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LIGHT CURVE SOLUTION OF THE CONTACT BINARY AW UMa[1]

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ABSTRACT

A total of 1088 observations (272 in B, 272 in V, 272 in R, and 272 in I) were made from January to February in 1995 at Chungbuk National University Observatory (CbNUO). We constructed $BVRI$ light curves with our data. The photometric solution of these light curves was obtained by means of the Wilson-Devinney method. Our result was compared with those by previous investigators.

1. INTRODUCTION

Since light variability of AW UMa was discovered by Paczynski (1964), many photometric and spectroscopic investigations have been carried out (Kalish 1965, Eggen 1967, Mochnacki & Doughty 1972, Rucinski 1973, Wilson & Devinney 1973, Lucy 1973, Dworak & Kurpinska 1975, Ferland & McMillan 1976, Binnendijk 1977, Al-Naimiy 1978, Woodward *et al.* 1980, Kurpinska-Winiarska 1980, Istomin *et al.* 1980, Mikolajewska & Mikolajewski 1980, McLean 1981, Hrivnak 1982, Srivastava 1989, Derman *et al.* 1990, Yim & Jeong 1995).

The spectral type of AW UMa is $F0 - F2$, and its orbital period is 0.4387317 day. The mass ratio of this system is $0.07 < q < 0.08$, which is known as a smallest one. The system belongd to W UMa A type, and shows very shallow total eclipse. The changes of eclipse depth were reported by Paczynski (1964), Kalish (1965), Dworak & Kurpinska (1975), Hrivnak (1982), and Derman *et al.* (1990).

Although there are many results of study, the physical characteristics of AW UMa are not yet clearly explained. These include light variation, period variation, the disparity on the H-R diagram related to the mass ratio determined by photometric studies and spectroscopic studies, and the evolution stage of this star.

In this paper we present a list of 1088 observations made in 1995 and the result of light curve solutions obtained by means of Wilson-Devinney method.

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Table 1. $BVRI$ observations of AW UMa in 1995.

