slightly from one another.

Using Helmert's formula $\gamma_0 = 978.030 (1 + 0.005302 \sin^2 \varphi - 0.000007 \sin^2 2\varphi)$, where γ_0 = required gravity at a station on the ideal earth above described in the latitude φ . On such an ideal earth the value of gravity at the surface would be a function of the latitude only. The numerical value of γ_0 is both the acceleration in centimetres per second per second, and the attraction in dynes on a unit mass (1 gram) at the station expressed in the centimetre-gram-second system.

The formula is thus fixed by theory. The three constants 978.030, 0.005302 and 0.000007 were derived from a great number of observations scattered over the surface of the earth. New and better values of these constants will no doubt be obtained from more observations. Up to the present time there have only been the few observations for gravity already referred to taken in Canada, and so the observed value of gravity at many stations scattered over the northern half of this continent should give information that will be of great value in determining the correct equation for gravity.

In computing the intensity of gravity in the United States, Helmert's formula was used; and from the observations there a small correction to the constant 978.030 was made. It became 978.038.

CORRECTIONS FOR ELEVATION, TOPOGRAPHY, AND ISOSTATIC COMPENSATION.

Elevation.—The correction for elevation was computed by the formula $-0.0003086 H$, in which H is the elevation of the station above sea-level in metres. This correction of the attraction upon a unit mass (1 gram)

at the station is in dynes and reduces from sea-level to the actual station. It takes account of the increased distance from the attracting mass, as if the station were in the air at the stated elevation and there were no topography on the earth.

Topography and Isostatic Compensation.—The stations at which observations are made are on the real earth, and are in general above sea-level. The second part of the computation of the intensity of gravity at any station must therefore take account of the topography which exists on the earth, take account as far as possible of the variations in density which exist on the real earth, and take account as far as possible of the variations in density beneath the surface of the true earth, and take account of the elevation of the observing station above sea-level.

To apply the corrections for topography and isostatic compensation, accurate topographical maps are required, at the present time there are no such maps of Canada, hence the discussion of these corrections will be treated in a later report. Messrs. Hayford and Bowie have discussed the whole matter very fully in their publication "The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity."

However, there are other methods of reducing the value of the force of gravity from sea-level to the observing station. These are known as the "free-air" method, Bouguer's method and Faye's method. The free-air method takes account only of the elevation above sea-level. The station is considered as if it were suspended in the air at a height equal to the elevation. In Bouguer's formula $dg = -\frac{2g \cdot H}{r} \left(1 - \frac{3\delta}{4\Delta}\right)$, on the supposition that the station is situated on an indefinitely extended plain. Here dg is the correction to computed gravity, g , at sea-level, H is the elevation above sea-level, r is the radius of the earth, δ is the density of the matter lying above sea-level, and Δ is the mean density of the earth. The Bouguer method takes no account of the isostatic compensation and neglects all curvature of the sea-level surface, the topography being treated as if it were standing on a plain of indefinite extent. The results from applying these two methods seem to lead to the conclusion that general continental

elevations are compensated by a deficiency of density in the matter below sea-level, but that local topographical irregularities, whether elevations or depressions, are not compensated for, such irregularities being maintained by the partial rigidity of the earth's crust.

The residuals with Bouguer's reduction should then be interpreted as a measure of the deficiency of density, and on the other hand, the residuals with the reduction for elevation should be taken as a measure of the lack of compensation, after allowing for uncertainties of observation and the effects of local geological conditions. Developing the idea of M. Faye, observed values of g may be corrected for this lack of compensation by adding or subtracting the vertical attraction of a horizontal plain whose thickness is the difference in elevation between the station and the average surrounding surface. This correction may be expressed by $dg = 2g \cdot \frac{h}{r} \cdot \frac{3\delta}{4\Delta}$, which represents the attraction of an indefinitely extended horizontal plain of thickness h and density δ . The correction is positive for stations below the average level and negative for stations above the average level. The average elevation may be secured from a contour map for the country within a radius of one hundred miles.

In the following Table I will be given the values for the periods of the pendulums at the different stations, and the deduced value of gravity in dynes. In Table II will be applied the corrections for elevation and topography according to the three different methods outlined above. In Table III will be found a comparison between the gravity obtained for Ottawa in 1902 and in 1914. The difference of .014 dynes is probably due in part to the situation of the two stations. The 1902 station was near the bank of the Ottawa river; the bank at this point rising about one hundred feet from the water in an almost perpendicular direction. The 1914 station is distant from the river about one and a half miles, and the country around the station is fairly level.

TABLE I.

Station.	PERIOD OF PENDULUM.		VALUE OF g IN DYNES.		
	1	3	1	3	Mean
Washington.....	s. ·5014261	s. ·5015449			980·112
Ottawa.....	·5012969	·5014160	980·618	980·616	
Washington.....	·5014273	·5015445			
Ottawa.....	·5012993	·5014157	980·613	980·615	980·615
Maniwaki.....	·5012811	·5013980	980·686	980·684	980·685
Kingston.....	·5013216	·5014383	980·528	980·526	980·527
Roberval.....	·5012357	·5013512	980·863	980·867	980·865
Tadoussac.....	·5012266	·5013422	980·900	980·903	980·901
Portneuf.....	·5012627	·5013785	980·759	980·761	980·760
St. Jérôme.....	·5012834	·5013993	980·677	980·679	980·678
Ste. Anne-de-Bellevue.....	·5012883	·5014035	980·657	980·663	980·660
Ottawa.....	·5013267	·5014101			980·615
Mattawa.....	·5013182	·5014022	980·647	980·646	980·647
Liskeard.....	·5012831	·5013666	980·785	980·785	980·785
Cochrane.....	·5012589	·5013424	980·880	980·880	980·880
Sault Ste. Marie.....	·5013107	·5013942	980·677	980·677	980·677
Chapleau.....	·5012884	·5013727	980·764	980·762	980·763
Port Arthur.....	·5012747	·5013587	980·818	980·816	980·817
Rose Point.....	·5013292	·5014140	980·605	980·600	980·603
Ottawa.....	·5013208	·5014101			980·615
Whitby.....	·5013615	·5014493	980·455	980·461	980·458
Woodstock.....	·5013891	·5014778	980·348	980·350	980·349
Windsor.....	·5013920	·5014806	980·337	980·340	980·338

TABLE II.

Station	Longi- tude	Lati- tude	Alti- tude	Com- puted g at sea-level	CORRECTIONS			Observed Gravity	ANOMALIES		
					Free-air	Bouguer	Faye		Free-air	Bouguer	Faye
	h. m. s.	° ' "	metres	dynes.	dynes.	dynes.	dynes.	dynes.	dynes.	dynes.	dynes.
Ottawa.....	5 02 52	45 23 39	83	980.651	-.026	-.016	-.033	980.615	-.010	-.020	-.003
Maniwaki.....	5 03 55	46 22 28	169	980.740	-.052	-.033	-.058	980.685	-.003	-.022	+0.003
Kingston.....	5 05 52	44 14 37	79	980.547	-.024	-.015	-.024	980.527	+0.004	-.005	+0.004
Roberval.....	4 48 54	48 30 54	107	980.933	-.033	-.021	-.065	980.865	-.035	-.047	-.003
Tadoussac.....	4 38 52	48 08 25	12	980.900	-.004	-.002	+0.027	980.901	+0.005	+0.003	-.026
Portneuf.....	4 47 35	46 42 32	59	980.770	-.018	-.011	-.014	980.760	+0.008	+0.001	+0.004
St. Jérôme.....	4 52 28	45 46 34	107	980.686	-.033	-.021	-.033	980.678	+0.025	+0.013	+0.025
Ste. Anne-de-Bellevue.....	4 55 48	45 24 27	34	980.653	-.010	-.006	-.012	980.660	+0.017	+0.013	+0.019
Mattawa.....	5 14 47	46 18 43	170	980.734	-.052	-.033	-.069	980.647	-.035	-.054	-.018
Liskeard.....	5 18 50	47 30 34	194	980.843	-.060	-.037	-.063	980.785	+0.002	-.021	+0.005
Cochrane.....	5 24 05	49 03 44	277	980.983	-.085	-.053	-.089	980.880	-.018	-.050	-.014
Sault Ste. Marie.....	5 37 18	46 30 26	186	980.752	-.057	-.036	-.067	980.677	-.018	-.039	-.008
Chapleau.....	5 33 36	47 50 27	430	980.872	-.133	-.083	-.126	980.763	+0.024	-.026	+0.017
Port Arthur.....	5 56 52	48 26 00	189	980.926	-.058	-.036	-.074	980.817	-.051	-.073	-.035
Rose Point.....	5 20 10	45 19 02	183	980.644	-.056	-.035	-.052	980.603	+0.015	-.006	+0.011
Whitby.....	5 15 46	43 52 43	84	980.514	-.026	-.016	-.030	980.458	-.030	-.040	-.026
Woodstock.....	5 23 07	43 08 33	299	980.448	-.093	-.060	-.093	980.349	-.006	-.039	-.006
Windsor.....	5 32 10	42 19 16	178	980.373	-.055	-.034	-.051	980.338	+0.020	-.001	+0.016
Indiscriminate mean.....									-.018	-.027	-.014
Algebraic mean.....									-.005	-.022	-.002

TABLE III.

COMPARISON OF OBSERVED GRAVITY, OTTAWA, 1902 AND 1914.

Station	Latitude	Diff. of Latitude	Altitude	Diff. of Altitude	Observed Gravity	1902 STATION TO 1914 STATION		Gravity at 1914 Station
						Corrections for		
						Latitude	Altitude	
	° ' "	' "	metres	metres	dynes	dynes	dynes	dynes
Ottawa (1902)...	45 25 23	1 44	73	.....	980.607	-.003	-.003	980.601
Ottawa (1914)...	45 23 39	.....	83	10	980.615	.....	.....	980.615
Difference								-.014

REASONS FOR THE PROSECUTION OF PENDULUM WORK*

“(1) The first scientific object of a geodetic survey is the determination of the earth’s figure. It is probable that pendulum experiments afford the best method of determining the amount of oblateness of the spheroid of the earth, for the calculated probable error in the determination of the quantity in question from pendulum observations does not exceed that of the best determination from triangulation and latitude observations. Besides, the measurement of astronomic arcs upon the surface of the earth cover only limited districts, and the oblateness deduced from them is necessarily affected. On the other hand, the pendulum determinations are subject to no great errors which least-squares cannot ascertain; they may be widely scattered over the earth, they may be very numerous, they are combined to obtain the ellipticity by a simple arithmetical process; and the calculated probable error deduced from them is worthy of unusual confidence. It is very significant that while the value derived from pendulum work has remained nearly constant, that derived from measurements of arc has been continually changing as more data has been secured, and the change has been in the direction to accord with the pendulum method. Also, the expense of the pendulum method is small compared with the geodetic method.

“(2.) Investigation has shown the importance of pendulum experiments to metrology.

“(3.) Geologists affirm that from the values of gravity at different points, useful inference can be drawn in regard to the geological formation of the underlying strata.

“(4.) Gravity is extensively employed as a unit in the measurement of forces. Thus, the pressure of the atmosphere is, in the barometer, balanced against the weight of a measured column of mercury; the mechanical equivalent of heat is measured in foot-pounds, etc. All such measurements refer to a standard which is different in different localities, and it is therefore very important to determine the amounts of these differences as the exactitude of measurement is improved.

“(5) It is hoped that as the knowledge of the constitution of the earth’s crust becomes, by the aid of pendulum experiments, more perfected we shall be able to establish methods by which we can with confidence infer

*United States C. & G. S. report 1882, Appendix No. 22.

from the vertical attraction of mountains, etc., what their horizontal attraction, and the resulting deflection of the plumb line must be.

“(6.) Although in laying out the plan of a geodetic survey the relative utility of the knowledge of different quantities ought to be taken into account, and such account must be favourable to pendulum work, yet it is true that nothing appertaining to such a survey ought to be neglected. The knowledge of the force of gravity is not a mere matter of utility alone, it is also one of the fundamental kinds of quantity which it is the duty of a geophysical survey to measure. Astronomical longitudes and latitudes are determinations of the direction of gravity; pendulum experiments determine its amount. The force of gravity is related in the same way to the latitude and longitude as the intensity of magnetic force is related to the magnetic declination and inclination, and, as a magnetic survey would be held to be imperfect in which measurements of intensity were omitted, to the same extent must a geodetic survey be held to be imperfect in which the determinations of gravity have been omitted.”

These reasons for the prosecution of pendulum determinations were given by Mr. C. S. Pierce before a conference on gravity determinations held in Washington in May, 1882. This conference was attended by the Superintendent of the United States Coast and Geodetic Survey, Major Herschel, R.E., Prof. C. S. Pierce, Prof. Newcomb, and Messrs. George Davidson and C. A. Schott. But what was true in 1882 applies with equal force in 1914, and especially in a country such as Canada where a geodetic survey is only in its infancy.

CONCLUSION.

In concluding this report the writer desires to express his gratitude for assistance which he has received from Mr. William Bowie, Chief of the Computing Division of the United States Coast and Geodetic Survey, from Mr. W. H. Burger in his article on “The Measurement of the Flexure of pendulum supports with the Interferometer”, and from Dr. W. F. King, Chief Astronomer, who gave many valuable suggestions.

Dominion Observatory,

Ottawa,

April, 1915.

DEPARTMENT OF THE INTERIOR
CANADA

HON. W. J. ROCHÉ, *Minister*. W. W. CORY, C.M.G., *Deputy Minister*.

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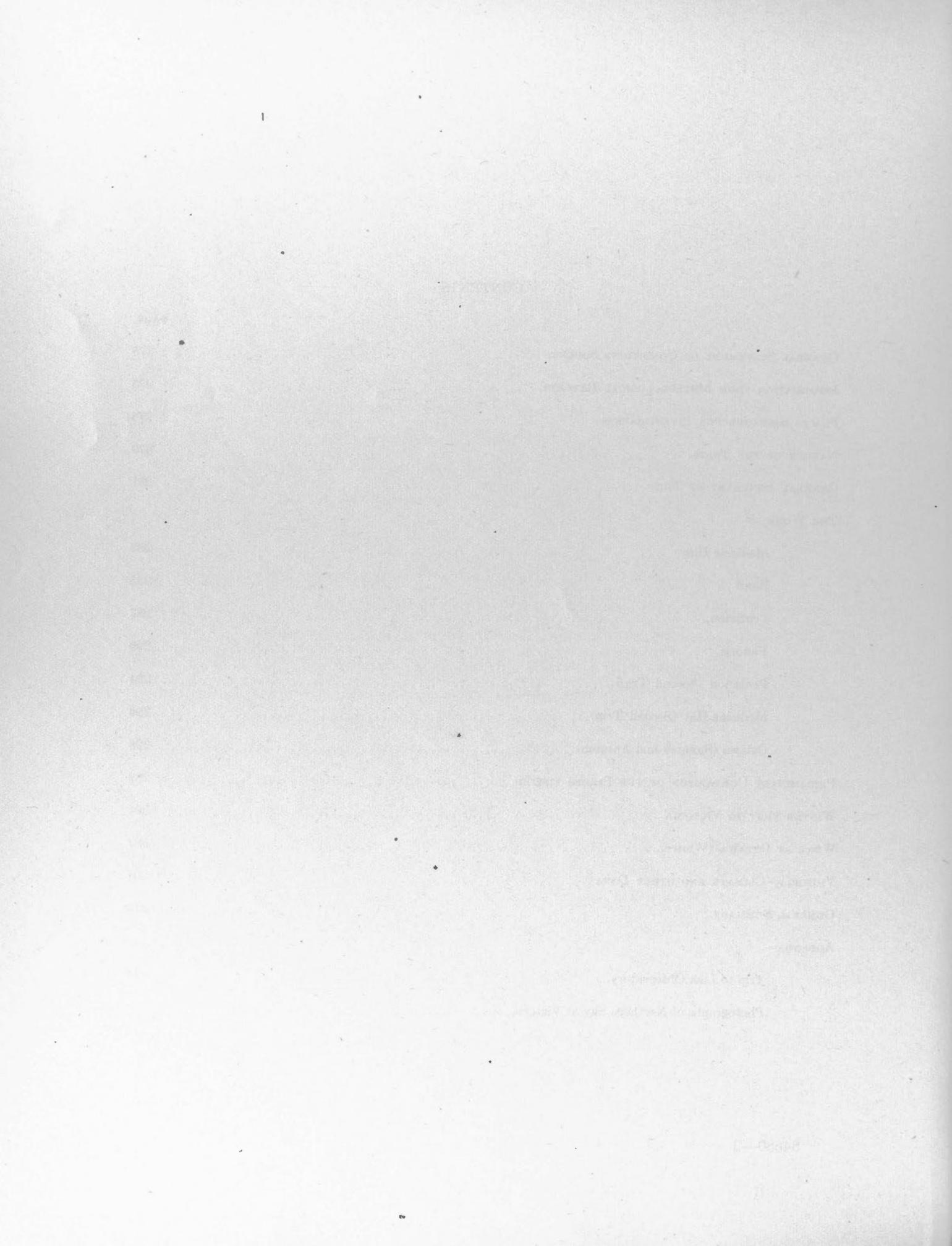
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TESTS MADE TO ASCERTAIN WHERE CONDITIONS WERE THE MOST SUITABLE FOR THE 72-INCH REFLECTOR.*

BY W. E. HARPER, M.A.

The proposal to instal a powerful reflecting telescope six feet in diameter necessitated testing where the atmospheric conditions were most suitable, as such an instrument would require the very best conditions attainable. The following report treats of the tests made at different stations in Canada with that end in view.

It seemed natural that the meteorological reports which give the general climatic conditions such as temperature, precipitation, amount of clear sky, etc., would be of first importance in selecting in a general way where such favourable places might be found. What was desired of course was the place having the greatest percentage of clear nights and the best conditions of seeing on these nights. Naturally the greatest number of clear nights might be expected where the precipitation was not excessive; the transparency would depend in a measure upon the altitude above sea-level, while steadiness would depend upon many things. Upon the degree to which these conditions were fulfilled would depend the suitability of the place, considered from an astronomical standpoint. Proximity or easy access to a large city and suitable conditions for living would also be important considerations and should have due weight.

INFORMATION FROM METEOROLOGICAL REPORTS.

A compilation of meteorological data from places all over Canada was accordingly made. The available data were much more comprehensive from some places than from others, but the following table contains all that there is valuable in this connection. The preliminary table compiled

*Somewhat abridged from a report to the Director in January, 1914.

included a number of other places, but from the data they were so inferior that this second limited number only was considered. In the table the days are reckoned as clear if there is less than 30 per cent. of cloud, partly cloudy if from 30 per cent. to 70 per cent., while excess of this percentage ranks a day as cloudy. The column headed "cloudiness" sums up these results and gives a fairly reliable index of the character of the day even though the personal equation of the observer must enter into it. Of recent years sunshine recorders have been introduced at a great many stations which do away with this personal equation. The results for the places given in the table bear out the estimates of the observers. Now, while the "day clearness" is not strictly the "night clearness," and local conditions can be imagined which would make the two differ, yet it is the consensus of opinion that in the long run the two will average up about the same and hence the percentage of cloudiness for the day may be taken as representative of the night as well. Later on mention will be made of special work having in view the determination of the "quantity" of seeing at some of the stations selected.

METEOROLOGICAL DATA 14 YEARS (1895-1908).

	Altitude. Feet.	TEMPERATURE.				DAYS.					Mean Total Precipitation. inches.	Mean Total Precipitation 20 years. inches.	Humidity.	Cloudiness. Days Completely Clouded.	Wind Velocity.	Remarks.	
		Highest. °	Lowest. °	Mean Daily Range. °	Mean Yearly. °	Clear.	Partly Cloudy.	Cloudy.	Precipitation .01 in. or over Snow.								
Ottawa.....	296	93.2	-23.3	18.2	43.0	93	137	135	126	57	32.98	33.40	83	58	62	6.7	
Gravenhurst.....	770	91.3	-31.7	20.2	.....	126	129	110	105	60	35.85	.....	50	..	5.8	1908 missing.	
Winnipeg.....	760	92.1	-39.2	22.8	34.9	117	135	113	103	53	20.95	20.81	81	53	94	13.9	
Battleford.....	1620	92.0	-40.8	22.3	34.4	127	136	103	99	49	14.64	13.79	78	50	41	7.9	
Medicine Hat.....	2161	98.9	-35.3	24.6	41.3	111	150	104	75	40	14.60	13.11	70	53	56	7.5	
Calgary.....	3389	89.5	-32.7	24.0	37.4	110	164	92	79	35	19.02	16.30	78	50	..	8.5	
Banff.....	4542	85.8	-35.7	21.7	35.6	103	156	106	138	73	21.09	21.11	70	52	..	4.1	
*Okanagan.....	1200	94.3	-11.2	21.1	.....	.....	.....	.....	70	27	12.58	.....	.....	.....	.....	.....	Years 1903-11 inclusive.
Kamloops.....	1193	98.5	- 8.6	19.1	47.7	94	149	122	71	17	9.86	10.62	71	56	55	3.8	1895, 6, 7 missing.
Victoria.....	85	84.7	+20.3	12.4	50.3	91	107	168	152	8	26.51	27.83	80	63	73	8.3	1895, 6, 7 missing.

*Years 1909-11 inclusive from Kelowna 10 miles northeast.

Since this table was compiled other data have come to hand, which bear upon the question and may be tabulated here. Most of this was secured when the writer visited the different stations and through the kindness of the observers had access to the detailed meteorological records at these places.

BANFF (SULPHUR MOUNTAIN, ALTITUDE 7484 FEET).

MEAN WIND VELOCITY FOR 1910.

Miles per Hour.			
January.....	24.3	July.....	17.6
February.....	18.8	August.....	14.2
March.....	21.5	September.....	15.8
April.....	19.0	October.....	23.2
May.....	18.0	November.....	17.0
June.....	15.4	December.....	24.5

This is a typical year and the average is 19.1 miles per hour. The observer, Mr. S. B. Sanson, says velocities as high as 100 miles per hour have been recorded and the total movement for one continuous hour has been as high as 72 miles.

VICTORIA, B.C.

Month.	1899 to 1912 Inclusive.		Hours sunshine in 1913.
	Mean total movement of wind in miles.	Mean number of hours sunshine.	
January.....	6704	53	50
February.....	5848	86	81
March.....	6330	143	121
April.....	6100	188	127
May.....	6248	202	166
June.....	6524	225	167
July.....	6252	296	274
August.....	5474	255	237
September.....	4280	190	198
October.....	4662	116	91
November.....	5927	56	56
December.....	6377	38	34

VICTORIA, B.C.

WIND VELOCITY 1899 TO 1912 INCLUSIVE.

Direction.	Total movement miles.	Number of hours.
S-W.....	322,459	26,472
N.....	120,774	22,100
W.....	164,434	16,586
S.....	106,469	15,374
N-E.....	78,909	11,153
E.....	72,512	10,682
S-E.....	101,332	9,240
N-W.....	23,264	4,633

In the general table the mean daily range for Okanagan is given as 21° F. As mentioned later Penticton, at the southern end of the Okanagan valley, was selected as one of the places to be tested. While there, the readings of the thermometer for 1910 and 1912 were given me by the observer, and from these the mean daily range for the years in question was 20° F. so that, although the place is about 30 miles from the Okanagan station, the data compiled for Okanagan will serve for Penticton.

No data as to the character of the days in the Okanagan were available for the years tabulated. However the sunshine recorder at Summerland, though installed only within recent years, shows the amount of clear sky to be about the average and thus from the table no one place has a commanding superiority in this regard. The low daily range of temperature at Victoria would lead one to expect fairly steady seeing at that place. The range there for the year is just one-half what it is at Ottawa.

PLACES SELECTED FOR INVESTIGATION.

Keeping in mind that preference be given to stations of southerly latitude, so that more stars could be reached in the southern hemisphere, the stations were simmered down to four which were thought to be typical of the various sections. The prairie section should produce uniform atmospheric conditions, particularly if an elevated plateau were available, and of the places on the prairie, Medicine Hat was deemed the most

promising. The Rocky Mountain section, where high altitudes are possible, was deemed worth testing and Banff was selected as typical. The dry belts of British Columbia were considered promising also, and the Okanagan valley, Penticton district, was selected as the particular place, while Victoria with its exceedingly small diurnal range of temperature seemed promising as regards steady seeing, and it made up the fourth station outside of Ottawa where specific tests were to be made. Incidentally during the progress of the work, a cursory examination of a number of other places was made.

NATURE OF THE TESTS.

Something of the nature of the tests at these five places will now be given. The principal instrument used was a Cooke $4\frac{1}{2}$ -inch telescope, equatorially mounted. This photo-visual telescope was equipped with eyepieces of magnifying powers 60, 120, 180 and 320, and a camera taking plates of cabinet size. While the programme was almost wholly planned for visual work, yet it was felt advisable to make some photographic tests which might serve as a check upon the visual work. The camera, belonging to the telescope, can be quickly attached and takes plates covering a field about 3° in diameter. Two fields were selected near the pole containing stars of various degrees of brightness. On the majority of the nights on which work was done, one or both fields were photographed by allowing the stars to trail across the plate for six or eight minutes. If care is taken to insure uniformity, particularly in the development of the plates, a comparison of the intensities of the star trails impressed upon the plates should give an indication of the relative transparency of the atmosphere from night to night. The photographic work was not considered of primary importance; it was intended to serve merely as a check upon the visual work upon which almost entire dependence was to be placed.

A list of close double stars was selected as was also a number of faint stars about the limit for the telescope. The steadier the seeing the smaller the star discs would be, and these would be the conditions most favourable to the resolution of close doubles. The theoretical limit for the size of

star disc for this telescope is approximately $1''\cdot0$ of arc but, owing to unfavourable conditions of seeing, it is not often that this theoretical limit of a telescope is attained. As will appear later, however, there were several nights experienced so favourable that this theoretical limit was reached. Thus the examination of close doubles, with a view to learning the minimum amount of separation that could be detected, formed the bulk of the observational work. The steadiness of the diffraction rings of bright stars would also give a clue to the seeing conditions and note was to be made of these. The transparency of the atmosphere could be arrived at, in a sense, from naked eye observations of objects about the limit in brightness for the eye and also in a certain measure from the ease with which faint stars could be picked up in the telescope. Caution would have to be exercised in this latter procedure, as it would be hard to dissociate transparency from steadiness. The theoretical limit of visibility for the telescope lies between $12\cdot0$ and $12\cdot5$ magnitudes.

Besides the telescope a few other instruments, mostly for meteorological purposes, were taken along. A thermograph was deemed useful to note the range in temperature, particularly during the night, as this is quite important in the case of large reflectors. A wet and dry bulb thermometer to note the humidity of the atmosphere, an aneroid barometer for use where no barometric readings were kept, and an anemometer for registration of wind movement completed the outfit.

The following table includes some of the more important objects used in the work. They are mostly double stars taken from Burnham's catalogue. The co-ordinates of position are only approximate.

PARTIAL LIST OF TEST OBJECTS.

