1982BASI...10..315A

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Light-time effect in AK Her and ER Ori

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Abstract : An analysis of the minimum-time data of AK Her and ER Ori reveals possible sinusoidal variations in their orbital periods. In the case of AK Her we suspect two additional components : one of mass 0.2 to 0.4 $M_\odot$ with a period of 62 yr and the other of mass 0.2 to 0.6 $M_\odot$ with a period of 207 yr. The probable third mass in ER Ori is less than 0.6 $M_\odot$ for $i \geqslant 60^\circ$ with a long-term period of 34.78 yr.

Key words : AK Her—ER Ori—minimum-time data

1. Introduction

AK Her and ER Ori are noted for the variability of their orbital periods. Many studies of the periods of these systems have been made by different authors. Nevertheless, in the present study an attempt is made to interpret the observed period changes in AK Her and ER Ori in terms of light-time effect. It is known that both systems possess visual members. However, the observed period changes cannot be wholly due to the visual members even though they might contribute to the changes to a small extent. Continuous observations of these systems may confirm the presence of additional components. In the following we discuss the two systems individually.

2. AK Herculis

It is the bright component of ADS 10408. The faint visual companion ADS 10408 B has been found to be a physical member of the system. The orbital period of this eclipsing system has been studied among others by Seyfert & Mason (1951), Kwee (1958), Binnendijk (1961), Bookmyer (1961, 1972). Schmidt & Herczeg (1959) and Herczeg (1962) interpreted the $(O - C)$ curve in terms of light-time effect due to the motion of the eclipsing system in an eccentric orbit about the hypothetical fourth component (the third one being a visual companion). But these fourth body orbital elements failed to represent later observations adequately. In a recent period study, Barker & Herczeg (1979) have revised the light-time orbital elements by Irwin's procedure. They find very small mass for the fourth body, maintaining that the

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1982BASI...10..315A

observed light-time effect cannot result from motion in the visual system, as the effect of this will be negligibly small over an interval of 70 or 80 yr.

Panchatsaram (1980) has studied the period change in AK Her on the basis of all the available photoelectric times of minima. The $(O - C)$ time residuals were calculated through the following light elements given by Kurutac & Ibanoglu (1969) :

$$\text{Min } (I) = \text{JD}_\odot\ 2438531.4318 + 0.42152309\ E. \qquad ...(1)$$

Assuming a long-term orbital period of 41.55 yr (36000 binary cycles) and a circular orbit Panchatsaram obtained the following representation by the least squares method :

$$(O - C)_1^{\mathrm{d}} = \underset{\pm 3}{-\,0.0035} + \underset{\pm 6}{0.0056} \sin [360°(E + \underset{\pm 5.5}{5184.3})/36000] \qquad ...(2)$$

But these elements do not represent the older observations. This discrepancy cannot be ignored because the residuals are found to be much larger than probable errors in the observations of photographic and visual minima.

We have, therefore, reanalysed all the available times of primary minima which are listed in table 1 along with the $(O - C)$'s calculated from the elements of equation (1). These residuals are plotted in figure 1 which, not only shows the inadequacy of the light-time orbit of equation (2), but also indicates the presence of a double sine wave characteristic of a four component system. By trial and error we have been able to obtain the following 4-body representation by the method of least squares assigning a weight of 10 for photoelectric and 1 for other types of minima :

