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BO CANUM VENATICORUM AND SS COMAE BERENICES: A PHOTOMETRIC STUDY OF AW UMa–TYPE BINARIES

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ABSTRACT

BO CVn and SS Com are two short-period W UMa–type binary stars with spectral types earlier than F5. In the present paper new CCD photometric light curves in *B*, *V*, and *R* bands of BO CVn and the first complete light curve in *V* band of SS Com are presented. The light curves of the two binaries are symmetric, and no variations of the light curves were found for both systems that are quite unlike those of cooler overcontact binaries. These observational properties may suggest weak photospheric dark spot activity in the two systems during the observational time intervals. Photometric solutions of the two W UMa–type binaries were derived by using the 2003 version of the Wilson-Devinney (W-D) method. The new solutions suggest that they are overcontact binary stars with degrees of overcontact of $f = 40.6\%$ for BO CVn and $f = 49.6\%$ for SS Com. Our new times of light minimum confirmed the long-time period increases of the two systems, and the rates of continuous period increase were revised. The long-time period increases, the orbital periods, the degrees of overcontact, and the mass ratios all suggest that they are on an evolutionary stage of mass transfer from the less massive component to the more massive one, and SS Com will reach the present evolutionary state of BO CVn. The slow evolution toward extreme mass ratio will cause them finally to coalesce to single stars. Therefore, both of them are AW UMa–type near-coalescent overcontact binary systems.

Key words: binaries: close — binaries: eclipsing — stars: evolution — stars: individual (BO CVn, SS Com)

Online material: machine-readable tables

1. INTRODUCTION

The light variability of BO CVn was discovered by Oja (1989), who classified it as a W UMa–type binary star. Oja (1989) published the first photoelectric light curves in *U*, *B*, and *V* bands and determined an initial period of about 0.51746 days. The spectral type of the binary star is F0. Albayrak et al. (2001) obtained *BV* light curves of the binary system. They found that the period of BO CVn increases continuously and derived a quadratic ephemeris,

$$\text{Min. I} = \text{HJD } 2{,}446{,}895.46145 + 0.51745754E + 3.034 \times 10^{-10}E^2, \quad (1)$$

which indicates a continuous period increase of 0.037 s yr^{-1}. With the Wilson-Devinney (W-D) code, Albayrak et al. (2001) determined preliminary photometric parameters of the binary star. It is shown that BO CVn is an overcontact binary with a degree of overcontact of $f = 18\%$ and a mass ratio of $q = 0.205$. However, the photoelectric photometric observations of Albayrak et al. (2001) showed large scatter. To determine high-precision photometric parameters and to understand the evolutionary state of the system, it was listed in our observational plan.

According to the fourth edition of the General Catalogue of Variable Stars (GCVS; Kholopov et al. 1985), the other sample star, SS Com, belongs to EW/KW type with a period of 0.4128093 days and a spectral type of F5. It is a neglected system to study. Up to now, neither photometric solutions nor spectroscopic parameters of the binary star have been published. Based on some collected photoelectric times of light minimum of the binary star, Qian & Ma (2001) found that the period of SS Com increases continuously. The following quadratic ephemeris was determined by them:

$$\text{Min. I} = \text{HJD } 2{,}445{,}026.5304(1) + 0.41280761(3)E + 3.34(2) \times 10^{-10}E^2, \quad (2)$$

which reveals a continuous period increase of 0.054 s yr^{-1}. Since no complete light curves of SS Com were published, we intended to observe it since 2000 to obtain complete light curves and give a detailed photometric study of the binary star.

2. NEW CCD OBSERVATIONS OF BO CANUM VENATICORUM AND SS COMAE BERENICES

2.1. *New CCD Light Curves of BO Canum Venaticorum*

BO CVn was observed on four nights (February 11, March 8, and April 14 and 15) in 2005 with the PI1024 TKB CCD photometric system attached to the 1.0 m reflecting telescope at the Yunnan Observatory in China. The effective field of view of the photometric system is 6.5×6.5 arcmin^2 at the Cassegrain focus. During the observation, *B*, *V*, and *R* filters were used. The integration time is 120 s for each image. The coordinates of the variable star, the comparison star, and the check star are listed in Table 1. The *B*, *V*, and *R* color systems used are close to the standard Johnson *UBVRI* system. In all, 123 images in each band were obtained. Data reduction was done by using the aperture photometry package of IRAF. Since the comparison star is very close to BO CVn, extinction corrections for the data were not made. Complete light curves in *B*, *V*, and *R* bands are displayed in Figure 1. The corresponding data are listed in Tables 2, 3, and 4 with their Heliocentric Julian Date, phases, and magnitude difference between BO CVn and the comparison star. The

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TABLE 1
COORDINATES OF BO CANUM VENATICORUM AND ITS COMPARISON AND CHECK STARS

Stars	$\alpha_{J2000.0}$	$\delta_{J2000.0}$
BO Canum Venaticorum..............	13 59 08.2	40 49 09.0
The comparison	13 58 44.1	40 53 43.4
The check.....................................	13 58 51.4	40 49 47.6

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

phases of those observations were calculated with the following ephemeris:

$$\text{Min. I} = \text{HJD } 2{,}453{,}413.3990 + (0.51746168 \text{ days})E, \quad (3)$$

where the period was taken from Albayrak et al. (2001). As shown in Figure 1, the light curves are symmetric and the data are quality. The light curves are typical EW type, and the depths of both minima are nearly the same. The observations obtained in 3 months overlap completely, which suggests that no short-time changes of the light curves were found. By using a parabolic fitting method, three epochs of minimum light were determined and are listed in Table 5.

2.2. *The First Complete CCD Light Curve of SS Comae Berenices*

SS Com is a neglected binary system to study. Up to now, no complete photoelectric or CCD light curves were published. This system was observed on three nights (March 7, April 30, and May 5) in 2000 and on one night (April 10) in 2005 with the 1.0 m reflecting telescope at the Yunnan Observatory. The photometric system is the same as that used for BO CVn. During the observation in 2000, the V filter was used, while during the observation in 2005, the B, V, and R filters were used. In all, 286 images in V band were obtained. The integration time for each image is 120 s. A star ($\alpha_{J2000.0} = 12^h49^m17^s.0$, $\delta_{J2000.0} = 18°44'05''.6$) very close to SS Com was chosen as the comparison star. Data reduction was done with the same method as that used for BO CVn. The light curve in V band is complete and is displayed in Figure 2. The corresponding data are listed in Table 6 with their Heliocentric Julian Date, phases, and magnitude difference between SS Com and the comparison star. The period of $P = 0.41281119$ days was used to compute the phases. By using a parabolic fitting method, four CCD epochs of minimum light were determined and are listed in Table 7. Two photoelectric times of light minimum, obtained with the WET high-speed three-channel photoelectric photometer attached to the 85 cm telescope at the Xinglong Station of National Astronomical Observatories (NAO), are also listed in this table.

As shown in Figure 2, the light curve is symmetric and belongs to A type according to Binnendijk's (1970) classification where the occultation minimum eclipsed by the less massive component is shallower than the transit one eclipsed by the more massive component. The duration time of the eclipse is about 50 minutes, indicating a total eclipsing binary system. The observations obtained in 2000 and those obtained in 2005 overlap completely, which may suggest that the light curve is stable during this time interval.

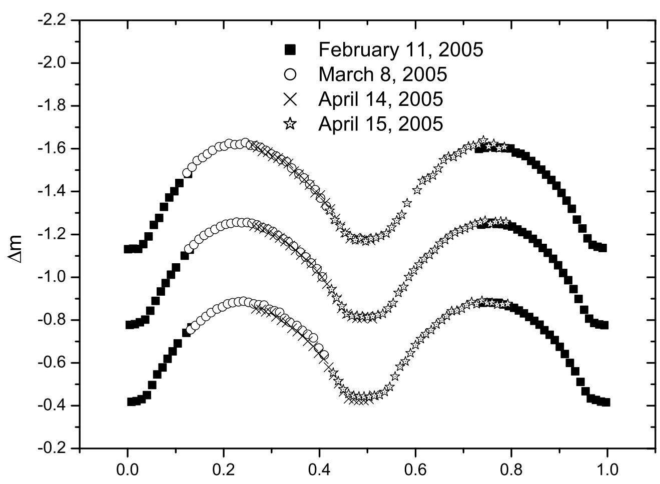

FIG. 1.—CCD photometric light curves in B, V, and R bands of BO CVn obtained in 2005.

