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Orbit of σ Geminorum

BY

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ORBIT OF σ GEMINORUM.

BY W. E. HARPER, M.A.

This star (α=7 h. 37·0 m., $\delta=+29° 07'$, photographic magnitude 5·4) was announced* as a spectroscopic binary by Reese in 1903. The four measures given about cover the total range in its velocity.

During 1907, 1910 and the present year thirty-eight spectrograms of this star have been obtained. Numbers 628 and 654 were made on Seed 27 plates using the Universal Spectroscope, dispersion at $H\gamma$ 18·6 tenth-metres per millimetre; numbers 3182 and 3237 on Sigma plates with a three-prism of the same dispersion, while numbers 3286, 3309 and 3335 were made on Sigma plates with three-prism dispersion of 20·2 tenth-metres per millimetre. The remaining plates were made on Seed 27 emulsion with the single-prism instrument having a dispersion at the same region of 33·4 tenth-metres per millimetre.

The spectrum is of K-type and should yield measurements with a small probable error. The probable error of a plate of ±2·17 km. per sec. obtained from our observations is larger than one should expect for a star of this type but there are many ways in which this may be accounted for. The use of the coarse grained plates when three-prism dispersion was used, made necessary from the faintness of the star; the low dispersion for the great majority of the spectrograms with consequent blending of the spectral lines, and the fact that none of the plates, however poor, have been rejected may be given as possible reasons for the large probable error of an observation. Reese's comment upon the spectrum, in announcing it as a binary was: "Numerous lines, hazy yet trustworthy."

* Lick Observatory Bulletin 2, 31, 1903.

An attempt was made to measure the plates on the spectro-comparator which in the case of stars having many spectral lines, is faster and regarded as more satisfactory than the ordinary method. However, from lack of intensity of the negatives and consequent diffuseness of the lines, the writer abandoned this in favour of the ordinary method. After several plates had been reduced in which all available lines had been measured in the region used, viz: from λ4600 down to λ4250, a table was constructed of the residuals of each line from the mean given by the plate. The object of this was to determine a working wave-length for two or three lines which were among the best measurable but whose wave-length was unknown. The wave-lengths determined in this way were:

λλ 4494·580
4430·517
4282·833

None of the other lines at this time gave evidences of a need of revision. Later, when all plates had been reduced, it was found that several would have given better agreement if a slight change in wave-length were adopted but from the thirteen plates used in this connection this was not noticeable. Probably the different dispersions for the plates masked the general trend of the residuals. A selection of thirteen lines of wave-lengths given below was accordingly used in the determination of the velocities.

LINES USED IN σ GEMINORUM

λλ 4586·163	4531·202	4430·517	4340·634
4571·763	4522·855	4415·293	4282·833
4549·766	4494·580	4404·927	4271·760
4535·965			

The observational data of the plates and the measures according to the above wave-lengths follow. The phases are reckoned from periastron passage J. D. 2,415,824·019 using the period 19·605 which seemed to suit all observations best. The residuals in the last column are scaled from the curve representing the final elements. After this table are given the detailed measures of the plates.

TABLE OF OBSERVATIONS OF σ GEMINORUM.

