X-ray Observations of the dMe Star EQ1839.6+8002 in 1980-1993

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1 Introduction

During *Ginga* observations of galaxy 3C390.3 on 1991 February 14, a large impulsive flare was detected between 22:30-23:00 UT (Inda et al. 1994). Inda et al. (1994) suggested that the flare was associated with EQ1839.6+8002, an M4Ve star at a distance of 15.2 pc (Fleming et al. 1988). The star has been observed previously with the *Einstein* IPC and *EXOSAT* LE (Gioia et al. 1990; Giommi et al. 1991), and more recently with the *ROSAT* PSPC.

In this paper we present the results of an analysis of the observations of EQ1839.6+8002 with *Ginga* and of the data obtained with the *Einstein* IPC (between 1980 January and May), the *EXOSAT* LE (in 1984-1986), and the *ROSAT* PSPC instruments (in 1991 March, 1992 April and 1993 April).

2 The Ginga flare

Figure 1 shows the (2-20 keV) light curve obtained with the *Ginga* LAC between 20:50-23:03 on 1991 February 14. After the start of the flare (at ~ 22:30), the flux increases rapidly from 28 to 172 counts s^{-1} in about two minutes, and then rises more slowly to 206 counts s^{-1} by 22:34. At the end of the observation, the flux is about 40 counts s^{-1}, nearly a factor of 2 above the pre-flare level.

The *Ginga* spectra, after subtracting the pre-flare X-rays, have been fitted with a one temperature Raymond-Smith (RS) model. Fig. 2 shows the time history of the derived plasma temperature T_e and volume emission measure $EM(V)$. The temperature reaches a maximum of $\sim 10.7 \times 10^7$ K within 2 minutes and then decays rapidly with an e-folding time ~ 350 s until 22:37. After that it slowly decreases to $\sim 3.8 \times 10^7$ K by the end of the observation. The emission measure, however, continues to increase after the temperature peak, and reaches a maximum two minutes after the temperature. After the peak, $EM(V)$ gradually decreases (decay time ~ 910 s) and has not returned to its pre-flare level by the end of the observation. The total energy released in the 2-20 keV energy band during the flare, after subtracting the pre-flare quiescent flux, is $\sim 10^{34}$ erg. At the flare peak, the total luminosity is $\sim 10^{31}$ erg s^{-1}.

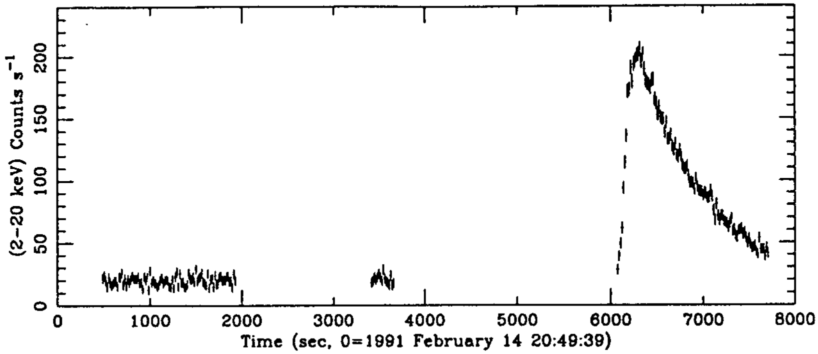

Fig. 1. The X-ray light curve before and during the flare on EQ1839.6+8002.

