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Orbits
of the Spectroscopic Components
of *d* Boötis

BY

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ORBITS OF THE SPECTROSCOPIC COMPONENTS OF *d* BOÖTIS.

BY W. E. HARPER, M.A.

This star ($\alpha=14^{\text{h}} 05^{\text{m}} 8$, $\delta=+25^{\circ} 34'$, photographic magnitude 5.3) was announced as a spectroscopic binary by Campbell and Wright in 1900. Approximate measures of the four plates secured showed a range of 75 km. Their measures referred solely to one component; they made no mention of the spectrum of the other component being visible, though no doubt such is the case on two of their plates.

Fifty-three spectrograms of the star have been obtained at this observatory during the years 1907, 1910 and the present year, and these form the basis of the present discussion of the orbit. The first four were made with the Universal spectroscope as adapted for radial velocity work, linear dispersion at $H\gamma$ 18.6 tenth-metres per millimetre, the next one with three-prism dispersion of 20.2 tenth-metres per millimetre at the same region, and the remainder of the plates with the new single-prism instrument, dispersion at same region of 33.4 tenth-metres per millimetre. For number 3368 a Sigma plate was used; all the other plates were of Seed 27 Emulsion.

As intimated above both spectra are visible, are quite similar and of type F5. For considerably over half the period the spectra are well resolved and measures were made on the lines of each component. At first all the lines that were at all measurable were used; gradually those were eliminated which from their complicated nature could not be depended upon. The final outcome was a selection of thirteen lines, given in the table below, upon which all the measures were based. When all the measures were completed a table of residuals of each line, from the mean

given by the plate as a whole, was formed and new wave-lengths were derived so that the sum of the residuals equalled zero for each line. The first column gives the wave-length as assumed at the start, the second the number of times measured, the third the average residual and the last the wave-length as corrected for this star. Outside of $H\gamma$ it will be noticed that practically all the lines selected were those due to iron or blends of iron.

LINES USED IN δ BOÖTIS.

| λ | Times Measured. | Average Residual. | Corrected λ |
|-----------|-----------------|-------------------|------------------------|
| 4549·766 | 34 | $\pm 0\cdot0$ km. | 4549·766 |
| 4415·293 | 41 | - 3·4 | 4415·343 |
| 4340·634 | 31 | - 1·8 | 4340·660 |
| 4325·829 | 43 | + 1·2 | 4325·812 |
| 4308·081 | 54 | + 2·7 | 4308·042 |
| 4271·760 | 53 | - 0·9 | 4271·773 |
| 4260·540 | 56 | + 3·2 | 4260·495 |
| 4143·928 | 49 | - 0·7 | 4143·938 |
| 4071·901 | 26 | - 2·9 | 4071·940 |
| 4063·756 | 38 | - 2·9 | 4063·795 |
| 4045·975 | 52 | - 0·2 | 4045·978 |
| 4005·430 | 47 | + 5·1 | 4005·362 |

With the exception of the last line, whose wave-length was very uncertain at the commencement of the measures, none of the wave-lengths as assumed are in very great need of correction. An unpublished investigation by the writer of the effect on the elements of an orbit of the use of wave-lengths which treated similarly gave residuals somewhat as those above, shows that the changes are almost inappreciable. However, as the last line needed correction it was decided to use the corrected wave-lengths throughout and the measured velocities were revised accordingly.

For convenience of reference the early observations of the Lick Observatory are given.

LICK OBSERVATIONS.

| Date. | Julian Date. | Velocity. | Residual from Curve. |
|-------------------|---------------|-----------|----------------------|
| 1900 Mar. 27..... | 2,415,106.881 | + 79 | + 3.6 |
| April 4..... | 114.953 | + 3 | - 0.3 |
| April 9..... | 119.905 | + 11 | - 1.7 |
| April 17..... | 127.814 | + 60 ± | + 0.6 |
| 1902 May 27*..... | 897.715 | + 11 | - 1.2 |

*Unpublished, but communicated through kindness of the Acting Director.

In the table of observations following, the phases are reckoned from the periastron passage finally accepted, J. D. 2,417,679.523, using the period 9.6045 days. The maximum weight assigned a plate was 10, depending for the most part on the sum of the weights given the separate lines when the measurement was being made. The residuals given are scaled from the final curve. These appear only for those plates where the spectrum lines of the components were resolved. The other velocities are derived from measures on blends and are subject to considerable error. For some distance on either side of the intersection of the curves with the γ -line, where the lines are more or less overlapping, the tendency is for the measured velocities to deviate from their true position towards the γ -line, and such observations can only be made use of to advantage when grouped over a large phase interval, the extent of the interval on each side of the crossing point being approximately the same.

TABLE OF OBSERVATIONS OF *d* BOÖTIS.

| Plate. | Observer* | Date. | Exposure. | Julian Date. | Phase. | COMPONENT I. | | | COMPONENT II. | | |
|--------|----------------|--------------|-----------|---------------|--------|--------------|-----|-------|---------------|-------|-------|
| | | | | | | Vel. | Wt. | O-C | Vel. | Wt. | O-C |
| 1907 | | | | | | | | | | | |
| 699 | P | April 5..... | 65 | 2,417,671.769 | 1.851 | +85.0 | 10 | + 6.0 | -59.9 | 9 | + 2.8 |
| 776 | H | May 23..... | 64 | 719.635 | 1.694 | +71.3 | 2 | - 7.5 | -71.5 | 2 | - 8.7 |
| 778 | P | May 24..... | 50 | 720.593 | 2.652 | +81.5 | 4 | +12.0 | -54.7 | 3 | - 2.2 |
| 798 | P | May 31..... | 65 | 7,727.653 | .108 | +17.8 | 6 | ..... | ..... | ..... | ..... |
| 1910 | | | | | | | | | | | |
| 3368 | H | Mar. 28..... | 120 | 8,759.854 | 4.627 | +17.1 | 5 | ..... | ..... | ..... | ..... |
| 3466 | P ¹ | June 3..... | 78 | 826.768 | 4.310 | + 7.6 | 7 | ..... | ..... | ..... | ..... |
| 3475 | P ¹ | June 9..... | 65 | 832.702 | .639 | +35.7 | 5 | ..... | ..... | ..... | ..... |
| 3512 | H | July 6..... | 90 | 859.591 | 8.319 | -54.2 | 10 | - 4.5 | +73.1 | 6 | + 0.7 |
| 3518 | H | July 11..... | 76 | 864.584 | 3.708 | +26.9 | 10 | ..... | ..... | ..... | ..... |
| 3524 | P ¹ | July 13..... | 65 | 866.581 | 5.705 | + 0.6 | 9 | ..... | ..... | ..... | ..... |
| 3550 | C | July 28..... | 72 | 881.586 | 1.501 | +73.4 | 9 | - 3.9 | -61.2 | 9 | 0.0 |
| 3577 | C | Aug. 19..... | 75 | 903.550 | 4.256 | +16.3 | 7 | ..... | ..... | ..... | ..... |
| 3594 | C | Aug. 29..... | 70 | 913.542 | 4.643 | +13.5 | 6 | ..... | ..... | ..... | ..... |
| 3609 | H | Sept. 1..... | 80 | 916.556 | 7.657 | -64.8 | 4 | - 5.2 | +69.3 | 3 | -11.7 |
| 3624 | H | Sept. 8..... | 54 | 8,923.534 | 5.031 | + 3.5 | 3 | ..... | ..... | ..... | ..... |
| 3896 | H | Dec. 21..... | 74 | 9,027.967 | 3.814 | +28.4 | 6 | ..... | ..... | ..... | ..... |
| 1911 | | | | | | | | | | | |
| 3926 | H | Jan. 11..... | 80 | 046.875 | 3.513 | +26.9 | 2 | ..... | ..... | ..... | ..... |
| 3945 | H | Jan. 16..... | 90 | 053.958 | .992 | +66.0 | 8 | 0.0 | -56.6 | 5 | - 7.0 |
| 3954 | H | Jan. 17..... | 86 | 054.925 | 1.959 | +83.2 | 9 | + 4.5 | -56.5 | 7 | + 5.8 |
| 3979 | P ¹ | Jan. 30..... | 87 | 067.890 | 5.319 | + 8.7 | 4 | ..... | ..... | ..... | ..... |
| 4044 | C | Mar. 2..... | 84 | 098.881 | 7.497 | +57.6 | 3 | - 0.2 | +78.4 | 2 | - 2.4 |
| 4052 | P ¹ | Mar. 3..... | 89 | 099.890 | 8.506 | -46.6 | 7 | - 1.8 | +69.5 | 5 | + 2.5 |
| 4064 | P ¹ | Mar. 6..... | 63 | 102.846 | 1.857 | +77.7 | 5 | - 1.0 | -62.8 | 5 | + 4.0 |
| 4074 | P | Mar. 7..... | 90 | 103.833 | 2.844 | +64.8 | 7 | - 0.4 | -60.7 | 5 | -12.4 |
| 4126 | P ¹ | Mar. 16..... | 89 | 112.892 | 2.299 | +79.6 | 8 | + 3.8 | -59.3 | 6 | 0.0 |
| 4142 | P ¹ | Mar. 24..... | 60 | 120.824 | .626 | +49.3 | 3 | - 1.7 | -30.6 | 2 | + 2.4 |
| 4159 | .H | April 2..... | 97 | 129.844 | .042 | +10.3 | 9 | ..... | ..... | ..... | ..... |