Plate.	Observer.*	Date.	Exposure.	Julian Date.	Phase.	Velocity.	Weight.	O-C.
		1907						
628	P	Feb. 22	85	2,417,629·667	1·988	+78·9	9	− 1·5
654	P	Mar. 8	100	7,643·586	15·907	33·0	9	− 7·2
		1910						
3183	P	Feb. 10	85	8,713·667	7·713	32·7	9	+ 0·1
3237	P	Feb. 25	70	728·673	3·114	72·3	6	− 3·7
3286	P	Mar. 5	60	736·673	11·114	8·0	4	− 4·4
3309	P	Mar. 10	65	741·664	16·105	42·0	9	− 0·5
3335	P	Mar. 17	75	8,748·605	3·441	74·8	9	+ 0·5
		1911						
3976	C-P[1]	Jan. 30	80	9,067·753	8·909	18·1	5	− 4·4
3998	H	Feb. 15	93	083·785	5·336	56·0	7	− 1·5
4022	C	Feb. 27	65	095·671	17·222	59·0	4	+ 4·0
4032	H	Feb. 28	75	096·633	18·184	67·3	7	+ 2·6
4047	H	Mar. 3	54	099·517	1·463	76·8	5	− 3·8
4055	H	Mar. 4	55	100·518	2·464	74·1	6	− 5·1
4070	H	Mar. 7	80	103·680	5·626	55·5	6	+ 1·0
4080	P[1]-C	Mar. 8	87	104·719	6·665	49·3	6	+ 6·0
4089	C	Mar. 10	70	106·641	8·587	27·7	8	+ 2·7
4102	C	Mar. 13	90	109·669	11·615	16·5	7	+ 4·0
4128	H	Mar. 14	90	110·668	12·614	9·0	6	− 5·5
4120	P	Mar. 16	80	112·687	14·633	28·3	8	+ 0·8
4134	C	Mar. 20	72	116·631	18·577	68·6	8	+ 0·1
4137	C	Mar. 24	72	120·642	2·983	79·6	8	+ 2·6
4144	H	Mar. 28	87	124·719	7·060	35·6	5	− 3·4
4155	H	April 2	80	129·709	12·050	12·0	6	− 0·7
4162	C	April 3	80	130·700	13·041	18·6	7	+ 2·3
4173	H	April 9	80	136·670	19·011	70·7	7	− 1·6
4177	C	April 10	81	137·597	·333	83·8	8	+ 6·0
4186	H	April 11	80	138·590	1·326	80·6	8	0·0
4196	H	April 14	110	141·619	4·355	67·6	7	+ 0·4
4202	H	April 18	83	145·593	8·329	27·6	5	+ 0·6
4211	P[1]	April 19	80	146·568	9·304	21·0	8	+ 1·5
4221	P	April 20	85	147·630	10·366	8·8	3	− 5·2
4228	P[1]	April 21	70	148·599	11·335	9·9	6	− 2·4
4247	C	April 24	80	151·597	14·333	25·3	6	+ 0·3
4253	H	April 25	75	152·548	15·284	31·1	7	− 2·7
4263	P[1]	April 26	75	153·609	16·345	46·8	5	+ 1·4
4271	C	April 28	90	155·552	18·288	69·7	4	+ 4·0
4280	C	May 3	80	160·566	3·697	73·4	5	+ 0·9
4283	H	May 4	76	9,161·555	4·686	+68·2	7	+ 4·2

*P = Plaskett, H = Harper, P[1] = Parker, C = Cannon.

MEASURES OF σ GEMINORUM.

λ	628		654		3182		3237		3286		3309		3335	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	...	...	...	...	+ 58·8	½	+ 93·6	1	+ 53·1	½	...	...	+ 103·5	½
4571	...	...	...	...	53·5	½	97·1	1	24·3	¾	+ 64·3	1	109·3	1
4549	+ 85·7	1	+ 49·7	1	52·5	1	93·9	½	22·4	¾	61·3	1½	90·0	1
4535	87·9	1	55·8	1½	44·4	1½	97·2	½	37·3	½	61·4	1½	102·2	1½
4531	106·6	1	70·4	1	...	...	92·3	½	36·5	½	68·2	1	103·7	1
4522	104·2	1	71·5	1	50·2	1	93·8	1	...	...	70·3	1	112·7	1
4494	101·7	1	52·0	1	44·5	1½	97·8	1	...	...	75·6	1½	97·5	1
4430	97·2	1	57·0	1	...	...	...	...	...	...	...	...	...	...
4415	102·1	1	56·6	1	43·2	1½	+ 75·9	½	...	...	...	...	95·0	1
4404	100·3	1	52·0	1	+ 49·2	1	...	...	+ 27·4	½	71·4	1	95·5	1
4340	...	...	...	...	...	...	...	...	...	...	+ 71·1	½	+ 119·7	½
4282	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4271	+ 107·5	1	+ 48·4	1	...	...	...	...	...	...	...	...	...	...
Weighted mean	+ 99·24		+ 57·96		+ 47·79		+ 93·66		+ 32·05		+ 67·47		+101·96	
V_a	− 19·69		− 24·39		− 14·77		− 20·91		− 23·60		− 25·05		− 26·73	
V_d	− ·11		− ·02		− ·05		− ·13		− ·15		− ·16		− ·11	
Curv.	− ·50		− ·50		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	+ 78·9		+ 33·0		+ 32·7		+ 72·3		+ 8·0		+ 42·0		+ 74·8	

