X-ray activity of three rapidly rotating active stars using AstroSat

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Abstract

We present X-ray study of three rapidly rotating active stars namely CC Eri, AB Dor, and FR Cnc is presented. A total of six flares are detected on two active stars CC Eri and AB Dor. The peak X-ray luminosities of the flares in the 0.3-7.0 keV energy band is found to be in the range of ~10^{31-32} erg s^{-1} for all flares. Spectral analysis indicates the presence of three and four temperature corona for CC Eri and AB Dor, respectively, where the highest temperature and corresponding emission meausure are found to vary along with the flare light curve. The flare-temperatures peaked at 51 - 59 MK for the flares observed in CC Eri and 29 - 44 MK for the flares from AB Dor. The abundances of the flaring plasma reached up to 0.5 and 0.7 times of the solar photospheric value for CC Eri and AB Dor, respectively. The loop-lengths for these flaring events are estimated to be of the order of 10^{11}cm for all flares. The energy for these flaring events is estimated to be 10^{32-35} erg. FR Cnc was was in a quiescent state during the observations and found to be rotationally modulated with a degree of modulation of 17%. The X-ray light curve of FR Cnc was anticorrelated with optical V-band light curve.

Introduction

Rapidly rotating late-type active stars show the enhance level of activity in the saturation level. The ratio of X-ray to bolometric luminosity (L_X/L_{bol}) at the saturation level is generally found as ~10^{-3} with saturation period between ~1 to ~4 days for different type of active stars (Pizzolato et al., 2003). Various explanations have been proposed for the saturation in active stars e.g. internal dynamo itself saturates and produces no more magnetic flux with increasing rotation (Vilhu 1987), maximum possible coverage of active regions on the stellar surface (Vilhu 1984), and a centrifugal stripping of the corona (Jardine 1999). Thus rapidly rotating late-type stars are important as they display an extremely enhanced level of stellar activity at saturation when compared with that of the Sun and other slow rotating stars. See Table 1 for introduction of individual stars and their observations form soft x-ray telesscope (SXT) of AstroSat (Singh et al. 2016; Agrawal et al. 2017). A detailed of data reduction is mentioned in Pandey et al. (2020).

Table 1 Basic parameters of target stars and brief log of observations.

Stars (►) Parameters (▼)	AB Dor	FR Cnc	CC Eri
Spetral Type	K0V	K7V	K7V
Rotational Period (d)	0.514275	0.82652	1.56
Distance (pc)	15.3	35.6	11.5
L_X/L_{bol}			
Date observations	15/02/2018	01/03/2019	22/11/2016
Exposure (eff/total)	50/193 ks	41/129 ks	46/185 ks

X-ray light curves

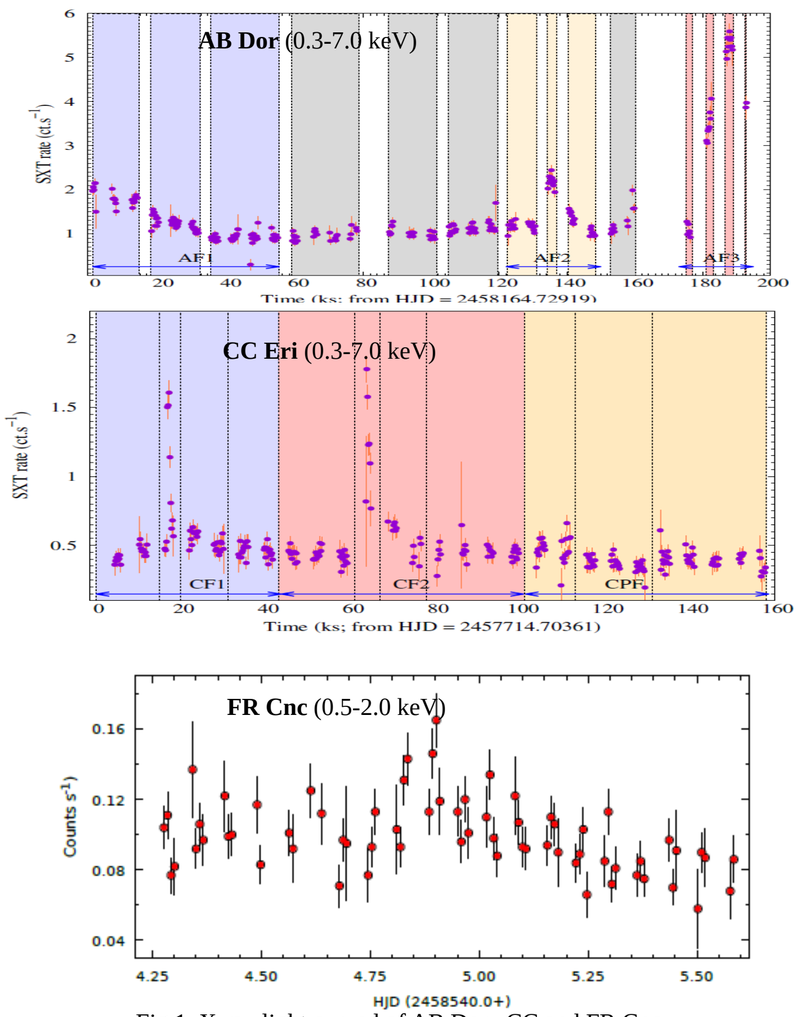


Fig 1. X-ray light curved of AB Dor, CC and FR Cnc.