TABLE OF OBSERVATIONS OF *d* BOÖTIS—*Concluded.*

| Plate. | Observer* | Date. | Exposure. | Julian Date. | Phase. | COMPONENT I. | | | COMPONENT II. | | |
|--------|------------------|---------------|-----------|---------------|--------|--------------|-----|-------|---------------|-----|-------|
| | | | | | | Vel. | Wt. | O-C. | Vel. | Wt. | O-C. |
| | | 1911 | m. | | | | | | | | |
| 4172 | P ¹ | April 7..... | 93 | 2,419,134.860 | 5.058 | + 8.4 | 10 | | | | |
| 4183 | P ¹ | April 10..... | 91 | 137.853 | 8.051 | -55.1 | 3 | + .02 | +75.0 | 3 | - .5 |
| 4190 | H | April 11..... | 105 | 138.712 | 8.910 | -29.6 | 4 | - 2.0 | +57.2 | 2 | + 8.2 |
| 4208 | P ¹ | April 18..... | 105 | 145.807 | 6.400 | -40.5 | 5 | + 0.2 | +66.9 | 4 | + 4.1 |
| 4218 | C | April 19..... | 92 | 146.816 | 7.409 | -52.2 | 7 | + 5.0 | +74.1 | 4 | - 6.0 |
| 4233 | C | April 21..... | 85 | 148.801 | 9.394 | + 6.4 | 7 | | | | |
| 4236 | P | April 22..... | 110 | 149.708 | .697 | +49.8 | 5 | - 4.2 | -35.4 | 2 | + 1.2 |
| 4252 | P ¹ | April 24..... | 102 | 151.784 | 2.773 | +66.6 | 7 | - 0.2 | -50.6 | 4 | - 0.9 |
| 4260 | H-P | April 25..... | 97 | 152.781 | 3.770 | +22.0 | 4 | | | | |
| 4278 | P ¹ | April 28..... | 106 | 155.812 | 6.801 | -45.3 | 4 | + 3.5 | +78.0 | 2 | + 6.2 |
| 4304 | H | May 16..... | 110 | 173.687 | 5.467 | -1.0 | 6 | | | | |
| 4312 | C-P ¹ | May 19..... | 118 | 176.740 | 8.520 | -40.9 | 4 | + 3.4 | +71.6 | 2 | + 4.8 |
| 4315 | H | May 21..... | 82 | 178.760 | .935 | +71.3 | 7 | + 7.8 | -47.8 | 5 | - 0.8 |
| 4328 | C-P ¹ | May 26..... | 95 | 183.716 | 5.891 | -17.4 | 2 | | | | |
| 4338 | H | May 30..... | 110 | 187.705 | .275 | +11.9 | 5 | | | | |
| 4344 | C | June 1..... | 100 | 189.666 | 2.236 | +73.6 | 5 | - 2.7 | -60.8 | 4 | - 0.8 |
| 4357 | P | June 8..... | 95 | 196.626 | 9.196 | - 0.7 | 7 | | | | |
| 4382 | C | June 23..... | 90 | 211.606 | 4.968 | +13.2 | 9 | | | | |
| 4390 | H | June 27..... | 73 | 215.646 | 9.008 | -34.8 | 2 | | | | |
| 4391 | C | June 28..... | 90 | 216.592 | .349 | + 9.9 | 2 | | | | |
| 4405 | C | July 3..... | 90 | 221.586 | 5.343 | +12.4 | 7 | | | | |
| 4411 | H | July 4..... | 115 | 222.674 | 6.431 | -37.0 | 2 | + 4.4 | +57.5 | 1 | - 5.8 |
| 4420 | C | July 7..... | 90 | 225.556 | 9.313 | + 6.4 | 8 | | | | |
| 4425 | P | July 13..... | 100 | 231.603 | 5.756 | + 5.0 | 6 | | | | |
| 4431 | C | July 14..... | 92 | 232.579 | 6.732 | -34.7 | 8 | +12.9 | +83.8 | 3 | +13.3 |
| 4440 | P | July 20 | 90 | 238.632 | 3.180 | +54.6 | 3 | - 2.2 | -39.9 | 3 | - 0.4 |

*P=Plaskett; H=Harper; P¹=Parker; C=Cannon.

MEASURES OF *d* BOÖTIS.

