AN ULTRAVIOLET STUDY OF THE NEAR-CONTACT BINARIES

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ABSTRACT. Five members of the class of near-contact binaries have been investigated in the ultraviolet using the IUE. The spectra have been analyzed to find masses of two of the systems and to indicate the possibility of mass transfer.

1. Introduction

A class of close binaries known as near-contact binaries has been defined by Shaw (1990). These systems have periods less than one day, show tidal interaction, and have their facing surfaces less than 0.1 orbital radius apart. However, they are not in contact like the W UMa systems. In the case of V1010 Oph, and stars in the subclass of the near-contact binaries named after it, the larger, hotter star (primary) is near its Roche surface. Members of the FO Virginis subclass have the smaller, cooler star (secondary) filling its Roche lobe. In both subclasses the primary star is one to two spectral classes early than its companion. These systems are of particular interest because of their involvement in the evolutionary scenarios of W Ursa Majoris binaries. The near-contact binaries may be in the early stages of mass transfer which will result in their eventually becoming contact systems or, alternately, they may be a stage of W UMa binary evolution in which one or both components have temporarily become detached from their Roche lobes.

While 40-50 of these systems have been studied photometrically in the visible (Shaw 1990), only 5 have been observed in the ultraviolet: VZ CVn, KR Cyg, FO Vir, V1010 Oph and RT Scl. This lack of interest is not surprising as almost all of the light of a near-contact system comes from the hot component which is an A or early F star. A and F stars have very little chromospheric activity to produce ultraviolet emission lines, nor do they have very much ultraviolet continuum. Nonetheless, ultraviolet observations have been undertaken which shed light on three problems concerning the near-contact binaries: 1) Suspected mass flows, 2) Chromospheric emission line activity, as shown in the type-A Ursa Majoris binaries and, 3) Spectroscopically determined mass ratios.

2. Mass Flow

Mass transfer has been suspected in the near-contact binaries for several reasons: the

Y. Kondo et al. (eds.), Evolutionary Processes in Interacting Binary Stars, 373–377.

primary or secondary component is at or near its Roche lobe, some systems have variable periods, and many systems have one maximum brighter than the other. For example the brightest of the near-contact binaries, V1010 Ophiuchi has its primary near the Roche Lobe, Maximum I brighter than Maximum II and it shows a period change of $dP/dt \simeq -3x10^{-2}$sec yr^{-1}. (Williams and Guinan, 1989, attribute this to mass transfer from the more massive to the less massive component at a rate of $dM/dt \simeq 3x10^{-7}M_{\odot}\ yr^{-1}$). All of these phenomena could be explained by a model with mass transfer from the primary impacting on the trailing hemisphere of the secondary causing a hot spot. Unfortunately, no ultraviolet signature of an extensive high temperature impact region was found in any of the systems observed. However, only V1010 Oph and FO Vir were observed with the IUE SWP camera at high dispersion so low levels of line emission would not have been detected in RT Scl, KR Cyg and VZ CVn. Nonetheless, Lyman α emission was detected from the cool component of V1010 Oph and FO Vir. Figure 1 shows the region around Lyman α, λ1215.667, for V1010 Oph and FO Vir taken at with the SWP camera of the IUE at high dispersion. Each exposure was centered at quadrature. The rapid orbital motion of the binary is sufficient to Doppler shift the cool, less massive stars Lyα emission away from its rest wavelength so that it is not masked by geocoronal Lyα emission.