3. ORBITAL PERIOD CHANGES OF BO CANUM VENATICORUM AND SS COMAE BERENICES

3.1. *BO Canum Venaticorum*

Times of light minimum of BO CVn obtained before 2001 were published by several authors (e.g., Hübscher et al. 1991, 1992, 1993, 1994; Agerer & Hübscher 1996, 1999, 2000, 2001; Albayrak et al. 2000, 2002. Those times of light minimum have been compiled by Albayrak et al. (2001), who pointed out that the period of BO CVn is increasing continuously and determined a period increase rate of 0.037 s yr^{-1}. After their collection, several times of light minimum have been obtained by Albayrak et al. (2002), Muyesseroglu et al. (2003), Selam et al. (2003), and the present authors and are displayed in Table 8. The $O - C$ curve with respect to the linear ephemeris derived by Oja (1989),

$$\text{Min. I} = \text{HJD } 2{,}446{,}895.455 + (0.5174597 \text{ days})E, \quad (4)$$

is plotted in Figure 3, where filled circles refer to the data published after the collection by Albayrak et al. (2001). With the least-squares method, a quadratic ephemeris,

$$\text{Min. I} = \text{HJD } 2{,}446{,}895.45824(2) + 0.517459048(12)E + 1.618(9) \times 10^{-10}E^2, \quad (5)$$

was derived. The continuous period increase rate of $dP/dt = (2.28 \pm 0.01) \times 10^{-7}$ days $yr^{-1} = 0.0197$ s yr^{-1} was determined, which is much smaller than that obtained by Albayrak et al. (2001). The residuals from the quadratic ephemeris are plotted in the bottom panel of Figure 3, where no changes can be traced.

3.2. *SS Comae Berenices*

Some photoelectric or CCD times of light minimum have been obtained by several investigators (e.g., Hoffmann 1983; Agerer & Hübscher 1997, 1998, 1999, 2000). Those eclipse times were compiled by Qian & Ma (2001), who derived a continuous period increase rate of $dP/dt = 6.23 \times 10^{-7}$ days yr^{-1}. Subsequent photoelectric or CCD times of light minimum were obtained by Agerer & Hübscher (2002, 2003), Pribulla

TABLE 2

CCD Photometric Data of BO Canum Venaticorum in *B* Band Observed in 2005

HJD 2,452,313+	Phase	Δm	HJD 2,452,313+	Phase	Δm	HJD 2,452,313+	Phase	Δm	HJD 2,452,313+	Phase	Δm
13.2545	0.7208	−1.570	13.2605	0.7323	−1.599	13.2668	0.7445	−1.604	13.2724	0.7554	−1.610
13.2780	0.7663	−1.605	13.2836	0.7770	−1.606	13.2891	0.7875	−1.603	13.2945	0.7980	−1.601
13.3000	0.8087	−1.582	13.3054	0.8191	−1.577	13.3109	0.8297	−1.565	13.3167	0.8409	−1.543
13.3221	0.8513	−1.525	13.3275	0.8619	−1.503	13.3329	0.8723	−1.479	13.3385	0.8830	−1.454
13.3440	0.8937	−1.427	13.3495	0.9044	−1.394	13.3549	0.9148	−1.358	13.3605	0.9256	−1.320
13.3661	0.9364	−1.269	13.3719	0.9477	−1.228	13.3775	0.9584	−1.182	13.3829	0.9689	−1.151
13.3883	0.9794	−1.142	13.3939	0.9902	−1.136	13.3994	0.0007	−1.131	13.4049	0.0114	−1.133
13.4104	0.0221	−1.132	13.4159	0.0327	−1.154	13.4215	0.0436	−1.191	13.4272	0.0544	−1.244
13.4328	0.0654	−1.277	13.4383	0.0759	−1.329	13.4438	0.0866	−1.372	13.4493	0.0972	−1.402
13.4548	0.1078	−1.440	13.4641	0.1259	−1.482	38.3010	0.1234	−1.487	38.3067	0.1343	−1.514
38.3123	0.1451	−1.545	38.3178	0.1558	−1.559	38.3233	0.1664	−1.576	38.3288	0.1770	−1.592
38.3358	0.1905	−1.609	38.3412	0.2011	−1.613	38.3468	0.2118	−1.625	38.3527	0.2233	−1.619
38.3583	0.2342	−1.621	38.3641	0.2452	−1.630	38.3696	0.2559	−1.616	38.3751	0.2665	−1.614
38.3806	0.2771	−1.607	38.3863	0.2882	−1.592	38.3919	0.2990	−1.576	38.3974	0.3096	−1.566
38.4028	0.3201	−1.549	38.4085	0.3311	−1.540	38.4141	0.3419	−1.511	38.4217	0.3567	−1.484
38.4274	0.3677	−1.463	38.4333	0.3791	−1.434	38.4393	0.3906	−1.408	38.4452	0.4021	−1.369
38.4513	0.4138	−1.332	75.1116	0.2602	−1.617	75.1170	0.2708	−1.606	75.1224	0.2811	−1.588
75.1279	0.2918	−1.583	75.1335	0.3025	−1.564	75.1391	0.3134	−1.556	75.1447	0.3241	−1.542
75.1504	0.3352	−1.531	75.1562	0.3465	−1.495	75.1619	0.3574	−1.480	75.1675	0.3683	−1.456
75.1731	0.3791	−1.431	75.1792	0.3910	−1.395	75.1847	0.4014	−1.384	75.1901	0.4119	−1.348
75.1955	0.4223	−1.319	75.2009	0.4328	−1.273	75.2063	0.4433	−1.237	75.2117	0.4538	−1.208
75.2172	0.4642	−1.180	75.2226	0.4748	−1.184	75.2280	0.4853	−1.170	75.2335	0.4957	−1.179
75.2390	0.5064	−1.173	76.2300	0.4216	−1.311	76.2355	0.4322	−1.267	76.2410	0.4428	−1.240
76.2465	0.4534	−1.205	76.2520	0.4640	−1.192	76.2575	0.4747	−1.173	76.2632	0.4856	−1.180
76.2687	0.4964	−1.167	76.2743	0.5072	−1.180	76.2799	0.5180	−1.184	76.2854	0.5286	−1.193
76.2910	0.5395	−1.204	76.2966	0.5502	−1.232	76.3021	0.5609	−1.265	76.3077	0.5716	−1.292
76.3132	0.5824	−1.345	76.3243	0.6038	−1.406	76.3299	0.6146	−1.450	76.3355	0.6254	−1.461
76.3411	0.6362	−1.475	76.3470	0.6476	−1.507	76.3526	0.6586	−1.546	76.3580	0.6689	−1.563
76.3633	0.6792	−1.561	76.3687	0.6897	−1.578	76.3741	0.7000	−1.592	76.3795	0.7104	−1.610
76.3848	0.7208	−1.614	76.3904	0.7314	−1.618	76.3957	0.7419	−1.639	76.4013	0.7526	−1.611
76.4069	0.7633	−1.623	76.4126	0.7744	−1.602	76.4183	0.7854	−1.608			

Note.—Table 2 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*.