- No Flares were observed in FR Cnc.
- A modulation is found in the X-ray light curve of FR Cnc.
- Frequent flaring events observed in AB Dor and CC Eri.
- Three Flares in AB Dor and two flares in CC Eri
- Flare durations were 2 – 37 ks.

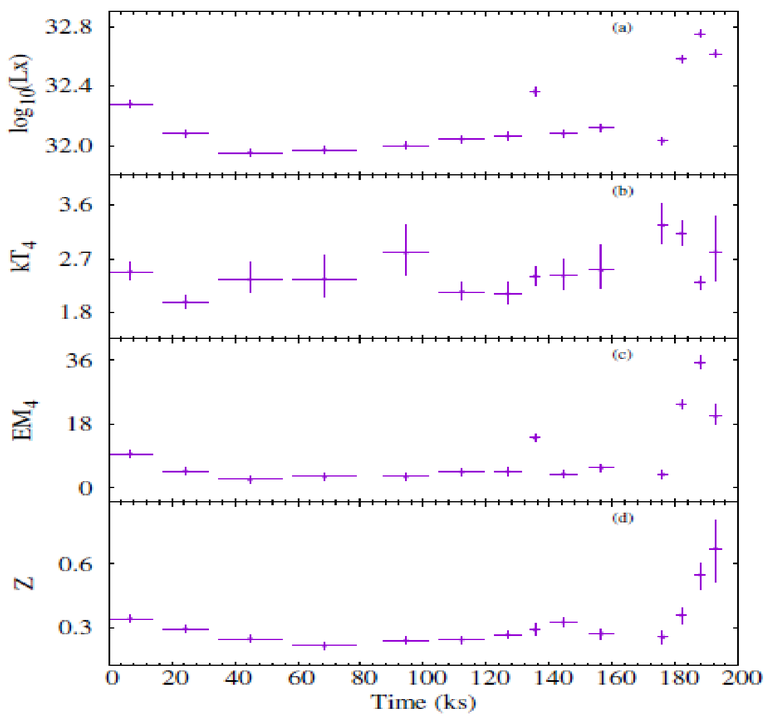
Flares

Quiescent state spectra:

- AB Dor: 3 T plasma; CC Eri: 2 T plasma, FR Cnc: 2 T plasma
- Quiescent state luminosity: 8x10^{31} (AB Dor), 1.2x10^{31} (CC Eri), 4.45x10^{29} (FR Cnc) erg s^{-1}.

Flare Spectra: One additional temperature

- Flare energy – 10^{34} -10^{37} erg
- Peak flare luminosity/ quiescent state luminosity: $L_{X,P}/L_{X,Q}$ = 2.0 – 8.0
- Flare Peak temperature: AB Dor: 2.5, 2.8, 3.3 keV; CC Eri : 4.4, 5.1 keV
- Peak to quiescent state emission measure: EM_P/EM_Q = 4 – 15
- Peak to quiescent state abundance Z_P/Z_Q = 1.5 – 2.3
- Peak to quiescent state hydrogen column density $N_{H,P}/N_{H,Q}$ = ~3.5



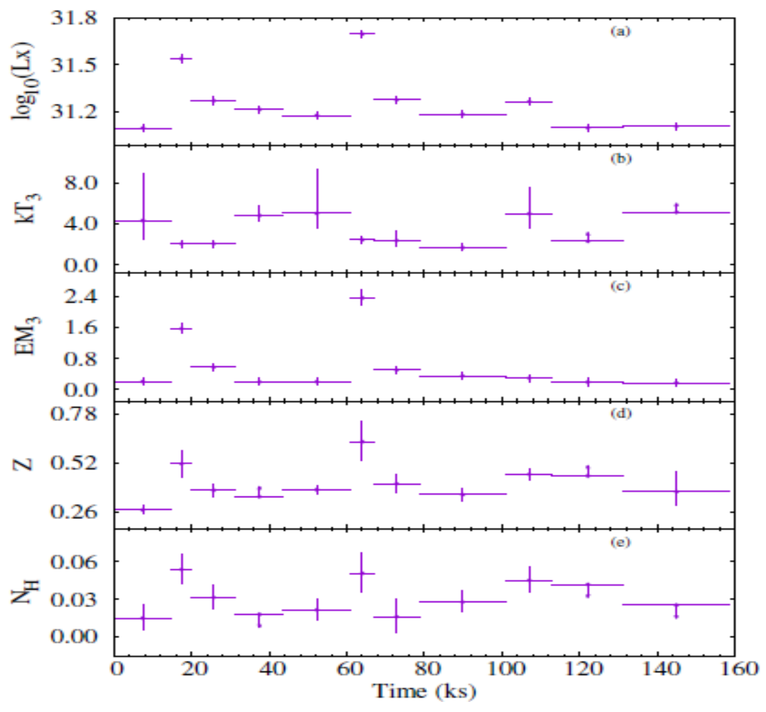


Fig 2. Evolution of spectral parameters AB Dor and CC Eri.