MEASURES OF σ GEMINORUM—*Continued.*

λ	3976		3998		4022		4032		4047		4055		4070	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	+ 41·4	½	+ 63·7	1	+ 82·1	½	+ 95·5	1	+ 78·5	½	......	......	......	......
4571	29·4	1½	94·5	½	78·5	½	96·4	1	108·6	¾	+ 88·3	½	+ 80·4	1
4549	25·6	1½	67·4	¾	64·0	½	91·4	1	119·0	¾	91·8	1	72·0	½
4535	33·7	1	71·0	1½	83·4	1½	78·9	½	85·1	½	92·0	½	64·9	½
4531	36·6	½	66·3	½	......	......	......	......	......	......	102·4	1	......	......
4522	......	......	78·9	½	87·3	½	91·8	1	118·9	½	......	......	74·7	1
4494	28·0	1	82·4	½	85·6	½	88·7	1	......	......	89·0	½	79·0	½
4430	33·3	½	76·3	1	69·5	½	85·4	1	95·7	½	97·8	1	86·1	1
4415	17·8	1	75·9	1	79·1	1	78·8	1	84·3	½	96·9	1½	72·0	1
4404	+ 13·3	½	73·3	¾	......	......	83·9	1	94·8	½	104·5	1	85·4	1
4340	......	......	78·5	½	......	......	98·7	1	103·2	1	106·4	½	107·6	½
4282	......	......	65·1	1	+ 86·7	1	91·7	1	91·4	1	97·7	1	72·5	1
4271	......	......	+ 82·0	½	......	......	+ 87·6	1	+ 104·6	1	+ 99·1	¾	+ 87·4	1
Weighted mean	+ 28·04		+ 73·42		+ 80·68		+ 89·51		+ 99·81		+ 97·49		+ 80·02	
V_a	− 9·48		− 16·91		− 21·54		− 21·88		− 22·85		− 23·17		− 24·12	
V_d	− ·14		− ·18		− ·12		− ·07		+ ·11		+ ·11		− ·17	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	+ 18·1		+ 56·0		+ 58·8		+ 67·3		+ 76·8		+ 74·1		+ 55·5	

MEASURES OF σ GEMINORUM—*Continued.*

λ	4080		4089		4102		4128		4120		4134		4137	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	+ 84·2	½	+ 61·4	½	+ 47·5	1	+ 26·3	½	....	....	....	....	....	....
4571	73·4	½	67·2	1	27·4	1	38·3	¾	+ 59·8	¾	+ 95·7	1	+ 105·5	¾
4549	66·3	½	40·7	½	34·7	1	25·0	½	59·4	1½	92·7	1	99·6	¾
4535	66·9	1	53·0	1½	....	....	32·9	1	49·0	1	89·4	1½	102·3	1
4531	83·8	1	47·6	1½	....	....	30·8	1	54·2	¾	106·5	½	90·1	½
4522	75·2	1	61·7	1	....	....	42·5	½	58·6	1	82·5	1	134·5	1
4494	71·1	¾	45·9	½	....	....	....	....	64·8	¾	....	....	118·0	½
4430	71·1	¾	52·3	1	47·9	1	29·1	1	56·5	1¼	100·5	1½	108·1	1
4415	61·5	¾	44·3	1	47·0	1½	33·4	¾	49·3	1	109·9	1½	103·0	1
4404	....	....	51·2	1	42·0	½	28·2	¾	46·0	1	101·8	1	106·0	1
4340	84·1	¾	61·8	1	42·8	1½	41·9	¾	62·6	1	100·9	1	101·0	1
4282	+ 77·5	1	53·2	1	49·0	1	48·6	1	45·0	1	93·7	1½	109·1	1
4271	....	....	+ 47·8	1	+ 43·4	1	+ 48·0	½	+ 58·9	1	+ 87·0	1	+ 112·6	1
Weighted mean	+ 74·25		+ 53·15		+ 42·69		+ 35·40		+ 55·27		+ 96·33		+108·05	
V_a	− 24·44		− 25·07		− 25·76		− 26·00		− 26·48		− 27·29		− 27·99	
V_d	− ·22		− ·14		− ·17		− ·17		− ·20		− ·15		− ·18	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	+ 49·3		+ 27·7		+ 16·5		+ 9·0		+ 28·3		+ 68·6		+ 79·6	

