HR 1099: A new bright RS CVn variable

Bernard W. Bopp*

Ritter Observatory, The University of Toledo, Toledo, Ohio 43606

Francis Fekel Jr.

The University of Texas at Austin, Austin, Texas 78712

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HR 1099 (ADS 2644A), a G-type system with strong Ca II H and K and H α emission, is shown to be an RS CVn binary system with period 2.84 days. The system is the brightest known member of the class to date, and bears a very close resemblance to the radio variable UX Arietis (HD 21242). The H α emission from the primary component shows marked profile variations. The presence of a visual companion (sp. K3 V) puts some significant constraints on the evolution of the system.

INTRODUCTION

IN THE course of a spectroscopic survey of Ca II H and K emission intensity in several visual binaries, O. C. Wilson (1963) noted the extraordinary strength of these reversals in the brighter component of the visual pair ADS 2644 (HR 1099; sp. G5 V). The widths of the H and K lines were of the order of 1 Å, and the absorption lines were broadened, presumably by rotation. In a subsequent note, Wilson (1964) reported his H α observations of this star. H α was visible as an emission line of moderate intensity, having a width of 5–6 Å.

The occurrence of very strong H and K emission and unusual Balmer emission in a G dwarf seemed sufficiently interesting that HR 1099 was placed on the program at Ritter Observatory. The initial spectrogram obtained in December 1974 showed doubled absorption lines, but apparently only one emission component at H and K, which shared the velocity of one set of absorption lines. Spectra obtained at Kitt Peak later that month confirmed this initial observation. Some photometric observations obtained at Kitt Peak in February 1975 indicated a small range of variation. Coudé spectra from McDonald and H α spectra from Ritter obtained later in the year showed HR 1099 to be very similar to the RS CVn system UX Arietis. By the fall of 1975 it became clear that HR 1099 was an RS CVn-type binary system. With $m_v \sim 5.9$, HR 1099 is in fact the brightest known member of the class.

I. ORBIT

Thirteen coudé spectra of HR 1099 were obtained with the 2.04-m Struve reflector at McDonald Obser-

vatory during 1975–1976. The dispersion was 8.5 Å mm⁻¹, covering the wavelength region $\lambda\lambda 3800$ –4600. Doubled absorption lines of approximately equal strength can be seen at this dispersion; both sets of lines are rotationally broadened. The H and K reversals are double also, but there is a marked difference in the intensities of the components, the primary (more massive) star having emission several times more intense than the secondary. The H and K lines and between 10 and 20 absorption lines were measured for radial velocity on oscilloscope measuring engines at either the Johnson Space Center or Ritter Observatory. No velocity differences between absorption and emission lines were seen. The observations are listed in Table I, with all spectrograms assigned equal weight. Because of their lower dispersion (30–60 Å mm⁻¹) with the danger of blends, the Ritter and Kitt Peak spectra were not included in the orbital solution.

The computer program described by Barker, Evans, and Laing (1967), modified for the double-line case, was used to solve for the orbit. Figure 1 shows the computed velocity curves compared with the observations. Orbital elements are given in Table II.

II. H α OBSERVATIONS

To investigate further the unusual H α emission in HR 1099, seven spectrograms (dispersion 38 Å mm⁻¹) were obtained of the region $\lambda\lambda 5700$ –6800 with the Ritter Observatory 1-m reflector. H α is moderately strong in emission on all the plates, with equivalent width ~ 0.5 –1.0 Å. Most of the spectra show a narrow H α profile, perhaps a little wider than instrumental (1 Å). One spectrogram near phase 0.79, however, shows H α as a very broad emission feature, identical to the spectrum illustrated in Wilson's 1964 paper.

Velocity measurements of H α were made to identify the source of the emission. These data are given in Table III, where the accuracy is estimated as ± 5 km sec⁻¹.

* Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association for Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE I. Velocities of HR 1099.

Plate No.	JD ₀ 2442000+	Phase	Velocity (km sec ⁻¹)		<i>O</i> - <i>C</i> (km sec ⁻¹)	
			primary	secondary	primary	secondary
9094	504.593	0.622	-50.2	+36.0	+2.4	+2.6
9102	505.594	0.974	+34.1	-77.2	-1.9	-1.8
9286	625.963	0.390	-48.8	+33.8	+1.1	+3.7
9299	627.979	0.101	+28.3	-67.3	-0.8	-0.3
9308	628.974	0.451	-57.3	+43.4	+2.1	+1.6
9461	708.959	0.637	-51.2	+30.7	-1.5	+0.8
9471	709.893	0.966	+32.7	-72.8	-2.5	+1.7
9487	711.876	0.665	-45.5	+21.0	-2.1	-1.2
9501	712.899	0.025	+38.3	-75.8	+1.0	+1.3
9546	762.871	0.634	-53.6	+28.3	-3.4	-2.1
9556	763.777	0.954	+37.0	-72.6	+3.2	+0.2
9593	793.786	0.528	-63.8	+42.7	-1.2	-3.0
9756	853.624	0.614	-53.4	+34.7	+0.5	-0.4

Clearly the primary component is the origin of the emission.