| λ | 699 | | | | 776 | | | | 778 | | | | 798 | | |
|--------------------|------|---------------|---------------|---------------|-------|---------------|---------------|---------------|-------|---------------|---------------|---------------|-------|---------------|-------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | |
| 4549 | + | 81.0 | $\frac{1}{2}$ | - | 58.0 | $\frac{1}{2}$ | ..... | ..... | + | 106.5 | $\frac{1}{4}$ | - | 38.8 | $\frac{1}{4}$ | |
| 4415 | 81.2 | 1 | ..... | ..... | + | 92.6 | $\frac{1}{2}$ | - | 47.4 | $\frac{1}{2}$ | ..... | ..... | 40.3 | 1 | |
| 4325 | 76.4 | $\frac{3}{4}$ | 62.2 | $\frac{3}{4}$ | 87.9 | $\frac{1}{2}$ | 69.3 | $\frac{1}{2}$ | 102.2 | $\frac{1}{2}$ | 36.4 | $\frac{1}{2}$ | 27.4 | $\frac{1}{2}$ | |
| 4308 | 74.5 | 1 | 65.8 | 1 | 82.9 | $\frac{1}{2}$ | 47.8 | $\frac{3}{4}$ | 93.6 | 1 | 46.9 | 1 | ..... | ..... |  |
| 4271 | 85.1 | 1 | 64.2 | 1 | 85.6 | $\frac{1}{2}$ | 75.6 | $\frac{1}{2}$ | 90.7 | $\frac{3}{4}$ | 40.2 | $\frac{1}{2}$ | 41.1 | $\frac{1}{2}$ | |
| 4260 | 86.1 | 1 | 59.4 | 1 | + | 91.1 | $\frac{1}{2}$ | - | 57.9 | $\frac{1}{2}$ | 104.2 | 1 | - | 29.0 | 1 |
| 4143 | 90.3 | 1 | 62.2 | 1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |
| 4045 | + | 91.8 | 1 | - | 55.5 | 1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |  |
| Weighted mean | + | 83.70 | | - | 61.24 | | + | 87.68 | | - | 55.13 | | + | 98.15 | |
| V_a | + | 1.85 | | + | 1.85 | | - | 16.10 | | - | 16.10 | | - | 16.38 | |
| V_d | - | .02 | | - | .02 | | .00 | | .00 | + | .06 | | + | .06 | |
| Curv. | - | .50 | | - | .50 | | -.28 | | -.28 | - | -.28 | | - | -.28 | |
| Radial Velocity | + | 85.0 | | - | 59.9 | | + | 71.3 | | - | 71.5 | | + | 81.5 | |
| | | | | | | | | | | | | | - | 54.7 | |
| | | | | | | | | | | | | | + | 17.8 | |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 3368 | | | | 3466 | | | | 3475 | | | | 3512 | | | | 3518 | | | |
|--------------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|-----|--------|---------------|------|-----|--|--|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | | |
| 4549 | 0.0 | 1 | | | + 34.3 | 1 | + 65.2 | 1 | | | | | | | | | | | | |
| 4415 | - 3.4 | 1 | | | 25.0 | 1 | 64.2 | 1 | | | | | | | | | | | | |
| 4340 | + 20.2 | 1 | | | 31.8 | $\frac{1}{2}$ | 56.8 | $\frac{1}{2}$ | - 26.0 | 1 | | | | | + 39.7 | 1 | | | | |
| 4325 | + 23.5 | 1 | - 18.7 | $\frac{1}{2}$ | 17.2 | $\frac{1}{2}$ | 57.2 | $\frac{1}{2}$ | 17.6 | 1 | | | | | 39.9 | $\frac{1}{2}$ | | | | |
| 4308 | + 15.6 | $\frac{1}{2}$ | | | | | 51.9 | $\frac{1}{2}$ | 35.0 | 1 | | | | | 54.6 | 1 | | | | |
| 4271 | + 22.3 | 1 | - 15.4 | $\frac{1}{2}$ | 13.7 | $\frac{1}{2}$ | | | 33.3 | 1 | + 91.8 | $\frac{1}{2}$ | | | | | | | | |
| 4260 | + 10.7 | $\frac{1}{2}$ | | | + 36.5 | $\frac{1}{2}$ | + 42.5 | 1 | 31.9 | 1 | 89.3 | 1 | | | | | | | | |
| 4143 | | | | | | | | | 37.6 | 1 | 92.1 | $\frac{1}{2}$ | | | 50.0 | $\frac{1}{2}$ | | | | |
| 4071 | | | | | | | | | 34.4 | $\frac{1}{2}$ | 102.4 | $\frac{1}{2}$ | | | 56.8 | $\frac{1}{2}$ | | | | |
| 4063 | | | | | | | | | 26.2 | 1 | 96.2 | $\frac{1}{2}$ | | | 52.1 | 1 | | | | |
| 4045 | | | | | | | | | 30.4 | 1 | 107.7 | $\frac{1}{2}$ | | | 43.8 | 1 | | | | |
| 4005 | | | | | | | | | - 26.1 | 1 | + 101.6 | $\frac{1}{2}$ | | | + 68.5 | 1 | | | | |
| Weighted mean | + 12.62 | | - 17.05 | | + 27.25 | | + 56.63 | | - 30.14 | | + 97.18 | | + 51.09 | | | | | | | |
| V_a | + 5.01 | | + 5.01 | | - 19.14 | | - 20.46 | | - 23.69 | | - 23.69 | | - 23.77 | | | | | | | |
| V_d | - .20 | | - .20 | | - .25 | | - .20 | | - .14 | | - .14 | | - .15 | | | | | | | |
| Curv. | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | | | | | | | |
| Radial Velocity | + 17.1 | | - 12.5 | | + 7.6 | | + 35.7 | | - 54.2 | | + 73.1 | | + 26.9 | | | | | | | |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 3524 | | 3550 | | 3577 | | 3594 | | 3609 | | | | |
|--------------------|---------|-------|---------|---------|---------|--------|---------|-------|---------|--------|---------|--|---------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | | | |
| 4549 | ..... | ..... | + 86.0 | ½ | ..... | ..... | + 22.2 | ½ | + 34.6 | 1 | | | |
| 4415 | + | 21.5 | ½ | 100.6 | 1 | | | 34.8 | 1½ | 38.6 | ½ | | |
| 4340 | 27.9 | ½ | 86.4 | ½ | ..... | ..... | 53.2 | ¾ | 33.5 | 1 | | | |
| 4325 | 33.7 | ½ | 78.2 | ½ | - 38.1 | ½ | 28.1 | ½ | 22.7 | ½ | | | |
| 4308 | 30.8 | ½ | 97.2 | 1 | 34.9 | 1 | ..... | ..... | 33.9 | 1 | | | |
| 4271 | 33.1 | 1 | 102.7 | 1½ | 45.1 | 1 | 40.8 | 1 | 35.6 | 1 | | | |
| 4260 | ..... | ..... | 103.6 | ½ | 36.0 | ½ | ..... | ..... | 36.2 | 1 | | | |
| 4143 | 21.9 | ½ | 99.7 | ½ | 43.4 | ½ | ..... | ..... | 29.1 | ½ | | | |
| 4071 | 21.6 | ½ | ..... | ..... | ..... | ..... | 39.2 | ½ | 15.1 | 1 | | | |
| 4063 | 23.9 | ½ | ..... | ..... | ..... | ..... | 18.0 | ½ | 28.2 | ½ | | | |
| 4045 | 18.0 | 1 | 96.3 | 1 | 34.2 | 1 | + 27.4 | ½ | 28.1 | 1 | | | |
| 4005 | + | 14.3 | ½ | + 100.1 | ½ | - 32.5 | ½ | | | + 24.1 | 1 | | |
| <hr/> | | | | | | | | | | | | | |
| Weighted mean | + 24.82 | | + 96.69 | | - 37.84 | | + 35.61 | | + 30.04 | | - 49.21 | | + 84.95 |
| V_a | - 23.76 | | - 22.83 | | - 22.83 | | - 18.82 | | - 16.10 | | - 15.18 | | - 15.18 |
| V_d | - .16 | | - .21 | | - .21 | | - .25 | | - .19 | | - .19 | | - .19 |
| Curv. | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | | - .28 |
| <hr/> | | | | | | | | | | | | | |
| Radial Velocity | + 0.6 | | + 73.4 | | - 61.2 | | + 16.3 | | + 13.5 | | - 64.8 | | + 69.3 |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 3624 | | 3896 | | 3926 | | 3945 | | 3954 | |
|--------------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|----------------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. |
| 4549 | + 17.0 | $\frac{1}{2}$ | | | | | | | + 78.7 | 1 |
| 4415 | 19.7 | $\frac{1}{2}$ | | | | | + 55.2 | $\frac{1}{2}$ | - 83.9 | $\frac{1}{2}$ |
| 4340 | 14.4 | $\frac{1}{2}$ | - 11.5 | $\frac{1}{2}$ | | | | | 44.5 | $\frac{1}{2}$ |
| 4325 | | | + 12.6 | $\frac{1}{2}$ | | | | | 63.0 | $\frac{1}{2}$ |
| 4308 | | | 3.1 | 1 | | | 39.1 | 1 | 57.8 | $\frac{1}{2}$ |
| 4271 | 18.3 | $\frac{1}{2}$ | 0.2 | $\frac{1}{2}$ | + 9.0 | 1 | 33.9 | 1 | 59.7 | $1\frac{1}{2}$ |
| 4260 | + 15.2 | $\frac{1}{2}$ | 16.3 | $\frac{1}{2}$ | | | 37.0 | 1 | 60.5 | $1\frac{1}{2}$ |
| 4143 | | | | | - 10.7 | $\frac{1}{2}$ | 49.7 | $\frac{1}{2}$ | 78.1 | $\frac{1}{2}$ |
| 4071 | | | + 13.9 | $\frac{1}{2}$ | | | | | 51.4 | $\frac{1}{2}$ |
| 4063 | | | | | | | 46.1 | $\frac{1}{2}$ | 82.3 | $\frac{1}{2}$ |
| 4045 | | | | | | | + 45.0 | 1 | 56.0 | $1\frac{1}{2}$ |
| 4005 | | | | | | | | | + 60.3 | 1 |
| Weighted mean | + 16.92 | | + 5.39 | | + 2.43 | | + 41.89 | | - 80.71 | |
| V_a | - 12.89 | | + 23.19 | | + 24.58 | | + 24.37 | | + 24.37 | |
| V_d | - .28 | | + .12 | | + .21 | | + .04 | | + .04 | |
| Curv. | - .28 | | - .28 | | - .28 | | - .28 | | - .28 | |
| Radial Velocity | + 3.5 | | + 28.4 | | + 26.9 | | + 66.0 | | - 56.6 | |
| | | | | | | | | | + 83.2 | |
| | | | | | | | | | - 56.5 | |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 3979 | | | | 4044 | | | | 4052 | | | | 4064 | | | | |
|-----------------|------|---------------|---------------|------|---------------|---------------|---------------|---------------|------|-------|---------------|---------|---------------|---------------|---------------|---------|---------------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | |
| 4549 | — | 19.1 | $\frac{1}{4}$ | | | | | | — | 55.1 | $\frac{1}{2}$ | + 45.5 | $\frac{1}{2}$ | | | | |
| 4415 | | 11.3 | $\frac{1}{2}$ | | | | | | | | | + 69.4 | 1 | | | | |
| 4340 | | | | | | | | | | | | | | | | | |
| 4325 | | | — | 72.5 | $\frac{1}{2}$ | + 68.3 | $\frac{1}{2}$ | | | | | | 78.1 | $\frac{1}{2}$ | — | 67.9 | $\frac{1}{2}$ |
| 4308 | 12.6 | $\frac{1}{2}$ | | 67.8 | $\frac{1}{2}$ | 66.4 | $\frac{1}{2}$ | | 62.5 | 1 | | 60.3 | 1 | 64.5 | 1 | 80.2 | 1 |
| 4271 | 18.2 | 1 | | 75.9 | $\frac{1}{2}$ | | | | 66.3 | 1 | | 57.3 | 1 | 66.3 | 1 | 82.4 | 1 |
| 4260 | 15.9 | $\frac{1}{4}$ | | | | | | | 61.6 | 1 | | 58.4 | 1 | 67.5 | $\frac{1}{2}$ | 69.8 | 1 |
| 4143 | | | | 71.4 | $\frac{1}{2}$ | 57.2 | $\frac{1}{2}$ | | 58.1 | 1 | | | + 49.3 | 1 | — | 76.1 | 1 |
| 4071 | | | | | | | | | | | | | | | | | |
| 4063 | | | | 66.3 | $\frac{1}{2}$ | | | | | | | | | | | | |
| 4045 | — | 4.0 | $\frac{1}{2}$ | 79.5 | $\frac{1}{2}$ | | | | 64.2 | 1 | | 56.9 | $\frac{1}{2}$ | | | | |
| 4005 | | | | — | 72.6 | $\frac{1}{2}$ | + 62.9 | $\frac{1}{2}$ | — | 55.2 | 1 | + 48.9 | 1 | | | | |
| Weighted | | | | | | | | | | | | | | | | | |
| mean | — | 13.95 | | — | 72.29 | | + 63.70 | | — | 60.84 | | + 55.22 | | + 64.46 | | — 76.10 | |
| V_a | + | 22.88 | | + | 15.00 | | + 15.00 | | + | 14.65 | | + 14.65 | | + 13.63 | | + 13.63 | |
| V_d | + | .09 | | — | .05 | | — .05 | | — | .08 | | — .08 | | — .08 | | — .08 | |
| Curv. | — | .28 | | — | .28 | | — .28 | | — | .28 | | — .28 | | — .28 | | — .28 | |
| Radial Velocity | | | | | | | | | | | | | | | | | |
| | + | 8.7 | | — | 57.6 | | + 78.4 | | — | 46.6 | | + 69.5 | | + 77.7 | | — 62.8 | |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 4074 | | | | 4126 | | | | 4142 | | | | 4159 | | | |
|--------------------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|--------|-------|-------|-------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. |
| 4549 | ..... | ..... | ..... | ..... | + 75.9 | 1 | - 69.9 | 1 | ..... | ..... | ..... | ..... | + 0.5 | 1 | ..... | ..... |
| 4415 | ..... | ..... | ..... | ..... | 74.8 | 2 | 60.4 | 2 | ..... | ..... | ..... | ..... | 18.3 | 1½ | ..... | ..... |
| 4340 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 15.0 | 1 | ..... | ..... |
| 4325 | + 50.6 | 1 | - 79.6 | 2 | 70.3 | 1 | 87.1 | 2 | + 59.8 | 1 | - 18.0 | 2 | 14.4 | 2 | ..... | ..... |
| 4308 | ..... | ..... | ..... | ..... | 73.1 | 1 | 73.8 | 1 | ..... | ..... | ..... | ..... | 12.5 | 1½ | ..... | ..... |
| 4271 | 54.1 | 1 | ..... | ..... | 76.5 | 2 | 74.1 | 2 | ..... | ..... | ..... | ..... | 0.6 | 1½ | ..... | ..... |
| 4260 | 53.4 | 1 | 85.2 | 2 | 62.1 | 1 | 70.2 | 2 | 50.5 | 1 | ..... | ..... | 4.9 | 1 | ..... | ..... |
| 4143 | 39.8 | 1 | 61.6 | 2 | 78.5 | 1 | 51.8 | 2 | 36.6 | 1 | 49.1 | 2 | 2.9 | 1½ | ..... | ..... |
| 4071 | ..... | ..... | ..... | ..... | 71.9 | 1 | ..... | ..... | ..... | ..... | ..... | ..... | 9.9 | 1 | ..... | ..... |
| 4063 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 6.1 | 1 | ..... | ..... |
| 4045 | 58.3 | 1 | 78.4 | 2 | 60.7 | 1 | 62.1 | 1 | + 25.4 | 2 | - 34.3 | 2 | 8.9 | 1½ | ..... | ..... |
| 4005 | + 54.8 | 1 | - 61.2 | 2 | + 57.6 | 1 | - 69.8 | 2 | ..... | ..... | ..... | ..... | + 0.9 | 1½ | ..... | ..... |
| Weighted mean | + 51.83 | ..... | - 73.72 | ..... | + 70.10 | ..... | - 68.80 | ..... | + 42.87 | ..... | - 36.96 | ..... | + 7.60 | ..... | ..... | ..... |
| V_a | + 13.27 | ..... | + 13.27 | ..... | + 9.90 | ..... | + 9.90 | ..... | + 6.76 | ..... | + 6.76 | ..... | + 3.07 | ..... | ..... | ..... |
| V_d | .00 | ..... | .00 | ..... | -.12 | ..... | -.12 | ..... | -.08 | ..... | -.08 | ..... | -.13 | ..... | ..... | ..... |
| Curv. | - .28 | ..... | - .28 | ..... | -.28 | ..... | -.28 | ..... | -.28 | ..... | -.28 | ..... | -.28 | ..... | ..... | ..... |
| Radial Velocity | + 64.8 | ..... | - 60.7 | ..... | + 79.6 | ..... | - 59.3 | ..... | + 49.3 | ..... | - 30.6 | ..... | + 10.3 | ..... | ..... | ..... |

