IUE SPECTRA OF A FLARE IN HR 5110:

A FLARING RS CVn OR ALGOL SYSTEM?[1]

Theodore Simon and Jeffrey L. Linsky[2,3]
Joint Institute for Laboratory Astrophysics
National Bureau of Standards and University of Colorado

Francis H. Schiffer III[4]
Computer Sciences Corporation

ABSTRACT

Ultraviolet spectra of the RS CVn-type binary system HR 5110 have been obtained with IUE on May 31, 1979 during a period of intense radio flaring of this star. High temperature transition region lines are present, but are not enhanced above observed quiescent strengths. The similarities of HR 5110 to the Algol system, AS Eri, suggest that the 1979 May-June flare may involve mass exchange rather than annihilation of coronal magnetic fields.

INTRODUCTION

We report here on IUE spectra of the close binary system HR 5110 (=HD 118216) obtained during a radio flare and subsequently during a presumably quiescent period. HR 5110 consists of an F2 IV primary and a G-K star secondary in a nearly circular orbit of period $2\overset{d}{.}61$ and mean separation 0.05 a.u. (1); the system is viewed nearly pole-on. Hall (2) includes HR 5110 in his list of RS CVn variables. The other stars in this group are close binaries with periods of 1-14 days, typically consisting of a chromospherically-active K0 IV star with intense Ca II H-K emission, and an F-G IV-V star, which is usually the brighter optical component but whose chromospheric emission lines are normally the weaker. Photometric light curves of RS CVn systems exhibit a unique quasi-sinusoidal distortion wave or "wave of darkening," which Eaton and Hall (3) have modeled in terms of dark starspots covering a large fraction of one hemisphere of the K subgiant star. Many RS CVn systems are strong sources of soft X-rays (4-6), with coronal temperatures near 10^7 K, and have been observed to flare at radio wavelengths (7,8). These nonthermal microwave bursts are most likely due to gyro-synchrotron emission (9,10). Ultraviolet observations of the RS CVn-systems HR 1099,

[1]This work was supported by NASA through grants NAS5-23274 and NGL-06-003-057 to the University of Colorado.

[2]Staff Member, Quantum Physics Division, National Bureau of Standards.

[3]Guest Observer with the International Ultraviolet Explorer (IUE) satellite.

[4]Resident Astronomer, IUE Observatory.

λ And, and Capella, obtained early during the IUE mission (11), revealed bright emission lines indicative of hot chromospheres ($T = 4\text{-}20 \times 10^3$ K) and transition regions ($T = 20\text{-}250 \times 10^3$ K). Quiescent chromospheric models to explain these IUE observations have been discussed by Simon and Linsky (12) for HR 1099 and UX Ari, and by Baliunas et al. (13) for λ And and Capella. Simon, Linsky and Schiffer (14) have also presented IUE observations obtained during a flare of UX Ari and, guided by solar coronal loop models, have proposed an interacting magnetic loop model for major flare events in RS CVn binaries.

HR 5110 is an unusual RS CVn-type system in several respects. The mass ratios of RS CVn's are typically within 30% of unity, and the more massive component is also the cooler, more highly evolved star (2,15). In HR 5110, however, the F star primary is clearly the more massive, since Conti (1) found $m_2/m_1 = 0.28 \pm 0.08$. He also concluded that the secondary of HR 5110 fills its Roche lobe, unlike the majority of RS CVn systems which are classified as detached binaries. Thus, HR 5110 resembles mass-exchange Algol systems, which also exhibit weak X-ray emission (16) and sporadic radio bursts (17,18). The photometric light curve of HR 5110 (19) shows evidence of a small reflection effect ($0\overset{m}{.}01$ in V), but no distortion wave. The apparent absence of a distortion wave could be due to the low inclination of the system, assuming starspots to be concentrated along equatorial regions of the secondary, and to the relatively small contribution of the secondary to the total light of the system in the V band.