$JD_{\odot}$ 2449000+	ΔB	ΔV	ΔR	ΔI	$JD_{\odot}$ 2449000+	ΔB	ΔV	ΔR	ΔI
724.1228	0.022	-0.061	-0.050	-0.085	742.2247	0.180	0.167	0.120	0.083
724.1258	-0.020	-0.046	-0.058	-0.116	742.2277	0.163	0.168	0.115	0.091
724.2165	0.258	0.181	0.189	0.144	742.2304	0.198	0.158	0.133	0.091
724.2209	0.221	0.248	0.188	0.117	742.2399	0.138	0.118	0.074	0.056
724.2234	0.224	0.226	0.159	0.108	742.2423	0.143	0.114	0.064	0.058
724.2303	0.199	0.163	0.131	0.126	742.2469	0.159	0.084	0.045	0.037
724.2352	0.263	0.158	0.135	0.106	742.2544	0.117	0.039	0.024	0.004
724.2372	0.241	0.195	0.131	0.109	742.2568	0.085	0.018	0.004	-0.016
724.2419	0.183	0.147	0.108	0.084	742.2602	0.072	-0.002	-0.001	-0.031
724.2811	0.050	0.023	-0.016	-0.050	742.2655	0.025	0.001	-0.021	-0.033
724.2833	0.020	-0.009	-0.037	-0.063	742.2676	0.024	-0.001	-0.020	-0.034
724.2880	-0.013	-0.042	-0.065	-0.076	742.2703	0.031	-0.003	-0.034	-0.052
724.2901	0.009	-0.021	-0.068	-0.095	742.2742	0.007	-0.018	-0.059	-0.075
724.3044	0.037	-0.039	-0.058	-0.095	742.2766	-0.008	-0.050	-0.084	-0.069
724.3087	0.017	-0.018	-0.034	-0.071	742.2819	0.014	-0.026	-0.043	-0.070
724.3118	-0.018	-0.050	-0.049	-0.088	742.2908	-0.023	-0.038	-0.081	-0.081
724.3157	-0.011	-0.050	-0.059	-0.102	742.2930	-0.030	-0.051	-0.079	-0.087
724.3251	-0.049	-0.089	-0.103	-0.147	742.2955	-0.031	-0.053	-0.079	-0.096
724.3274	-0.038	-0.092	-0.100	-0.121	742.3049	-0.032	-0.044	-0.086	-0.105
724.3295	-0.041	-0.095	-0.100	-0.121	742.3071	-0.032	-0.053	-0.090	-0.106
724.3363	-0.074	-0.112	-0.101	-0.134	742.3094	-0.045	-0.040	-0.073	-0.101
724.3395	-0.057	-0.128	-0.137	-0.158	742.3143	-0.004	-0.034	-0.067	-0.094
724.3424	0.012	-0.039	-0.087	-0.102	742.3165	0.004	-0.051	-0.067	-0.095
724.3506	0.025	-0.045	-0.042	-0.080	742.3186	-0.028	-0.048	-0.062	-0.095
724.3527	0.049	0.003	-0.032	-0.061	742.3229	-0.005	-0.059	-0.086	-0.102
724.3557	-0.005	-0.037	-0.050	-0.072	742.3258	-0.022	-0.022	-0.080	-0.083
724.3606	0.042	-0.020	-0.048	-0.065	742.3295	-0.034	-0.016	-0.063	-0.080
724.3627	0.036	-0.018	-0.049	-0.071	742.3446	0.015	0.023	-0.036	-0.054
724.3649	0.031	0.017	-0.017	-0.040	742.3481	0.012	0.017	-0.037	-0.045
724.3699	0.041	-0.018	-0.024	-0.052	742.3508	0.064	-0.001	-0.028	-0.038
724.3721	0.082	0.016	-0.038	-0.044	742.3555	0.036	0.005	-0.031	-0.039
724.3744	0.070	0.022	-0.031	-0.016	742.3576	0.045	0.024	-0.008	-0.026
724.3789	0.165	0.038	0.014	-0.006	742.3602	0.068	0.041	-0.006	-0.020
724.3812	0.102	0.042	0.019	-0.011	742.3665	0.082	0.072	0.040	0.013
724.3832	0.146	0.071	0.036	0.024	742.3718	0.069	0.074	0.032	-0.014
742.1126	-0.049	-0.023	-0.065	-0.121	742.3783	0.120	0.091	0.059	0.030
742.1159	0.026	-0.014	-0.056	-0.086	742.3806	0.117	0.102	0.066	0.045
742.1207	0.011	-0.015	-0.082	-0.082	742.3852	0.111	0.126	0.069	0.062
742.1258	-0.053	-0.030	-0.054	-0.091	744.0686	-0.034	-0.023	-0.116	-0.075
742.1283	0.005	-0.011	-0.038	-0.079	744.0711	-0.034	-0.028	-0.068	-0.088
742.1306	0.006	0.006	-0.039	-0.043	744.0799	-0.020	-0.022	-0.055	-0.096
742.1568	0.072	0.063	0.039	0.012	744.0897	0.049	-0.013	-0.043	-0.048
742.1602	0.095	0.111	0.046	0.027	744.0938	0.053	-0.018	-0.058	-0.056
742.1625	0.116	0.095	0.060	0.046	744.0996	0.043	-0.019	-0.041	-0.068
742.1670	0.133	0.118	0.074	0.076	744.1030	0.050	0.011	-0.019	-0.034
742.1741	0.205	0.165	0.135	0.116	744.1081	0.062	0.021	-0.018	-0.045
742.1762	0.180	0.158	0.126	0.094	744.1362	0.156	0.086	0.081	0.026
742.2092	0.241	0.182	0.153	0.113	744.1401	0.160	0.122	0.110	0.070
742.2144	0.213	0.188	0.142	0.136	744.1454	0.185	0.160	0.123	0.094
742.2168	0.224	0.186	0.143	0.119	744.1549	0.212	0.186	0.141	0.120

Table 1. (continued).