MEASURES OF *d* BOÖTIS—Continued.

| | 4172 | | | | 4183 | | | | 4190 | | | | 4208 | | | | | | | | |
|--------------------|------|------|---------------|-----|-------|---------------|------|-------|---------------|------|---------------|---------------|---------------|---------------|---------------|------|---------------|---|---|-------|---|
| λ | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | | | | | |
| 4549 | + | 8.0 | 1 | | | | | | | | | | | | | | | | | | |
| 4415 | - | 1.7 | 1 | | | | | | - | 18.0 | $\frac{1}{4}$ | + | 89.3 | $\frac{1}{4}$ | | | | | | | |
| 4340 | + | 6.3 | 1 | | | | | | | | | | | | | | | | | | |
| 4325 | - | 3.8 | $\frac{1}{2}$ | | | | | | | | | | | | | | | | | | |
| 4308 | + | 15.4 | 1 | - | 47.0 | 1 | + | 69.4 | 1 | 14.3 | $\frac{1}{2}$ | 65.4 | $\frac{1}{2}$ | 32.4 | $\frac{1}{2}$ | 82.6 | $\frac{1}{2}$ | | | | |
| 4271 | + | 13.1 | 1 | | 54.7 | 1 | | 74.6 | $\frac{1}{2}$ | 37.9 | $\frac{1}{2}$ | 39.7 | $\frac{1}{2}$ | | | | | | | | |
| 4260 | + | 22.4 | 1 | | 45.9 | 1 | | 59.9 | $\frac{1}{2}$ | 41.3 | $\frac{1}{2}$ | | | 39.1 | $\frac{1}{2}$ | 73.2 | $\frac{1}{2}$ | | | | |
| 4143 | + | 3.7 | 1 | | 54.0 | $\frac{1}{2}$ | | 81.5 | $\frac{1}{2}$ | 31.2 | $\frac{1}{2}$ | | | | | | | | | | |
| 4071 | + | 4.3 | 1 | | 55.4 | $\frac{1}{2}$ | | 84.7 | 1 | 28.2 | $\frac{1}{2}$ | 51.2 | $\frac{1}{2}$ | 41.5 | $\frac{1}{2}$ | | | | | | |
| 4063 | + | 3.3 | $\frac{1}{2}$ | | 75.6 | $\frac{1}{2}$ | | 79.5 | 1 | 26.0 | $\frac{1}{2}$ | | | 40.2 | $\frac{1}{2}$ | | | | | | |
| 4045 | + | 8.6 | 1 | | 56.2 | 1 | | 70.2 | $\frac{1}{2}$ | 38.1 | $\frac{1}{2}$ | | | 34.3 | $\frac{1}{2}$ | 52.6 | $\frac{1}{2}$ | | | | |
| 4005 | + | 9.2 | 1 | - | 57.4 | 1 | + | 75.2 | 1 | - | 35.7 | $\frac{1}{2}$ | + | 55.7 | $\frac{1}{2}$ | - | 35.8 | 1 | + | 63.1 | 1 |
| Weighted | | | | | | | | | | | | | | | | | | | | | |
| mean | + | 7.70 | | - | 54.38 | | + | 75.75 | | - | 28.76 | | + | 58.05 | | - | 36.57 | | + | 70.85 | |
| V_a | + | 1.13 | | - | 0.25 | | - | 0.25 | | - | 0.60 | | - | 0.60 | | - | 3.51 | | - | 3.51 | |
| V_d | - | .18 | | - | .18 | | - | .18 | | + | .06 | | + | .06 | | - | .13 | | - | .13 | |
| Curv. | - | .28 | | - | .28 | | - | .28 | | - | .28 | | - | .28 | | - | .28 | | - | .28 | |
| Radial Velocity | | | | | | | | | | | | | | | | | | | | | |
| | + | 8.4 | | - | 55.1 | | + | 75.0 | | - | 29.6 | | + | 57.2 | | - | 40.5 | | + | 66.9 | |

MEASURES OF *d* BOÖTIS—Continued.

| | 4218 | | | | 4233 | | | | 4236 | | | | 4252 | | | | |
|--------------------|-------|---------------|---------------|---------|---------------|---------------|---------------|---------|-------|---------------|--------|---------------|-------|---------|---------------|--------|--------|
| λ | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | |
| 4549 | - | 41.1 | $\frac{1}{2}$ | ..... | + | 26.0 | $\frac{3}{4}$ | ..... |  |  |  |  |  |  |  |  |  |
| 4415 | 44.0 | 1 | ..... |  |  | 0.5 | $\frac{3}{4}$ | ..... |  |  |  |  | + | 80.9 | $\frac{3}{4}$ | ..... |  |
| 4340 | 58.5 | $\frac{1}{2}$ | ..... |  |  | 15.6 | 1 | + | 44.5 | $\frac{1}{2}$ | ..... |  |  | 61.9 | $\frac{1}{2}$ | ..... |  |
| 4325 | 59.3 | $\frac{1}{2}$ | ..... |  |  | 17.0 | $\frac{1}{2}$ | ..... |  |  |  |  |  |  |  |  |  |
| 4308 | 45.1 | 1 | + | 78.1 | 1 | 21.7 | $\frac{1}{2}$ | ..... | 59.0 | 1 | ..... |  |  | 55.8 | $\frac{1}{2}$ | - 55.9 | |
| 4271 | 62.3 | 1 | ..... | 73.4 | $\frac{1}{2}$ | 14.2 | $\frac{1}{2}$ | ..... |  |  |  |  |  |  |  |  |  |
| 4260 | 35.1 | $\frac{1}{2}$ | ..... | 69.0 | $\frac{1}{2}$ | 10.1 | $\frac{1}{2}$ | ..... | 55.8 | $\frac{1}{2}$ | ..... |  |  | 63.8 | 1 | 59.2 1 | |
| 4143 | 41.0 | 1 | ..... | 87.4 | 1 | 0.5 | 1 | ..... |  |  |  |  |  | 84.0 | 1 | 24.0 1 | |
| 4071 | ..... | ..... | ..... | ..... | ..... | 2.2 | $\frac{1}{2}$ | ..... | 53.3 | $\frac{1}{2}$ | - 27.9 | $\frac{1}{2}$ | ..... | 73.6 | $\frac{1}{2}$ | ..... |  |
| 4063 | 42.1 | $\frac{1}{2}$ | ..... | 81.1 | $\frac{1}{2}$ | 16.7 | 1 | ..... | 60.9 | $\frac{1}{2}$ | - 32.1 | $\frac{1}{2}$ | ..... | 76.9 | 1 | 45.7 | |
| 4045 | 40.8 | 1 | ..... | 88.3 | $\frac{1}{2}$ | + | 6.8 | 1 | 52.1 | $\frac{1}{2}$ | ..... |  |  | 79.6 | $\frac{1}{2}$ | 43.6 | |
| 4005 | - | 55.3 | 1 | + | 59.1 | $\frac{1}{2}$ | | + | 56.9 | $\frac{1}{2}$ | | | | + | 70.6 | 1 | - 46.9 |
| Weighted mean | - | 47.82 | ..... | + 78.52 | ..... | + 11.52 | ..... | + 55.19 | ..... | - 30.00 | ..... | + 72.81 | ..... | - 44.41 | | | |
| V_a | - | 3.93 | ..... | - 3.93 | ..... | - 4.72 | ..... | - 5.09 | ..... | - 5.09 | ..... | - 5.83 | ..... | - 5.83 | | | |
| V_d | - | .16 | ..... | - .16 | ..... | - .14 | ..... | .00 | ..... | .00 | ..... | - .13 | ..... | - .13 | | | |
| Curv. | - | .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | | | |
| Radial Velocity | - | 52.2 | ..... | + 74.1 | ..... | + 6.4 | ..... | + 49.8 | ..... | - 35.4 | ..... | + 66.6 | ..... | - 50.6 | | | |

- MEASURES OF *d* BOÖTIS—Continued.

