PHOTOELECTRIC PHOTOMETRY OF THE ECLIPSING BINARY EE AQR

T. D. PADALIA
Uttar Pradesh State Observatory, Naini Tal, India

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Abstract. The system EE Aqr has been observed in *UBV* colours. A consistent set of orbital elements and a slightly improved period of $0^d.5089954$ have been obtained. The eclipse is partial and variability is of β Lyrae-type. The colour of the components has been determined.

1. Introduction

A photographic light curve of the system EE Aqr (BV 320, HD 213863, BD $-20°6454$) was given by Strohmeier *et al.* (1962), who classified it as an Algol-type eclipsing binary with no evidence of a secondary eclipse. They found its period to be $0^d.5089951$. The system was put on our observing programme in October 1973, as no photoelectric *UBV* photometry of the system was then available. However, while the observations were still in progress, Williamon (1974) published photoelectric *UBV* observations of the system and established it to be a β Lyrae-type binary. He found its period to be $0^d.50899555$. Our observations were continued through November 1975 and were analysed to see if our findings differed significantly from those by Williamon. We find that:

(1) Computed from the epoch of primary minimum = JD Hel 2429881.310 used by Strohmeier (1962), a period of $0^d.5089954$, which is not too different from the one given by Williamon, fits the observations better. The mean O–C values based on our period determination and that by Williamon are, respectively, $0^d.000$ and $-0^d.004$.

(2) The mean oblateness of 0.122 ± 0.004 determined by us is significantly less than that of 0.170 ± 0.026 reported by Williamon and is internally consistent. Thus, tidal forces and the interaction between the components appear to be less dominant.

(3) The effects of ellipticity and reflection on the *U* light curve are much more than those reported by Williamon. We could not measure the depth of secondary minimum in *U* filter after rectification, while Williamon obtained a depth of $1 - l_0^{oc} = 0.04$.

In addition to the above, we find that computation of the Fourier coefficients up to the 4θ term, as against up to the 3θ term considered by Williamon, provide better estimates of the unknown perturbations and complications within the system. We have computed O–C intensities outside the eclipse, including the 4θ term. The standard deviation of the O–C for the former values in intensity units, are ± 0.023 (*U*), ± 0.017 (*B*) and ± 0.007 (*V*), whereas for the latter these are ± 0.002 (*U*), ± 0.004 (*B*) and ± 0.003 (*V*). These clearly show that estimations based on Fourier expansion

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including the 4θ term are a significant improvement over previous ones. Also the colours of the components have been estimated and their position shown on the colour–colour diagram.

2. The Observations

The observations were made on the 38-cm reflector of the Uttar Pradesh State Observatory. A total of 17 nights of observations were secured during the period October 1973–November 1975. The conventional *UBV* filters of Johnson and Morgan (1953) and standard d.c. techniques were employed. The observations collected in 1973 were obtained with an unrefrigerated 1P21 photomultiplier tube, while the remaining ones were obtained using a similar tube refrigerated to −20 °C. All the reductions were done using BD −20°6446 (HD 213623, SAO 165157) as the comparison star. The standard deviations of the comparison star on typical nights during 1973 (when an unrefrigerated photomultiplier tube was used) were $0\overset{m}{.}015$ (*U*), $0\overset{m}{.}0.11$ (*B*) and $0\overset{m}{.}012$ (*V*), while those in 1974 and 1975, when a cooled photomultiplier was used, were $0\overset{m}{.}007$ (*U*), $0\overset{m}{.}010$ (*B*) and $0\overset{m}{.}008$ (*V*). Ten standard stars taken from the list of Johnson and Morgan (1953) have been observed to reduce the data to standard system. The individual observations are reported in Table I and the *UBV* light curves are given in Figure 1.

3. Epoch and Period

The primary minimum was observed on three nights, and on two of these observations on both sides of the primary minimum were secured. The method by Kwee and van Woerden (1956) and the graphical bisection method were both used to determine the times of minima, there being no difference in the two determinations up to the third decimal place. Based on the epoch of primary minimum = JD Hel 2429881.3100, given by Strohmeier *et al.* (1962), a period of $0\overset{d}{.}5089954$ has been determined. The O–C values are given in Table II. Also, we have derived a period of $0\overset{d}{.}5089956$ based only on our own three observations of primary minima. A comparison of the two periods given above strongly indicates that the period has remained constant since 1940. This further indicates that the period of $0\overset{d}{.}5089954$ obtained by us is more reliable than (though still not significantly different from) the value of $0\overset{d}{.}50899555$ given by Williamon.

4. Rectification

The light variation (in intensity units) outside the eclipse was expressed by the usual truncated Fourier series:

$$l(\theta) = A_0 + \sum_{n=1}^{4} A_n \cos n\theta + \sum_{n=1}^{4} B_n \sin n\theta$$