Star No.	α		δ		Separation.	Magnitudes.	Remarks.
	h	m	°	'			
6243.....	12	37	- 0	58	6.0	3.0 3.0	103" distant is 11.6 ^m
6993.....	14	41	+27	30	2.3	3.0 6.3	
7031.....	14	46	+49	06	3.5	5.8 6.5	
7120.....	15	01	+48	00	3.7	5.2 6.1	
7127.....	15	03	+ 9	34	4.2	7.0 7.0	
7259.....	15	21	+37	39	1.4	6.7 7.3	
7563.....	16	11	+34	06	4.6	5.0 6.1	
					65.0	10.5	
7705.....	16	35	+20	38	3.7	7.2 10.1	
7739.....	16	40	+23	40	1.6	7.3 7.6	
					25.3	11.0	
7914.....	17	10	+14	30	4.6	3.0 6.1	
					84.8	10.6	
8243.....	17	52	+18	20	2.6	7.0 7.0	
8398.....	18	06	+16	23	1.2	6.0 7.1	
8692.....	18	34	+38	42	55.0	1.0 10.5	
8783.....	18	41	+39	45	3.0	4.6 6.3	Two stars fainter than 11.0 ^m lying between ϵ^1 and ϵ^2 designated β and δ .
					46.7	10.1	
8785.....	18	41	+39	43	2.4	4.9 5.2	
9982.....	20	08	+ 0	37	3.2	7.1 7.4	
10437.....	20	38	+32	00	2.8	6.0 8.1	
10605.....	20	51	+ 4	10	2.0	6.2 7.7	
10713.....	21	00	+56	10	1.7	6.0 7.0	
12196.....	23	07	+74	54	0.9	5.2 7.5	
12675.....	23	55	+33	04	2.0	6.0 6.0	
1438.....	2	43	+60	01	2.1	7.1 9.0	
1568.....	3	03	+71	17	1.7	7.5 7.5	
1952.....	3	52	+80	30	0.9	5.2 6.1	Between κ^1 and κ^2 Tauri.
2178.....	4	20	+22	00	5.4	9.2 9.3	

The highest power was used wherever possible. The use of this power, which is about 70 to the inch, would give a fairly severe test of the seeing and would compensate to a certain extent for the small aperture used. Certainly any tendency to unsteadiness of the air would be at once apparent from its use, and it would be only on nights of the very best seeing when it could be used at all.

GENERAL ITINERARY OF TRIP.

Having in mind the four places just mentioned as being typical of the conditions in their respective districts, I left Ottawa on June 13th to examine more specifically the quality of the seeing at each of these places. While

some thought was to be given casually to the day seeing, the main consideration was to be the night seeing and the suitability of the place for research with a large reflecting telescope. It may be readily understood, that as my stay would necessarily be limited at each place, that unusual weather conditions might prevail which would result in a false impression of the place being gained, consequently it was thought best to visit the places both going and returning, so that different seasons of the year be experienced, and thus average conditions the more likely to be assured. The wisdom of this was apparent from my first stay in Medicine Hat, the latter part of June. Previous to my visit the weather for some considerable time had been fine but during my stay it was mostly wet and cloudy. The same thing was true, though not to so marked an extent, on my return trip to Penticton.

I arrived in Medicine Hat June 16th and left for Banff July 1st, reaching there on the morning of July 2nd. During my stay at the latter place the weather was about normal, about two-thirds of the nights being wholly or partially clear. I left Banff for Penticton July 14th, arriving there the evening of the 15th. During my stay here this time, the weather was very favourable as both days and nights were in general clear. Incidentally the days were hot too, the thermometer being in the nineties nearly every day. Leaving Penticton July 28th I proceeded to Victoria, arriving on the morning of July 30th. I remained until Aug. 13th when I left for mount Hamilton, Cal., to visit the Lick Observatory and make some comparisons with conditions there, of which I shall speak later.

Returning to Victoria Aug. 23rd I remained until Aug. 30th. During my stay both periods in Victoria the weather was favourable, only three cloudy nights being experienced. From Victoria I returned to Penticton on Sept. 1st. Here I encountered some cloudy weather which caused me to prolong my stay until Sept. 23rd. It seems to be the rule that a break in the weather occurs about this season of the year, and from reports it was pretty general over the west. Conditions at Banff during my first visit warranted its omission on the return trip, so I returned directly to Medicine Hat,

arriving the morning of Sept. 25th. From reports the weather for three weeks previous to my coming was very beautiful and certainly during the first seven or eight days of my stay it was all that could be desired, hardly a cloud being seen in the sky. After ten days or so the weather broke and I left for Ottawa on Oct. 6th. Snow had begun to fall.

During the latter part of October and the first half of November, I continued similar work at Ottawa and a preliminary relative value of the places was arrived at. As will be shown later, Victoria, of the outside places, was the most favourable and another visit was made there during the month of December to ascertain the quality of the seeing during its worst weather. Returning to Ottawa the beginning of 1914, a couple of weeks more were similarly spent before the available data was considered sufficient to decide the question.

I shall now treat more in detail of the seeing conditions found in the various places outside of Ottawa, taking them in the order visited.

MEDICINE HAT.

Medicine Hat is situated in the dry belt of Southern Alberta, 650 miles west of Winnipeg on the main line of the C.P.R. The city of something less than 15,000 people, lying in the valley of the South Saskatchewan, is noted for its immense resources in natural gas. In view of the cheap power thus afforded it is claimed that here will be the manufacturing centre of western Canada. This would be aside from our discussion were it not that the vicinity of a manufacturing city is usually considered a poor place to locate an astronomical observatory. As there is, however, no smoke from the use of gas it would seem that no drawback would thereby result. Apart from the railway trains, which use coal, it is a smokeless city.

In looking over the place for a suitable location for my telescope I decided upon the tableland to the north of the city. Its elevation above the city is about 135 feet and hence above sea level 2,300 feet. To the north and east and west stretches the plateau, while immediately to the

south lies the valley about a mile wide, through which the river runs, and beyond the valley the plateau is continued. There was no noticeable difference of seeing in the various directions for altitude of 25° and greater, but for lower than 25° altitude the seeing over the river seemed a little more unsteady.

As intimated above, unfavourable weather greeted me here. The average total precipitation for the year is 14.6 inches, and during the two weeks I was here about one-sixth of that amount of rain fell. In all, there were 9 nights on which no work of any account could be done, 5 nights which were more or less cloudy permitting some work to be done and only one which could be called clear.

No rapid changes of the barometer were noted; the maximum range during the two weeks visit was only 0.55 inches. The average velocity of the wind was 10.8 miles per hour. As a rule the wind dropped in the evening, though this rule was not without exception. I have noted it calm in the evening on commencing work and during the night the wind would rise and attain a velocity of 10 or 12 miles an hour. In such cases it was necessary to use a wind shield to prevent undue jarring of the telescope. The general direction of the wind is east and west following the valley of the river. Sometimes for short periods of the day it attained a velocity of from 50 to 60 miles an hour.

The following remarks describe the conditions on the nights upon which work was done.

June 20.—Worked until midnight on clear spaces. Clouded then. Considerable unsteadiness. Magnitude 10.1 about the limit. 6^m stars have $1''\cdot3$ disc. Rate, what seeing there was, 2.5.

June 23.—From 8.30 to 9.30 seeing very steady. Remarkably so considering the broken sky. At 9.30 haze and clouds thickened over and steadiness vanished. At 10.20 a heavy dew started to fall and object glass coated as fast as it could be cleaned. Transparency the first hour not on a par with steadiness, which was 4.5 for stars near zenith.

June 24.—Just a few clear patches. Steadiness again very good. Clouded completely at 10.20. Rate, the little seeing obtained, 3.0.

June 28.—Cloudy and hazy in places and seeing very variable. Star discs from $1''.3$ to $1''.7$ in diameter in best seeing. Worked till midnight; no further use. Seeing varied from 2 to 4 but most of the former.

June 29.—With the exception of an hour at the beginning and an hour at midnight, the night was clear. A twelve mile breeze blew most of the night. After the haze of early hours of night lifted, the transparency was good. Both β and γ in ϵ Lyræ seen, the former persisting while the star was within 2 or 3 hours of the meridian. In rare moments 7^m stars had discs $1''$ in diameter, in general they were $1''.3$ and $1''.4$, and doubles of this separation could be nicely identified. There was no such thing as uniform seeing throughout the night; the steadiness at best was easily 4 or better but at times it was less than 2, especially for the lower altitudes. The night might be rated 3.

June 30.—The first hour after sundown was remarkably steady. Haze was overspreading most of the sky. About 9 o'clock the haze thickened and steadiness vanished. Clouded completely at 11 o'clock, so dismantled. While examined, seeing decreased from 4.5 rapidly to 2.

BANFF.

Banff is a small town in the heart of the Canadian Rockies, about eighty miles west of Calgary. It is a famous resort for tourists, its sulphur baths attracting many visitors. Its elevation above sea level is 4521 feet, which is considerable to start with. It was my intention to locate on some of the surrounding mountains, but on looking them over, only two, Tunnel and Sulphur, seemed at all practicable. On the summit of the latter is located the meteorological station, to which trips are made every second week by the observer. Its altitude is 7484 feet. The western slope, as well as considerable of the eastern slope, is devoid of vegetation and in other respects it did not appear, upon further examination, suitable even for my preliminary testing much less as the location of a permanent

observatory. The wind averages 19 miles per hour and gales of 100 miles an hour have been recorded. I went up Tunnel mountain, altitude 5540 feet, but it too is quite rocky and barren near the top, and has such a limited area on its summit that no permanent building would be advisable even were conditions of seeing suitable. In the valley at an altitude of about 4800 feet, where some rising ground gave air drainage, it was decided to locate. Considerable hesitancy was felt in adopting this course but it seemed the only feasible one.

Below is given in some detail the conditions existing on the nights on which work could be done.

July 2.—Considerable number of floating clouds. Worked on bright stars in openings in clouds. There was no such thing as steadiness. Doubles of 3" and 4" separation just identified as elongated blur. The brilliancy of the sky struck me as good. The 10.1^m in system of ϵ Lyræ shone like a 9^m star. I rated the night 2, but this may not give much of an idea. The transparency was good in spite of the utter lack of steadiness.

July 4.—Slightly steadier than July 2nd but very poor yet, could barely detect companion in ϵ Boötis. Star 7120, about 3".7 separation, could no more than be suspected double from the blurred image. Vega when right on meridian presented a very diffuse image. The night was clear except for some floating clouds. There seemed to be no difference in steadiness depending upon direction. Seeing noted as 2.

July 5.—The day was calm and practically clear. The night was calm also with not a cloud. Hence better seeing expected. About sundown and at odd intervals during the night there was some semblance of steadiness but on the whole there was not a great improvement. For example, Arcturus when 2 hours west of meridian gave a fairly steady image. Fifteen minutes later, in looking at it a second time, the seeing had become exceedingly bad. To the unaided eye the night seemed brilliant, the Milky Way standing out conspicuously, yet, probably from the lack of steadiness, faint stars could not be picked up. The word "flux" seems to best describe the star images. The night rated 2.

July 7.—For an hour or so in the twilight hours the seeing was fair. Star discs, in the case of stars of 6th and 7th magnitudes, had diameters as small as $1''.5$ and seeing was noted as from 2.5 to 3.5. This did not last very long. The images assumed their usual flux. The transparency was not good as the 10.1 in ϵ Lyræ was by no means brilliant. Summing up the night it would not rate over 2.

July 8.—Slight haze till 9 o'clock, otherwise all clear. Again no such thing as steadiness, even near zenith. With power 320 it was all one could do to detect double stars of $3''.5$ separation like 7031, 7120, etc. Power 180 was better of course but even this could not be used. All images in state of flux. No wind whatever. Rated night 1.5.

July 10.—Conditions similar to previous nights. Clouded at 10 o'clock and rained.

July 11.—The amount of sky clear at start was 20 per cent. This increased but the night was never perfectly cloudless. The seeing was more steady than usual. The images were not always in that state of flux which characterized almost every night; the diffraction rings in the cases of bright stars could be seen. Star discs not over $1''.3$ and $1''.2$ were noted, and in the zenith for a short while the seeing was as good as 4 but this did not last over a few minutes. Lateral displacements of the images to the extent of $1''.4$ noted. The night rated between 2 and 2.5.

The nights of July 12th and 13th were cloudy and on 14th I left for Penticton. During my stay at Banff no rapid change in the barometer took place; in fact during the first week not over 0.1 inch variation was noted. There were successive days and nights clear and calm so that if steadiness existed at all, it might be expected to show up on such nights. It was never seriously the case; in fact unsteadiness to a marked degree was the feature of every night.

PENTICTON.

Penticton lies at the south end of Okanagan lake, which is about ninety miles long and from one to three miles wide. It is reached by rail from

Sicamous on the main line to Okanagan Landing 50 miles, thence 90 by boat to Penticton. The Okanagan valley especially the southern end is one of the dry belts of B.C., the total average precipitation according to best available data being about 12 inches per year. It is the centre of a great fruit raising district, the orchards being located on the benches which rise about 200 feet above the level of the lake. These benches extend from the lake shore on either side back from 1 to 2 miles before the base of the mountains is reached, and this is the stretch of land which has been irrigated and turned into fruit lands. The land itself is of fine volcanic silt and owing to the dry climate considerable dust is experienced. South of the town is Dog lake. The winds which attain considerable velocity here are mostly in a north-south direction between the two lakes.

The morning after my arrival I went up the mountain which Dr. Plaskett had previously looked over. It lies to the east of the town about two miles in an air line. In shape it is long and narrow with its ridge running in a northeasterly, southwesterly direction. The highest point, subsequently determined by an aneroid, is approximately 1600 feet above lake level. Thus its elevation is 2730 feet above sea level. This point is about due east of the wharf. To the northeast it slopes off quite gradually for some distance and then rises to a higher mountain; to the southwest it falls off in a succession of terraces, of which there are two extensive ones, until it reaches the Penticton creek. I came down these southern slopes and decided to set up on the middle one, but failure to get the instruments up on pack horses necessitated my setting up at an elevation of about 1630 feet where there was a sufficient commanding sweep of the sky. While the place was suitable enough, the higher altitude would have been preferable and it was a disappointment not to have succeeded in getting there. During my stay here I went up the mountain from the north and saw that the equipment could be got up from that side. On the return trip, therefore, I was able to locate on the crest. The tests at the two levels have an additional advantage of furnishing a comparison of the seeing at different altitudes.

Owing to unavoidable delays I did not get set up on the 16th, which was a beautiful clear night. Before my arrival the weather had been quite wet and disagreeable, but almost coincident with my coming it cleared up and remained so while I was there.

July 17.—At the start the wind affected the instrument somewhat as the wind shield was not perfectly satisfactory. However this was allowed for. There seemed to be smoke in the air as if from forest fires, though none in immediate neighbourhood. The distinctness with which double stars showed up was a change from what I had been accustomed to at Banff, though much to be desired yet. In lulls, estimated star discs to have diameters $1''.2$ and $1''.3$. Could not get β and δ in ϵ Lyræ. Rated the night 3.5.

July 18.—The day was clear and calm, the smoke of previous day seemingly gone. The early part of the night up to 11.30 was fair, both as regards steadiness and transparency. From that time till 3 o'clock the seeing was almost perfect, star discs having approximately their theoretical diameters of $1''.0$. About 3.30 a.m. humidity began to increase and seeing became somewhat unsteady. The night rated 4.

July 19.—Not quite as good as previous night though very fair. Star discs more like $1''.3$ diameter. Picked up different ones of that separation, 7259 in Burnham's catalogue, separation $1''.4$, a case in point. The night rated 3.6.

July 20.—A broken night. Clouded about 4 o'clock in day, cleared at 9 o'clock, clouded again 1 o'clock. What seeing there was, was unsteady and rated 2.

July 21.—A very hot day. While the southern half of the sky was always clear, an electric storm was raging to the north. This may have had something to do with the seeing which was exceedingly bad. No attempt was made to estimate diameters of discs from close doubles, as all in a state of flux. True there were moments when this could be done but they were fleeting. The night rated 2.

July 22.—The night was broken by fleeting clouds. It was transparent enough, but the steadiness was not the best. It varied from 2 to 4 depending upon the altitude. Continued watching, showed flashes of ϵ Lyræ. Rated 2.5.

July 23.—The night was peculiar in that the seeing was very variable. It would be almost perfect for a while and almost the next instant be absolutely useless so far as steadiness is concerned. Changed from 4.5 to 1.5 in few moments. An electric storm to the east may have had some connection with such variable seeing conditions. Rated the night 3 which is sufficiently high.

July 24.—There was considerable floating haze throughout the night as seen by temporary extinction of 10^m stars. No 11^m stars seen. The steadiness varied from 4 in the zenith to 2.5 for altitudes of 25° to 30°. 7^m pairs of 1".4 separation could not be identified. Outside of the little haziness, which could be noted with the unaided eye, the night was very fair though and was rated 3.

July 25.—Day clear and somewhat cooler. Sky deep blue early part of night. Later a whitish haze crept up from horizon. Could see indications of faint stars in ϵ Lyræ though they were not striking. Could pick up doubles of 1".3 separation. The steadiness was not so good as on the best night (18th) but everything taken into account the night would be rated 4.

VICTORIA.

Victoria was reached on July 30. That day was spent in looking over possible places for my preliminary testing. Beacon hill, Gonzales point and the sight of the new meteorological station were visited in the forenoon. In the afternoon, I have to thank Mr. A. S. Barton, who, being interested in scientific work, placed his automobile at my disposal and directed me to several of the elevations in the vicinity which I wished to look over. Mount Tolmie, mount Douglas, Strawberry hill, Knockan hills and other elevations were examined. The prevailing southwest winds would strongly militate against elevations to north or east of the city, and I decided to locate on a

rocky eminence in the midst of a considerable block of timber in the Hudson's Bay Company's reserve near Esquimalt. There I was not affected by the smoke from the city.

July 31.—First glance showed surprising steadiness. Star discs down to theoretical 1" diameter, and seemed like steel engravings so steady and beautiful was the diffraction pattern. Transparency good, as 11^m and 12^m stars in ϵ Lyræ persisted. Only for a few moments was there anything but perfect seeing. Rated 4.6 so as to leave a margin for the theoretically unattainable.

August 1.—The day became hazy and the night was more or less cloudy. Extensive forest fires in the state of Washington and southwest wind carried smoke this way. Worked on the brighter stars as they only were available. Rated the night 1.

August 2.—Was cloudy until near evening when it cleared. As somewhat smoky and atmosphere very humid, good seeing not expected. The stars 3 and 5 in ϵ Lyræ persisted *at times*, which was better than the average transparency at other places. Aside from this little lack of transparency it was a perfect night. The steadiness fine; the close doubles stood out with clear cut definition, diffraction pattern of bright stars very steady. Rated night 3.5.

August 3.—The night was apparently similar to preceding. Somewhat indisposed and did not go out.

August 4.—This night the first appearance of unsteadiness was noted. It was by no means bad but, being the first noted here, attention was directed to it. The night seemed somewhat foggy to the naked eye, though the humidity of 74 per cent. is less than some nights when good seeing existed. Lack of definition was the nature of the defect in seeing; star discs were about 1".5 diameter in the case of 6^m stars. Seeing valued at 2.7.

August 6.—Up to 11 o'clock the night was very good. Double stars of 1".3 and 1".4 separation easily detected. Below 40° altitude it was

very thick. After 11 o'clock all stars more or less milky. However, flashes of β (11^m) in ϵ Lyræ seen. Just a poor to fair night and rated 2.5.

August 7.—Mostly clear but high wind prevented work, as telescope could not be properly protected from wind which at times reached 50 miles an hour.

August 8.—In the first three hours or so, up to 10 o'clock, the seeing was excellent, rating about 4.5. Then some unsteadiness crept in and images not perfectly defined, though about this time one could see stars as faint as 11^m . Later the seeing could not be rated more than 3.5 when averaged over the working regions of the sky, *i.e.*, above 30° altitude. This at Ottawa we would rank, I think, as an exceptionally good night. Rated 4.0.

August 9—This was practically a perfect night, and the best yet. Before twilight ceased many close doubles examined and star discs for 6^m and 7^m stars averaged $1''.1$ in diameter. Doubles as close as $1''.2$ nicely separated and defined. Star 8398 in Burnham's catalogue a case in point. Fainter companion nicely dissociated from brighter. Excellent definition and night rated 4.3.

August 10.—A few "floaters" in the sky with horizon hazy in the southeast, which seems to be customary. The night otherwise apparently fine to the naked eye, yet it was by no means good. True, doubles of $1''.4$, $1''.3$ and even $1''.2$ separation could be suspected but no definition. Magnitude 10.5 was lowest reached. The night described as "Banff flux on small scale" and rated 2.4.

August 12.—Quite cloudy in evening but cleared, and mostly clear during night, though "lanes" of haze at times spread over clear spaces. The humidity stayed about 82 all night. Transparency fair, 10.5^m about limit. β in ϵ Lyræ seen occasionally, γ quite rarely. 10.5 magnitudes quite distinct. The steadiness was very good, diameters of discs slightly over limiting value. Rated night 3.9.

August 23.—At start, 6.30 p.m., 80 per cent. clouds. They broke and night remained clear. Humidity very high, around 90 most of night.

Transparency noted as not the best, yet 11^m stars seen. β in ϵ Lyræ did not persist, δ was not seen. Slight fuzziness or lack of definition of image in early evening but this wore off as night progressed. Lateral displacements not greater than 0".5. Star discs had diameters from 1".3 to 1".0. In zenith, seeing 5, lower down less; on the whole the night worth 4.

August 24.—Clear and calm all day; night similar and exceptionally good. Transparency the poorest factor, β and δ in ϵ Lyræ showed at times but did not persist. The 11^m in α Herculis glimpsed at times. On other hand definition was perfect, the diameters of star discs not much exceeding 1".0 on the average. An example may be noted: star 7259 Burnham's catalogue, separation 1".4. There was a clear line of separation between the 6.7^m and 7.3^m stars equalling one-third of diameter of brighter. Hence 7^m star has disc 1" diameter, which indicates perfect conditions of instrument and steadiness. The steadiness might be said to run from 3.5 for altitudes of 25°, rapidly increasing up to 4.8 for stars in the zenith. The night rated 4.3.

August 25.—Night clear but strong wind, so much the case that I had to discontinue work. The horizon was the clearest of any night yet, the Olympian mountains standing out clear cut in the early evening, yet there was considerable unsteadiness apart from the vibrations due to the wind.

August 26.—While the steadiness was in general good, there were bodily displacements of the images ranging from 0".3 to 0".5. Got a glimpse of the 11^m \pm in α Herculis, but on the whole it was not easy to pick up faint stars. β and δ could be known to be present from a certain milkiness surrounding their position, but they were by no means prominent. Considering that it just cleared entirely about 8 o'clock I think the seeing was exceptional. Rated 4.

August 27.—Day clear and calm and good night expected. Did not quite come up to expectations. Images lacked clear cut definition experienced on previous nights. Also small bodily displacements of 0".3.

Yet 11^m stars showed quite bright, almost the equal of the best experienced so far. Got glimpses also of 12^m stars. Worked only till midnight. Rated 3.7.

August 29.—The night was not the best for transparency. A haze extended up 20° in the east, in other directions noticeable but not marked. Fluctuations in brightness of faint objects showed better transparency possible. Were I rating this factor alone it would run 3.5 to 3.8 on scale of 5. On the other hand the steadiness was excellent. I marked it 4.8 in very many cases which means as good as ever seen. If this had *always* been the state of the seeing and *in all positions*, the night would be rated thus but it was poorer than the maximum for low altitudes, say those around 25°. Possibly 4.3 would sum up the seeing in all particulars for the night.

PENTICTON (SECOND TRIP).

As stated previously, after spending a short time at Victoria on my return from mount Hamilton, details of which have already been given, I returned for a second visit to Penticton. This time I was located on the crest of the mountain, altitude 2,730 feet.

September 4.—Cleared about 5 o'clock. While not expecting the best of seeing, I thought it would gradually improve as the night wore on but it did not. The wind dropped early at night and it was calm, and to the unaided eye a good night but there was absolutely no such thing as steadiness. Star images were nebulous and fully 3" or 4" in diameter. With power 180 could distinguish some doubles of 3".0 separation but that about the limit. Humidity ran from 70 in the early evening to 90 at daylight. Could not rate the night, as had not experienced such previously.

September 5.—Cleared completely about sundown. The first hour after sundown was good, about 4.0. Then a north wind arose, it got cold, and seeing became exceedingly bad. For an hour it was no good, then it gradually improved and remained about 3.5. Doubles of 2".0 were nicely measurable though they jumped considerably. Night rated 3.5.

September 6.—Clear calm day and good night followed. The humidity was quite low, around 40 all night. The unfavourable criticism was in regard to transparency caused by a veil of haze, which seemed to prevent faint stars from being detected or rather from persisting in vision. While not perfect, the steadiness was so nearly so that nothing unfavourable need be said. Night rated 4.4.

September 8.—Clouded in day. Cleared at 7.30 in evening but unsteady and shortly afterwards clouded over.

September 9.—Seeing first three hours after sundown absolutely no good. Then it improved slightly so that some semblance of an image was given. Doubles of $3''\cdot0$ could be detected by elongation but that was about the limit. Seeing like this till midnight. Humidity around 60. Night rated 1.5.

September 10.—The night up to midnight was fair for steadiness, a great improvement on the past few nights but not quite equalling September 6. A film of haze hung over most of the sky till midnight when it disappeared. The transparency was much improved though the steadiness remained about the same. To the unaided eye the 10th and 11th stars in the Pleiades showed up better than I had ever seen before in Canada though not so good as at mount Hamilton. Rated the night 4.

September 11.—The night one of the best. All close doubles clearly defined. A marked feature was the greater steadiness in the south and west caused by haze which persisted in that part of the sky. In the west the stars of low altitudes were remarkably steady. The transparency of course was not the best, 3 and 5 in ϵ Lyræ persisted only about 10 per cent. of the time. The definition best factor—the steadiness would have been 4.6 save for the northeast—the transparency not over 4.0. The night rated 4.3.

September 16.—Cleared at 5 o'clock but broken by clouds most of the night. Up to 9.30 p.m. considerable ill definition and bodily displacements

of $1''.0$. Transparency poor. It was with difficulty that 10^m stars were seen. Some improvement 9.30 to 11 o'clock. Best hour around midnight, when seeing much steadier though transparency not improved much. The feature of poor seeing in eastern heavens was again noticeable. Rated night 3.0.

September 18.—Night brilliant but quite unsteady. Power 320 entirely out of question. It kept improving particularly after 9 o'clock, when wind dropped completely, and at 1.30 in the zenith it could be rated 4.2 but deteriorated very rapidly with decreasing altitudes. Same characteristic of poorer seeing to east than in other directions. Early evening, doubles of $2''.0$ was the limit. This improved so that $1''.2$ could be detected, though far from being definite. Night valued at 3.3.

September 19.—The best all round night experienced here. Doubles of $1''.0$ could be immediately identified. Diffraction rings steady and similar to steel engraving effect noted in best seeing at Victoria. Slight lack of transparency, but night worth 4.6.

MEDICINE HAT (SECOND TRIP).

September 25.—Part of night devoted to setting up and adjusting instrument but conditions noted from 9.30 on till near daylight. The diffraction pattern was fairly steady. I should say steadiness on the whole about 3.4. Towards morning dew began to form on object glass and by 3.30 formed as fast as could be cleaned off. Rated night 3.4.

September 26.—Day and night clear. Wind first from south then dropped entirely for few hours, then rose from north and later again shifted to south. Seeing was almost useless at any time so far as steadiness was concerned. This night and September 4 at Penticton were very much alike. Images extremely diffuse. No rating.

September 27.—The night started off fine. For an hour after sundown the seeing was excellent, but after that time the definition began to deteriorate. Bodily displacements crept in and general unsteadiness the rule. From 8.30 the seeing practically useless. Doubles of $2''.0$ could be

suspected but that the limit. Power 120 highest usable. Night rated 2.5.

September 28.—Here was a night of which one might expect the best. Clear at least for four successive days and nights, with a steady barometer all day and no wind. It was woefully disappointing. Star images nebulous, being 3" or 4" in diameter. Night not worth over 2.

September 29.—Clear till 9.30 p.m., partly cloudy rest of night. North wind which however dropped completely. Seeing a marked improvement on former nights. Could detect doubles down to 1".2 though they were not well defined. Transparency only fair when perfectly clear, as β and δ in ϵ Lyrae did not persist. Rated night 3.5.

September 30.—With the exception of some hazy clouds in south and west which lasted till 9 o'clock, the night clear. Fairly transparent, as β and δ in ϵ Lyrae and others similar persisted half time. Bodily displacements were not large; star discs improved from 1".6 to 1".3 diameter. Seeing rated 3.3.

October 1.—Sky perfectly clear down to horizon. Some wind from west which died down. Great unsteadiness. Neither 320 nor 180 nor 120 powers any use. Images must be 5" or 6" in diameter. Rated 1.3.