MEASURES OF σ GEMINORUM—*Continued.*

λ	4144		4155		4162		4173		4177		4186		4196	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	....	......	....	......	+ 57·7	½	....	......	....	......	....	......	+ 94·2	½
4571	+ 66·2	¾	+ 44·6	1	56·0	1	+ 109·0	1	+ 114·9	¾	+ 110·9	1	99·5	½
4549	71·8	¾	41·3	1	48·6	1	103·4	½	114·7	½	93·4	½	85·9	1
4535	69·5	½	30·3	¾	46·3	½	101·9	1	115·7	1	102·8	1	88·0	1
4531	56·0	½	40·5	1	38·7	¼	113·9	¾	108·1	1¼	111·0	1	106·0	1
4522	....	......	51·3	1	46·4	1	107·9	1	116·1	¾	....	......	108·8	1
4494	64·1	½	44·4	¾	39·8	¾	100·8	½	108·5	½	128·8	½	108·5	½
4430	62·6	1	39·6	1	42·9	¾	92·6	1½	116·1	1	110·0	1½	105·4	1
4415	55·6	1	35·4	1	39·4	1	99·2	1	116·0	1½	110·5	1½	83·0	1
4404	58·1	1	40·9	½	50·0	1	87·4	¾	118·7	1	108·5	1	95·7	½
4340	88·5	¾	51·2	½	46·9	1	108·8	¾	105·7	1	118·9	½	91·4	½
4282	63·9	½	+ 39·7	½	59·0	¾	92·4	¾	+ 114·8	1½	111·7	1½	100·9	1
4271	+ 59·1	¾	....	......	+ 54·5	½	+ 104·0	1	....	......	+ 113·5	1	+ 105·7	½
Weighted mean	+ 64·68		+ 41·62		+ 48·26		+100·60		+113·72		+110·51		+ 97·55	
V_a	− 28·56		− 29·07		− 29·14		− 29·41		− 29·43		− 29·45		− 29·40	
V_d	− ·26		− ·27		− ·26		− ·25		− ·18		− ·16		− ·22	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	+ 35·6		+ 12·0		+ 18·6		+ 70·7		+ 83·8		+ 80·6		+ 67·6	

MEASURES OF σ GEMINORUM—*Continued.*

λ	4202		4211		4221		4228		4247		4253		4263	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	....	....	....	....	....	....	+ 46·4	¾	....	....	....	....	+ 76·8	½
4571	+ 62·2	½	+ 48·9	¾	+ 39·2	½	46·0	1	+ 51·4	1	+ 63·3	¾	80·7	1
4549	54·7	½	53·4	1	37·7	½	30·3	1	53·0	1	54·7	1	....	....
4535	51·0	¾	57·0	1¼	34·5	½	33·7	¾	46·9	½	55·7	1	76·0	1
4531	60·8	½	43·1	1	33·3	½	....	....	60·8	½	56·8	1	84·1	1
4522	66·2	½	52·0	½	48·5	½	....	....	66·3	½	70·9	½	91·8	½
4494	68·4	½	....	....	....	....	53·4	½	51·8	½	....	....	....	....
4430	47·7	1	49·3	1½	37·7	½	41·3	½	62·0	1	64·5	1	82·4	1
4415	59·5	1	47·7	1½	41·5	½	33·2	1	50·6	1	59·0	1¼	57·7	1
4404	55·2	¾	49·4	1	39·7	½	38·9	1	61·8	1	57·3	1	73·0	½
4340	64·8	½	52·8	¾	+ 33·2	½	42·3	½	46·9	½	71·4	¾	....	....
4282	51·8	1	51·6	1¼	....	....	37·1	1½	46·9	1	64·2	1¼	+ 77·1	½
4271	+ 62·8	½	+ 54·0	1	....	....	+ 44·7	½	+ 58·0	½	+ 58·3	½	....	....
Weighted mean	+ 57·32		+ 50·72		+ 38·38		+ 39·44		+ 54·56		+ 60·16		+ 75·86	
V_a	− 29·24		− 29·20		− 29·11		− 29·03		− 28·74		− 28·64		− 28·54	
V_d	− ·20		− ·17		− ·25		− ·22		− ·22		− ·16		− ·24	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	+ 27·6		+ 21·0		+ 8·8		+ 9·9		+ 25·3		+ 31·1		+ 46·8	

