Photographic measures of double stars made on plates taken with the 36-inch refractor of the Lick Observatory

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COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

Photographic measures of double stars made on plates taken with the 36-inch refractor of the Lick Observatory, by *Ejnar Hertzsprung*.

During my stay at the Lick Observatory as the first Morrison research associate from July to November 1937 I was by kind permission of Dr. W. H. WRIGHT enabled to use the 36-inch refractor for the photography of double stars.

In the taking of the plates I had the able assistance of Messrs. H. W. BABCOCK, G. E. KRON and D. M. POPPER. I want to thank each of these young astronomers for the skill and patience with which they took part in my work.

The visual 36-inch refractor is probably the best instrument in existence for photography of double stars because of its size and quality combined with the situation in a good climate.

Technical details, e.g. about the use of gratings placed in front of the objective, will be found in *Potsdam Publ.* No. 75, 1920 and in *Publ. of the Astron. Soc. of the Pacific*, Vol. **49**, 313, 1937.

All the plates have been taken through a yellow screen on Eastman-Kodak G1 plates or other brands of similar kind showing a sharp maximum of spectral sensitiveness in the green. The average effective wavelength as derived from 102 plates taken with a grating in front of the objective is 5575 A, which is practically independent of the colour of the star but varies somewhat with the kind of plate used. By the kindness of Dr. C. E. KENNETH MEES of the Eastman-Kodak Company I was provided with some specially sensitized plates, which used behind the yellow screen showed an effective wavelength of 5640 A against 5572 A of the G 1 plates, while the wavelength at which the focal length of the 36-inch refractor passes the minimum is 5658 A.

In the *Publ. of the Lick Observatory*, Vol. **3**, 174 the shape of the secondary spectrum of the 36-inch refractor is tabulated. If we confine ourselves to the photovisually most important part of the spectrum by omitting the extreme wavelengths, a least squares solution yields the formula

$$r = -65{\cdot}432 + 112{\cdot}728\, l - 20{\cdot}619\, l^2,$$

where $l = 1/(\lambda - {\cdot}2)$, λ expressed in μ, or

$$r = 88{\cdot}65 - 20{\cdot}6186\,(2{\cdot}7336 - l)^2$$

The constant 2·7336 determines the wavelength at which the focal length passes the minimum, viz. 5658 A.

If the formula is written in the form

$$\frac{f - f_{\min}}{f_{\min}} = {\cdot}0012\left(2{\cdot}7336 - \frac{1}{\lambda - {\cdot}2}\right)^2,$$

the constant ·0012 is a measure of the extension of the secondary spectrum and may be compared with that found for other refractors.

The comparison between observation and calculation is as follows

λ	$\frac{1}{\lambda - {\cdot}2}$	r(O)	r(C)	O—C
μ				
·4340	4·274	39·8	39·8	·0
·4861	3·495	76·6	76·7	— ·1
·5005	3·328	81·5	81·4	+ ·1
·5178	3·147	85·2	85·2	·0
·5893	2·569	88·0	88·1	— ·1
·6563	2·192	82·7	82·6	+ ·1

The distribution of the zenith distances at which the plates were taken is characterized by the median value 26°·6 and the mean deviation ± 9°·7. The largest actual zenith distance was 56°·4.

The normal scale value (temperature + 15°c, focal reading 15mm) is 11·7231 ″/mm on the Gaertner machine of the Lick Observatory and 11·7212 ″/mm on the Toepfer machine (temporarily in Leiden) of the Danish Carlsberg Foundation. In these scale values