October 2.—Clouded in afternoon and turned quite cold. Cleared at 7 o'clock. Seeing absolutely useless, but on account of sudden cold change in weather there is some excuse for it tonight which there was not on previous nights. As an illustration of poor seeing one case may be noted. Star 7120, 3".7 separation with powers 320 or 180 just one elongated blur, with 120 can note some form of images. Clouded quickly at 8.30. Rated 1.0.

As the nights of 3rd and 4th were cloudy and snow was falling on the 5th, and further as I considered I had sufficient information regarding this place, I decided on the 5th to pack up and leave next day for the east.

OTTAWA (SUMMER AND AUTUMN).

Here will be given a summary at least of the work done at Ottawa. The instrument was partly set up on May 14th, but repairs and alterations occupied some time and, further, considerable trouble was experienced in getting a perfectly uniform image. Some time was spent in arranging a programme of test objects, fields for photographic purposes, etc., but conditions of seeing were noted at the same time. The following summary is sufficient to indicate the general conditions experienced. The rating assigned in the early summer has been lowered to that given in the table in view of my standard being raised, as will be mentioned later.

SEEING CONDITIONS AT OTTAWA.

Date.	Remarks.	Rating.
1913		
May 14	Cirrus clouds, some haziness and unsteadiness.....	2.0
" 20	Images lack definition.....	2.3
" 24	Floating clouds, steadier than previous night (20th).....	2.4
" 29	Steadiness and transparency fair, best yet.....	2.8
" 30	Fair; diameters of star discs 1".8 and up.....	2.6
June 4	Diameters of star discs 1".7 or more.....	2.6
" 5	Poor night.....	2.0
" 7	Transparency 3.8; steadiness 3.3.....	3.4
" 9	Transparency 4.0; steadiness 3.6.....	3.7
" 10	Very hazy and unsteady.....	1.0

SEEING CONDITIONS AT OTTAWA—Continued.

Date.	Remarks.	Transparency.	Steadiness.
1913.			
Oct. 14	Doubles of 2".5 separation barely distinguished.....	3.7	1.2
" 16	What little seeing there was, was very fair.....	2.0	3.0
" 30	Steadiness fair in view of two weeks previous broken weather.....	2.4	3.0
" 31	Reverse of last night; transparency better than steadiness.....	3.6	2.7
Nov. 2	Cleared at 10 o'clock; seeing improved to 2.30.....	3.0	2.7
" 4	Transparency seemingly good, but fluctuations of faint stars.....	3.8	2.4
" 5	Indian Summer day; images very nebulous.....	3.2	2.2
" 6	Second Indian Summer day; images at times as much as 5".0.....	2.4	1.8

PRELIMINARY COMPARISON OF THE PLACES VISITED.

SUMMARY OF THE VISUAL WORK.

Place.	Nights.	Transparency.	Steadiness.
Medicine Hat*.....	14	3.5	2.3
Banff.....	6	3.2	1.3
Penticton.....	18	3.6	3.1
Victoria.....	14	3.7	3.8
Ottawa.....	18	3.0	2.4

As stated previously in this publication, the seeing experienced at Banff, under what should have been good conditions, was so poor as to render it unsuitable as a site for a large reflector and consequently it was omitted on the return trip. While the first visit at Medicine Hat was made at a season of broken weather when the best seeing could not be hoped for, yet during the bulk of my second stay the weather was all that could be desired. Hardly a cloud was seen for 6 days and 6 nights, and report stated that such conditions had existed for two or three weeks previous to my coming. The average wind velocity was below the normal, the barometer was fairly steady, and in these settled conditions the best seeing that the place could produce might be looked for. It was very disappointing that the seeing experienced fell away below expectations. From what little seeing had been experienced the first visit, together with other observers' experiences at similar places, particularly in the plateau regions of South America, I had been led to expect much from it in favourable weather, but from whatever cause the poor seeing resulted—and local conditions can not be blamed for it—the place may be rejected as unsuitable.

Before treating of Penticton and Victoria—both of which have points in their favour—and comparing them with Ottawa, the statement should be made that in the writer's opinion the figures given in the above table for Ottawa seeing are lower than they should be, for the reason that much poorer conditions than the average existed during my work here. For the

*Most weight given to second visit; few nights on first visit would be classed as workable.

past 5 years we have kept a record of the seeing experienced while making spectrograms, rating it on the customary scale of 5 for the best seeing. The observers were Plaskett, Parker, Cannon and the writer. The three last mentioned, by whom the bulk of the rating was done, agreed fairly closely in the number assigned the seeing,—there being ample opportunity to compare estimates. Dr. Plaskett usually rated lower: his standard was naturally higher owing to his having experienced better seeing while visiting other observatories. The following table will give the average value assigned the nights on which the spectrograph was in use, for the years 1909 to 1913 inclusive.

OTTAWA SEEING (RECORD OF SPECTROGRAMS).

July	50 nights.....	3.5	} Average=3.46.
Aug.	49 ".....	3.5	
Sept.	63 ".....	3.6	
Oct.	55 ".....	3.4	
Nov.	27 ".....	3.3	

Now, to bring these estimates into conformity with the writer's ratings for this special work, they would have to be lowered by about 25 per cent., for my standard of what constitutes perfect seeing has, during my visits to Penticton, Victoria and mount Hamilton, been correspondingly raised. Thus we may put down Ottawa seeing as averaging 2.6. The transparency may be denoted by 3.3 and steadiness 2.6. These numbers are better indices of the seeing here than those in the above table. They may be high or they may be low, but what is vital they represent Ottawa seeing according to the present standard of the writer, by whom of course the comparisons at the other places were made. The three places then still under consideration would rate as follows:—

RELATIVE SEEING VALUES.

Place.	Transparency.	Steadiness.
Penticton.....	3.6	3.1
Victoria.....	3.7	3.8
Ottawa.....	3.3	2.6

Photographic Tests.—Mention has been made of the photographic work. Twenty plates were made at Penticton and fifteen at Victoria of the selected star fields and developed under uniform conditions after my return to Ottawa. While the plates in general bore out the relative ratings for steadiness—the Victoria plates showing trails much sharper than those at Penticton—yet, owing to possible slight changes in focus, too much dependence ought not to be placed upon them when considering this factor. In comparing the intensities of the trails on the plates other members of the staff were kind enough to give their estimates so as to check my own.

The result of this photographic work shows that Penticton excels Victoria in transparency about 20 per cent. Now, as it happens, the visual rating for the two places is about the same. But there is no doubt about the superiority of Penticton over Victoria in the matter of transparency. One could almost say as much from knowing the altitudes above sea-level: Penticton, first visit, 1630 feet, second visit, 2730 feet; Victoria about 200 feet. From general unaided eye observations I had judged that Penticton was superior in this regard and the photographic plates indicate such to be the case. The explanation of my apparently high rating for Victoria in this regard is the following: Two things were taken into account in assigning a number to represent the transparency; (1) the general appearance of the sky and the faint objects reached with the naked eye; (2) the ease with which faint objects could be picked up with the telescope. Now in regard to (2) Victoria excelled Penticton considerably. The theoretical limiting magnitude for the telescope lies between 12.0 and 12.5. Stars of 11.5 magnitude could be picked up and persisted more or less in vision almost every night at Victoria, while such was not possible at Penticton on more than half the nights. Now the reason for this is no doubt the greater steadiness experienced at the former place. The light from the faint objects was concentrated into small compass making a distinct impression on the eye, which could not be the case where the image was not perfectly defined and steady. Transparency, in so far as faint objects to be reached is concerned, cannot be dissociated from steadiness.

The conclusion that seems to be warranted from a consideration of both visual and photographic work is that whereas Penticton excels Victoria in transparency, yet where steadiness is concerned Victoria is vastly superior to Penticton. The ratings of 3.6 for Penticton and 3.4 for Victoria in the matter of transparency would not be far astray.

Clear Sky.—As no specific data regarding the amount of clear sky at Penticton were available, arrangements were made for a resident of that place to photograph the northern heavens each night by simply directing a camera to the pole star and allowing the stars to trail across the sensitive film. For comparison a similar arrangement was effected at Medicine Hat. For obvious reasons these latter films have not been fully worked up. Between March 19 and October 7, 204 records had come in from Penticton and of these 177 have been considered. Comparison with the record of September 19, which was my best night at that place, has been made and the result shows that the nights averaged at least 46 per cent. as good as that night. At Summerland, about five or six miles distant, a sunshine recorder has been in operation for a few years and from it the percentage of bright sunshine is 45. We may thus assume that the percentage of clear sky at Penticton is in the neighbourhood of 46. There is the additional suggestion in these figures that the day and night amounts of clear sky are interchangeable.

Wind.—No records for wind at Penticton were available. Considerable wind movement was experienced during my stay, the prevailing winds being north and south between Okanagan lake and lake Skaha. Some idea of the average wind velocity may be gained from a comparison of the anemometer records during my stay at each place. At Medicine Hat the instrument was fully exposed to the wind, while at Penticton and Victoria it was sheltered to some extent by trees, slightly less so at the latter place.

Medicine Hat.....	11.2	miles per hour.
Penticton.....	4.6	“ “
Victoria.....	5.7	“ “

From my short stay at each place the best I could say would be that the wind velocity at Penticton would be similar to that at Victoria, which in exposed places is about 8 miles per hour.

Temperature Range.—As a further aid in arriving at the relative values of the places the temperature gradients will be given here. In the table at the beginning, the average diurnal range was given; but what is of more specific importance is the range in temperature during the time the reflector is in actual operation, because at other times protection can be given it. The range in temperature between sundown and the time of minimum value during the night, usually just before sunrise, was noted from the thermograph sheets. The clear nights only were considered, the range being greater in general on clear than on cloudy nights. The figures for Ottawa are for all the clear nights during the four months' work.

MEAN NIGHT RANGE.

Banff.....	9.2 C	Victoria.....	3.8 C
Medicine Hat.....	7.5 C	Ottawa.....	7.6 C
Penticton.....	7.2 C		

Victoria's superiority in this regard is very pronounced.

Summary.—Considering the two most favourable places outside of Ottawa, the data bearing directly upon the question of a site may be crystallized into the following table:—

Place.	Wind.	Clear Sky.	Range of Night Temperature.	Transparency.	Steadiness.
		Per cent.	°		
Penticton.....	Approximately 7 or 8 miles per hour.....	46 ±	7.2 C	3.6	3.1
Victoria.....	“ “	37	3.8 C	3.4	3.8
Ottawa.....	“ “	42	7.6 C	3.3	2.6

The main columns in the above table are the amount of clear sky, transparency, range of night temperature and steadiness. I am not prepared

to say what the relative importance of these factors is, but I think it will be admitted that the last mentioned—the steadiness—is by far the most important, and in this regard Victoria leads, being about 50 per cent. superior to Ottawa. In conversation with different astronomers during the summer, at the Lick Observatory and at the Yerkes, the emphasis in making a selection of a site for a large reflector was laid upon (1) the steadiness and (2) a low range in temperature. The consensus of opinion seemed to be that these qualifications were of paramount importance, "Better far to work one night with good seeing than two with seeing only fair."

As regards the amount of clear sky there is no marked difference. What advantage there is lies with Penticton, with Ottawa second.

Preference should again be given Victoria when the temperature range is considered. Those who have experienced the changes produced in reflectors by rapid changes in temperature would heartily favour the place where low range is to be found, and Victoria's range is only half that of Ottawa's.

Thus of the two places, Penticton and Victoria, the latter is the more desirable if removal from Ottawa be decided upon. As the observations at Victoria extended over the month of August, which is probably one of the best months of the year, it was felt advisable before deciding such an important question to make further investigation at Victoria and see what conditions were like there at other seasons of the year.

WINTER VISIT TO VICTORIA.

With the object then of ascertaining the seeing conditions at Victoria during the winter months, as referred to above, I made a second visit there, arriving on November 28.

In addition to the continuation of specific tests, general local conditions which might have a bearing upon the question were to be considered. The percentage of clear nights at this season of the year is very small and my stay extended over four weeks before I felt that sufficient data had been secured. I left Christmas Day and arrived in Ottawa on December 30.

During this stay at Victoria I worked on 14 nights or parts of nights, though on many of these only a few hours' seeing could be had. Other nights I had made ready to work but did not get sufficient seeing to be worth recording. Out of these 14 nights it is doubtful if more than six could be called workable; the rest were so broken that were we on regular work with a telescope we would probably discontinue work unless something especially was desired.

December 1.—Images jumping somewhat but fair definition. Diffraction pattern nicely formed. Transparency about 3.0, steadiness about 3.0.

December 2.—Transparency not quite the equal of last night, but the steadiness somewhat better. Some jumping of images still, but not over $\frac{1}{2}$ ". The definition slightly better also. Rated steadiness 3.2.

December 7.—Just few open spaces and worked on bright stars. Diffraction pattern nicely formed. Worst feature was the short quick jumps of image amounting to $\frac{3}{4}$ ". Rated seeing at 3.0.

December 8.—The stars were fluctuating in brightness considerably and transparency not over 2.8. Seeing improved from sundown to 8 p.m. and then remained about constant. Doubles of 1".5 were noted easily. A marked feature was the rapid decrease in the quality of the seeing with decreasing altitudes. Never so marked before. The seeing averaged 2.5.

December 9.—First glimpse at sundown was rated 4. This lasted for 15 minutes then the seeing decreased in quality rapidly and by 7 p.m. was not over 1. The images became nebulous first and then lateral displacements crept in. Temperature began to rise about this time. The few hours' observing not worth over 1.3.

December 12.—Just a few openings in sky and seeing not over 1.0.

December 13.—Five hours partly clear and the seeing varied from 1.2 to 2.5. Averaged up would be worth about 1.5.

December 15.—Less than one hour's seeing but it was very fair. Star discs about 1.3 diameter. The definition fair but short quick jumps again a feature. Rated as 2.4.

December 17.—Uncertain in evening as to whether it would be clear or not. The seeing surprisingly good. Entered in my notes as "a night that got lost in the summer and strayed in now," as the quality of the seeing was so good. Two examples may be given: Star 1952 of Burnham's catalogue, a double, magnitudes 5.2 and 6.1, 1".0 apart, at altitudes 45° had components separated and discs just touching each other. Stars 2712 (η Orionis) magnitudes 4 and 5, separation 1".0 also, at altitude 33° though jumping had components separated also and discs just touching, power 320 easily usable. Down as low as 15° altitude the diffraction pattern was continuous and seeing better than 3. This is not usually the case for such low altitudes. While sky not perfectly clear yet, the first half of the night was workable. Seeing rated 4.0.

December 18.—No marked criticism could be made of the steadiness for the two hours clear. Lack of definition was the most noticeable feature. Transparency not over 2.5 and very humid. Seeing rated as 3.6.

December 19.—Perfectly clear day and clear night. Early evening floating haze kept extinguishing faint stars like Celæno and Sterope. Later this haze disappeared and the average transparency for the night was given as 3.8. There was considerable shimmering of the diffraction pattern and also short quick jumps of the star disc but the seeing was worth 3.6.

December 20.—Wholly clear all day. Workable first half of night but latter half broken. The seeing best from 5 to 7 o'clock when it averaged 4.0. Later it was worth only 3.4. Averaged up for the 5 hours workable as 3.7.

December 22.—Clouded in afternoon but cleared up in evening. Five hours work, transparency 3.6, steadiness 3.9.

December 23.—Fancy mostly cloudy during the day but all clear on return to city at 6.30 p.m. Night clear till 1.30 a.m. Transparency rated as 3.6 but steadiness poor and not worth over 2.2.

Taking into consideration the 14 nights on which more or less work was done the average seeing was 3.0. As mentioned above, a great many of the nights were so broken that under ordinary circumstances work would be discontinued unless some special observation were required. There were, however, 6 nights which could be said to be workable and they are as follows:—

WORKABLE NIGHTS.

Date.	Transparency.	Steadiness.	Date.	Transparency.	Steadiness.
December 8.....	2.8	2.5	December 20.....	2.6	3.7
“ 17.....	2.8	4.0	“ 22.....	3.0	3.9
“ 19.....	3.8	3.6	“ 23.....	3.6	2.2

Average transparency..... 3.1

Average steadiness..... 3.3

These two numbers sum up the result of the visual work.

WORK AT OTTAWA (WINTER).

December 31, 1913.—Returning to Ottawa on the 30th I began working on the night of the 31st. It was clear till 10.45 when it hazed over. While clear the transparency was as good as 3.3 but steadiness very poor and rated 2.0. Temperature -8°F .

January 1, 1914.—Neither transparency nor steadiness were the equal of preceding night. The images were jumping badly. Rated transparency 3.0 and steadiness 1.8. Temperature -9°F .

January 4.—Afternoon clear but clouds hanging around horizon at night and somewhat hazy; night warmer (25°F .) than preceding two nights, and steadiness considerably better. Rated it 2.5 and transparency 3.0.

January 5.—Day mostly clear but considerable haze over sky at night. Thickened over at 10.30. The steadiness was quite variable, ranging from 1.3 to 2.6 but averaged up for the part night as 2.0. Transparency 2.5.

January 10.—Cleared in evening and quite cold (-14°F). The transparency was very good, being rated 3.6, and the steadiness was considerably better than expected. There were short quick jumps of the image and some lack of definition but the seeing was worth 2.8.

January 12.—Clear and cold all day. The seeing was the best here since returning. The lateral displacements were not over $\frac{3}{4}''$. The first four hours rated 3.0 which is the outside limit. Toward midnight it got poorer. Transparency 3.4. Night minimum -30°F .

January 13.—Up to 10.30 there was considerable jumping of image though the nucleus was fairly distinct. It became more diffuse however. Transparency rated as 3.4, steadiness 2.0. Night minimum -31°F .

The mean rating for seeing conditions at Ottawa for these seven nights is 2.3, which is just the same as that for the nights I worked in October and November. As the time of my visit to Victoria in December falls in between these two dates we may compare the seeing conditions at the two places as follows, the rating being on the customary scale of 5:—

	Summer Seeing.	Winter Seeing.
Ottawa	2.6	2.3
Victoria.....	3.8	3.3

VICTORIA, B.C.

CLIMATE AND OTHER DATA.

During my stay in December at Victoria, I took the opportunity of looking over the local conditions tending to produce the climate which it enjoys, and a few brief remarks on these conditions may not be out

of place. The city is situated on the southeast point of Vancouver island. Its mean temperature varies from 40° F. in winter to 60° F. in summer, so that extremes of temperature are not met with. The absence of low temperatures is likely to be welcomed by observers, who often work in temperatures much below zero. The mean yearly precipitation taken over a period of 24 years is 27·8 inches. Some winters there is a fall of snow of a foot or so but it quickly disappears.

The reasons suggested for this low range in temperature and moderate rainfall are the presence of the warm ocean currents—winter temperature 45°F., summer temperature 65°F.—and the fact that Victoria, and a limited area adjoining, is practically surrounded by mountain ranges which extract the moisture from the ocean winds. To the south of the strait of Juan de Fuca rise the majestic Olympians 7,000 to 8,000 feet. The range circles to the east and culminates in mount Baker (11,000 feet). To the north again are snow capped mountains, while to the west extend ranges sufficiently high to cut off the bulk of the precipitation that comes from the ocean winds. The precipitation along the western coast varies in localities from 100 to 140 inches per year, then this relatively dry belt is reached. Crossing the Gulf the winds again become charged with moisture which is precipitated on the mainland, where it amounts to about 70 inches per year.

Wind.—Through the gap to the southwest—the entrance to the strait—come the prevailing winds. Every month in the year this is the prevailing direction, though during the winter a greater proportion than usual comes from a northerly direction. This was especially the case during my winter visit. Whether this abnormality of direction had any effect on the seeing or not I cannot say. The average wind velocity as previously given is 8·3 miles per hour. In a somewhat sheltered position the wind movement, according to my anemometer, averaged 5·5 miles per hour during my stay so that conditions in this regard were about normal.

Temperature.—Considering the clear nights alone during my winter visit to Victoria, the average range in temperature from sundown to the minimum for the night was 3°·8 C. This value is identical with that of

the summer visit. The night range at Ottawa on the clear nights in December, 1913, and on those worked in January, 1914, was $8^{\circ} \cdot 1$ C., so that whether summer or winter the range at Ottawa is about double that at Victoria.

As this data was for such a limited number of nights, I was led to examine the thermograph sheets kept at the Meteorological Office, Victoria, and those at our own observatory. The table shows the range from sundown to the minimum for the night for two years sufficiently typical of the two places in regard to sunshine to make the comparison fair.

RANGE IN NIGHT TEMPERATURE.

—	Ottawa, 1911.	Victoria, 1906.	—	Ottawa, 1911.	Victoria, 1906.
	°	°		°	°
January.....	7.2 C	2.4 C	July.....	5.3 C	3.9 C
February.....	6.5	3.9	August.....	5.9	4.9
March.....	7.0	4.8	September.....	6.3	4.0
April.....	6.6	4.5	October.....	6.9	3.5
May.....	6.8	3.8	November.....	4.7	3.1
June.....	4.1	3.2	December.....	4.1	2.8

The means of these are: Ottawa $6^{\circ} \cdot 0$ C., Victoria $3^{\circ} \cdot 7$ C. Thus when all the nights, regardless of whether they were clear or not, are considered, the range at Ottawa is about 60 per cent. greater than the range at Victoria. Just which of these two relative values is best to take may be a matter of opinion. It might be thought that more weight should be given to the greater number of observations, but on the other hand as we cannot tell just how the range varies from cloudy to clear nights and the latter only are concerned, it may be best to adhere to the figures obtained for the nights which were known to be clear. One thing struck me forcibly in looking over the Victoria thermograms and that was the rapid drop in temperature just at sundown. It was much more marked on the Victoria than on the Ottawa sheets. Now as the observational work does not strictly start at sundown, though it is considered advisable to open up

about that time, the range during the working hours at Victoria would be reduced in a greater proportion than at Ottawa. I think we may with safety conclude that the range during the working hours of clear nights is at least 75 per cent. greater at Ottawa than at Victoria.

The altitudes above sea level of Ottawa and the observing station at Victoria are 278 and 230 feet respectively. If a site of greater elevation were taken it would probably be found that the range in temperature would be lessened. In the selection of a site for the D. O. Mills' expedition to the southern hemisphere some evidence was obtained bearing on this question. The site selected was about 1,000 feet above the National Observatory and quoting from the report* "The ratio of the range in temperature during the night on the hill to that of the lower country is about 1 to 3 in summer, and less in winter." There are in the vicinity of Victoria, elevations of from 700 to 1000 feet, well wooded,—which is important—so that if one of these were chosen the range of $3^{\circ}\cdot 8$ C. would probably be lessened, though it could hardly be hoped to reduce it in such a marked degree as in the case at Santiago.

In the general table of meteorological data at the beginning of this publication, the amount of clear sky was put down as Ottawa 42 per cent., Victoria 37 per cent. Since then, through the kindness of the director of the Meteorological Service, Mr. R. F. Stupart, to whom we are indebted for much valuable information, I have secured the data from sunshine recorders at each place. The data for Ottawa is for the years 1898 to 1912 inclusive, that for Victoria covers the years 1899 to 1912 inclusive.

PERCENTAGE OF BRIGHT SUNSHINE.

—	Ottawa.	Victoria.	—	Ottawa.	Victoria.
	%	%		%	%
January.....	31	19	July.....	54	61
February.....	38	30	August.....	54	57
March.....	41	39	September.....	44	50
April.....	45	46	October.....	40	34
May.....	47	43	November.....	28	20
June.....	51	46	December.....	33	15

*Publications Lick Observatory, vol. IX, page 19.

The mean percentages, Ottawa 44, Victoria 41, are in good agreement with the eye estimates mentioned above. These numbers require some explanation. They represent the percentage of *bright* sunshine only, and consequently the amount of clear sky is greater than indicated by these numbers. As there is no information available, I can not state just what altitude the sun has to be before its rays are strong enough to burn the paper, but it has to be considerable, especially if the horizon is hazy, and hence the numbers fall short of the actual clear sky. These positive corrections should be applied to every month in the year, though they should be largest in the winter months when the sun's altitude is always low. The corrections added to both would not change the relative amounts of clear sky at the two places. Local conditions however do affect the records. The recorder at Ottawa is situated at the Experimental Farm about three miles from the centre of the city, while that at Victoria is on the top of the Post Office block in the heart of the city, where volumes of smoke from the soft coal used are pouring out in winter and thus cutting off the strength of the sun's rays. I have in mind a particular instance which I shall give, though probably it is an extreme case. Intending to examine the recorder one day about the middle of December I kept note of the condition of the sky before going to see it. The sun had been up two hours and a half, and though the horizon was thick I should have classed the sky as 90 per cent. clear. The record showed 20 minutes bright sunshine. The effect on the record of the smoke from neighbouring chimneys and a hazy horizon was impressed upon me upon that occasion. This was probably, as I have said, an extreme case, but it goes to show that when the two places are compared in regard to amount of clear sky a special allowance in the case of Victoria should be made.

I have thought well to consider these percentages further. It will be noticed that the percentages for Victoria during the winter are lower than those for Ottawa. Part of this, though by no means all, can be ascribed to Victoria's higher latitude taken in connection with local conditions previously referred to. I have taken the average time interval from sunset to sunrise, less one hour, for each month in connection with the percentages

given above and I find a weighted mean amount of observational time for Ottawa as 40 per cent., Victoria 35 per cent. These figures would be better indices than those previously given if we could free them from the errors caused by the circumstances mentioned. There should be a positive correction applied to each; it should be greater for Victoria than Ottawa; but any correction that I might suggest would be more in the nature of a guess than otherwise, so I shall refrain from changing them.

Precipitation.—The precipitation at Victoria is confined principally to the winter months, there being less than 3 inches altogether during the four summer months. The following figures are based on 32 years' records:—

PRECIPITATION AT VICTORIA.

January.....	4.3 inches	July.....	0.4 inches
February.....	3.2 "	August.....	0.6 "
March.....	2.5 "	September.....	1.6 "
April.....	1.5 "	October.....	2.5 "
May.....	1.0 "	November.....	4.4 "
June.....	0.8 "	December.....	5.1 "

If curves for the precipitation and cloudiness were plotted they would, using a suitable scale, coincide completely excepting for the months of April, May and June, when the cloudiness is considerably in excess of that suggested by the precipitation. The total precipitation at Ottawa is about 5 inches greater per year than at Victoria.

Humidity.—Though we speak of the vicinity of Victoria as a relatively dry belt, yet intense humidity is a marked feature. The summer months are slightly less so in this respect than the winter but only slightly. A summary of the hygrographic sheets* from June to November inclusive shows that the humidity is least about 2 o'clock in the afternoon, when it is 68, that it rises gradually to 94 about 2 o'clock in the morning and continues thus until about 6 a.m. when it falls somewhat more rapidly than it rose to 70 about noon. Were this district selected, it would be necessary to adopt some scheme to prevent the mirror from being affected, but this should not prove difficult.

*This hygrograph was 200 feet from ocean and 20 feet above its level.

Some mention has been made earlier in this publication of the scarcity of suitable sites close to the city, as the prevailing southwest winds carry the smoke over the elevations to the north and east of the city. It was felt that possibly in the Highland district about 10 to 15 miles northwest of the city, where there are elevations of 1,200 to 1,500 feet, that a site could be had free not only from the present city's smoke but from any ill effects of the future development of the city, particularly in the Esquimalt district. The only doubt in my mind was as to whether climatic conditions were similar there. No weather stations were there, hence no data were available from the Meteorological Bureau. However, the city six years ago thought of tapping this district for a water supply and records were taken of the precipitation at three places in the district. Mr. Reed, the meteorological agent, secured these for me. For 7 months the precipitation totalled 44 inches and the yearly precipitation would probably be in the neighbourhood of 60 inches. West of here in the mountains proper the precipitation increases markedly, so it is probable that the precipitation diminishes rapidly as we come from the west to the eastern edge of the Highland district. Quite frequently during my winter stay I had noticed it raining over the whole western range and Highland district while the sun was shining at Victoria, and I could not but feel that the precipitation and corresponding cloudiness would be such as to render inadvisable selecting a site anywhere in the Highland district west of meridian $123^{\circ} 27'$. This restricted the suitable area to the immediate vicinity of Victoria and the Saanich peninsula. The general climatic conditions of this peninsula are similar to that of Victoria. Furthermore, as intimated previously, there are in this Saanich district elevations from 700 to 1,000 feet free from the city's smoke and lights, and suitable for an observatory.

