Measures of double stars on photographic plates taken by W. J. Luyten

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Measures of double stars on photographic plates taken by W. J. Luyten,

by *W. H. van den Bos.*

With the photographic refractor of 33 cm aperture and 524 cm focal length Dr. LUYTEN has taken a series of 54 plates of double stars in the periods February 6 to June 9, 1920 and October 21, 1920 to January 16, 1921. The programme chiefly consisted of faint stars with small difference in brightness between the components. No other precautions against magnitude equation have been taken.

In distinction to the work of HERTZSPRUNG*) and MÜNCH at Potsdam, in the visual focus of a visual refractor, the ordinary photographic measures of double stars may at the greater zenith distances be sensibly affected by atmospheric dispersion, in case of a difference in colour of the components. It is therefore advisable to restrict measures of this kind to small zenith distances, or to double stars with components of equal colour.

The photographic effects mentioned by HERTZSPRUNG (*l. c.* p. 14) may appear at distances below 6″ with a focal length of 5 m. Several objects with smaller distances have been observed to test these effects, and to determine at what distance the results will be safe.

For the determination of the parallel sometimes a sufficiently bright star was allowed to trail over the plate, but more often the double star itself was moved to the following side of the plate, and after an exposure had been taken the driving clock was stopped until the star had reached the preceding side, after which a second exposure was made. By noting the times when the clock is stopped and when the star passes the thread in the field of view of the guiding telescope, the two exposures are put symmetrically to the middle of the plate, the effect of the curvature of the trail thus being eliminated.

All the plates have been taken in the position „guiding telescope north" of the instrument, which has the form known as the English equatorial, and at the same reading for focus, viz: 20·2 mm. The plates were Ilford Monarch 9 × 12 cm, with the longer side in the direction of declination; the trail exposures are some 7 or 8 cm apart.

The scale of the plates has been determined by LUYTEN from various large distances, and by the writer from differences in declination of stars in the Hyades*):

LUYTEN	1 mm = 39″·366 ± 0″·01	(mean error)
VAN DEN BOS	39″·368 ± 0″·008	„ „

The best type of instrument for measuring double star plates is one in which the plate is moved by the measuring screw, and the microscope serves only to point on the star. No such instrument being at hand in Leiden, the plates were measured by the writer at Potsdam, with the instrument described by HERTZSPRUNG (*l.c.* p. 25). We are indebted to Director H. LUDENDORFF for his permission to use this instrument.

The measures, comprising about 13000 single settings in all, have been made from November 15 to December 12, 1921. In general a plate contains 3 or 4 different objects, the number of exposures of each being 10 to 15, sometimes more, seldom less. There are in all 142 observations of 68 pairs. A few plates have not been measured because of insufficient conditions (images hazy and very irregular).

The relative position of the components was measured in rectangular coordinates $\Delta\alpha \cos \delta$ and $\Delta\delta$, each coordinate in two positions of the plate, film up and film down (through the glass), to eliminate some of the systematic errors of measurement. The best part of the screw, between divisions 6 and 13, has always been used. From a number of large, well determined distances the scale value on this part was found to be:

1 double-revolution = 39″·379 ± 0″·008 (mean error).

This value has been used throughout.

The power of the microscope was 180 or 130 in most cases, and 25 for the wide pairs. Bad images have been rejected beforehand. Only one setting was made on the same image in every position of the plate.

*) *Publikationen des Astrophysikalischen Observatoriums zu Potsdam* Nr. 75, Bd XXIV.

*) *B. A. N.* 22.

The mean error of the single exposure (one setting on each component), determined by means of the deviations of the separate exposures on the same plate from their mean, i. e. without regard to a possible plate error, ranges from ± 0″·05 to ± 0″·31, the median value being ± 0″·13 in both coordinates.