ADS	Σ	1937·	Δα cos δ	Δδ	·01/(m.e.)² Δα cos δ	·01/(m.e.)² Δδ	ρ	θ epoch	θ 2000
			″	″			″	°	°
48	OΣ547	·807	+ 2·386	− 4·707	102	167	5·277	153·11	153·11
246	Grb34	·798	+ 32·417	+ 19·626	41	54	37·895	58·81	58·83
671	60	·746	− 9·025	+ 1·293	869	898	9·117	278·15	278·27
683	61	·774	+ 3·961	− 1·991	325	505	4·433	116·69	116·77
824	79	·828	− 1·772	− 7·591	117	197	7·795	193·14	193·25
899	88	·763	+ 10·433	− 27·903	220	212	29·790	159·50	159·60
1339	147	·768	+ 2·648	+ ·050	44	110	2·649	88·91	89·06
1507	180	·805	− ·022	+ 8·028	694	1107	8·028	359·84	·01
1615	202	·801	− 1·864	+ 1·300	295	465	2·272	304·90	305·07
1697	227	·768	+ 3·668	+ 1·142	111	274	3·841	72·71	72·92
1723	232	·744	+ 6·066	+ 2·682	69	86	6·632	66·15	66·36
1860	262	·829	− 2·190	− ·980	124	210	2·400	245·89	246·40
1860	262	·829	+ 6·804	− 2·829	115	147	7·369	112·58	113·09
1933	272	·842	+ 1·172	+ 1·470	188	200	1·880	38·55	38·94
2046	295	·774	− 3·027	+ 3·017	80	141	4·274	314·90	315·12
2081	296	·796	− 15·815	+ 9·674	311	416	18·539	301·46	301·79
2080	299	·804	− 2·658	+ 1·218	177	345	2·924	294·62	294·83
2091	300	·818	− 2·436	+ 1·968	33	53	3·131	308·93	309·19
2257	333	·801	− ·553	− 1·232	61	64	1·350	204·18	204·43
2468	368	·839	− ·734	+ 2·050	120	190	2·178	340·30	341·00
2582	401	·818	− 11·385	− ·071	49	127	11·386	269·64	269·95
2644	422	·807	− 6·349	− 1·489	110	306	6·521	256·80	257·07
2668	425	·803	+ 2·138	+ ·239	142	317	2·152	83·63	83·97
2757	443	·810	+ 6·242	+ 5·152	130	268	8·094	50·46	50·84
2767	450	·830	− 6·156	− ·583	74	397	6·183	264·59	264·90
2795	OΣ64	·825	− 2·755	− 1·761	62	272	3·270	237·42	237·73
2795	OΣ64	·825	− 8·457	− 5·706	47	194	10·203	235·99	236·31
2984	485	·774	− 14·802	+ 10·045	180	96	17·889	304·16	304·80
3019	494	·794	− ·674	− 5·172	154	147	5·215	187·42	187·75
3297	559	·763	− 2·997	+ ·382	40	52	3·021	277·27	277·60
3353	572	·774	+ 1·127	+ 3·732	150	160	3·898	16·80	17·16
3417	589	·812	− 4·287	+ 1·612	154	355	4·580	290·61	290·94
3572	616	·829	− ·229	+ 5·494	66	87	5·499	357·61	358·03
3568	622	·804	+ ·494	− 2·435	119	151	2·485	168·54	168·87
3734	644	·807	− 1·054	− 1·202	118	131	1·598	221·24	221·67
3823	668	·810	− 3·665	− 8·772	142	80	9·507	202·67	203·01
3853	666	·842	+ 2·922	+ ·838	98	277	3·040	73·99	74·39
3922	686	·826	− 6·431	− 6·736	132	244	9·312	223·67	224·05
4119	718	·843	+ 7·443	+ 2·228	99	197	7·769	73·34	73·86
4179	738	·804	+ 2·996	+ 3·169	59	101	4·361	43·40	43·74
4263	774	·813	+ ·879	− 2·220	393	497	2·388	158·39	158·74
4390	795	·801	− ·630	− 1·117	59	77	1·283	209·43	209·78
4490	813	·817	+ 1·643	− 2·615	196	316	3·089	147·86	148·23
5197	932	·810	− 1·222	+ 1·542	46	72	1·968	321·60	321·96
5559	982	·802	+ 2·976	− 6·070	103	160	6·760	153·88	154·23
5570	981	·826	+ 1·574	− 1·976	96	222	2·526	141·47	141·86
6175	1110	·826	− 1·590	− 3·589	394	310	3·925	203·90	204·28
7067	1280	·843	+ 2·866	+ 1·884	166	247	3·430	56·69	57·49
9979	2032	·599	− 3·904	− 4·042	283	428	5·619	224·00	223·63
10044	2044	·690	− 2·529	+ 8·001	123	262	8·391	342·46	342·06
10129	2078	·625	+ 3·232	− 1·152	216	235	3·431	109·63	109·09
10152	2092	·628	+ ·733	+ 8·202	132	152	8·235	5·11	4·44
10329	2128	·710	+ 9·069	+ 7·989	50	66	12·086	48·62	47·96
10345	2130	·595	+ 2·142	− ·515	331	409	2·203	103·53	102·95
10386	2138	·727	+ 15·662	− 15·828	27	50	22·267	135·30	134·72