Fogs.—When Victoria was suggested I had the impression that fog might prove a drawback, and in compiling the data from the meteorological reports I kept glancing at the column of days on which there was fog. As there was nothing to alarm one, no note was made of it. I do not think that there is any cause for uneasiness on this score now, but a word on the subject may be in order. From the reports, there are on the average about 10 days

a year on which fog occurs. For Ottawa the average is given as 6. At Victoria these fogs may be expected from September to February inclusive, the greatest number occurring in the months of September and October. If there were any data giving the height to which they extend it would be valuable but there is none such. This can be said though, that I was never bothered with fogs any night during either visit. I have watched them in the day time on several occasions from various points,—mount Douglas (725 ft.), mount Newton (1,000 ft.), mount Wark (1,420 ft.), mount Malahat (2,000 ft.), and others—and my opinion is that they only rarely exceed 300 to 500 feet. There are times when they do exceed 1,000 feet but these are rare and are in cloudy weather, when no observing could be done anyway. No objection to the place can be taken because of fogs.

The question of earthquakes was considered also but no alarm was felt on that score.

GENERAL SUMMARY.

1. From the meteorological reports a number of localities in western Canada, deemed most promising as a site for the proposed 72-inch reflecting telescope, were selected where special tests of the seeing conditions were to be made and compared with conditions at Ottawa.

2. Observations were carried on from June to October, visits being made going and coming.

3. Of the places outside of Ottawa, Victoria showed up the best in regard to the conditions desired and it alone had to be considered if removal from Ottawa were contemplated.

4. A return visit to Victoria in December was made to ascertain the conditions during the early winter which is naturally the poorest season.

5. The number of clear nights at Victoria and Ottawa is about the same, the latter having any advantage there is. The transparency of the sky is in general the same. Suitable selection of site at Victoria would make that

place slightly better in this regard. The wind velocity at the two places is practically the same. The two most important items in the case of a large reflector are the low range in night temperature and the seeing conditions, *i.e.*, steadiness of image, sharpness of definition, etc. The range of temperature on working nights at Ottawa is at least 75 per cent. greater than at Victoria. The summer seeing conditions at Victoria are 50 per cent. better than at Ottawa, in winter they are 43 per cent. better.

6. The limited duration of the tests made one hesitate to pronounce authoritatively on the relative merits of the two places, but in view of the decided advantages which Victoria possesses in regard to low range of temperature and steady conditions—factors without which a large reflector would be next to useless—it could hardly be gainsaid that the extra cost and inconvenience ought to be overlooked and the telescope located at Victoria.

ADDENDA.

TRIP TO LICK OBSERVATORY.

It was deemed expedient to make some comparisons with the seeing on mount Hamilton, California, where is located the great 36-inch refractor of the Lick Observatory. Accordingly I left Victoria on Aug. 13, arriving at mount Hamilton at noon of Aug. 16, and remained until noon of Aug. 20 when I returned to Victoria.

The nearest point of railroad connection with mount Hamilton is San Jose, 50 miles south of San Francisco. Mount Hamilton, by the highway, is 26 miles from San Jose, nearly east, and is reached by auto-stage over a fairly good road constructed by the Santa Clara county. The country is rolling in character and mount Hamilton is the climax of a succession of rising slopes. Its altitude is 4,209 feet. This place was selected as the site for the telescope after investigations of the seeing conditions on the site had been carried on in 1879 by Mr. S. W. Burnham, now connected with the Yerkes Observatory. It enjoys the reputation of being one of the most suitable sites in the world for stellar research. The weather, during

the entire summer and well on into the winter, is practically unbroken and the observers count upon a succession of clear nights during that time. Less dependence is placed upon the winter season, which is however short.

While there I looked over their weather records, which at that time had not been published; part of the data is here summarized and may be of interest. The data given are the means for the 12½ years from July 1st, 1888, to Dec. 31st, 1900.

Maximum temperature.....	74°·2 F.
Minimum temperature.....	32°·2 F.
Daily range.....	12°·7 F.
Temperature.....	52°·1
Humidity.....	61·3 per cent.
Total precipitation yearly.....	29·9 inches
Wind velocity.....	12·9 miles per hour.
Clear days.....	214 per year.

The following additional items are of interest:

Highest barometer.....	26·269 inches.
Lowest barometer.....	25·055 inches.
Highest temperature.....	94° F.
Lowest temperature.....	13° F.
Greatest rainfall in 24 hours.....	4·36 inches.
Lowest humidity.....	1 per cent.
Highest wind velocity recorded.....	80 miles per hour.

In connection with the daily range in temperature, which is extremely low, it must further be stated that the range during the observing hours of the night is very low indeed. There is a sharp drop in the temperature in the early hours of the evening and then it remains almost constant for the rest of the night, not over 2° or 3° difference in temperature being the rule. This is most favourable and accounts in some measure for the uniform seeing throughout the night which is experienced on mount Hamilton.

The director, Dr. Campbell, was absent in Europe but Mr. R. H. Tucker, the acting director, and in fact every member of the staff did

everything possible to make the four days which I spent as their guest both pleasant and profitable. Somewhat unusual unsteadiness prevailed on the four nights I spent there. The summer had been quite out of the ordinary as the number of nights of good seeing had been much more limited than all past records showed. The first night, Saturday, after the visitors were dismissed, I spent with Dr. Aitken with the 36-inch. I had previously noted conditions with the 12-inch. The seeing was very unsteady. The evening was very cold for August and the fog, which had all evening been lying in the valley, rose and covered the mountain putting an end to all work. On Sunday the weather became warmer and it was hoped that the steadiness would thereby be improved, but though some improvement was noted it was far from perfect, not being over 2 on a scale of 5. On Monday evening conditions were again noted with the 12-inch both before and after midnight, but on the scale of 5 for perfect seeing, 2.5 would be the maximum assignable. The humidity ran from 45 per cent. to 35 per cent. during the interval examined. The appearance of the star image in the 36-inch, to which the spectroscope was attached, confirmed my estimate of 2.5. On Tuesday night I used the 12-inch for a short time and afterwards, with Dr. Aitken, the 36-inch and 6-inch finder. The latter is comparable to the Cooke telescope I used at the selected sites. Thus a comparison of the same seeing using different apertures was possible and this was extremely helpful. Several doubles were examined and though separations as low as $0''.25$ are measurable with the 36-inch on good nights, nothing under six times that distance could that night be measured. The night was not better than 2.

Naturally it was disappointing to the members of the staff of the Lick Observatory, as well as to myself, that such unusually poor seeing conditions had been experienced during my stay. Nevertheless, from a comparison of our estimates of the quality of the seeing on various occasions, I think that our conceptions of what constitutes perfect seeing are probably about the same, and, that being so, I believe we have sites in Canada where seeing conditions, in so far as steadiness is concerned, are as good as those enjoyed by the observers on mount Hamilton.

There is one characteristic of the seeing on mount Hamilton which impressed me very much and that is the transparency. I am bound to admit that it is superior to that found at any of the sites tested as well as at Ottawa. I can illustrate by a reference to the well known group of stars, the Pleiades. On good nights at Ottawa nine stars are easily seen by me with the unaided eye, I have occasionally picked up eleven but with considerable straining of the eyes. At the Lick Observatory, when the cluster had about the same altitude, the first glance was sufficient to show the eleven, the two faintest ones standing out quite conspicuously. At one other place, Penticton, the eleven could be seen much more readily than at Ottawa but not nearly so easily as at the Lick Observatory, so as regards this feature of the seeing the sites tested show up somewhat less favourable than mount Hamilton.

Apart from this particular investigation, my visit to mount Hamilton was helpful to me in other respects and I wish here to record my appreciation of the many kindnesses shown me while there.

PHOTOGRAPHS OF NORTHERN SKY AT VICTORIA.

During the occasion of my last visit to Victoria it was arranged to have photographs made of the northern heavens by simply exposing a camera to the sky for a number of hours each night. The work has been very carefully done by Mr. James Pearce, and we thus have records of the night sky from December, 1913, to the end of May, 1915, when the work was discontinued.

For the year 1914, which in the matter of bright sunshine is about normal, an inspection shows the following:—

Number of nights perfectly clear.....	70
Number of nights clear (less than 20 per cent. clouded)....	43
Number of nights partly clear (broken sky).....	28
Number of nights perfectly clear at start.....	21

Probably on all these 162 nights, work would be attempted at least. At Ottawa during the same year, which was away above normal for observing, we started work on 181 nights. Thus while the quality of the seeing at Victoria is much superior to Ottawa, we cannot hope for very much improvement in the quantity.

DOMINION OBSERVATORY,

OTTAWA,

June, 1915.

DEPARTMENT OF THE INTERIOR
CANADA

HON. W. J. ROCHE, *Minister.*

W. W. CORY, C.M.G., *Deputy Minister.*

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W. F. KING, C.M.G., LL.D., *Director.*

Vol. II, No. 12

Mean distance of stars whose radial
velocities, proper motions and
parallaxes have been
determined

BY

REYNOLD K. YOUNG, Ph. D.

OTTAWA
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MOTIONS AND PARALLAXES HAVE BEEN
DETERMINED.

BY REYNOLD K. YOUNG, Ph.D.

The following investigation was undertaken to answer the question,—
Will the mean distance of the stars as determined from their proper motions
and radial velocities agree with the mean distance as formed from the
directly measured parallaxes?

The data for the parallaxes were selected from the list published by
Kapteyn and Weersma in 1910*. For one hundred and ninety-five stars
of this list, radial velocities were obtained from the Mount Wilson† and Lick
Observatory‡ results. The proper motions of all these stars are very large,
and indeed for the most part the stars were selected for parallax measure-
ment on this account. The excessive magnitude of the cross motion may
be due

1. to the proximity of the stars,
2. to the excessive speed,
3. to exceptionally large values of the inclination of the motion to
the line of sight.

An examination of the data seemed to show that the first factor was
by far the most potent. If we reject twenty-eight stars with exceptional
velocities, over fifty kilometres per second, the remaining ones have a mean
radial velocity very little above the average of the stars in general.

*Grönigen Publications, No. 24.

†Ap. J. Vol. 39.

‡Lick Observatory Bulletin 214.

From one hundred and sixty-seven stars whose radial velocities were less than fifty kilometres per second, a solution for the sun's motion was made with the result:—

Right Ascension of Apex.....	270°·0
Declination of Apex.....	+14°·7
Velocity of Sun.....	-17·7

If the motion of each star is corrected with these values, we find that the average radial velocity for the one hundred and sixty-seven stars is 15·2 kilometres. The list of stars includes nine B-type stars, seventeen A, forty-eight F, forty-eight G, thirty-four K, seven M, and four of unknown type. Campbell's average radial velocities for this distribution of stellar types would be 13·8. The agreement of the two values supports the conclusion that the mean velocity of the stars employed is not greatly in excess of the average.

The proper motions at right angles to the solar motion (τ components) and along the direction of solar motion (ν components) were also computed with the above values for the solar motion. The position of the apex as given by this special group of stars is preferred, because we then demand only that the motions shall be at random among themselves which is a less radical assumption than that they be at random with respect to a given direction, an assumption we would have to make if we had adopted any other position of the apex.

The direction of the solar motion determined from this solution has very little weight when applied to the universe in general, but it is interesting to note in passing that it is the declination which shows the variation from the usually accepted values. Nearly all the stars used are in the northern hemisphere. This was true also of the stars employed by Campbell* in his first solution for the sun's way from two hundred and eighty velocities. Both solutions give low values for the declination of the apex. Whether the small declinations are due to the northern positions of the stars or are to be ascribed to the chance operation of unsymmetrical data is hard to say. The agreement would tend to show that the northern hemisphere gives low values for the declination of the apex.

*Ap. J. vol. 13, 80.

The mean distance of the group of stars was evaluated from the formula

$$\pi_m = 4.738 \frac{\tau_m}{V_m}$$

Where π_m is the mean [parallax.

τ_m is the mean component of proper motion at right angles to the solar motion.

V_m is the mean radial velocity.

Eighty-three τ 's are positive and eighty-four negative, and their average value is $0''.339$, which makes π_m computed $0''.106$. The mean parallax as observed for the same stars is $0''.072$. If we reject a dozen stars whose proper motions are large and which were not rejected by the condition that the radial velocity be under fifty kilometres, we obtain a computed mean parallax $0''.085$ as opposed to $0''.060$ observed. The rejection of these stars does not alter the ratio of the computed and observed parallaxes materially.

Methods of determining the mean distance of the stars based upon the data from the v components are still available, and while these can not be considered as having as much weight as those based on the τ components, it is of interest to see how they agree with the results above.

The first method is based upon the magnitude of the parallactic motion. We have determined by a system of trials, that mean distance, such that when each star is corrected for the solar motion, the total sum of the positive v components is equal to the sum of the negative. The mean parallax that will accomplish the result is $0''.105$, a value almost in exact agreement with the value found from the τ components. Rejecting the same dozen stars as before would yield the value $0''.092$.

When the v components have been corrected on the basis of this mean distance, the corrected values may be treated as the τ components to yield a third value for the mean distance of the stars.

$$\pi_m = 4.738 \times \frac{v_m^1}{V_m}$$

where v'_m is now the mean value of the corrected v components. From this data the value $0''.133$ was obtained or $0''.098$ if twelve stars were omitted. The collected results are shown in the table below:—

	OBSERVED.	COMPUTED.		
		τ Components.	Parallactic motion.	v Components.
From 167 stars.....	$0''.072$	$0''.106$	$0''.105$	$0''.133$
From 155 stars.....	$0''.060$	$0''.085$	$0''.092$	$0''.098$

What effect should the phenomenon of star streaming have on the result? In order to ascertain if this were present, the stars were tested both from their radial velocities and from their proper motions. For the radial velocities, the mean value for stars within sixty degrees of the vertices of preferential motion was 17.6 kilometres as opposed to 13.6 in the remaining part of the sky. To test the proper motions, each star was corrected for the solar component on the basis of the observed parallax. The stars were then divided into two groups, those within sixty degrees of the vertex and those outside this region. If the stars are moving more rapidly along the line joining the vertices, the proper motions should be greatest at right angles to this line. The average values in the two regions were $0''.584$ and $0''.577$. The method is doubtless crude and the regions rather large but we would have expected the star streaming to have shown more than these numbers indicate.

Let us consider however what the effect of such a preferential motion would be on the results. The directions of this motion as given by Kapteyn are

Right ascension... 91° and 271°

Declination... $+13^\circ$ and -13°

a line which is not very far from the apex of the sun's way used in this solution. The τ components of proper motion should not be much affected, while the radial velocities should be increased, and we would expect that the application of the formula

$$\pi_m = 4.738 \times \frac{\tau_m}{V_m}$$

should give too small rather than too large a value for the mean parallax.

In treating the corrected v components by the same formula

$$\pi_m = 4.738 \frac{v_m^1}{V_m}$$

the effect will depend on the distribution of the stars. If nearly all the stars were found near the vertices, V_m^1 would be increased while v_m^1 would remain about the same. If on the other hand most of the stars were midway between the vertices, then v_m^1 would be increased and V_m remain constant. A symmetrical distribution should leave the results of the application of this formula entitled to as much weight as the value from the τ components.

As regards the adjusted value which removes the parallactic effect, it depends directly upon the velocity of the sun adopted. The higher the velocity of the sun chosen, the smaller will be the value of the parallax. If we had used a velocity of the sun about twenty-five kilometres per second, the observed and computed values of the mean parallax from this source would have been in agreement.

The parallactic method of determining the mean distance of a group of stars is applicable without a knowledge of the radial velocities and so could have been applied to a much larger number of stars. This solution has been practically carried out by Lewis Boss.* From 559 stars with mean proper motion over $31''.9$ per century he determined the parallactic motion and assuming the parallaxes to be correct, reversed the problem to determine the speed of the sun. It is very interesting that the velocity obtained was 24.5 kilometres; a value which is undoubtedly too high, but which is almost in exact agreement with the speed that would have to be assumed for the present list of stars to make the observed and computed mean parallaxes agree.

*Astronomical Journal, vol. 26, 118.

Other explanations of the difference between the observed and computed parallaxes suggest themselves. The first is that in choosing stars with large proper motions we have selected stars whose mean angle of inclination to the line of sight is larger than the law of random motion would make it. If this is true the present results would be explained. The operation of this factor would affect relations connecting parallax and proper motions in general, for such relations are derived from stars with large proper motions. Another explanation might be that the stellar system as a whole is rotating, a phenomenon which would affect the proper motions and not the radial velocities. However this latter explanation seems very improbable, as the major part of any rotational effect in proper motions must be eliminated by solutions for the position of the vernal equinox. There remains the possibility that the stars employed contain an unusual number of negative parallaxes.

Dominion Observatory,

Ottawa,

July, 1915.

DEPARTMENT OF THE INTERIOR

CANADA

HON. W. J. ROCHE, *Minister.*

W. W. COBY, C.M.G., *Deputy Minister.*

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W. F. KING, C.M.G., LL.D., *Director.*

Vol. II, No. 13

Orbit of B.A.C. 5890

BY

T. H. PARKER, M.A.

OTTAWA
GOVERNMENT PRINTING BUREAU
1915

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ORBIT OF B.A.C. 5890.

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This star ($\alpha=17^h 21^m \cdot 3$, $\delta=-5^\circ$) was confirmed as a spectroscopic binary by Mr. Burns from the measures of a plate obtained at the Lick Observatory on June 21, 1905. This plate showed a doubling of the lines with a ratio of intensity of about two to one. Two plates had been previously obtained in 1899 and 1900 which had only single lines. In A. J. Vol. 25, a list of measures of eight plates is given. Of this series three gave the velocities of both components with a range of 151 km. The star is an F-type, with fairly broad lines and is of photographic magnitude 4.9. The following orbit was determined from the measures of nineteen plates taken at Ottawa showing both spectra, together with the three Lick observations already mentioned. A large number of plates of this star were obtained here, which were later found to be unsuitable in the determination of the orbit on account of the blending of the two spectra. The latter were only found separated near the primary maximum. Fortunately, however, one of the Lick observations showed double lines at a phase near apastron due to the larger dispersion of the Mills spectrograph. The velocities given by this plate were of great use in finding the values of K in the case of each component, as will be noted later. In all thirty-one lines were measured on the various plates of which about a dozen occurred but a few times. A selection was made of eleven of the best lines remaining for which the wave-lengths were corrected as follows:—

TABLE I.

Element.	Wave-Length.	Element.	Wave-Length.
Iron.....	4549.753	Magnesium-Iron.....	4233.483
Magnesium.....	4481.548	Iron.....	4226.968
Magnesium-Chromium.....	4352.035	Iron.....	4143.832
Hydrogen.....	4340.646	Hydrogen.....	4101.890
Iron.....	4271.689	Iron.....	4045.935
Iron.....	4260.654		

A summary of the observations used is given in the following tables. In Table II will be found the Lick observations giving the velocities as kindly communicated from the director by Dr. Moore, the Julian day for each plate having been sent previously. It will be noted that the values of the velocity in this table, as recently received, are slightly different from those already published, and which were used in the following solutions. These changes are due to a small correction determined from a discussion of the residuals given by the line λ 4500 on all spectrograms of F-type stars. In each case the residuals of these corrected values of the observed velocities from the final curve are less than those given by the former measures. Table III contains the Ottawa observations and, as in Table II, in each case the phase is reckoned from periastron and the residual from the final curve. The measures are given in detail after Table III.

TABLE II.
LICK OBSERVATIONS.

Plate.	Date.	Julian Day.	Phase.	COMPONENT I.		COMPONENT II.	
				Vel.	O-C.	Vel.	O-C.
	1905						
3851B	June 21.....	2,417,018.828	26.104	*+69.0		*-82.0	
				+69.6	-0.6	-80.1	-6.1
	1906						
4324B	July 22.....	414.795	1.690	*+29.0		*-31.0	
				+28.8	-1.6	-31.2	+0.5
4348A	Aug. 1.....	424.714	11.600	-23.8	+0.4	+30.0	+3.3
				*-25.0			

*Values published in L.O.B. vol. 4, p. 96.

TABLE III.

OTTAWA OBSERVATIONS.

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	COMPONENT I.			COMPONENT II.		
						Vel.	Wt.	O-C.	Vel.	Wt.	O-C.
1910											
			m.								
3477	P ¹	June 9.....	58	2,418,832.796	0.875	+44.8	3	- 5.0	-57.2	$\frac{1}{2}$	- 4.8
3506	H-C	July 4.....	93	857.695	25.774	+68.6	7	- 1.6	-71.7	5	+ 2.6
3587	P ¹	Aug. 26.....	65	910.605	26.135	+65.0	5	- 5.4	-76.9	3	- 3.6
1911											
4219	C	April 19.....	65	9,146.873	25.936	+74.8	6	+ 4.1	-58.1	4	+16.3
4226	H	April 20.....	67	147.856	0.644	+61.9	5	+ 4.0	-56.9	2	+ 3.9
4307	P ¹	May 16.....	74	173.849	0.363	+66.1	3	+ 3.4	-81.8	2	- 4.0
4416	P	July 6.....	65	224.633	24.873	+62.6	6	+ 4.0	-50.7	3	+10.7
4421	C	July 7.....	80	225.660	25.900	+80.3	5	+ 9.9	-58.9	2	+15.5
4466	H	Aug. 1.....	85	250.575	24.541	+46.8	3	- 4.5	-63.6	2	- 9.2
4502	H	Aug. 29.....	74	278.574	26.266	+65.0	6	- 3.7	-71.8	4	+ 1.1
4586	C	Sept. 22.....	68	302.522	23.939	+25.7	4	-14.8	-61.9	1	-19.8
4595	H	Sept. 26.....	75	306.515	1.658	+43.4	5	+12.8	-27.6	2	+ 5.7
4656	C	Oct. 19.....	70	329.500	24.643	+52.7	1	- 3.9	-71.8	$\frac{1}{2}$	-15.5
1912											
4921	P ¹	Mar. 25.....	83	487.902	25.400	+73.0	4	+ 5.7	-64.4	2	+ 8.5
4975	P ¹	April 20.....	72	513.833	25.057	+52.9	3	- 7.5	-82.6	2	-19.0
5045	P	June 12.....	100	566.773	25.448	+73.0	4	+ 3.6	-66.9	1	+ 3.3
5051	C-H	June 13.....	90	567.742	0.143	+64.6	5	0.0	-65.1	3	+ 4.0
5172	C	Aug. 29.....	90	644.557	24.410	+51.8	5	+ 2.0	-46.6	2	+ 5.7
1913											
5589	C-P ¹	June 16.....	70	935.743	0.305	+81.6	1	+16.3	-80.7	1	-11.9

*P=Plaskett; H=Harper; C=Cannon; P¹=Parker.

MEASURES OF B.A.C. 5890.

λ	3477 p.*		3477 s.*		3506 p.		3506 s.		3587 p.		3587 s.			
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549-753	+ 35.90	$\frac{1}{2}$	.....		+ 82.86	$\frac{1}{2}$	- 69.01	$\frac{1}{2}$	+ 92.04	$\frac{1}{2}$	.....		.....
4481-548	+ 34.20	$\frac{1}{2}$	.....		+ 77.51	$\frac{1}{2}$	- 29.33	$\frac{1}{2}$	+ 61.99	$\frac{1}{2}$	.....		.....
4352-035	.....		.....		.....		.....		.....		.....		.....
4340-646	.....		.....		+ 69.55	1	- 85.90	$\frac{1}{2}$	+100.01	$\frac{1}{2}$	- 79.10	$\frac{1}{2}$	.....
4271-689	.....		.....		+ 98.45	$\frac{1}{2}$	- 70.69	$\frac{1}{2}$	.....		- 56.60	$\frac{1}{2}$	.....
4260-654	.....		.....		+ 81.24	1	- 68.83	$\frac{1}{2}$	.....		- 40.00	$\frac{1}{2}$	.....
4233-483	.....		.....		+ 73.13	1	- 56.09	$\frac{1}{2}$	.....		- 50.90	$\frac{1}{2}$	.....
4226-968	+ 63.64	$\frac{1}{2}$	- 72.18	$\frac{1}{2}$	+ 88.14	1	- 58.80	1	+108.26	$\frac{1}{2}$	.....		.....
4143-832	+ 55.46	$\frac{1}{2}$	- 26.63	$\frac{1}{2}$	+ 87.27	1	- 52.54	$\frac{1}{2}$	+ 91.89	$\frac{1}{2}$	.....		.....
4101-890	.....		.....		+ 78.57	1	- 53.52	$\frac{1}{2}$	.....		.....		.....
4045-935	.....		.....		+ 60.38	$\frac{1}{2}$	- 35.75	$\frac{1}{2}$	.....		- 42.30	$\frac{3}{4}$	.....
Weighted mean	+ 44.97		- 57.01		+ 79.59		- 60.71		+ 92.34		- 49.52		.....
V_a	+ .24		+ .24		- 10.64		- 10.64		- 26.94		- 26.94		.....
V_s	- .16		- .16		- .09		- .09		- .16		- .16		.....
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		.....
Radial Velocity	+ 44.8		- 57.2		+ 68.6		- 71.7		+ 65.0		- 76.9		.....

*p. = primary.
s. = secondary.

MEASURES OF B.A.C. 5890—Continued.

λ	4219 p.		4219 s.		4226 p.		4226 s.		4307 p.		4307 s.		Vel.	Wt.
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.		
4549.753	+ 59.61	$\frac{1}{2}$	.....	.....	+ 60.01	$\frac{1}{2}$	- 80.25	$\frac{1}{2}$	+ 56.90	$\frac{1}{2}$	- 49.84	$\frac{1}{2}$	.....	.....
4481.548	+ 56.50	$\frac{1}{2}$	- 73.83	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4352.035	+ 52.99	$\frac{1}{2}$	- 101.02	$\frac{1}{2}$	+ 33.76	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340.646	+ 58.80	$\frac{1}{2}$	.....	.....	+ 39.61	$\frac{1}{2}$	.....	.....	+ 52.39	$\frac{1}{2}$	.....	.....	.....	.....
4271.689	.....	.....	- 85.45	$\frac{1}{2}$	.....	.....	.....	.....	+ 58.92	$\frac{1}{2}$	- 111.56	$\frac{1}{2}$	.....	.....
4260.654	+ 50.06	$\frac{1}{2}$	- 73.27	$\frac{1}{2}$	+ 36.82	$\frac{1}{2}$	- 87.22	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4233.483	+ 46.63	$\frac{1}{2}$	.....	.....	+ 35.07	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4226.968	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4143.832	.....	.....	.....	.....	.....	.....	.....	.....	+ 47.16	$\frac{1}{2}$	- 64.76	$\frac{1}{2}$	.....	.....
4101.890	.....	.....	.....	.....	+ 31.17	$\frac{1}{2}$	- 58.77	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4045.935	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 52.98		- 79.86		+ 40.48		- 78.36		+ 54.45		- 93.48			
V _a	+ 22.09		+ 22.09		+ 21.79		+ 21.79		+ 12.05		+ 12.05			
V _s	- .02		- .02		- .09		- .09		- .12		- .12			
Curv.	- .28		- .28		- .28		- .28		- .28		- .28			
Radial Velocity	+ 74.8		- 58.1		+ 61.9		- 56.9		+ 66.1		- 81.8			

MEASURES OF B.A.C. 5890—Continued.

