The orbit of Bu. G. C. 8933 = β648

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COMMUNICATIONS FROM THE OBSERVATORY AT LEIDEN.

The Orbit of Bu. G. C. 8933 = β 648, by *W. H. van den Bos.*

R. A. 1900: $18^h53^m17^s$	mag.: 5·2 and 8·7
Decl. 1900: + 32°46′	parallax: 0″095
Boss P. G. C. 4815	prop. mot.: 0″236 in 132°8

From the measures to 1906 LOHSE derived a provisional orbit with a period of 50·85 years. AITKEN, from the large residual in angle between this orbit and his measures in 1912, concludes that the period is too long, and reduces it to 45·85 years. At present the measures indicate that LOHSE's period is even too short.

The observations from 1878 to 1922 determine an arc of a little over 270 degrees, and the present orbit may therefore be considered a good approximation.

The position angles, corrected for precession to 1925, and the distances were plotted against the time, and smooth curves drawn. In testing these curves for the law of areas pretty large discrepancies were found. It is a well known fact, that the measures of close unequal pairs are affected by considerable systematic errors. Therefore, paying no heed to a possible perturbation, the curves were somewhat changed, so as to satisfy the law of areas, and eight sets of elements were computed, by ZWIERS' semi-graphical and THIELE's analytical method.

The following set of elements (THIELE's notation) agrees best of all with the measures:

μ	0·11040	a	0″682
e	0·227	A	93°61
T	1911·78	b	1″131
		B	40°61

An ephemeris is most easily computed by these elements, taking the excentric anomaly as the argument; we have:

$$\rho \cos \theta = -0''0430 (\cos E - 0·227) + 0''8584 \sin E$$
$$\rho \sin \theta = +0''6810 (\cos E - 0·227) + 0''7360 \sin E$$
$$t = 1911·78 + \frac{E - 0·227 \sin E}{0·11040}$$

E being expressed in radians.

In CAMPBELL'S notation the elements are:

P	56·91 years	a	1″247
n	− 6°326	i	± 66°02
e	0·227	ω	293°61
T	1911·78	☊	50°69

motion retrograde, angles for 1925.

The hypothetical parallax (sum of the masses equal to the sun's mass) is 0″084.

The parallax has been determined at the Allegheny Observatory, the Sproul Observatory, by FLINT and by JEWDOKIMOW; the mean result is given in Mount Wilson Contributions Nr. 199 as 0″095, together with the spectroscopic parallax 0″083, in excellent agreement with the hypothetical parallax 0″084. If the parallax is 0″095, the sum of the masses is 0.69 ☉.

By KAPTEYN and VAN RHIJN's formula:

$$\log p_{m,\mu} = -0·690 - 0·0713\, m + 0·645 \log \mu$$

we have $p_{m,\mu}$ = 0″032, not in good agreement with the other parallaxes.

The relative radial velocity of the companion may be computed by the formula:

$$\frac{dz}{dt} = \pm 6·42\ [0·091 + \cos (v + \omega)]\ \text{km/sec},$$

again supposing p = 0″095, the positive sign applying to the case $\sin i > 0$.

We have: 1922·6	± 6·27	K. M. per sec.
1934·5	± 0.59	„ „ „
1954·6	± 5·84	„ „ „

Putting $k = \frac{\text{mass of companion}}{\text{sum of the masses}}$, and supposing the radial velocity of the primary (spectr. G1, mag. 5·2) determined this year and again in 1934, the difference between the two determinations being a km./sec., we should have $k = \frac{a}{5.68}$, and the sign of i should be determined. A new determination in 1954 (companion near node), giving a difference with 1922 of b km./sec., should give $k = \frac{b}{12{\cdot}11}$.

If the ratio of the masses has been determined by micrometer measures of independent stars, or by measures on photographic plates, the determination of the radial velocity gives an independent value for the parallax.