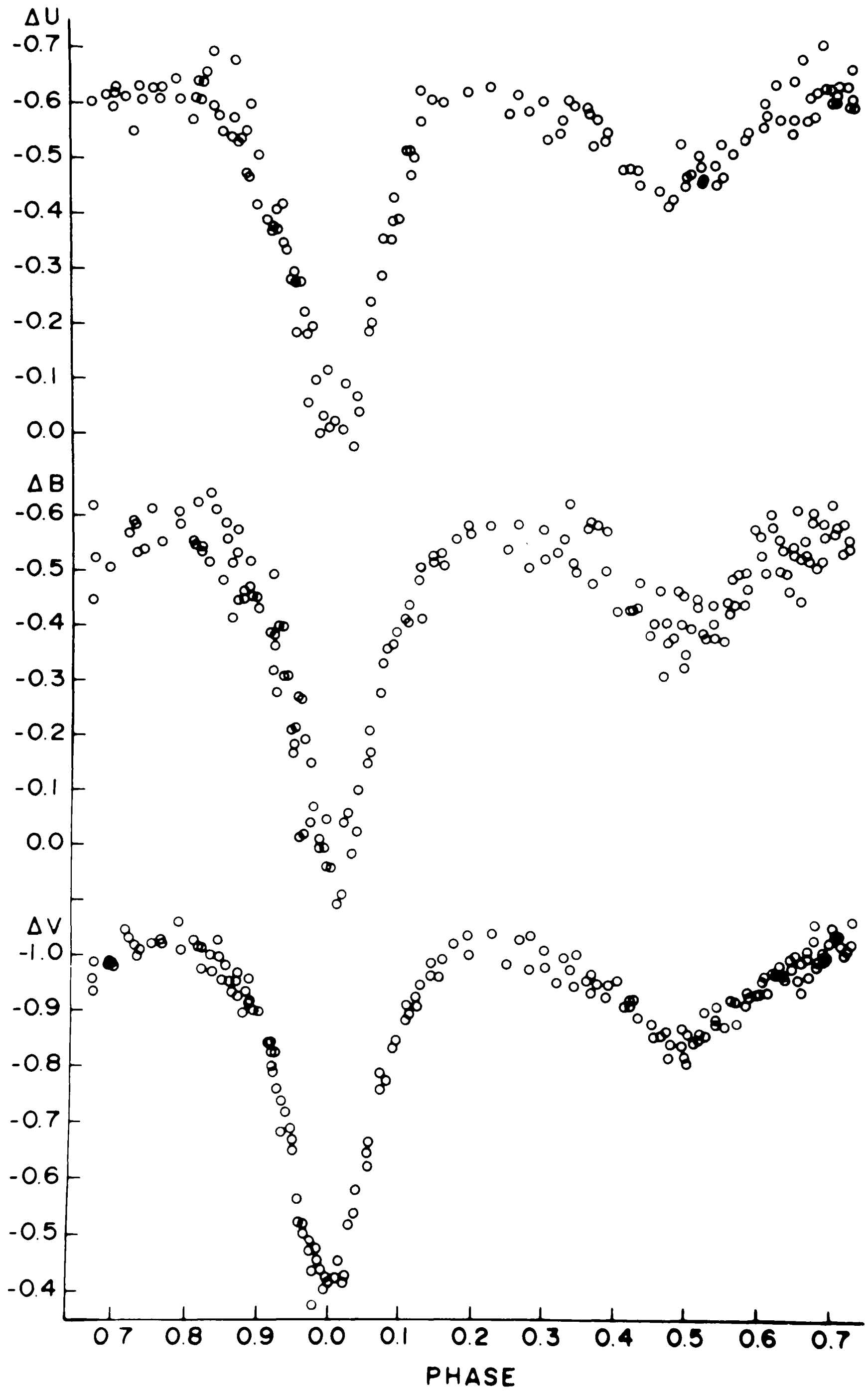

Fig. 1. Observed light curves of EE Aqr in *U*, *B*, *V*.

TABLE I

Standard U magnitudes of EE Aqr

JD (Hel)	Phase in days	$\Delta m(U)$ $V-C$
2441		
985.1282	−0.0928	$-0^{\rm m}.639$
1483	−0.0727	$-0^{\rm m}.540$
1629	−0.0581	$-0^{\rm m}.598$
1803	−0.0407	$-0^{\rm m}.409$
1940	−0.0270	$-0^{\rm m}.184$
2072	−0.0138	$-0^{\rm m}.098$
2212	+0.0002	$-0^{\rm m}.024$
2354	0.0144	$+0^{\rm m}.024$
2484	0.0274	$-0^{\rm m}.202$
2620	0.0410	$-0^{\rm m}.354$
2765	0.0555	$-0^{\rm m}.470$
986.1021	−0.1369	$-0^{\rm m}.592$
1178	−0.1212	$-0^{\rm m}.627$
1310	−0.1080	$-0^{\rm m}.607$
1458	−0.0932	$-0^{\rm m}.606$
1608	−0.0782	$-0^{\rm m}.548$
1762	−0.0628	$-0^{\rm m}.474$
987.1025	−0.1545	$-0^{\rm m}.626$
1185	−0.1385	$-0^{\rm m}.627$
1594	−0.0976	$-0^{\rm m}.611$
1721	−0.0849	$-0^{\rm m}.594$
1866	−0.0704	$-0^{\rm m}.572$
2383	−0.0187	$-0^{\rm m}.058$
994.1290	+0.2551	$-0^{\rm m}.467$
1395	0.2656	$-0^{\rm m}.485$
1503	0.2764	$-0^{\rm m}.451$
1624	0.2885	$-0^{\rm m}.508$
1749	0.3010	$-0^{\rm m}.542$
1845	0.3106	$-0^{\rm m}.599$
1924	0.3185	$-0^{\rm m}.630$
2116	0.3377	$-0^{\rm m}.675$
2223	0.3484	$-0^{\rm m}.616$
2370	0.3631	$-0^{\rm m}.628$
2442		
008.1435	+0.0177	$-0^{\rm m}.140$
1527	0.0269	$-0^{\rm m}.240$
1614	0.0356	$-0^{\rm m}.355$
1719	0.0461	$-0^{\rm m}.391$
1810	0.0552	$-0^{\rm m}.515$
1897	0.0639	$-0^{\rm m}.567$
2056	0.0798	$-0^{\rm m}.603$
009.0785	−0.0652	$-0^{\rm m}.534$
0900	−0.0537	$-0^{\rm m}.507$
0996	−0.0441	$-0^{\rm m}.371$
1076	−0.0361	$-0^{\rm m}.347$
1157	−0.0280	$-0^{\rm m}.296$
1389	−0.0048	$-0^{\rm m}.116$
1497	+0.0060	$-0^{\rm m}.007$
1603	0.0166	$-0^{\rm m}.068$
1690	0.0253	$-0^{\rm m}.188$
1781	0.0344	$-0^{\rm m}.288$
1868	0.0431	$-0^{\rm m}.431$
1961	0.0524	$-0^{\rm m}.514$
2058	0.0621	$-0^{\rm m}.622$
2149	0.0712	$-0^{\rm m}.607$
015.0740	+0.3313	$-0^{\rm m}.543$
0859	0.3432	$-0^{\rm m}.608$
0997	0.3570	$-0^{\rm m}.624$
1183	0.3756	$-0^{\rm m}.588$
1805	0.4378	$-0^{\rm m}.607$
1938	0.4511	$-0^{\rm m}.512$
2010	0.4583	$-0^{\rm m}.430$
2072	0.4645	$-0^{\rm m}.452$
342.1539	+0.1274	$-0^{\rm m}.581$
1815	0.1550	$-0^{\rm m}.534$
1899	0.1634	$-0^{\rm m}.547$
2013	0.1748	$-0^{\rm m}.597$
2141	0.1876	$-0^{\rm m}.525$
355.2541	−0.1711	$-0^{\rm m}.600$
2700	−0.1552	$-0^{\rm m}.619$
2842	−0.1410	$-0^{\rm m}.549$
2966	−0.1286	$-0^{\rm m}.629$
3295	−0.0957	$-0^{\rm m}.643$
3441	−0.0811	$-0^{\rm m}.577$
3711	−0.0541	$-0^{\rm m}.531$
3859	−0.0393	$-0^{\rm m}.417$
4028	−0.0224	$-0^{\rm m}.224$
357.2122	−0.0842	$-0^{\rm m}.694$
2270	−0.0694	$-0^{\rm m}.675$
2356	−0.0608	$-0^{\rm m}.466$
360.0992	+0.2578	$-0^{\rm m}.527$
1127	0.2713	$-0^{\rm m}.506$
1242	0.2828	$-0^{\rm m}.489$
1386	0.2972	$-0^{\rm m}.526$
1483	0.3069	$-0^{\rm m}.545$
1590	0.3176	$-0^{\rm m}.555$
1706	0.3292	$-0^{\rm m}.568$
1815	0.3401	$-0^{\rm m}.568$
1952	0.3538	$-0^{\rm m}.573$
2085	0.3671	$-0^{\rm m}.598$
2218	0.3804	$-0^{\rm m}.659$
2318	0.3904	$-0^{\rm m}.639$