λ	4416 p.		4416 s.		4421 p.		4421 s.		4466 p.		4466 s.		Vel.	Wt.
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.		
4549.753	+ 61.43	$\frac{1}{2}$	.....	.....	.....	.....	- 46.52	$\frac{1}{2}$	+ 74.51	$\frac{1}{2}$	- 39.18	$\frac{1}{2}$	.....	.....
4481.548	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4352.035	.....	.....	.....	.....	+ 100.90	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4340.646	+ 95.63	$\frac{1}{2}$	.....	.....	+ 92.51	$\frac{1}{2}$	.....	.....	+ 43.43	$\frac{1}{2}$	- 51.04	$\frac{1}{2}$	.....	.....
4271.689	+ 78.94	$\frac{1}{2}$	- 48.97	$\frac{1}{2}$	.....	.....	.....	.....	+ 69.38	$\frac{1}{2}$	- 41.40	$\frac{1}{2}$	.....	.....
4260.654	+ 68.68	$\frac{1}{2}$	- 37.20	$\frac{1}{2}$	+ 82.26	$\frac{1}{2}$	- 43.18	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4233.483	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4226.968	.....	.....	.....	.....	+ 83.04	$\frac{1}{2}$	- 67.17	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4143.832	+ 64.85	$\frac{1}{2}$	- 33.46	$\frac{1}{2}$	+ 94.58	$\frac{1}{2}$	- 33.75	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4101.890	.....	.....	.....	.....	.....	.....	.....	.....	+ 68.21	$\frac{1}{2}$	- 37.46	$\frac{1}{2}$	.....	.....
4045.935	+ 68.95	$\frac{1}{2}$	- 42.34	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 74.36		- 39.08		+ 92.46		- 46.80		+ 67.21		- 40.10			
V_0	- 11.47		- 11.47		- 11.81		- 11.81		- 21.60		- 21.60			
V_s	+ .01		+ .01		- .04		- .04		\pm .00		\pm .00			
Curv.	- .28		- .28		- .28		- .28		- .28		- .28			
Radial Velocity	+ 62.6		- 50.7		+ 80.3		- 58.9		+ 45.3		- 62.0			

MEASURES OF B.A.C. 5890—Continued.

λ	4466*p.		4466*s.		4502 p.		4502 s.		4586 p.		4586 s.			
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.753	+ 85.40	$\frac{1}{2}$	- 21.95	$\frac{1}{2}$	+ 98.43	$\frac{1}{2}$	- 50.64	$\frac{1}{2}$	+ 59.70	$\frac{1}{2}$	.....	.....	.....	.....
4481.548	.....	.....	.....	.....	+100.53	$\frac{1}{2}$	- 24.84	$\frac{1}{2}$	+ 31.47	$\frac{1}{2}$	.....	.....	.....	.....
4352.035	+ 70.10	$\frac{1}{2}$	- 41.70	$\frac{1}{2}$	.....	.....	.....	.....	+ 46.42	$\frac{1}{2}$	- 24.62	$\frac{1}{2}$	.....	.....
4340.646	.....	.....	.....	.....	+ 91.01	$\frac{1}{2}$	- 51.51	$\frac{1}{2}$	+ 62.97	$\frac{1}{2}$	.....	.....	.....	.....
4271.689	+ 67.10	$\frac{1}{2}$	- 55.50	$\frac{1}{2}$	+ 83.79	$\frac{1}{2}$	- 44.70	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4260.654	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4233.483	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4226.968	.....	.....	.....	.....	.....	.....	.....	.....	+ 57.70	$\frac{1}{2}$	- 42.80	$\frac{1}{2}$	.....	.....
4143.832	.....	.....	.....	.....	.....	.....	.....	.....	+ 72.47	$\frac{1}{2}$	.....	.....	.....	.....
4101.890	+ 63.80	$\frac{1}{2}$	- 60.10	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4045.935	.....	.....	.....	.....	+ 94.97	$\frac{1}{2}$	- 39.78	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
Weighted mean	+ 71.60		- 44.80		+ 92.74		- 44.12		+ 53.89		- 33.71		.....	.....
V _a	- 21.60		- 21.60		- 27.29		- 27.29		- 27.75		- 27.75		.....	.....
V _d	\pm .00		\pm .00		- .16		- .16		- .16		- .16		.....	.....
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		.....	.....
Radial Velocity	+ 49.7		- 66.7		+ 65.0		- 71.8		+ 25.7		- 61.9		.....	.....

*Check measures.

MEASURES OF B.A.C. 5890—Continued.

λ	4595 p.		4595 s.		4656 p.		4656 s.		4921 p.		4921 s.				
	Vel.	Wt.													
4549.753											+ 53.96	$\frac{1}{2}$	- 93.18	$\frac{1}{2}$	
4481.548	+ 87.94	$\frac{1}{2}$	+ 16.08	$\frac{1}{2}$											
4352.035															
4340.646	+ 70.93	$\frac{1}{2}$	+ 23.89	$\frac{1}{2}$							+ 66.02	$\frac{1}{2}$			
4271.689															
4260.654					+ 75.96	$\frac{1}{2}$	- 48.61	$\frac{1}{2}$	+ 38.39	$\frac{1}{2}$	- 97.23	$\frac{1}{2}$			
4233.483	+ 62.89	$\frac{1}{2}$	- 25.94	$\frac{1}{2}$											
4226.968															
4143.832	+ 74.00	$\frac{1}{2}$	+ 3.42	$\frac{1}{2}$							+ 26.44	$\frac{1}{2}$	- 69.07	$\frac{1}{2}$	
4101.890															
4045.935	+ 52.28	$\frac{1}{2}$	- 13.85	$\frac{1}{2}$											
Weighted mean	+ 71.22		+ 0.20		+ 75.96		- 48.61		+ 46.20		- 89.18				
V _a	- 27.36		- 27.36		- 22.78		- 22.78		+ 27.02		+ 27.02				
V _d	- .18		- .18		- .24		- .24		+ .04		+ .04				
Curv.	- .28		- .28		- .28		- .28		- .28		- .28				
Radial Velocity	+ 43.4		- 27.6		+ 52.7		- 71.9		+ 73.0		+ 62.4				

MEASURES OF B.A.C. 5890—Continued.

λ	4975 p.		4975 s.		5045 p.		5045 s.		5051 p.		5051 s.		Vel.	Wt.
	Vel.	Wt.												
4549.753	+ 4.99	$\frac{1}{2}$	-132.10	$\frac{1}{2}$	+103.62	$\frac{1}{2}$	- 59.29	$\frac{1}{2}$	+ 48.12	$\frac{1}{2}$	.....	.....	.....	.....
4481.548	.....	.....	.....	.....	+ 62.60	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4352.035	.....	.....	.....	.....	+ 78.76	$\frac{1}{2}$	.....	.....	+ 69.89	$\frac{1}{2}$	.....	.....	.....	.....
4340.646	+ 32.74	$\frac{1}{2}$	.....	.....	+ 47.85	$\frac{1}{2}$	- 72.51	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4271.689	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4260.654	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 53.50	$\frac{1}{2}$	.....	.....
4233.483	+ 57.12	$\frac{1}{2}$	-104.40	$\frac{1}{2}$	+ 72.04	$\frac{1}{2}$	.....	.....	+ 73.43	$\frac{1}{2}$	.....	.....	.....	.....
4226.968	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4143.832	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4101.890	+ 33.52	$\frac{1}{2}$	- 88.30	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4045.935	.....	.....	- 78.70	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	- 66.80	$\frac{1}{2}$	.....	.....
Weighted mean	+ 31.62		-104.08		+ 73.94		- 65.90		+ 66.22		- 63.47		.....	.....
V _a	+ 21.55		+ 21.55		- .78		- .78		- 1.28		- 1.28		.....	.....
V _s	+ .04		+ .04		+ .07		+ .07		- .07		- .07		.....	.....
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		.....	.....
Radial Velocity	+ 52.9		- 82.8		+ 73.0		- 66.9		+ 64.4		- 65.1		.....	.....

MEASURES OF B.A.C. 5890—*Concluded.*

λ	5172 p.		5172 s.		5589 p.		5589 s.							
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.753	+ 67.68	$\frac{1}{2}$												
4481.548	+ 52.07	$\frac{1}{2}$												
4352.035														
4340.646	+ 97.59	$\frac{1}{2}$			+ 84.55	$\frac{1}{2}$	- 77.82							
4271.689	+100.34	$\frac{1}{2}$	- 18.15	$\frac{1}{2}$										
4260.654														
4233.483														
4226.968														
4143.832														
4101.890														
4045.935	+ 80.04	$\frac{1}{2}$	- 19.63	$\frac{1}{2}$										
Weighted mean	+ 79.54		- 18.89		+ 84.55		- 77.82							
V_a	- 27.35		- 27.35		- 2.58		- 2.58							
V_d	- .14		- .14		- .09		- .09							
Curv.	- .28		- .28		- .28		- .28							
Radial Velocity	+ 51.8		- 46.6		+ 81.6		- 80.7							

The nineteen Ottawa observations were grouped into five normal places, and those from Lick were taken separately to form three additional places. In the latter case equal weights were assigned and each place was given approximately three times the weight of an average single Ottawa observation. The normal places for both components are given in Table IV, together with the mean phase from periastron, mean velocity, weight, and residual from computed velocities of the preliminary elements.

TABLE IV.
NORMAL PLACES I.

Number.	Mean Phase.	Mean Velocity.	Weight.	O-C.
1	25.026	+42.1	1.5	+ 0.8
2	25.645	+58.9	1.0	- 2.2
3	0.194	+74.9	3.0	- 1.0
4	0.567	+69.0	1.5	- 2.7
5	0.834	+63.3	2.0	- 2.9
6	1.829	+48.5	1.5	+ 6.5
7	2.421	+29.0	1.5	- 0.5
8	12.340	-25.0	1.5	- 1.4
9	25.108	-56.0	0.5	-10.5
10	25.660	-64.5	0.5	- 2.4
11	0.227	-64.2	1.5	+10.7
12	0.567	-82.0	1.0	-10.2
13	0.818	-73.6	1.5	- 6.5
14	1.860	-45.5	0.5	- 2.4
15	2.421	-31.0	1.0	+ 0.9
16	12.340	+30.0	1.0	+11.8

Using the graphical method, these preliminary elements were obtained:—

$$P = 26.2742 \text{ days}$$

$$e = .55$$

$$\omega_1 = 350^\circ$$

$$\omega_2 = 170^\circ$$

$$K_1 = 50 \text{ km.}$$

$$K_2 = 47.3 \text{ km.}$$

$$\gamma = -2.08 \text{ km.}$$

$$T = 2,418,410.794 \text{ J. D.}$$

As previously noted, one of the Lick observations was a great help in fixing the values of K_1 and K_2 above. This plate (4348A) is the third in Table II, with velocities of -25.0 km. and $+30$ km. for the first and second components respectively. It is the only plate giving any idea of the minimum of the primary or the maximum of the secondary. The note accompanying the measure speaks of the secondary as the strong, and the primary as the weak component. This is just the opposite to what has been found in all other plates. Although as will be seen later, the masses

of the two bodies are not very different, and consequently the secondary may show stronger than the primary in some cases.

A least-squares solution was employed to improve the elements obtained in this way. The period, deduced by using the early Lick observations in connection with our own, covering a great number of cycles, was taken as fixed. As had been previously suggested by Dr. King*, the observations of both components were combined into one set of observation equations, from the solution of which only one set of elements result. For the value of ω in the case of the first component we must use $180^\circ + \omega$ in the second. Sixteen observation equations were formed as follows:—

TABLE V.
OBSERVATION EQUATIONS I.

No.	x	y_1	y_2	z	u	v	$-n$	Weight.
1	1	+ .867	.....	-.852	+ .521	-.758	- .800	1.5
2	1	+1.263	.....	-.186	+ .394	-.735	+ 2.200	1.0
3	1	+1.541	.....	+ .484	+ .036	+ .028	+ 1.000	3.0
4	1	+1.475	.....	+ .163	-.132	+ .389	+ 2.700	1.5
5	1	+1.365	.....	-.192	-.236	+ .550	+ 2.900	2.0
6	1	+ .881	.....	-.899	-.423	+ .563	- 6.500	1.5
7	1	+ .631	.....	-.898	-.450	+ .453	+ .500	1.5
8	1	- .430	.....	+ .476	-.072	+ .024	+ 1.400	1.5
9	1	.....	- .918	+ .755	-.484	+ .732	+10.500	.5
10	1	.....	-1.269	+ .163	-.370	+ .691	+ 2.400	.5
11	1	.....	-1.540	-.446	-.021	-.057	-10.700	1.5
12	1	.....	-1.475	-.154	+ .125	-.368	+10.200	1.0
13	1	.....	-1.374	+ .157	+ .217	-.512	+ 6.500	1.5
14	1	.....	- .868	+ .855	+ .402	-.528	+ 2.400	.5
15	1	.....	- .631	+ .849	+ .426	-.428	- .900	1.0
16	1	.....	+ .430	-.450	+ .068	-.023	-11.800	1.0

Where

$$x = \delta\gamma$$

$$y_1 = \delta K_1$$

$$y_2 = \delta K_2$$

$$z = 100\delta e$$

$$\omega = 100\delta\omega$$

$$v = \frac{100\mu\delta T}{(1-e^2)^{\frac{3}{2}}}$$

*P.D.O. vol. I, p. 327.

Normal equations were derived from these as follows:—

$$\begin{aligned}
 21x + 13.754y_1 - 7.575y_2 - 1.432z - .117u + .229v + 5.800 &= 0 \\
 + 18.877y_1 + .000y_2 - 1.613z - .533u + 1.736v + 11.231 &= 0 \\
 + 10.752y_2 - .619z - .539u + 1.444v - 15.617 &= 0 \\
 + 6.651z + .835u - .592v + 27.569 &= 0 \\
 + 1.824u - 2.690v + 2.132 &= 0 \\
 + 4.383v - 4.080 &= 0
 \end{aligned}$$

The solution of these gave

$$\begin{aligned}
 x &= +2.170 \\
 y_1 &= -3.499 \\
 y_2 &= +1.688 \\
 z &= -6.115 \\
 u &= +25.681 \\
 v &= +16.585
 \end{aligned}$$

whence,

$$\begin{aligned}
 \delta\gamma &= +2.17 \text{ km.} \\
 \delta K_1 &= -3.50 \text{ km.} \\
 \delta K_2 &= +1.69 \text{ km.} \\
 \delta e &= -.061 \\
 \delta\omega &= +14^\circ.71 \\
 \delta T &= +.404 \text{ day.}
 \end{aligned}$$

Hence the corrected values of the elements,

$$\begin{aligned}
 e &= .489 \\
 \omega_1 &= 4^\circ.71 \\
 \omega_2 &= 184^\circ.71 \\
 K_1 &= 46.5 \\
 K_2 &= 48.99 \\
 \gamma &= +.09 \text{ km.} \\
 T &= 2,418,411.198 \text{ J. D.}
 \end{aligned}$$

These new values of the elements reduced Σpvv from 642 to 463, or nearly 28 per cent. The agreement however between the computed and observation equation residuals was not satisfactory and a second solution was accordingly carried through.

New normal places were formed as in Table VI.

TABLE VI.
NORMAL PLACES II.

No.	Mean Phase.	Mean Velocity.	Weight.	O-C.	Equation-Ephemeris.
1	24.626	+42.1	1.5	- 3.7	+ 0.7
2	25.246	+58.9	1.0	+ 0.2	- 0.8
3	26.070	+74.0	3.0	+ 4.9	+ 1.1
4	0.166	+69.0	1.5	+ 0.8	+ 2.6
5	0.466	+63.3	2.0	- 1.6	+ 2.8
6	1.426	+48.5	1.5	+ 4.4	+ 1.0
7	2.026	+29.0	1.5	- 1.6	+ 0.3
8	11.936	-25.0	1.5	- 1.3	- 0.6
9	24.706	-56.0	.5	- 6.2	0.0
10	25.256	-64.5	.5	- 2.6	+ 0.8
11	26.100	-64.2	1.5	+ 8.5	- 1.4
12	0.166	-82.0	1.0	-10.3	- 2.4
13	0.426	-73.6	1.5	- 5.0	- 2.5
14	1.456	-45.5	.5	0.0	- 0.7
15	2.026	-31.0	1.0	+ 1.1	0.0
16	11.936	+30.0	1.0	+ 4.8	0.0

Whence the observation equations as below:—

TABLE VII.
OBSERVATION EQUATIONS.

No.	x	y_1	y_2	z	u	v	$-n$	Weight.
1	1	+ .983	.000	-.599	+ .385	-.588	+ 3.700	1.5
2	1	+1.261	.000	-.170	+ .276	-.538	- .200	1.0
3	1	+1.484	.000	+ .444	+ .019	-.082	- 4.900	3.0
4	1	+1.464	.000	+ .421	-.118	+ .218	- .800	1.5
5	1	+1.395	.000	+ .246	-.214	+ .416	+ 1.600	2.0
6	1	+ .946	.000	-.577	-.432	+ .655	- 4.400	1.5
7	1	+ .656	.000	-.774	-.477	+ .577	+ 1.600	1.5
8	1	- .512	.000	+ .460	-.033	+ .004	+ 1.300	1.5
9	1	.000	-1.019	+ .589	-.395	+ .623	+ 6.200	.5
10	1	.000	-1.265	+ .170	-.289	+ .565	+ 2.600	.5
11	1	.000	-1.486	-.476	-.008	+ .061	- 8.500	1.5
12	1	.000	-1.464	-.443	+ .124	-.230	+10.300	1.0
13	1	.000	-1.401	-.276	+ .218	-.425	+ 5.000	1.5
14	1	.000	- .930	+ .626	+ .459	-.688	.000	.5
15	1	.000	- .656	+ .816	+ .503	-.608	- 1.100	1.0
16	1	.000	+ .512	-.485	+ .035	-.004	- 4.800	1.0

with the same substitutions as before.

The normals obtained from these were:—

$$\begin{aligned}
 21x + 13.809y_1 - 7.547y_2 - .497z - .243u + .211v - 6.050 &= 0 \\
 +19.135y_1 + .000y_2 + .556z - .912u + 1.224v - 19.570 &= 0 \\
 +10.846y_2 + 808z - .763u + 1.135v - 13.186 &= 0 \\
 +5.197z + .613u - .622v - 3.773 &= 0 \\
 +1.603u - 2.385v + 3.591 &= 0 \\
 +3.680v - 6.795 &= 0
 \end{aligned}$$

from which,

$$\begin{aligned}
 x &= .289 \\
 y_1 &= .861 \\
 y_2 &= +1.359 \\
 z &= -.149 \\
 u &= +18.1321 \\
 v &= +12.8532
 \end{aligned}$$

and hence,

$$\begin{aligned}
 \delta\gamma &= +.29 \text{ km.} \\
 \delta K_1 &= +.86 \text{ km.} \\
 \delta K_2 &= +1.36 \text{ km.} \\
 \delta e &= -.0015 \\
 \delta\omega &= +10^\circ.39 \\
 \delta T &= +.357 \text{ day.}
 \end{aligned}$$

These gave the second corrected values of the elements as follows:—

$$\begin{aligned}
 e &= .4875 \\
 \omega_1 &= 15^\circ.10 \\
 \omega_2 &= 195^\circ.10 \\
 K_1 &= 47.36 \\
 K_2 &= 50.35 \\
 \gamma &= +.38 \\
 T &= 2,418,411.555 \text{ J. D.}
 \end{aligned}$$

The value of Σpv was now reduced from 463 to 380, but still the agreement between the computed and observation equation residuals was not satisfactory, as will be seen from a glance at the last column in Table VIII.

Another least-squares solution was therefore applied, and the normal places were again set up as in Table VIII.

TABLE VIII.
NORMAL PLACES III.

No.	Mean Phase.	Mean Velocity.	Weight.	O-C.	Equation-Ephemeris.
1	24.269	+42.1	1.5	- 4.5	-0.11
2	24.889	+58.9	1.0	+ 0.7	-0.01
3	25.713	+74.0	3.0	+ 4.7	+0.57
4	26.083	+69.0	1.5	- 0.7	+0.61
5	.089	+63.3	2.0	- 4.1	+0.41
6	1.069	+48.5	1.5	+ 2.5	-0.15
7	1.669	+29.0	1.5	- 1.5	-0.14
8	11.579	-25.0	1.5	- 0.6	-0.09
9	24.349	-56.0	.5	- 5.7	+0.18
10	24.899	-64.5	.5	- 3.2	-0.05
11	25.743	-64.2	1.5	+ 8.9	-0.62
12	26.083	-82.0	1.0	- 8.6	-0.68
13	.069	-73.6	1.5	- 2.5	-0.53
14	1.099	-45.5	.5	+ 1.8	+0.21
15	1.669	-31.0	1.0	+ 0.6	+0.11
16	11.579	+30.0	1.0	+ 3.3	+0.14

Fresh observation equations were formed as in the following table:—

TABLE IX.
OBSERVATION EQUATIONS III.

No.	x	y_1	y_2	z	u	v	$-w$	Weight.	$v - v^1$
1	1	+ .975	.000	-.644	+ .349	-.520	+4.460	1.5	+0.01
2	1	+1.221	.000	-.320	+ .253	-.504	-0.700	1.0	-0.01
3	1	+1.456	.000	+ .347	+ .022	-.170	-4.680	3.0	-0.01
4	1	+1.465	.000	+ .483	-.113	+ .116	+0.740	1.5	+0.01
5	1	+1.415	.000	+ .422	-.216	+ .343	+4.110	2.0	+0.01
6	1	+ .964	.000	-.444	-.472	+ .743	-2.470	1.5	+0.04
7	1	+ .636	.000	-.770	-.527	+ .676	+1.480	1.5	0.00
8	1	- .523	.000	+ .473	-.006	-.015	+0.620	1.5	-0.02
9	1	.000	-1.007	+ .656	-.361	+ .557	+5.680	.5	-0.01
10	1	.000	-1.225	+ .332	-.267	+ .535	+3.220	.5	+0.01
11	1	.000	-1.459	-.388	-.012	+ .158	-8.900	1.5	0.00
12	1	.000	-1.465	-.514	+ .120	-.124	+8.640	1.0	0.00
13	1	.000	-1.421	-.458	+ .221	-.348	+2.450	1.5	-0.01
14	1	.000	- .947	+ .497	+ .507	-.790	-1.800	.5	-0.02
15	1	.000	- .636	+ .819	+ .561	-.719	-0.630	1.0	-0.01
16	1	.000	+ .523	-.503	+ .006	+ .016	-3.300	1.0	0.00

The normal equations resulting were:—

$$\begin{aligned}
 21x + 13.695y_1 - 7.489y_2 - .512z - .328u + .212v - .685 &= 0 \\
 + 18.913y_1 + .000y_2 + .691z - 1.124u + .838v - 4.163 &= 0 \\
 + 10.755y_2 + 1.024z - .869u + .809v - 3.707 &= 0 \\
 + 5.434z + .473u - .738v - 2.424 &= 0 \\
 + 1.744u - 2.551v + .246 &= 0 \\
 + 3.875v + .038 &= 0
 \end{aligned}$$

Solving these,

$$\begin{aligned}
 x &= .061 \\
 y_1 &= .131 \\
 y_2 &= .321 \\
 z &= .367 \\
 u &= -1.085 \\
 v &= -.753.
 \end{aligned}$$

whence,

$$\begin{aligned}
 \delta\gamma &= +.06 \text{ km.} \\
 \delta K_1 &= +.13 \text{ km.} \\
 \delta K_2 &= +.32 \text{ km.} \\
 \delta e &= +.0037 \\
 \delta\omega &= -0^\circ.62 \\
 \delta T &= -.021 \text{ day.}
 \end{aligned}$$

giving the third corrected values as follows:—

$$\begin{aligned}
 P &= 26.2742 \text{ days} \\
 e &= .4912 \\
 \omega_1 &= 14^\circ.48 \\
 \omega_2 &= 194^\circ.48 \\
 K_1 &= 47.49 \text{ km.} \\
 K_2 &= 50.67 \text{ km.} \\
 \gamma &= +.44 \text{ km.} \\
 T &= 2,418,411.534 \text{ J. D.}
 \end{aligned}$$

The value of the elements will be seen to be little changed. The value of Σpv was found to be reduced very slightly, from 380 to 378, but the agreement between the computed and observation equation residuals was now excellent, as may be seen in Table IX ($v-v^1$), and these elements were accepted as final. The following table contains a summary of the preliminary,

first, second and third corrected values, together with the probable error of each element.

TABLE X.

Element.	Preliminary.	I.	II.	III.	Prob. Error.
P	26.2742 days	26.2742	26.2742	26.2742 days	
e	.55	.489	.4875	.4912	$\pm .011$
ω_1	350°	$4^\circ.71$	$15^\circ.10$	$14^\circ.48$	$\pm 7^\circ.55$
ω_2	170°	$184^\circ.71$	195.10	$194^\circ.48$	
K_1	50 km.	46.5 km.	47.36 km.	47.49 km.	± 1.03 km.
K_2	47.3 km.	48.99 km.	50.35 km.	50.67 km.	± 1.18 km.
γ	-2.08 km.	+ .09 km.	+ .38 km.	+ .44 km.	± 1.03 km.
T	2,418,410.794 J. D.	2,418,411.198 J. D.	2,418,411.555 J. D.	2,418,411.524 J. D.	$\pm .30$ day
$a \sin i$	.....	.....	.....	14,950,000 km.	

The probable error of a single observation of average weight was found to be ± 5.6 for the primary component and ± 6.6 for the secondary.

The probable error of a normal place for the primary is ± 4.0 and for the secondary component ± 5.2 .

In the published note in L.O.B. Vol. IV, it is stated that it seems probable that the masses of the stars are not very different, and from the elements determined above this would appear to be the case.

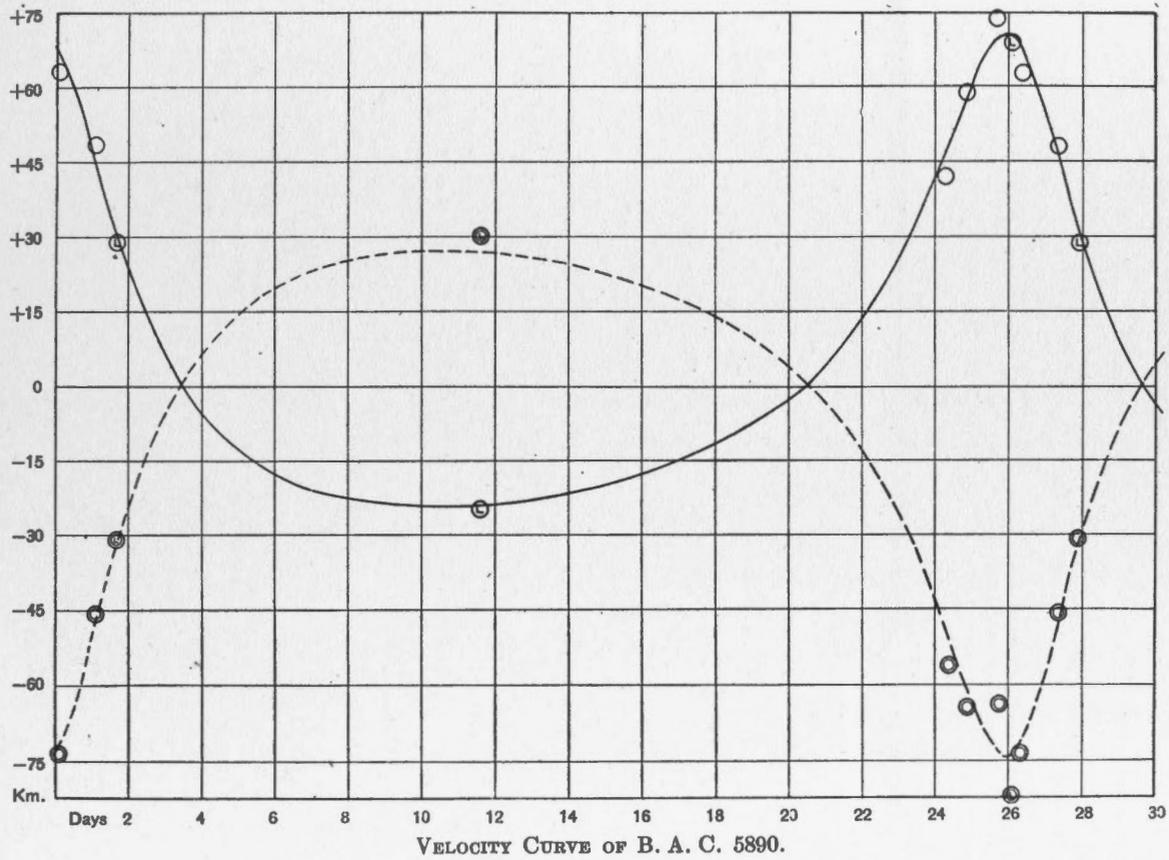
The relation between the masses of the two stars is given by $M_1 : M_2 = K_2 : K_1 = 25 : 24$.