TABLE 3

CCD Photometric Data of BO Canum Venaticorum in *V* Band Observed in 2005

HJD 2,453,360+	Phase	Δm	HJD 2,453,360+	Phase	Δm	HJD 2,453,360+	Phase	Δm	HJD 2,453,360+	Phase	Δm
13.2563	0.7243	−1.212	13.2629	0.7370	−1.246	13.2686	0.7481	−1.249	13.2744	0.7591	−1.254
13.2799	0.7699	−1.249	13.2855	0.7806	−1.248	13.2909	0.7911	−1.242	13.2964	0.8016	−1.237
13.3018	0.8122	−1.223	13.3072	0.8227	−1.211	13.3129	0.8336	−1.198	13.3184	0.8443	−1.179
13.3238	0.8547	−1.159	13.3293	0.8653	−1.136	13.3348	0.8759	−1.114	13.3402	0.8865	−1.086
13.3458	0.8972	−1.056	13.3513	0.9078	−1.020	13.3568	0.9184	−0.986	13.3624	0.9294	−0.944
13.3678	0.9398	−0.899	13.3738	0.9513	−0.848	13.3793	0.9619	−0.806	13.3847	0.9723	−0.786
13.3902	0.9829	−0.780	13.3957	0.9936	−0.776	13.4012	0.0043	−0.777	13.4067	0.0149	−0.781
13.4122	0.0256	−0.789	13.4178	0.0364	−0.802	13.4235	0.0473	−0.844	13.4291	0.0581	−0.890
13.4346	0.0689	−0.933	13.4401	0.0794	−0.973	13.4457	0.0902	−1.012	13.4511	0.1007	−1.046
13.4605	0.1188	−1.101	13.4660	0.1294	−1.129	38.3030	0.1272	−1.132	38.3085	0.1378	−1.152
38.3141	0.1487	−1.177	38.3196	0.1593	−1.196	38.3251	0.1699	−1.209	38.3313	0.1819	−1.223
38.3375	0.1940	−1.238	38.3430	0.2046	−1.248	38.3486	0.2154	−1.252	38.3546	0.2270	−1.257
38.3602	0.2377	−1.254	38.3659	0.2488	−1.256	38.3714	0.2594	−1.252	38.3769	0.2700	−1.244
38.3824	0.2807	−1.232	38.3881	0.2917	−1.225	38.3937	0.3025	−1.214	38.3992	0.3131	−1.196
38.4048	0.3239	−1.178	38.4104	0.3348	−1.166	38.4159	0.3455	−1.146	38.4236	0.3603	−1.117
38.4294	0.3715	−1.094	38.4353	0.3830	−1.066	38.4413	0.3945	−1.040	38.4472	0.4059	−1.002
75.1134	0.2638	−1.240	75.1188	0.2742	−1.233	75.1242	0.2846	−1.226	75.1298	0.2953	−1.210
75.1353	0.3061	−1.197	75.1409	0.3169	−1.184	75.1466	0.3279	−1.167	75.1522	0.3388	−1.148
75.1582	0.3503	−1.127	75.1638	0.3611	−1.104	75.1694	0.3719	−1.083	75.1752	0.3831	−1.063
75.1810	0.3944	−1.029	75.1864	0.4049	−0.999	75.1919	0.4153	−0.968	75.1973	0.4258	−0.933
75.2027	0.4363	−0.896	75.2081	0.4468	−0.855	75.2135	0.4572	−0.829	75.2190	0.4677	−0.817
75.2244	0.4783	−0.809	75.2298	0.4887	−0.809	75.2353	0.4993	−0.815	75.2408	0.5099	−0.806
76.2318	0.4250	−0.943	76.2373	0.4357	−0.903	76.2428	0.4463	−0.864	76.2483	0.4569	−0.828
76.2538	0.4676	−0.819	76.2593	0.4782	−0.820	76.2650	0.4892	−0.816	76.2706	0.5001	−0.813
76.2762	0.5109	−0.816	76.2817	0.5216	−0.823	76.2872	0.5321	−0.829	76.2928	0.5430	−0.854
76.2984	0.5537	−0.879	76.3039	0.5643	−0.927	76.3095	0.5753	−0.955	76.3150	0.5859	−1.001
76.3206	0.5966	−1.031	76.3262	0.6075	−1.059	76.3317	0.6182	−1.085	76.3373	0.6290	−1.104
76.3432	0.6403	−1.128	76.3489	0.6514	−1.157	76.3544	0.6621	−1.174	76.3597	0.6723	−1.194
76.3651	0.6826	−1.208	76.3706	0.6932	−1.220	76.3759	0.7035	−1.228	76.3813	0.7139	−1.240
76.3867	0.7243	−1.249	76.3922	0.7349	−1.256	76.3975	0.7453	−1.263	76.4031	0.7561	−1.249
76.4088	0.7670	−1.258	76.4144	0.7780	−1.260	76.4202	0.7890	−1.258			

Note.—Table 3 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*.

TABLE 4

CCD Photometric Data of BO Canum Venaticorum in *R* Band Observed in 2005

HJD 2,453,360+	Phase	Δ*m*	HJD 2,453,360+	Phase	Δ*m*	HJD 2,453,360+	Phase	Δ*m*	HJD 2,453,360+	Phase	Δ*m*
13.2584.............	0.7283	−0.847	13.2649.............	0.7408	−0.880	13.2705.............	0.7517	−0.883	13.2762.............	0.7627	−0.880
13.2817.............	0.7734	−0.880	13.2872.............	0.7839	−0.873	13.2927.............	0.7946	−0.865	13.2982.............	0.8052	−0.857
13.3035.............	0.8155	−0.845	13.3091.............	0.8262	−0.831	13.3147.............	0.8372	−0.814	13.3202.............	0.8477	−0.796
13.3257.............	0.8584	−0.778	13.3311.............	0.8688	−0.753	13.3366.............	0.8795	−0.731	13.3421.............	0.8900	−0.706
13.3476.............	0.9007	−0.675	13.3531.............	0.9114	−0.641	13.3586.............	0.9220	−0.600	13.3643.............	0.9328	−0.560
13.3701.............	0.9441	−0.511	13.3755.............	0.9546	−0.467	13.3811.............	0.9654	−0.434	13.3865.............	0.9759	−0.427
13.3921.............	0.9867	−0.419	13.3975.............	0.9970	−0.416	13.4031.............	0.0079	−0.418	13.4086.............	0.0185	−0.421
13.4141.............	0.0291	−0.430	13.4196.............	0.0399	−0.449	13.4254.............	0.0510	−0.496	13.4310.............	0.0618	−0.546
13.4365.............	0.0724	−0.579	13.4420.............	0.0830	−0.619	13.4475.............	0.0937	−0.654	13.4529.............	0.1042	−0.691
13.4623.............	0.1223	−0.740	13.4677.............	0.1328	−0.766	38.3049.............	0.1308	−0.755	38.3103.............	0.1414	−0.774
38.3159.............	0.1523	−0.796	38.3214.............	0.1628	−0.816	38.3269.............	0.1734	−0.834	38.3338.............	0.1867	−0.851
38.3394.............	0.1975	−0.861	38.3449.............	0.2082	−0.875	38.3507.............	0.2194	−0.882	38.3565.............	0.2307	−0.885
38.3620.............	0.2412	−0.888	38.3677.............	0.2523	−0.883	38.3732.............	0.2629	−0.875	38.3787.............	0.2736	−.8720
38.3844.............	0.2846	−0.869	38.3900.............	0.2954	−0.850	38.3955.............	0.3060	−0.844	38.4010.............	0.3166	−0.836
38.4066.............	0.3275	−0.808	38.4122.............	0.3383	−0.790	38.4198.............	0.3529	−0.775	38.4255.............	0.3639	−0.752
38.4313.............	0.3752	−0.733	38.4373.............	0.3868	−0.717	38.4432.............	0.3983	−0.669	38.4492.............	0.4097	−0.637
75.1152.............	0.2673	−0.853	75.1206.............	0.2777	−0.849	75.1261.............	0.2882	−0.839	75.1316.............	0.2989	−0.834
75.1372.............	0.3097	−0.815	75.1428.............	0.3205	−0.799	75.1485.............	0.3315	−0.788	75.1543.............	0.3429	−0.761
75.1600.............	0.3538	−0.746	75.1656.............	0.3647	−0.725	75.1712.............	0.3754	−0.701	75.1772.............	0.3870	−0.677
75.1828.............	0.3978	−0.645	75.1882.............	0.4084	−0.618	75.1937.............	0.4188	−0.580	75.1991.............	0.4293	−0.543
75.2045.............	0.4398	−0.503	75.2099.............	0.4503	−0.465	75.2153.............	0.4607	−0.432	75.2208.............	0.4712	−0.428
75.2262.............	0.4817	−0.425	75.2316.............	0.4922	−0.425	75.2371.............	0.5028	−0.430	75.2426.............	0.5134	−0.448
76.2337.............	0.4286	−0.554	76.2391.............	0.4392	−0.514	76.2446.............	0.4498	−0.476	76.2501.............	0.4604	−0.455
76.2556.............	0.4711	−0.446	76.2613.............	0.4820	−0.442	76.2669.............	0.4928	−0.443	76.2725.............	0.5036	−0.440
76.2781.............	0.5145	−0.446	76.2836.............	0.5251	−0.449	76.2892.............	0.5359	−0.464	76.2947.............	0.5466	−0.487
76.3003.............	0.5573	−0.536	76.3058.............	0.5680	−0.582	76.3114.............	0.5788	−0.606	76.3169.............	0.5895	−0.645
76.3224.............	0.6002	−0.683	76.3280.............	0.6110	−0.711	76.3336.............	0.6218	−0.734	76.3392.............	0.6325	−0.753
76.3451.............	0.6440	−0.780	76.3509.............	0.6551	−0.800	76.3562.............	0.6655	−.8190	76.3615.............	0.6756	−0.841
76.3669.............	0.6862	−0.843	76.3724.............	0.6967	−0.852	76.3777.............	0.7070	−0.869	76.3830.............	0.7173	−0.884
76.3884.............	0.7277	−0.874	76.3939.............	0.7384	−0.889	76.3994.............	0.7490	−0.880	76.4049.............	0.7596	−0.881
76.4107.............	0.7707	−0.872	76.4164.............	0.7817	−0.873	76.4219.............	0.7924	−0.875			

Note.—Table 4 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*.