Table 1. Primary minima of AK Her

$\text{JD}_\odot$	Type	*E*	$(O-C)$	Residual	References
241 4999.961	pg	−55825	+.05600	+.00648	1(a)
5599.782	pg	−54402	+.04900	−.00101	1(a)
6499.735	pg	−52267	+.05100	+.00080	1(a)
7199.887	pg	−50606	+.05300	+.00316	1(a)
7990.027	pg	−48945	+.04300	−.00599	1(a)
8799.984	pg	−46810	+.04800	+.00085	1(a)
9799.834	pg	−44438	+.04500	+.00088	1(a)
242 0499.975	pg	−42777	+.03600	−.00542	1(a)
1200.123	pg	−41116	+.03500	−.00328	1(a)
1999.751	pg	−39219	+.03300	−.00124	1(a)
2799.798	pg	−37321	+.02900	−.00080	1(a)
2935.948	vis	−36998	+.02748	−.00154	1(b)
2977.254	vis	−36900	+.02422	−.00456	1(b)
3100.343	vis	−36608	+.02848	+.00042	1(b)
3573.703	pg	−35485	+.01805	−.00721	1(b)
3999.877	pg	−34474	+.03200	+.00930	1(a)
4312.624	pg	−33732	+.00907	−.01174	1(b)
4680.626	vis	−32859	+.02141	+.00282	1(b)
4949.555	vis	−32221	+.01868	+.00171	1(b)
4999.720	pg	−32102	+.02200	+.00533	1(a)
5413.227	vis	−31121	+.01528	+.00107	2
5442.738	vis	−31051	+.01967	+.00563	1(b)
5999.989	pg	−29729	+.01700	+.00619	1(a)
6141.195	vis	−29394	+.01291	+.00289	1(b)
6699.719	pg	−28069	+.01900	+.01203	1(a)

Continued

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1982BASI...10..315A

Table 1—*Continued*

JD⊙	Type	*E*	(*O*−*C*)	Residual	References
242 6894.449	pe	−27607	+.00515	−.00080	1(b)
7200.044	pg	−26882	−.00400	−.00840	1(a)
7563.3972	vis	−26020	−.00380	−.00645	1(b)
7624.5231	vis	−25875	+.00125	−.00111	1(b)
7980.294	pg	−25031	+.00657	+.00590	1(b)
8000.105	pg	−24984	+.00600	+.00532	1(a)
8329.7288	pg	−24202	−.00118	−.00048	1(b)
8398.9421	vis	−24039	+.00386	−.00483	1(b)
8726.3758	vis	−23261	−.00640	−.00417	1(b)
8753.3563	vis	−23197	−.00438	−.00205	1(b)
8900.051	pg	−22849	00000	+.00285	1(a)
9399.977	pg	−21663	00000	+.00447	1(a)
9486.805	pg	−21457	−.00586	−.00113	1(b)
9799.998	pg	−20714	−.00500	+.00059	1(a)
243 0169.673	pg	−19837	−.00526	+.00122	1(b)
0914.500	vis	−18070	−.00956	−.00172	2
2362.430	vis	−14635	−.01138	−.00248	2
3515.718	pe	−11899	−.01055	−.00212	2
3731.5405	vis	−11387	−.00787	+.00036	2
3750.513	pe	−11342	−.00391	+.00430	3
4153.4827	pe	−10386	−.01029	−.00253	2
4213.160	vis	−10243	−.01079	−.00311	2
4253 384	vis	−10149	−.00996	−.09233	2
4492.814	pe	− 9581	−.00507	+.00224	3
4813.59075	pe	− 8820	−.00740	−.00056	2
4859.53645	pe	− 8711	−.00771	−.00094	2
5305.0876	pe	− 7654	−.00647	−.00043	3
5933.576	pe	− 6163	−.00900	−.00407	4
5960.5588	pe	− 6099	−.00367	+.00121	2
6025.4708	pe	− 5945	−.00623	−.00147	2
6317.586	pe	− 5252	−.00653	−.00230	3
6404.4205	pe	− 5046	−.00579	−.00172	2
6726.4667	pe	− 4282	−.00323	+.00024	3
6754.7085	pe	− 4215	−.00348	−.00006	2
6757.6601	pe	− 4208	−.00254	+.00088	2
6788.433	pe	− 4135	−.00082	+.00254	3
7111.7411	pe	− 3368	−.00093	+.00185	2
7112.5836	pe	− 3366	−.00148	+.00130	3
7114.6214	pe	− 3361	−.00129	+.00148	3
8171.4512	pe	− 854	+.00012	+.00116	3
8176.5076	pe	− 842	−.00176	−.00073	3
8227.511	pe	− 721	−.00265	−. 0169	3
8531.432	pe	0	+.00020	+.00074	5
9278.7936	pe	+ 1773	+.00137	+.00107	3
9280.9017	pe	+ 1778	+.00185	+.00155	3
9281.7442	pe	+ 1780	+.00130	+.00099	3
9283.8513	pe	+ 1785	+.00078	+.00047	3
9616.432	pe	+ 2574	−.00023	−.00081	3
9683.453	pe	+ 2733	−.00140	−.00203	3
9981.4730	pe	+ 3440	+.00177	+.00097	3
244 0354.5208	pe	+ 4325	+.00164	+.00071	6
0368.429	pe	+ 4358	−.00043	−.00136	3
0381.4986	pe	+ 4389	+.00196	+.00102	6
0387.8211	pe	+ 4404	+.00162	+ 00068	3
0392.455	pe	+ 4415	−.00126	−.00220	3
0392.4565	pe	+ 4415	+.00024	−.00070	3
0395.8297	pe	+ 4423	+.00127	+.00033	3

