


## A Giant X-ray/optical Flare on II Peg


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### 1. Introduction

Two groups of stars show magnetic activity similar to that seen on the Sun but on a much enhanced scale, i.e. the UV Cet/BY Dra stars and the RS CVn stars. The former are, typically, late K- or M-type main sequence stars, either single or components of binary systems. The RS CVn stars, on the other hand, are generally G- or K-type sub-giants in close binaries. The common factor between the two is rapid rotation with periods of, typically, a few days. This rapid rotation, in combination with deep convection, leads to a powerful dynamo action.

The UV Cet stars are the classical “Flare Stars”, characterised by optical continuum brightenings (or flares) on a time scale of ≈20-60 min (Byrne, 1983). The origin of this continuum brightening is not yet fully resolved but it is accompanied by brightening over most of the electromagnetic spectrum, from radio to X-rays (Byrne, 1989).

Flares also occur on the RS CVn systems but these have been detected mainly in the microwave region of the spectrum (Kuijpers, 1985). Evidence has recently been mounting for the occurrence of RS CVn flares in the ultraviolet and X-ray regimes (Byrne, 1989 and references therein). The observation of optical continuum flares in RS CVn’s has

**Figure 3**: Right ascension versus declination plot for cells producing sporadic impulsive emission.
been extremely rare however and this fact has led to the suggestion that the different gravities of the main-sequence dMe and the sub-giant RS CVn stars lead to a very different atmospheric response to the same primary flare heating mechanism (Doyle et al. 1989). Simultaneous, multiwavelength flare monitoring of RS CVn stars is rare and so a campaign to monitor the RS CVn system II Peg with ground-based optical photometry and spectroscopy, and space-satellite ultraviolet and X-ray spectroscopy was mounted in August 1989 (Doyle, 1989). Here we present a preliminary account of a large X-ray flare recorded by the Japanese GINGA X-ray satellite (Makino et al. 1987). The flare was also recorded in broadband optical light and in hydrogen Balmer emission. These latter data are being analysed and will be reported later.

2. The observations and results

II Peg was monitored by the Large Area Proportional Counter (LAC, Turner et al. 1989) on board GINGA from August 14.52-17.44(UT). Because of GINGA’s low orbit, the source was occulted by the Earth for $\approx 35\%$ of each orbit. In addition, during passage through the South Atlantic Anomaly, the detectors were shut off to prevent damage from the high particle background. The result of these restrictions was that the effective observing time on II Peg was reduced to $\approx 26$ hrs in total. GINGA’s LAC detectors are sensitive ($\approx 10\%$) over the energy range from 1-36keV with an energy resolution $\Delta E/E \leq 0.2$. Spectra were accumulated for periods of 16sec. II Peg was detected in quiescence (non-flaring) throughout the observing period with an intensity corresponding to a luminosity $L_{2-10^3eV} \approx 7 \times 10^{29}$ erg sec$^{-1}$ at the distance of II Peg.

Two X-ray flares were recorded during the time of observation. The first of these was observed also with the IUE satellite but was relatively weak in X-rays. Analysis of this flare will require a more detailed extraction of the data than is attempted here.

The second, larger flare was present when the source was reacquired after Earth occultation on August 17 at $\approx 02:48$(UT). At this time the global X-ray flux from II Peg had increased over quiescence by a factor of $\approx 50$, corresponding to an X-ray luminosity at that time of $L_{1-30keV} \approx 3 \times 10^{31}$ erg sec$^{-1}$. The decay of the X-ray flare was observed for the following 1-30keV $\approx 32$ min, after which the satellite slewed to a new target according to a pre-programmed sequence. The X-ray light curve recorded by GINGA is shown in Fig. 1.

Optical observations of the flare were carried out on the 30-inch Cassegrain reflector of the Department of Geodetic Astronomy of the University of Thessaloniki Stephanid Observatory in Greece. The telescope was equipped with a three-channel UBV photometer, described by Mavridis et al. (1982). The resulting U-band light curve, shown in Fig. 2, suggests that the optical flare began at $\approx 02:05$(UT) with a slow rise, the main rise to maximum beginning at $\approx 02:08 - 02:09$(UT). As can be seen in Fig. 2 the maximum of the optical flare was extremely complex, with many peaks. It is unfortunate that X-ray coverage of the flare was only in
the late decay phase and after optical observations had ceased due to the onset of dawn.

3. Discussion

3.1 Flare energy

We may, however, use the observations of the onset of the optical flare to analyse the X-ray flare further by making a few simple assumptions. During the time the decay of the flare was observed it approximated well to an exponential form with a e-folding time of $\approx 11$ hr. If the time scale of the decay of the X-ray intensity was approximately constant over the period from $\approx 02:15$ (UT), i.e. $\approx 2000$ s before the beginning of the GINGA observations, then, extrapolating backwards, the peak flare X-ray luminosity was $\approx 5 \times 10^{31}$ erg s$^{-1}$. Again, assuming an exponential behaviour, the time integrated X-ray energy in the flare was $\approx 2 \times 10^{35}$ erg.

