X-RAY EMISSION FROM FLARE STARS

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Flare stars are a group of mostly dMe stars, which show intense flaring activity in the optical as well as in the radio and X-ray bands. These stars are characterized by the presence of chromospheric emission lines like H_α and CaII H and K which are present even during the quiescent state. The presence of transition regions and coronae have been inferred from the detection of UV emission lines like NV, CIV, SiIV etc. with IUE and X-ray observations made with the Einstein Observatory. We report here X-ray observations of flare stars made with Einstein to measure their coronal X-ray emission during the quiescent state.

Seven nearby flare stars were observed with the Imaging Proportional Counter on Einstein. Optical properties of the stars and details of the X-ray observations are summarised in Table 1. All are single UV Cet

Table 1.

Gliese No. of the Star	Other Name	Spectral Type	V	Distance (pc)	Effective Exposer Time (secs)	IPC Counts Rate ($\times 10^{-2}$ Counts sec^{-1})	Log L_X	Log (L_X/L_{Bol})
229	BD-21°1377	dM 2·5e	8·13	5·7	10500	1·07 ± 0·22	26·8	-5·60
-	PZ Mon	dK 2e	10·8	16	5343	2·10 ± 0·35	28·0	-3·66
398	L1113-55	dM4e	12·61	15·2	1426	7·42 ± 0·86	28·5	-3·17
493·1	FN Vir*	dM5e	13·34	10·1	1282	2·54 ± 0·69	27·6	-3·55
729	V1216 Sgr.	dM4·5e	10·60	2·9	3676	26·8 ± 0·90	27·6	-3·44
735	V1285Aql	dM 3e	10·07	10·9	7518	26·7 ± 0·60	28·7	-3·57
791·2	HU Del	dM 6e	13·06	9·4	5265	6·32 ± 0·45	27·8	-3·53

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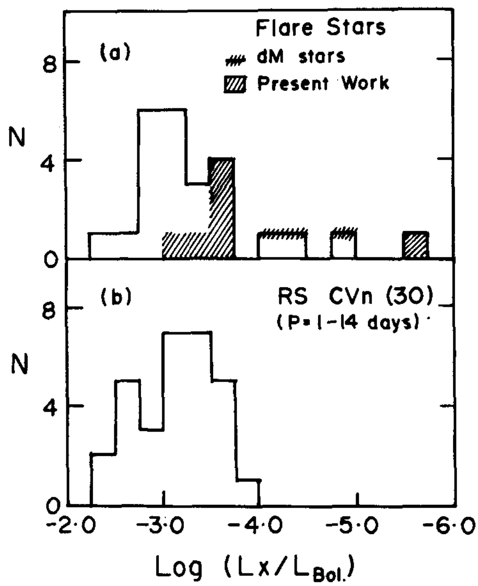

Figure 1. The distribution of L_X/L_{bol} for (a) flaring and non-flaring dM stars and (b) regular period RS CVn stars.

flare stars except FN Vir which is a spectroscopic binary, and all were detected in X-rays. Two stars, Gl729 and Gl735 were detected as bright X-ray emitters with a count rate of 0.27 count sec^{-1}. A conversion factor of $1.4x10^{-11}$ erg cm^{-2} sec^{-1} per IPC count sec^{-1} derived from the energy spectra of Gl729, Gl735 and Gl791.2 obtained with the IPC, is used to convert the observed count rate to flux values. Using these we computed X-ray luminosity (L_X) and the ratio of X-ray luminosity to bolometric luminosity (L_X/L_{bol}) for the observed stars and these are shown in Table 1. With the exception of the star Gl729 from which a weak X-ray flare was detected, there was no compelling evidence for flaring activity in any of the other stars during the X-ray observations. The observed L_X values therefore represent the quiescent state coronal emission of these stars. Except for Gl229, which has a rather low $L_X=6x10^{26}$ ergs sec^{-1}, the L_X values lie within a narrow range of $(0.4-5)x10^{28}$ ergs sec^{-1}, with a median $L_X=1.8x10^{28}$ ergs sec^{-1}. Note that the ratio L_X/L_{bol} agrees within a factor of 3 for these six stars, with a mean value of $3.5x10^{-4}$. The distribution of L_X/L_{bol} for 22 X-ray emitting flare stars, including the 7 from the present work, and 3 non-flaring dM stars reported so far, is shown in fig.1(a). The observed L_X/L_{bol} distribution indicates that coronae of non-flaring dM stars are one to two orders of magnitude fainter compared to those of the flare stars. Although Gl229 is classified as a dMe flare star, its X-ray emission characteristic resembles that of the non-flaring dM stars.

In Fig.1(b) we have also shown the L_X/L_{bol} distribution for the 30 regular period (P=1-14 days) RS CVn binaries for comparison (Walter and Bowyer 1981). The Two L_X/L_{bol} distributions appear to be similar with about the same median value for the two groups of stars. This suggests that coronae of the flare stars are as active as those of the RS CVn stars. This is however not surprising since enhanced coronal

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ctivity of the RS CVn systems is attributed to the presence of large-scale starspots on their surface and such starspots have also been detected on the photospheres of many flare stars as seen by their BY Dra type variability.