In the accompanying figure, the single circles indicate the observations of the primary and the double circles those of the secondary component. The Lick observations are shown by an L within the circle.

Dominion Observatory,

Ottawa,

June, 1915.



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ORBIT OF μ PERSEI.

BY J. B. CANNON, M.A.

μ Persei ($\alpha = 4^h 8^m \cdot 6$, $\delta = +48^\circ 11'$) was announced a spectroscopic binary in L.O.B. 199, which gives seven measures having a range of 39 km. It was under observation here during the years 1913, 1914 and 1915. Forty-eight plates in all were taken, fourteen in 1913, eighteen in 1914 and the remainder in 1915. On these forty-eight plates the following work is based. The period, being exceptionally long, —284 days— cannot be considered very closely defined, as the epoch between the first of the Lick observations and the last of ours covers only a little over 22 periods. The spectrum is of G-type and a good number of lines were employed, most of which admit of fairly close measurement. Table I gives the lines used and the elements to which they are due. The wave-lengths were computed by averaging the line-residuals in all plates.

TABLE I.
LINES MEASURED IN μ PERSEI.

Wave-Length.	Element.	Wave-Length.	Element.
4861·334.....	Hydrogen	*4271·746.....	Iron
4583·963.....	Iron	4260·569.....	Iron
*4572·082.....	Titanium	4233·370.....	Mangan-Iron
*4549·759.....	Iron	4227·213.....	Iron
4481·400.....	Magnesium	*4215·780.....	Iron
4468·987.....	Titanium	4202·161.....	Iron
4437·718.....	Iron	4198·494.....	Iron
*4415·405.....	Iron	4143·749.....	Iron
*4404·986.....	Iron	4136·985.....	Iron
4395·548.....	Titan-Ven.	4131·047.....	Silicon
*4351·745.....	Chrom-Mag.	4128·075.....	Silicon
*4340·749.....	Hydrogen	*4101·904.....	Hydrogen
*4325·687.....	Iron	4071·901.....	Iron
*4314·848.....	Iron-Titan.	4063·956.....	Iron
4294·301.....	Iron	*4045·909.....	Iron
*4289·972.....	Chrom-Titan.	*4005·421.....	Iron

Those marked with an asterisk are the lines most generally used. The others are used only in a few plates.

Table II gives the Lick observations, Table III the Ottawa observations, the phase being from the final periastron date and the residual from the final curve.

TABLE II.

LICK OBSERVATIONS.

Date.	Julian Day.	Phase.	Velocity.	Residual.
1897, Dec. 23·808.....	2,414,282·808	184·84	- 8·1	+ 3·7
1898, Feb. 2·721.....	323·721	225·75	- 6·8	+ 0·1
Oct. 26·960.....	589·960	207·99	- 9·1	+ 1·9
1905, Oct. 10·900.....	7,129·900	191·93	- 9·3	+ 3·7
1908, Feb. 26·673.....	998·673	208·70	-10·8	± 0·0
1910, Sept. 1·001.....	8,916·001	274·03	+15·0	+ 0·6
Oct. 7·940.....	952·940	26·97	+28·4	+ 0·3

TABLE III.

OTTAWA OBSERVATIONS.

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Weight.	O-C.
		1913	m.					
5329(a)	H	Jan. 28.....	75	2,419,796·60	18·62	+24·0	8	- 1·8
5338	P ¹	Feb. 3.....	90	802·70	24·73	+24·0	7	- 3·0
5349	H	Feb. 6.....	88	805·66	27·69	+30·3	8	+ 2·5
5383	H	Feb. 18.....	60	817·56	39·59	+30·2	7	+ 1·3
5391	C	Feb. 24.....	60	823·57	45·60	+32·5	7	+ 3·7
5415	C	Mar. 7.....	65	834·53	36·56	+27·0	6	- 0·6
5426	C	Mar. 11.....	65	838·54	60·57	+23·8	7	- 3·0
5696	G	Sept. 24.....	65	20,035·90	257·93	+ 5·5	6	+ 1·3
5757	C	Oct. 6.....	60	047·90	269·93	+13·4	5	+ 0·9
5782	P ¹	Oct. 13.....	67	054·89	276·92	+19·9	5	+ 4·4
5795	G-P ¹	Nov. 5.....	60	077·75	15·78	+20·6	5	- 4·5
5803	Y	Nov. 6.....	80	078·66	16·69	+22·1	4	- 3·1
5864	P	Dec. 31.....	55	133·68	71·71	+25·3	6	+ 1·1
		1914						
5871	Y	Jan. 1.....	45	134·62	72·65	+20·5	7	- 3·6
5886	P ¹	Jan. 12.....	40	145·71	83·74	+15·5	5	- 9·7

TABLE III.
OTTAWA OBSERVATIONS—Continued.

Plate	Observer.*	Date	Exposure.	Julian Day	Phase	Velocity	Weight.	O-C.
		1914	m.					
5921	P ¹	Feb. 9.....	60	2,420,173.63	111.66	+ 6.7	7	- 2.7
5943	P ¹	Feb. 16.....	60	180.58	118.61	+ 9.7	6	+ 3.0
5956	C	Feb. 23.....	60	187.61	125.64	+ 5.6	5	+ 1.9
5975	C	Mar. 13.....	25	205.52	143.55	-10.4	2	- 7.6
5986	C	Mar. 20.....	60	212.59	150.62	- 8.5	4	- 3.2
6387	C	Sept. 16.....	60	392.81	46.84	+36.7	4	+ 7.9
6449	C	Sept. 30.....	60	406.80	60.83	+40.9	4	+14.1
6501	H	Oct. 13.....	60	419.86	73.89	+28.1	5	+ 4.3
6518	P ¹	Oct. 21.....	55	427.94	81.97	+18.0	7	- 8.0
6572	C-P ¹	Nov. 23.....	65	460.75	114.78	+ 8.6	4	+ 0.2
6583	C	Nov. 27.....	107	464.77	118.80	+ 3.1	3	- 3.6
6592	C	Dec. 4.....	85	471.69	125.72	+ 1.7	4	- 2.0
6616	C	Dec. 11.....	80	478.68	132.71	+ 0.8	5	- 0.1
6628	Y	Dec. 15.....	55	482.68	136.71	+ 0.2	3	+ 0.7
6654	Y	Dec. 22.....	60	489.66	143.69	- 9.6	3	- 6.8
6666	Y	Dec. 30.....	60	497.52	151.55	- 4.2	6	+ 1.3
		1915						
6693	C	Jan. 8.....	75	506.68	160.71	- 2.4	7	- 5.6
6719	C	Jan. 20.....	63	518.56	172.59	- 2.6	5	+ 7.9
6730	Y	Jan. 24.....	55	522.57	176.60	-17.6	4	- 6.6
6734	C	Jan. 25.....	56	523.65	177.68	- 8.5	3	+ 2.5
6744	P ¹	Jan. 27.....	75	525.69	179.72	-11.7	6	- 0.3
6761	P	Jan. 30.....	60	528.50	182.53	-11.8	7	- 0.1
6782	C	Feb. 12.....	55	541.60	195.63	-13.5	7	- 1.6
6787	H	Feb. 17.....	55	546.55	200.58	-11.1	7	+ 0.6
6818	Y	Feb. 28.....	60	557.55	211.58	-10.2	8	+ 0.3
6827	H	Mar. 3.....	55	560.56	214.59	- 8.9	8	+ 0.9
6855	H	Mar. 11.....	60	568.57	222.60	-13.6	7	- 5.9
6863	Y	Mar. 14.....	55	571.56	225.59	-10.6	7	- 3.8
6883	H	Mar. 22.....	50	579.57	233.60	- 2.6	8	+ 1.2
6892	H	Mar. 29.....	44	586.55	240.58	+ 4.1	7	+ 5.5
6905	H	April 7.....	60	595.54	249.57	+ 4.4	8	+ 1.9
6923	H	April 14.....	64	602.54	256.57	+ 3.2	6	+ 2.8
6966	H	May 6.....	60	624.56	278.59	+14.6	3	- 2.1

*P=Plaskett; H=Harper; P¹=Parker; Y=Young; G=Gibson; C=Cannon.

MEASURES OF μ PERSEI.

λ	5329 (a)		5338		5349		5383		5391		5415		5426	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4861.334	+44.65	$\frac{1}{2}$	+47.86	$\frac{1}{2}$					+66.49	$\frac{1}{4}$	+61.67	$\frac{1}{4}$	+41.54	$\frac{1}{4}$
4583.963					+44.57	$\frac{1}{4}$			+44.78	$\frac{1}{4}$	+41.65	$\frac{1}{4}$		
4572.082	+45.69	$\frac{1}{2}$	+50.91	$\frac{1}{2}$	+39.20	$\frac{1}{4}$	+63.36	$\frac{1}{2}$	+61.87	$\frac{1}{2}$	+52.13	$\frac{1}{2}$	+47.19	$\frac{1}{2}$
4549.759	+43.22	$\frac{1}{2}$	+47.49	$\frac{1}{2}$	+52.69	$\frac{1}{2}$	+47.49	$\frac{1}{2}$	+63.67	$\frac{1}{2}$	+54.08	$\frac{1}{2}$	+64.21	$\frac{1}{4}$
4481.400							+55.04	$\frac{1}{2}$					+51.69	$\frac{1}{4}$
4468.987	+51.36	$\frac{1}{2}$	+51.61	$\frac{1}{2}$	+55.53	$\frac{1}{2}$	+55.79	$\frac{1}{4}$	+61.73	$\frac{1}{4}$	+55.10	$\frac{1}{4}$	+60.95	$\frac{1}{2}$
4437.718	+25.87	$\frac{1}{2}$									+66.45	$\frac{1}{2}$	+53.37	$\frac{1}{4}$
4415.405	+48.72	$\frac{1}{2}$	+47.29	$\frac{1}{2}$	+51.50	$\frac{1}{2}$	+51.31	$\frac{1}{2}$	+55.83	$\frac{1}{2}$				
4404.986	+46.90	$\frac{1}{2}$	+46.35	$\frac{1}{4}$	+65.60	$\frac{1}{4}$	+60.16	$\frac{1}{4}$						
4351.745	+49.86	$\frac{1}{4}$	+41.66	$\frac{1}{4}$	+60.65	$\frac{1}{2}$	+57.39	$\frac{1}{4}$	+55.99	$\frac{1}{2}$			+42.01	$\frac{1}{4}$
4340.749	+47.39	1	+47.04	1	+55.12	1	+55.01	1	+51.08	$\frac{1}{2}$	+59.39	$\frac{1}{2}$	+47.62	$\frac{1}{2}$
4325.687	+47.67	$\frac{1}{2}$	+50.54	$\frac{1}{2}$	+57.64	$\frac{1}{4}$	+50.65	$\frac{1}{2}$	+52.48	$\frac{1}{4}$			+53.81	$\frac{1}{4}$
4289.972	+46.34	$\frac{1}{2}$	+52.47	$\frac{1}{2}$	+53.58	$\frac{1}{2}$	+66.61	$\frac{1}{2}$	+62.27	$\frac{1}{2}$	+61.94	$\frac{1}{4}$	+50.35	$\frac{1}{2}$
4271.746	+46.34	$\frac{1}{2}$			+61.33	$\frac{1}{2}$	+57.04	$\frac{1}{2}$	+57.04	$\frac{1}{2}$	+54.62	$\frac{1}{2}$		
4260.569	+43.94	$\frac{1}{2}$			+56.71	$\frac{1}{4}$							+53.31	$\frac{1}{2}$
4233.370	+47.66	$\frac{1}{2}$	+55.63	$\frac{1}{4}$	+54.11	$\frac{1}{2}$			+65.42	$\frac{1}{4}$			+42.61	$\frac{1}{2}$
4227.213	+47.11	$\frac{1}{2}$			+60.93	$\frac{1}{2}$							+35.85	$\frac{1}{4}$
4128.075	+43.55	$\frac{1}{2}$												
4101.904	+32.22	$\frac{1}{2}$	+40.89	$\frac{1}{4}$	+52.06	1	+57.36	$\frac{1}{2}$					+53.26	$\frac{1}{2}$
4045.909	+50.93	$\frac{1}{2}$	+46.52	$\frac{1}{4}$	+51.39	$\frac{1}{2}$	+65.43	$\frac{1}{2}$	+60.29	$\frac{1}{4}$	+72.50	$\frac{1}{4}$	+49.83	$\frac{1}{4}$
Weighted mean	+47.46		+ 48.86		+ 55.77		+ 56.87		+ 58.46		+ 55.08		+ 50.49	
V_s	-23.08		- 24.41		- 24.96		- 26.46		- 26.79		- 26.36		- 26.30	
V_d	- .09		- .19		- .17		- .10		- .14		- .12		- .12	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 24.0		+ 24.0		+ 30.3		+ 30.0		+ 32.2		+ 28.1		+ 23.8	

MEASURES OF μ PERSEI—Continued.

λ	5696		5757		5782		5795		5803		5864		5871	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4583.963	-11.98	$\frac{1}{2}$	-2.18	$\frac{1}{2}$	-8.03	$\frac{1}{2}$	+3.95	$\frac{1}{2}$	+18.92	$\frac{1}{2}$				
4572.082	-16.31	$\frac{1}{2}$	-5.50	$\frac{1}{2}$	-4.82	$\frac{1}{2}$	-3.07	$\frac{1}{2}$	+8.96	$\frac{1}{2}$	+57.30	$\frac{1}{2}$	+39.64	$\frac{1}{2}$
4549.759	-21.93	$\frac{1}{2}$	-8.92	$\frac{1}{2}$	+9.06	$\frac{1}{2}$	+2.45	$\frac{1}{2}$	+25.71	$\frac{1}{2}$	+39.72	$\frac{1}{2}$	+25.09	$\frac{1}{2}$
4481.400	-16.89	$\frac{1}{2}$	-0.77	$\frac{1}{2}$										
4415.405			-10.39	$\frac{1}{2}$	+1.90	$\frac{1}{2}$	-9.31	$\frac{1}{2}$			+40.87	$\frac{1}{2}$	+24.18	$\frac{1}{2}$
4404.986	-24.86	$\frac{1}{2}$	-15.65	$\frac{1}{2}$	-5.24	$\frac{1}{2}$	+0.45	$\frac{1}{2}$						
4395.548			+2.28	$\frac{1}{2}$									+29.95	$\frac{1}{2}$
4351.745							+15.33	$\frac{1}{2}$	+13.93	$\frac{1}{2}$	+39.65	$\frac{1}{2}$	+51.12	$\frac{1}{2}$
4340.749	-15.85	1	-7.54	$\frac{1}{2}$	+9.90	1	+8.98	1	+5.86	$\frac{1}{2}$	+37.38	$\frac{1}{2}$	+27.95	$\frac{1}{2}$
4325.687	-21.24	$\frac{1}{2}$	-6.36	$\frac{1}{2}$	-2.47	$\frac{1}{2}$	+18.35	$\frac{1}{2}$	+9.42	$\frac{1}{2}$	+38.64	$\frac{1}{2}$	+35.03	$\frac{1}{2}$
4314.848			-9.78	$\frac{1}{2}$	+0.66	$\frac{1}{2}$	+5.99	$\frac{1}{2}$	+6.79	$\frac{1}{2}$	+40.06	$\frac{1}{2}$		
4289.972	-12.81	$\frac{1}{2}$									+41.48	$\frac{1}{2}$	+42.46	$\frac{1}{2}$
4271.746	-19.51	$\frac{1}{2}$	-15.13	$\frac{1}{2}$	-1.09	$\frac{1}{2}$	+5.72	$\frac{1}{2}$	+11.88	$\frac{1}{2}$	+29.70	$\frac{1}{2}$		
4233.370	-9.59	$\frac{1}{2}$	-5.65	$\frac{1}{2}$			+14.74	$\frac{1}{2}$					+25.79	$\frac{1}{2}$
4227.213			-12.46	$\frac{1}{2}$			+4.02	$\frac{1}{2}$			+28.90	$\frac{1}{2}$	+31.50	$\frac{1}{2}$
4202.161	-13.73	$\frac{1}{2}$			-1.87	$\frac{1}{2}$								
4136.985	-15.38	$\frac{1}{2}$			-6.94	$\frac{1}{2}$	+14.48	$\frac{1}{2}$					+36.06	$\frac{1}{2}$
4131.047	-28.43	$\frac{1}{2}$					+1.28	$\frac{1}{2}$	+10.82	$\frac{1}{2}$				
4101.904	-22.02	$\frac{1}{2}$	-18.66	$\frac{1}{2}$	+4.95	$\frac{1}{2}$	+15.22	$\frac{1}{2}$	+10.04	$\frac{1}{2}$	+31.75	$\frac{1}{2}$	+31.28	$\frac{1}{2}$
4045.909					-3.87	$\frac{1}{2}$	+14.21	$\frac{1}{2}$					+36.83	$\frac{1}{2}$
4005.421											+44.00	$\frac{1}{2}$	+43.57	$\frac{1}{2}$
Weighted mean	-18.36		-8.07		+0.51		+9.40		+11.24		+39.45		+34.90	
V_a	+24.36		+21.78		+19.82		+11.49		+11.10		-13.75		-14.13	
V_d	-.19		-.07		-.11		+.01		+.06		-.10		-.03	
Curv.	-.28		-.28		-.28		-.28		-.28		-.28		-.28	
Radial Velocity	+5.5		+13.4		+19.9		+20.6		+22.1		+25.3		+20.5	

MEASURES OF μ PERSEI—Continued.

λ	5886		5921		5943		5956		5975		5986		6387		
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	
4583·963														+ 9·49	$\frac{1}{2}$
4572·082	+37·50	$\frac{1}{2}$	+21·31	$\frac{1}{2}$	+32·15	$\frac{1}{2}$	+46·20	$\frac{1}{2}$	+10·87	$\frac{1}{2}$	+19·30	$\frac{1}{2}$	- 2·49	$\frac{1}{2}$	$\frac{1}{2}$
4549·759	+39·85	$\frac{1}{2}$	+19·16	$\frac{1}{2}$	+31·68	$\frac{1}{2}$	+18·23	$\frac{1}{2}$	+ 3·21	$\frac{1}{2}$	+ 1·89	$\frac{1}{2}$	+29·49	$\frac{1}{2}$	$\frac{1}{2}$
4415·405			+42·08	$\frac{1}{2}$							+11·21	$\frac{1}{2}$	+25·61	$\frac{1}{2}$	$\frac{1}{2}$
4404·986	+25·82	$\frac{1}{2}$	+33·57	$\frac{1}{2}$	+39·17	$\frac{1}{2}$	+37·98	$\frac{1}{2}$							
4395·548	+41·67	$\frac{1}{2}$			+35·52	$\frac{1}{2}$	+29·12	$\frac{1}{2}$							
4351·745			+37·02	$\frac{1}{2}$	+26·46	$\frac{1}{2}$					+ 1·34	$\frac{1}{2}$	+32·35	$\frac{1}{2}$	$\frac{1}{2}$
4340·749	+34·66	$\frac{1}{2}$	+34·77	$\frac{1}{2}$	+38·86	1	+35·91	1	+ 9·75	$\frac{1}{2}$	+22·60	1	+ 4·71	$\frac{1}{2}$	$\frac{1}{2}$
4325·687			+36·84	$\frac{1}{2}$	+36·61	$\frac{1}{2}$	+31·32	$\frac{1}{2}$	+21·65	$\frac{1}{2}$	+15·12	$\frac{1}{2}$			
4314·848	+32·81	$\frac{1}{2}$	+35·60	$\frac{1}{2}$	+30·88	$\frac{1}{2}$	+30·44	$\frac{1}{2}$	+20·21	$\frac{1}{2}$	+13·93	$\frac{1}{2}$	+ 3·43	$\frac{1}{2}$	$\frac{1}{2}$
4289·972			+29·99	$\frac{1}{2}$	+37·43	$\frac{1}{2}$	+26·60	$\frac{1}{2}$			+18·83	$\frac{1}{2}$	+ 5·98	$\frac{1}{2}$	$\frac{1}{2}$
4271·746	+23·77	$\frac{1}{2}$	+41·79	$\frac{1}{2}$									+12·64	$\frac{1}{2}$	$\frac{1}{2}$
4260·569							+32·85	$\frac{1}{2}$							
4233·370					+41·50	$\frac{1}{2}$	+40·56	$\frac{1}{2}$			+18·39	$\frac{1}{2}$			
4227·213											+16·09	$\frac{1}{2}$	+20·44	$\frac{1}{2}$	$\frac{1}{2}$
4215·780													+ 1·16	$\frac{1}{2}$	$\frac{1}{2}$
4143·749			+28·28	$\frac{1}{2}$											
4128·075			+28·24	$\frac{1}{2}$										+13·04	$\frac{1}{2}$
4101·904			+24·78	$\frac{1}{2}$	+48·31	$\frac{1}{2}$	+30·90	$\frac{1}{2}$			+24·50	1	+12·64	$\frac{1}{2}$	$\frac{1}{2}$
4045·909			+34·15	1	+15·93	$\frac{1}{2}$					+17·54	$\frac{1}{2}$			
4005·421			+32·54	$\frac{1}{2}$											
Weighted															
mean	+ 34·25		+ 32·53		+ 34·37		+ 32·75		+ 16·02		+ 17·09		+ 11·28		
V_a	- 18·30		- 25·41		- 24·27		- 26·74		- 26·19		- 25·19		+ 25·55		
V_d	- ·16		- ·16		- ·12		- ·16		\pm 0·00		- ·15		+ ·09		
Curv.	- ·28		- ·28		- ·28		- ·28		- ·28		- ·28		- ·28		
Radial															
Velocity	+ 15·5		+ 6·7		+ 9·7		+ 5·6		- 10·4		- 8·5		+ 36·7		

MEASURES OF μ PERSEI—Continued.

λ	6449		6501		6518		6572		6583		6592		6616	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4583.963	+25.92	$\frac{1}{2}$	+16.58	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4572.082	+22.64	$\frac{1}{2}$	- 0.76	$\frac{1}{2}$	-10.08	$\frac{1}{2}$	+11.79	$\frac{1}{2}$	+ 8.33	$\frac{1}{2}$	- 9.51	$\frac{1}{2}$	- 1.52	$\frac{1}{2}$
4549.759	.....	.....	+ 6.35	$\frac{1}{2}$	-14.29	$\frac{1}{2}$	+ 1.16	$\frac{1}{2}$	- 1.86	$\frac{1}{2}$	- 4.48	$\frac{1}{2}$	+ 2.47	$\frac{1}{2}$
4468.987	+35.70	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4415.405	.....	.....	+18.71	$\frac{1}{2}$	+ 4.66	$\frac{1}{2}$	.....	.....	.....	.....	+ 4.95	$\frac{1}{2}$	+ 9.01	$\frac{1}{2}$
4404.986	+14.07	$\frac{1}{2}$	+17.31	$\frac{1}{2}$	+ 4.74	$\frac{1}{2}$	- 2.70	$\frac{1}{2}$	- 1.06	$\frac{1}{2}$	+14.38	$\frac{1}{2}$	+ 3.35	$\frac{1}{2}$
4395.548	.....	.....	.....	.....	.....	.....	- 5.63	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4351.745	+ 6.53	$\frac{1}{2}$	+ 4.75	$\frac{1}{2}$	- 5.48	$\frac{1}{2}$	.....	.....	+ 2.03	$\frac{1}{2}$	+10.13	$\frac{1}{2}$	+ 0.89	$\frac{1}{2}$
4340.749	+ 9.78	$\frac{1}{2}$	+ 7.87	$\frac{1}{2}$	+10.35	$\frac{1}{2}$	+ 6.93	$\frac{1}{2}$	- 8.56	1	- 2.01	$\frac{1}{2}$	+ 8.40	1
4325.687	+14.83	$\frac{1}{2}$	- 7.85	$\frac{1}{2}$	+ 8.51	$\frac{1}{2}$	+ 9.45	$\frac{1}{2}$	+ 7.44	$\frac{1}{2}$	- 1.84	$\frac{1}{2}$	+ 8.78	$\frac{1}{2}$
4314.848	+20.46	$\frac{1}{2}$	+11.49	$\frac{1}{2}$	+ 0.23	$\frac{1}{2}$	+ 4.48	$\frac{1}{2}$	- 3.84	$\frac{1}{2}$	+ 2.59	$\frac{1}{2}$	+ 4.81	1
4289.972	+14.85	1	+ 1.43	$\frac{1}{2}$	+ 0.68	1	+ 0.68	$\frac{1}{2}$	+ 6.44	$\frac{1}{2}$	+ 4.49	$\frac{1}{2}$	+ 1.66	$\frac{1}{2}$
4271.746	+ 8.58	$\frac{1}{2}$	+ 9.34	$\frac{1}{2}$	+ 7.83	$\frac{1}{2}$	+ 9.69	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4260.569	.....	.....	.....	.....	- 0.29	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4227.213	+17.84	$\frac{1}{2}$	+12.40	$\frac{1}{2}$	.....	.....	+ 5.27	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4215.780	+18.24	$\frac{1}{2}$	+14.46	$\frac{1}{2}$	+ 7.42	1	+11.90	1	+ 2.71	$\frac{1}{2}$	+ 8.21	$\frac{1}{2}$	+12.43	$\frac{1}{2}$
4198.494	.....	.....	+19.23	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4128.075	.....	.....	.....	.....	- 8.31	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4101.904	+24.80	1	+ 6.78	$\frac{1}{2}$	+ 4.75	$\frac{1}{2}$	+ 3.48	1	- 3.05	1	+ 8.70	$\frac{1}{2}$	+ 6.00	$\frac{1}{2}$
4071.901	.....	.....	.....	.....	+ 2.24	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4063.756	.....	.....	+ 6.38	$\frac{1}{2}$	+ 0.09	$\frac{1}{2}$	- 2.71	$\frac{1}{2}$	+11.55	$\frac{1}{2}$	.....	.....	.....	.....
4045.909	+17.89	1	- 1.71	$\frac{1}{2}$	+ 1.12	$\frac{1}{2}$	+ 7.31	$\frac{1}{2}$	+11.39	$\frac{1}{2}$	+10.77	$\frac{1}{2}$	+10.06	$\frac{1}{2}$
4005.421	.....	.....	+ 3.17	$\frac{1}{2}$	+ 1.13	$\frac{1}{2}$	+10.82	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
Weighted mean	+ 17.90		+ 8.49		+ 1.70		+ 5.32		+ 1.81		+ 3.59		+ 5.91	
V _a	+ 23.27		+ 19.91		+ 17.28		+ 3.59		+ 1.71		- 1.54		- 4.81	
V _d	+ .05		± .00		- .11		- .05		- .09		- .04		- .04	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 40.9		+ 28.1		+ 18.0		+ 8.6		+ 3.1		+ 1.7		+ 0.8	

MEASURES OF μ PERSEI—Continued.