For a number of plates of different quality the difference of the two deviations in $\Delta\delta$ of the same exposure in the two positions film up and film down was determined to get an idea of the mean error of measurement. As $\Delta\delta$ is already the difference of the settings on two images, the mean error of the difference: deviation $\Delta\delta$(up)—deviation $\Delta\delta$(down) is twice the mean error of a single setting of the thread on an image. The latter quantity was found to be: ± 1·2 μ for a good, ± 1·9 μ for a normal, and ± 3·0 μ for a bad plate, or in seconds of arc ± 0″·047, ± 0″·075 and ± 0″·118 respectively. Multiplying these quantities by $\sqrt{2}$, we have for the mean error of measurement of the single exposure: ± 0″·066, ± 0″·106 and ± 0″·166 respectively. The total mean error for the same groups being ± 0″·09, ± 0″·15 and ± 0″·25, we get for the mean error inherent to the images ± 0″·06, ± 0″·11 and ± 0″·19, i. e. sensibly equal to the error due to measurement for the good and normal, and larger for the bad plates (compare HERTZSPRUNG, *l.c.* p. 27). Measuring the plate in two positions should therefore give the mean errors ± 0″·08, ± 0″·13 and ± 0″·22 for the three groups. The gain in accuracy by remeasuring the same plate will not pay for the additional labour.

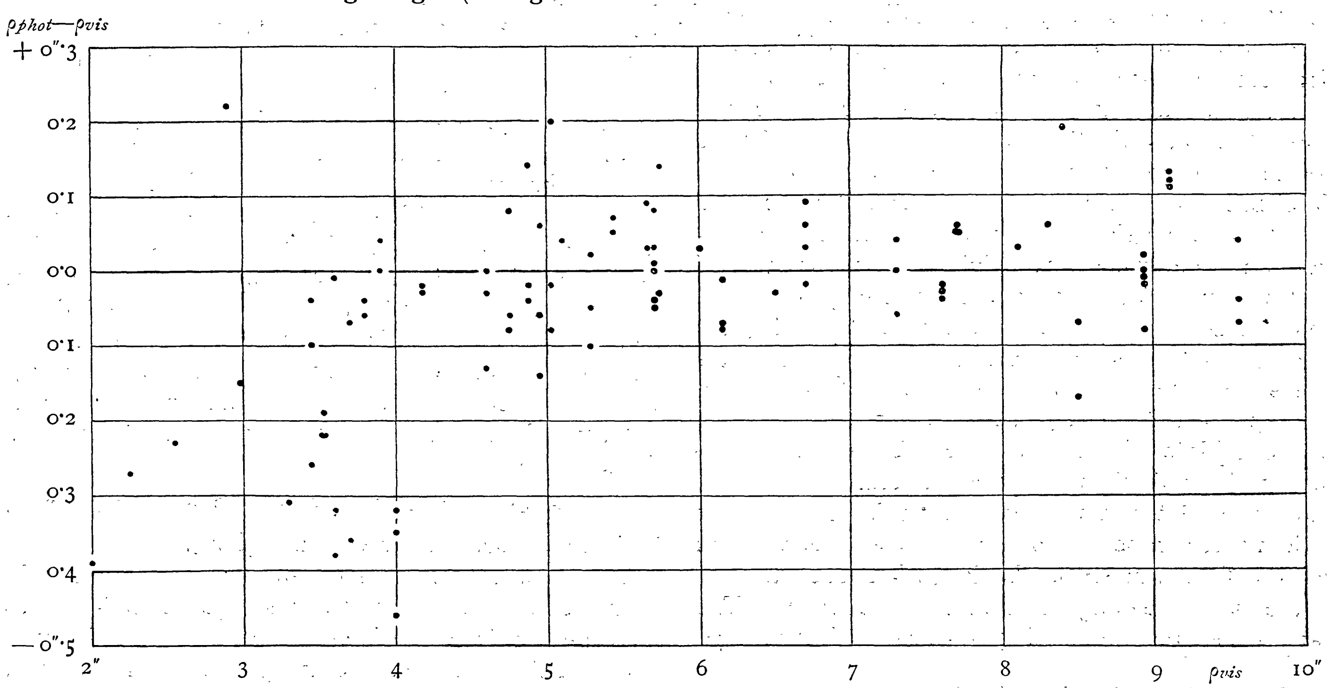
The mean error of a single night (taking a normal plate containing 12 exposures of the same object) will be ± 0″·038, if the plate error may be neglected.