Table I.—Continued

JD (Hel)	Phase in days	$\Delta m(U)$ V − C
2404	0.3990	$-0^{m}.734$
687.1674	+0.0422	$-0^{m}.387$
1835	0.0583	$-0^{m}.503$
2226	0.0974	$-0^{m}.623$
2384	0.1132	$-0^{m}.631$
2587	0.1335	$-0^{m}.619$
2953	0.1701	$-0^{m}.608$
3105	0.1853	$-0^{m}.582$
3157	0.1905	$-0^{m}.570$
3226	0.1974	$-0^{m}.546$
697.1438	−0.1613	$-0^{m}.614$
1579	−0.1472	$-0^{m}.612$
1693	−0.1358	$-0^{m}.606$
1820	−0.1231	$-0^{m}.607$
1938	−0.1113	$-0^{m}.645$
2044	−0.1007	$-0^{m}.571$
2161	−0.0890	$-0^{m}.657$
2278	−0.0773	$-0^{m}.578$
2435	−0.0616	$-0^{m}.549$
2576	−0.0475	$-0^{m}.391$
2616	−0.0435	$-0^{m}.375$
2649	−0.0402	$-0^{m}.373$
2683	−0.0368	$-0^{m}.417$
2713	−0.0338	$-0^{m}.332$
2749	−0.0302	$-0^{m}.283$
2781	−0.0270	$-0^{m}.277$
2818	−0.0233	$-0^{m}.277$
2854	−0.0197	$-0^{m}.183$

JD (Hel) days	Phase in	$\Delta m(U)$ V − C
2894	−0.0157	$-0^{m}.196$
2944	−0.0107	$+0^{m}.002$
2978	−0.0073	$-0^{m}.033$
3013	−0.0038	$-0^{m}.010$
3131	+0.0080	$-0^{m}.091$
727.0769	+0.2141	$-0^{m}.483$
0839	0.2211	$-0^{m}.453$
1048	0.2420	$-0^{m}.415$
1217	0.2589	$-0^{m}.472$
1306	0.2678	$-0^{m}.466$
1445	0.2817	$-0^{m}.464$
1599	0.2971	$-0^{m}.533$
1756	0.3128	$-0^{m}.576$
1939	0.3311	$-0^{m}.638$
2043	0.3415	$-0^{m}.566$
2154	0.3526	$-0^{m}.700$
2252	0.3624	$-0^{m}.598$
732.0579	+0.1411	$-0^{m}.587$
0681	0.1513	$-0^{m}.605$
0826	0.1658	$-0^{m}.571$
1001	0.1833	$-0^{m}.593$
1129	0.1961	$-0^{m}.533$
1267	0.2099	$-0^{m}.481$
1363	0.2195	$-0^{m}.431$
1523	0.2355	$-0^{m}.442$
1622	0.2454	$-0^{m}.427$
1715	0.2547	$-0^{m}.451$
1835	0.2667	$-0^{m}.455$

Standard *B* magnitudes of EE Aqr

JD (Hel)	Phase in days	$\Delta m(B)$ V − C
2441		
985.1265	−0.0945	$-0^{m}.543$
1434	−0.0776	$-0^{m}.589$
1470	−0.0740	$-0^{m}.412$
1608	−0.0602	$-0^{m}.470$
1781	−0.0429	$-0^{m}.382$
1928	−0.0282	$-0^{m}.166$
2058	−0.0152	$-0^{m}.040$
2200	−0.0010	$+0^{m}.042$
2343	+0.0133	$+0^{m}.015$
2471	0.0261	$-0^{m}.208$
2608	0.0398	$-0^{m}.354$
2751	0.0541	$-0^{m}.409$