MEASURES OF σ GEMINORUM—*Concluded.*

λ	4271		4280		4283									
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4586	+ 120·1	½	......	......	......	......	......	......	......	......	......	......	......	......
4571	108·7	¾	+ 106·9	½	......	......	......	......	......	......	......	......	......	......
4549	78·8	¾	108·0	¾	+ 101·4	1	......	......	......	......	......	......	......	......
4535	86·2	¾	110·1	¾	82·4	1	......	......	......	......	......	......	......	......
4531	91·7	½	99·5	½	88·0	½	......	......	......	......	......	......	......	......
4522	104·1	½	119·7	¼	104·1	½	......	......	......	......	......	......	......	......
4494	......	......	......	......	92·5	½	......	......	......	......	......	......	......	......
4430	99·3	½	105·8	1	95·6	1¼	......	......	......	......	......	......	......	......
4415	101·4	¾	80·6	½	95·0	1¼	......	......	......	......	......	......	......	......
4404	102·7	½	94·0	1	94·7	1¼	......	......	......	......	......	......	......	......
4340	......	......	107·2	½	101·3	1	......	......	......	......	......	......	......	......
4282	+ 100·2	½	96·5	1½	94·6	1	......	......	......	......	......	......	......	......
4271	......	......	+ 101·4	¾	+ 107·9	¾	......	......	......	......	......	......	......	......
Weighted mean	+ 98·40		+101·40		+ 95·98									
V_a	− 28·24		− 27·45		− 27·27									
V_d	− ·19		− ·22		− ·21									
Curv.	− ·28		− ·28		− ·28		......	......	......	......	......	......	......	......
Radial Velocity	+ 69·7		+ 73·4		+ 68·2									

For convenience of reference the Lick observations are given here.

OBSERVATIONS OF σ GEMINORUM AT LICK OBSERVATORY.

Date.	Julian Date.	Phase.	Velocity.	Residual from Ottawa Curve.
1902 Mar. 16	2,415,825·7*	1·7	+ 74·	− 6·
1903 Jan. 12	6,127·7	9·6	12·	− 5·
Jan. 13	6,128·7	10·6	9·	− 4·
Feb. 15	6,161·7	4·4	+ 69·	+ 2·

* The decimal of a day is assumed.

A slight increase in the period with the introduction of a correction for possible systematic differences in the measures would cause the residuals from the curve to become very much smaller but the increase of period would affect our second observation making the residual, already large, much greater. Hence the period decided upon, 19·605 days, was an attempt to equalize these discrepancies.

With this period the observations were grouped, according to phase, into sixteen normal places, and weights assigned to the groups which were in general the sums of the weights of the individual plates.

NORMAL PLACES.

	Mean Phase	Mean Velocity	Weight	O–C		Mean Phase	Mean Velocity	Weight	O–C
1	1·379	+ 79·14	1·5	−1·45	9	10·381	+13·61	2·5	− ·61
2	2·457	77·90	2·5	−1·23	10	12·068	12·71	2·0	− ·05
3	3·407	73·70	2·0	− ·75	11	13·637	21·70	1·5	+2·09
4	4·521	67·90	1·5	+2·19	12	14·936	29·61	1·5	− ·80
5	5·470	55·77	1·5	− ·60	13	16·006	37·50	1·5	−4·10
6	6·844	43·07	1·0	+1·34	14	16·735	52·22	1·0	+2·49
7	7·933	30·88	1·5	+ ·12	15	18·370	68·35	2·0	+1·51
8	8·711	+24·01	1·5	+ ·02	16	19·505	+77·69	1·5	+2·12

The observations are well represented by a sine curve; the eccentricity is so small that it cannot be differentiated from zero by graphical methods, hence the values of ω and T are indeterminate in this way.

