Optical flares on the RS CVn binary II Peg

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SUMMARY
During 57.4 hr of optical monitoring in the Johnson U- and B-bands of the RS CVn binary II Peg, 10 flares were detected. The absolute energies of these events are in the range 1–180 x 10^{33} erg. This implies a flare activity in the U-band of 0.17 flares per hour, compared with 0.12 flares per hour from ultraviolet C IV data. A double power-law distribution is required to fit the cumulative flare-frequency distribution of the U-band flares.

1 INTRODUCTION
Chromospheric activity in late-type stars has been established by the presence of emission in the core of spectral lines such as Ca II H and K and the Balmer lines. This activity is linked with the magnetic field topology, and as a result is generated by fast rotation coupled with sufficiently deep convection. The RS CVn stars are detached binaries, with periods in the range of 0.5–20 d, some rotating synchronously due to tidal forces. They generally compromise a K-type subgiant or giant, with a main-sequence or subgiant companion. The evolutionary status of RS CVn stars has been a matter of controversy for many years. Both the pre- and post-main-sequence interpretations of the observed properties have been considered, the latter being the more favoured interpretation (Hall 1975).

II Peg is a well-known RS CVn single-line spectroscopic binary classified as K2 IV-V. Despite several attempts, its companion has yet to be observed. It shows sinusoidal variations usually interpreted as due to sunspot-like features in the photosphere and plages in the chromospheric/transition region (Rodonò et al. 1987; Doyle et al. 1989a). Although IUE observations have shown that the star has a high rate of flare activity in the ultraviolet (Doyle, Byrne & van den Oord 1989b), the only report of optical flare activity is that of Doyle et al. (1991). It has been generally assumed that optical flares on RS CVn stars are an extremely rare phenomenon. The only previous report known to the authors is the one by Patkó (1981) on the short-period eclipsing system SV Cam. In this paper, we report the results of a flare-monitoring study of II Peg in the U-band, which shows that the flaring activity of the system in the optical regime is very high, similar to that determined from UV observations.

2 OBSERVATIONS AND DATA REDUCTION
The observations reported here were carried out between 1989 August 2–8, 1989 August 14–17, 1990 July 25–August 22 and 1990 September 3–10 at the Stephanson Observatory in Peloponissos, Greece, using the 30-inch Cassegrain reflector of the Department of Geodetic Astronomy, University of Thessaloniki. The telescope, photometer and the observing procedure have been described elsewhere (Mavridis, Asteriadis & Mahmoud 1982). Our observations consisted of (i) continuous flare monitoring in the Johnson U-band with an integration time between 2.4 and 6 s and (ii) three-colour photoelectric observations in the international UBV system. Here we report only on the results of the flare monitoring programme. During the monitoring, interruptions of 30–90 s were performed in order to record sky background, while 8–13 min interruptions were required to observe nearby comparison stars. The total monitoring time in the U-band for the four observing periods was 57 hr, 8 min. The star was also monitored for 15 min in the B-band on 1990 July 26.

3 RESULTS
Table 1 contains the characteristics of the flares, i.e. the date and universal time at maximum, and the observed duration of the flare before and after maximum $t_b$ and $t_a$. Also listed is the ratio $(I_b - I_o)/I_o$, the equivalent duration $P_U = \Sigma (I_b - I_o)/I_o \Delta t$, and the absolute energy of each flare $E_U$. All flares are more than 3σ detections. The absolute energy of the flares (in ergs) is calculated with the help of the formula

$$ E_U = 4\pi d^2 10^{-0.4m} \Pi_U 60 P_U, $$

(1)
where $d$ is the distance to the star, $m_U$ the quiescent magnitude and $\Pi_U$ the flux produced by a zero apparent magnitude star, which for the $U$-band is $\Pi_U = 2.32 \times 10^{-6}$ erg cm$^{-2}$ s$^{-1}$ (see Bessell 1979). We note here that the flare on 1990 July 26 was observed in the Johnson B-band. The energy of this flare in the B-band was estimated in a manner similar to that given above, with its $U$-band energy estimated using the relation $E_B = 1.20 E_U$. This relation was derived from a large sample of flares on dMe stars, observed in more than one band (Lacy, Moffett & Evans 1976). Light curves for several of the flares observed may be found in Doyle et al. (1991) and Avgoloupis et al. (1991).

