ROSAT Observation of a Giant X-ray Flare on the Active Binary Algol

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Abstract: ROSAT/PSPC observations of a long-duration, giant X-ray flare on the eclipsing binary Algol are presented. With a total thermally radiated energy of $7 \cdot 10^{36}$ erg, this flare is one of the largest events ever observed. The flare decay is modeled by means of the quasi-static cooling method, which yields a height of the flare loop arcade of $\simeq 1R_K$, and a plasma density of 10^{11} cm^{-3}.

1 Introduction

Active binary systems — like the RS CVn and the Algol type binaries — show the most intense and energetic flares among the late-type stars. Large flares on these systems can reach soft X-ray luminosities of 10^{32} erg s^{-1} and thermally radiated energies of 10^{37} erg, which exceed the luminosities and energies of solar two-ribbon (2R) flares by about 5 orders of magnitude.

Up to now, it is not clear whether large stellar flares can be described by a 2R flare scenario, or whether they involve a different flare type. Even if a 2R flare model is assumed, it is not known whether the large energy release of stellar flares compared to solar ones is the result of a large flaring volume or electron density.

Soft X-ray observations provide the most direct way to investigate the physical properties of the flare plasma. During the last decade, intensive X-ray flares have been detected on Proxima Centauri by the *Einstein* satellite (Haisch et al. 1983), on Algol by the *EXOSAT* satellite (White et al. 1986, van den Oord & Mewe 1989) and by the *Ginga* satellite (Stern et al. 1992), and on σ^2 CrB by *EXOSAT* (van den Oord et al. 1988). Recently, the X-ray satellite *ROSAT* detected large flares with a high S/N ratio on the RS CVn-type binaries AR Lac (Ottmann & Schmitt 1994) and CF Tuc (Kürster & Schmitt 1995), and on Algol (B8 V + K2 IV; $P_{orb} = 2.87d$) (Ottmann 1995).

As the Algol flare has a particularly good coverage of the rise and decay phase, it is well suited for a detailed study of the flare plasma parameters. Further, as the Algol flare occurred in the middle of a long *ROSAT* PSPC pointed observation, we are able to extract the flare-only emission, and to search for a re-structuring of the corona in the course of the flare.

2 ROSAT observation

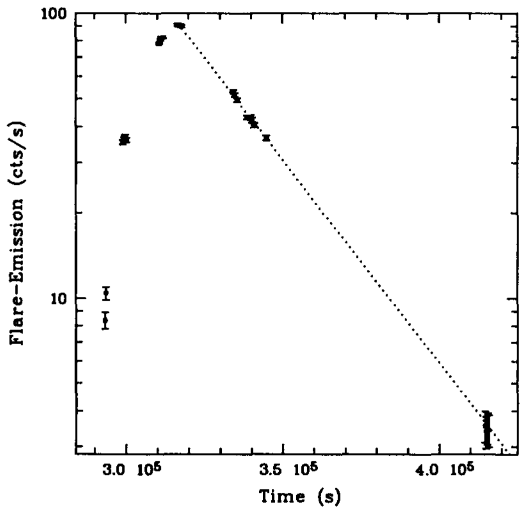

Fig. 1. Flare-only light curve plotted vs. time. The *dotted line* represents the best fit exponential decay with an e-folding decay time $\tau_d = 30400\, s$.

The *ROSAT* PSPC observation of Algol was performed from 1992 August 16 to 23, thus comprising three successive orbital periods (Ottmann 1994). During the second orbit, a giant flare event occurred, lasting for about half the orbital period. Fig. 1 shows the flare-only light curve as a function of time. Thereby, the quiescent contribution (i.e., the count rate level of the first orbit) has been subtracted from the total count rate.

The flare has a total rise time of about 6.6 hours. The flare countrate shows an exponential decay with an e-folding decay time of about 8.3 hours. There is an enhanced emission already 11 hours before the onset of the large flare, continuing for about 36 hours after the exponential decay of the large flare. The enhanced emission undergoes an orbital modulation. Therefore, it is caused either by the emergence of new magnetic flux, in the course of which also the flare occurs, or by additional heating prior and after the large flare.

The PSPC pulse height spectra are described as the superposition of a two-temperature Raymond-Smith quiescent spectrum and a one-temperature flare spectrum. The parameters $T1$, $EM1$, $T2$, $EM2$ describing the quiescent spectrum are fixed, while the flare temperature $T3$ and emission measure $EM3$ as well as the hydrogen column density are varied. The resulting best fit flare temperature and emission measure are shown in Fig. 2. Obviously, the emission measure follows the X-ray light curve, while the temperature is highest during the early rise phase, reaching about 8 keV or 90 MK.