Recourse was had to the method of least-squares for finding the most probable values of the elements. Since the number of unknowns remained constant it was assumed that the elements which gave the least value for Σpvv would be the most probable. Several solutions were made using the following preliminary values:

$$P = 19\cdot605 \text{ days}$$
$$e = 0\cdot$$
$$\omega = 270°, 330°, 360°$$
$$T = \text{J. D. } 2{,}415{,}820\cdot752 \ldots\ldots\ldots 4\cdot019 \ldots\ldots\ldots 5\cdot653$$
$$\gamma = +\ 45\cdot75 \text{ km.}$$
$$K = 33\cdot75 \text{ km.}$$

Using the notation* of Lehmann-Filhés and adding a term with coefficient unity for the velocity of the system, observation equations were formed for each of these three sets of preliminary values. A previous solution with ω equal to 190° had given a negative value for the eccentricity showing that the major axis should be rotated in the neighbourhood of 90°. In each solution δT was considered $=0$ and substitutions were as follows:

$$x = \delta\gamma$$
$$y = \delta K$$
$$z = K.\delta e$$
$$u = K\cdot\delta\omega$$

*Astronomische Nachrichten 3242.

OBSERVATION EQUATIONS FOR σ GEMINORUM, ω =270°.

	Weight.	x	y	z	u	$-n$
1	2·0	1·000	−·980	−·394	+·201	− ·02=0
2	1·5	1·000	−·761	−·987	+·648	−1·64
3	1·5	1·000	−·434	−·782	+·901	+1·49
4	1·5	1·000	−·106	−·211	+·994	+4·67
5	1·0	1·000	+·127	+·252	+·992	−2·18
6	2·0	1·000	+·606	+·964	+·795	−2·13
7	1·5	1·000	+·850	+·896	+·527	−3·27
8	1·5	1·000	+·997	+·163	+·082	+ ·25
9	2·5	1·000	+·965	−·504	−·261	+ ·43
10	2·0	1·000	+·843	−·907	−·538	+ ·49
11	1·5	1·000	+·602	−·961	−·799	−1·85
12	1·5	1·000	+·335	−·631	−·942	+1·28
13	1·0	1·000	−·099	+·196	−·995	− ·65
14	1·5	1·000	−·433	+·781	−·901	+ ·25
15	1·5	1·000	−·642	+·985	−·767	+ ·07
16	2·5	1·000	−·943	+·626	−·332	+ ·30

whence the normal equations,

$$
\begin{aligned}
26\cdot500x + 1\cdot633y - 1\cdot041z - \cdot955u - 2\cdot450 &= 0 \\
14\cdot004y - 1\cdot864z - \cdot519u - 6\cdot492 &= 0 \\
13\cdot570z + \cdot467u - 9\cdot007 &= 0 \\
12\cdot486u - 1\cdot145 &= 0
\end{aligned}
$$

The solution of these gave as corrections,

$$
\begin{aligned}
\delta\gamma &= + \cdot09 \text{ km.} \\
\delta K &= + \cdot56 \text{ km.} \\
\delta e &= + \cdot022 \\
\delta\omega &= + 0^\circ\cdot17
\end{aligned}
$$

and a value of Σpvv for the normal places of 70·5.

OBSERVATION EQUATIONS FOR σ GEMINORUM, ω =360°.

	Weight	x	y	z	u	$-n$
1	2·0	1·000	−·980	+·919	+·201	− ·02=0
2	1·5	1·000	−·761	+·160	+·648	−1·64
3	1·5	1·000	−·434	−·623	+·901	+1·49
4	1·5	1·000	−·106	−·977	+·994	+4·67
5	1·0	1·000	+·127	−·968	+·992	−2·18
6	2·0	1·000	+·606	−·264	+·795	−2·13
7	1·5	1·000	+·850	+·443	+·527	−3·27
8	1·5	1·000	+·997	+·987	+·082	+ ·25
9	2·5	1·000	+·965	+·867	−·261	+ ·43
10	2·0	1·000	+·843	+·421	−·538	+ ·49
11	1·5	1·000	+·602	−·276	−·799	−1·85
12	1·5	1·000	+·335	−·776	−·942	+1·28
13	1·0	1·000	−·099	−·981	−·995	− ·65
14	1·5	1·000	−·433	−·625	−·901	+ ·25
15	1·5	1·000	−·642	−·175	−·767	+ ·07
16	2·5	1·000	−·943	+·780	−·332	+ ·30

whence the normal equations,

$$26{\cdot}500x + 1{\cdot}633y + 1{\cdot}528z - {\cdot}955u - 2{\cdot}450 = 0$$
$$14{\cdot}004y + 1{\cdot}171z - {\cdot}519u - 6{\cdot}492 = 0$$
$$12{\cdot}936z - {\cdot}900u - 5{\cdot}638 = 0$$
$$12{\cdot}486u - 1{\cdot}145 = 0$$

The solution of these gave as corrections,

$$\delta\gamma = +{\cdot}05 \text{ km.}$$
$$\delta K = +{\cdot}43 \text{ km.}$$
$$\delta e = +{\cdot}012$$
$$\delta\omega = +0^\circ{\cdot}24$$

and a value of Σpvv for the normal places of 73·8.