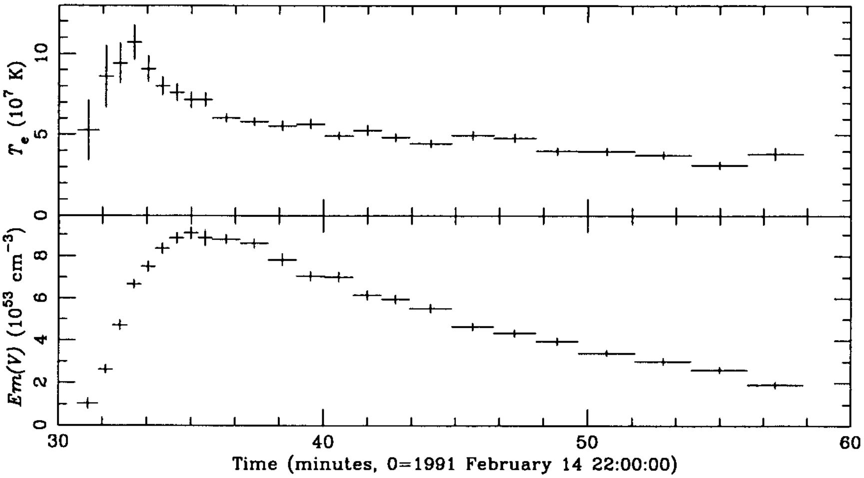

Fig. 2. The evolution of the flare temperature and emission measure.

The time lag between the peak temperature and emission measure illustrated in Fig. 2 strongly suggests that the flaring region of EQ1839.6+8002 relaxes back to the quiescent state by the 'evaporation/condensation' mechanism (e.g. Cheng & Pallavicini 1991). The temperature in the flaring loop increases when excess heating is being supplied. The high temperature results in an excess conductive flux into the transition region, causing chromospheric material to expand up the loop. Thus the emission measure can continue to increase after the heating has stopped or decreased. The density rise in the corona increases the radiative cooling since the radiative losses scale as the square of the density. The decrease in the emission measure may result from a decrease in the density as material flows back to the chromosphere, or to material cooling to temperatures not recorded by the 2-20 keV energy band.

3 The soft X-ray emissions

Figure 3 shows the (0.2-2 keV) luminosity of EQ1839.6+8002 derived from the observations made with the *Einstein* IPC, *EXOSAT* LE and *ROSAT* PSPC. The luminosity varies between 1.3×10^{27} erg s^{-1} to 2.4×10^{29} erg s^{-1}. The source was in a flaring state on 1980 April 8-10. The ratio of the peak to the quiescent flux is ~ 23. At the peak of the flare the star is the brightest X-ray source in the field of view. On 1985 November 7 EQ1839.6+8002 was the brightest X-ray source in the LE image. The source stayed in the high luminosity state ($\sim 5.7 \times 10^{28}$ erg s^{-1}) for over one and half hour without significant variation, which implies that a long duration flare might have occurred.

The soft X-ray spectra obtained with *Einstein* IPC and *ROSAT* PSPC have been modelled with a two temperature RS model. There is no significant differences between the temperatures of the flare and quiescent spectra. However, the emission measures of the low and high temperature components of the flare spectrum are about a factor of 10 larger than the quiescent emission measures. The mean spectral parameters in the quiescent state are $T_1 = 1.5 \times 10^6$ K, $EM_1 = 4.3 \times 10^{50}$ cm^{-3}, $T_2 = 7.6 \times 10^6$ K, and $EM_2 = 6.3 \times 10^{50}$ cm^{-3}.

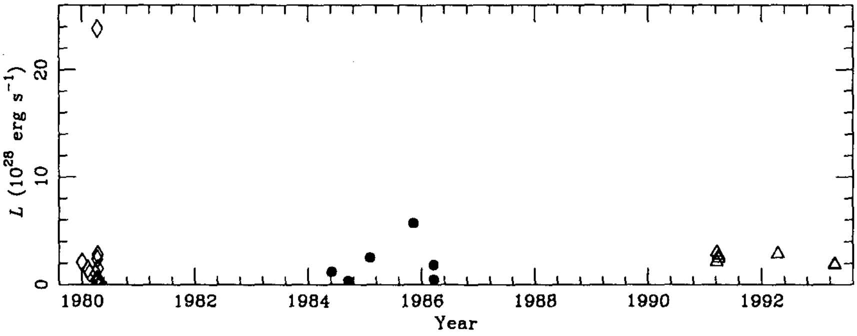

Fig. 3. The X-ray (0.2-2 keV) luminosity (L) of EQ1839.6+8002 from the measurements of the *Einstein* IPC, *EXOSAT* LE and *ROSAT* PSPC