$JD_\odot$ 2449000+	ΔB	ΔV	ΔR	ΔI	$JD_\odot$ 2449000+	ΔB	ΔV	ΔR	ΔI
744.1642	0.204	0.165	0.138	0.112	751.1679	0.134	0.137	0.122	0.089
744.1680	0.204	0.171	0.140	0.135	751.1696	0.120	0.134	0.112	0.091
744.1772	0.180	0.154	0.139	0.125	751.1721	0.143	0.128	0.107	0.103
744.1805	0.206	0.167	0.140	0.127	751.1817	0.169	0.161	0.135	0.103
744.1831	0.203	0.174	0.139	0.106	751.1833	0.175	0.160	0.139	0.111
744.1989	0.172	0.168	0.135	0.115	751.1864	0.190	0.147	0.142	0.120
744.2017	0.168	0.165	0.132	0.102	751.1884	0.176	0.128	0.128	0.101
744.2056	0.166	0.147	0.143	0.096	751.1905	0.201	0.135	0.122	0.111
744.2127	0.160	0.129	0.105	0.078	751.1930	0.179	0.143	0.126	0.109
744.2152	0.158	0.117	0.075	0.067	751.1939	0.155	0.137	0.131	0.095
744.2267	0.101	0.081	0.037	0.030	751.2137	0.189	0.139	0.111	0.098
744.2354	0.100	0.051	0.017	-0.003	751.2164	0.212	0.126	0.120	0.075
744.2379	0.052	0.047	0.016	-0.020	751.2206	0.163	0.153	0.121	0.072
744.2453	0.032	0.015	-0.011	-0.044	751.2302	0.134	0.159	0.115	0.096
744.2507	0.063	0.014	-0.016	-0.042	751.2325	0.114	0.138	0.104	0.087
744.2539	0.017	0.003	-0.019	-0.037	751.2353	0.183	0.133	0.084	0.060
744.2753	0.007	-0.045	-0.069	-0.114	751.2944	0.017	-0.044	-0.086	-0.092
744.2818	-0.029	-0.052	-0.061	-0.093	751.2974	-0.013	-0.051	-0.089	-0.088
744.2845	-0.018	-0.048	-0.057	-0.132	751.3018	0.011	-0.052	-0.075	-0.097
744.2884	-0.012	-0.025	-0.054	-0.096	751.3415	0.001	-0.024	-0.044	-0.070
744.2956	-0.035	-0.054	-0.081	-0.103	751.3459	-0.012	-0.023	-0.037	-0.073
746.0851	-0.011	-0.010	-0.025	-0.029	751.3497	0.030	0.005	-0.024	-0.056
746.0861	-0.023	-0.008	-0.032	-0.033	751.3574	0.029	0.017	-0.011	-0.032
746.0941	0.093	0.009	-0.010	-0.012	751.3638	0.096	0.040	0.011	-0.005
746.0991	0.091	0.078	0.038	0.019	751.3662	0.115	0.058	0.031	-0.005
746.1002	0.059	0.069	0.017	0.044	751.3712	0.083	0.091	0.049	0.021
746.1038	0.100	0.084	0.029	0.041	751.3738	0.134	0.116	0.064	0.044
746.1048	0.079	0.085	0.039	0.036	751.3760	0.102	0.099	0.064	0.037
746.1143	0.147	0.092	0.083	0.065	751.3802	0.156	0.128	0.080	0.062
746.1241	0.155	0.153	0.141	0.100	759.1253	0.160	0.124	0.100	0.105
746.1297	0.205	0.156	0.146	0.091	759.1325	0.182	0.119	0.103	0.083
746.1333	0.208	0.175	0.163	0.117	759.1376	0.143	0.107	0.072	0.027
746.1357	0.154	0.151	0.141	0.113	759.1398	0.148	0.109	0.079	0.038
746.1424	0.201	0.177	0.153	0.134	759.1460	0.109	0.060	0.025	-0.006
746.1612	0.223	0.171	0.150	0.133	759.1504	0.059	0.056	0.010	-0.016
746.1639	0.205	0.177	0.164	0.132	759.1537	0.066	0.029	0.013	-0.008
746.1662	0.202	0.193	0.159	0.116	759.1701	0.102	0.023	-0.026	-0.053
751.0728	-0.001	-0.041	-0.071	-0.092	759.1739	0.057	0.013	-0.012	-0.042
751.1002	0.019	-0.032	-0.088	-0.096	759.1775	-0.004	-0.039	-0.074	-0.075
751.1028	0.005	-0.052	-0.089	-0.080	759.1836	0.057	0.012	-0.010	-0.042
751.1149	0.031	-0.003	-0.044	-0.080	759.1959	0.042	-0.032	-0.082	-0.132
751.1189	0.030	-0.011	-0.040	-0.078	759.2070	0.015	-0.016	-0.054	-0.098
751.1214	0.049	0.009	-0.027	-0.058	763.0710	0.198	0.167	0.132	0.069
751.1236	0.055	0.013	-0.050	-0.057	763.0893	0.122	0.093	0.071	0.024
751.1322	0.018	0.003	-0.019	-0.050	763.0930	0.111	0.084	0.041	0.019
751.1373	0.044	0.029	0.000	-0.030	763.1015	0.096	0.058	0.003	0.002
751.1402	0.129	0.042	0.011	-0.012	763.1037	0.094	0.051	-0.006	-0.016
751.1420	0.055	0.026	0.022	0.004	763.1099	0.097	0.042	-0.021	-0.015
751.1443	0.062	0.050	0.013	0.007	763.1145	0.086	0.013	-0.015	-0.036
751.1491	0.096	0.068	0.033	0.022	763.1167	0.033	0.012	-0.021	-0.046