OBSERVATION EQUATIONS FOR σ GEMINORUM, ω =330°.

	Weight	x	y	z	u	$-n$
1	2·0	1·000	−·980	+·599	+·201	− ·02=0
2	1·5	1·000	−·761	−·355	+·648	−1·64
3	1·5	1·000	−·434	−·931	+·901	+1·49
4	1·5	1·000	−·106	−·952	+·994	+4·67
5	1·0	1·000	+·127	−·712	+·992	−2·18
6	2·0	1·000	+·606	+·253	+·795	−2·13
7	1·5	1·000	+·850	+·832	+·527	−3·27
8	1·5	1·000	+·997	+·936	+·082	+ ·25
9	2·5	1·000	+·965	+·496	−·261	+ ·43
10	2·0	1·000	+·843	−·089	−·538	+ ·49
11	1·5	1·000	+·602	−·720	−·799	−1·85
12	1·5	1·000	+·335	−·988	−·942	+1·28
13	1·0	1·000	−·099	−·751	−·995	− ·65
14	1·5	1·000	−·433	−·151	−·901	+ ·25
15	1·5	1·000	−·642	+·340	−·767	+ ·07
16	2·5	1·000	−·943	+·988	−·332	+ ·30

whence the normal equations,

$$
\begin{aligned}
26{\cdot}500x + 1{\cdot}633y + {\cdot}791z - {\cdot}955u - 2{\cdot}450 &= 0\\
14{\cdot}004y + {\cdot}081z - {\cdot}519u - 6{\cdot}492 &= 0\\
12{\cdot}637z - {\cdot}542u - 9{\cdot}401 &= 0\\
12{\cdot}486u - 1{\cdot}145 &= 0
\end{aligned}
$$

The solution of these gave as corrections,

$$
\begin{aligned}
\delta\gamma &= +{\cdot}05 \text{ km.}\\
\delta K &= +{\cdot}46 \text{ km.}\\
\delta e &= +{\cdot}022\\
\delta\omega &= +0^\circ{\cdot}25
\end{aligned}
$$

and a value of Σpvv for the normal places of 68·6.

The following table shows the main result of the solutions. For a circular orbit $\Sigma pvv = 79 \cdot 1$.

ω	δe	Σpvv
270°	·022	70·5
330°	·022	68·6
360°	·012	73·8

The values of the other elements varied but little in each solution. In none of the solutions did the residuals as obtained by computing directly and by substituting in the observation equations differ more than ·05 km. Though there is little to choose between the various cases it was decided to accept that one for which ω was equal to 330° as a preliminary value.

The resulting values of the elements with their probable errors are then as follows:

$$P = 19 \cdot 605 \text{ days.}$$
$$e = \cdot 022 \pm \cdot 018$$
$$\omega = 330^\circ\, 15' \pm 1^\circ\, 03'$$
$$K = 34 \cdot 21 \text{ km.} \pm \cdot 58 \text{ km.}$$
$$\gamma = + 45 \cdot 80 \text{ km.} \pm \cdot 42 \text{ km.}$$
$$T = \text{J. D. } 2{,}415{,}824 \cdot 019$$
$$A = 34 \cdot 86 \text{ km.}$$
$$B = 33 \cdot 56 \text{ km.}$$
$$a \sin i = 9{,}220{,}400 \text{ km.}$$

The curve shown represents these final values.

After the determination of the orbit was completed it occurred to the writer to test the effect on the orbital elements of a change in the wave-lengths of the lines used in obtaining the velocities. It was mentioned that thirteen of the earlier plates had been used to obtain wave-lengths for three lines which seemed to be blends of two or more separate lines and yet were among the best measurable. The entire thirty-eight plates were now considered and the average residual of each line from the mean of the plate was determined. The three previously mentioned and two others λ4531·202 and λ4404·927 gave negligible residuals; the others are as follows:

Wave-Length.	Residual.	Corresponding $d\lambda$	Corrected Wave-Length.
4586·163	−4·18 km.	+·064	4586·227
4571·763	−2·46 km.	+·037	4571·800
4549·766	+3·91 km.	−·059	4549·707
4535·965	+4·22 km.	−·064	4535·901
4522·855	−6·93 km.	+·105	4522·901
4415·293	+4·74 km.	−·070	4415·223
4340·634	−4·77 km.	+·069	4340·703
4271·760	−2·93 km.	+·047	4271·807

The necessary changes being made, new velocities were obtained for each plate, the average numerical difference in the results not exceeding 0·5 km. It seemed almost useless to pursue the subject further; nevertheless the observations were combined into the same grouping and a least-squares solution performed.