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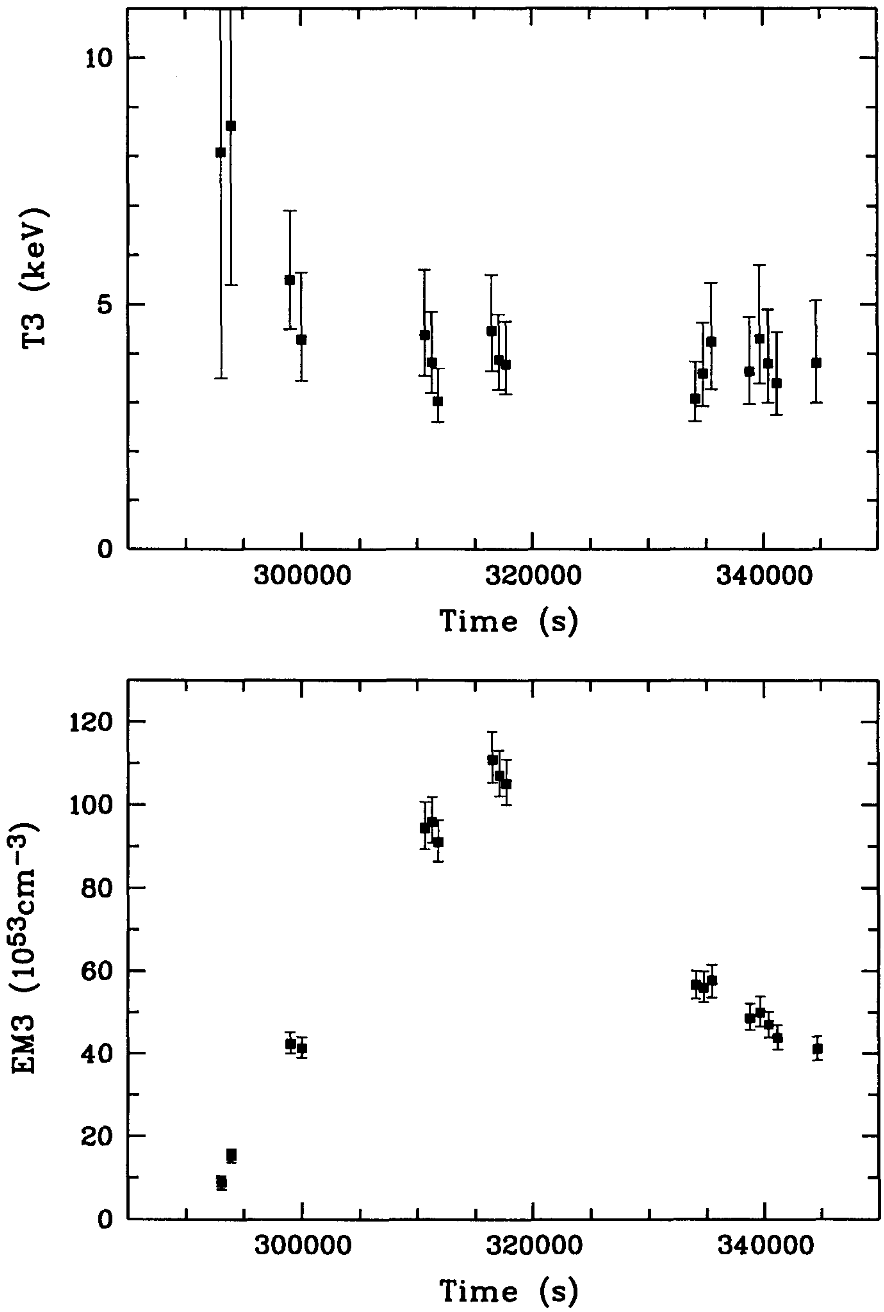

Fig. 2. Temporal evolution of the flare plasma temperature $T3$ and emission measure $EM3$. The errors bars represent 95.4% confidence with one parameter.

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3 Physical flare parameters

From the X-ray light curve and spectral results, the physical flare parameters – like the energy content, the spatial extent of the flaring region, and the resulting electron density and gas pressure – can be derived.

For this purpose, the quasi-static cooling formalism (van den Oord & Mewe 1989) is applied to the observed decay of the flare temperature and emission measure. In doing so, we allowed for additional heating during the decay phase. The resulting best fit parameters are as follows. The height of the flare loop arcade amounts to $H = 2.5 \cdot 10^{11}$ cm $\simeq 1R_K$, resulting in a flaring volume of $V = 5 \cdot 10^{33}$ cm^3. This is about 10^5 times the volume of typical solar 2R flares. Additional heating is not present.

For this Algol flare, a peak soft X-ray luminosity of $L_X \simeq 2 \cdot 10^{32}$ erg s^{-1}, and a the total thermally radiated energy of $E_X \simeq 7 \cdot 10^{36}$ erg is estimated, which exceeds the energy release of solar 2R flares by about 5 orders of magnitude. If the solar analogy holds at all, then this Algol flare should be classified as a 2R event on the basis of its long rise and decay time and its large energy release.

From $EM3$ and H, a flare plasma density of $n_e \simeq 10^{11}$ cm^{-3} and a gas pressure of $p \simeq 10^3$ dyne cm^{-2} is derived, which are comparable to the values found for solar flares. Thus, it seems to be the large flaring volume which is responsible for the much larger energy release of stellar compared to solar flares.

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I. Pustylnik: Is there any contamination of the Algol X-ray data originating from the Perseus Cluster?

R. Ottmann: Due to the high spatial resolution of the ROSAT XRT/PSPC, a source extraction radius of 3.′6 was used. As the distance between Algol and the Perseus Cluster is $> 1°$, a contamination of the X-ray data due to the Perseus cluster can be excluded.

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