λ	6628		6654		6666		6693		6719		6730		6734	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572.082	+ 8.73	$\frac{1}{2}$	+ 3.67	$\frac{1}{2}$	+14.06	$\frac{1}{2}$	+22.18	$\frac{1}{2}$	+28.44	$\frac{1}{2}$	+ 2.47	$\frac{1}{2}$	+ 5.00	$\frac{1}{4}$
4549.759	+18.99	$\frac{1}{2}$	- 1.99	$\frac{1}{2}$	+11.65	$\frac{1}{2}$	+12.18	$\frac{1}{2}$	+10.47	$\frac{1}{2}$	- 1.86	$\frac{1}{2}$	.....	.....
4415.405	+12.24	$\frac{1}{2}$	+ 3.52	$\frac{1}{2}$	+ 5.67	$\frac{1}{2}$	+ 9.01	$\frac{1}{2}$	+20.84	$\frac{1}{2}$	- 2.46	$\frac{1}{2}$	- 4.73	$\frac{1}{4}$
4404.986	+17.40	$\frac{1}{2}$	+ 5.25	$\frac{1}{2}$	+14.15	$\frac{1}{2}$	+14.38	$\frac{1}{2}$	+10.71	$\frac{1}{2}$	+ 0.03	$\frac{1}{2}$	.....	.....
4351.745	+ 2.94	$\frac{1}{2}$	- 7.44	$\frac{1}{2}$	.....	.....	+24.85	$\frac{1}{2}$	+16.63	$\frac{1}{2}$	.....	.....	+26.55	$\frac{1}{4}$
4340.749	- 0.31	$\frac{1}{2}$	-24.40	$\frac{1}{2}$	+ 4.78	$\frac{1}{2}$	- 2.91	$\frac{1}{2}$	+13.37	$\frac{1}{2}$	+ 1.39	$\frac{1}{2}$	+ 2.25	$\frac{1}{2}$
4325.687	- 4.97	$\frac{1}{2}$	+10.90	$\frac{1}{2}$	+ 6.83	$\frac{1}{2}$	+13.81	$\frac{1}{2}$	+18.90	$\frac{1}{2}$	- 0.50	$\frac{1}{2}$	+25.89	$\frac{1}{4}$
4314.848	- 4.17	$\frac{1}{2}$	+ 7.47	$\frac{1}{2}$	+ 7.25	$\frac{1}{2}$	+12.24	$\frac{1}{2}$	.....	.....	+ 9.47	$\frac{1}{2}$	.....	.....
4289.972	- 6.07	$\frac{1}{2}$	- 0.52	$\frac{1}{2}$	+ 2.42	$\frac{1}{2}$	+17.00	$\frac{1}{2}$	+ 4.38	$\frac{1}{2}$	+10.64	$\frac{1}{2}$	+11.79	$\frac{1}{2}$
4215.780	+10.06	$\frac{1}{2}$	+11.80	$\frac{1}{2}$	+14.16	$\frac{1}{2}$	+19.19	$\frac{1}{2}$	+17.34	$\frac{1}{2}$	+11.19	$\frac{1}{2}$	+18.61	1
4101.904	- 0.70	$\frac{1}{2}$	+ 6.28	$\frac{1}{2}$	+10.01	$\frac{1}{2}$	+14.95	$\frac{1}{2}$	+21.67	$\frac{1}{2}$	+10.76	$\frac{1}{2}$	+20.90	$\frac{1}{2}$
4045.909	+18.28	$\frac{1}{2}$	.....	.....	+12.72	$\frac{1}{2}$	+22.74	$\frac{1}{2}$	+32.59	$\frac{1}{2}$	+ 6.86	$\frac{1}{2}$	+13.95	$\frac{1}{2}$
Weighted mean	+ 7.17		+ 0.88		+ 9.32		+ 14.73		+ 18.46		+ 4.65		+ 14.06	
V_s	- 6.66		- 10.15		- 13.17		- 16.77		- 20.78		- 21.92		- 22.13	
V_d	- .06		- .04		- .10		- .12		\pm .00		- .03		- .13	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 0.2		- 9.6		- 4.2		- 2.4		- 2.6		- 17.6		- 8.5	

MEASURES OF μ PERSEI—Continued.

λ	6744		6761		6782		6787		6818		6827		6855	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572.082	+ 9.57	$\frac{1}{2}$	+13.26	$\frac{1}{2}$	+12.99	$\frac{1}{2}$	- 1.80	$\frac{1}{2}$	+12.73	$\frac{1}{2}$	+18.05	$\frac{1}{2}$	+ 8.20	$\frac{1}{2}$
4549.759	+13.10	$\frac{1}{2}$	+17.82	$\frac{1}{2}$	+12.70	$\frac{1}{2}$	+ 6.28	$\frac{1}{2}$	+18.61	$\frac{1}{2}$	+27.28	$\frac{1}{2}$	+14.54	$\frac{1}{2}$
4415.405	+ 8.05	$\frac{1}{2}$	+ 0.24	$\frac{1}{2}$	+ 8.65	$\frac{1}{2}$	+11.04	$\frac{1}{2}$	+19.16	$\frac{1}{2}$	+15.58	$\frac{1}{2}$	+ 7.21	$\frac{1}{2}$
4404.986	+ 4.57	$\frac{1}{2}$	+16.62	$\frac{1}{2}$	+ 3.75	$\frac{1}{2}$	+21.50	$\frac{1}{2}$	+10.94	$\frac{1}{2}$	+26.92	$\frac{1}{2}$	+ 8.92	$\frac{1}{2}$
4351.745	.....	.....	+11.27	$\frac{1}{2}$	+ 9.71	$\frac{1}{2}$	.....	.....	+ 7.72	$\frac{1}{2}$	+27.59	$\frac{1}{2}$	.....	.....
4340.749	+14.62	$\frac{1}{2}$	+12.13	$\frac{1}{2}$	+17.80	$\frac{1}{2}$	+10.89	$\frac{1}{2}$	+ 8.40	$\frac{1}{2}$	+15.46	$\frac{1}{2}$	+14.50	$\frac{1}{2}$
4325.687	+ 4.65	$\frac{1}{2}$	.....	.....	+20.79	$\frac{1}{2}$	.....	.....	+18.39	$\frac{1}{2}$	.....	.....	+20.85	$\frac{1}{2}$
4314.848	+11.91	$\frac{1}{2}$	+ 5.39	$\frac{1}{2}$	- 0.82	$\frac{1}{2}$	+12.69	$\frac{1}{2}$	+ 9.49	$\frac{1}{2}$	+19.45	$\frac{1}{2}$	+16.24	$\frac{1}{2}$
4294.301	.....	.....	.....	.....	+16.39	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4289.972	+16.45	$\frac{1}{2}$	+11.55	$\frac{1}{2}$	+16.59	$\frac{1}{2}$	+17.30	$\frac{1}{2}$	+15.90	$\frac{1}{2}$	+15.90	$\frac{1}{2}$	+ 1.94	$\frac{1}{2}$
4271.746	+10.97	$\frac{1}{2}$	+ 9.15	$\frac{1}{2}$	+16.15	$\frac{1}{2}$	+17.20	$\frac{1}{2}$	+19.99	$\frac{1}{2}$	+11.51	$\frac{1}{2}$	+ 8.50	$\frac{1}{2}$
4215.780	+16.91	$\frac{1}{2}$	+14.36	$\frac{1}{2}$	+11.19	$\frac{1}{2}$	+22.05	$\frac{1}{2}$	+26.88	$\frac{1}{2}$	+14.18	$\frac{1}{2}$	+17.02	$\frac{1}{2}$
4101.904	.....	.....	+ 8.61	$\frac{1}{2}$	+14.20	$\frac{1}{2}$	+11.86	$\frac{1}{2}$	+17.65	$\frac{1}{2}$	+21.56	$\frac{1}{2}$	+16.43	$\frac{1}{2}$
4045.909	.....	.....	+11.12	$\frac{1}{2}$	+13.77	1	+27.70	$\frac{1}{2}$	+24.85	$\frac{1}{2}$	+18.57	$\frac{1}{2}$	+23.54	$\frac{1}{2}$
4005.421	.....	.....	.....	.....	+ 7.82	$\frac{1}{2}$	+15.00	$\frac{1}{2}$	+27.40	$\frac{1}{2}$	+22.46	$\frac{1}{2}$	+16.11	$\frac{1}{2}$
Weighted mean	+ 11.52		+ 11.88		+ 12.57		+ 15.68		+ 17.08		+ 18.36		+ 13.14	
V_c	- 22.74		- 23.42		- 25.71		- 26.34		- 26.84		- 26.80		- 26.35	
V_d	- .17		+ .03		- .12		- .12		- .12		- .14		- .16	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 11.7		- 11.8		- 13.5		- 11.1		- 10.2		- 8.9		- 13.6	

MEASURES OF μ PERSEI—*Concluded.*

λ	6863		6883		6892		6905		6923		6966			
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4572.082	+ 7.13	$\frac{1}{2}$	+18.86	$\frac{1}{4}$	+29.28	$\frac{1}{2}$	+35.12	$\frac{1}{2}$	+36.70	$\frac{1}{2}$	+25.96	$\frac{1}{2}$	.....	.....
4549.759	+18.06	$\frac{1}{2}$	+20.98	$\frac{1}{2}$	+29.76	$\frac{1}{4}$	+35.34	$\frac{1}{2}$	+23.62	$\frac{1}{2}$	+23.51	$\frac{1}{2}$	.....	.....
4415.405	+ 8.76	$\frac{1}{2}$	+19.28	$\frac{1}{4}$	+26.20	$\frac{1}{2}$	+17.01	$\frac{1}{2}$	+18.31	$\frac{1}{4}$	.....	.....	.....	.....
4404.986	+ 7.74	$\frac{1}{2}$	+18.30	$\frac{1}{2}$	+12.24	$\frac{1}{4}$	.....	.....	+28.11	$\frac{1}{2}$	+27.18	$\frac{1}{4}$	.....	.....
4395.548	.....	.....	+14.71	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4351.745	+16.52	$\frac{1}{4}$	+26.71	$\frac{1}{2}$	+36.49	$\frac{1}{4}$	+25.76	$\frac{1}{4}$	+20.96	$\frac{1}{2}$	+27.20	$\frac{1}{4}$	.....	.....
4340.749	+24.66	$\frac{1}{2}$	+26.22	$\frac{1}{4}$	+20.16	$\frac{1}{2}$	+23.30	1	+27.23	$\frac{1}{2}$	+35.41	$\frac{1}{2}$	.....	.....
4325.687	+24.10	$\frac{1}{4}$	+25.55	$\frac{1}{2}$	+32.26	$\frac{1}{4}$	+28.45	$\frac{1}{4}$	+26.40	$\frac{1}{4}$	+45.78	$\frac{1}{4}$	.....	.....
4314.848	+25.33	$\frac{1}{2}$	+22.72	$\frac{1}{2}$	+34.64	$\frac{1}{2}$	+22.56	$\frac{1}{2}$	+17.48	$\frac{1}{2}$	+27.20	$\frac{1}{2}$	.....	.....
4289.972	+11.45	$\frac{1}{4}$	+24.18	$\frac{1}{2}$	+18.95	$\frac{1}{4}$	+22.52	$\frac{1}{4}$	+13.23	$\frac{1}{2}$	+23.18	$\frac{1}{2}$	.....	.....
4271.746	+17.85	$\frac{1}{2}$	.....	.....	.....	.....	+20.54	$\frac{1}{2}$	+21.09	$\frac{1}{4}$	+10.29	$\frac{1}{2}$	.....	.....
4215.780	+21.02	$\frac{1}{2}$	+35.61	$\frac{1}{2}$	+26.90	$\frac{1}{2}$	+26.77	$\frac{1}{2}$	+19.49	$\frac{1}{2}$	+26.00	$\frac{1}{4}$	.....	.....
4101.904	+21.18	$\frac{1}{2}$	+ 9.55	$\frac{1}{4}$	+25.95	$\frac{1}{2}$	+22.31	$\frac{1}{2}$	+22.38	$\frac{1}{4}$	.....	.....	.....	.....
4077.885	.....	.....	.....	.....	.....	.....	+32.56	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4045.909	+ 9.82	$\frac{1}{2}$	+21.58	$\frac{1}{2}$	+32.12	$\frac{1}{4}$	+30.71	$\frac{1}{2}$	+24.95	$\frac{1}{4}$	.....	.....	.....	.....
4005.421	.....	.....	+22.26	$\frac{1}{4}$	+36.80	$\frac{1}{2}$	+24.81	$\frac{1}{4}$	+15.32	$\frac{1}{4}$	.....	.....	.....	.....
Weighted mean	+ 15.91		+ 22.76		+ 28.08		+ 26.18		+ 22.90		+ 26.07			
V_a	- 26.04		- 24.91		- 23.53		- 21.28		- 19.18		- 11.05			
V_d	- .16		- .19		- .19		- .19		- .21		- .19			
Curv.	- .28		- .28		- .28		- .28		- .28		- .28			
Radial Velocity	- 10.6		- 2.6		+ 4.1		+ 4.4		+ 3.2		+ 14.6			

Eleven normal places were formed which are given in Table IV with the mean Julian day, mean phase, velocity, weight and residual.

TABLE IV.
NORMAL PLACES.

No.	Julian Day	Phase	Velocity	Weight	Residual
1.....	2,419,958.950	50.87	+30.8	4.0	+ 2.3
2.....	20,248.930	77.03	+21.3	3.5	- 1.3
3.....	276.812	115.44	+ 7.4	2.0	- 0.4
4.....	392.131	129.69	+ 2.3	2.0	+ 0.2
5.....	439.197	152.50	- 5.7	2.5	- 0.3
6.....	524.307	178.34	-10.5	2.5	+ 0.6
7.....	552.066	206.10	-10.8	3.5	+ 0.4
8.....	573.519	227.55	- 8.6	2.5	- 2.2
9.....	470.400	250.65	+ 4.3	3.0	+ 1.2
10.....	183.669	274.61	+16.2	1.5	+ 1.3
11.....	19,879.385	21.54	+24.8	3.5	- 1.9

By the graphical method of Dr. King the following preliminary elements were obtained:—

$$\gamma = 7.92 \text{ km.}$$

$$K = 21.50 \text{ km.}$$

$$e = .1$$

$$\omega = 300^\circ$$

$$T = 2,420,058.70 \text{ J. D.}$$

The observation equations following were formed for a least-squares solution. The period was not included in the solution as the early Lick observations all occurred at the low part of the curve, where a variation of several days would make no appreciable difference in the residual, and hence no improvement could be hoped for by this means.

OBSERVATION EQUATIONS.

No.	x	y	z	u	v	$-n$	Weight.
1.....	1	+·991	-·177	-·251	+·350	-1·6	4·0
2.....	1	+·657	-·954	-·708	+·735	+0·7	3·5
3.....	1	-·047	-·294	-·909	+·823	-0·5	2·0
4.....	1	-·301	+·205	-·850	+·761	-0·9	2·0
5.....	1	-·649	+·842	-·628	+·583	-0·3	2·5
6.....	1	-·902	+·901	-·221	+·264	-1·0	2·5
7.....	1	-·920	+·031	+·331	-·231	-1·0	3·5
8.....	1	-·698	-·826	+·750	-·690	+1·5	2·5
9.....	1	-·225	-·945	+1·048	-1·100	-1·2	3·0
10.....	1	+·400	+·172	+1·023	-1·130	+0·3	1·5
11.....	1	+·978	+·983	+·459	-·434	+4·1	3·5

In the above

$$x = \delta\gamma$$

$$y = \delta K$$

$$z = K\delta e$$

$$u = K\delta\omega$$

$$v = \frac{K\mu\delta T}{(1-e^2)^{\frac{3}{2}}}$$

The normal equations resulting from these observation equations were:—

$$30\cdot500x + \cdot073y - \cdot961z + \cdot195u + \cdot210v + 1\cdot450 = 0$$

$$16\cdot630y - \cdot941z - 1\cdot406u + 1\cdot527v + 14\cdot225 = 0$$

$$15\cdot183z - 1\cdot733u + 1\cdot681v + 10\cdot221 = 0$$

$$13\cdot602u - 13\cdot472v + 8\cdot259 = 0$$

$$13\cdot497v - 8\cdot285 = 0$$

Solving these gave

$$x = -\cdot0869$$

$$y = -\cdot9835$$

$$z = -\cdot8288$$

$$u = +\cdot7490$$

$$v = +1\cdot5772$$

and therefore the corrections:—

$$\delta\gamma = -\cdot09 \text{ km.}$$

$$\delta K = -\cdot98 \text{ km.}$$

$$\delta e = -\cdot0385$$

$$\delta\omega = +1^\circ\cdot99$$

$$\delta T = +3\cdot27 \text{ days.}$$

Hence the new values of the elements, to which the probable errors are appended.

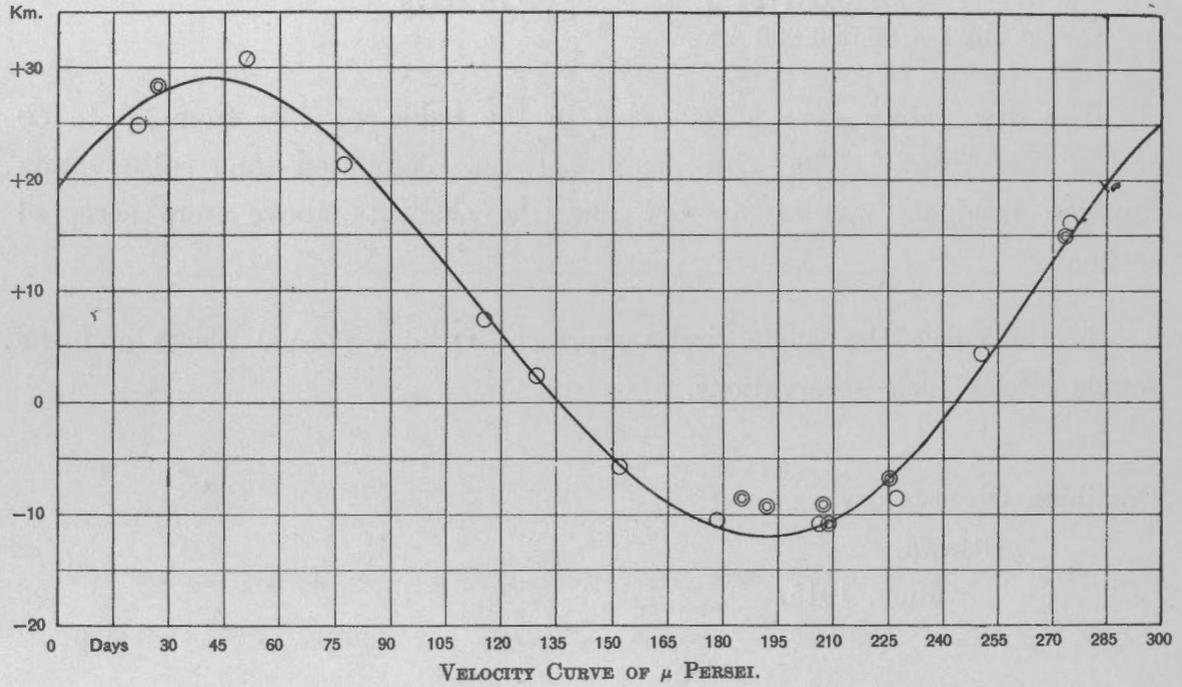
$$\begin{array}{ll}
 \gamma = 7.83 \text{ km.} & \pm .36 \text{ km.} \\
 K = 20.50 \text{ km.} & \pm .62 \text{ km.} \\
 e = .0615 & \pm .0313 \\
 \omega = 301^{\circ}.99 & \pm 18^{\circ}.04 \\
 T = 2,420,061.97 \text{ J. D.} & \pm 14.18 \text{ days} \\
 a \sin i = 80,000,000 \text{ km.} &
 \end{array}$$

The new values gave a reduction in the value of Σpvv from 90 to 60 or 33 per cent. The agreement between computed and observation equation residuals was satisfactory and the elements above were accepted as final.

In the curve the single circles represent Ottawa normal places and the double circles Lick observations.

Dominion Observatory,
Ottawa,

June, 1915.



DEPARTMENT OF THE INTERIOR

CANADA

HON. W. J. ROCHE, *Minister.*

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ORBIT OF BOSS 3323

BY J. B. CANNON, M.A.

Three measures of this star ($\alpha=12^{\text{h}} 41^{\text{m}}.2$, $\delta=+8^{\circ} 9'$) were published by Adams in the *Astronomical Journal of the Pacific*, December, 1914, and gave a range of 56.8 km. The spectrum is of A5p type. The wave-lengths of the lines measured are given in Table I together with the elements to which they are due.

TABLE I.

Wave-Length.	Element.	Wave-Length.	Element.
4549.766	<i>Fe</i>	4233.328	<i>Mn-Fe</i>
4481.400	<i>Mg</i>	4215.668	<i>Fe</i>
4352.006	<i>Mg-Cr</i>	4198.494	<i>Fe</i>
4340.634	<i>H</i>	4101.890	<i>H</i>
4325.939	<i>Fe</i>	4077.885	<i>Sr</i>
4315.178	<i>Fe-Ti</i>	4063.756	<i>Fe</i>
4289.915	<i>Cr-Ti</i>	4045.975	<i>Fe</i>
4271.760	<i>Fe</i>	4005.355	<i>Fe</i>
4260.640	<i>Fe</i>	3933.825	<i>Ca</i>
4250.616	<i>Fe</i>		

Thirty-nine plates were taken between February 17 and June 6 of this year. The period, 38.3 days, cannot be considered very closely determined as the period of observation is short, and furthermore Adams' observations were only taken in 1913 and their positions, as will be seen in the figure, are such that a change in the period, either increase or decrease, would improve one of them while making a greater residual for the other.

On twelve plates double lines were measured, and as these occur only at maximum and minimum it would appear that they are real instances of doubling.

Table II gives the Adams' observations, their phases, and residuals from the final curve. Table III gives the Ottawa observations of the primary component and Table III A, the Ottawa observations of the secondary.

TABLE II.
ADAMS' OBSERVATIONS.

Date.	Julian Day.	Phase.	Velocity.	Residual.
1913.				
May 25.....	2,419,913.798	29.743	-42.8	-3.0
June 17.....	936.705	14.350	+34.0	+4.0
July 16.....	965.700	5.045	-10.7	-5.0

TABLE III.
OTTAWA OBSERVATIONS.

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Weight.	O-C.
1915								
6791	C	Feb. 17.....	m. 70	2,420,546.764	11.609	+30.7	2	+ 2.7
6815	Y	Feb. 21.....	75	550.661	15.506	+20.6	2	- 8.4
6821	Y	Feb. 28.....	70	557.712	22.557	+ 5.6	4	+ 3.8
6824	H	Mar. 1.....	72	558.840	23.635	- 0.8	6	+ 3.7
6831	C	Mar. 3.....	95	560.796	25.641	-16.1	6	+ 0.1
6839	Y	Mar. 4.....	70	561.759	26.604	-21.3	7	+ 0.9
6853	Y	Mar. 9.....	55	566.710	31.555	-57.3	6	-10.1
6858	H	Mar. 11.....	60	568.710	33.555	-54.1	7	- 2.5
6871	H	Mar. 15.....	68	572.730	37.575	-49.0	7	- 4.0
6877	H	Mar. 18.....	55	575.686	2.231	-19.2	2	+ 7.1
6885	H	Mar. 22.....	80	579.676	6.221	+ 7.0	5	+ 4.4
6888	Y	Mar. 23.....	70	580.656	7.201	+ 4.8	5	+ 4.5
6894	H	Mar. 29.....	70	586.661	13.206	+20.3	4	- 9.7

TABLE III.
OTTAWA OBSERVATIONS—Continued.

[Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Weight.	O-C.
		1915	m.					
6898	Y	Mar. 30.....	60	2,420,587.698	14.243	+28.7	4	- 1.3
6903	Y	Apr. 4.....	65	592.640	19.185	+13.4	4	- 5.0
6907	H	Apr. 7.....	80	595.637	22.182	+12.3	2	+ 8.3
6914	H	Apr. 8.....	80	596.657	23.202	- 0.1	4	+ 1.5
6916	H-P ¹	Apr. 12.....	66	600.734	27.279	-27.5	5	- 1.1
6925	H	Apr. 14.....	65	602.641	29.186	-35.8	5	+ 1.2
6931	Y	Apr. 15.....	45	603.644	30.189	-38.7	4	+ 3.3
6933	P	Apr. 17.....	70	605.733	32.278	-56.8	4	- 7.4
6936	P ¹	Apr. 19.....	79	607.802	34.347	-43.7	6	+ 8.3
6940	Y	Apr. 20.....	60	608.667	35.212	-52.0	7	- 0.8
6949	C-P ¹	Apr. 21.....	72	609.725	36.270	-46.3	3	+ 2.9
6957	Y	Apr. 28.....	60	616.622	4.867	- 9.1	5	- 2.6
6968	H	May 6.....	75	624.650	12.895	+34.1	5	+ 4.3
6973	Y	May 9.....	65	627.651	15.896	+28.9	7	+ 0.5
6980	P ¹	May 10.....	85	628.682	16.927	+35.9	4	+ 9.8
6984	H	May 11.....	75	629.719	17.964	+24.2	2	+ 1.2
6987	H	May 13.....	72	631.638	19.883	+12.2	7	- 3.3
7004	C	May 19.....	48	637.747	25.992	- 8.2	2	+10.6
7007	Y	May 23.....	70	641.663	29.908	-39.2	2	+ 1.8
7010	C	May 24.....	80	642.639	30.884	-50.5	4	- 5.6
7016	P ¹¹	May 27.....	70	645.618	33.863	-46.4	4	+ 5.5
7022	C	May 28.....	75	646.651	34.896	-55.1	4	+ 3.5
7038	Y	June 1.....	70	650.587	00.532	-42.9	5	- 4.5
7044	P ¹¹	June 2.....	86	651.616	01.561	-43.1	1	-12.1
7047	C	June 4.....	80	653.604	03.549	- 4.9	3	+12.1
7050	Y	June 6.....	70	655.656	05.601	- 0.4	5	+ 1.0

TABLE III A
OTTAWA OBSERVATIONS (SECONDARY).

Plate.	Observer.*	Date.	Exposure.	Julian Day.	Phase.	Velocity.	Number of Lines.	O-C.
		1915.	m.					
6791	C	Feb. 17.....	70	2,420,546.764	11.609	-71.8	1	+ 8.7
6853	Y	Mar. 9.....	55	566.710	31.555	+75.0	4	+ 9.0
6858	H	Mar. 11.....	60	568.710	33.555	+53.6	2	-21.2
6894	H	Mar. 29.....	70	586.661	13.206	-96.4	1	-11.9
6898	Y	Mar. 30.....	60	587.698	14.243	-80.0	3	+ 4.8
6936	P ¹	Apr. 19.....	79	607.802	34.347	+83.1	1	+ 7.3
6940	Y	Apr. 20.....	60	608.667	35.212	+65.8	1	- 8.7
6949	C-P ¹	Apr. 21.....	72	609.725	36.270	+68.9	1	- 1.6
6968	H	May 6.....	75	624.650	12.895	-75.6	1	+ 8.4
6973	Y	May 9.....	65	627.651	15.896	-89.8	3	- 8.0
6980	P ¹	May 10.....	85	628.682	16.927	-92.2	3	-14.7
6984	H	May 11.....	75	629.719	17.964	-64.8	1	+ 6.2

*P=Plaskett; H=Harper; C=Cannon; Y=Young; P¹=Parker; P¹¹=H. H. Plaskett.

The detailed measures follow:

MEASURES OF BOSS 3323.

