MODELLING THE X-RAY LIGHT CURVE OF CC ERI

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ABSTRACT We show in this paper that the X-ray variability of CC Eri observed with the ROSAT PSPC detector on 1990 July 10 can be modelled either by stellar rotational modulation or by a flare, adopting a magnetic reconnection model.

INTRODUCTION

During the ROSAT PSPC observations on 1990 July 10 16:14-21.34 (UT), an X-ray flare-like event (see Fig. I) was observed from BY Dra flare star CC Eri (Pan and Jordan 1993). The event has a one hour (or less) exponential rise time and a two hour decay time. The ratio of the peak to minimum flux is about 2 and the X-ray luminosity of the source varies in the range $\sim 3 - 7 \times 10^{28}$ erg/s.

It is believed that the optical photometric and spectroscopic variations of CC Eri are caused by the presence of magnetic starspots (in active regions) on the surface with a temperature a few hundred degrees cooler than the surrounding photosphere (e.g. Bopp and Evans 1973; Busko et al. 1977). Such a starspot model may provide a ready explanation for the X-ray activity observed with ROSAT, in which the X-ray flux increases and decreases when the active regions pass in and out of the line of sight.

It is also possible that CC Eri may be in a flaring state during the ROSAT observations and the observed event may be a stellar counterpart of a solar two ribbon flare. The energy released during the decay phase of the flare is a consequence of magnetic reconnection (e.g. Poletto et al. 1988).

Based on these scenarios we have modelled the X-ray light curve of CC Eri using the starspot model as in Bopp and Evans (1973) and the magnetic reconnection theory of Poletto et al. (1988).

MODEL CALCULATIONS

(a) The Starspot Model

In a spherical coordinate system, $\gamma$, the angle between the line of sight and the normal line of an X-ray emitting area cell can be written as

$$\cos \gamma = \cos(\psi - \phi) \sin \theta \sin i + \cos \theta \cos i$$  \hspace{1cm} (1)

where $\phi$ is the stellar longitude and $\theta$ the co-latitude; $\psi$ is defined as the rotational phase and $i$ as the orbital inclination which is $42^\circ$ (Bopp and Evans 1973).
The X-ray region is visible if the angle $\gamma$ is less than 90$^\circ$.

Two starspots, one located in the north hemisphere with $\phi \sim 0^\circ - 45^\circ$ and $\theta \sim 60^\circ - 100^\circ$, and another in the south with $\phi \sim 15^\circ - 31^\circ$ and $\theta \sim 128^\circ - 144^\circ$, are required to reproduce the X-ray light curve on 1990 July 10. Each spot is divided into 100x100 X-ray emitting cells and the X-ray light curve is synthesized by adding the contribution of each cell according to equation (1). The synthesized light curve is normalized to the observed one (Fig. I) and the X-ray surface flux of each spot is derived from the normalization constant and by considering the response function of the PSPC detector. The surface flux is $0.35 \times 10^9$ erg/cm$^2$/s for the north spot and $19.20 \times 10^9$ for the south. The synthesized light curve from the starspot model is plotted in solid line in Fig. I.

(b) The Magnetic Reconnection Model

We have made the same assumptions as in Poletto et al. (1988) regarding the location and size of the active region. Details of the model and the assumptions made can be found in Poletto et al. (1988). Briefly, the energy release rate per radian of longitude during the magnetic reconnection is given by:

$$\frac{dE}{dt} = \frac{1}{8\pi} 2n(n + 1)(2n + 1)^2 R_*^3 \frac{I_{1,2}(n)}{P_{n}^2(\theta_{1,2})} \frac{y^{2n}[y^{(2n+1)} - 1]}{[n + (n + 1)y^{(2n+1)}]^{3/2}} \frac{dy}{dt}$$  \hspace{1cm} (2)

where $I_{1,2} = \int P_2^2(\theta)d(\cos \theta)$, and $P_n(\theta)$ is the Legendre polynomial of degree $n$, which is 5, 9, 17 and 35, corresponding to the latitude width of the region 33$^\circ$, 20$^\circ$, 10$^\circ$, and 5$^\circ$ respectively. The longitude width is assumed to be 1.5 times the latitude width. $B_m$ is the maximum surface field in the region and $R_*$ is the stellar radius of CC Eri, which is estimated to be $\sim 0.60 R_\odot$ from the absolute visual magnitude given by Evans (1959). The time dependent function $y$ is of
the form \( y(t) = 1 + (H_m/R_s)[1 - \exp(t/t_0)] \). The parameter \( H_m \) is the maximum height reached by the reconnection point during its upward movement and is assumed to be equal to the separation of the loop footpoints. \( t_0 \) is the time constant of the process. Following Poletto et al. (1988) it is assumed that 10 percent of the energy released by the magnetic reconnection process is radiated in the X-ray band.

The energy release rates during the 1990 July 10 event are estimated by fitting the difference spectra of CC Eri. The measured rates are then compared with those predicted by equation (2), integrated along the longitude and multiplied by a constant 0.1. The agreement between the data and the model results in a well-defined set of physical parameters for the emitting region. With these parameters the luminosity of CC Eri during the decay phase is calculated and folded with the response matrix of the PSPC detector to estimate the count rates. The model light curve is also plotted in Fig. I (dashed line).

DISCUSSION

It is obvious that both the starspot model and the magnetic reconnection theory can reproduce the X-ray variability observed with the ROSAT PSPC on 1990 July 10 reasonably well. The X-ray variability of CC Eri may be caused by flaring events or by the rotational modulation of stellar active regions, or maybe by both.

In the case of the starspot model, we can estimate the magnetic field in the spotted regions from the X-ray surface fluxes found from the light curve modelling. If the thickness of the spotted areas is \( \Delta r \) km, and the X-ray emission results from the dissipation of the magnetic energy \( \frac{B^2}{8\pi} V \) with an energy conversion efficiency \( \sim 10\% \), the magnetic field of the north spot is \( \sim 300(\frac{\Delta r}{10\text{km}})^{-1/2} \) Gauss and \( \sim 2000(\frac{\Delta r}{10\text{km}})^{-1/2} \) Gauss for the south spot. For the magnetic reconnection model the surface magnetic field is estimated to be 253, 426, 812 and 1629 Gauss for \( n = 5, 9, 17 \) and 35 respectively.

Owing to the incomplete coverage of stellar rotation phase by PSPC and the lack of simultaneous optical observations we are unable to distinguish which mechanism is really responsible for the observed X-ray variation. Ideally, CC Eri should be monitored simultaneously in optical, ultra-violet, and X-ray wavelengths over a complete binary cycle in future observations. Such observations would enable us to determine what really causes the variations of CC Eri. With the multi-wavelength observations we could map the X-ray distribution over the stellar disc and place strict constraints on the active region.

REFERENCES