OBSERVATIONS

We observed HR 5110 initially on 1979 May 31 at 17^hUT as a target of opportunity observation with IUE after notification by Paul Feldman that a major radio flare was underway in the system. Feldman (20) measured a 10.76 GHz flux of 0.425 Jy on May 29 at 8^h26^mUT with continued flaring activity in the range 0.20-0.35 Jy over the next two days. Our IUE observations thus occurred during a period of intense radio flaring. On February 1, 1980 comparison spectra were taken at the identical orbital phase when the system was presumably quiescent. The circumstances of the observations are given in Table 1. By convention, orbital phase 0.5 corresponds to conjunction with the F star in front of the secondary.

The two SWP spectra have been calibrated in absolute flux units at Earth using the standard IUE calibration factors and the latest ITF. Longward of about 1700 Å both SWP spectra are saturated due to the rapidly rising photospheric flux of the F2 IV primary. The HR 5110 emission line spectrum looks qualitatively similar to spectra of β Cas, a rapidly-rotating F2 IV single star discussed by Linsky and Marstad (21), and the RS CVn binary UX Ari (12), if allowance is made for the weak underlying continuum of the cooler stars (G5 + K0 IV) in the UX Ari system.

Integrated fluxes of the strongest emission features present in these spectra are listed in Table 2. Probable identifications of the ions responsible for the emission features are given in order of their estimated relative importance. In proposing identifications, we have been guided by line lists for the solar limb spectrum (22) and Capella (23). The line strengths are presented in the form of surface fluxes, assuming that all of the flux originates from the cooler star, for which we compute an angular diameter of 0.45 milliarcsec from the Barnes-Evans relation (24). We comment on this assumption later. At a distance of 52 pc from the Sun, the secondary has a radius of 2.6 $R_{\odot}$ and therefore fills its Roche lobe (1); for simplicity, we ignore geometrical distortion of the secondary. For comparison with the HR 5110 data, Table 2 also presents surface fluxes for β Cas, UX Ari in both quiescent and flare states, and the quiet Sun.

DISCUSSION

The first conclusion that can be drawn directly from inspection of Table 2 is that the accurately measured strong lines (e.g., those of N V, C II, O I, C IV, and He II) are fainter in the "flare" spectrum than in the "nonflare" spectrum. While this may appear surprising, it is important to realize that image SWP 5415 was obtained almost 2 1/2 days after the radio flare was first detected. HR 1099 was observed on 1978 March 1, also long after the onset of a major radio flare, and the ultraviolet emission lines showed no enhancement over quiescent values (11,12). By contrast, IUE spectra of the January 1, 1979 flare of UX Ari (14) were obtained only 26 hours after the initial detection of the radio flare, while the radio flare was still active, and showed a factor of 5.5 enhancement of the UV line strengths

These three examples suggest that the time scales of radio and UV flares in RS CVn systems may be quite different. Since the intense radio flux and the enhanced ultraviolet line emission may originate at different heights in the stellar atmosphere and since solar flares exhibit strong radio emission long after the ultraviolet aspects of the flare are completed, it is not implausible that stellar radio flares would be of longer duration than the associated UV flare events. We therefore conclude that both SWP 5415 and SWP 7834 represent quiescent conditions, and that the different flux levels observed are representative of normal time variations in the activity of the system.

The HR 5110 "flare" differs from the earlier UX Ari flare in another significant detail. In the high dispersion UX Ari flare spectra, we observed prominent asymmetries in the profiles of the Mg II resonance lines at 2800 Å, corresponding to Doppler velocities of 475 km s^{-1}, and we interpreted those asymmetries as evidence for gas flowing along a magnetic flux tube coupling the primary and secondary stars. No similar line asymmetries appear in the HR 5110 spectra, although mass transfer taking place at velocities less than 150 km s^{-1} might be impossible to detect because of the ~13° inclination of the system.