We may compare this to the energy observed in the optical flare in Fig. 2. At the time of the flare, the measured U-band quiescent magnitude of II Peg was $U = 9.05$. Using the calibration of the Johnson photometric system in Allen (1973), this would correspond to a quiescent flux at the star of $F_U \approx 7 \times 10^{31}$ erg s$^{-1}$. Using the data in Fig. 2 we can then derive an observed U-band energy at the star, $E_U \approx 9 \times 10^{34}$ erg. Unfortunately the optical record of the flare is incomplete but if we assume a subsequent exponential decay of the optical light, on the same time scale as the X-ray decay, this figure is increased to $E_U \approx 2 \times 10^{35}$ erg. This figure is remarkably close to the estimated total X-ray energy of the flare above.

3.2 Flare temperature, emission measure and volume

Spectral information is provided by the GINGA observations in the form of pulse height spectra over 48 energy channels, covering the range 1-36 keV. A thermal bremsstrahlung model gave a good fit to these spectra, except in the region of $\approx 6.8$ keV where a clear excess was present. The latter was interpreted as emission from H-like FeXXVI. An example of the fit will be found in Fig. 3 and the derived parameters of the emitting plasma will be found in Table 1.

The emission measure, $N_e^2 dV$, may be derived from the observed flux using the volume emissivity of an optically thin plasma, from Mewe et al. (1985), at the derived temperatures. These emission measures are also listed in Table 1. We estimate the electron density of the flare plasma by using the expressions in Byrne and McKay (1989) viz., $N_e = \frac{3kT}{\tau_{rad}} \Lambda(T)$ where $\tau_{rad}$ is the radiative $1/e$ cooling time and $\Lambda(T)$ is the Mewe et al. plasma emissivity. Several processes may contribute to the observed cooling time, including radiation, conduction and mass flows. Therefore, if we assume that the observed cooling time equals the radiative cooling time we are underestimating $\tau_{rad}$ and overestimating $N_e$. Bearing this in mind, we may derive an upper limit electron density estimate from the observed decay of the X-ray light curve as $N \approx 2 \times 10^{11}$ cm$^{-3}$. Combining this result with the emission...
Table 1.

Derived physical parameters of the flare. EM is the emission measure derived from the X-ray continuum, $T_e$ is its temperature and $V$ is the volume of the flare plasma, derived from the emission measure using an electron density, $N_e \approx 2 \times 10^{11}$ cm$^{-3}$ (see text). EM(FeXXV) is the emission measure derived from the 6.8keV FeXXV line emission.

<table>
<thead>
<tr>
<th>UT</th>
<th>$T_e$ (10$^6$K)</th>
<th>EM ($10^{52}$cm$^{-3}$)</th>
<th>$V$ ($10^{21}$cm$^3$)</th>
<th>EM(FeXXV) ($10^{54}$cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>02:50:20-02:54:10</td>
<td>71</td>
<td>2.0</td>
<td>5.0</td>
<td>5.9</td>
</tr>
<tr>
<td>02:54:10-03:00:30</td>
<td>63</td>
<td>1.8</td>
<td>4.5</td>
<td>6.5</td>
</tr>
<tr>
<td>03:00:30-03:06:55</td>
<td>57</td>
<td>1.6</td>
<td>4.0</td>
<td>6.1</td>
</tr>
<tr>
<td>03:06:55-03:08:30</td>
<td>51</td>
<td>1.8</td>
<td>4.5</td>
<td>$\approx$10</td>
</tr>
</tbody>
</table>

Measures given in Table 1 we derive a lower limit to the emitting volume of the flare plasma with time, also given in the Table.

We note that, while the value for $N_e$ is very similar to those found for the transition regions flares (Doyle et al. 1989), the emitting volumes ($\approx 10^{31}$ cm$^3$) are relatively constant with time and an order of magnitude larger than typical transition region values. The flare plasma temperatures are similarly larger than solar values, at the same late stage of a flare, by a factor of $\approx 5$.

3.3 FeXXVI emission

We have drawn attention above to the observation of a line feature at $\approx$6.8keV. This feature is of instrumental width and coincides closely in energy to the position of the H-like FeXXVI line at 1.79Å. This line has a temperature of formation close to log $T_e \approx 8.0$. This range agrees well with the temperatures for the flaring plasma derived from the bremsstrahlung fits given in Table 1. Using the line emissivity given in Mewe et al. (1985) we may derive an independent emission measure from the flux of this line. These are given in the Table. It will be seen that there is good agreement (within a factor $\approx 30-40\%$, except after 03:06 when the signal from the flare was weakening) between the emission measures derived from the continuum emission and that from this line, increasing our confidence in this result.

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References