Table 1. (continued).

$JD_\odot$ 2449000+	ΔB	ΔV	ΔR	ΔI	$JD_\odot$ 2449000+	ΔB	ΔV	ΔR	ΔI
763.1189	0.025	-0.002	-0.041	-0.048	765.1956	0.098	0.099	0.063	0.036
763.1250	-0.011	-0.022	-0.062	-0.063	765.1966	0.121	0.097	0.069	0.041
763.1288	0.023	-0.029	-0.077	-0.099	765.2014	0.157	0.117	0.088	0.066
763.1297	0.013	-0.049	-0.077	-0.106	765.2022	0.161	0.139	0.087	0.075
763.1318	-0.001	-0.042	-0.079	-0.084	765.2046	0.156	0.147	0.107	0.083
763.1392	-0.010	-0.039	-0.088	-0.084	765.2071	0.169	0.149	0.117	0.095
763.1421	-0.010	-0.044	-0.076	-0.102	765.2081	0.144	0.139	0.108	0.103
763.1444	-0.026	-0.042	-0.066	-0.084	765.2151	0.148	0.162	0.123	0.105
763.1546	-0.030	-0.052	-0.095	-0.096	765.2178	0.163	0.154	0.116	0.105
763.1569	-0.042	-0.036	-0.079	-0.084	765.2392	0.196	0.170	0.139	0.115
763.1599	-0.033	-0.058	-0.087	-0.110	765.2415	0.188	0.173	0.129	0.111
763.1645	-0.004	-0.031	-0.070	-0.091	765.2438	0.177	0.173	0.142	0.114
763.1668	-0.006	-0.037	-0.085	-0.099	765.2455	0.167	0.171	0.139	0.106
763.1689	-0.058	-0.053	-0.099	-0.108	765.2541	0.179	0.178	0.138	0.127
763.1879	-0.028	-0.008	-0.068	-0.090	765.2550	0.186	0.176	0.124	0.110
763.1901	-0.008	-0.003	-0.051	-0.062	765.2576	0.190	0.172	0.128	0.112
763.1926	-0.012	-0.011	-0.039	-0.064	765.2607	0.192	0.165	0.130	0.114
763.2062	0.036	0.014	-0.033	-0.041	765.2742	0.182	0.155	0.096	0.070
763.2085	0.062	0.034	0.001	-0.026	765.2773	0.165	0.117	0.098	0.055
763.2113	0.054	0.016	0.014	-0.013	765.2799	0.122	0.119	0.081	0.045
765.0606	0.083	0.061	0.007	0.021	765.2941	0.092	0.057	0.014	-0.002
765.0648	0.075	0.049	0.003	0.008	765.2976	0.067	0.061	0.018	-0.008
765.0724	0.044	-0.010	-0.010	-0.018	765.3010	0.073	0.057	0.011	-0.013
765.0757	-0.009	-0.001	-0.017	-0.038	765.3099	0.065	0.040	0.002	-0.026
765.0789	0.001	-0.015	-0.019	-0.050	765.3122	0.050	0.039	-0.019	-0.030
765.0842	-0.039	-0.037	-0.062	-0.082	765.3153	0.036	0.039	-0.019	-0.030
765.0875	-0.020	-0.023	-0.037	-0.056	765.3221	0.057	0.003	-0.032	-0.063
765.0914	-0.062	-0.044	-0.077	-0.085	765.3246	0.039	-0.001	-0.034	-0.076
765.0974	-0.054	-0.066	-0.086	-0.106	765.3401	0.021	-0.012	-0.050	-0.079
765.1007	-0.060	-0.058	-0.099	-0.088	765.3427	-0.024	-0.004	-0.041	-0.090
765.1034	-0.079	-0.076	-0.105	-0.116	765.3452	0.014	-0.009	-0.054	-0.097
765.1096	-0.069	-0.088	-0.102	-0.096	765.3503	0.002	-0.022	-0.062	-0.092
765.1137	-0.059	-0.078	-0.111	-0.129	765.3526	0.003	-0.019	-0.073	-0.106
765.1411	-0.044	-0.068	-0.089	-0.106	765.3563	0.040	-0.016	-0.068	-0.081
765.1463	-0.063	-0.066	-0.093	-0.103	765.3617	0.037	-0.015	-0.046	-0.100
765.1492	-0.052	-0.060	-0.082	-0.099	765.3626	0.032	-0.014	-0.045	-0.097

