GENERAL PROPERTIES OF ULTRAVIOLET FLARES IN RS CVn SYSTEMS

J. E. NEFF[1], A. BROWN[2], and J. L. LINSKY[2]

[1]NASA Goddard Space Flight Center
[2]JILA, U. of Colorado and NBS

ABSTRACT: Approximately 10 very bright flares in RS CVn systems have been observed with the IUE. In several cases, high-resolution spectra of the Mg II k line profiles were obtained before, during, and after the flare. Such data permit us to measure the position and size of the flaring region, the amount of line broadening, and any systematic flow velocity. In two cases, several spectra were obtained during the flare decay, permitting us to study the change in these quantities during the flare decay.

1. The 19 September 1985 Flare on AR Lac

During 18–19 September 1985, we observed AR Lac continuously with IUE for 40 h, obtaining a series of high-resolution LWP spectra of the Mg II k (2795.5 Å) line. A low-resolution SWP spectrum of the 1200 to 1900 Å region was obtained following each LWP spectrum. The high-resolution spectra were used to construct images of the chromospheres (Neff 1987; Neff *et al.* 1988a) of both stars in the system. The spectrum obtained at 1510 UT on 19 September showed a dramatic increase in the flux of the Mg II k emission from the G star compared to previous spectra. By subtracting the mean emission line profile of the G star prior to this flare from this and subsequent spectra, the emission from the flare alone was isolated. The decay in flux and width of the flare Mg II k emission is shown in Figure 1.

We estimated the maximum area of the flaring region (1 to 3% of the visible hemisphere) from the line width in the latest decay phases by assuming that the width is due only to rotational smearing and that the region is circular. The line was 60 km s^{-1} broader near flare peak, due to an additional broadening mechanism.

The peak Mg II k surface flux in the flare was $\geq 2.7 \times 10^8$ erg s^{-1} cm^{-2}, nearly 100 times greater than the mean non-flaring level for the G star. The rise time to peak flux was <2.4 h, and the 1/e decay time scale at Mg II k was 3.5 h. The minimum total radiative energy output in the Mg II k line alone during the flare was $\geq 2.5 \times 10^{31}$ erg.

At flare peak, the measured radial velocity of the flare component (Figure 2) was redshifted by ~25 km s^{-1} with respect to the radial velocity of the G star. Near the end of the flare, the measured relative velocity was ~10 km s^{-1} redward of line center. The rotation of a discrete region would cause its emission profile to move ~15 km s^{-1} from blue to red during this phase interval. There was therefore a systematic redshift of the flare emission of ~30 km s^{-1} near the flare peak.

2. The 3 October 1981 Flare on V 711 Tau

The analysis of the high-resolution spectra obtained during the 3 October 1981 flare on V711 Tau (Linsky *et al.* 1988) was performed in the same fashion as used for the AR Lac

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flare. By subtracting the pre-flare profile from those during the flare, we were able to recover the Mg II k profile of the flare near its peak.

Near flare peak, the flare emission was broad (~60 km s^{-1}) and was centered at 90±30 km s^{-1} relative to the central meridian of the K star. This velocity shift is the sum of the projected rotational velocity of the flaring region and of systematic flows. Since the projected rotational velocity of the K star is 40 km s^{-1}, the downflow velocity would be 50 km s^{-1} if the flare were located near the receeding limb of the K star, or larger if it were at other positions on the star. The density- sensitive ratio of SiIII](1892 Å)/CIII](1908 Å) changed radically during the flare, permitting us to measure the mean density of the flaring plasma.

3. Other Ultraviolet Flares Observed with IUE

3.1 AR Lac

Walter *et al.* (1987) reported on the 5 October 1983 flare on AR Lac. A radio flare was observed at nearly the same time with the VLA. By subtracting the pre-flare K star profile from the observed profile, they determined the flux and width of the flare near flare peak. The measured width of the flare profile corresponded to 85 km s^{-1}. Unfortunately, the phase coverage of this data set was relatively poor, so it also is possible to interpret the excess emission as rotational modulation of the profile due to plages on the stellar surface. The association with the radio flare is therefore inconclusive.