A D S	Σ	1937·	Δα cos δ	Δδ	·01/(m.e.)² Δα cos δ	·01/(m.e.)² Δδ	ρ	ϑ epoch	ϑ 2000
			″	″			″	°	°
10418	2140	·650	+ 4·430	− 1·634	398	419	4·722	110·24	109·90
10526	2161	·707	− 2·797	+ 2·815	106	170	3·968	315·18	314·75
10597	2180	·606	− 3·150	− ·442	188	260	3·180	262·01	261·47
10750	2202	·694	+ 20·540	− 1·187	15	41	20·574	93·31	92·96
10759	2241	·729	+ 8·182	+ 29·304	107	63	30·424	15·60	14·47
10993	2264	·659	− 6·184	− 1·239	540	574	6·306	258·67	258·30
11005	2262	·620	− 2·026	− ·145	315	327	2·032	265·90	265·55
11046	2272	·621	+ 6·008	− 3·057	1134	1898	6·741	116·97	116·62
11089	2280	·613	− ·676	− 14·173	347	560	14·189	182·73	182·34
11336	2323	·729	− ·366	+ 3·684	267	394	3·702	354·33	353·67
11483	OΣ358	·615	− ·006	− 1·836	88	237	1·836	180·18	179·82
11500	2351	·712	− 1·816	+ 4·850	66	102	5·179	339·48	339·02
11558	2368	·706	− 1·082	+ 1·546	200	261	1·887	325·01	324·45
11640	2375	·732	+ 2·145	− 1·052	218	107	2·389	116·12	115·78
11635	2382	·626	+ ·254	+ 2·900	173	333	2·911	5·01	4·57
11635	2383	·631	+ 2·089	− ·796	312	398	2·235	110·86	110·42
11632	2398	·632	+ 6·412	− 15·175	79	297	16·474	157·09	156·42
11853	2417	·685	+ 21·472	− 5·260	182	295	22·106	103·76	103·43
11997	2451	·749	+ 2·034	+ ·667	108	176	2·141	71·84	71·31
12061	2461	·708	− 3·016	+ 2·141	76	150	3·699	305·37	304·98
12145	2481	·689	− 2·389	− 3·672	110	138	4·380	213·05	212·62
12169	2486	·672	− 4·922	− 7·132	327	389	8·666	214·61	214·10
12540	I 43	·632	+ 27·962	+ 20·011	79	166	34·385	54·41	54·05
12815	I 46	·691	+ 27·737	− 27·075	73	118	38·761	134·31	133·82
12962	2583	·588	+ 1·204	− ·503	40	89	1·305	112·68	112·36
13007	2603	·620	+ ·556	+ 3·010	107	188	3·061	10·47	9·57
13148	2605	·732	+ ·031	− 3·250	187	296	3·251	179·46	178·96
13209	2611	·710	+ 2·372	+ 4·702	271	366	5·266	26·77	26·32
13392	2642	·749	+ ·066	− 2·100	140	203	2·101	178·19	177·53
13542	2651	·683	− 1·457	+ ·246	69	154	1·478	279·58	279·27
13553	2655	·594	+ ·279	+ 6·157	138	252	6·163	2·59	2·28
13692	2671	·710	− 1·214	+ 3·154	220	354	3·380	338·95	338·45
—	2703	·762	− 23·737	+ 8·799	50	76	25·316	290·34	290·06
14270	2725	·645	+ ·546	+ 5·478	40	126	5·505	5·69	5·42
14279	2727	·718	− 10·316	− ·123	202	300	10·317	269·32	269·04
14556	2742	·654	− 1·728	− 2·116	181	251	2·731	219·24	218·99
14575	2751	·749	− ·220	+ 1·590	74	68	1·605	352·14	351·70
14636	2758	·665	+ 17·633	− 18·604	385	532	25·633	136·54	136·22
14878	2789	·718	+ 5·871	− 2·759	268	358	6·487	115·18	114·80
15076	2804	·734	− ·911	+ 2·852	149	202	2·994	342·29	342·06
15405	2840	·762	− 4·912	− 17·964	106	143	18·623	195·29	194·96
15407	2843	·749	+ 1·089	− 1·389	303	373	1·765	141·91	141·47
15600	2863	·732	− 7·230	+ 1·251	150	163	7·337	279·81	279·42
15971	2909	·677	− 2·302	+ ·812	196	219	2·441	289·42	289·28
16008	2917	·733	+ 4·400	+ 1·537	244	524	4·661	70·75	70·52
16030	2915	·719	+ 8·285	− 10·132	99	130	13·088	140·73	140·59
16095	2922	·763	− 2·198	− 22·263	112	132	22·371	185·64	185·47
16145	2928	·733	− 3·151	+ 2·143	219	265	3·811	304·22	304·09
16291	2947	·728	+ 3·545	+ 1·897	212	306	4·021	61·85	61·56
16317	2950	·749	− 1·608	+ ·973	159	267	1·880	301·17	300·95
16394	2961	·754	− ·391	+ 1·825	196	244	1·867	347·91	347·70
16666	3001	·676	− 1·348	− 2·601	530	500	2·930	207·39	207·21
16979	Sh 356	·582	+ 4·334	− 4·652	86	110	6·358	137·02	136·99
17054	3042	·744	+ 5·185	+ ·233	34	63	5·190	87·43	87·40
17149	3050	·755	− 1·467	− ·705	82	38	1·628	244·35	244·34