JD (Hel)	Phase in days	$\Delta m(B)$ V − C
986.0793	−0.1597	$-0^{m}.505$
0998	−0.1392	$-0^{m}.584$
1166	−0.1224	$-0^{m}.551$
1295	−0.1095	$-0^{m}.585$
1442	−0.0948	$-0^{m}.535$
1590	−0.0800	$-0^{m}.483$
1743	−0.0647	$-0^{m}.449$
2296	−0.0094	$-0^{m}.010$
2421	+0.0031	$+0^{m}.111$
987.0861	−0.1709	$-0^{m}.444$
1166	−0.1404	$-0^{m}.532$
1577	−0.0993	$-0^{m}.547$
1703	−0.0867	$-0^{m}.514$

Table I.—Continued

JD (Hel)	Phase in days	$\Delta m(B)$ $V-C$
1847	−0.0723	$-0^{m}.513$
1890	−0.0680	$-0^{m}.444$
2367	−0.0203	$-0^{m}.018$
992.1564	+0.3185	$-0^{m}.578$
1684	0.3305	$-0^{m}.461$
1814	0.3435	$-0^{m}.516$
1925	0.3546	$-0^{m}.586$
2184	0.3805	$-0^{m}.499$
2334	0.3955	$-0^{m}.591$
994.1134	+0.2395	$-0^{m}.308$
1279	0.2540	$-0^{m}.323$
1383	0.2644	$-0^{m}.434$
1494	0.2755	$-0^{m}.402$
1611	0.2872	$-0^{m}.420$
1738	0.2999	$-0^{m}.469$
1835	0.3096	$-0^{m}.562$
1914	0.3175	$-0^{m}.602$
1990	0.3251	$-0^{m}.536$
2101	0.3362	$-0^{m}.610$
2213	0.3474	$-0^{m}.605$
995.0980	+0.2061	$-0^{m}.426$
1092	0.2173	$-0^{m}.428$
1218	0.2299	$-0^{m}.382$
1339	0.2420	$-0^{m}.404$
1467	0.2548	$-0^{m}.452$
1833	0.2914	$-0^{m}.437$
1974	0.3055	$-0^{m}.574$
2442		
008.1439	+0.0181	$-0^{m}.100$
1531	0.0273	$-0^{m}.166$
1620	0.0362	$-0^{m}.330$
1724	0.0466	$-0^{m}.289$
1814	0.0556	$-0^{m}.439$
1902	0.0644	$-0^{m}.412$
1981	0.0723	$-0^{m}.513$
2060	0.0802	$-0^{m}.509$
2144	0.0886	$-0^{m}.558$
2236	0.0978	$-0^{m}.582$
009.0791	−0.0646	$-0^{m}.465$
0906	−0.0531	$-0^{m}.431$
1001	−0.0436	$-0^{m}.317$
1081	−0.0356	$-0^{m}.307$
1162	−0.0275	$-0^{m}.182$
1298	−0.0139	$-0^{m}.066$
1395	−0.0042	$-0^{m}.045$
1502	+0.0065	$+0^{m}.092$
1609	0.0172	$-0^{m}.023$

JD (Hel)	Phase in days	$\Delta m(B)$ $V-C$
1696	0.0259	$-0^{m}.198$
1784	0.0347	$-0^{m}.275$
1873	0.0436	$-0^{m}.365$
1966	0.0529	$-0^{m}.411$
2062	0.0625	$-0^{m}.504$
2154	0.0717	$-0^{m}.529$
015.0726	+0.3299	$-0^{m}.493$
0844	0.3417	$-0^{m}.554$
0979	0.3552	$-0^{m}.560$
1167	0.3740	$-0^{m}.554$
1793	0.4366	$-0^{m}.585$
1924	0.4497	$-0^{m}.447$
1997	0.4570	$-0^{m}.466$
2061	0.4634	$-0^{m}.408$
342.1527	+0.1262	$-0^{m}.581$
1803	0.1538	$-0^{m}.534$
1886	0.1621	$-0^{m}.547$
2002	0.1737	$-0^{m}.597$
2127	0.1862	$-0^{m}.525$
355.2529	−0.1723	$-0^{m}.616$
2828	−0.1424	$-0^{m}.584$
2952	−0.1300	$-0^{m}.612$
3281	−0.0971	$-0^{m}.624$
3561	−0.0691	$-0^{m}.532$
3693	−0.0559	$-0^{m}.451$
3844	−0.0408	$-0^{m}.275$
4002	−0.0250	$-0^{m}.270$
4010	−0.0242	$-0^{m}.014$
357.2129	−0.0835	$-0^{m}.611$
2276	−0.0688	$-0^{m}.575$
2365	−0.0599	$-0^{m}.453$
2525	−0.0439	$-0^{m}.493$
360.0996	+0.2582	$-0^{m}.463$
1132	0.2718	$-0^{m}.447$
1248	0.2834	$-0^{m}.438$
1390	0.2976	$-0^{m}.485$
1486	0.3072	$-0^{m}.494$
1595	0.3181	$-0^{m}.528$
1710	0.3296	$-0^{m}.556$
1821	0.3407	$-0^{m}.527$
1957	0.3543	$-0^{m}.587$
2091	0.3677	$-0^{m}.620$
2223	0.3809	$-0^{m}.657$
2322	0.3908	$-0^{m}.662$
687.1696	+0.0444	$-0^{m}.356$
1865	0.0613	$-0^{m}.482$
2035	0.0783	$-0^{m}.532$
2242	0.0990	$-0^{m}.568$