IDENTIFICATION OF THE ACTIVE STAR

A critical question is: Which star in the HR 5110 system contributes most of the flux seen in the bright UV emission lines? It is not possible to answer this question directly because the maximum radial velocity separation between the component stars is only 43.7 km s^{-1}, so the high dispersion mode of IUE and an accurate absolute wavelength scale would be needed to identify the emitting star on the basis of line splitting or absolute wavelength displacement. This approach was followed in our analysis of the UX Ari system (12), where the maximum velocity difference is 126 km s^{-1}. On the basis of Doppler shifts of the Mg II lines, we identified the K0 IV star as the dominant contributor in this system. Some caution is warranted because Ayres and Linsky (23) show that the Ca II H-K emission features and the transition region lines of the Capella system are contributed by the G6 III primary and F9 III secondary, respectively. However, the circumstance leading to this dichotomy for the Capella system, viz. a factor of 10 difference in rotational velocities of the primary and secondary, does not seem to be repeated in the short-period synchronously rotating RS CVn binaries.

Circumstantial evidence for associating the secondary in HR 5110 with the strong UV emission lines comes from a comparison of the derived surface fluxes with those measured in β Cas (F2 IV) and UX Ari (G5 V + K0 IV). We choose β Cas as a comparison star because it has the same spectral type as the HR 5110 primary and is a very rapid rotator like HR 5110 (25). Despite its early spectral type, β Cas exhibits a chromospheric and transition region emission line spectrum. We assume that the existence of a chromosphere and a transition region in this star is due to the effectiveness of rapid rotation in producing a strong hydromagnetic dynamo even though the stellar convection zone is thin.

Comparing the surface fluxes listed in Table 2, we see that the emission lines of HR 5110 are a factor of 10 brighter than the corresponding lines in β Cas. If for stars of the same spectral type the rotational velocity is the dominant variable determining outer atmosphere heating (23), we conclude that the F2 IV star in HR 5110 contributes no more than ~10% to the observed emission line flux. Furthermore, the closer agreement between the surface fluxes of HR 5110 and UX Ari, assuming that the cooler stars in both cases are the dominant emitters, suggests that the secondary in HR 5110 is the more likely source of the observed line emission.

RS CVn OR ALGOL?

Although different time scales for radio and UV flares may account for our failure to observe an enhancement of the emission lines of HR 5110 in May, 1979 we now briefly consider an alternative explanation: namely, that radio flares in this system are the result of episodic mass transfer from the secondary to the primary, instead of magnetic field annihilation processes in large coronal loops, as we proposed for UX Ari (14). We note, however, that chromospheric models based on the IUE fluxes for HR 5110 would yield approximately the same surface pressures (0.7-1.1 dyn cm^{-2}) as derived earlier for UX Ari, and so the hydrostatic coronal loop model of Rosner, Tucker, and Vaiana (25) would predict loop dimensions comparable to the separation (~10 R_o) of the components in this system.

To summarize, we have repeated Conti's (1) analysis of UBVRI photometry of HR 5110, supplemented with new JHKLM data that we have obtained at Kitt Peak. For this purpose, we required that the radius of the secondary be the same as the Roche lobe (2.6 R_o, see Ref. 1), we adopted a parallax of 0".019, and we used the Barnes-Evans relation. With these assumptions, the observed spectral energy distribution, 3600 Å-5 μm, can be matched by a composite spectrum, F2 IV + G5 IV, except for a small ($0^{m}.3$) infrared excess which might be due to intrasystem material (e.g., a circumstellar ring). The magnitude difference between the components is $\Delta V = V_G - V_F = 1^{m}.15$, while the absolute bolometric magnitudes for the primary and secondary are $M_{bol} = +1.60$ and $M_{bol} = +2.65$, respectively. In this calculation, the secondary is twice as luminous as found by Conti.

We now compute the luminosity ratio L_x/L_{bol}, where L_x is the X-ray luminosity. Ayres and Linsky (23) have shown that this ratio is correlated with equatorial rotation velocity: the more rapid the rotation, the larger the ratio, and hence the more active the chromosphere-corona. The range of L_x/L_{bol} values for RS CVn binaries is $5 \times 10^{-4} - 2 \times 10^{-3}$, with a corresponding spread of 20-80 km s^{-1} in rotational velocity.