TABLE 5

New Times of Light Minimum for BO Canum Venaticorum

HJD	Error (days)	Minimum	Method	Filter
2,453,475.2376...........	±0.0054	II	CCD	*B*
2,453,475.2321...........	±0.0019	II	CCD	*V*
2,453,475.2303...........	±0.0019	II	CCD	*R*
2,453,476.2692...........	±0.0004	II	CCD	*B*
2,453,476.2691...........	±0.0005	II	CCD	*V*
2,453,476.2681...........	±0.0006	II	CCD	*R*
2,453,413.3989...........	±0.0004	I	CCD	*B*
2,453,413.3990...........	±0.0004	I	CCD	*V*
2,453,413.3991...........	±0.0004	I	CCD	*R*

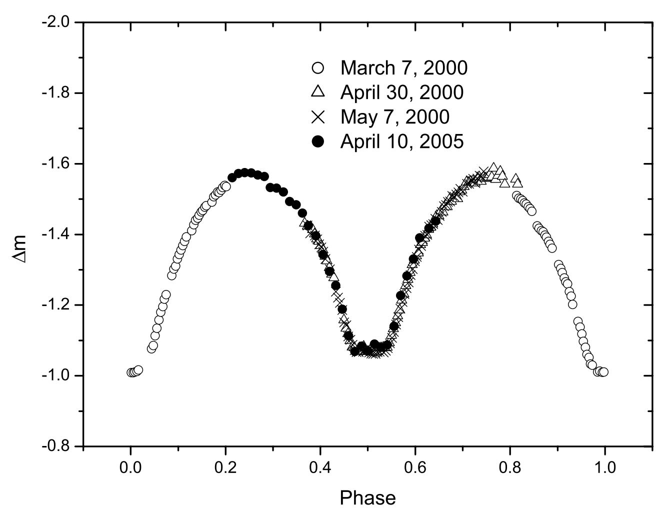

Fig. 2.—CCD light curve in *V* band of SS Com obtained from 2000 to 2005.

TABLE 6

CCD Photometric Data of SS Comae Berenices in V Band

HJD	Phase	Δm	HJD	Phase	Δm	HJD	Phase	Δm	HJD	Phase	Δm
HJD 2,451,600+			HJD 2,451,600+			HJD 2,451,600+			HJD 2,451,600+		
11.2357	0.8137	−1.510	11.2374	0.8178	−1.503	11.2393	0.8224	−1.500	11.2409	0.8263	−1.496
11.2424	0.8300	−1.489	11.2441	0.8340	−1.486	11.2457	0.8379	−1.478	11.2473	0.8418	−1.473
11.2489	0.8456	−1.466	11.2535	0.8569	−1.424	11.2551	0.8607	−1.418	11.2572	0.8657	−1.411
11.2587	0.8694	−1.408	11.2602	0.8731	−1.398	11.2618	0.8769	−1.392	11.2633	0.8805	−1.381
11.2648	0.8842	−1.372	11.2664	0.8880	−1.361	11.2724	0.9025	−1.315	11.2739	0.9062	−1.304
11.2754	0.9099	−1.292	11.2769	0.9136	−1.277	11.2784	0.9173	−1.266	11.2800	0.9210	−1.260
11.2815	0.9246	−1.238	11.2830	0.9284	−1.225	11.2846	0.9321	−1.202	11.2891	0.9431	−1.154
11.2908	0.9472	−1.138	11.2923	0.9509	−1.119	11.2939	0.9546	−1.097	11.2954	0.9584	−1.080
11.2970	0.9621	−1.061	11.2985	0.9658	−1.052	11.3000	0.9695	−1.033	11.3015	0.9732	−1.030
11.3063	0.9847	−1.011	11.3080	0.9888	−1.013	11.3101	0.9940	−1.010	11.3117	0.9978	−1.011
11.3132	0.0016	−1.009	11.3148	0.0053	−1.009	11.3163	0.0090	−1.011	11.3179	0.0128	−1.012
11.3195	0.0166	−1.017	11.3308	0.0440	−1.076	11.3323	0.0478	−1.086	11.3339	0.0515	−1.113
11.3354	0.0552	−1.134	11.3373	0.0597	−1.158	11.3389	0.0636	−1.180	11.3404	0.0674	−1.196
11.3420	0.0712	−1.217	11.3435	0.0749	−1.230	11.3485	0.0869	−1.284	11.3502	0.0910	−1.302
11.3517	0.0948	−1.311	11.3533	0.0985	−1.331	11.3548	0.1022	−1.344	11.3564	0.1061	−1.356
11.3579	0.1098	−1.369	11.3595	0.1135	−1.380	11.3610	0.1172	−1.393	11.3658	0.1289	−1.411
11.3674	0.1329	−1.427	11.3691	0.1369	−1.440	11.3707	0.1407	−1.446	11.3722	0.1445	−1.454
11.3738	0.1484	−1.464	11.3754	0.1521	−1.468	11.3769	0.1559	−1.477	11.3785	0.1596	−1.481
11.3832	0.1710	−1.492	11.3849	0.1751	−1.507	11.3866	0.1792	−1.512	11.3881	0.1829	−1.520
11.3897	0.1867	−1.518	11.3912	0.1904	−1.525	11.3928	0.1942	−1.533	11.3943	0.1980	−1.539
11.3958	0.2016	−1.535	65.1294	0.3665	−1.431	65.1320	0.3730	−1.423	65.1472	0.4097	−1.338
65.1490	0.4141	−1.325	65.1509	0.4187	−1.306	65.1531	0.4239	−1.287	65.1548	0.4283	−1.277
65.1637	0.4497	−1.158	65.1654	0.4539	−1.134	65.1672	0.4582	−1.119	65.1690	0.4626	−1.099
65.1708	0.4670	−1.081	65.1727	0.4714	−1.079	65.1752	0.4775	−1.069	65.1770	0.4820	−1.079
65.1788	0.4864	−1.078	65.1808	0.4912	−1.083	65.1828	0.4961	−1.068	65.1847	0.5005	−1.069
65.1865	0.5050	−1.072	65.1883	0.5092	−1.070	65.1345	0.3791	−1.422	65.1901	0.5136	−1.065
65.1918	0.5179	−1.069	65.1943	0.5238	−1.078	65.1960	0.5281	−1.079	65.1978	0.5324	−1.080
65.1996	0.5367	−1.079	65.2014	0.5410	−1.080	65.2032	0.5455	−1.093	65.2050	0.5498	−1.114
65.2068	0.5540	−1.133	65.1364	0.3836	−1.413	65.2086	0.5585	−1.150	65.2104	0.5629	−1.169
65.2122	0.5672	−1.186	65.2140	0.5714	−1.214	65.2158	0.5758	−1.231	65.2175	0.5801	−1.255
65.2194	0.5846	−1.272	65.2213	0.5892	−1.292	65.2231	0.5937	−1.314	65.2249	0.5981	−1.327
65.1382	0.3880	−1.401	65.2268	0.6025	−1.339	65.2285	0.6067	−1.347	65.2303	0.6111	−1.371
65.2321	0.6154	−1.377	65.2338	0.6196	−1.389	65.2356	0.6239	−1.398	65.2374	0.6283	−1.414
65.2392	0.6326	−1.420	65.2410	0.6369	−1.429	65.2427	0.6412	−1.443	65.1401	0.3925	−1.387
65.2445	0.6455	−1.453	65.2463	0.6498	−1.452	65.2481	0.6542	−1.467	65.2499	0.6585	−1.463
65.2517	0.6629	−1.482	65.2536	0.6675	−1.478	65.2554	0.6719	−1.499	65.2572	0.6762	−1.493
65.2590	0.6806	−1.504	65.2608	0.6849	−1.510	65.1418	0.3968	−1.380	65.2626	0.6893	−1.501
65.2644	0.6937	−1.520	65.2662	0.6981	−1.525	65.2682	0.7029	−1.535	65.2703	0.7079	−1.548
65.2724	0.7130	−1.547	65.2741	0.7173	−1.550	65.2759	0.7215	−1.551	65.2777	0.7259	−1.545
65.2795	0.7303	−1.555	65.1436	0.4010	−1.368	65.2813	0.7346	−1.563	65.2831	0.7390	−1.550
65.2851	0.7438	−1.562	65.2869	0.7481	−1.558	65.2887	0.7524	−1.561	65.2905	0.7568	−1.569
65.2922	0.7611	−1.562	65.2940	0.7653	−1.587	65.2959	0.7698	−1.555	65.2976	0.7742	−1.567
65.1454	0.4054	−1.356	65.2998	0.7794	−1.578	65.3016	0.7838	−1.564	65.3038	0.7890	−1.542
65.3132	0.8118	−1.556	65.3149	0.8160	−1.542	72.1498	0.3729	−1.425	72.1520	0.3782	−1.403
72.1561	0.3882	−1.397	72.1581	0.3931	−1.386	72.1599	0.3974	−1.372	72.1617	0.4017	−1.363
72.1634	0.4060	−1.351	72.1653	0.4104	−1.330	72.1692	0.4198	−1.301	72.1744	0.4326	−1.238
72.1762	0.4369	−1.221	72.1780	0.4412	−1.206	72.1799	0.4458	−1.186	72.1817	0.4501	−1.151
72.1835	0.4545	−1.143	72.1853	0.4588	−1.111	72.1870	0.4632	−1.102	72.1889	0.4677	−1.088
72.1908	0.4721	−1.072	72.1925	0.4764	−1.067	72.1943	0.4808	−1.067	72.1962	0.4854	−1.073
72.1980	0.4897	−1.068	72.1998	0.4940	−1.072	72.2016	0.4984	−1.071	72.2034	0.5028	−1.066
72.2052	0.5072	−1.063	72.2070	0.5115	−1.062	72.2089	0.5161	−1.062	72.2107	0.5205	−1.067
72.2125	0.5247	−1.068	72.2143	0.5291	−1.072	72.2160	0.5333	−1.066	72.2178	0.5377	−1.071
72.2196	0.5421	−1.078	72.2214	0.5464	−1.092	72.2232	0.5509	−1.107	72.2250	0.5552	−1.124
72.2268	0.5595	−1.145	72.2287	0.5640	−1.166	72.2305	0.5684	−1.190	72.2323	0.5728	−1.209
72.2341	0.5771	−1.231	72.2359	0.5816	−1.248	72.2377	0.5860	−1.264	72.2395	0.5903	−1.285
72.2413	0.5946	−1.302	72.2431	0.5990	−1.324	72.2449	0.6033	−1.336	72.2467	0.6078	−1.357
72.2485	0.6120	−1.367	72.2503	0.6164	−1.387	72.2521	0.6207	−1.396	72.2539	0.6251	−1.399
72.2556	0.6293	−1.422	72.2574	0.6336	−1.426	72.2592	0.6380	−1.420	72.2611	0.6425	−1.444
72.2630	0.6472	−1.441	72.2648	0.6515	−1.452	72.2666	0.6559	−1.464	72.2684	0.6602	−1.480
72.2703	0.6648	−1.483	72.2720	0.6690	−1.492	72.2738	0.6733	−1.493	72.2756	0.6778	−1.509
72.2775	0.6822	−1.507	72.2793	0.6866	−1.513	72.2810	0.6909	−1.519	72.2828	0.6952	−1.529
72.2848	0.7001	−1.521	72.2886	0.7091	−1.543	72.2903	0.7133	−1.543	72.2921	0.7177	−1.553
72.2939	0.7221	−1.557	72.2958	0.7266	−1.545	72.2976	0.7309	−1.558	72.2994	0.7354	−1.566
72.3012	0.7397	−1.564	72.3030	0.7440	−1.578						