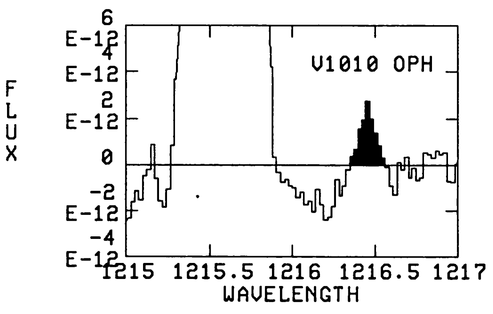

Fig. 1a) SWP36631 of V1010 Oph

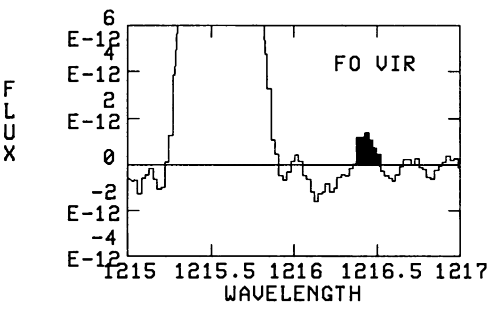

Fig. 1b) SWP39185 of FO Vir

Both spectra were taken at 0.25 phase. Lyman α emission from the cool component is shaded in. Doppler shift due to the binary system's orbital motion moves it away from the strong geocoronal feature which extends out of the figures.

Table 1 lists the radial velocities and fluxes of the cool component's Lyα emission. For V1010 Oph the Lyα flux at phase 0.25 is approximately 2 times that at phase 0.75. FO Vir showed Lyα only at phase 0.25. In both cases mass flow impacting in the cool star's chromosphere could deposit energy which would be reprocessed into emission lines. Lyman α is by far the strongest of these for chromospheres. Our detection was weak so it is not a surprise that other ultraviolet emission lines did not appear.

3. Relationship to Ultraviolet Emission Lines in Contact Binaries

The lack of strong emission lines in near-contact binaries is also somewhat puzzling as W UMa binaries with similar periods and which contain late A and early F stars show

https://doi.org/10.1017/S007418090012251X Published online by Cambridge University Press

Table 1. Lyman α Emission Lines in Near-Contact Binaries

Binary	Image	Phase	Radial Velocity $km\ s^{-1}$	Net Flux $erg\ s^{-1}\ cm^{-2}$
V1010 Oph	SWP36631	.025	193	2.6×10^{-13}
	SWP36629	.075	-246	1.1×10^{-13}
FO Vir	SWP39185	.025	-234	1.5×10^{-13}

strong emission line features, particularly in the short wavelength region, $\lambda\lambda$1150-2000 (Dupree and Preston, 1981, Rucinski and Vilhu, 1983, and Eaton,1983). None of the near-contact binaries show emission lines on the scale of the W UMa systems (Shaw and Guinan, 1983)! While the absence of strong ultraviolet line emission in the near-contact binaries or their presence in the W UMa systems is still somewhat of a mystery. We suggest the important difference between the W UMa type systems and the near-contact binaries may be that the W UMa systems are contact or over-contact systems sharing a common convective envelope whereas the near-contact binaries are detached or semi-detached systems and do not have a common envelope and therefore are thermally decoupled.

4. Determination of Masses

Due to the substantial difference in brightness between their components, the near-contact binaries are single lined spectroscopic binaries. Consequently, spectroscopically determined orbital elements have relied on cross-correlation techniques applied to the few systems with less brightness difference between the components (see Hilditch, et. al., 1988 for references). Recently, however we have used the Lyα line originating on the cool component (Figure 1) to find the radial velocity of the secondary at the quadratures of the orbit and thus determine the orbital and physical properties of the system. For this study each exposure was carefully centered at quadrature. The rapid orbital motion of the binary is sufficient to Doppler shift the star's Lyα emission away from its rest wavelength so that it is not masked by geocoronal Lyα emission. Table 1 lists the radial velocities and fluxes of the cool component's Lyα emission for the only two systems which have high dispersion SWP spectra.

Solutions of the light curves from Guinan (1970), and the radial velocity curve from Guinan and Koch (1977) were combined with the new information to yield the complete physical parameters of V1010 Oph as show in Table 2. The photometric and spectroscopic solution of Mochnacki, et. al. (1986) was used for FO Vir.