Because of the photographic effects acting in the distance only, the rectangular coordinates were transformed into position angle and distance for each plate separately. From the results the mean error of the single plate was computed for the double stars which occur on 3 or more plates.

$\rho > 6''$	m.e. of single plate	in θ, reduced to arc:	± 0″·037
		in ρ	± 0″·034
$\rho < 6''$	" " " "	in θ, " " "	± 0″·051
		in ρ	± 0″·096

For the wider pairs there is therefore no trace of plate error, while for the close pairs the distance is much more uncertain than the position angle (photographic effects). For the pairs with distances below 10″ the best visual distance has been derived, and the difference $\rho_{\text{phot}} - \rho_{\text{vis}}$ plotted against ρ_{vis}. The accompanying diagram shows that the photographic effect is insensible in all distances > 5″, and that distances < 4″ are uncertain and on the average too small. It was noticed that the better exposures gave the larger distances (compare HERTZSPRUNG, *l.c.* p. 15). An example of the distance coming out too large is given by Castor, where 5″·24 instead of 5″·04 is found. This is probably due to the Eberhard effect, local exhaustion of the developer in the region between the two (overexposed) components.

The total weight of all the plates is 82000 (seconds of arc)$^{-2}$ in θ and 77000 in ρ, the greatest part of which falls on the stars with distances > 6″.



The following table gives the result of the measures; the columns give respectively the number in BURNHAM's General Catalogue, the star's name, the magnitudes taken from the G.C., the date, $\Delta\alpha \cos\delta$, $\Delta\delta$, mean error of single exposure in $\Delta\alpha \cos\delta$ and $\Delta\delta$, number of exposures measured, position angle, distance and number of nights. A bracketed number refers to the notes at the end of the table.

G. C.	Name		mag.		1920 +	Δα cos δ	Δδ	m. e. of 1 exp. Δα cos δ	m. e. of 1 exp. Δδ	exp.	θ	ρ	n.	
					y	″	″	″	″		°	″		
37	Σ	3	7.5	8.5	0.920 1.036	4.962 4.792	0.606 0.524	± .106 .150	± .079 .114	11 10	83.0 83.8	5.00 4.82		
					0.978						83.4	4.91	2	
73	Σ	9	8.5	8.5	0.920 1.036 1.042	4.970 4.871 4.934	19.390 19.374 19.371	.118 .122 .134	.087 .075 .091	10 9 10	345.62 345.89 345.71	20.02 19.98 19.99		
					0.999						345.74	20.00	3	(1)
85	Kr.	3	9	9	0.920 1.036 1.042	2.237 2.284 2.241	2.441 2.441 2.441	.106 .071 .162	.102 .110 .189	6 6 10	42.5 43.1 42.6	3.31 3.34 3.31		
					0.999						42.7	3.32	3	(2)
102	Σ	16	7.7	9.0	0.920 1.036 1.042	3.587 3.548 3.540	4.489 4.454 4.446	.095 .142 .118	.095 .095 .130	6 10 10	38.6 38.5 38.5	5.75 5.69 5.69		
					0.999						38.6	5.71	3	
114	Weisse	1	8.0	8.2	0.920 1.036 1.042	5.096 4.989 4.970	1.489 1.595 1.469	.079 .205 .217	.079 .252 .134	10 11 10	106.3 107.7 106.5	5.31 5.24 5.19		
					0.999						106.8	5.25	3	
448	Σ	65	8.0	8.0	0.997	1.953	2.434	.154	.146	10	38.7	3.12	1	
1396	Σ	297	8.0	8.3	1.042	15.614	2.134	.126	.099	15	277.8	15.76	1	
1415	Σ	301	7.3	8.3	1.042	2.292	7.856	.110	.110	14	16.3	8.18	1	(3)
4122	Σ	1110	2.7	3.7	0.099	3.068	4.245	.208	.177	36	215.9	5.24	1	
4497	Σ	1200	8.5	8.5	0.222	0.043	8.356	.096	.088	11	179.7	8.36	1	(4)
4595	Espin	18	8.5	9.2	0.222	10.160	6.990	.102	.126	4	235.5	12.33	1	
4798	Σ	1282	7.0	7.0	0.222 0.241	3.603 3.312	0.465 0.449	.067 .193	.099 .114	10 10	277.4 277.7	3.63 3.34		
					0.231						277.5	3.53	2	(5)
4928	Σ	1309	8.0	8.3	0.241	11.652	0.740	.154	.158	10	273.6	11.68	1	(6)
4972	Σ	1321	7.4	7.4	0.222	17.689	6.454	.142	.114	12	70.0	18.83	1	
5003	Σ	1332	7.2	7.5	0.222 0.241	2.217 2.236	5.332 5.257	.063 .197	0.47 .193	11 10	22.6 23.0	5.78 5.71		
					0.231						22.8	5.75	2	(7)
5188	Σ	1376	8.2	8.2	0.241	3.851	3.324	.225	.244	10	131.5	5.14	1	(8)
5468	Σ	1443	9.0	9.0	0.241	1.615	4.560	.170	.276	10	160.5	4.84	1	(9)
5901	Σ	1570	8.3	8.8	0.304 0.310	8.183 8.163	7.151 7.124	.099 .091	.126 .067	9 9	48.9 48.9	10.87 10.83		
					0.307						48.9	10.85	2	
5944	Σ	1575	7.0	8.0	0.310	15.255	26.506	.095	.110	13	209.92	30.70	1	
5960	OΣ App	112	7.8	8.1	0.310	42.624	59.628	.126	.102	21	35.56	73.30	1	(10)