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1982BASI...10..315A

Table 1—*Continued*

JD⊙	Type	*E*	(*O*−*C*)	Residual	References
2440 771.4080	pe	+ 5314	+.00250	+.00154	3
1077.8537	pe	+ 6041	+.00091	00000	3
1080.8042	pe	+ 6048	+.00075	−.00016	3
1126.3280	pe	+ 6156	+.00006	−.00083	3
1188.292	pe	+ 6303	+.00016	−.00071	3
1512.445	pe	+ 7072	+.00191	+.00120	3
1786.435	pe	+ 7722	+.00190	+.00138	3
1826.8987	pe	+ 7818	−.00061	−.00110	3
1829.8496	pe	+ 7825	−.00038	−.00087	3
1830.6925	pe	+ 7827	−.00053	−.00102	3
1832.3799	pe	+ 7831	+.00078	+.00030	3
1853.456	pe	+ 7881	+.00073	+.00026	3
2186.4592	pe	+ 8671	+.00069	+.00055	3
2240.4139	pe	+ 8799	+.00044	+.00036	3
2532.5291	pe	+ 9492	+.00013	+.00040	3
2665.3091	pe	+ 9807	+.00036	+.00081	3
2914.4284	pe	+10398	.00049	+.00034	3
3266.3968	pe	+11233	−.00387	−.00245	3

References : 1(a). Woodward (1942, p.14); 1(b). Woodward (1942, p.18); 2. Binnendijk (1961); 3. Barker & Herczeg (1979); 4. Szczepanowska (1962); 5. Pohl & Kizilirmak (1966); 6. Battistini (1974).

[pg = photographic, vis = visual, pe = photoelectric]