Table I.—Continued

JD (Hel)	Phase in days	$\Delta m(B)$ $V-C$	JD (Hel)	Phase in days	$\Delta m(B)$ $V-C$
2398	0.1146	$-0^m.581$	729.0779	+0.2151	$-0^m.427$
2599	0.1347	$-0^m.584$	0852	0.2224	$-0^m.479$
2966	0.1714	$-0^m.622$	0952	0.2324	$-0^m.403$
3118	0.1866	$-0^m.591$	1065	0.2437	$-0^m.369$
3166	0.1914	$-0^m.582$	1150	0.2522	$-0^m.401$
3239	0.1987	$-0^m.572$	1227	0.2599	$-0^m.394$
697.1346	−0.1705	$-0^m.523$	1321	0.2693	$-0^m.374$
1585	−0.1466	$-0^m.568$	1458	0.2830	$-0^m.370$
1699	−0.1352	$-0^m.539$	1614	0.2986	$-0^m.439$
1942	−0.1109	$-0^m.607$	1765	0.3137	$-0^m.494$
2047	−0.1004	$-0^m.555$	1861	0.3233	$-0^m.499$
2165	−0.0886	$-0^m.641$	1951	0.3323	$-0^m.544$
2284	−0.0767	$-0^m.557$	2056	0.3428	$-0^m.529$
2443	−0.0608	$-0^m.516$	2166	0.3538	$-0^m.516$
2585	−0.0466	$-0^m.387$	2271	0.3643	$-0^m.579$
2623	−0.0428	$-0^m.362$	732.0696	+0.1528	$-0^m.575$
2655	−0.0396	$-0^m.400$	0839	0.1671	$-0^m.557$
2688	−0.0363	$-0^m.398$	0927	0.1759	$-0^m.497$
2718	−0.0333	$-0^m.306$	1011	0.1843	$-0^m.578$
2752	−0.0299	$-0^m.207$	1143	0.1975	$-0^m.499$
2786	−0.0265	$-0^m.213$	1375	0.2207	$-0^m.432$
2823	−0.0228	$-0^m.266$	1540	0.2372	$-0^m.463$
2860	−0.0191	$-0^m.190$	1632	0.2464	$-0^m.376$
2900	−0.0151	$-0^m.148$	1726	0.2558	$-0^m.347$
2949	−0.0102	$+0^m.005$	1846	0.2678	$-0^m.384$
2982	−0.0069	$+0^m.006$	1933	0.2765	$-0^m.376$
3017	−0.0034	$+0^m.035$	2031	0.2863	$-0^m.442$
3137	+0.0086	$-0^m.040$	2107	0.2939	$-0^m.496$
3165	0.0114	$-0^m.056$			

Standard V magnitudes of EE Aqr

JD (Hel)	Phase in days	$\Delta m(V)$ $V-C$	JD (Hel)	Phase in days	$\Delta m(V)$ $V-C$
2441			986.0792	−0.1598	$-0^m.987$
985.1274	−0.0936	$-1^m.013$	1011	−0.1379	$-1^m.010$
1477	−0.0733	$-0^m.957$	1172	−0.1218	$-1^m.017$
1621	−0.0589	$-0^m.917$	1304	−0.1086	$-1^m.011$
1794	−0.0416	$-0^m.789$	1452	−0.0938	$-0^m.975$
1934	−0.0276	$-0^m.668$	1600	−0.0790	$-0^m.955$
2066	−0.0144	$-0^m.489$	1754	−0.0636	$-0^m.898$
2208	−0.0002	$-0^m.415$	2302	−0.0088	$-0^m.455$
2348	+0.0138	$-0^m.517$	2431	+0.0041	$-0^m.423$
2477	0.0267	$-0^m.645$	987.0862	−0.1708	$-0^m.988$
2614	0.0404	$-0^m.778$	1018	−0.1552	$-0^m.980$
2758	0.0548	$-0^m.909$	1176	−0.1394	$-0^m.998$

Table I.—Continued

JD (Hel)	Phase in days	$\Delta m(V)$ $V - C$
1587	−0.0983	$-0^{m}.978$
1713	−0.0857	$-0^{m}.971$
1858	−0.0712	$-0^{m}.933$
1905	−0.0665	$-0^{m}.926$
2377	−0.0193	$-0^{m}.518$
2475	−0.0095	$-0^{m}.374$
992.1465	+0.3086	$-0^{m}.931$
1570	0.3191	$-0^{m}.969$
1689	0.3310	$-0^{m}.975$
1818	0.3439	$-0^{m}.962$
1930	0.3551	$-0^{m}.991$
2047	0.3668	$-1^{m}.017$
2192	0.3813	$-1^{m}.057$
2339	0.3960	$-1^{m}.068$
2465	0.4086	$-1^{m}.031$
994.1157	+0.2418	$-0^{m}.862$
1285	0.2546	$-0^{m}.816$
1390	0.2651	$-0^{m}.858$
1499	0.2760	$-0^{m}.884$
1619	0.2880	$-0^{m}.920$
1744	0.3005	$-0^{m}.924$
1841	0.3102	$-0^{m}.953$
1920	0.3181	$-0^{m}.969$
1996	0.3257	$-0^{m}.965$
2108	0.3369	$-0^{m}.955$
2219	0.3480	$-1^{m}.058$
2330	0.3591	$-1^{m}.023$
995.0987	+0.2068	$-0^{m}.954$
1100	0.2181	$-0^{m}.918$
1229	0.2310	$-0^{m}.875$
1348	0.2429	$-0^{m}.815$
1477	0.2558	$-0^{m}.804$
1839	0.2920	$-0^{m}.877$
1984	0.3065	$-0^{m}.930$
2182	0.3263	$+0^{m}.957$
2442		
008.1443	+0.0185	$-0^{m}.579$
1536	0.0278	$-0^{m}.663$
1626	0.0368	$-0^{m}.787$
1729	0.0471	$-0^{m}.847$
1821	0.0563	$-0^{m}.894$
1906	0.0648	$-0^{m}.946$
1987	0.0729	$-0^{m}.966$
2065	0.0807	$-0^{m}.993$
2148	0.0890	$-1^{m}.021$
2244	0.0986	$-1^{m}.035$
009.0818	−0.0619	$-0^{m}.933$
0911	−0.0526	$-0^{m}.897$
1007	−0.0430	$-0^{m}.842$
1086	−0.0351	$-0^{m}.736$
1167	−0.0270	$-0^{m}.650$
1307	−0.0130	$-0^{m}.435$
1403	−0.0034	$-0^{m}.402$
1507	+0.0070	$-0^{m}.454$
1614	0.0177	$-0^{m}.539$
1701	0.0264	$-0^{m}.620$
1790	0.0353	$-0^{m}.757$
1880	0.0443	$-0^{m}.833$
1972	0.0535	$-0^{m}.883$
2067	0.0630	$-0^{m}.907$
2161	0.0724	$-0^{m}.988$
015.0734	+0.3307	$-0^{m}.993$
0852	0.3425	$-1^{m}.007$
0989	0.3562	$-0^{m}.997$
1176	0.3749	$-1^{m}.020$
1799	0.4372	$-0^{m}.979$
1932	0.4505	$-0^{m}.942$
2007	0.4580	$-0^{m}.882$
2067	0.4640	$-0^{m}.855$
342.1533	+0.1268	$-0^{m}.985$
1694	0.1429	$-0^{m}.976$
1809	0.1544	$-0^{m}.979$
1893	0.1628	$-0^{m}.954$
2007	0.1742	$-0^{m}.944$
2135	0.1870	$-0^{m}.932$
2417	0.2152	$-0^{m}.918$
355.2533	−0.1719	$-0^{m}.957$
2688	−0.1564	$-0^{m}.978$
2836	−0.1416	$-1^{m}.017$
2959	−0.1293	$-1^{m}.020$
3289	−0.0963	$-1^{m}.015$
3434	−0.0818	$-0^{m}.998$
3569	−0.0683	$-0^{m}.967$
3701	−0.0551	$-0^{m}.900$
3851	−0.0401	$-0^{m}.823$
4018	−0.0234	$-0^{m}.564$
357.2136	−0.0828	$-1^{m}.026$
2283	−0.0681	$-0^{m}.953$
2369	−0.0595	$-0^{m}.958$
2535	−0.0429	$-0^{m}.823$
360.1012	+0.2598	$-0^{m}.837$
1137	0.2723	$-0^{m}.847$
1251	0.2837	$-0^{m}.876$
1394	0.2980	$-0^{m}.918$
1490	0.3076	$-0^{m}.934$