G. C.	Name	mag.		1920 +	Δα cos δ	Δδ	m. e. of 1 exp. Δα cos δ	m. e. of 1 exp. Δδ	exp.	θ	ρ	n.
				y	″	″	″	″		°	″	
5993	OΣ App 114	7.5	8.0	0.304	85.897	12.562	± .166	± .130	11	81.68	86.81	1
6018	Σ 1596	6.0	7.5	0.304	3.178	1.969	0.83	.130	10	238.1	3.74	
				0.310	3.174	2.020	.091	.095	20	237.5	3.76	
				0.307						237.8	3.75	2
6025	Σ 1600	7.0	8.0	0.310	7.754	0.362	.122	.122	10	92.7	7.76	
				0.362	7.734	0.433	.118	.150	10	93.2	7.75	
				0.367	7.738	0.358	.087	.102	14	92.6	7.75	
				0.346						92.8	7.75	3 (11)
6040	Σ 1603	6.9	7.3	0.310	22.143	3.107	.075	.087	10	82.01	22.35	
				0.362	22.127	3.131	.126	.134	15	81.95	22.35	
				0.367	22.119	3.154	.182	.150	14	81.94	22.34	
				0.346						81.97	22.35	3 (12)
6134	Σ 1633	7.1	7.2	0.304	8.120	3.792	.095	.083	20	245.0	8.96	
				0.310	8.108	3.761	.099	.071	13	245.1	8.94	
				0.359	8.120	3.773	.106	.110	25	245.1	8.95	
				0.362	8.140	3.780	.102	.091	24	245.1	8.98	
				0.367	8.053	3.745	.130	.130	20	245.1	8.88	
				0.340						245.1	8.94	5
6166	Σ 1642	8.0	8.8	0.304	0.016	2.315	.114	.130	9	179.6	2.32	1
6179	Σ 1645	7.0	7.5	0.304	3.690	9.451	.067	.110	10	158.7	10.15	1
6212	Σ 1657	4.7	6.2	0.304	20.217	0.386	.091	.118	27	271.09	20.22	
				0.310	20.182	0.354	.118	.071	23	271.01	20.19	
				0.359	20.276	0.398	.150	.150	25	271.12	20.28	
				0.362	20.276	0.390	.079	.095	22	271.10	20.28	
				0.367	20.205	0.339	.158	.118	20	270.96	20.21	
				0.340						271.06	20.24	5
6243	Σ 1670	3.0	3.0	0.211	3.702	4.757	.095	.099	12	322.1	6.03	1
6289	Σ 1685	6.8	7.3	0.310	5.797	14.822	.067	.099	10	201.4	15.92	
				0.362	5.789	14.850	.205	.166	15	201.3	15.94	
				0.367	5.789	14.838	.118	.158	8	201.3	15.93	
				0.346						201.3	15.93	3
6321	OΣ 257	7.5	8.2	0.367	1.685	12.798	.162	.180	10	352.5	12.91	
				0.386	1.662	12.885	.146	.154	9	352.6	12.99	
				0.377						352.6	12.95	2
6512	OΣ 268 rej.	7.0	7.4	0.367	69.303	14.456	.185	.185	25	258.21	70.80	
				0.378	69.283	14.472	.170	.166	17	258.20	70.78	
				0.386	69.248	14.602	.146	.185	12	258.09	70.77	
				0.377						258.17	70.78	3 (13)
6527	Σ 1758	8.0	8.2	0.362	2.942	1.957	.158	.150	10	303.6	3.54	
				0.367	3.099	1.989	.091	.114	12	302.7	3.68	
				0.378	3.072	1.961	.122	.142	10	302.6	3.65	
				0.370						302.8	3.64	3 (14)
6536	Σ 1760	8.0	8.0	0.367	7.852	3.761	.095	.126	10	64.4	8.71	
				0.378	7.860	3.800	.146	.102	13	64.2	8.73	
				0.386	7.864	3.765	.126	.134	10	64.4	8.72	
				0.377						64.3	8.72	3 (15)

