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THE RS CANUM VENATICORUM SYSTEM BD +61°1211 = 2A 1052+606

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ABSTRACT

Spectroscopic observations of BD +61°1211, which is associated with the weak variable X-ray source 2A 1052+606, show that it is a single-lined binary of the RS Canum Venaticorum type with variable Hα and Ca II emission reversals. The period is 7.492 ± 0.009 days and the semi-amplitude of the velocity curve is 28 ± 2 km s^{-1}. The mass function is 0.016 $M_{\odot}$. This is the first member of the RS Canum Venaticorum class to be recognized via its X-ray emission, and the second such object to emit *both* hard (1–3 Å) and soft (>10 Å) X-rays.

Subject headings: stars: binaries — stars: individual — X-rays: binaries

I. INTRODUCTION

BD +61°1211 = SAO 015338, a ninth magnitude K star with Hα emission, was suggested as the optical counterpart of the X-ray source 2A 1052+606 by Liller (1978) on the basis of an accurate *HEAO 1* position (Schwartz *et al.* 1979). Although included in an early version of the 2A catalog (Cooke *et al.* 1978), the source does not actually appear in the published version.

Preliminary spectroscopic observations made at Victoria at the suggestion of G. Wallerstein revealed a spectrum of a late-type star with strong H and K emission reversals very similar to that of stars in the RS Canum Venaticorum class. Hall (1976) has defined this class of stars as consisting of binaries with periods between 1 day and 2 weeks in which the hotter component has an F or G spectrum and strong H and K emission reversals are present. Most of the established members of the class are systems in which the spectra of both components are visible, and many are eclipsing. Another characteristic, near-sinusoidal wavelike distortions which slowly migrate through the light curves of many of the eclipsing systems, has been interpreted as resulting from large-scale spot activity on one side of one of the components (Hall 1972).

Several RS Canum Venaticorum stars are now known to be variable soft X-ray sources (Walter, Charles, and Bowyer 1978*a*) and radio sources (e.g., Owen and Gibson 1978). BD +61°1211 and HR 1099 (White, Sanford, and Weiler 1978) apparently emit hard X-rays as well. Current models are based on X-ray emission from coronae associated with the star spot model.

II. OBSERVATIONS

The spectroscopic observations at Victoria were made at a variety of dispersions with the Cassegrain spectrographs on the 1.8 m telescope. The majority of the spectra were taken with an ITT 4089 image tube in the blue spectral region at a dispersion of 30 Å mm^{-1} and widened to 0.8 mm.

The Lick observations were made with the Lick Observatory 0.6 m coudé auxiliary telescope and a cooled Varo image tube yielding spectra covering the λλ6300–6800 range, widened to 0.6 mm with a dispersion of 16 Å mm^{-1}. In addition, scans with 8–10 Å resolution were made on seven nights with the Robinson-Wampler Cassegrain scanner on the Lick 0.6 m and 3.0 m reflectors, generally in the λλ3600–8000 range.

A summary of all observations is given in Tables 1 and 2, together with radial velocities derived from absorption lines, and from emission lines of Ca II H and K and Hα. An indication of the strength of the emission features on each spectrum is also given. Since the Victoria observations were so heterogeneous, equivalent widths were not measured except on a few of the best spectra, so only eye estimates are given. The few measurements made indicate that the emission was called strong, *s*, when the equivalent width was greater than 2.5 Å and moderate, *m*, when it was between 1 and 2 Å. The line widths are not significantly larger than the instrumental profile. Both these observations and measurements of the Hα equivalent widths from the Lick data (see also Table 2) suggest that, although the emission strength is dramatically variable, no orbital phase dependence is present. For example, the Hα emission strength increased markedly between JD 2,443,668 and 2,443,673, whereas a few days later the Ca II emission was observed to decrease between JD 2,443,680 and 2,443,695. This behavior is apparently characteristic of the RS Canum Venaticorum systems, where the sporadic emission correlates with flare activity rather than with orbital phase (e.g., Bopp and Talcott 1978). The Hα emission in BD +61°1211 is