4 Discussion

Using *EXOSAT* data (mostly from the LE instrument), Pallavicini et al. (1990) find that the X-ray quiescent luminosity and bolometric luminosity of dMe stars are correlated in terms of $\log L_X = -9.83 + 1.21 \log L_{Bol}$. The quiescent X-ray luminosity of EQ1839.6+8002 during the *ROSAT* observations (see Fig. 3) is $\sim 2.4 \times 10^{28}$ erg s^{-1}, which is consistent with the calculation using the above relationship and $L_{Bol} = 3.9 \times 10^{31}$ erg s^{-1}.

On the basis of the short rise time, the *Ginga* flare can be classified as an impulsive stellar flare, whose solar counterparts are associated with confined

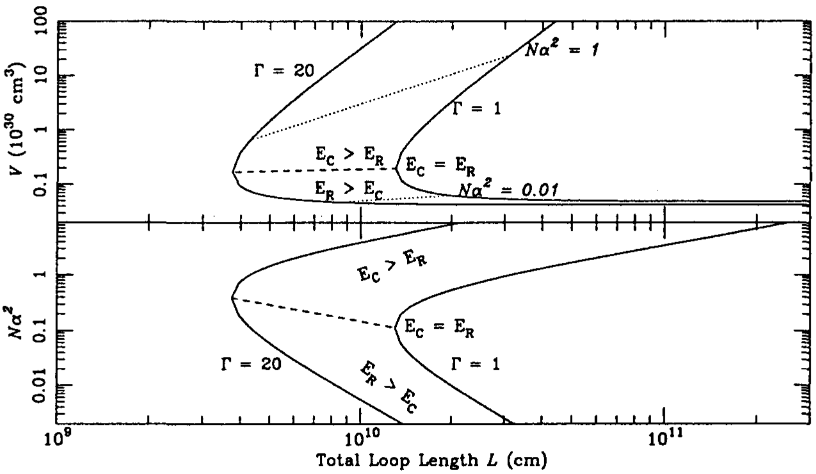

Fig. 4. The loop volume V and $N\alpha^2$ as a function of L for a loop with constant cross section, $\Gamma = 1$, and a loop with cross section expanding towards the apex, $\Gamma = 20$

magnetic loops. Using the observed time variability of the emission measure and temperature, we can put constraints on the loop volume and length.

We assume that the flare is generated by N identical flaring loops, each having a length L and expanding linearly towards its apex. If the loop aspect ratio is α and the ratio between the apex and footpoint cross-sections is Γ, the volume of the N loops can be expressed as $V = (\Gamma + 1)\frac{\pi}{8}N\alpha^2L^3$. In the case of the Sun, $N\alpha^2$ can range from 0.01, for a single loop with $\alpha = 0.1$, to nearly 1, for a very compact flare made of many loops (e.g. Pallavicini et al. 1990).

If there is no heating in the flare decay phase and the loop plasma loses energy mainly by radiation (E_R) and conduction (E_C), relationships between $N\alpha^2$, V and L can be derived from the loop energy equation. Figure 4 shows the derived value of $N\alpha^2$ and V as a function of the loop length for $\Gamma = 1$ and 20. If $N\alpha^2$ is in the range of 0.01-1, similar to that of a solar flare, we find 3.7×10^9 cm $< L < 3.1 \times 10^{10}$ cm, and 4.7×10^{28} cm^3 $< V < 2.4 \times 10^{31}$ cm^3 for $1 \leq \Gamma \leq 20$.

References

Cheng C.C., Pallavicini R., 1991, ApJ 381, 234
Fleming T.A., et al., 1988, ApJ 331, 958
Gioia I.M., et al., 1990, ApJS 72, 567
Giommi P., et al., 1991, ApJ 378, 77
Inda M., et al., 1994, ApJ 420, 143
Pallavicini R., Tagliaferri G., Stella I., 1990, A&A 228, 403