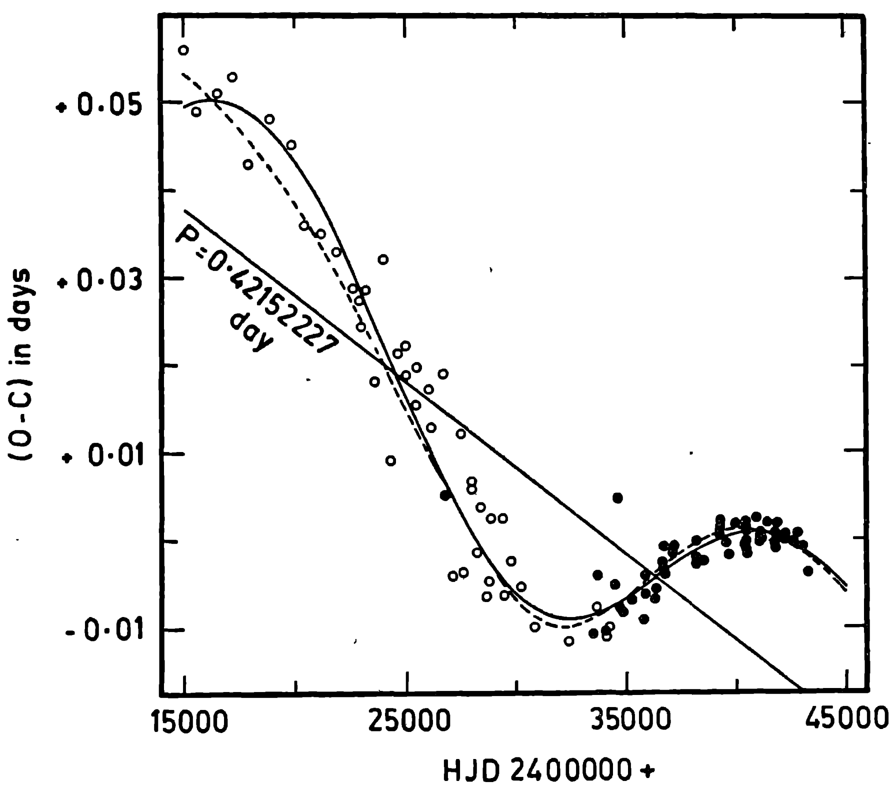

Figure 1. The (*O*−*C*) diagram for AK Her. Open circle refer to photographic and visual measurements and filled circle to photoelectric measurements. The continuous curve represents the 4-body solution of this paper and the dashed curve the eccentric third body orbit of Barker and Herczeg (1979).

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1982BASI...10..315A

$$(O - C)_2^d = \underset{\pm 85}{0.01982} - \underset{\pm 82}{0.02909} \cos \theta_1 - \underset{\pm 64}{0.01320} \sin \theta_1 + \underset{\pm 17}{0.00874} \cos \theta_2 + \underset{\pm 23}{0.00872} \sin \theta_2 \quad \ldots(3)$$

where $\theta_1 = 0.002\,E$ and $\theta_2 = 0.02E/3$ in degrees. Combining the corresponding cosine and sine terms we get

$$(O - C)_2^d = \underset{\pm 85}{0.01982} - \underset{\pm 104}{0.03195} \cos [360°(E - \underset{\pm 846}{12206})/180000] + \underset{\pm 29}{0.01234} \cos [360°(E - \underset{\pm 86}{6725})/54000]. \quad \ldots(4)$$

Equation (4) is represented by the continuous line in figure 1, and the parameters of the corresponding circular orbits of the third and fourth components (the fifth being the visual companion) are given in table 2. Since Barker & Herczeg (1979), who used a different eclipse period of 0.42152227 d, had obtained an eccentric third body orbit, we have compared our result with theirs. The straight line and the dashed curve in figure 1 indicate respectively the residuals for the constant period and the eccentric light time orbit derived by them. A comparison of the continuous and dashed curves shows that the currently available observations cannot distinguish between the two models. We have to wait for future observations of minima to remove the ambiguity. In both cases, however, the estimated masses of the additional components are below half a solar mass which makes them normally undetectable.

Table 2. Circular orbits and masses of additional components

System / Component	AK Herculis 3	AK Herculis 4	ER Ori 3
$a_{12} \sin i$ (AU)	2.13	5.52	4.14
P (yr)	62	207	34.78
$f(m)/M_\odot$	.00252	.00393	.0587
$m_{12}/M_\odot$	1.5[1]	$1.5 + m_3$	0.93[2]
$m_{3 \text{or} 4}/M_\odot$			
$i = 90°$	0.20	0.24	0.49
$i = 60°$	0.22	0.31	0.60
$i = 30°$	0.43	0.58	1.36

[1]Barker and Herczeg (1979; [2]Binnendijk (1962)

3. ER Orionis

ER Ori is a W UMa-type eclipsing binary having variable oribital period. Kwee (1958) and Binnendijk (1962) found sudden period changes in this system. Only a few photoelectric times of minima are available in the literature. Therefore we have undertaken a study of its orbital period, including visual and photographic times of minima. These less accurate minima are not as such invalid for period studies in the case of ER Ori because the observed scattering of points in its $(O - C)$ diagram is relatively less.

All the available times of minima are listed in table 3. The minimum time residuals have been computed from the linear ephemeris :

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1982BASI...10..315A

$$\text{Min }(I) = \text{JD}_{\odot}\ 2428566.6577 + 0^{d}.42339958\ E, \quad ...(5)$$

which is based on the photoelectric times of minima near $E = 19220$ and $E = 31414$. The $(O - C)$ diagram shown in figure 2 has been fitted with a sine curve for an