For V1010 Oph previous solutions relied on photometrically determined mass ratios or assigned standard main sequence values to the brighter star. We now see the primary is somewhat undermassive and oversized for a main sequence A7 star. That fact coupled with the primary being near its Roche lobe suggests the primary star is evolving off the main sequence and in the process has lost mass. Interpretation of the new information about V1010 Ophiuchi's elusive secondary component is much more problematical. Guinan's (1970) solution to multicolored light curves estimated the cooler component's spectral type to be late F. However, the light of the cooler star

Table 2. Physical Parameters for V1010 Oph and FO Vir

	V1010 Oph	FO Vir
mass ratio (cool/hot)	0.48 ± 0.03	0.16 ± 0.04
a	2.98 ± 0.1 x 10^6 km	3.04 ± .02 × 10^6 km
hot star	A7	A7
	1.62 ± 0.1 $M_\odot$	1.61 ± 0.1 $M_\odot$
	2.01 ± 0.07 $R_\odot$	2.35 ± 0.1 $R_\odot$
cool star	F7?	K2
	0.78 ± 0.07 $M_\odot$	0.25 ± 0.1 $M_\odot$
	1.07 ± 0.04 $R_\odot$	1.00 ± 0.1 $R_\odot$

contributes so little to the system this spectral type could be in error by as much as a whole spectral class. The measured size is roughly correct for the F7 spectral type found from the photometric light curve solution but it is a factor of 0.6 undermassive for an F7 star. If we assign a spectral type to the secondary dependent on its mass rather than on the unsure photometric estimate of spectral type, it would be a K0 star. Yet a K0 main sequence star would be much smaller than the measured radius. One possible solution is that mass flow from the primary is heating the secondary so it appears in the photometric light curve solution as a late F star. The problem posed by the undermassive secondary in this system is similar to the difficulty posed by the type type-A W UMa systems whose secondaries are 2-3 times undermassive for their spectral types.

The situation for FO Vir is much more problematical. The hot component is much like V1010 Oph in being an evolved main sequence star. The cool component can only be explained in term of its definite similarity to the type-A W UMa systems such as AW Uma. these also have very undermassive secondary components. In fact it is this strong similarity that suggests the FO Vir near-contact binaries are closely related to the type-A W UMa systems.

5. Ultraviolet Light Curves

Of the five near-contact binaries observed in the ultraviolet, only three have measures at more than one phase. Of these only V1010 Oph has adequate phase coverage for a reasonable light curve. The limited precision inherent in using the IUE cameras as photometers results in light curves with noticeable scatter. At this point in ultraviolet astronomy it seems unlikely that ultraviolet light curves of these objects will yield geometric parameters as precise as available from light curves in the visible. However, one interesting aspect occurs in the short wavelength region ($\lambda\lambda$1150-2000) covered by the IUE's SWP camera. Light from the cool star is virtually zero in this wavelength region, so the changing light intensity is completely due to the change of temperature over the primary star and its eclipse by an essentially lightless cool companion. Since very little energy is absorbed from the cool star (the reflection effect), the change in temperature is due entirely to 'gravity darkening'. For A and early F stars a small change in temperature results in a very large change in ultraviolet luminosity Consequently ultraviolet light curves can give information on the temperature variation over the face of the hot star. We have modeled ultraviolet light curves of V1010 Oph with the standard Wilson-Devinney model using the geometric solution of Guinan (1970). In all cases the model light curve was substantially too shallow in secondary minimum. We have rectified this problem by including Kurucz's (1991) newest atmospheric models in the Wilson-Devinney program. While the fits are fairly close we are in the process of revising Wilson's code to create an entire ultraviolet spectra with the hope of mapping the hot star's surface temperature and gravity darkening even more accurately.

This research was supported by NASA grant NAG5-1148.

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https://doi.org/10.1017/S007418090012251X Published online by Cambridge University Press