For the purpose of determining the mass-ratio, ABETTI connects two faint stars:

AB,C (mag 12·1)	1912·62	285°17	54″14	4*n*	15 inch
AB,D („ 12.2)	1912·62	187°35	93″30	„	„	„

I have tried to measure those stars and two others, but with an aperture of 10½ inch and the moist Dutch atmosfere the measures, especially of distance, are unreliable. The star *D* is nearly invisible in my telescope. ABETTI points on the „mass of light" of the system *AB*, whereas I have pointed on *A*. My measures are:

A and *C*				mag *C*
1921·531	287°18	55″26		11·5
·534	286°77	55″37		12·0
·645	286°97	54″58		12·0
1921·57	286°97	55″07	3*n*	11·8

A and *D*				mag *D*
1921·534	188°57	(90″05)		13·0
·677	189°02	(92″56)		12·8
1921·61	188°80	.....	2*n*	12·9

A and *E*				mag *E*
1921·531	319°95	101″92	1*n*	11·3

A and *F*				mag *F*
1921·531	88°48	100″51		11·2
·534	88°57	100″27		11·8
1921·53	88°52	100″39	2*n*	11·5

The pair has been observed on three nights by Mr. C. H. HINS, Observator at Leiden Observatory, with the meridian circle; a good proper motion may be derived to simplify the determination of the mass-ratio.

Measures and residuals.

The columns give: time of observation, observer (usual symbol, T = TARRANT, Wi = H. C. WILSON, Dy = DYSON, L = LEWIS, B = BRYANT, WB = BOWYER, Lv = LEAVENWORTH, Bn = S. J. BROWN, Lo = LOHSE, Dl = DOOLITTLE, Bs = VAN BIESBROECK, Br = F. L. BROWN, vB = VAN DEN BOS), aperture of the telescope in inches, number of nights (* denoting that the number of distance measures is one less), observed position angle reduced to 1925, observed distance, observed minus computed angle, same multiplied by computed distance and divided by 57·3, and observed minus computed distance.

t	Obs.	Apert.	n	θ obs	ρ obs	O–C θ	O–C θ (arc)	O–C ρ
				°	″	°	″	″
1878·47	β	18½	2	312·2	0·60	+ 0·1	+ ·001	– ·01
79·47	β	18½	1	298·0	0·66	– 4·1	– ·047	+ ·01
83·64	HΣ	30	2	273·1	1·00	+ 1·1	+ ·017	+ ·14
85·61	HΣ	30	1	257·7	1·19	– 5·0	– ·086	+ ·21
89·87	Sp	18	1	247·2	1·04	– 1·7	– ·036	– ·17
91·33	β	36	3	247·2	1·26	+ 2·0	+ ·044	– ·01
·63	T	10¼	3	249·4	1·10	+ 4·9	+ ·110	– ·18
·84	HΣ	30	1	241·2	1·37	– 2·8	– ·063	+ ·08
92·38	β	36	5	245·4	1·29	+ 2·6	+ ·059	– ·01
·70	Sp	18	4	241·7	1·21	– 0·4	– ·009	– ·10
93·43	Wi	16	2	245·9	1·26	+ 5·4	+ ·127	– ·06
·49	Lv	16	2	240·0	1·40	– 0·3	– ·007	+ ·07
·78	Sp	18	1	240·6	1·12	+ 0·9	+ ·021	– ·21
94·79	Sp	18	4*	237·7	1·22	+ 0·3	+ ·007	– ·12
95·90	L	28	3	237·7	1·49	+ 2·7	+ ·063	+ ·15
96·45	β	40	1	238·5	1·62	+ 4·7	+ ·109	+ ·29
·47	Dy	28	1	224·9	1·33	– 8·9	– ·206	·00
·49	A	12	3	231·1	1·34	– 2·6	– ·060	+ ·01
·57	Lv	10½	3	233·2	1·45	– 0.3	– ·007	+ ·12