Table I.—Continued

JD (Hel)	Phase in days	$\Delta m(V)$ $V-C$	JD (Hel)	Phase in days	$\Delta m)V)$ $V-C$
1601	0.3187	$-0^{m}.961$	2866	−0.0185	$-0^{m}.501$
1714	0.3300	$-0^{m}.982$	2905	−0.0146	$-0^{m}.471$
1827	0.3413	$-1^{m}.000$	2955	−0.0096	$-0^{m}.474$
1963	0.3549	$-1^{m}.027$	2988	−0.0063	$-0^{m}.438$
2096	0.3682	$-1^{m}.053$	3023	−0.0028	$-0^{m}.426$
2229	0.3815	$-1^{m}.060$	3143	+0.0092	$-0^{m}.414$
2328	0.3914	$-1^{m}.086$	3167	0.0116	$-0^{m}.429$
687.1701	+0.0449	$-0^{m}.811$	729.0782	+0.2154	$-0^{m}.906$
1871	0.0619	$-0^{m}.924$	0857	0.2229	$-0^{m}.890$
2041	0.0789	$-0^{m}.960$	0957	0.2329	$-0^{m}.854$
2246	0.0994	$-1^{m}.001$	1070	0.2442	$-0^{m}.841$
2408	0.1156	$-1^{m}.040$	1155	0.2527	$-0^{m}.869$
2605	0.1353	$-1^{m}.028$	1231	0.2603	$-0^{m}.843$
2971	0.1719	$-0^{m}.972$	1327	0.2699	$-0^{m}.855$
3124	0.1872	$-0^{m}.965$	1464	0.2836	$-0^{m}.870$
3171	0.1919	$-0^{m}.947$	1618	0.2990	$-0^{m}.911$
3244	0.1992	$-0^{m}.945$	1768	0.3140	$-0^{m}.932$
697.1349	−0.1702	$-0^{m}.935$	1866	0.3238	$-0^{m}.960$
1448	−0.1603	$-0^{m}.984$	2061	0.3433	$-0^{m}.995$
1594	−0.1457	$-1^{m}.032$	2170	0.3542	$-1^{m}.002$
1829	−0.1222	$-1^{m}.029$	2278	0.3650	$-1^{m}.038$
1945	−0.1106	$-1^{m}.060$	732.0598	+0.1430	$-1^{m}.038$
2053	−0.0998	$-1^{m}.028$	0701	0.1533	$-1^{m}.013$
2171	−0.0880	$-1^{m}.000$	0844	0.1676	$-0^{m}.994$
2290	−0.0761	$-0^{m}.981$	0932	0.1764	$-1^{m}.004$
2451	−0.0600	$-0^{m}.912$	1015	0.1847	$-0^{m}.952$
2593	−0.0458	$-0^{m}.842$	1147	0.1979	$-0^{m}.923$
2629	−0.0422	$-0^{m}.800$	1283	0.2115	$-0^{m}.909$
2660	−0.0391	$-0^{m}.756$	1378	0.2210	$-0^{m}.887$
2694	−0.0357	$-0^{m}.682$	1543	0.2375	$-0^{m}.854$
2723	−0.0328	$-0^{m}.719$	1732	0.2564	$-0^{m}.857$
2758	−0.0293	$-0^{m}.689$	1851	0.2683	$-0^{m}.898$
2790	−0.0261	$-0^{m}.648$	1939	0.2771	$-0^{m}.906$
2828	−0.0223	$-0^{m}.521$			

TABLE II

Observed epochs of primary minima (JD Hel)	O–C based on the period by	
	This author	Williamon
2441985.221	$0^{d}.000$	$-0^{d}.004$
2442009.144	0.000	−0.004
2442697.306	0.000	−0.004

and the constants were determined from the method given by Merrill (1970). The values of the reflection rectification coefficients D_0, D_1 and D_2 in the formulation were determined after the method given by Binnendijk (1970). For the purpose of initial rectification, an inclination of 70° was assumed. Limb-darkenings of 0.4 for B and V and 0.6 for U seem to fit the observations best. The rectification in intensity and phase angle are given (Binnendijk, 1970) by

$$l_r = \frac{l - B_1 \sin\theta - B_2 \sin 2\theta + D_0 + D_1 \cos\theta + D_2 \cos^2\theta}{(C_0 + D_0) + (C_2 + D_2)\cos^2\theta},$$

$$\sin^2\theta_r = \frac{\sin^2\theta}{1 - z\cos^2\theta},$$

where z is the ellipticity coefficient. The Fourier coefficients and the rectification constants for U, B, V filters are given in Table III. The O–C intensities determined for the non-eclipsed region – that is, from phase 40° to 140° and 220° to 320° – for the U, B, V light curves have been reported in Table IV. These values of intensities indicate quite a good fit of the curve represented by the above equation for the non-eclipsed light variation of the system.