G. C.	Name	mag.		1920 +	Δα cos δ	Δδ	m. e. of 1 exp. Δα cos δ	m. e. of 1 exp. Δδ	exp.	θ	ρ	n.
				y	"	"	"	"		°	"	
6597	Σ 1776	8.0	8.0	0.362	2.410	6.828	± .217	± .162	10	199.4	7.24	
				0.367	2.390	6.927	.087	.102	10	199.0	7.34	
				0.378	2.351	6.911	.158	.182	10	198.8	7.30	
				0.369						199.1	7.29	3 (16)
6852	Σ 1838	7.2	7.3	0.378	4.001	8.293	.106	.087	10	334.2	9.21	
				0.386	4.005	8.313	.106	.122	10	334.3	9.23	
				0.389	4.005	8.309	.087	.118	10	334.3	9.22	
				0.384						334.3	9.22	3
6987	Σ 1873	7.8	8.3	0.378	6.671	0.331	.181	.095	9	272.8	6.68	
				0.386	6.781	0.335	.122	.126	9	272.8	6.79	
				0.389	6.746	0.410	.110	.087	11	273.5	6.74	
				0.384						273.0	6.74	3
7080	Σ 1895	7.8	8.3	0.367	8.652	9.128	.063	.099	11	43.5	12.58	
				0.378	8.636	9.081	.130	.102	9	43.6	12.53	
				0.386	8.573	9.152	.087	.110	13	43.2	12.56	
				0.377						43.4	12.56	3
7111	Σ 1904	7.0	7.0	0.367	2.260	9.569	.174	.236	25	346.7	9.84	
				0.378	2.319	9.632	.099	.118	11	346.5	9.91	
				0.386	2.233	9.632	.102	.122	16	346.9	9.89	
				0.377						346.7	9.88	3 (17)
7127	Σ 1910	7.0	7.0	0.378	2.166	3.540	.146	.142	11	211.5	4.15	
				0.386	2.186	3.536	.106	.170	16	211.7	4.16	
				0.382						211.6	4.16	2 (18)
7162	Σ 1919	6.1	7.0	0.367	4.190	23.757	.304	.288	10	10.00	24.12	
				0.378	4.198	23.738	.181	.178	16	10.03	24.11	
				0.386	4.190	23.761	.158	.304	14	10.00	24.13	
				0.377						10.01	24.12	3 (19)
7226	Σ 1935	8.5	8.7	0.436	8.112	2.816	.118	.122	8	289.1	8.59	1
7284	Σ 1947	8.3	8.7	0.392	2.985	6.029	.300	.166	9	26.3	6.73	1
7341	Σ 1963	7.3	7.7	0.378	4.245	1.934	.178	.186	14	294.5	4.67	
				0.389	4.403	1.993	.083	.079	10	294.4	4.83	
				0.392	4.269	1.937	.205	.170	10	294.4	4.69	
				0.386						294.4	4.73	3 (20)
7428	Σ 1984	6.2	8.5	0.438	6.435	0.646	.150	.138	11	275.7	6.47	1
7429½	A. G. 199	8.8	8.9	0.436	8.998	2.780	.087	.106	10	252.8	9.04	1
7461	Σ 1990 AB	8.5	8.5	0.378	1.804	3.457	.154	.134	13	27.5	3.90	
				0.436	1.780	3.513	.099	.138	10	26.9	3.94	
				0.407						27.2	3.92	2
	AC	8.5	8.0	0.378	48.700	27.750	.280	.221	13	240.33	56.05	
				0.436	48.901	27.628	.130	.150	10	240.53	56.17	
				0.407						240.43	56.11	2 (21)
7466	Σ 1993	8.2	8.2	0.378	17.350	21.091	.174	.146	10	39.44	27.31	
				0.436	17.335	21.099	.075	.106	10	39.41	27.31	
				0.407						39.42	27.31	2 (22)