TABLE 6—*Continued*

HJD	Phase	Δm	HJD	Phase	Δm	HJD	Phase	Δm	HJD	Phase	Δm
HJD 2,453,400+			HJD 2,453,400+			HJD 2,453,400+			HJD 2,453,400+		
71.1602..........	0.2139	−1.561	71.1656..........	0.2270	−1.573	71.1711..........	0.2403	−1.575	71.1769..........	0.2544	−1.574
71.1824..........	0.2677	−1.568	71.1880..........	0.2812	−1.564	71.1934..........	0.2943	−1.533	71.1989..........	0.3077	−1.531
71.2047..........	0.3217	−1.520	71.2102..........	0.3350	−1.493	71.2158..........	0.3486	−1.484	71.2213..........	0.3619	−1.460
71.2267..........	0.3750	−1.425	71.2331..........	0.3905	−1.396	71.2393..........	0.4055	−1.343	71.2448..........	0.4189	−1.295
71.2505..........	0.4326	−1.256	71.2560..........	0.4460	−1.188	71.2615..........	0.4593	−1.113	71.2671..........	0.4728	−1.069
71.2728..........	0.4867	−1.084	71.2784..........	0.5003	−1.071	71.2841..........	0.5140	−1.090	71.2897..........	0.5276	−1.080
71.2953..........	0.5411	−1.087	71.3010..........	0.5550	−1.140	71.3067..........	0.5688	−1.227	71.3123..........	0.5823	−1.283
71.3179..........	0.5959	−1.331	71.3235..........	0.6094	−1.390	71.3314..........	0.6286	−1.417	71.3374..........	0.6432	−1.438

Note.—Table 6 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*.

et al. (2002), Nelson (2004), and the present authors, which are listed in Table 9. With the same linear ephemeris used by Qian & Ma (2001), the $O-C$ curve was formed and is displayed in Figure 4. The quadratic ephemeris derived is

$$\text{Min. I} = \text{HJD } 2{,}445{,}026.53050(4) + 0.412807257(6)E + 3.726(3)\times 10^{-10}E^2, \quad (6)$$

which indicates a continuous period increase rate of $dP/dt = 6.59\times 10^{-7}$ days yr^{-1} = 0.057 s yr^{-1}. The derived period increase rate is close to that determined by Qian & Ma (2001). The residuals from the quadratic ephemeris (eq. [6]) are plotted in the bottom panel of Figure 4. As shown in this figure, the scatter of the residuals is less than 0.002 days, indicating that equation (6) can fit those observations very well. The rate of the period increase of BO CVn is very large among W UMa–type binary stars. The similar period increases have been observed in some overcontact binaries, e.g., 0.053 s yr^{-1} for XY Boo (Molík & Wolf 1998) and 0.031 s yr^{-1} for UZ Leo (Hegedüs & Jäger 1992).

4. PHOTOMETRIC SOLUTIONS WITH THE W-D METHOD

4.1. *Analysis of the Light Curves of BO Canum Venaticorum*

The preliminary photometric solutions of BO CVn were derived by Albayrak et al. (2001). Since their observations show a large scatter, those data were averaged into 49 and 50 normal points by them, which were used in their photometric analysis. In order to obtain reliable photometric solutions and to understand the geometrical structure of the binary system, we intend to analyze our data with the 2003 version of the W-D code (Wilson & Devinney 1971; Wilson 1990, 1994; Wilson & Van Hamme 2003). The original data points, 123 points for each band, were used.

The same temperature for star 1 (star eclipsed at primary light minimum) as that used by Albayrak et al. (2001; $T_1 = 7240$ K) was fixed, which corresponds to the spectral type of F0 (Oja 1989). The gravity-darkening coefficients $g_1 = g_2 = 1.0$ and the bolometric albedo $A_1 = A_2 = 1.0$ were used because of the common radiative envelope (CRE) of both component stars. The limb-darkening coefficients of 0.653 in *B* and 0.572 in *V* were applied (Claret & Gimenez 1990), and that in *R* band was from Claret et al. (1995). The adjustable parameters were the orbital inclination, i; the mean temperature of star 2, T_2; the monochromatic luminosity of star 1, L_{1B}, L_{1V}, and L_{1R}; and the dimensionless potential of star 1 ($\Omega_1 = \Omega_2$, mode 3 for overcontact configuration).