MEASURES OF *d* BOÖTIS—Continued.

| λ | 4315 | | 4328 | | 4338 | | 4344 | | | | 4357 | | 4382 | |
|--------------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|----------------|
|  | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. |
| 4549 | ..... | ..... | ..... | ..... | + 24.6 | $\frac{1}{2}$ | + 98.0 | $\frac{1}{2}$ | - 42.1 | $\frac{1}{2}$ | + 32.6 | $\frac{1}{2}$ | + 36.2 | 1 |
| 4415 | - 55.9 | $\frac{1}{4}$ | + 0.4 | $\frac{1}{4}$ | 19.7 | $\frac{1}{2}$ | 118.2 | $\frac{1}{2}$ | ..... | ..... | 6.3 | $\frac{3}{4}$ | 36.8 | 1 |
| 4340 | ..... | ..... | ..... | ..... | 28.4 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | 30.0 | $\frac{3}{4}$ | 31.8 | 1 |
| 4325 | 49.2 | $\frac{1}{4}$ | ..... | ..... | 38.2 | $\frac{1}{2}$ | 91.2 | $\frac{1}{2}$ | 53.0 | $\frac{1}{2}$ | 24.9 | $\frac{1}{4}$ | 33.6 | 1 |
| 4308 | 68.5 | $\frac{1}{4}$ | ..... | ..... | 26.0 | $\frac{1}{2}$ | 81.7 | $\frac{1}{2}$ | 43.1 | $\frac{1}{2}$ | ..... | ..... | 39.2 | 1 |
| 4271 | 56.7 | $\frac{1}{4}$ | ..... | ..... | 32.4 | $\frac{1}{2}$ | 99.3 | $\frac{1}{2}$ | 58.7 | $\frac{1}{2}$ | 11.6 | $\frac{3}{4}$ | 44.5 | $1\frac{1}{2}$ |
| 4260 | 40.6 | $\frac{1}{4}$ | ..... | ..... | 42.7 | $\frac{1}{2}$ | 70.8 | $\frac{1}{2}$ | 25.3 | $\frac{3}{4}$ | 20.9 | $\frac{1}{2}$ | 49.3 | 1 |
| 4143 | ..... | ..... | - 3.5 | $\frac{1}{4}$ | 24.1 | $\frac{3}{4}$ | 97.4 | $\frac{1}{2}$ | 34.1 | $\frac{1}{2}$ | 2.1 | $\frac{3}{4}$ | 36.6 | 1 |
| 4071 | 24.3 | $\frac{3}{4}$ | ..... | ..... | ..... | ..... | 97.1 | $\frac{1}{2}$ | ..... | ..... | 14.8 | $\frac{1}{2}$ | 30.6 | 1 |
| 4063 | 16.4 | $\frac{3}{4}$ | ..... | ..... | 16.0 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | 31.9 | $\frac{1}{2}$ | 37.4 | 1 |
| 4045 | 22.1 | 1 | + 2.8 | $\frac{1}{2}$ | 40.5 | $\frac{3}{4}$ | 94.1 | $\frac{1}{2}$ | 42.4 | $\frac{3}{4}$ | 22.6 | $\frac{3}{4}$ | 24.4 | $1\frac{1}{2}$ |
| 4005 | - 27.6 | $\frac{1}{2}$ | - 1.1 | $\frac{3}{4}$ | + 40.5 | $\frac{1}{2}$ | + 79.1 | $\frac{3}{4}$ | - 43.7 | $\frac{1}{2}$ | + 32.6 | $\frac{1}{2}$ | + 36.7 | 1 |
| Weighted mean | - 31.81 | 0.00 | + 30.45 | ..... | + 92.13 | ..... | - 42.26 | ..... | + 19.86 | ..... | + 36.27 | ..... | ..... | ..... |
| V_a | - 15.54 | ..... | - 16.99 | ..... | - 18.07 | ..... | - 18.14 | ..... | - 18.14 | ..... | - 20.18 | ..... | - 22.68 | ..... |
| V_d | - .21 | ..... | - .16 | ..... | - .16 | ..... | - .10 | ..... | - .10 | ..... | - .09 | ..... | - .11 | ..... |
| Curv. | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... | - .28 | ..... |
| Radial Velocity | - 47.8 | ..... | - 17.4 | ..... | + 11.9 | ..... | + 73.6 | ..... | - 60.8 | ..... | - 0.7 | ..... | + 13.2 | ..... |

MEASURES OF *d* BOÖTIS—Continued.

| λ | 4390 | | 4391 | | 4405 | | 4411 | | 4420 | | 4425 | | | | |
|--------------------|-------|-------|---------------|-------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|----------------|-------|----------------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | | | |
| 4549 | + | 5.7 | $\frac{1}{2}$ | + | 20.0 | $\frac{1}{2}$ | + | 16.2 | 1 | ..... | + | 43.0 | 1 | | |
| 4415 | | | | | 36.0 | $\frac{1}{2}$ | ..... | 35.0 | $\frac{1}{2}$ | ..... | 19.8 | 1 | 9.5 | | |
| 4340 | - | 26.7 | $\frac{3}{4}$ | 43.9 | $\frac{1}{2}$ | 40.5 | $\frac{1}{4}$ | + | 6.8 | $\frac{1}{2}$ | 32.2 | $\frac{1}{2}$ | 35.5 | | |
| 4325 | | | | | 29.6 | $\frac{1}{2}$ | 37.9 | $\frac{1}{2}$ | - | 39.4 | $\frac{1}{2}$ | 41.3 | $\frac{1}{2}$ | | |
| 4308 | - | 22.8 | $\frac{1}{2}$ | 50.7 | $\frac{1}{2}$ | 40.6 | $\frac{3}{4}$ | ..... | ..... | ..... | 28.4 | $\frac{1}{2}$ | 39.0 | | |
| 4271 | | | | | 38.9 | $\frac{1}{2}$ | 44.4 | 1 | - | 12.6 | $\frac{1}{2}$ | 28.4 | $1\frac{1}{2}$ | | |
| 4260 | | | | | | | 41.7 | $\frac{1}{2}$ | ..... | ..... | 39.2 | 1 | ..... |  |  |
| 4143 | | | | | | | | 7.1 | $\frac{1}{2}$ | ..... | 25.9 | 1 | ..... |  |  |
| 4071 | | | | | | | | | | | | 25.4 | $\frac{1}{2}$ | | |
| 4063 | + | 6.4 | $\frac{1}{2}$ | ..... | ..... | ..... | 48.0 | $\frac{1}{2}$ | ..... | ..... | 18.5 | 1 | 34.7 | | |
| 4045 | | | | + | 15.3 | $\frac{1}{2}$ | ..... | 31.2 | $\frac{1}{2}$ | ..... | 32.9 | 1 | 23.1 | | |
| 4005 | | | | + | 35.2 | $\frac{1}{2}$ | - | 12.2 | $\frac{1}{2}$ | + | 84.4 | $\frac{1}{2}$ | + | 32.2 | $1\frac{1}{2}$ |
| <hr/> | | | | | | | | | | | | | | | |
| Weighted mean | - | 11.27 | + | 33.48 | + | 36.31 | - | 12.90 | + | 81.70 | + | 30.59 | + | 29.20 | |
| V_e | - | 23.11 | - | 23.20 | - | 23.55 | - | 23.62 | - | 23.62 | - | 23.72 | - | 23.77 | |
| V_d | - | .18 | - | .11 | - | .12 | - | .25 | - | .25 | - | .15 | - | .20 | |
| Curv. | - | .28 | - | .28 | - | .28 | - | .28 | - | .28 | - | .28 | - | .28 | |
| <hr/> | | | | | | | | | | | | | | | |
| Radial Velocity | - | 34.8 | + | 9.9 | + | 12.4 | - | 37.0 | + | 57.5 | + | 6.4 | + | 5.0 | |

MEASURES OF *d* BOÖTIS—Concluded.