G. C.	Name		mag.		1920 +	Δα cos δ	Δδ	m. e. of 1 exp. Δα cos δ	m. e. of 1 exp. Δδ	Exp.	θ	ρ	n.
					y	"	"	"	"		°	"	
8783	Σ	2382	4.6	6.3	0.211	0.433	2.788	± .154	± .122	10	8.8	2.82	1 (23)
8785	Σ	2383	4.9	5.2	0.211	1.705	0.981	.174	.134	10	119.9	1.97	1 (24)
9910	Ku	58	9.5	9.7	0.805	0.512	2.859			2	190.2	2.90	1
9925	Σ	2631	8.0	9.4	0.805	1.717	4.241	.099	.122	5	338.0	4.58	
					0.808	1.563	4.162	.110	.091	5	339.4	4.45	
					0.811	1.721	4.214	.106	.114	5	337.8	4.55	
					0.808						338.4	4.53	3
9956	Σ	2639	7.7	8.7	0.805	4.844	2.926	.138	.110	10	301.1	5.66	
					0.808	4.824	3.048	.114	.091	8	302.3	5.70	
					0.811	4.788	2.993	.126	.099	11	302.0	5.65	
					0.808						301.8	5.67	3
10022	Σ	2655	7.5	7.5	0.805	0.287	6.155	.162	.122	9	2.7	6.16	
					0.808	0.345	6.092	.174	.126	10	3.2	6.10	
					0.811	0.256	6.049	.126	.114	10	2.4	6.09	
					0.808						2.8	6.12	3 (25)
12173	Σ	2978	6.8	8.0	0.808	4.773	6.840	.099	.079	10	145.2	8.33	
					0.811	4.800	6.907	.209	.201	10	145.0	8.43	
					0.810						145.1	8.38	2
12294	Σ	3000	8.7	8.8	0.898	2.642	2.056	.249	.134	8	52.1	3.35	
					0.901	2.690	2.091	.181	.146	5	52.2	3.41	
					0.920	2.556	1.914	.138	.118	6	53.2	3.19	
					0.906						52.5	3.32	3
12312	OΣ	494	7.4	8.1	0.808	2.946	0.524	.202	.126	9	79.9	2.99	1 (26)
12317	Σ	3006	8.5	9.0	0.863	1.611	5.458	.174	.229	9	163.6	5.69	
					0.877	1.642	5.627	.095	.146	11	163.7	5.86	
					0.870						163.6	5.78	2
12420	Σ	3024	8.2	9.0	0.857	3.713	3.052	.106	.122	10	309.4	4.81	
					0.863	3.776	3.103	.146	.110	10	309.4	4.89	
					0.877	3.847	3.217	.063	.083	10	309.9	5.01	
					0.866						309.6	4.90	3
12427	A. G.	293	9.2	9.3	0.898	1.394	3.229	.236	.174	7	23.3	3.52	
					0.901	1.449	3.335	.276	.102	6	23.5	3.64	
					0.920	1.355	3.150	.110	.205	7	23.3	3.43	
					0.906						23.4	3.53	3
12428	OΣ	499	7.2	8.8	0.898	9.333	2.197	.087	.166	7	76.8	9.59	
					0.901	9.270	2.115	.209	.185	6	77.1	9.51	
					0.920	9.242	2.103	.110	.142	7	77.2	9.48	
					0.906						77.0	9.53	3
12601	Σ	3042	7.0	7.0	0.808	4.997	0.217	.110	.114	10	87.5	5.00	
					0.811	4.934	0.256	.158	.134	10	87.0	4.94	
					0.810						87.3	4.97	2 (27)
12635	A. G.	296	9.1	9.2	0.901	4.458	3.194	.197	.138	6	54.4	5.48	
					0.920	4.438	3.245	.248	.142	8	53.8	5.50	
					0.910						54.1	5.49	2