t	Obs.	Apert.	*n*	θ obs	ρ obs	O–C θ	O–C θ (arc)	O–C ρ
				°	″	°	″	″
1896·62	L	28	4	233·0	1·27	– 0·4	– ·009	– ·06
·77	Sp	18	3	232·4	1·29	– 0·7	– ·011	– ·04
97·44	WB	28	1	228·9	1·36	– 2·7	– ·062	+ ·05
·54	L	28	4	231·0	1·14	– 0·4	– ·009	– ·17
·66	C	15½	3	234·7	1·28	+ 3·6	+ ·082	– ·03
·70	A	12	3	229·6	1·34	– 1·4	– ·032	+ ·03
·74	Bn	26	2	235·3	1·40	+ 4·3	+ ·098	+ ·09
98·40	A	12	3	227·5	1·33	– 1·8	– ·040	+ ·05
·54	L	28	1	230·0	1·50	+ 1·0	+ ·022	+ ·22
·65	C	15½	3	230·1	1·33	+ 1·3	+ ·029	+ ·05
·67	B	28	2	228·1	1·24	– 0·6	– ·013	– ·03
·92	β	40	4	228·0	1.21	– 0·1	– ·002	– ·05
99·34	A	12	3	223·1	1·26	– 4·0	– ·087	+ ·01
·44	L	28	1	222·2	0·96	– 4·6	– ·100	– ·28
·56	C	15½	1	221·8	1·24	– 4·7	– ·102	+ ·01
1900·45	A	12	2	222·0	1·12	– 2·1	– ·043	– ·06
·54	A	36	1	222·1	1·21	– 1·7	– ·035	+ ·03
·54	Lo	11	2	221·0	1·34	– 2·8	– ·057	+ ·16
·62	L	28	2	224·0	1·17	+ 0·7	+ ·014	·00
·73	β	40	4	222·1	1·27	– 1·2	– ·024	+ ·10
·73	B	28	1	228·7	1·10	+ 5·4	+ ·110	– ·06
01·57	Dl	18	5	221·5	1·23	+ 0·7	+ ·013	+ ·13
·61	L	28	2	219·8	1·11	– 0·9	– ·017	+ ·01
·62	A	36	3	218·8	1·07	– 1·9	– ·036	– ·03
·74	C	15½	3	218·9	1·12	– 1·3	– ·025	+ ·03
02·32	A	36	1	216·5	0·94	– 1·7	– ·031	– ·10
·49	A	12	2	215·1	1·08	– 2·5	– ·045	+ ·05
·63	L	28	1	217·1	1·00	0·0	·000	– ·02
·76	C	15½	1	217·0	1·18	+ 0·3	+ ·005	+ ·17
03·59	A	12	1	208·2	0·80	– 5·0	– ·081	– ·13
·69	C	15½	3	213·9	1·09	+ 1·2	+ ·019	+ ·17
·70	Lo	11	2	208·9	0·90	– 3·8	– ·061	– ·02
·95	Bs	15	3	212·1	1·27	+ 0·6	+ ·009	+ ·38
04·45	A	36	1	202·1	0·96	– 6·8	– ·099	+ ·12
·64	Lo	11	5*	208·0	0·88	+ 0·2	+ ·003	+ ·06
05·50	A	36	3	200·8	0·65	– 1·3	– ·016	– ·07
·52	Lo	11	4	202·1	0·65	+ 0·1	+ ·001	– ·07
06·37	A	36	2	190·3	0·58	– 4·3	– ·047	– ·05
·52	Lo	11	5*	197·1	0·61	+ 3·5	+ ·037	·00
·55	C	15½	1	189·6	0·47	– 3·2	– ·034	– ·14
07·56	A	36	1	182·6	0·46	+ 2·7	+ ·024	– ·04
·69	L	28	1	178·9	0·42	+ 0·9	+ ·008	– ·07
·73	WB	28	2	182·1	0·51	+ 4·7	+ ·040	+ ·02
08.37	Bs	15	2	167·3	0·41	+ 1·9	+ ·015	– ·03
·45	A	36	1	175·2	0·35	+ 11·4	+ ·087	– ·08
·83	A	36	3*	158·1	0·38	+ 2·4	+ ·017	– ·03
09·64	Bs	15	2	150·2	0·45	+ 14·0	+ ·098	+ ·05
·67	A	36	2*	140·4	0·31	+ 4·9	+ ·034	– ·09
10·81	WB	28	1	115·3	0·39	+ 5·5	+ ·043	– ·06