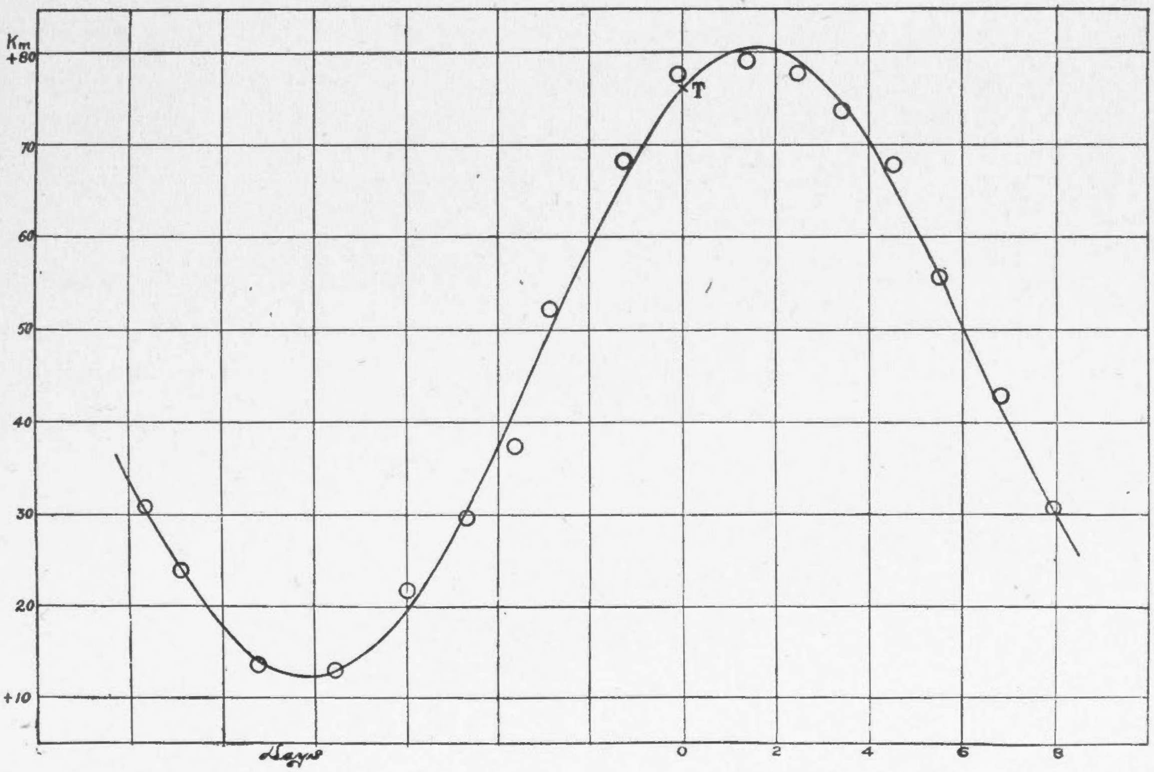
Without giving the observation and normal equations, as the results were not used, it will suffice to state the differences between the newly derived elements and those previously accepted where the preliminary value of ω was 330°.

Differences in γ = ·06 km.
" " K = ·07 km.
" " e = ·000
" " ω = 0°·22.

These differences being of an infinitesimal order would seem to show that the question of wave-length is not a vital one. Better agreement among the various lines will be secured by adopting an arbitrary set of wave-lengths but any resulting changes in the orbit will generally be small.

Though the results obtained from the revised system of wave-lengths have not been made use of in this case the extra labour is not necessarily valueless as the wave-lengths here determined for K-type stars will be useful for future work.

Dominion Observatory,
Ottawa,
June, 1911.



Velocity Curve of σ Geminorum.