Table 3. Times of minima of ER Ori

JD$_{\odot}$		Method	E	$(O-C)$	Reference
242 6327.338		vis	−5289	+0.04070	1
6336.438	II	vis	−5267	+0.04083	1
6386.184		vis	−5150	+0.03409	1
6387.243	II	vis	−5147	+0.03789	1
6409.267	II	vis	−5095	+0.04516	1
6420.271	II	vis	−5069	+0.04079	1
6600.2089	II	vis	−4644	+0.03385	2
7133.268	II	vis	−3385	+0.03281	3
7430.497	II	vis	−2683	+0.03534	4
7461.3938	II	vis	−2610	+0.02393	3
7873.364	II	vis	−1637	+0.02641	5
8189.4225		vis	− 891	+0.01380	3
8566.460	II	vis	0		6
8566.675		vis	0	+0.01727	6
8906.445	II	vis	+ 803	+0.01243	6
8930.370		vis	+ 859	+0.01200	6
9265.481	II	vis	+1651	+0.00554	6
9283.688	II	pg	+1694	+0.00640	1
9284.325		vis	+1695	+0.00500	6
9287.293		vis	+1702	+0.00921	3
9291.519		pg	+1712	+0.00122	1
9291.735	II	pg	+1713	+0.00883	1
9307.612		pg	+1750	+0.00497	1
9311.636	II	pg	+1760	+0.00999	1
9547.893	II	vis	+2318	+0.01002	1
9549.790		vis	+2322	−0.00157	1
9552.757		vis	+2329	+0.00164	1
9554.872		vis	+2334	−0.00036	1
9556 780	II	vis	+2339	+0.00565	1
9570.752	II	vis	+2372	+0.00549	1
9577.738		vis	+2388	+0.00211	1
9651.614	II	vis	+2563	−0.00185	1
9660.521	II	vis	+2584	+0.01377	1
9664.536		pg	+2593	+0.00318	1
9671.524	II	pg	+2610	+0.00841	1
9675.544		pg	+2619	+0.00272	1
9686.551		pg	+2645	+0.00135	1
243 0327.362	II	vis	+4159	+0.00045	3
0350.425		vis	+4213	+0.01518	3
1175.420	II	vis	+6162	−0.01091	4
2941.407	II	vis	+10333	−0.02362	7
2944.379	II	vis	+10340	−0.01541	7
2950.301	II	vis	+10354	−0.02099	7
2955.372	II	vis	+10366	−0.03078	7
2971.895	II	vis	+10405	−0.02043	8
3282.665	II	pe	+11139	−0.02596	9
3306.385	II	pe	+11195	−0.01609	3
3682.354	II	pe	+12083	−0.02592	7
3685.320	II	pe	+12090	−0.02371	10
3929.6175	II	pe	+12667	−0.02775	11

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1982BASI...10..315A

Table 3—*Continued*

JD⊙		Method	*E*	(*O*−*C*)	References
243 3960.9464	II	pe	+12741	−0.03045	12
3972.1707		pe	+12767	−0.02952	13
3976.1903	II	pe	+12777	−0.02890	13
3979.1533	II	pe	+12784	−0.02979	13
4366.564	II	vis	+13699	−0.02959	8
4765.4166	II	pe	+14641	−0.01935	11
4776.4259	II	pe	+14667	−0.01851	11
5474.6264	II	pe	+16316	−0.00394	14
5858.6557	II	pe	+17223	+0.00195	14
6215.5793	II	pe	+18066	−0.00034	14
6227.6482		pe	+18094	−0.00160	14
6508.7851		pe	+18758	−0.00203	14
7260.7457		pe	+20534	+0.00091	14
7309.6472	II	pe	+20650	+0.00307	14
244 1626.4155		pe	+30845	−0.00241	15
1664.3099	II	pe	+30935	+0.00111	15
1990.54294		pe	+31705	+0.00137	16
1990.5430		pe	+31705	+0.00143	17
2023.3516	II	pe	+31783	−0.00007	17
2030.5501	II	pe	+31800	+0.00065	17
2433.625	II	vis	+32752	−0.00090	18
2446.540		vis	+32782	−0.00286	18
2446 541		vis	+32782	−0.00285	19
2751.593	II	vis	+33503	−0.00601	18
2760.703		vis			19
3211.616		vis	+34589	−0.00988	20
3479.649		vis	+35222	+0.00916	20