Assuming synchronous rotation, we calculate v_{eq}=49 km s^{-1} for the G5 IV secondary in HR 5110 (but v sin i=10 km s^{-1}). For this rotational velocity, we then expect $L_x/L_{bol} \geq 5 \times 10^{-4}$. The observed $L_x = 3.0 \pm 0.9 \times 10^{30}$ ergs s^{-1} (4) and our estimated L_{bol}, however, yield $L_x/L_{bol} = 1 \times 10^{-4}$, which is a factor of 5 below typical values for RS CVn systems. An upper limit on this ratio, based on the implicit uncertainties, would still place HR 5110 at least a factor of 2 below the least active of the remaining RS CVn binaries.

Despite the large UV fluxes observed for HR 5110, this calculation suggests that the RS CVn designation for this system may be misleading and that the interacting coronal loop model may not apply to flare episodes of this star. In view of its Algol-like characteristics, the most attractive alternative is mass exchange from the cool secondary to the F2 primary through the inner Lagrangian point (26). Only a modest flow of material ($\sim 5 \times 10^{16}$ g s^{-1}) is required to account for the radio, ultraviolet, and X-ray power observed. HR 5110 closely resembles the Algol system AS Eri (27), which consists of an A3 V primary of mass 1.9 $M_\odot$ and a cool secondary of mass 0.2 $M_\odot$, which fills its Roche lobe. The secondary of AS Eri appears to be collapsing to the white-dwarf state (28), and we speculate that the same evolutionary picture may apply to HR 5110 and other RS CVn-type systems.

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Table 1

Summary of IUE Observations of HR 5110[a]

IUE Image	Dispersion	Exposure (min)	Date (JD 2440000+)	Orbital Phase[b]	Comment
SWP 5415	Low	30	4025.2003	0.6412	"Flare"
LWR 4652	High	10	4025.2192	0.6484	"Flare"
LWR 6838	High	10	4270.7214	0.5963	"Nonflare"
SWP 7834	Low	25	4270.7361	0.6019	"Nonflare"

[a]All observations were made through the 10" × 20" large aperture.

[b]Phases computed from ephemeris given in Ref. 19.

Table 2

Comparison of Line Surface Fluxes (ergs cm^{-2} s^{-1})

Line or Multiplet	HR 5110[a]		UX Ari[b]		β Cas[c]	Quiet Sun[d]
	Flare	Quiet	Flare	Quiet		
C III 1175 Å	7.1(5)	1.1(6)	1.2(6)	2.0(5)	4.5(4)	1.6(3)
N V 1239 Å	4.1(5)	8.4(5)	1.2(6)	1.9(5)	1.4(4)	8.6(2)
O I 1304 Å	1.2(6)	1.5(6)	1.3(6)	4.4(5)	1.4(5)	4.0(3)
C II 1335 Å	1.1(6)	1.4(6)		4.4(5)	8.6(4)	4.6(3)
Si IV 1394 Å	2.2(5)	7.2(5)	7.0(5)	1.3(5)	3.1(4)	1.7(3)
Si IV+O IV 1403 Å	5.9(5)	5.0(5)	6.5(5)	1.2(5)	4.6(4)	7.9(2)
C IV 1549 Å	1.7(6)	2.2(6)		6.5(5)	1.8(5)	5.8(3)
C I 1561 Å	1.4(5)	1.9(5)			2.0(4)	2.0(3)
He II 1640 Å	7.2(5)	1.1(6)		3.5(5)		1.3(3)
C I 1657 Å	3.5(5)	9.2(5)				5.3(3)
Mg II 2796 Å	1.9(7)	2.1(7)	1.7(7)	6.8(6)		6.8(5)
Mg II 2803 Å	1.7(7)	1.7(7)	1.4(7)	5.8(6)		5.3(5)

[a]Assuming all the emission comes from the secondary with an angular diameter of 0.45 milliarcsec. If the emission is assumed to come from the F star only (angular diameter of 0.53 milliarcsec), then all surface fluxes should be divided by factor of 1.4.

[b]Assuming all the emission comes from the K0 IV star whose angular diameter is 0.62 milliarcsec. Data from Refs. 12 and 14.

[c]Assuming an angular diameter of 2.0 milliarcsec. Data from Ref. 21.

[d]Quiet Sun fluxes cited in Ref. 11.