t	Obs.	Apert.	n	θ obs	ρ obs	O–C θ	O–C θ (arc)	O–C ρ
				°	″	°	″	″
1911·51	A	36	1	98·3	0·35	+ 0·6	+ ·005	– ·15
·54	Bs	15	4	99·6	0·42	+ 2·3	+ ·020	– ·08
12·65	A	36	3	80·4	0·52	– 2·8	– ·030	– ·10
·74	Bs	15	1	90·7	0·39	+ 8·3	+ ·091	– ·24
·76	WB	28	1	83·7	0·42	+ 1·5	+ ·016	– ·21
13·71	WB	28	3	64·1	0·60	– 10·2	– ·130	– ·13
14·49	Bs	15	2	74·1	0·58	+ 5·2	+ ·073	– ·23
·49	A	36	2	68·1	0·68	– 0·8	– ·011	– ·13
15·92*)	Bs	40	3	62·3	0·88	+ 0·8	+ ·013	– ·05
16·53	Br	18½	3	60·3	0·97	+ 1·0	+ ·017	·00
·68	A	36	3*	56·4	0·80	– 1·9	– ·033	– ·18
17·60*)	Bs	40	3	55.6	0·99	+ 0·8	+ ·014	– ·05
18·50*)	Bs	40	3	53·8	0·96	+ 2·2	+ ·041	– ·11
·64	A	36	2	49·2	0·95	– 1·9	– ·036	– ·13
19·60	Lv	40	3	52·1	1·38	+ 4·1	+ ·079	+ ·28
·63	Lv	12	3*	49·6	1·35	+ 1·7	+ ·033	+ ·25
·71	Lv	10½	5	46·5	1·13	– 1·1	– ·021	+ ·03
20·47	A	36	4	45·4	1·16	0·0	·000	+ ·05
·65*)	Bs	40	3	46·9	1·07	+ 2·2	+ ·043	– ·04
·76	Lv	10½	6	43·8	1·01	– 0·5	– ·010	– ·10
21.45	vB	10½	4	43·4	1·13	+ 1·2	+ ·023	+ ·02
·77	A	36	3	39·7	1·07	– 1·4	– ·027	– ·03

The unpublished measures by Prof. AITKEN and Prof. VAN BIESBROECK*) were kindly communicated by them at my request.

As the pair has been abundantly observed and the measures cover an arc of 270 degrees, it may be justified to treat the residuals somewhat more in detail. The most striking features, which are easily seen from the curves, are:

1. The observed angles have a tendency to be greater than the computed in the period 1890-96, smaller 1899-1905, and again greater 1907-10, while in the remaining years there is no evidence of systematic deviation. If these deviations are real, which is not certain in consequence of the large differences between the measures by different observers, they may be due to three causes, viz.:

a. defects in the elements, which will become apparent from the observations in the next ten or twenty years.

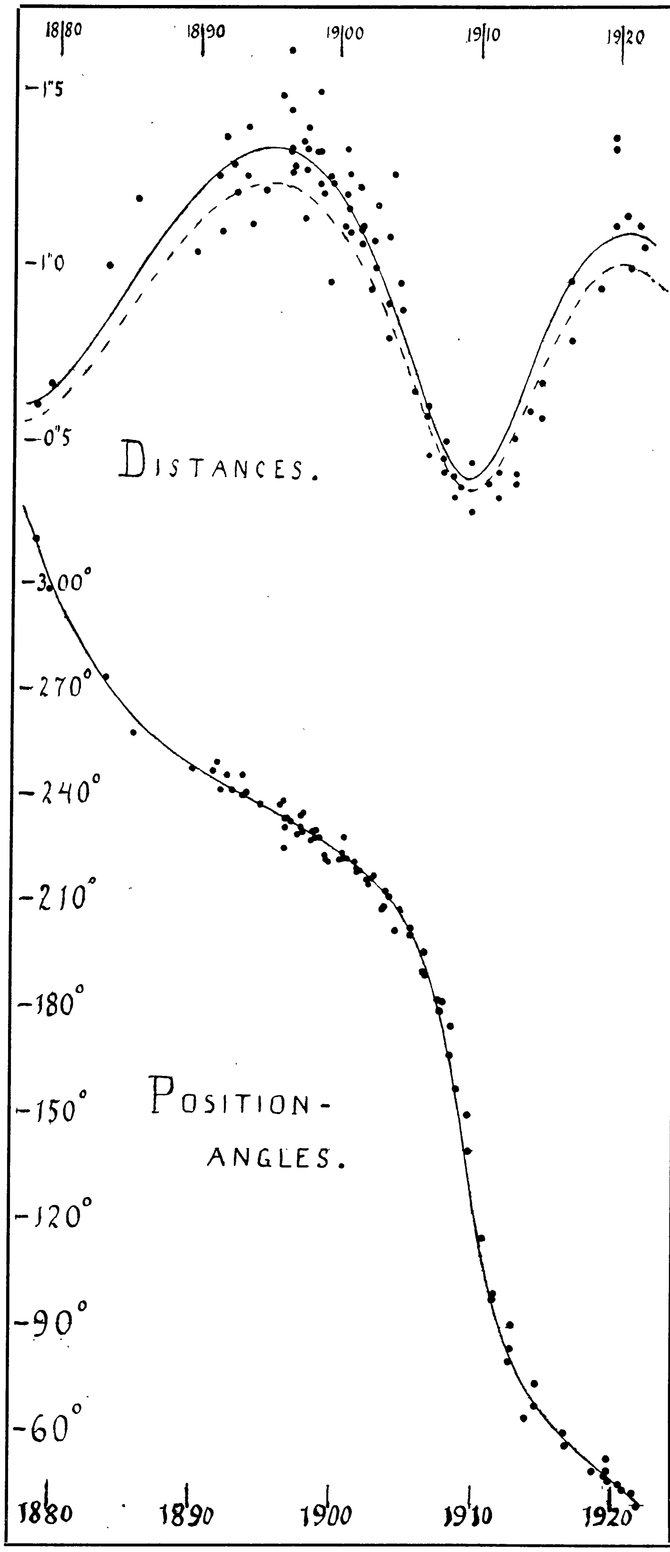
b. a real perturbation.