III. DISCUSSION

HR 1099 fulfills Hall's (1975) spectroscopic criteria for membership in the RS CVn group of binaries. Photometry by Landis and Hall (1976) shows no eclipses, but a quasisinusoidal variation $\Delta V \sim 0^m1$ with period $P = 2^d822$ is evident. The system bears a striking resemblance to another noneclipsing RS CVn system, UX Arietis (HD 21242). Both stars show H α emission, with about the same intensity (Weiler 1975; Mulligan and

Bopp 1975). An 8.5-Å mm⁻¹ coude spectrogram of UX Ari obtained by us reveals the Ca II H and K intensity of the primary component to match closely the strong H and K emission in HR 1099. Finally, as Landis and Hall (1976) remark, the light curve of HR 1099 is virtually identical to that of UX Ari in 1972 (Hall, Montle, and Atkins 1975).

The above similarities, along with the radio detection of UX Ari (Gibson, Hjellming, and Owen 1975) suggested that HR 1099 was a likely candidate for radio observations. Our preliminary spectroscopic results were communicated to Dr. Owen. He has subsequently reported (Owen 1976) that HR 1099 was detected at 2695

FIG. 1. The radial velocity curves of HR 1099. Phase is computed from periastron passage. The primary component has negative radial velocity at phase 0.50.

TABLE II. Orbital elements of HR 1099.

P	$= 2.83782 \pm 0.00022$ days (m.e.)
γ	$= -14.01 \pm 0.45$ km sec $^{-1}$
e	$= 0.027 \pm 0.014$
T_0 (JD)	$= 2442763.909 \pm 0.221$
K_1	$= 50.2 \pm 0.8$ km sec $^{-1}$
K_2	$= 61.6 \pm 1.5$ km sec $^{-1}$
ω_1	$= 356^\circ \pm 27$
$a_1 \sin i$	$= 1.96 \pm 0.03 \times 10^6$ km
$a_2 \sin i$	$= 2.41 \pm 0.06 \times 10^6$ km
$M_1 \sin^3 i$	$= 0.227 \pm 0.009 M_\odot$
$M_2 \sin^3 i$	$= 0.185 \pm 0.006 M_\odot$

and 8085 mHz with flux densities ranging from 10 to 170 mJy. Flare-like behavior similar to that seen in UX Ari has been noted. Owen remarks (private communication) that the level of radio activity in HR 1099 may be significantly higher than that UX Ari. In the latter star, the strongest radio flare seen peaked near ~ 160 mJy; the observations extended over several months. A more intense flare was seen from HR 1099 after only a few days of observation.

There are some differences between the two systems, however. In UX Ari, the equivalent width of the H α emission is quite variable (Mulligan and Bopp 1975) but no profile changes were evident at $38 \text{ \AA mm}^{-1}$. Our observations of HR 1099 show no convincing evidence for variation in H α equivalent width, but the profile can change radically, as evidenced by the very broad H α emission seen near phase 0.79. This behavior may be phase dependent, or it may be a result of sporadic surface activity on the primary component. Including Wilson's data, two out of eight H α spectrograms show this peculiarity; whatever the origin, the circumstances producing this unusual profile must occur reasonably often.

A second difference between HR 1099 and UX Ari is in the spectral types of the components. Carlos and Popper (1971) give G5 V and K0 IV for the types in UX Ari. The lines of the hotter (less massive) component dominate the blue region of the spectrum. Wilson's composite spectra type is G5 V for HR 1099 (an older Mt. Wilson classification is dG9). The absorption lines of the two components are nearly equal with the weaker emission line component (spectroscopic secondary) having the slightly stronger absorption lines. This suggests temperature and luminosity differences between the primary and secondary must be small and the individual types very near G5. Blending problems on our spectra make an accurate luminosity classification impossible, though we might expect one component to be a subgiant (Hall 1975). However, *UBV* photometry by Eggen (1966) for component A of the visual binary gives $(B - V) = 0.92$ and $(U - B) = 0.43$. These colors are very close to those of a K0 V star [$(B - V) = 0.89$, $(U - B) = 0.47$] as given by Allen (1973), suggesting a spectral type later than G5.