G. C.	Name	mag.		1920 +	Δα cos δ	Δδ	m. e. of 1 exp. Δα cos δ	Δδ	exp.	θ	ρ	n.
				y	″	″	″	″		°	″	
12675	Σ 3050	6.0	6.0	0.808	1.146	1.154	± .114	± .142	8	224.8	1.63	1 (28)
12701	β 733 AB, C	6.0	8.5	0.863	26.998	53.217	.197	.114	10	333.10	59.67	1
12746	Σ 3061	8.0	8.0	0.898	4.040	6.395	.122	.150	5	147.7	7.56	
				0.901	4.084	6.391	.075	.095	6	147.4	7.58	
				0.920	4.080	6.379	.055	.083	7	147.5	7.57	
				0.906						147.5	7.57	3
12750	Σ 3060	8.5	8.7	0.898	2.634	1.819	.245	.166	5	125.0	3.22	
				0.901	3.040	1.906	.205	.087	5	122.1	3.59	
				0.920	2.780	1.733	.154	.197	7	121.9	3.28	
				0.906						123.0	3.36	3

NOTES.

(1) The north preceding star is a trifle fainter on the plate.
(2) Magnitudes equal; distance probably too small.
(3) The magnitudes are equal on the plate, hence different colours. STRUVE gives: yellowish, bluish.
(4) The south component is fainter on the plate.
(5) The second distance weight $\frac{1}{2}$. Components equal.
(6) Magnitudes equal; a little increase in distance.
(7) Angle increasing. Dynamical parallax (JACKSON and FURNER's formula) $p_2 = ''\cdot 032$.
(8) Magnitudes equal. Common proper motion of 0″·116, in 186°·9 (FURUHJELM). The angle has decreased 5° in 100 years at a mean distance of 5″·10. $p_1 = ''\cdot 018$.
(9) Magnitudes equal. A small increase in angle.
(10) Common proper motion of 0″·5 in 270°. No relative change.
(11) Magnitudes nearly equal on the plates; different colours.
(12) Common proper motion of 0″·2 in 260°; relatively fixed.
(13) Change from proper motion. The difference in magnitude seems larger on the plate than visually.
(14) First measure weight $\frac{1}{2}$. Distance probably too small.
(15) The north following star is fainter on the plate.
(16) Magnitudes equal.
(17) The north preceding star is fainter on the plate.
(18) The south preceding star is fainter on the plate.
(19) Common proper motion of 0″·7 in 296°. Change in distance. $p_3 = ''\cdot 046$.
(20) Angle and distance slowly increasing.
(21) STRUVE's *A*, *B* and *C* are resp. *C*, *A* and *B* here. STRUVE gives *C* $0^m\cdot 5$ brighter than the components of the close pair; on the plate it is much fainter. STRUVE gives the colour yellowish, and the close pair white.
(22) The north following star is fainter on the plate.
(23) ε_1 Lyrae. Distance too small.
(24) ε_2 Lyrae. Distance much too small; not separated.
(25) Magnitudes equal.
(26) Distance probably too small. Maybe a little change in angle.
(27) The following star is a trifle fainter on the plate.
(28) The distance much too small. Not separated.