c. systematic errors of „the mean observer" depending on the position angle or rather on the angle which the line joining the two stars makes with a horizontal line. In this case the use of a reversing prism (BOSLER and SALET's method) may be an improvement. VAN BIESBROECK's later measures and my own have been made in this manner.

*) The observations by VAN BIESBROECK of 1915—20 have been received when this paper was already in print, and have not been used in the derivation of the orbit and the discussions.

2. The observed distances fall short of the computed in the period 1905-15, where, from experience with similar pairs, we should expect them on the contrary to be too large. I have tried to remedy this, but then the agreement of the position angles was totally disturbed. A change of the semi-axis major by 7½ %, indicated in the diagram by the broken line, makes nearly all the measured distances too large in the periods 1878-1905 and 1915-22, without entirely removing the difficulty in the remaining period. Considering the angles as far more trustworthy than the distances, I have paid no further heed to this defect. Mutatis mutandis the causes *a*, *b*, *c*, cited under **1** apply here also.

3. The residuals in angle, after multiplication by the factor $\frac{\rho_c}{57{\cdot}3}$ (last column but one), can be compared with those in distance. It is easily seen that the angles are far more accurate than the distances, a well known fact. The mean error of a single night's measure, computed from the residuals, is ± 0″077 in angle and ± 0″18 in distance. For some observers, whose residuals in distance have a marked systematic character (HΣ and Sp), the mean error computed



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from their residuals will be too large, but in general the errors are purely accidental.

It has been frequently remarked, that in measures of pairs of this type the distances observed with small apertures are systematically greater than the observations of the large refractors. I have combined the instruments used in four groups:

Group I: apertures from 10 up to 15 inches, 59 nights in angle and 56 in distance with 6 different telescopes by 5 different observers,

Group II: 15 to 20 inch, 57, 56 nights, 6 instruments, 8 observers,

Group III: 26 inch (Washington), 28 inch (Greenwich), 30 inch (Pulkowa), 37 nights, 6 observers,

Group IV: 36 and 40 inch, 56, 54 nights, 3 observers.

Then we have the following table, the columns giving respectively group, aperture, average residual in distance, mean error of a single night's distance, and mean error of a single night's angle:

Group	aperture	aver. res. θ	*m. e.* ρ	*m. e.* θ
		"	"	"
I	10–15	+0·006	±0·16	±0·084
II	15–20	+0·004	±0·22	±0·071
III	20–30	−0·015	±0·16	±0·092
IV	30–40	−0·007	±0·17	±0·068

So far as this pair is concerned, the systematic difference between small and large refractors is negligible. As to accuracy in distance measures, the unexpected fact is clearly shown, that the large refractors are not superior to the smaller ones. The accuracy of the measures of position angle appears to increase slowly with the aperture. We may perhaps conclude, that the powerful instruments, which are in use for double star work, should take only the narrow and the faint pairs, which are too difficult for moderate apertures.

Ephemeris.

t	*E*	θ (1925)	ρ
	°	°	"
1920·33	+ 66	45·71	1·112
·76	69	44·28	1·112
21·21	72	42·95	1·109
·65	75	41·51	1·105
22·10	78	40·10	1·098
·56	81	38·60	1·088
23·01	84	37·04	1·076
·48	87	35·42	1·063
·95	90	33·75	1·045
24·42	93	32·01	1·026
·92	96	30·20	1·005
25·40	99	28·28	0·981
·89	102	26·24	0.957
26·40	105	24·04	0·931