| λ | 4431 | | | | 4440 | | | | | | | |
|--------------------|------|-------|---------------|----------|---------------|---------|---------------|---------|---------------|-------|-------|-------|
| | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. | Vel. | Wt. |
| 4549 | — | 14.9 | $\frac{1}{2}$ | ..... | + | 71.7 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | ..... |
| 4415 | — | 26.9 | $\frac{1}{2}$ | + 114.1 | $\frac{1}{2}$ | 94.4 | $\frac{1}{2}$ | + 2.2 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4340 | + | 12.5 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 4325 | — | 9.1 | $\frac{1}{2}$ | 123.8 | $\frac{1}{2}$ | 66.6 | $\frac{1}{2}$ | — 42.2 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4308 | — | 21.0 | $\frac{1}{2}$ | 103.8 | $\frac{1}{2}$ | 67.8 | $\frac{1}{2}$ | — 8.0 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4271 | + | 0.1 | $\frac{1}{2}$ | ..... | ..... | 83.0 | $\frac{1}{2}$ | — 32.8 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4260 | — | 10.8 | $\frac{1}{2}$ | 97.5 | $\frac{1}{2}$ | 76.5 | $\frac{1}{2}$ | — 25.5 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4143 | — | 7.3 | 1 | ..... | ..... | 77.3 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | ..... |
| 4071 | + | 7.8 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 4063 | — | 12.5 | 1 | 102.8 | $\frac{1}{2}$ | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 4045 | — | 10.2 | 1 | 109.1 | $\frac{1}{2}$ | ..... | ..... | — 10.8 | $\frac{1}{2}$ | ..... | ..... | ..... |
| 4005 | — | 21.1 | 1 | + 115.6 | $\frac{1}{2}$ | + 80.7 | $\frac{1}{2}$ | — 16.8 | $\frac{1}{2}$ | ..... | ..... | ..... |
| Weighted mean | — | 10.48 | ..... | + 107.95 | ..... | + 78.64 | ..... | — 15.83 | ..... | ..... | ..... | ..... |
| V_a | — | 23.75 | ..... | — 23.75 | ..... | — 23.52 | ..... | — 23.52 | ..... | ..... | ..... | ..... |
| V_d | — | .16 | ..... | — .16 | ..... | — .26 | ..... | — .26 | ..... | ..... | ..... | ..... |
| Curv. | — | .28 | ..... | — .28 | ..... | — .28 | ..... | — .28 | ..... | ..... | ..... | ..... |
| Radial Velocity | — | 34.7 | ..... | + 83.8 | ..... | + 54.6 | ..... | — 39.9 | ..... | ..... | ..... | ..... |

The period deduced from our own observations and the published ones of Lick, assuming their observations on the meridian, was 9.605 days. This was the period used throughout. A correction of -0.0005 days was made to this when the G. M. T. of the Lick plates was received. With the exception of the first four, all our observations are practically of one year so that the small correction to the period will not affect the results. Likewise three out of the four 1907 plates are at the crests of the curve and no appreciable change will result from the use of the revised period. The correction, however, will accumulate to approximately 0.070 days in the interval over which our observations extend and accordingly a correction of +0.070 days was added to the derived value of T , making it 2,417,679.523 as given in final elements.

The observations on component I were first grouped according to phase into thirteen normal places. The peculiar deviation effect near the intersection of the curve with the γ -line, previously referred to, was in evidence in four or five normal places, abnormal residuals for these groups being the rule.

FIRST GROUPING d BOÖTIS, COMPONENT I.

| | Mean Phase. | Mean Velocity. | Weight. | | Mean Phase. | Mean Velocity | Weight. |
|---|-------------|----------------|---------|----|-------------|---------------|---------|
| 1 | 1.590 | + 78.08 | 2.5 | 8 | 7.350 | - 57.95 | 1.5 |
| 2 | 1.994 | + 79.54 | 2.0 | 9 | 8.116 | - 54.66 | 1.5 |
| 3 | 2.638 | + 68.88 | 2.0 | 10 | 8.510 | - 40.62 | 2.0 |
| 4 | 3.586 | + 26.15 | 2.0 | 11 | 9.379 | + 8.43 | 4.5 |
| 5 | 4.740 | + 10.90 | 6.5 | 12 | .506 | + 43.82 | 1.5 |
| 6 | 5.597 | + 0.49 | 1.5 | 13 | .808 | + 68.13 | 1.5 |
| 7 | 6.472 | - 39.03 | 2.0 | | | | |

Preliminary elements by the graphical method were obtained, which outside of the groups mentioned, satisfied the observations quite well. They were the following:

$$\begin{aligned}P &= 9.605 \text{ days} \\e &= .15 \\ \omega &= 280^\circ \\K &= 68 \text{ km.} \\ \gamma &= +9.23 \text{ km.} \\ T &= \text{J. D. } 2,417,679.600\end{aligned}$$

It could be seen that in a least-squares solution the large residuals, alternately above and below the curve on each side of the crossing points, would play the most important part and would cause considerable changes in the elements; nevertheless, as a matter of interest merely to see the extent of such changes, a solution was made. The period was considered determined. The notation of Lehmann-Filhés was used and for sake of homogeneity the following substitutions were made:

$$\begin{aligned}x &= \delta\gamma \\y &= K\delta \\z &= K.\delta e \\u &= K.\delta\omega \\v &= \frac{K}{(1-e^2)^{\frac{3}{2}}} \cdot \mu \cdot \delta T\end{aligned}$$

OBSERVATION EQUATIONS FOR FIRST SOLUTION, COMPONENT I.

| | Weight. | <i>x</i> | <i>y</i> | <i>z</i> | <i>u</i> | <i>v</i> | <i>-n</i> |
|----|---------|----------|----------|----------|----------|----------|-----------|
| 1 | 2.5 | 1.000 | + 1.023 | + .324 | + .222 | - .080 | + .74 = 0 |
| 2 | 2.0 | 1.000 | + 1.004 | - .248 | - .059 | + .205 | - 2.01 |
| 3 | 2.0 | 1.000 | + .844 | - .858 | - .428 | + .504 | - 2.27 |
| 4 | 2.0 | 1.000 | + .446 | - .821 | - .760 | + .698 | +13.39 |
| 5 | 6.5 | 1.000 | - .117 | + .117 | - .842 | + .715 | - 9.66 |
| 6 | 1.5 | 1.000 | - .511 | + .788 | - .696 | + .626 | -25.98 |
| 7 | 2.0 | 1.000 | - .828 | + .933 | - .372 | + .422 | - 8.06 |
| 8 | 1.5 | 1.000 | - .964 | + .231 | + .119 | + .027 | + .98 |
| 9 | 1.5 | 1.000 | - .853 | - .774 | + .625 | - .524 | + 5.90 |
| 10 | 2.0 | 1.000 | - .669 | - 1.069 | + .866 | - .851 | + 4.34 |
| 11 | 4.5 | 1.000 | - .001 | - .266 | + 1.147 | - 1.315 | + .71 |
| 12 | 1.5 | 1.000 | + .610 | + .943 | + .960 | - 1.047 | + 6.86 |
| 13 | 1.5 | 1.000 | + .798 | + 1.067 | + .783 | - .826 | - 4.62 |

These resulted in the following normal equations:

$$\begin{aligned} 31 \cdot 000x + 2 \cdot 007y - .372z + 1 \cdot 422u - 2 \cdot 125v - 72 \cdot 255 &= 0 \\ 13 \cdot 200y + .137z + .518u - .211v + 32 \cdot 526 &= 0 \\ 12 \cdot 589z - 1 \cdot 265u + 1 \cdot 101v - 83 \cdot 916 &= 0 \\ 17 \cdot 591u - 17 \cdot 665v + 89 \cdot 564 &= 0 \\ 18 \cdot 154v - 81 \cdot 911 &= 0 \end{aligned}$$

whence the corrections:

$$\delta\gamma = +2 \cdot 54 \text{ km.}$$

$$\delta K = -2 \cdot 48 \text{ km.}$$

$$\delta e = +.090$$

$$\delta\omega = -13^\circ 11'$$

$$\delta T = -.235 \text{ days}$$

so that the first corrected set of elements for component I are:

$$P = 9 \cdot 605 \text{ days}$$

$$e = .240$$

$$\omega = 266^\circ 49'$$

$$K = 65 \cdot 52 \text{ km.}$$

$$\gamma = +11 \cdot 77 \text{ km.}$$

$$T = J. D. 2,417,679 \cdot 365$$

If we compare these with the values finally accepted we notice differences of considerable magnitude. The eccentricity is here considerably increased. Another marked effect is the lowering of both positive and negative maxima from that given by the final elements, which latter maxima seem well substantiated by the observations at a time when the observed velocities can be relied upon.

Though a second solution according to the foregoing grouping should have been carried out to satisfy the agreement between equation and ephemeris residuals, yet any changes thereby deduced would have been of a vanishing order, and as the grouping at basis was faulty no good purpose could have been served by such solution. A new set of normal places was formed differing from the former chiefly in having numbers 4, 5 and 6

of the old grouping combined into one place. Other observations taken in the meantime made up a new group. In this new grouping all the plates whereon the component spectra were not distinctly resolved were grouped into two normal places at or near the two points of intersection of the curves. They have, owing to the number of plates involved, relatively high weights.