References : 1. Alexander (1940); 2. Florja (1932); 3. Dworak (1977); 4. Tsesevich (1954); 5. Soloview (1935); 6. Tecza (1939); 7. Szezepanowska (1950); 8. Ashbrook (1953); 9. Wood *et al.* (1963); 10. Szezepanowska (1956); 11. Kwee (1958); 12. Huruhata (1957); 13. Szafraniec (1962); 14. Binnendijk (1962); 15. Kizilirmak & Pohl (1974); 16. Zavatti & Burchi (1975); 17. Burchi and Zavatti (1975); 18. Mallama *et al.* (1977); 19. Stephan (1977); 20. Stephan (1978).

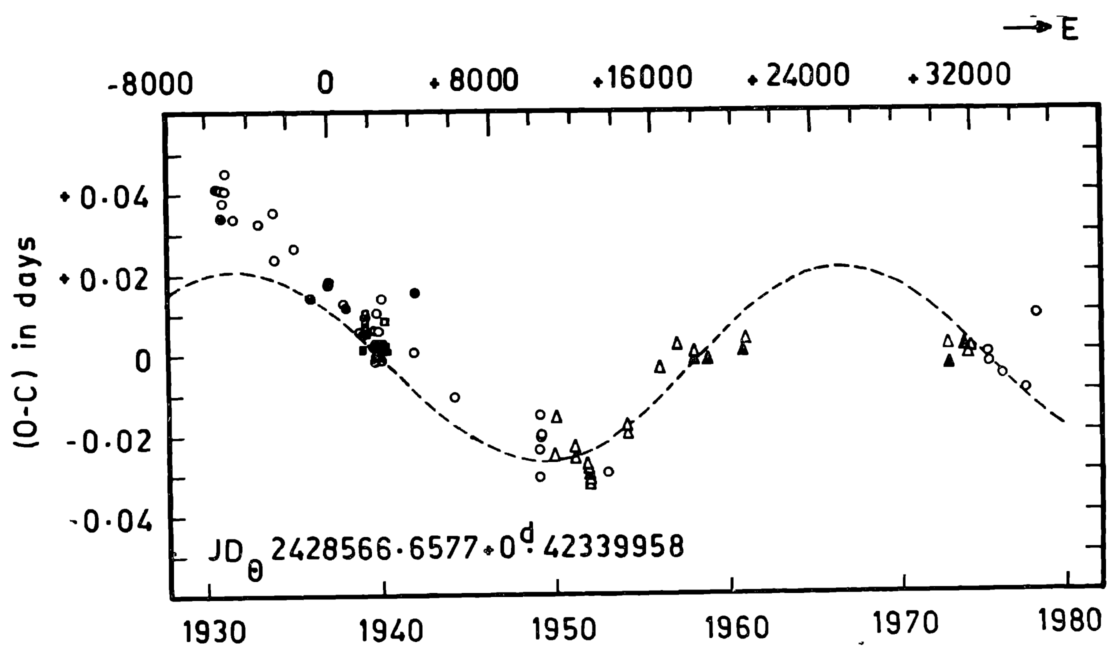

Figure 2. The (*O*−*C*) diagram for ER Ori, the sinusoid indicates the computed light-time orbit.

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1982BASI...10..315A

assumed long-term period of 34.78 yr (30000 cycles). For the minimum-time residuals the following representation has been obtained by the least squares method assigning weights 1, 1 and 10 for visual, photographic and photoelectric points respectively :

$$(O-C) = -\underset{\pm 5}{0^{d}.0030} - \underset{\pm 3}{0^{d}.024} \sin \frac{360^{\circ}}{30000} [E - \underset{\pm 4.2}{2951.4}] \qquad \ldots(6)$$

The parameters of the corresponding circular orbit and the mass for the third component are given in table 2, detection of this component should be possible. Whether the visual companion of this system is really a physical member is yet to be known.

4. Conclusions

AK Her and ER Ori are in all probability multipte systems. The period changes occurring in these systems should be due to light-time effect. The presence of additional components in these system is rather difficult to confirm through visual or spectroscopic means; continued astrometric work is desirable for them.

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