To check the mass ratio derived by Albayrak et al. (2001), solutions were carried out for several values of the mass ratio $q = M_2/M_1$ (q = 0.12, 0.16, 0.2, 0.25, 0.3). For each value of q, the solutions usually converged to mode 3 (overcontact configuration). The correlation between the resulting sum Σ of weighted square deviations and q is plotted in Figure 5. A minimum at $q = 0.2$ was obtained. Therefore, we made q an adjustable parameter and chose its initial value as 0.2. A photometric solution with the differential correction code suggests that the solutions converged at $q = 0.2039 \pm 0.0034$. The photometric parameters are listed in Table 10, and the theoretical light curves computed with those photometric elements are plotted in Figure 6. Our solutions indicate that BO CVn is an overcontact binary system with a degree of overcontact of $f = 40.6\%$. The temperature difference between both components is $\Delta T = 236$ K. Our mass ratio is very close to that determined by Albayrak et al. (2001), while the degree of overcontact and the temperature difference between both components are much different from those derived by Albayrak et al. (2001). We think that this may occur because (1) their light curves show a large scatter, especially at both minima, and (2) they used the normal data points.

On the other hand, the spectral type of BO CVn is F0, and it is possible that it has convective atmospheres. Therefore, solutions with common convective envelope (CCE), i.e., $g_1 = g_2 = 0.32$ and $A_1 = A_2 = 0.5$, were also derived and are listed in Table 11. The light curves of BO CVn are typical A type according to Binnendijk's classification. However, the solutions with CCE reveal a secondary temperature of 7303 K, which is 63 K higher

TABLE 7
New Times of Light Minimum for SS Comae Berenices

HJD	Error (days)	Minimum	Method	Filter
2,451,611.3126..........	±0.0003	I	CCD	*V*
2,451,665.1866..........	±0.0003	II	CCD	*V*
2,451,672.2049..........	±0.0002	II	CCD	*V*
2,452,340.1472..........	±0.0005	II	pe	*V*
2,452,340.3557..........	±0.0006	I	pe	*V*
2,453,471.2773..........	±0.0013	II	CCD	*B*
2,453,471.2787..........	±0.0011	II	CCD	*V*
2,453,471.2788..........	±0.0011	II	CCD	*R*

TABLE 8
Photoelectric and CCD Times of Light Minimum for BO Canum Venaticorum Obtained after the Study by Albayrak et al. (2001)

HJD 2,400,000+	Minimum	Method	E	$O-C$	Residuals	References
52,070.3231	II	pe	10000.5	+0.0124	−0.0005	1
52,375.3677	I	pe	10590	+0.0145	+0.0000	1
52,740.4401	II	pe	11295.5	+0.0191	+0.0026	2
52,757.5142	II	pe	11328.5	+0.0170	+0.0004	3
52,813.3986	II	pe	11436.5	+0.0157	−0.0012	3
53,413.3990	I	CCD	12596	+0.0216	+0.0009	4
53,475.2333	II	CCD	12715.5	+0.0195	−0.0016	4
53,476.2688	II	CCD	12717.5	+0.0201	−0.0010	4

References.—(1) Albayrak et al. (2002); (2) Muyesseroglu et al. (2003); (3) Selam et al. (2003); (4) this paper.

than that of the primary component. This situation was also encountered in several low-mass ratio systems, i.e., V802 Aql (Samec et al. 2004), FG Hya (Qian & Yang 2005), V902 Sgr (Samec & Corbin 2002), CU Tau (Qian et al. 2005a), and V857 Her (Qian et al. 2005b). The solutions with CCE fit the observations slightly better than those with CRE. Therefore, although the spectral type of BO CVn is slightly early (F0), it may have a CCE.

4.2. *Analysis of the Light Curves of SS Comae Berenices*

The 2003 version of the W-D program was applied to analyze our V light curve of SS Com. The original 286 data points were used for the recent analysis. According to the 4th edition of the GCVS (Kholopov et al. 1985), the spectral type of SS Com is F5; thus, we take the temperature for star 1 as $T_1 = 6750$ K. The spectral type of SS Com is on the transition between late and early types. We assume that the photospheric surface of the binary star is convective. Therefore, the gravity-darkening coefficients $g_1 = g_2 = 0.32$ and the values of the bolometric albedo $A_1 = A_2 = 0.5$ were fixed. The limb-darkening coefficient 0.595 in V was used (Claret & Gimenez 1990). The adjustable parameters were the same as those adjusted for BO CVn, i.e., the orbital inclination, i; the mean temperature of star 2, T_2; the monochromatic luminosity of star 1, L_{1V}; and the dimensionless potential of star 1 ($\Omega_1 = \Omega_2$, mode 3 for overcontact configuration).

Since no mass ratios of SS Com were published, a q-search method was used to determine the mass ratio. Solutions were carried out at a series of values of mass ratio $q = M_2/M_1$ ($q =$ 0.2, 0.3, 0.4, 0.5, 0.7). For each value of q, the computation started at mode 2 (detached mode), and we found that the solutions were usually converged to mode 3 (overcontact mode). Figure 7 shows the relation between the resulting sum Σ of weighted square deviations and q. It is displayed in the figure that a minimum of Σ was obtained at $q = 0.3$. Then, we chose q also as an adjustable parameter and take 0.3 as its initial parameter. The final solutions are listed in Table 12, and the theoretical light curve computed with those photometric parameters is plotted in Figure 8.

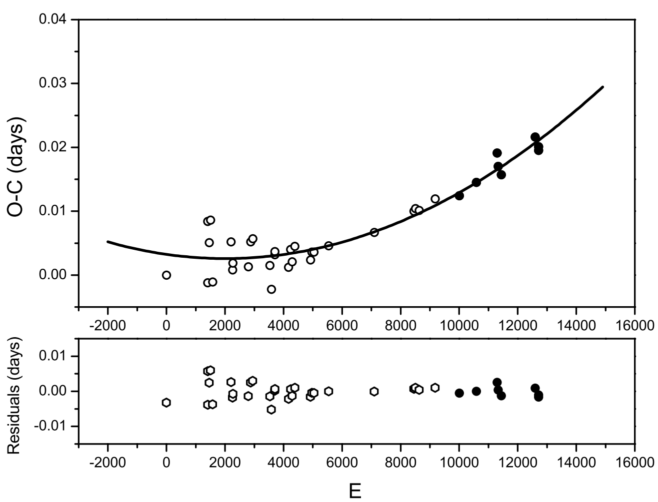

Fig. 3.—$O-C$ diagram of the W UMa–type binary system BO CVn based on all available times of light minimum. Those $O-C$ values were computed by using the linear ephemeris derived by Oja (1989). The solid line represents a long-time period decrease. Open and filled circles refer to the data published before and after the study by Albayrak et al. (2001), respectively. Residuals with respect to eq. (5) are also displayed in the bottom panel.

5. DISCUSSIONS AND CONCLUSIONS

Light curves of late-type (spectral type later than F5) overcontact binaries are usually found to be variable, which was explained as the result of dark spot activity on the photospheric surfaces. Some examples are VW Cep (G5+K0 V; Pustylnik & Niarchos 2000), CE Leo (K1+K2; Kang et al. 2004), FG Hya (G0; Qian & Yang 2005), BX Peg (G8; Lee et al. 2004), and AD Cnc (K0; Qian et al. 2006). However, as shown in Figure 1, the observations of BO CVn obtained in 3 months overlap completely, indicating that there are no changes in the light curve during this time interval. For SS Com, the data obtained in 2000 and 2005 also overlap completely, which may indicate that the light curve of SS Com in the time interval is stable. These properties may suggest that the dark star spot activity on the photospheric surfaces of the two systems is weak during the observational time intervals.

Our new times of light minimum of BO CVn and SS Com including other eclipse times compiled from the literature were used to improve the rates of continuous period increase as $dP/dt = 2.28 \times 10^{-7}$ and 6.59×10^{-7} days yr^{-1}, respectively. Although the period increase rate of SS Com reaches the highest value among overcontact binaries, it is acceptable. Other overcontact binaries (e.g., XY Boo; Molík & Wolf 1998) also show this kind of rapid period increase. Recently, based on the period changes of 59 overcontact binary systems, Qian (2001a, 2001b, 2003) found that the period change of overcontact binaries may correlate with the mass of the more massive component M_1 and with the mass ratio q. Hotter overcontact binaries usually show their periods increasing continuously. The period changes of BO CVn and SS Com are in agreement with these conclusions.