NORMAL PLACES, COMPONENT I.

| | Mean Phase. | Mean Vel. | Weight. | O-C | Equation-Ephemeris. |
|----|-------------|-----------|---------|--------|---------------------|
| 1 | 1.590 | + 78.53 | 2.5 | - .62 | + .14 |
| 2 | 1.994 | + 79.71 | 2.0 | + 1.64 | + .06 |
| 3 | 2.638 | + 69.21 | 2.0 | + .75 | - .07 |
| 4 | 3.022 | + 54.60 | .3 | - 5.10 | - .11 |
| 5 | 4.635 | + 12.08 | 10.0 | - .31 | + .02 |
| 6 | 6.472 | - 38.70 | 2.0 | + 2.73 | + .10 |
| 7 | 7.350 | - 56.96 | 1.5 | - .92 | + .12 |
| 8 | 8.116 | - 54.41 | 1.5 | - 2.41 | + .21 |
| 9 | 8.510 | - 39.87 | 2.0 | + .48 | + .06 |
| 10 | 9.379 | + 8.41 | 4.5 | + .90 | - .43 |
| 11 | .506 | + 44.26 | 1.5 | - 7.11 | - .21 |
| 12 | .808 | + 68.47 | 1.5 | + 4.16 | + .32 |

The same set of preliminary elements as before were used and with substitutions for homogeneity as before we have:

OBSERVATION EQUATIONS FOR SECOND SOLUTION, COMPONENT I.

| | Weight. | x | y | z | u | v | -n |
|----|---------|-------|---------|---------|---------|---------|-----------|
| 1 | 2.5 | 1.000 | + 1.023 | + .324 | + .222 | - .080 | + .29 = 0 |
| 2 | 2.0 | 1.000 | + 1.004 | - .248 | - .059 | + .205 | - 2.18 |
| 3 | 2.0 | 1.000 | + .844 | - .858 | - .428 | + .504 | - 2.60 |
| 4 | .3 | 1.000 | + .698 | - .969 | - .593 | + .611 | + 2.08 |
| 5 | 10.0 | 1.000 | - .066 | + .020 | - .848 | + .720 | - 7.36 |
| 6 | 2.0 | 1.000 | - .828 | + .933 | - .372 | + .422 | - 8.39 |
| 7 | 1.5 | 1.000 | - .964 | + .231 | + .119 | + .027 | - .01 |
| 8 | 1.5 | 1.000 | - .853 | + .774 | + .625 | - .524 | + 5.65 |
| 9 | 2.0 | 1.000 | - .669 | - 1.069 | + .866 | - .851 | + 3.59 |
| 10 | 4.5 | 1.000 | - .001 | - .266 | + 1.147 | - 1.315 | + .73 |
| 11 | 1.5 | 1.000 | + .610 | + .943 | + .960 | - 1.047 | + 6.42 |
| 12 | 1.5 | 1.000 | + .798 | + 1.067 | + .783 | - .826 | + 4.96 |

These when transformed gave the normal equations:

$$\begin{aligned} 31.300x + 2.190y - .763z + .801u - 1.724v - 77.476 &= 0 \\ 12.512y + 1.350z + .459u - .158v - .924 &= 0 \\ 10.507z - 1.047u + .930v - 25.925 &= 0 \\ 18.398u - 18.253v + 89.628 &= 0 \\ 18.565v - 82.093 &= 0 \end{aligned}$$

from which the corrections resulted:

$$\begin{aligned} \delta\gamma &= +2.38 \text{ km.} \\ \delta K &= - .16 \text{ km.} \\ \delta e &= + .030 \\ \delta\omega &= -12^\circ 01' \\ \delta T &= - .206 \text{ days.} \end{aligned}$$

The corrected elements for component I then are:

$$\begin{aligned} P &= 9.605 \text{ days} \\ e &= .180 \\ \omega &= 267^\circ 59' \\ K &= 68.16 \text{ km.} \\ \gamma &= +11.61 \text{ km.} \\ T &= \text{J. D. } 2,417,679.394 \end{aligned}$$

The sum of the squares of the residuals was reduced from 883.5 to 147.1.

Elements corresponding almost to the above corrected values were used as preliminary in a least-squares solution for component II. The maximum positive for the curve seemed to be fixed about +79 by the observations, while the maximum negative was -61. This with corresponding values for e and ω gave a somewhat discrepant value for γ , nevertheless the elements following were assumed as preliminary for the solution.

$$\begin{aligned}
 P &= 9.605 \text{ days} \\
 e &= .180 \\
 \omega &= 88^\circ \\
 K &= 70 \text{ km.} \\
 \gamma &= +8.56 \text{ km.} \\
 T &= \text{J. D. } 2,417,679.394
 \end{aligned}$$

The two normal places for component I previously referred to as comprising all the plates on which the lines were blended were also used in this solution. This seemed a reasonable procedure as the blended observations refer equally to both components.

NORMAL PLACES, COMPONENT II.

| | Mean Phase. | Mean Vel. | Weight. | O-C. | Equation—Ephemeris. |
|---|-------------|-----------|---------|--------|---------------------|
| 1 | 1.839 | — 60.70 | 3.5 | + 1.94 | — .06 |
| 2 | 2.327 | — 59.90 | 1.0 | — .06 | — .06 |
| 3 | 2.921 | — 52.65 | 1.5 | — 4.01 | — .22 |
| 4 | 4.841 | + 12.08 | 10.0 | — .17 | — .25 |
| 5 | 6.634 | + 73.25 | 1.0 | + 4.77 | — .03 |
| 6 | 7.702 | + 73.83 | 1.0 | — 7.99 | + .38 |
| 7 | 8.546 | + 69.60 | 1.5 | + 3.61 | — .17 |
| 8 | 9.585 | + 8.41 | 4.5 | — .27 | — .04 |
| 9 | .931 | — 46.72 | 1.5 | — 2.18 | + .02 |

With the usual substitutions we have:

OBSERVATION EQUATIONS, COMPONENT II.

| | Weight. | x | y | z | u | v | -n |
|---|---------|-------|--------|--------|--------|--------|-----------|
| 1 | 3.5 | 1.000 | — .993 | — .059 | — .225 | + .046 | — .23 = 0 |
| 2 | 1.0 | 1.000 | — .957 | + .550 | + .089 | — .240 | + 1.52 |
| 3 | 1.5 | 1.000 | — .810 | + .933 | + .398 | — .458 | + 4.50 |
| 4 | 10.0 | 1.000 | — .011 | + .002 | + .820 | — .672 | — 4.30 |
| 5 | 1.0 | 1.000 | + .763 | — .926 | + .474 | — .515 | — 11.29 |
| 6 | 1.0 | 1.000 | +1.004 | — .106 | — .112 | — .067 | + 5.01 |
| 7 | 1.5 | 1.000 | + .843 | +1.013 | — .728 | + .668 | — 2.05 |
| 8 | 4.5 | 1.000 | + .060 | + .077 | —1.178 | +1.391 | + 4.34 |
| 9 | 1.5 | 1.000 | — .727 | —1.091 | — .860 | + .849 | + 4.39 |

whence the normal equations:

$$\begin{aligned}
 25 \cdot 500x - 3 \cdot 546y + 962z + 778u + 467v - 18 \cdot 775 &= 0 \\
 8 \cdot 816y + 223z + 072u + 534v - 15 \cdot 438 &= 0 \\
 5 \cdot 840z + 131u - 204v + 8 \cdot 225 &= 0 \\
 15 \cdot 533u - 15 \cdot 275v - 64 \cdot 600 &= 0 \\
 15 \cdot 623v + 61 \cdot 579 &= 0
 \end{aligned}$$

resulting in the corrections:

$$\begin{aligned}
 \delta\gamma &= +1 \cdot 07 \text{ km.} \\
 \delta K &= +2 \cdot 29 \text{ km.} \\
 \delta e &= -025 \\
 \delta\omega &= +2^\circ 10' \\
 \delta T &= -031 \text{ days,}
 \end{aligned}$$

so that the corrected values for component II are:

$$\begin{aligned}
 P &= 9 \cdot 605 \text{ days} \\
 e &= .155 \\
 \omega &= 90^\circ 10' \\
 K &= 72 \cdot 29 \text{ km.} \\
 \gamma &= +9 \cdot 63 \text{ km.} \\
 T &= \text{J. D. } 2,417,679 \cdot 363
 \end{aligned}$$

These values reduced Σpvv from 490.8 to 143.0.

The question now arises as to the best method of combining the results arrived at from each component to secure uniform values for the elements. For the values of γ , e and T must be identical, whilst the values for ω must differ by 180° . As we have determined them they are:

| | Component I. | Component II. |
|----------|---------------------|---------------------|
| γ | + 11.61 km. | + 9.63 km. |
| e | .180 | .155 |
| ω | 267° 59' | (270° 10'—180°) |
| T | J. D. 2,417,679.394 | J. D. 2,417,679.363 |

One might combine them according to the relative weights of the observations, which in this case are 31.3 and 25.5 for components I and II respectively. Again we might combine according to the probable errors of the determined quantities, weighting as the inverse square of the probable errors. Both these have been performed, but before giving the results a better method than either, suggested by the Director, Dr. W. F. King, will be given. It consists in combining all observations on both components into one set of observation equations from which of course only one set of elements result. It is the only rigid determination possible. In building up the observation equations, one must be careful to remember that for ω in one case we must use $180^\circ + \omega$ in the other. The equations of Lehmann-Filhés then assume the following form.

$$\begin{aligned} \delta \left(\frac{\delta z}{\delta t} \right) &= \delta \gamma + (\cos u + e \cos \omega) \delta K_i + (\cos u + e \cos \omega) \delta K_s, \\ &+ \left[(\cos \omega - \frac{\sin u \sin v}{1-e^2} \cdot 2 + e \cos v) K_i + (\cos \omega - \frac{\sin u \sin v}{1-e^2} \cdot 2 + e \cos v) K_s \right] \delta e \\ &- \left[(\sin u + e \sin \omega) K_i + (\sin u + e \sin \omega) K_s \right] \delta \omega \\ &+ \left[\sin u (1 + e \cos v)^2 K_i + \sin u (1 + e \cos v)^2 K_s \right] \frac{\mu}{(1-e^2)^{\frac{3}{2}}} \cdot \delta T \end{aligned}$$