In Fig. 2 we have plotted log L_X vs. log L_{bol} for the flare stars and the regular period RS CVn binaries. The figure strongly suggests linear dependence of L_X on L_{bol}. The stright line in the figure corresponds to the relation $L_X=10^{(3.21\pm0.63)}L_{bol}$.

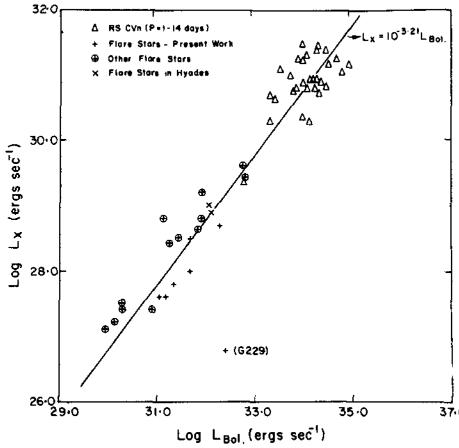

Figure 2. Diagram of L_X vs. L_{bol} for flare stars and the regular period RS CVn stars.

For three of the stars i.e. Gl729, Gl735 and Gl791.2, the number of detected photons was large and therefore we attempted an analysis of the IPC spectral data to estimate temperatures of their coronae. Best fit Raymond-Smith models gave temperature values in the range of (2-5)x 10^6K which indicate that the spectra of quiescent state coronae of flare stars are somewhat softer than those of the RS CVn binaries (Swank and White 1981).

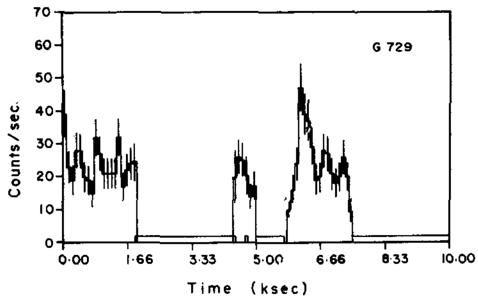

Figure 3. IPC count rate vs.time plot for the flare star Gl729. A moderate X-ray flare is seen at 6k sec after the start of observation.

There is indication of a moderate X-ray flare in Gl729 during the X-ray observations. A plot of counts rate in 100 sec time bins vs.time is shown for Gl729. There is an unmistakable increase in the counting rate starting at 6 ksec after the start of observation which corresponds to 5.063 hour UT on 24th March 1981. The observed increase is at a significance level of 4.9 σ above the average count rate before and after the flare. The rise time of the flare is$\sim$50sec, and decay time is $\sim$300 sec. The peak L_X value is $7\text{x}10^{27}$ ergs sec^{-1} and the total senergy release in the X-ray flare is$\sim$$1\text{x}10^{30}$ ergs. The rise and decay times of the observed X-ray flare are similar to those of the optical flares detected from Gl729 (Cristaldi & Rodonò 1973). Detection of a flare in about one hour of observing time is not inconsistent with the reported optical flare frequency of 0.15-0.35 flare hour^{-1}(Feix 1974, Jarrett and Grabner 1974).

A detailed version of this paper will shortly be submitted to Astrophysical Journal.

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DISCUSSION

Rosner: Where did the data come from for the integral luminosity function?

Agrawal: From the present work, from a paper by Vaiana et al. from a paper by Johnson et al. and two stars are from HEAO-1 observations.

Rosner: When preparing a luminosity function you have to be careful that you are dealing with a volume-limited sample. Many of the stars in your sample are very far away. When this is so, you bias your sample towards very luminous sources.

Agrawal: All of the flare stars included in the sample are in catalogues of nearby stars and so are all within 25pc. Those included from the surveys of Vaiana et al and Johnson et al are also nearby stars.

Bopp: Caution should be exercised in using the dMe star classification. You referred to Gliese 229 as dMe star while Pettersen specifically referred to this star as having the Balmer lines in absorption. So perhaps we could agree to reserve the dMe designation for those stars with the Balmer series in emission. That may be more than a minor point because the behaviour of Hα may be rather different from CaII. So perhaps Gliese 229 is a plage star rather than a spotted star as defined by Pettersen earlier.

Agrawal: That could be true. I called it dMe because it is classified like that by Kunkel.

Evans: I would like to underline what Bopp has said and ask that the dMe classification be reserved for those stars showing the Balmer lines in emission. Secondly, there are problems with this since there are cases of stars which would at one time have been classified dMe and not at others. An example is BY Dra which has shown considerable variation in the intensity of its Balmer emission.

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Agrawal: The point which I was trying to make is this, that the dM stars appear to be two orders of magnitude fainter in X-rays compared to the dMe stars. In the paper by Johnson et al are also some dM stars and these have luminosities of 10^{27} ergs s^{-1} or less. So the flare stars which are all dMe stars are two orders of magnitude more luminous in X-rays than the dM stars.

Vaiana: Perhaps I may make a comment here. We should remember what happened to the RSCVn stars. These expanded from a relatively pure definition to include a wider range of stars. Perhaps the same thing is happening to the dMe stars. I personally believe this is no harm as long as one has good reason for it. It is appropriate that this should be discussed at this meeting.