TABLE III

Rectification coefficients for EE Aqr

Filter	Fourier coefficients				
	A_0	A_1	A_2	A_3	A_4
U	0.8350 ± 60	−0.0286 ± 26	−0.1060 ± 96	−0.0143 ± 13	−0.0300 ± 48
B	0.8440 ± 60	−0.0345 ± 30	−0.0850 ± 96	−0.0103 ± 15	−0.0210 ± 48
V	0.8780 ± 60	−0.0364 ± 32	−0.0880 ± 96	−0.0222 ± 16	−0.0080 ± 48

Filter	Fourier coefficients			
	B_1	B_2	B_3	B_4
U	−0.0012 ± 14	0.0060 ± 12	−0.0002 ± 26	0.0015 ± 26
B	−0.0023 ± 14	−0.0060 ± 12	0.0001 ± 26	−0.0027 ± 26
V	−0.0029 ± 14	0.0020 ± 12	0.0051 ± 26	−0.0025 ± 26

Filter	Reflection and ellipticity coefficients			
	D_0	D_1	D_2	Z
U	0.0158	0.0286	0.0139	0.1878
B	0.0252	0.0345	0.0228	0.1939
V	0.0250	0.0364	0.0221	0.1914

TABLE IV

Observed (O) minus computed (C) intensities for non-eclipsed region

Phase in degrees	*U*			*B*			*V*		
	O	C	O–C	O	C	O–C	O	C	O–C
40	0.825	0.835	−0.010	0.810	0.819	−0.009	0.850	0.857	−0.007
50	0.876	0.879	−0.003	0.855	0.859	−0.004	0.896	0.899	−0.003
60	0.906	0.906	0.000	0.886	0.885	0.001	0.930	0.931	−0.001
70	0.911	0.915	−0.004	0.902	0.899	0.003	0.945	0.949	−0.004
80	0.911	0.914	−0.003	0.902	0.904	−0.002	0.948	0.954	−0.006
90	0.910	0.910	0.000	0.905	0.906	−0.001	0.950	0.950	0.000
100	0.910	0.907	0.003	0.905	0.907	−0.002	0.945	0.940	0.005
110	0.906	0.905	0.001	0.905	0.907	−0.002	0.930	0.928	0.002
120	0.896	0.898	−0.002	0.905	0.905	0.000	0.915	0.916	−0.001
130	0.884	0.881	0.003	0.905	0.895	0.010	0.900	0.902	−0.002
140	0.850	0.852	−0.002	0.890	0.876	0.014	0.880	0.888	−0.008
220	0.880	0.867	0.013	0.872	0.865	0.007	0.886	0.886	0.000
230	0.896	0.894	0.002	0.892	0.889	0.004	0.910	0.907	0.003
240	0.906	0.908	−0.002	0.900	0.903	−0.003	0.930	0.928	0.002
250	0.907	0.912	−0.005	0.906	0.909	−0.003	0.945	0.946	−0.001
260	0.911	0.912	−0.001	0.910	0.911	−0.001	0.955	0.959	−0.004
270	0.911	0.912	−0.001	0.910	0.910	0.000	0.965	0.966	−0.001
280	0.912	0.913	−0.001	0.910	0.910	0.000	0.965	0.964	0.001
290	0.910	0.912	−0.002	0.907	0.906	0.001	0.950	0.952	−0.002
300	0.900	0.900	0.000	0.895	0.895	0.000	0.930	0.928	0.002
310	0.875	0.871	0.004	0.870	0.872	−0.002	0.895	0.893	0.002
320	0.822	0.824	−0.002	0.820	0.836	−0.016	0.850	0.850	0.000

5. Orbital Solution

The primary minima alone were used to obtain the photometric elements because the rectified depth of the secondary minima is very small. In the *U* filter, the depth of secondary minimum is almost undetectable. Hence, the solution could be possible in *B* and *V* filters only. In Figure 2, l_r (rectified) versus sin θ_r (rectified phase) have been plotted for the *B* and *V* filters, all the individual and normal points having been considered. The χ-values indicate that the primary eclipse is a transit while the secondary eclipse is an occultation. The elements have been derived with the help of tables of the χ-function (Merrill, 1950), the procedure described by Russell and Merrill (1952) having been followed. Solutions for each of the two light curves were calculated independently. The computed points for the primary minima have been obtained through use of the relation:

$$\sin^2 \theta_r(n) = \sin^2 \theta_r(\tfrac{1}{2})\chi(x, k, \alpha_0, n),$$

where θ_r is the rectified phase and x is the limb-darkening. The computed points for the primary minima are plotted as filled circles in Figure 2. The orbital elements in

