Properties of X-ray Flares on Young Stars

Th. Preibisch[1], *R. Neuhäuser*[2]

[1] Universität Würzburg, Astronomisches Institut, Am Hubland, D-97074 Würzburg, Germany

[2] Max-Planck-Institut für Extraterrestrische Physik, D-85740 Garching, Germany

Abstract: The interest in the giant flares found on young stars results from the fact that their energetics is vastly different from solar flares. The recent *ROSAT* observations of young clusters yield a good basis for a systematic study of these flares.

We have investigated 18 very deep pointed observations of star forming regions in IC348, Chamaeleon, ρ Ophiuchi, and Orion. To study the age dependence of the flare properties we also investigated the observations of the young clusters IC2391, Pleiades, and Hyades. In this way we have evaluated the X-ray emission of several hundred young stars with ages ranging from about 10^6 years to $7 \cdot 10^8$ years. We have found 36 large flares on identified cluster members and have determined the flare properties with a simple flare model.

The flares show the same relation between the total X-ray flare energy and the quiescent X-ray luminosity as the dM star flares. The total X-ray flare energies decrease smoothly from the very high values found for very young stars to solar values with increasing cluster age. Our results indicate that the large flares on young stars are similar to scaled-up solar-like activity rather than to accretion processes.

1 Introduction

Since the observations of the *Einstein* satellite young stars are known to show giant X-ray flares. While on the Sun the total flare energies radiated in X-rays usually do not exceed 10^{31} erg even for the largest flares, values of up to $4 \cdot 10^{36}$ erg have been found for flares on T Tauri stars (Montmerle et al. 1983, Preibisch et al. 1993). The vastly different energetics of the flares on the Sun and on young stars raise the question of the origin of these large flares: are these giant flares just the result of scaled up solar-like coronal activity commonly found on young stars, or are they somehow related to accretion processes (see Gahm 1995, these proceedings) or to a disk corona? To address this question, we have made a systematic search for X-ray flares in deep *ROSAT* observations of several young clusters.

https://doi.org/10.1017/S0252921100035016 Published online by Cambridge University Press

2 ROSAT observations and data analysis

We have used ROSAT observations[3] of the Orion nebula region, the star-forming regions in Chameleon, ρ Oph, IC348 and the young clusters IC2391, Pleiades, and Hyades. While the age of the stars in the first four regions is about a few million years, the age of the Pleiades is $7 \cdot 10^7$ years and the age of the Hyades $7 \cdot 10^8$ years. The flares on stars in the Orion nebula region have been detected by Gagné et al. (1995) and re-analyzed by us.

We have investigated the light curves of all identified cluster members that showed variability in their X-ray emission and we have found 36 large flares. In the subsequent analysis we used only flares where the pre-flare count rate was high enough to extract and fit a pre-flare spectrum and where the decay phase was covered well enough to derive the decay time (the low orbit of the satellite causes frequent gaps in the light curves).

We extracted an X-ray spectrum in the pre-flare phase to determine the quiescent X-ray luminosity and emission measure. The flare spectrum was obtained by subtracting the pre-flare spectrum from the spectrum at flare maximum. The spectra were fitted with Raymond-Smith plasma emission models (Raymond & Smith 1977) including interstellar absorption. The best fit parameters were determined using a χ^2 method. We used several spectral models: an isothermal model, a two temperature model, and a model with a power-law temperature distribution (see Schmitt et al. 1990 for a discussion of these models). From the fit to the flare spectrum we obtained the maximum X-ray luminosity and the temperature and emission measure of the flaring plasma. In nearly all cases we found increased plasma temperatures during the flare. The plasma temperatures at flare maximum were always around or above $3 \cdot 10^7$ K.

This detailed spectral modeling was possible for about one third of the flares. For the rest of the flare sources, where the signal-to-noise ratio of the X-ray data did not allow such an analysis, we could only fit the pre-flare spectrum. In these cases we calculated the peak X-ray luminosity and emission measure from the ratio of the maximum and the pre-flare count rate. For the flare plasma we assumed a temperature of $3 \cdot 10^7$ K.

3 Flare modeling

To estimate the flare parameters we used the same analysis as Pallavicini et al. (1990) for their study of dM star flares. We estimated the plasma density by assuming only radiative cooling and the minimum magnetic field strength by equating magnetic pressure and gas pressure. We estimated the loop length by assuming the flaring plasma to be trapped in a loop with a ratio of diameter to length of 1:10. We are aware that this analysis may give only rough estimates, but it should give at least the right orders of magnitude.

[3] Most of the data were taken from the *ROSAT* data archive.