λ	4791 p.*		4791 s.*		6815		6821		6824		6831		6839	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766					+ 10.10	$\frac{1}{2}$	- 21.91	$\frac{1}{2}$	- 9.71	$\frac{1}{2}$	- 28.60	$\frac{1}{2}$		
4481.400							+ 1.75	$\frac{1}{2}$	- 5.00	$\frac{1}{2}$			- 19.28	$\frac{1}{2}$
4352.006													- 30.00	$\frac{1}{2}$
4340.634	+ 9.40	$\frac{1}{2}$			- 9.62	$\frac{1}{2}$	- 2.07	$\frac{1}{2}$	- 22.82	$\frac{1}{2}$	- 19.56	$\frac{1}{2}$	- 30.98	$\frac{1}{2}$
4325.939	- 12.30	$\frac{1}{2}$			- 0.55	$\frac{1}{2}$	- 12.96	$\frac{1}{2}$	- 16.76	$\frac{1}{2}$			- 22.51	$\frac{1}{2}$
4289.915	+ 39.23	$\frac{1}{2}$	- 90.00	$\frac{1}{2}$	+ 21.72	$\frac{1}{2}$	- 9.35	$\frac{1}{2}$	- 3.37	$\frac{1}{2}$			- 35.20	$\frac{1}{2}$
4271.760							- 20.59	$\frac{1}{2}$	- 10.87	$\frac{1}{2}$	- 15.77	$\frac{1}{2}$	- 23.80	$\frac{1}{2}$
4215.668	+ 15.80	$\frac{1}{2}$			+ 27.09	$\frac{1}{2}$	+ 9.64	$\frac{1}{2}$					- 23.18	$\frac{1}{2}$
4198.494							- 1.62	$\frac{1}{2}$						
4101.890	- 8.30	$\frac{1}{2}$					- 15.20	$\frac{1}{2}$			- 26.96	$\frac{1}{2}$	- 41.59	$\frac{1}{2}$
4077.885									- 11.22	$\frac{1}{2}$	- 31.30	$\frac{1}{2}$	- 37.60	$\frac{1}{2}$
4045.975							- 19.68	$\frac{1}{2}$	- 10.55	$\frac{1}{2}$	- 41.15	$\frac{1}{2}$	- 51.22	$\frac{1}{2}$
4005.355							- 2.48	$\frac{1}{2}$	- 25.40	$\frac{1}{2}$	- 28.89	$\frac{1}{2}$	- 37.38	$\frac{1}{2}$
Weighted mean	+ 12.50		- 90.00		+ 3.91		- 7.89		- 13.47		- 28.10		- 32.77	
V_a	+ 18.32		+ 18.32		+ 16.68		+ 13.57		+ 13.05		+ 12.16		+ 11.70	
V_z	+ .12		+ .12		+ .27		+ .15		- .09		\pm .00		+ .04	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 30.7		- 71.8		+ 20.6		+ 5.6		- 0.8		- 16.1		- 21.3	

*p. = primary.

s. = secondary.

MEASURES OF BOSS 3323—Continued.

λ	6853 p.		6853 s.		6858 p.		6858 s.		6871		6877		6885	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	- 88.60	$\frac{1}{2}$	.....	.....	- 46.42	$\frac{1}{2}$	.....	.....	- 37.40	$\frac{1}{2}$	.....	.....	+ 11.33	$\frac{1}{2}$
4481.400	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 23.03	$\frac{1}{2}$
4352.006	.....	.....	.....	.....	- 41.75	$\frac{1}{2}$	.....	.....	- 48.22	$\frac{1}{2}$	.....	.....	- 1.71	$\frac{1}{2}$
4340.634	- 49.81	$\frac{1}{2}$	+ 22.94	$\frac{1}{2}$	- 35.50	$\frac{1}{2}$	.....	.....	- 44.50	$\frac{1}{2}$	.....	.....	+ 2.49	$\frac{1}{2}$
4325.939	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	- 3.47	$\frac{1}{2}$
4289.915	- 75.22	$\frac{1}{2}$	.....	.....	- 66.95	$\frac{1}{2}$	.....	.....	- 59.48	$\frac{1}{2}$	- 28.09	$\frac{1}{2}$	+ 7.18	$\frac{1}{2}$
4215.668	- 53.41	$\frac{1}{2}$	+ 85.20	$\frac{1}{2}$	- 69.21	$\frac{1}{2}$	.....	.....	- 56.61	$\frac{1}{2}$	- 32.30	$\frac{1}{2}$	+ 8.21	$\frac{1}{2}$
4198.494	- 88.90	$\frac{1}{2}$	.....	.....	- 55.21	$\frac{1}{2}$	.....	.....	- 53.30	$\frac{1}{2}$	- 9.61	$\frac{1}{2}$	+ 18.81	$\frac{1}{2}$
4101.890	- 43.18	$\frac{1}{2}$	+ 70.75	$\frac{1}{2}$	- 72.85	$\frac{1}{2}$	+ 45.52	$\frac{1}{2}$	- 60.55	$\frac{1}{2}$	.....	.....	- 8.39	$\frac{1}{2}$
4077.885	- 60.30	$\frac{1}{2}$	.....	.....	- 80.10	$\frac{1}{2}$	.....	.....	- 56.98	$\frac{1}{2}$	.....	.....	- 10.94	$\frac{1}{2}$
4063.756	.....	.....	.....	.....	- 65.22	$\frac{1}{2}$	+ 45.25	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4045.975	- 69.35	$\frac{1}{2}$	+ 65.10	$\frac{1}{2}$	- 85.20	$\frac{1}{2}$	.....	.....	- 67.20	$\frac{1}{2}$	- 26.31	$\frac{1}{2}$	- 12.96	$\frac{1}{2}$
4005.355	.....	.....	.....	.....	- 67.21	$\frac{1}{2}$	.....	.....	- 67.50	$\frac{1}{2}$	.....	.....	.....	.....
Weighted mean	- 66.45		+ 65.85		- 62.33		+ 45.38		- 55.19		- 24.08		+ 4.31	
V_a	+ 9.32		+ 9.32		+ 8.35		+ 8.35		+ 6.38		+ 4.99		+ 2.85	
V_d	+ .12		+ .12		+ .12		+ .12		+ .09		+ .12		+ .12	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 57.3		+ 75.0		- 54.1		+ 53.6		- 49.0		- 19.2		+ 7.0	

MEASURES OF BOSS 3323—Continued.

λ	6888		6894 p.		6894 s.		6898 p.		6898 s.		6903		6907	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	+ 5.12	$\frac{1}{2}$	+ 14.43	$\frac{1}{2}$	.....		+ 30.07	$\frac{1}{2}$	- 94.20	$\frac{1}{2}$	+ 4.85	$\frac{1}{2}$	+ 12.34	$\frac{1}{2}$
4481.400	+ 31.16	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4352.006	+ 7.04	$\frac{1}{2}$	+ 14.72	$\frac{1}{2}$	.....		+ 51.38	$\frac{1}{2}$	.....		.....		+ 6.02	$\frac{1}{2}$
4340.634	+ 6.42	$\frac{1}{2}$	+ 28.82	$\frac{1}{2}$	.....		+ 11.88	$\frac{1}{2}$	.....		+ 32.81	$\frac{1}{2}$	+ 17.86	$\frac{1}{2}$
4325.939	- 10.00	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4289.915	+ 2.07	$\frac{1}{2}$	+ 46.30	$\frac{1}{2}$	.....		+ 41.15	$\frac{1}{2}$	.....		+ 25.25	$\frac{1}{2}$	+ 39.61	$\frac{1}{2}$
4271.760	- 16.53	$\frac{1}{2}$	- 1.29	$\frac{1}{2}$	.....		.....		.....		+ 3.97	$\frac{1}{2}$	- 12.66	$\frac{1}{2}$
4250.616	+ 6.01	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4233.328	- 0.62	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4215.668	+ 6.36	$\frac{1}{2}$	+ 35.28	$\frac{1}{2}$	- 95.66	$\frac{1}{2}$	+ 33.98	$\frac{1}{2}$	- 70.41	$\frac{1}{2}$	+ 29.66	$\frac{1}{2}$	+ 25.42	$\frac{1}{2}$
4198.494	+ 3.16	$\frac{1}{2}$	.....		.....		.....		.....		+ 27.19	$\frac{1}{2}$	+ 35.38	$\frac{1}{2}$
4101.890	- 4.56	$\frac{1}{2}$	+ 3.08	$\frac{1}{2}$	.....		+ 28.41	$\frac{1}{2}$	.....		+ 7.74	$\frac{1}{2}$	.....
4077.885	- 9.68	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
4063.756	.....		.....		.....		+ 23.88	$\frac{1}{2}$	- 67.58	$\frac{1}{2}$	+ 16.71	$\frac{1}{2}$	.....
4045.975	- 1.15	$\frac{1}{2}$	.....		.....		+ 20.38	$\frac{1}{2}$	.....		+ 9.75	$\frac{1}{2}$	.....
4005.355	.....		+ 41.70	$\frac{1}{2}$	.....		.....		.....		+ 21.71	$\frac{1}{2}$	.....
Weighted mean	+ 2.49		+ 21.08		- 95.66		+ 30.26		- 77.39		+ 17.32		+ 17.04	
V_a	+ 2.41		- 0.61		- 0.61		- 1.14		- 1.14		- 3.60		- 4.59	
V_d	+ .15		+ .12		+ .12		- .17		- .17		- .04		+ .12	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 4.8		+ 20.3		- 96.4		+ 28.7		- 78.9		+ 13.4		+ 12.3	

MEASURES OF BOSS 3323—Continued.

λ	6914		6916		6925		6931		6933		6936 p.		6936 s.	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	+ 2.21	$\frac{1}{2}$	.....	.....	- 45.30	$\frac{1}{2}$	- 49.60	$\frac{1}{2}$	- 30.19	$\frac{1}{2}$	- 26.97	$\frac{1}{2}$	.....	.....
4481.400	+ 2.87	$\frac{1}{2}$	- 30.15	$\frac{1}{2}$	- 9.61	$\frac{1}{2}$	- 17.07	$\frac{1}{2}$	- 37.16	$\frac{1}{2}$	- 2.12	$\frac{1}{2}$	.....	.....
4352.006	+ 7.50	$\frac{1}{2}$	- 12.20	$\frac{1}{2}$	- 27.70	$\frac{1}{2}$	- 12.60	$\frac{1}{2}$	- 36.50	$\frac{1}{2}$	- 13.97	$\frac{1}{2}$	.....	.....
4340.634	+ 0.37	$\frac{1}{2}$	- 27.49	$\frac{1}{2}$	- 18.81	$\frac{1}{2}$	- 24.41	$\frac{1}{2}$	- 73.40	$\frac{1}{2}$	- 36.81	$\frac{1}{2}$	.....	.....
4325.939	+ 1.56	$\frac{1}{2}$	- 25.02	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4289.915	+ 30.82	$\frac{1}{2}$	+ 8.37	$\frac{1}{2}$	- 15.70	$\frac{1}{2}$	- 37.01	$\frac{1}{2}$	- 50.16	$\frac{1}{2}$	- 40.82	$\frac{1}{2}$	.....	.....
4271.760	- 4.06	$\frac{1}{2}$	- 11.80	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4215.668	+ 1.12	$\frac{1}{2}$	- 18.48	$\frac{1}{2}$	- 30.12	$\frac{1}{2}$	- 36.71	$\frac{1}{2}$	- 51.64	$\frac{1}{2}$	- 50.21	$\frac{1}{2}$	+ 94.51	$\frac{1}{2}$
4198.494	.....	.....	+ 3.84	$\frac{1}{2}$	- 6.14	$\frac{1}{2}$	- 15.91	$\frac{1}{2}$	.....	.....	- 37.36	$\frac{1}{2}$	.....	.....
4101.890	+ 9.38	$\frac{1}{2}$	.....	.....	- 43.59	$\frac{1}{2}$	- 34.83	$\frac{1}{2}$	.....	.....	- 49.85	$\frac{1}{2}$	.....	.....
4077.885	+ 7.26	$\frac{1}{2}$	- 31.20	$\frac{1}{2}$	- 25.31	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4045.975	- 0.09	$\frac{1}{2}$	- 31.62	$\frac{1}{2}$	- 42.55	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4005.355	+ 1.22	$\frac{1}{2}$	- 30.85	$\frac{1}{2}$	- 23.72	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 5.69		- 19.51		- 27.15		- 28.52		- 46.51		- 32.26		+ 94.51	
V_a	- 5.60		- 7.57		- 8.48		- 9.91		- 9.93		- 10.88		- 10.88	
V_d	+ .08		- .10		+ .09		+ .04		- .12		- .25		- .25	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 0.1		- 27.5		- 35.8		- 38.7		- 56.8		- 43.7		+ 83.1	

MEASURES OF BOSS 3323—Continued.

λ	6940 p.		6940 s.		6949 p.		6949 s.		6957		6968 p.		6968 s.	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	- 37.39	$\frac{1}{2}$	.....		- 41.98	$\frac{1}{2}$	.....		+ 0.13	$\frac{1}{2}$	+ 70.70	$\frac{1}{2}$	.....
4481.400	- 12.85	$\frac{1}{2}$	.....		- 6.24	$\frac{1}{2}$	.....		+ 21.58	$\frac{1}{2}$	.....		.....
4352.006	.....		.....		- 37.58	$\frac{1}{2}$	.....		- 8.07	$\frac{1}{2}$	+ 55.00	$\frac{1}{2}$	.....
4340.634	- 39.85	$\frac{1}{2}$	.....		- 11.15	$\frac{1}{2}$	.....		+ 22.09	$\frac{1}{2}$	.....		.....
4325.939	.....		.....		- 48.41	$\frac{1}{2}$	.....		- 4.70	$\frac{1}{2}$	+ 34.29	$\frac{1}{2}$	.....
4315.178	.....		.....		.....		.....		- 11.36	$\frac{1}{2}$	+ 59.24	$\frac{1}{2}$	.....
4289.915	- 36.70	$\frac{1}{2}$	.....		- 54.56	$\frac{1}{2}$	.....		+ 16.56	$\frac{1}{2}$	.....		.....
4260.640	.....		.....		.....		.....		+ 5.49	$\frac{1}{2}$	.....		.....
4215.668	- 54.05	$\frac{1}{2}$	.....		- 59.10	$\frac{1}{2}$	.....		+ 13.47	$\frac{1}{2}$	+ 54.76	$\frac{1}{2}$	.....
4198.494	- 30.01	$\frac{1}{2}$	.....		- 18.41	$\frac{1}{2}$	.....		+ 20.52	$\frac{1}{2}$	.....		.....
4101.890	- 47.90	$\frac{1}{2}$	+ 77.40	$\frac{1}{2}$	.....		.....		- 1.57	$\frac{1}{2}$	+ 44.22	$\frac{1}{2}$	.....
4077.885	- 40.78	$\frac{1}{2}$	.....		.....		.....		+ 1.95	$\frac{1}{2}$	+ 46.92	$\frac{1}{2}$	- 56.36	$\frac{1}{2}$
4045.975	- 61.72	$\frac{1}{2}$	.....		- 58.03	$\frac{1}{2}$	+ 80.02	$\frac{1}{2}$	- 2.73	$\frac{1}{2}$	+ 42.82	$\frac{1}{2}$	.....
4005.355	- 62.99	$\frac{1}{2}$	.....		.....		.....		.....		.....		.....
Weighted mean	- 40.40		+ 77.40		- 34.10		+ 80.02		+ 5.87		+ 53.36		- 56.36	
V_a	- 11.28		- 11.28		- 11.76		- 11.76		- 14.73		- 18.85		- 18.85	
V_z	\pm .00		\pm .00		- .12		- .12		+ .03		- .09		- .09	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 52.0		+ 65.8		- 46.3		+ 68.9		- 9.1		+ 34.1		- 75.6	

MEASURES OF BOSS 3323—Continued.

λ	6973 p.		6973 s.		6980 p.		6980 s.		6984 p.		6984 s.		6987	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	+ 43.65	$\frac{1}{4}$	.....	.....	+ 24.46	$\frac{1}{4}$	.....	.....	+ 36.81	$\frac{1}{2}$	.....	.....	+ 39.52	$\frac{1}{4}$
4481.400	.....	.....	.....	.....	.....	.....	.....	.....	+ 32.02	$\frac{1}{2}$	.....	.....	+ 13.08	$\frac{1}{4}$
4352.006	+ 25.88	$\frac{1}{4}$	.....	.....	+ 20.55	$\frac{1}{4}$	.....	.....	+ 37.92	$\frac{1}{4}$	.....	.....	+ 29.40	$\frac{1}{4}$
4340.634	+ 46.72	$\frac{1}{2}$	.....	.....	+ 48.41	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	+ 37.70	$\frac{1}{2}$
4289.915	+ 65.20	$\frac{1}{2}$	- 74.21	$\frac{1}{2}$	+ 75.21	$\frac{1}{2}$	- 95.30	$\frac{1}{2}$	+ 79.25	$\frac{1}{4}$	- 44.50	$\frac{1}{2}$	+ 33.12	$\frac{1}{2}$
4215.668	+ 46.19	$\frac{1}{2}$	- 67.78	$\frac{1}{4}$	+ 55.43	$\frac{1}{4}$	- 59.15	$\frac{1}{4}$	.....	.....	.....	.....	+ 38.30	$\frac{1}{4}$
4198.494	+ 65.61	$\frac{1}{4}$	.....	.....	+ 73.98	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	+ 29.60	$\frac{1}{4}$
4101.890	+ 46.50	$\frac{1}{4}$	- 66.32	$\frac{1}{4}$	+ 62.76	$\frac{1}{4}$	- 59.80	$\frac{1}{2}$	.....	.....	.....	.....	+ 27.50	$\frac{1}{4}$
4077.885	+ 54.25	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 41.82	$\frac{1}{4}$
4063.756	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+ 35.90	$\frac{1}{4}$
4045.975	+ 35.75	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Weighted mean	+ 49.24		- 69.44		+ 56.67		- 71.42		+ 44.55		- 44.50		+ 33.06	
V_a	- 20.07		- 20.07		- 20.43		- 20.43		- 19.85		- 19.85		- 20.52	
V_d	- .04		- .04		- .08		- .08		- .20		- .20		- .09	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	+ 28.9		- 89.8		+ 35.9		- 92.2		+ 24.2		- 64.8		+ 12.2	

MEASURES OF BOSS 3323—Continued.

λ	7004		7007		7010		7016		7022		7038		7044	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4549.766	+ 8.27	$\frac{1}{2}$	- 11.24	$\frac{1}{2}$	- 30.70	$\frac{1}{2}$	.....	.....	- 17.79	$\frac{1}{2}$	- 30.56	$\frac{1}{2}$	- 13.20	$\frac{1}{2}$
4481.400	+ 23.52	$\frac{1}{2}$	+ 12.60	$\frac{1}{2}$	- 20.94	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	.....
4352.006	.....	.....	- 29.41	$\frac{1}{2}$	.....	.....	- 30.56	$\frac{1}{2}$	.....	.....	- 11.81	$\frac{1}{2}$	.....	.....
4340.634	+ 19.22	$\frac{1}{2}$	.....	.....	- 33.42	$\frac{1}{2}$	- 12.82	$\frac{1}{2}$	- 16.55	$\frac{1}{2}$	- 4.38	$\frac{1}{2}$	- 24.09	$\frac{1}{2}$
4289.915	.....	.....	- 23.48	$\frac{1}{2}$	.....	.....	- 8.34	$\frac{1}{2}$	- 30.73	$\frac{1}{2}$	- 7.04	$\frac{1}{2}$	.....	.....
4227.010	.....	.....	.....	.....	.....	.....	- 25.95	$\frac{1}{2}$	.....	.....	.....	.....	.....	.....
4215.668	.....	.....	- 24.18	$\frac{1}{2}$	- 8.99	$\frac{1}{2}$	- 36.18	$\frac{1}{2}$	- 39.51	$\frac{1}{2}$	- 30.22	$\frac{1}{2}$	.....	.....
4198.494	.....	.....	.....	.....	.....	.....	- 5.84	$\frac{1}{2}$	.....	.....	- 7.15	$\frac{1}{2}$	.....	.....
4077.885	.....	.....	.....	.....	- 35.31	$\frac{1}{2}$	- 29.30	$\frac{1}{2}$	- 42.55	$\frac{1}{2}$	- 10.71	$\frac{1}{2}$	.....	.....
4045.975	.....	.....	.....	.....	- 28.40	$\frac{1}{2}$	- 22.14	$\frac{1}{2}$	- 44.62	$\frac{1}{2}$	- 28.78	$\frac{1}{2}$	.....	.....
Weighted mean	+ 14.81		- 15.14		- 26.30		- 21.40		- 29.77		- 16.79		- 16.83	
V_s	- 22.47		- 23.61		- 23.89		- 24.64		- 24.89		- 25.78		- 26.00	
V_d	- .28		- .15		- .06		- .12		- .17		- .08		- .20	
Curv.	- .28		- .28		- .28		- .28		- .28		- .28		- .28	
Radial Velocity	- 8.2		- 39.2		- 50.5		- 46.4		- 55.1		- 42.9		- 43.1	

The observations were grouped into eight normal places which are given in Table IV and from these, graphical elements of the orbit were obtained.

TABLE IV.
NORMAL PLACES.

No.	Julian Day.	Phase.	Velocity.	Weight.	Residual.
1	2,420,594.281	13.166	+28.5	2	-1.2
2	612.611	16.982	+25.6	2.5	-0.3
3	590.576	22.116	+ 5.5	3	+1.0
4	578.813	26.423	-20.0	2.5	+1.2
5	604.194	30.739	-47.4	3	-3.0
6	609.249	34.558	-50.0	4	+2.0
7	604.336	0.241	-42.6	2	-3.1
8	614.081	5.656	- 0.1	3	+1.4

The elements obtained graphically were:

$$\begin{aligned}
 P &= 38.3 \text{ days} \\
 \gamma &= -8.95 \text{ km.} \\
 K &= 41 \text{ km.} \\
 e &= .1 \\
 \omega &= 240^\circ \\
 T &= 2,420,575.4 \text{ J.D.}
 \end{aligned}$$

A least-squares solution was carried through involving the elements γ , K , e , ω and T .

Observation equations were formed as follows:—

TABLE V.
OBSERVATION EQUATIONS.

x	y	z	u	v	$-n$	Weight.
1	+ .948	- .379	+ .155	- .063	+ 1.4	2.0
1	+ .834	- .981	- .380	+ .391	- 0.3	2.5
1	+ .326	- .256	- .840	+ .752	- 1.1	3.0
1	- .257	+ .773	- .892	+ .838	+ 0.5	2.5
1	- .807	+ .784	- .566	+ .629	+ 5.4	3.0
1	-1.048	- .392	+ .028	+ .064	- 1.9	4.0
1	- .812	- .960	+ .734	- .776	+ 0.4	2.0
1	+ .161	+ .874	+1.064	-1.127	- 2.3	3.0

In the above

$$x = \delta\gamma$$

$$y = \delta K$$

$$z = K\delta e$$

$$u = K\delta\omega$$

$$v = \frac{K\mu\delta T}{(1-e^2)^{\frac{3}{2}}}$$

Normal equations formed from the observation equations were:—

$$22x - 3.437y - 0.560z - 2.316u + 2.412v + 2.500 = 0$$

$$11.764y - 1.784z - 0.172u - 0.180v - 6.237 = 0$$

$$10.976z - 0.256u + 0.044v + 10.367 = 0$$

$$9.953u - 9.952v - 13.761 = 0$$

$$10.060v + 14.955 = 0$$

Solving these, the following corrections, $\delta\gamma$, etc., were found:—

$$\delta\gamma = +.06 \text{ km.}$$

$$\delta K = -.01 \text{ km.}$$

$$\delta e = -.028$$

$$\delta\omega = -16^{\circ}.65$$

$$\delta T = -1.945 \text{ days.}$$

Hence the new values for the elements, to which has been appended the probable error of each:

$$\begin{aligned}
 P &= 38.3 \text{ days} \\
 \gamma &= -8.89 \text{ km.} & \pm .55 \text{ km.} \\
 K &= 40.99 \text{ km.} & \pm .81 \text{ km.} \\
 e &= .072 & \pm .019 \\
 \omega &= 223^\circ.35 & \pm 11^\circ.59 \\
 T &= 2,420,573.455 \text{ J. D.} & \pm 1.216 \text{ days.} \\
 a \sin i &= 21,530,000.
 \end{aligned}$$

The twelve plates of the secondary were grouped in normal places corresponding to those of the primary. These fell in four places corresponding with groups 1, 2, 5 and 6 of the primary, four falling in group 1, three in group 2, one in group 5, and four in group 6.

The means are found below:—

Group.	Phase.	Velocity.	Residual.
1.....	12.988	-80.9	+3.2
2.....	16.929	-82.3	-5.0
5.....	31.555	+75.0	+9.0
6.....	34.846	+67.8	-7.2

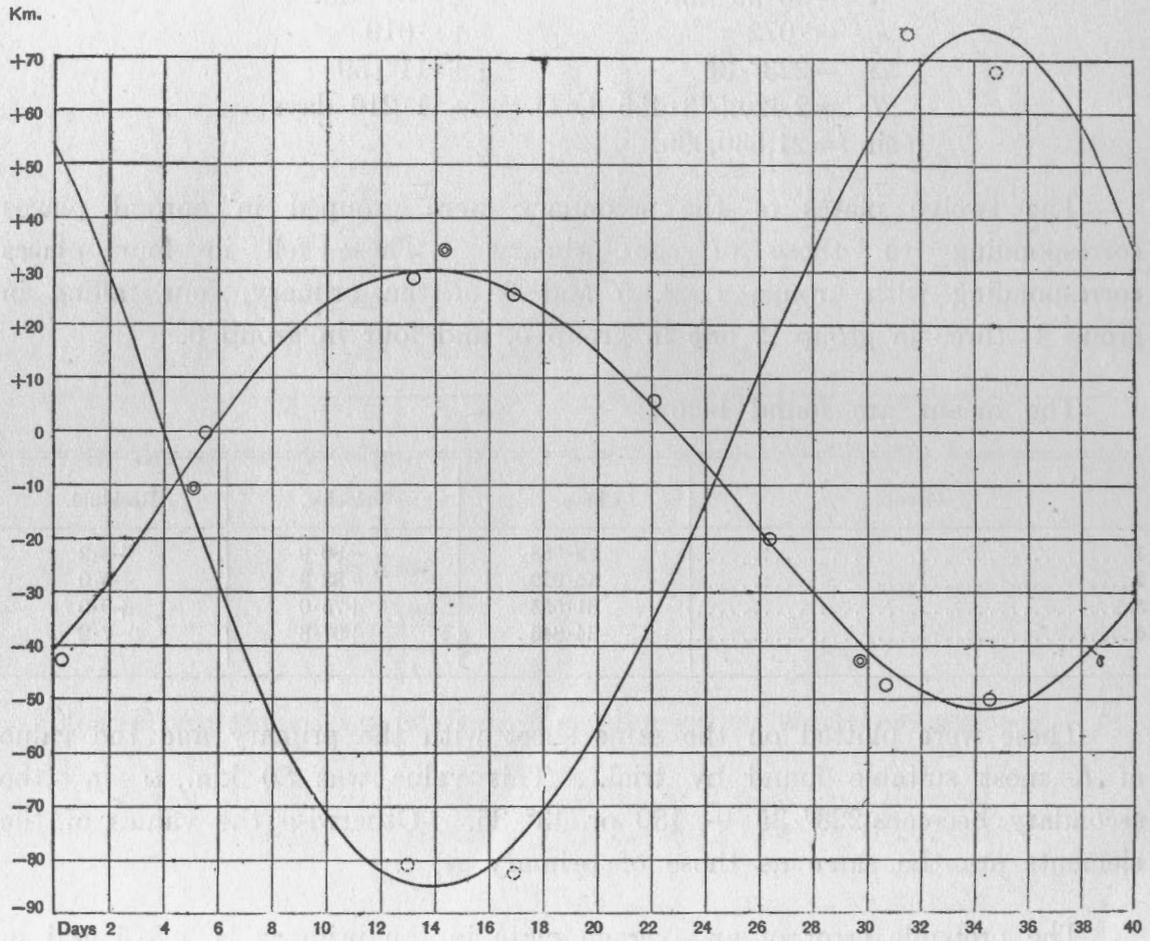
These were plotted on the same sheet with the primary and the value of K most suitable found by trial. This value was 80 km., ω in the secondary becomes $223^\circ.35 + 180$ or $43^\circ.35$. Otherwise the values of the elements are the same as those of primary.

The probable error of an average plate in the primary is ± 3.5 and in the secondary ± 7.3 . That of a normal place, (primary) ± 3.4 .

The comparative values of the masses are given by $M_1 : M_2 = K_2 : K_1 = 80 : 40.99$ or very close to 2 : 1.

In the figure the circles are Ottawa normal places; the double circles, Adams' observations; and the broken circles, secondary normals.

Dominion Observatory,
Ottawa,
August, 1915.



VELOCITY CURVE OF BOSS 3323.