For preliminary elements the following were assumed:

$$P = 9.605 \text{ days}$$

$$e = .180$$

$$\omega = 268^\circ \text{ and } 88^\circ$$

$$\gamma = +8.56 \text{ km.}$$

$$K_i = 67.87 \text{ km.}$$

$$K_s = 70 \text{ km.}$$

$$T = \text{J. D. } 2,417,679.394$$

Making the following substitutions:

$$\begin{aligned}x &= \delta\gamma \\y_1 &= \delta K_1 \\y_2 &= \delta K_2 \\z &= 100 \delta e \\u &= 100 \delta\omega \\v &= \frac{100 \mu}{(1-e^{\frac{1}{k}})^{\frac{1}{k}}} \cdot \delta T\end{aligned}$$

we get the following set of observation equations:

OBSERVATION EQUATIONS, BOTH COMPONENTS.

| | Weight. | x | y_1 | y_2 | z | u | v | $-n$ |
|----|---------|-------|--------|---------|--------|--------|--------|------------|
| 1 | 2.5 | 1.000 | + .991 | .000 | + .082 | + .173 | -.050 | - 2.72 = 0 |
| 2 | 2.0 | 1.000 | + .975 | .000 | -.282 | -.008 | + .120 | - 4.98 |
| 3 | 2.0 | 1.000 | + .834 | .000 | -.616 | -.246 | + .296 | - 4.04 |
| 4 | .3 | 1.000 | + .705 | .000 | -.656 | -.355 | + .360 | + 1.84 |
| 5 | 2.0 | 1.000 | - .778 | .000 | + .645 | -.309 | + .342 | - 5.55 |
| 6 | 1.5 | 1.000 | - .992 | .000 | + .204 | + .010 | + .107 | - 1.84 |
| 7 | 1.5 | 1.000 | - .933 | .000 | -.522 | + .377 | -.294 | - .37 |
| 8 | 2.0 | 1.000 | - .762 | .000 | -.737 | + .566 | -.560 | - 3.31 |
| 9 | 1.5 | 1.000 | + .583 | .000 | + .726 | + .670 | -.714 | + 3.89 |
| 10 | 1.5 | 1.000 | + .773 | .000 | + .718 | + .547 | -.521 | - 7.44 |
| 11 | 3.5 | 1.000 | .000 | - .993 | -.041 | -.157 | + .032 | - .23 |
| 12 | 1.0 | 1.000 | .000 | - .957 | + .385 | + .062 | -.168 | + 1.52 |
| 13 | 1.5 | 1.000 | .000 | - .810 | + .653 | + .280 | -.321 | + 4.50 |
| 14 | 10.0 | 1.000 | .000 | - .011 | + .001 | + .574 | -.470 | - 4.30 |
| 15 | 1.0 | 1.000 | .000 | + .763 | -.648 | + .332 | -.360 | - 11.29 |
| 16 | 1.0 | 1.000 | .000 | + 1.004 | -.074 | -.078 | -.047 | + 5.01 |
| 17 | 1.5 | 1.000 | .000 | + .843 | + .709 | -.510 | + .468 | - 2.05 |
| 18 | 4.5 | 1.000 | .000 | + .060 | + .054 | -.825 | + .974 | + 4.34 |
| 19 | 1.5 | 1.000 | .000 | - .727 | -.764 | -.602 | + .594 | + 4.39 |

whence the normal equations:

$$\begin{aligned}42.300x + 2.372y_1 - 3.546y_2 + .390z + 3.282u - 1.427v - 69.327 &= 0 \\12.457y_1 + .000y_2 + .502z + .223u + .027v - 11.024 &= 0 \\8.816y_2 + .155z + .050u + .374v - 15.438 &= 0 \\9.105z + .298u - .467v + 8.696 &= 0 \\13.274u - 13.055v - 66.682 &= 0 \\13.365v + 59.990 &= 0\end{aligned}$$

giving as corrections:

$$\begin{aligned}\delta\gamma &= +1.25 \text{ km.} \\ \delta K_1 &= +.53 \text{ km.} \\ \delta K_2 &= +2.05 \text{ km.} \\ \delta e &= -.011 \\ \delta\omega &= +5^\circ 00' \\ \delta T &= +.059 \text{ days.}\end{aligned}$$

Hence the final values which are considered as definitive, with their probable errors are the following:

FINAL VALUES.

$$\begin{aligned}P &= 9.6045 \text{ days} \\ e &= .169 \pm .011 \\ \omega_1 &= 273^\circ \pm 2^\circ 55' \\ \omega_2 &= 93^\circ \pm 2^\circ 55' \\ K_1 &= 68.40 \text{ km.} \pm 0.92 \text{ km.} \\ K_2 &= 72.05 \text{ km.} \pm 1.15 \text{ km.} \\ A_1 &= 69.00 \text{ km.} \\ B_1 &= 67.80 \text{ km.} \\ A_2 &= 71.41 \text{ km.} \\ B_2 &= 72.69 \text{ km.} \\ T &= \text{J. D. } 2,417,679.523 \pm .073 \\ \gamma &= + 9.80 \text{ km.} \pm 0.56 \text{ km.} \\ a_1 \sin i &= 8,904,000 \text{ km.} \\ a_2 \sin i &= 9,380,000 \text{ km.} \\ m_1 \sin^3 i &= 1.36 \odot \\ m_2 \sin^3 i &= 1.29 \odot\end{aligned}$$

The value of Σpvv for the normal equations was reduced from 786.5 in the case of the preliminary elements to 429.8 and, as may be noted in the following table, last column, satisfactory agreement was obtained between equation and ephemeris residuals. The phases in the table are referred to the final value for T .

NORMAL PLACES, COMBINED SOLUTION.

| | Mean Phase. | Mean Vel. | Weight. | O-C. | Equation— Ephemeris. |
|----|-------------|-----------|---------|--------|-------------------------|
| 1 | 1.737 | + 78.53 | 2.5 | - .18 | + .06 |
| 2 | 2.141 | + 79.71 | 2.0 | + 2.59 | + .09 |
| 3 | 2.785 | + 69.21 | 2.0 | + 2.76 | + .22 |
| 4 | 3.169 | + 54.60 | .3 | - 2.42 | + .16 |
| 5 | 6.619 | - 38.70 | 2.0 | + 6.67 | - .08 |
| 6 | 7.497 | - 56.96 | 1.5 | + .73 | - .08 |
| 7 | 8.263 | - 54.41 | 1.5 | - 3.17 | - .12 |
| 8 | 8.657 | - 39.87 | 2.0 | - 1.17 | - .14 |
| 9 | .653 | + 44.26 | 1.5 | - 7.65 | - .09 |
| 10 | .955 | + 68.47 | 1.5 | + 4.00 | + .05 |
| 11 | 1.780 | - 60.70 | 3.5 | + 2.18 | - .02 |
| 12 | 2.268 | - 59.90 | 1.0 | - .29 | - .05 |
| 13 | 2.862 | - 62.65 | 1.5 | - 4.62 | - .13 |
| 14 | 4.782 | + 12.08 | 10.0 | - .14 | - .07 |
| 15 | 6.575 | + 73.25 | 1.0 | + 6.35 | + .04 |
| 16 | 7.643 | + 73.83 | 1.0 | - 7.38 | + .23 |
| 17 | 8.487 | + 69.60 | 1.5 | + 2.08 | - .29 |
| 18 | 9.526 | + 8.41 | 4.5 | - 2.28 | + .13 |
| 19 | .872 | - 46.72 | 1.5 | - 2.06 | + .11 |

The probable error of a plate obtained from the residuals as scaled, with their corresponding weights, is ± 3.21 km. per sec. In the curves shown, which represent the final elements, the continuous curve and circles refer to component I and the broken ones to component II.

A comparison of the elements common to both components, arrived at in the various ways, is given in the following table.

COMPARISON OF ELEMENTS.

| Elements. | Solution Component I. | Solution Component II. | Combined According to Weights. | Combined According to Probable Errors. | One Direct Solution. |
|-----------|-----------------------|------------------------|--------------------------------|--|----------------------|
| γ | + 11.61 km. | + 9.63 km. | + 10.72 km. | + 10.80 km. | + 9.80 km. |
| e | .180 | .155 | .169 | .170 | .169 |
| ω | 267° 59' | 90° 10' | 268° 58' | 269° 11' | 273° and 93° |
| T |9.394 |9.363 |9.380 |9.377 |9.453 |

There seems no doubt to the writer that the last solution wherein all the observations on both components are grouped into one set of observation equations resulting in a uniform set of values, is the only rigid one, and as previously stated the suggestion for such a procedure came from the Director, Dr. W. F. King, to whom my acknowledgements are due for this and other valuable suggestions.

One detail in which, for future work, the foregoing can be improved upon—the two groupings representing the blend plates should be broken up into four with residuals scaled from each curve, the total weight assigned the four normal places being equal to that formerly given the two; or, retaining the two normal places, adjust the corresponding residuals in the observation equations so that they represent the deviations from both curves instead of from one alone as in the present discussion.

Dominion Observatory,

Ottawa,

August, 1911.