2. OBSERVATIONS AND LIGHT CURVES

Using the 35-cm Schmidt-cassegrain reflector and Optec SSP-3A photometer of CbNUO, we observed AW UMa on 7 nights from January to February 1995. SAO62550 as comparison star and SAO62545 as check one were used. A total of 1088 observations in $BVRI$ is listed in Table 1. The probable errors of our data were ± 0.028 in B, ± 0.012 in V, ± 0.012 in R, and ± 0.011 in I, respectively. The observed data were reduced using CRED reduction program (Yim 1995).

We constructed $BVRI$ light curves of AW UMa with our data as shown in Figure 1. While the light curves of 1994 by Yim & Jeong (1995) have shown large scatter and night to night variations, those of 1995 show relatively little variation and scatter except those of January 6 (Figure 2) and

February 16 (Figure 3). Especially, the *B* and *V* light curves in Figure 3 show remarkably the higher luminosity at 0.2-0.3 phase (JD2449765.13) and the lower luminosity at 0.7-0.8 phase (JD 2449765.38).

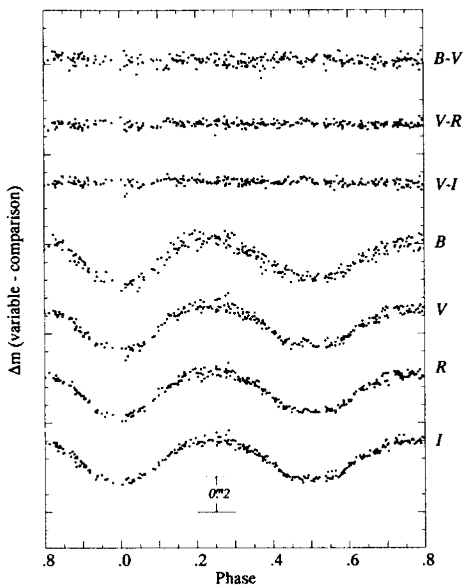

Figure 1. Light curves of AW UMa in 1995.

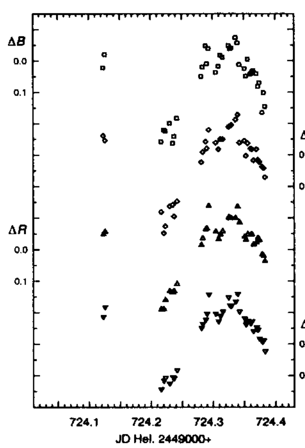

Figure 2. Light curves of AW UMa for January 6, 1995.

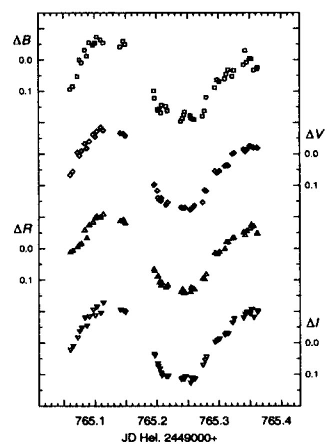

Figure 3. Light curves of AW UMa for February 16, 1995.

3. LIGHT CURVE SOLUTIONS

In order to calculate the photometric solution of AW UMa using Wilson-Devinney code, we made 40 normal points with our data in each filter. For this process, we do not include the data observed on January 6 and February 16 because it was considered that the light curves of those nights were represented by transient light variation.