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TABLE 1

OBSERVATIONS OF BD +61°1211

Heliocentric J.D. 2440000+	ϕ†	Absorption Lines R.V. km s-1	m.e. km s-1	wt.	Emission Lines Ca II km s-1	Hα km s-1	I‡	Dispersion A mm-1
				Victoria Observations				
3636.714	0.34	-19.7	2.9	1		-23.7	s	60
3638.718	.60	-23.1	2.7	2	-19.3		m	30
3638.744	.61	-22.4	0.9	2		-34.2	m	30
3638.774	.61	-23.1	3.4	2		-41.2	m	30
3638.812	.62	-21.1	2.8	2	- 9.6		wm	30
3680.758	.22	- 6.7	2.2	4	- 9.7		m	30*
3681.777	.35	-22.7	4.5	3	-24.4		m	30*
3682.764	.48	-35.4	1.9	4	-32.0		m	30*
3687.728	.15	+17.9	4.3	2	+ 6.6		wm	30
3688.725	.28	-10.2	4.0	2	- 8.0		wm	30
3690.733	.55	-33.4	4.0	2	-33.6		w	30
3692.724	.81	+ 0.9	3.5	2	+ 3.0		w	30
3693.737	.95	+12.0	6.0	1	+53.:		vw	60
3695.723	.21	- 1.3	5.6	1	+43:		vw	60
3849.977	.80	+ 5.2	4.1	2	+ 9.4		m	30
3849.985	.80	+11.3	3.7	2	+11.0		m	30
3874.045	.01	+22.8	2.0	2	+32.3		m	60*
3878.911	.66	-22.9	1.2	4	-22.4		s	30*
3880.038	.81	- 9.3	2.4	2	-11.0		wm	78*
3881.042	.95	+29.7	7.8	1	+39.9		w	60
				Lick Coudé Observations				
3670.740	.88	+11.6	0.5	4		-22.3	m	16
3672.737	.14	+15.0	0.3	4		+15.4	w	16
3673.736	.28	- 7.8	0.8	4		-22.2	m	16
3848.972	.67	-20.1	0.9	4		-24.9	s	16
3849.978	.80	- 2.4	0.7	4		-36.8	w	16
3853.948	.33	-30.4	1.3	4		-47.7	m	16
3870.942	.60	-30.4	0.9	4		-40.0	m	16
3871.965	.74	-11.0	0.9	4		-19.1	s	16

* Photographic (non–image tube) spectra.

† The phases are calculated from the ephemeris ϕ = JD 2,443,881.4 + 7.492E.

‡ I refers to a visual estimate of emission strength: s = strong, m = moderate, w = weak, vw = very weak.

somewhat stronger than normal for the RS Canum Venaticorum stars, only a small fraction of which consistently exhibit Hα emission (Bopp and Talcott 1978). Comparison with spectra of MK standard stars indicates that the spectral type is K2 III–IV.

TABLE 2

LICK SCANNER OBSERVATIONS

Heliocentric JD 2,440,000+	ϕ	Hα E.W. (Å)	Telescope (m)
3668.766	0.61	0.6	0.6
3669.677	0.73	1.0	0.6
3671.670	0.00	1.9	3
3672.698	0.14	2.0	0.6
3673.701	0.27	5.8	0.6
3846.083	0.28	2.4	3
3870.994	0.61	2.7	0.6

III. ORBITAL PARAMETERS

The radial velocities clearly show that the orbital period is ~7.5 days. Since the velocities are derived from a rather heterogeneous set of spectra, a weighting system was adopted based on the expected reliability of the velocities. As shown in Table 1, the 16 Å mm^{-1} Lick image tube spectra and the 30 Å mm^{-1} Victoria photographic spectra were given the highest weight, 4. Orbital solutions for the DAO observations alone and the combined DAO and Lick observations show that systematic errors between the data sets are negligible.

In Table 3, the results of least-squares orbital solutions are shown for both circular and eccentric orbits for the absorption lines and the Ca II H and K emission reversals. The orbits listed in the second and third columns are identical except that one discrepant point was omitted in the solution in the third column. The effect of this one point on the eccentricity and the fact

TABLE 3

ORBITAL SOLUTIONS[a]

Orbital Element		Absorption Lines		Ca II Emission
V_0 km s^{-1}	−6.9 ± 1.2	−6.5 ± 1.2	−5.5 ± 1.2	−6.2 ± 2.3
K km s^{-1}	27.6 ± 1.8	29.1 ± 1.8	28.0 ± 1.7	25.7 ± 3.6
e	0[b]	0.11 ± 0.05	0.06 ± 0.05	0[b]
ω radians	0[b]	1.0 ± 0.6	1.6 ± 1.1	0[b]
T_0[c] JD 2,443,800+	81.4 ± 0.1	75.1 ± 0.7	76.0 ± 1.3	81.3 ± 0.1
P days	7.492 ± 0.009	7.491 ± 0.009	7.499 ± 0.010	7.492
SD km s^{-1}	5.5	5.2	4.8	8.3
N	28	28	27	14

[a] Explanations of the four different solutions are given in the text.