TABLE 9

Photoelectric and CCD Times of Light Minimum for SS Comae Berenices Obtained after the Study by Qian & Ma (2001)

HJD 2,400,000+	Minimum	Method	E	$O - C$	Residuals	References
51,611.3126	I	CCD	15951	+0.0605	−0.0012	1
51,659.4074	II	pe	16067.5	+0.0630	+0.0001	2
51,665.1866	II	CCD	16081.5	+0.0628	−0.0002	1
51,672.2049	II	CCD	16098.5	+0.0634	+0.0002	1
52,002.4600	II	pe	16898.5	+0.0710	−0.0004	2
52,039.4081	I	pe	16988	+0.0727	+0.0004	2
52,340.1472	II	pe	17716.5	+0.0802	−0.0001	1
52,340.3557	I	pe	17717	+0.0823	+0.0020	1
52,401.4510	I	pe	17865	+0.0819	+0.0000	3
52,403.5158	I	CCD	17870	+0.0826	+0.0006	4
52,404.3402	I	CCD	17872	+0.0814	−0.0006	4
52,404.5485	II	CCD	17872.5	+0.0823	+0.0013	4
52,704.4616	I	pe	18599	+0.0904	+0.0000	3
52,705.9055	II	CCD	18602.5	+0.0895	−0.0009	5
52,743.4739	II	pe	18693.5	+0.0923	+0.0009	3
53,471.2783	II	CCD	20456.5	+0.1139	+0.0003	1

References.—(1) This paper; (2) Agerer & Hübscher (2002); (3) Agerer & Hübscher (2003); (4) Pribulla et al. (2002); (5) Nelson (2004).

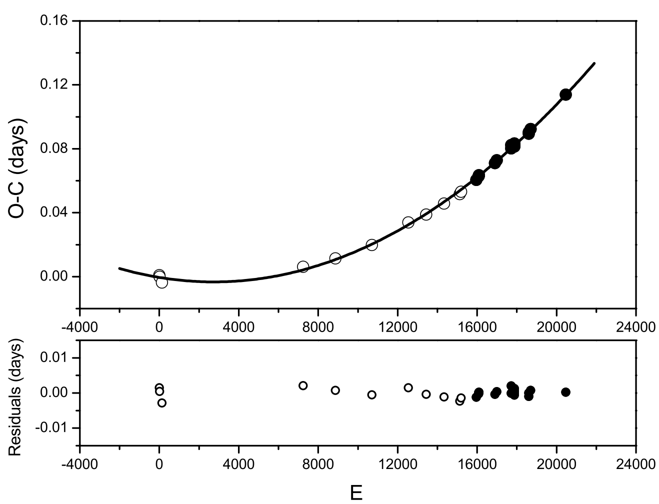

Fig. 4.—$O - C$ diagram of the short-period close binary SS Com based on all available photoelectric and CCD times of light minimum. Open and filled circles represent data published before and after the study by Qian & Ma (2001), respectively. The solid line indicates a long-time period decrease. Residuals with respect to eq. (6) are shown in the bottom panel.

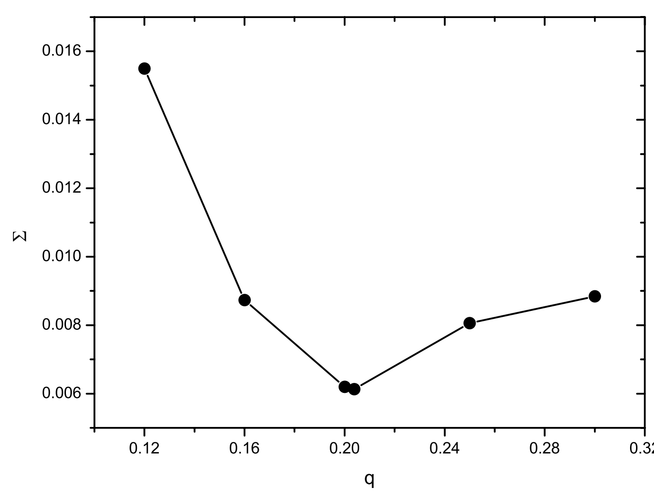

Fig. 5.—Relation between Σ and q for BO CVn.

TABLE 10

Photometric Solutions for BO Canum Venaticorum with CRE

Parameters	Photometric Elements	Errors
$g_1 = g_2$	1.0	Assumed
$A_1 = A_2$	1.0	Assumed
$x_{1B} = x_{2B}$	0.653	Assumed
$x_{1V} = x_{2V}$	0.572	Assumed
$x_{1R} = x_{2R}$	0.474	Assumed
T_1 (K)	7240	Assumed
q (M_2/M_1)	0.2039	±0.0034
$\Omega_{\rm in}$	2.2423	...
$\Omega_{\rm out}$	2.1124	...
T_2 (K)	7004	±27
i	82.16	±0.57
$L_1/(L_1 + L_2)$ (B)	0.8173	±0.0004
$L_1/(L_1 + L_2)$ (V)	0.8217	±0.0004
$L_1/(L_1 + L_2)$ (R)	0.8265	±0.0004
$\Omega_1 = \Omega_2$	2.1896	±0.0097
r_1(pole)	0.4982	±0.0025
r_1(side)	0.5261	±0.0037
r_1(back)	0.5729	±0.0048
r_2(pole)	0.2483	±0.0053
r_2(side)	0.2604	±0.0065
r_2(back)	0.3080	±0.0153
Degree of overcontact, f (%)	40.6	±7.5
$\Sigma\omega(O - C)^2$	0.00613	...

TABLE 11

Photometric Solutions for BO Canum Venaticorum with CCE

Parameters	Photometric Elements	Errors
$g_1 = g_2$	0.32	Assumed
$A_1 = A_2$	0.50	Assumed
$x_{1B} = x_{2B}$	0.653	Assumed
$x_{1V} = x_{2V}$	0.572	Assumed
$x_{1R} = x_{2R}$	0.474	Assumed
T_1 (K)	7240	Assumed
q (M_2/M_1)	0.2136	±0.0017
$\Omega_{\rm in}$	2.2662	...
$\Omega_{\rm out}$	2.1304	...
T_2 (K)	7303	±14
i	82.29	±0.45
$L_1/(L_1 + L_2)$ (B)	0.7782	±0.0005
$L_1/(L_1 + L_2)$ (V)	0.7809	±0.0004
$L_1/(L_1 + L_2)$ (R)	0.7835	±0.0004
$\Omega_1 = \Omega_2$	2.1875	±0.0066
r_1(pole)	0.5009	±0.0017
r_1(side)	0.5505	±0.0025
r_1(back)	0.5799	±0.0033
r_2(pole)	0.2586	±0.0030
r_2(side)	0.2723	±0.0038
r_2(back)	0.3308	±0.0102
Degree of overcontact, f (%)	58.0	±4.9
$\Sigma\omega(O - C)^2$	0.00514	...

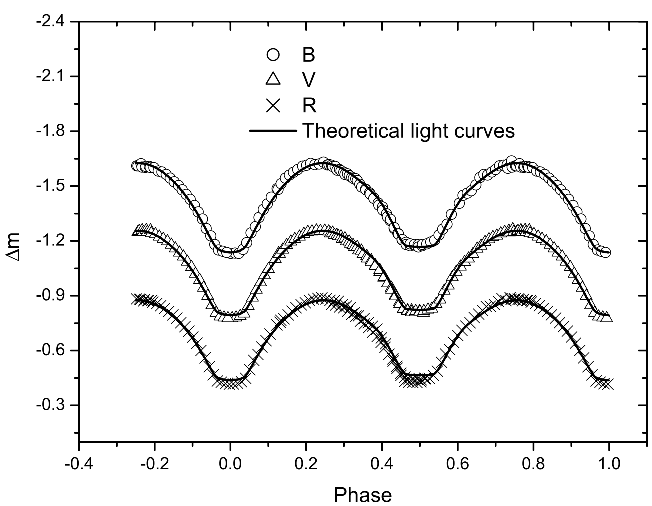

Fig. 6.—Observed and theoretical light curves of BO CVn in B, V, and R bands.