Mode 3 and model atmosphere were applied. i, g, T_1, A, q are used as fixed parameters and T_2, Ω_1, L_1 were used as adjusted parameters. Final adjusted and fixed parameters are listed in the last column of Table 2 with other solutions including ours of 1994's light curve (Yim 1995). From two solutions of light curves of 1994 and 1995, we find that temperatures of two stars are nearly the same. Theoretical light curves calculated using our solution parameters are presented with solid lines in Figure 4.

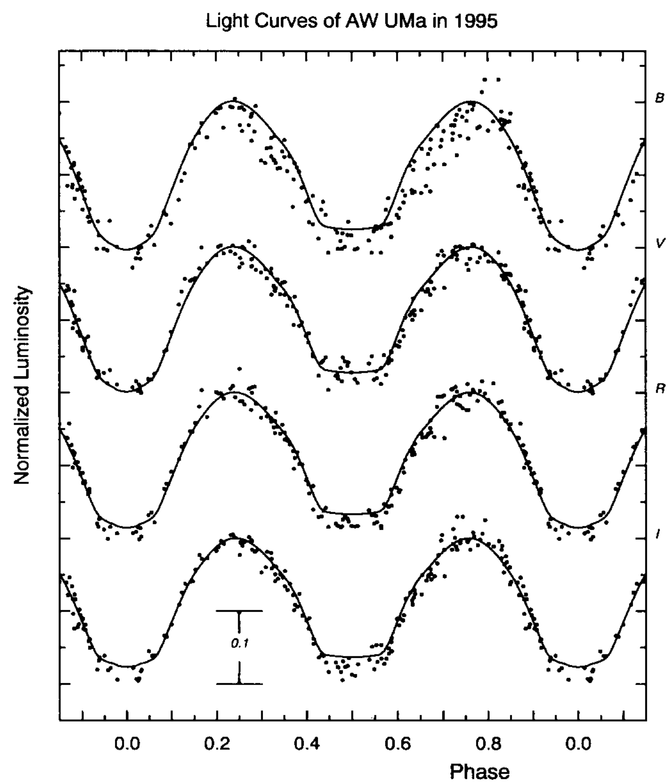

Figure 4. Normalized light curves of AW UMa with theoretical light curves (solid line).

Table 2. Light curve solutions of AW UMa.

Parameter	(1)	(2)	(3)	(4)	(5)	(6)	(7)
i	79.10± 0.36	79.1	79.1	79.1	79.1	79.1	79.1
g	0.45± 0.06	0.62	0.63	0.45	0.45	0.45	0.45
T_1	7000	7175	7175	7175	7175	7175	7175
T_2	6739	6975	6560	6910	7146	6660±32	7005±30
A	1.000	1.0	1.0	1.0	1.0	1.0	1.0
Ω	1.832± 0.0018	1.8527	0.821	1.8261	1.8461	1.8301±0.0026	1.8360± 0.0015
q	0.0716± 0.0005	0.0716	0.0716	0.0716	0.0716	0.0713±0.0005	0.0713
$L_1(\lambda$ 3600)	——	0.932	——	——	——	——	——
$L_1(\lambda$ 4250)	0.9148± 0.0099	0.909	——	——	——	0.9333±0.0023	0.9221±0.0017
$L_1(\lambda$ 5300)	0.9176± 0.0125	0.909	——	0.914	0.908	0.9255±0.0018	0.9310±0.0015
$L_1(\lambda$ 6600)	——	——	0.925	——	——	0.9220±0.0015	0.9231±0.0013
$L_1(\lambda$ 8400)	——	——	——	——	——	0.9190±0.0014	0.9179±0.0012
$L_2(\lambda$ 3600)	——	0.068	——	——	——	——	——
$L_2(\lambda$ 4250)	——	0.091	——	——	——	0.0667	0.08670
$L_2(\lambda$ 5300)	——	0.091	——	——	——	0.0745	0.08928
$L_2(\lambda$ 6600)	——	——	0.075	——	——	0.0780	0.08967
$L_2(\lambda$ 8400)	——	——	——	——	——	0.0810	0.08971
r_1(pole)	0.5650± 0.0006	0.559	——	0.5669	0.5606	0.5661±0.0007	0.5636±0.0005
r_1(point)	——	0.750	——	——	——	——	——
r_1(side)	0.6457± 0.0011	0.633	——	0.6492	0.6378	0.6476±0.0012	0.6431±0.0009
r_1(back)	0.6644± 0.0012	0.651	——	0.6680	0.6553	0.6663±0.0012	0.6613±0.0010
r_2(pole)	0.1860± 0.0008	0.177	——	0.1887	0.1799	0.1861±0.0046	0.1835±0.0007
r_2(point)	——	——	——	——	——	——	——
r_2(side)	0.1956± 0.0010	0.185	——	0.1986	0.1881	0.1957±0.0057	0.1925±0.0008
r_2(back)	0.2537± 0.0039	0.221	——	0.2670	0.2303	0.2566±0.0256	0.2437±0.003