[b] These quantities were held constant at the listed values.

[c] Time of periastron passage or time of maximum positive velocity in a circular orbit.

that it is so small lead us to conclude that, while a small eccentricity is possible, the circular orbit adequately represents the data, and so the solution in the first column is adopted. Although the errors are considerably larger, the orbit representing the Ca II emission reversals appears to be identical to the absorption-line solution. The data are shown plotted in Figure 1 together with the adopted orbit. The available data indicate that the radial velocities of the Ca II emission and the absorption lines are identical to within the errors of measurement. The Hα velocities, on the other hand, are consistently more negative by 10–30 km s^{-1}. This may be indicative of some net mass outflow from the system. Further observations are required to understand the variations in the velocity and strength of the Hα feature.

If $K = 27.6$ km s^{-1} and $P = 7^{d}492$, then the mass function $f(m) = 0.016\ M_\odot$ and the separation $a_1 \sin i = 2.8 \times 10^6$ km. For equal masses the minimum masses of the stars are 0.065 $M_\odot$. The average mass of components of RS Canum Venaticorum systems is ~1.2 $M_\odot$ with a standard deviation of only 0.3 $M_\odot$, and the mass ratios are usually very close to unity (Hall 1976; Popper and Ulrich 1977). If the values $M_1 = 1.2\ M_\odot$ and $q = M_1/M_2 = 1$ are assumed, then $i \sim 22°$. Since there is no visible evidence for a companion, it must be at least 1.5 mag fainter, and, if the masses are equal, would presumably be a degenerate object. Most RS Canum Venaticorum systems consist of two slightly evolved stars, so it is probably preferable to assume that the companion is not degenerate but that $q > 1$. For example, if $q = 2$, then $M_1 \sim 1.2\ M_\odot$, then $i \sim 40°$ satisfies the mass function. With such masses BD +61°1211 would be similar to RT Lacertae, an RS Canum Venaticorum object atypical in that the mass ratio is far from unity (Popper and Ulrich 1977). According to Walter, Charles, and Bowyer (1978*b*), X-ray flares which are considerably harder than the quiescent spectrum may be expected from active RS Canum Venaticorum systems so that accretion onto a degenerate companion is not required to explain the observed X-ray emission of 2A 1052+606.

A photometric study of BD +61°1211 should be carried out to look for variation with a 7.5 day period.

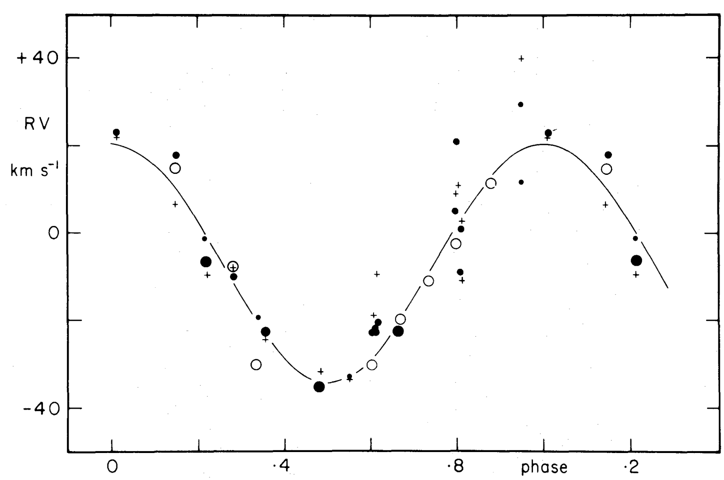

FIG. 1.—The radial-velocity variation of BD +61°1211 as a function of orbital phase. *Open circles*, velocities from Lick observations; *filled circles*, DAO observations; *crosses*, DAO velocities of Ca II emission. The different sizes of the filled circles indicate the relative weights of the observations. The curve represents the adopted circular orbit fitted through the absorption-line velocities.

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