4 DISCUSSION

A very important parameter which indicates the level of flare activity is the time-averaged flare luminosity ($L^*$) observed in a particular band. This is defined as the sum of the energies of individual flares, divided by the total monitoring time. Using the present data, we estimate a value of $1.9 \times 10^{30}$ erg s$^{-1}$ for $L^*$ $U$. This value is dominated by the two very strong flares, however since the total monitoring is sufficiently long (57 hr), the value of $L^*$ should be good to within a factor of 2.

In the M-dwarf stars, Doyle & Butler (1985) have found a strong correlation between the quiescent X-ray emission and the time-averaged flare energy in the $U$-band ($L^*$). They calculate $L^* = 14 L^*_U$ (with $L^*_U \geq 10 L^*_U$). This has lead to the suggestion that the coronae of active dwarf stars could be significantly heated by flares. This may also be the case for II Peg since the time-averaged flare energy in the $U$-band is equal to its quiescent X-ray emission (Tagliaferri et al. 1991).

Gershberg (1972) and Lacy et al. (1976) have suggested that a better estimate of the flare activity of a star can be obtained from the cumulative flare-frequency distribution diagram, i.e., log $v$ of the frequency of flares of energy $E_U$ or greater, against log $E_U$. In Fig. 1(a), we present such a diagram for the $U$-band II Peg flares. It has been suggested by Byrne (1983) that flares observed from different telescopes can introduce deviations in the linear part of the distribution.

Fortunately, all the data we present in Fig. 1(a) have been obtained with the same telescope.

Comparing the distribution of the II Peg flares with those of the classical flare stars given by Lacy et al. (1976), we find a substantial difference. For most of the flare stars, a single power law is required to fit the part of the distribution where the signal-to-noise ratio is best. However, for II Peg a double power-law distribution is required, one for the high-energy events and the other for the low-energy flares, with a gap of more than one order of magnitude separating the two curves. It should be noted that since the late decay phase in both flares was not observed, due to sunrise, their quoted energies are only lower limits. This would have the effect of making the double power-law distribution in Fig. 1(a) more pronounced. It is interesting to note that a similar two-component diagram has been presented for the very active dMe spectroscopic eclipsing binary star YY Gem, where it has been suggested that the most energetic flares could represent flares due to magnetic interaction between the two stars (Doyle & Mathioudakis 1990). In fact, a similar suggestion was first made for II Peg, based on IUE observations (Doyle et al. 1989b). Although the statistics here are rather poor and obviously further monitoring is required, it is interesting to note that the two most energetic optical flares on II Peg were observed very close to orbital quadrature (phases 0.26 and
0.82 – the ephemeris being that of Vogt 1981). A double
power-law distribution has also been published by Mavridis
& Avgoloupis (1987) for the dMe flare star EV Lac, 
although in this instance the authors suggested the cause to
be due to a 5-yr periodicity in the star’s flare activity rate.

In Fig. 1(b), we present the cumulative flare-frequency
distribution of the flares observed in the C iv line. (For fur-
ther details on the method used to estimate the total chromo-
spheric/corona flare energy based on the strength of the C iv
line see Doyle et al. 1989b.) A total of 10 flares have been
observed in C iv so far, during 80 hr, 09 min of IUE observa-
tions, implying a flare frequency of 0.12 flares per hour. This
compares with 0.17 flares per hour in the U-band. For the
C iv flares however, a single power law is sufficient to fit
the data. The data for the C iv flares were taken from Rodonò et al. (1987), Doyle et al. (1989a,b) Tagliaferri et al. (1991) and Doyle et al. (in preparation).

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