(1): Wilson & Devinney (1973), (2)&(3): Woodward *et al.* (1980), (4)&(5): Hrivnak (1982), (6): Yim (1995), (7): This paper.

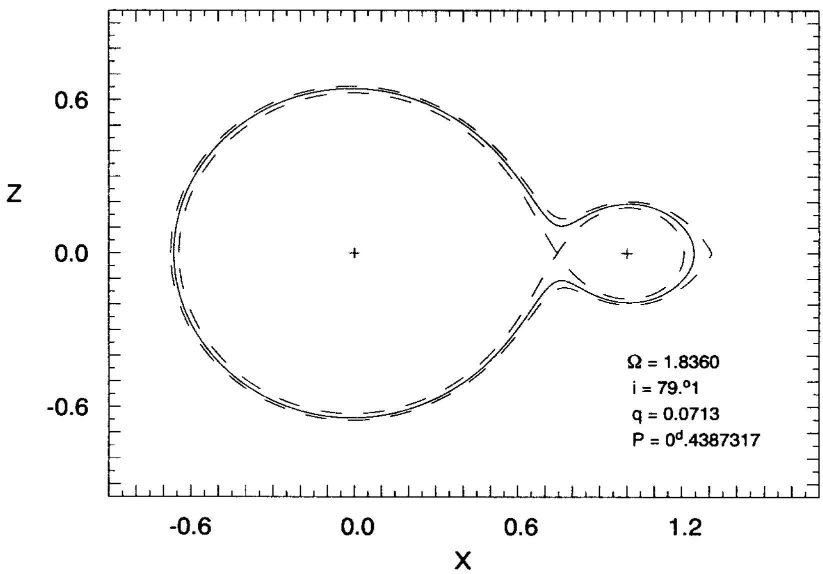

Figure 5. Configuration of AW UMa.

Using the result of our solution, we constructed the configuration of AW UMa as shown in Figure 5. It shows that the system almost fills its outer Lagrangian potential surface.

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REFERENCES

Al-Naimiy, H. M. K. 1978, ApSS, 56, 219
Binnendijk, L. 1977, Vistas Astron. 21, 359
Derman, E., Demircan, O. & Müyesseroglu, Z. 1990, IBVS 3540
Dworak , T. Z. & Kurpinska, M. 1975, AcA, 25, 417
Eggen, O. 1967, MmRAS, 70, 111
Ferland, G. J. & McMillan, R. S. 1976, IBVS 1176
Hrivnak, B. 1982, ApJ, 260, 744
Istomin, L. F., Orlov, L. M. & Kulagin, V. V. 1980, IBVS 1802
Kalish, M. S. 1965, PASP, 77, 36
Kurpinska-Winiarska, M. 1980, IBVS 1843
Lucy, L. B. 1973, ApSS, 22, 381
McLean, B. J. 1981, MNRAS, 195, 931
Mikolajewska, J. & Mikolajewski, M. 1980, IBVS 1812
Mochnacki, S. W. & Doughty, N. A. 1972, MNRAS, 156, 51
Paczynski, B. 1964, AJ, 69, 124
Rucinski, S. M. 1973, AcA, 23, 79
Srivastava, R. K. 1989, ApSS, 154, 179
Wilson, R. E. & Devinney, E. J. 1973, ApJ, 182, 539
Woodward, E. J., Koch, R. H. & Eisenhardt, P. R. 1980, AJ, 85, 50
Yim, J. R. 1995, M. S. thesis (Chungbuk National University: Cheongju)
Yim, J. R. & Jeong, J. H. 1995, JA&SS, 12, 44