An intense ultraviolet flare on AR Lac was observed on 31 August 1984 (Walter *et al.* 1984). Unfortunately, only low-resolution observations were obtained. As fate would have it, the simultaneous observing campaign at other wavelengths did not begin until the following day.

3.2 HD 199178

Four or perhaps five flares have been observed on HD 199178 (which has been classified as an "FK Comae" star). Three of these flares occurred at approximately the same photometric phase (see Neff, Vilhu, and Walter 1988b). On 19 September 1987, the overall Mg II k profile was observed to brighten and broaden considerably, but only one spectrum was obtained during the flare.

We obtained two high-resolution spectra of the 6 September 1986 flare. Unfortunately, no low-resolution SWP spectra were obtained during the flare. No increase in broading was seen in the two flare spectra.

3.3 UX Ari

Simon, Linsky, and Schiffer (1980) reported on the 1 January 1979 flare of UX Ari. The Mg II k line during the flare was strongly asymmetric, with the red wing of the line blending with the Mg II h line at 2802 Å!

3.4 Other Systems

We are interested high-resolution observations of rapidly rotating systems, so that we can apply our spectral imaging techniques. There have been a few flares observed from other,

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more slowly rotating RS CVn systems. Linsky *et al.* (1988) and Catalano (1986) summarized the parameters of these flares.

4. Conclusions

- The observing strategy we use for spectral imaging studies allows us to obtain time-resolved, high-resolution spectra of flares. We are therefore able to measure the flux, width, and wavelength of the flare emission line profile and the change of each of these properties during the flare decay. These six parameters can be used to study line broadening, to measure systematic flows, to determine the flare location, and to derive realistic surface fluxes.
- In order to determine these parameters well, high-resolution spectra must be obtained before, during, and after the flare. This has been done only twice (the K star flare on V711 Tau and the G star flare on AR Lac).
- The similar aspects of these two flares are (1) the flux decay timescales, (2) the amount of additional line broadening near flare peak, (3) a systematic redshift of the flare emission near flare peak, and (4) a rapid decay of this broadening.
- The far ultraviolet integrated line fluxes from these and other flares behave similarly. The transition region lines are enhanced by greater factors and decay more rapidly than the chromospheric lines.
- AR Lac, V711 Tau, and HD 199178 have been observed on several occasions. A crude estimate of the flare frequency is one per rotation (i.e. 2 or 3 days), but no flares were observed from AR Lac during a 4 day observing run in September 1987.
- High-resolution spectra should be obtained throughout the rotational cycle, not just during the flare.

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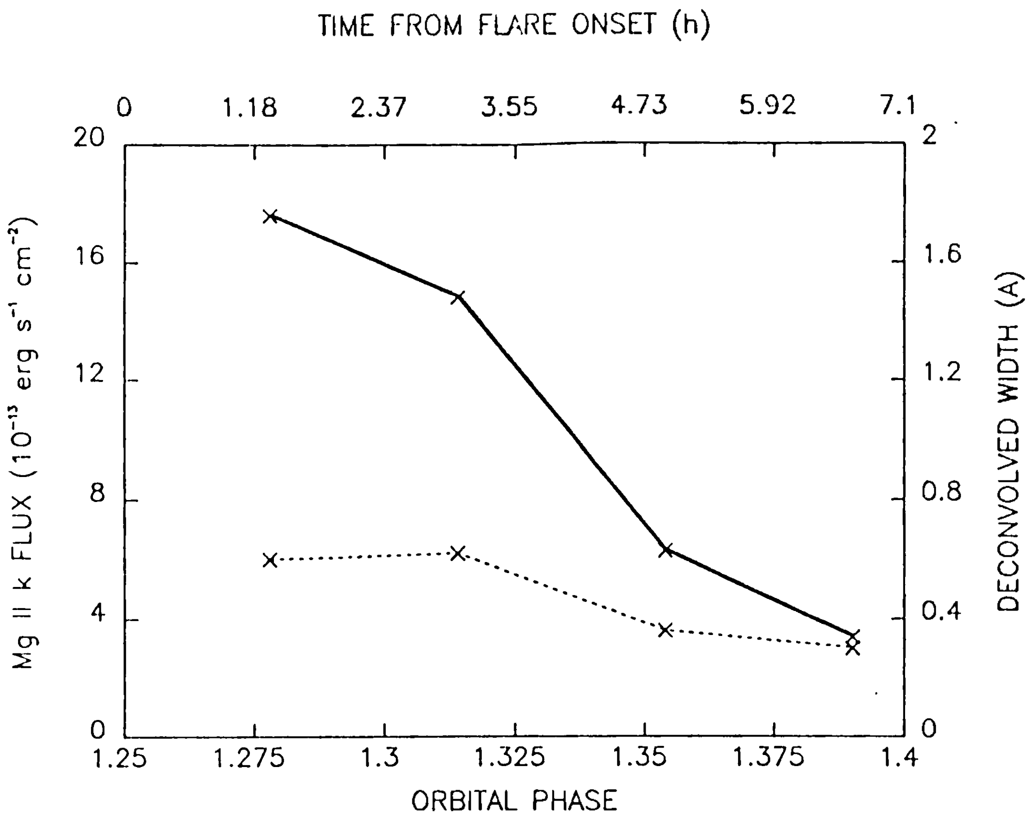