Because the minimum masses of the spectroscopic system are low, it is of interest to consider the possible

inclination of the system. Popper (1976) lists 27 RS CVn-type binaries. Of these all but one are eclipsing systems and 21 have masses listed. The average mass of those seven systems whose primary spectral type is G2 or later and whose mass ratio ~ 1 is 2.36. Using our derived mass ratio of 1.23, the masses are $1.3 M_\odot$ for the stronger emission component and $1.1 M_\odot$ for the weak emission component. This leads to an inclination $i \sim 34^\circ$. If the mass of the primary is reduced to $1.0 M_\odot$, then i increases to 38° .

Tracings of several absorption features yield a rotational broadening $v \sin i \sim 30$ km sec $^{-1}$ for both components. With an assumed $i \sim 35^\circ$, the rotational velocity at the equator, $v_{\text{eq}} \sim 52$ km sec $^{-1}$. Assuming synchronous rotation, the radii of both components are then on the order of $3 R_\odot$.

This value for the radius may be checked in the following way: Using a visual magnitude $V = 5^m.88$ for ADS 2644A (Eggen 1966) and applying a $0^m.75$ correction for duplicity, we find $V = 6^m.63$ for each component. The trigonometric parallax $\pi = 0''.028 \pm 0''.005$ (Jenkins 1963) yields $d = 35.7$ pc. A dynamical parallax yields a distance in good agreement with this value: Assuming the mass of the spectroscopic pair is $2.36 M_\odot$ and the fainter K3 V visual companion has a mass $\sim 0.7 M_\odot$, the total mass of the triple system is $\sim 3 M_\odot$. The visual orbit of Hopmann (1964) gives $P = 2101$ yr, with a semimajor axis of 8 arcsec. Kepler's third law gives $a = 237$ AU, and the distance is then 29.6 pc. Taking 33 pc as the average, and $V = 6.63$, we get $M_v = 4^m.04$ for each component, considerably above the main-sequence value for late-G dwarfs ($M_v \sim 5.5$) and closer to the subgiant value ($M_v \sim 3.2$). With the observed $(B - V) = 0.92$ and taking the associated effective temperature (4780 K) and bolometric correction ($-0^m.25$) along with the derived $M_v \sim 4.0$, the radius of each component is then $\sim 2.3 R_\odot$, in reasonable agreement with the spectroscopy.

Finally, we note that the presence of the visual companion, ADS 2644B, puts some interesting constraints on the evolution of the system. The physical association is not in doubt; in his *Catalogue Aitkin* remarks: "The relative motion shown by the measures is doubtless orbital." *The Index Catalogue of Visual Double Stars* (Jeffers and van den Bos 1963) lists 28 arcsec of orbital motion in 145 years, and a separation of $6''.1-6''.2$. In

TABLE III. HR 1099:H α velocities.

Plate No.	JD ₀ 2442000+	Phase	V (H α) (km sec $^{-1}$)
75120502	751.672	0.69	-34
75120701	753.569	0.36	-38
75121901	765.722	0.64	-62
75122301	770.576	0.35	-70
76011701	794.716	0.86	+23
76011901	796.565	0.51	-84
76020301	811.561	0.79	+ 1:a

^a Very broad emission.

addition, measurement of a $10\text{-}\text{\AA}\text{ mm}^{-1}$ spectrogram of ADS 2644B loaned by Dr. Wilson yields a radial velocity $V_r = -15.3 \pm 0.6$ (m.e.) km sec^{-1} , in good agreement with the γ velocity of the short-period pair.

Wilson (1964) gives K3 V as the spectral type of ADS 2644B. H and K reversals are seen in the spectrum, but they are rather weak; according to Wilson, they are about one-half to one-third as strong as the emission in corresponding Hyades members. Wilson's (1963) inverse relationship between H and K intensity and age, along with later extensions by Skumanich (1972) and Blanco *et al.* (1974) then implies an age on the order of 2×10^9 yr. Though Hall (1972) has argued that the RS CVn stars are in a pre-main-sequence stage of evolution, the implied age of HR 1099 clearly shows this is not so in this case. A similar conclusion may be reached for the only other RS CVn star with a visual companion, WW Draconis (Hall 1975). However, the masses of both components of HR 1099 are about $1.2 M_\odot$, and such stars leave the main sequence after only $\sim 3 \times 10^9$ yr. The close agreement between 2 and 3 billion years may be important in indicating that the Ulrich and Popper (1974) post-main-sequence model for RS CVn stars is more viable than the binary fission model recently proposed by Biermann and Hall (1976).

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