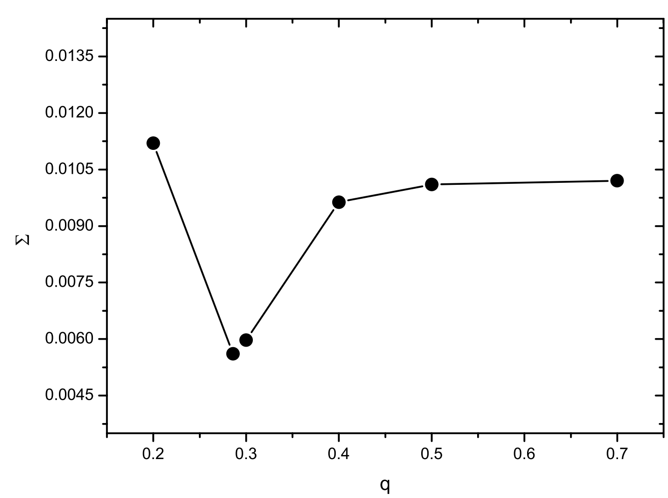

Fig. 7.—Relation between Σ and q for SS Com.

TABLE 12
Photometric Solutions for SS Comae Berenices

Parameters	Photometric Elements	Errors
$g_1 = g_2$	0.32	Assumed
$A_1 = A_2$	0.50	Assumed
$x_{1V} = x_{2V}$	0.595	Assumed
T_1 (K)	6750	Assumed
q (M_2/M_1)	0.2859	$\pm$0.0017
Ω_{in}	2.4348	...
Ω_{out}	2.2560	...
T_2 (K)	6699	$\pm$17
i	83.66	$\pm$0.41
$L_1/(L_1 + L_2)$ (V)	0.7516	$\pm$0.0004
$\Omega_1 = \Omega_2$	2.3460	$\pm$0.0045
r_1(pole)	0.4789	$\pm$0.0011
r_1(side)	0.5214	$\pm$0.0016
r_1(back)	0.5534	$\pm$0.0021
r_2(pole)	0.2787	$\pm$0.0018
r_2(side)	0.2935	$\pm$0.0023
r_2(back)	0.3481	$\pm$0.0056
Degree of overcontact, f (%)	49.6	$\pm$2.5
$\Sigma\omega(O - C)^2$	0.00561	...

The symmetries and complete eclipses of the light curves of BO CVn and SS Com enable us to determine high-precision photometric parameters of the two binary systems. A photometric analysis of our new *BVR* light curves indicates that BO CVn is an overcontact binary with a degree of overcontact of $f = 40.6\%$ and a mass ratio of $q = 0.2039$. For SS Com, the first photometric solution in the previous section suggests that it is also an overcontact binary with a degree of overcontact of $f = 49.6\%$ and a mass ratio of $q = 0.2859$. The secular period increases in both systems may be caused by mass transfer from the less massive component to the more massive one. With the statistical relation between M_1 and q for hotter overcontact binary systems ($P > 0.41$ days; spectral type earlier than F5) given by Qian (2003),

$$M_1 = (0.761 \pm 0.150) + (1.82 \pm 0.28)P, \qquad (7)$$

the values of M_1 were estimated to be $M_1 = 1.70 \pm 0.21\ M_\odot$ for BO CVn and $M_1 = 1.51 \pm 0.19\ M_\odot$ for SS Com, which are consistent with the spectral types of F0 and F5, respectively. Therefore, the values of M_2 were estimated to be $M_2 = 0.35\ M_\odot$ for BO CVn and $M_2 = 0.43\ M_\odot$ for SS Com. By using the well-known equation

$$\frac{\dot{P}}{P} = 3\dot{M}_2\left(\frac{1}{M_2} - \frac{1}{M_1}\right), \qquad (8)$$

the mass transfer rates between both components were determined to be $dM_2/dt = 6.5 \times 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$ for BO CVn and $dM_2/dt = 3.2 \times 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$ for SS Com. However, absolute parameters determined here are only preliminary ones with large errors. To derive highly precise parameters, spectroscopic observations are urgently required.

The physical properties of the two systems are displayed in Table 13. For SS Com, the secular period increase indicates a mass transfer from the secondary to the primary. Meanwhile, its mass ratio (q) and the degree of overcontact (f) both will decrease. The primary component becomes hotter (earlier spectral type) and the orbital period is longer. Finally, it will reach the present evolutionary state of BO CVn, and BO CVn may be the offspring of SS Com. The evolutionary sequences of both systems are shown in Figure 9. All these indicate that both SS Com and BO CVn are on an evolutionary stage of mass transfer from the less massive

TABLE 13
Physical Properties of the Two Overcontact Binary Stars SS Comae Berenices and BO Canum Venaticorum

Parameters	BO Canum Venaticorum	SS Comae Berenices
Spectral type	F0	F5
P (days)	0.5174597	0.4128093
dP/dt (days yr^{-1})	2.28×10^{-7}	6.59×10^{-7}
i (deg)	82.16	83.66
f (%)	40.6	49.6
q	0.2039	0.2859
M_1 ($M_\odot$)	1.70	1.51
M_2 ($M_\odot$)	0.35	0.43
dM_2/dt ($M_\odot\ \mathrm{yr}^{-1}$)	6.5×10^{-8}	3.2×10^{-7}

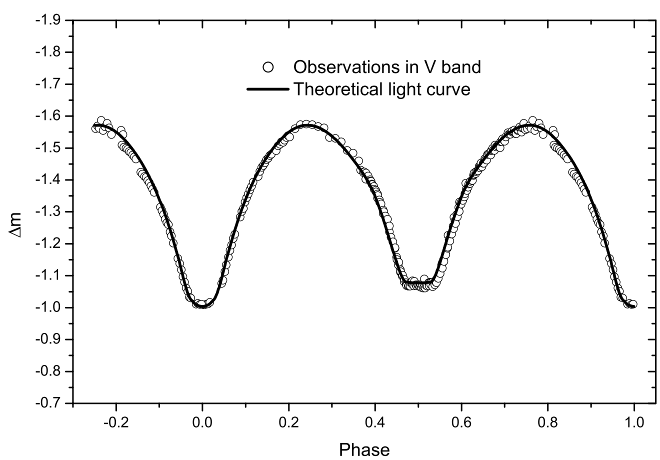

Fig. 8.—Observed and theoretical light curves of SS Com in V band.

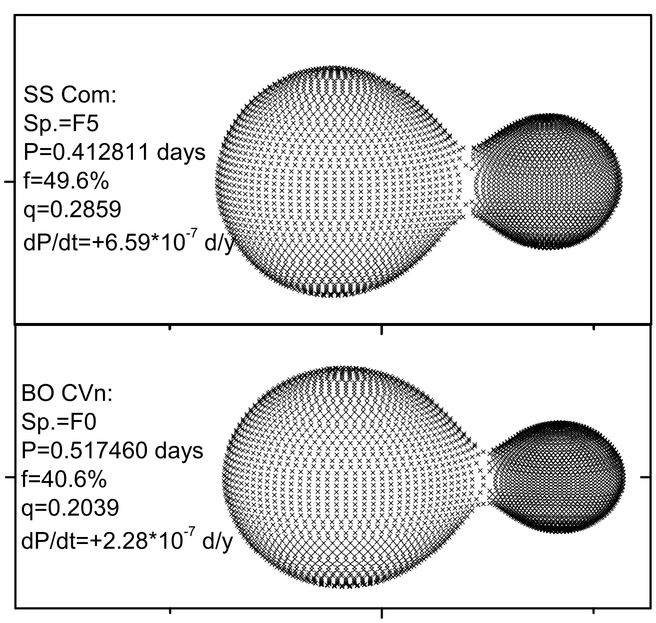

Fig. 9.—Different evolutionary stages of BO CVn and SS Com. The astrophysical parameters of the two overcontact binary systems suggest that SS Com will reach the present evolutionary state of BO CVn.

component to the more massive one. BO CVn and SS Com are low mass ratio overcontact systems with mass ratios of 0.20 and 0.28, respectively. The slow evolution toward extreme mass ratio will cause them finally to coalesce to single rapidly rotating stars when they meet the more familiar criterion that the orbital angular momentum is less than 3 times the total spin angular momentum, i.e., $J_{\rm orb} < 3J_{\rm rot}$ (Hut 1980). Therefore, like AW UMa, all of them are near-coalescent overcontact binary systems.

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