the factor n (refractive index of the air at Mount Hamilton) $= 1{\cdot}00025 = 1 + k$ for the shortening by refraction in zenith has been included. The generally unimportant rest of the differential refraction in zenith distance has been accounted for by the formulae

$$\Delta\alpha \cos\delta = [1 + k \operatorname{tg}^2 z \cos^2(\vartheta - S)] \cdot [\Delta'\alpha \cos\delta - \Delta'\delta \cdot k \operatorname{tg}^2 z \cos\vartheta \sin(\vartheta - 2S)]$$
$$\Delta\delta = [1 + k \operatorname{tg}^2 z \cos^2(\vartheta - S)] \cdot [\Delta'\delta + \Delta'\alpha \cos\delta \cdot k \operatorname{tg}^2 z \cos\vartheta \sin(\vartheta - 2S)]$$

Here $\Delta'\alpha \cos\delta$ and $\Delta'\delta$ are the rectangular coordinates as measured on the plate, k the constant of refraction $= {\cdot}00025$ for the effective wavelength of the plates as mentioned above, z the zenith distance, ϑ the position angle of the double star and S the parallactic angle pole-star-zenith. The first factor, which aims at the distance between the components, has in each individual case been included in the scale value. The second factor refers to the alteration of the position angle by refraction relative to the trail (also affected by refraction) of the star on the plate.

In units of ·0001 ″/mm the correction of the scale value for temperature is + 6 at + 2°·2 and − 6 at + 27°·8. For focal reading the correction is + 47 at 8·0 mm and − 46 at 21·9 mm.

The internal mean error of a single image in $\Delta\alpha \cos\delta$ or in $\Delta\delta$ has been derived from the deviations from the mean of all exposures, separately for the measures with film up and through the glass. To find the m.e. of the mean the m.e. of a single image has been divided by the square root of the mean number of images measured with film up and through the glass. The improvement obtained by the double measurement was thus neglected. Approximately it may be assumed that half of the square of the m.e. of a single image is due to errors intrinsic in the image and the other half to errors of pointing (compare *Potsdam Publ.* No. 63, 16, 1911).

The internal m.e. of the mean thus derived has been somewhat increased in the following way in order to approach the external m.e. The square of the m.e. of the mean was multiplied by 1·6 and then ·000010 square seconds of arc were added. In this way account was taken of the evidence that a small internal m.e. needs a greater factor than a large one. E.g. if the internal m.e. of the mean is found to be ± ″·005 its square multiplied by 1·6 is ·000040. After addition of ·000010 to this the assumed square of the external m.e. is ·000050 and the weight 20000 $''^{-2}$, or in the units used in the table of the measures 200.

The total weight of the present photographic measures is thus found to be 4806100$''^{-2}$, of which 1959300 belong to $\Delta\alpha \cos\delta$ and 2846800 to $\Delta\delta$.

In the accompanying table mean values are given for each of the 110 double stars observed.

For 61 Cygni = Σ 2758 the result is 1937ᵃ·665, 25″·633, 136°·54, while the ephemeris given by ALAN FLETCHER in *Month. Not.* Vol. **92**, 127 has 25″·693, 136°·54. The difference in distance, ″·060 may be due to a systematic error in the visual distances.

A comparison with the ephemerides given by K. AA. STRAND in *Leiden Ann.* Vol. **18**, part 2 can be made in the following three cases

Σ	STRAND, Ephemeris $\Delta\alpha \cos\delta$	$\Delta\delta$	Lick Observatory $\Delta\alpha \cos\delta$	$\Delta\delta$
	″	″	″	″
η Cas 60	− 9·039	+ 1·295	− 9·025	+ 1·293
σ CrB 2032	− 3·881	− 4·104	− 3·904	− 4·042
70 Oph 2272	+ 6·021	− 3·054	+ 6·008	− 3·057

Only σ CrB shows a serious deviation from the ephemeris, but the orbit of this double star is still relatively uncertain.

The total number of single settings used in the present measures is 112445. Of these 1593 were made by G. V. SIMONOW and 1256 by K. AA. STRAND for remeasurement of respectively three plates of ϑ Per and one plate of 70 Oph. Of the rest 30251 were made by the writer on Mount Hamilton and 79345 at Leiden.

Perhaps the most urgent problem of today in the photography of double stars is the elimination of the systematic errors in the distance of pairs separated by less than, say ·15 mm on the plate. One way to obtain this elimination would be to make a row of exposures in such a way that a series of equidistant images is produced •●•●•●. This can be done by keeping the double star in the axis of the telescope and then between each exposure to shift the plate in the direction of the position angle by an amount equal to the double distance between the components.