Figure 1: The flux (solid line) and width (dashed line) of the flaring component alone were determined by subtracting the pre-flare G star profile from the observed profile and then fitting the residual emission with a gaussian. The probable phase of flare onset was ϕ =1.255, during the previous SWP spectrum.

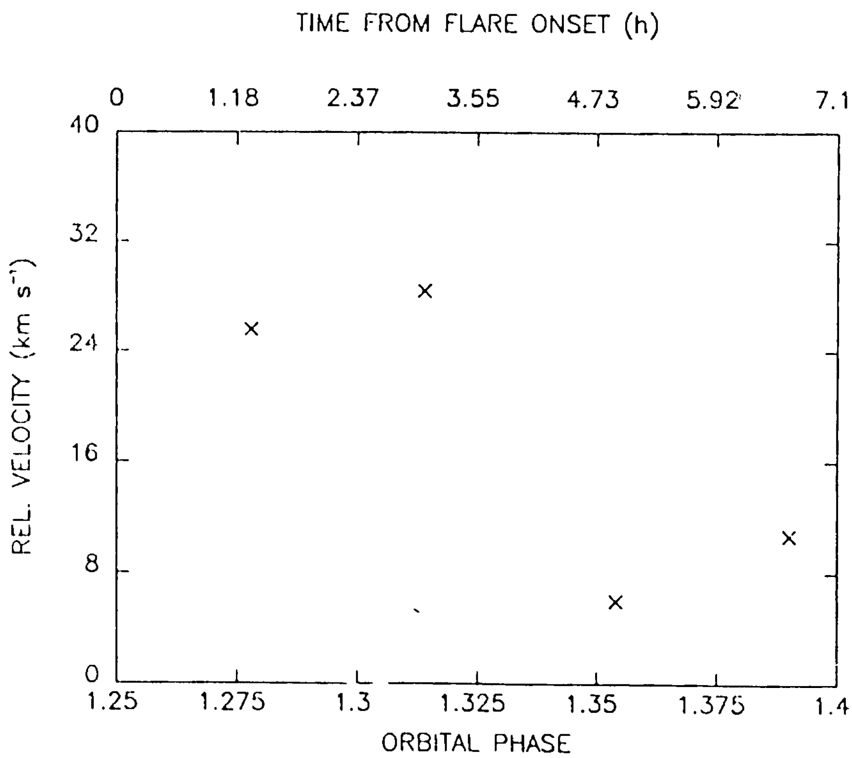

Figure 2: The measured radial velocities of the flare component relative to the mean radial velocity of the G star. This red-to- blue motion is counter to the rotational (blue-to-red) velocity shift, so the systematic redshift at flare peak is ~30 km s^{-1}.

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