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4 Results and discussion

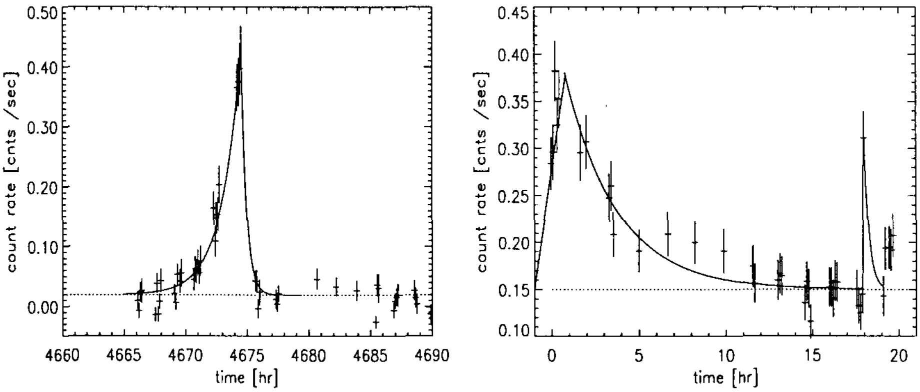

Fig. 1. Lightcurves of the flares on HGC 144 (left) and Hz 2411 (right). The solid lines represent fitted light curves.

The decay times range from a few minutes to several hours. For most flares the rise time is clearly shorter than the decay time with one remarkable exception: the flare found on the Pleiades member HGC 144 (Fig. 1) shows an exponential rise phase with a rise time (1.8 hours) considerably longer than the decay time (0.4 hours).

A couple of flare stars show more than one flare during the *ROSAT* observation. A particular example is the Hyades member Hz 2411, a well-known dMe flare star, for which Gurzadyan (1980) finds a mean frequency of optical flares of 1 every 11 hours. In the 20 hour patrol time of the *ROSAT* observation there are two large X-ray flares (Fig. 1).

A comparison of the flare properties of our sample with those of solar and dM star flares yields the following results: the total X-ray flare energies range from $3 \cdot 10^{32}$ erg to $4 \cdot 10^{36}$ erg (for the flare on LHα 92) and are much larger than the ones found in solar flares. The plasma density ($10^{11} - 10^{12}\,\mathrm{cm}^{-3}$) and magnetic field strength ($\approx 100 - 1000$ G) are in the same range as for solar flares. The much larger energy output of flares in young stars is related to the much larger volumes and loop lengths of the flaring plasma: the loop lengths range from 10^{10} cm to $6 \cdot 10^{11}$ cm and are much larger (l/R_* up to 8.5) than for solar flares (l/R_* usually below 0.1).

In their study of dM star flares Pallavicini et al. (1990) found a good correlation between the total X-ray energy of the flares and the quiescent X-ray luminosity. In our sample we find the same correlation, only shifted towards higher flare energies and luminosities. This may indicate that the same flare mechanism is at work in both samples.

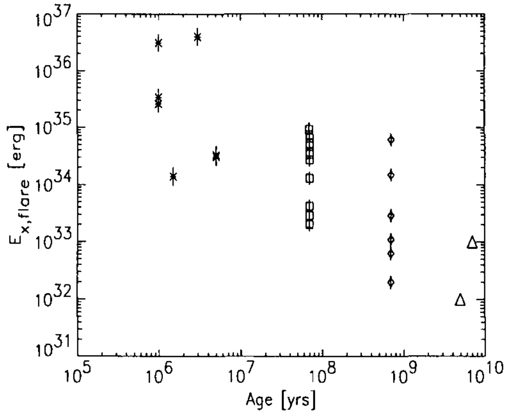

Fig. 2. Total X-ray flare energy vs. cluster age; the triangles in the right corner indicate the maximum values found for solar (left) and dM star (right) flares.

In Fig. 2 we have plotted the total X-ray flare energy vs. the cluster age. One can see a smooth decrease from the very high values for the youngest stars towards solar values. This is very similar to the decrease of the X-ray luminosity with age, probably caused by the decrease of the rotation velocity during early stellar evolution (see Neuhäuser et al. 1995). The same age dependence is found for the loop length.

These results suggest that a relation of the flaring process to accretion processes or a disk corona seems improbable: in this case we would expect to find a sharp decrease of the flare energies at the age of a few million years, when the disks are getting dispersed. In contrast to this, we find a smooth decrease extending over more than 10^9 years. Our results can be best explained by the decrease of scaled-up solar-like coronal activity usually found for young stars.

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https://doi.org/10.1017/S0252921100035016 Published online by Cambridge University Press