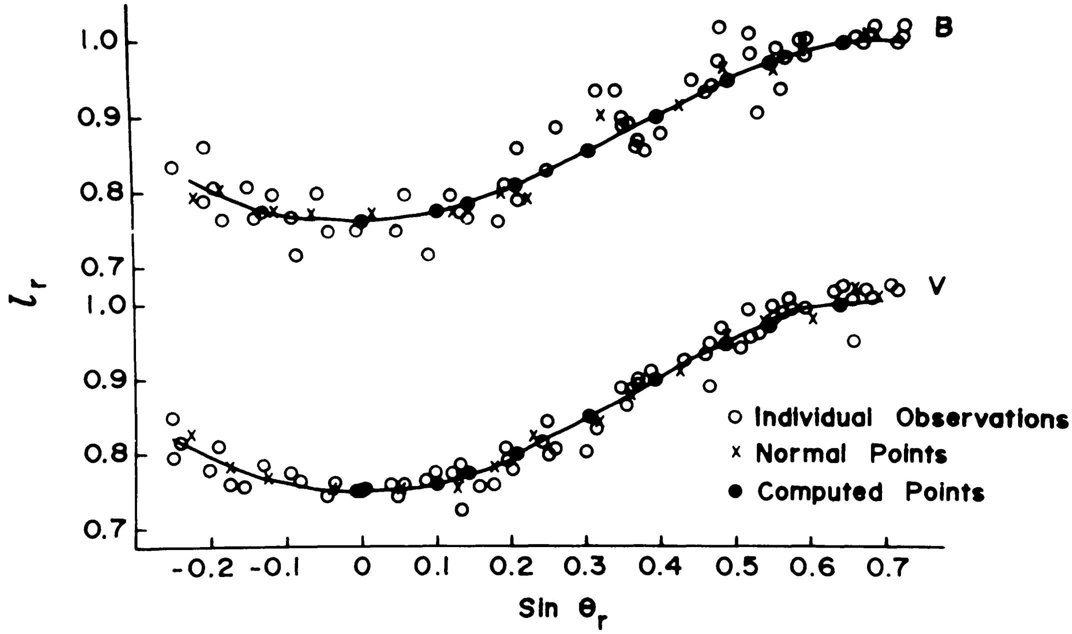

Fig. 2. Intensity curves for EE Aqr in B and V.

TABLE V

Orbital elements of EE Aqr

Elements	B-filter	V-filter	Mean
x	0.4 (assumed)	0.4 (assumed)	0.4
k	0.90	0.90	0.90
r_g	0.362	0.441	0.402
r_s	0.326	0.396	0.361
L_g	0.839	0.877	0.858
L_s	0.161	0.123	0.142
θ_e	39°81	39°90	39°86
i	66°73	61°68	64°21
J_g/J_s	4.222	5.775	4.998
z	0.194	0.191	0.193
j	69°23	64°75	66°99
a_g	0.362	0.441	0.402
a_s	0.326	0.396	0.361
b_g	0.319	0.386	0.353
b_s	0.288	0.347	0.318
ε	0.118	0.125	0.122
p	0.100	0.085	0.093
α_0^{oc}	0.280	0.285	0.283
α_0^{tr}	0.334	0.340	0.337
$1 - l_0^{oc}$	0.045	0.035	0.040
$1 - l_0^{tr}$	0.235	0.250	0.243
τ	0.8383	0.8383	0.8383

TABLE VI

Filter	Primary component L_g	Secondary component L_s $(=1 - L_g)$
U	0.779 (0.922)	0.221 (0.078)
B	0.839 (0.941)	0.161 (0.059)
V	0.877 (0.881)	0.123 (0.119)

the B and V colours are summarized in Table V, where the symbols have their usual meanings.

6. The Colour of the Components

The average V-magnitude for the system (outside eclipse) is $+6\overset{m}{.}06$ and the average $B - V$ and $U - B$ colours as read out from Figure 2 of Williamon are, respectively, $+0\overset{m}{.}36$ and $+0\overset{m}{.}05$. Following the method given by Kitamura (1976), the colour of the individual components based on the fractional luminosities given by Williamon are:

Primary component: $B - V = 0\overset{m}{.}290$; $U - B = 0\overset{m}{.}072$;

Secondary component: $B - V = 1\overset{m}{.}124$; $U - B = -0\overset{m}{.}254$.

However, based on the fractional luminosities derived by us, the colours are found to be:

Primary component: $B - V = 0\overset{m}{.}410$; $U - B = 0\overset{m}{.}130$;

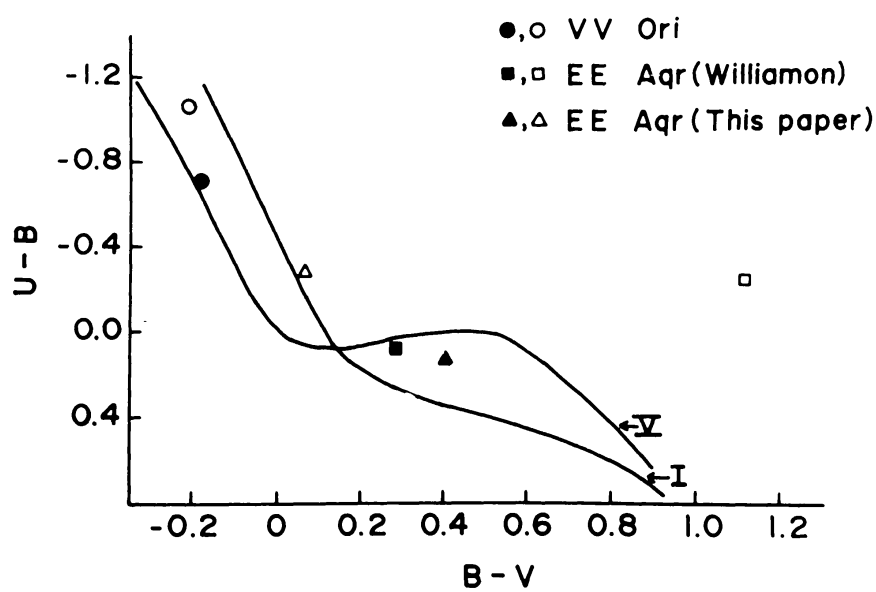

Fig. 3. Two-colour diagram for EE Aqr. The filled symbols stand for the primary component and the open ones for the secondary component.

Secondary component: $B - V = 0^m.070$; $U - B = -0^m.294$

Further, the values of fractional luminosities of the components have also been determined. These are given in Table VI; the corresponding values determined by Williamon are given within brackets.

The above colours of the individual components, assuming there is no reddening, are plotted on the two-colour diagram (Figure 3). The position of VV Ori (a β Lyrae-type star) is also plotted for comparison. It appears that the primary component belongs to spectral class FV while the secondary component is an evolved A-type star.

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