- Variation of Z: Chromospheric evaporation
- Variation of N_H : Coronal mass ejection
- Temperature peaked before the emission measure: Harder emission peaks before the softer.

Flare Modeling: Quasi-static cooling model (van den Oord & Mewe (1989)

$$L(cm) = R_{\odot}\left(\frac{\tau_{qs}}{10ks}\right)\left(\frac{kT(t_0)}{keV}\right)^{7/8}$$

T_{qs} – quasi-static cooling time, kT(t0) -peak temperature
Loop lenght (L) -- $10^{10\text{-}11}$cm

X-ray Rotational modulation

- Rotational modulation was found for the star FR Cnc and absent in AB Dor and CC Eri (probably due to the flaring events).
- Rotational modulation was found to be 17% in FR Cnc.
- Simultaneous optical observations from Zvenogorod observatory (Russia).
- X-ray and optical emission are anti-correlated.
- Two active longitude separated by 180^0 are found on the surface of FR Cnc.
- The surface coverage of dark spots was ~12% of total surface area.

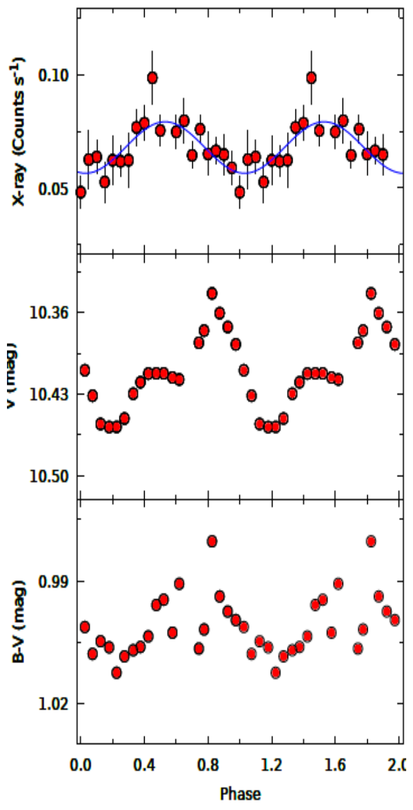


Fig 3. Phase folded X-ray and optical lightcurves of FR Cnc.

Long-term X-ray activity cycle

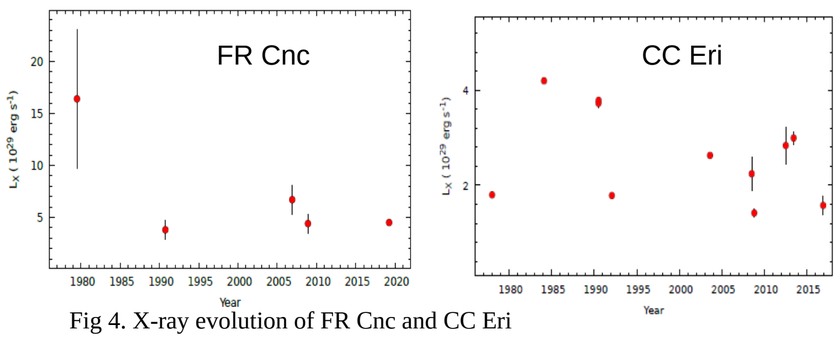


Fig 4. X-ray evolution of FR Cnc and CC Eri

- X-ray long term variability was searched in 0.5-2.0 keV energy band.
- X-ray luminosity is not constant in long term in case of CC Eri and almost constant in FR Cnc.
- No cyclic variability is found to present in these rapidly rotating stars but marginaly present in AB Dor in the past.
- Past observations also indicates absence of long term cyclic varibility in highly active stars.
- Could be due to the different dynamo mechanism.

Conclusions

- ✓ All three active stars are found to highly active in X-rays with X-ray luminosity 10^{29} – 10^{30} erg s^{-1}.
- ✓ A total of 5 flares are detected with flare energy more than 10^{34} erg and loop lengths of $10^{10\text{-}11}$ cm.
- ✓ A hint of chromospheric evaporation and coronal mass ejection was observed during the flaring events.
- ✓ Rotational modulation was detected and found to be anti-correlated with optical modulation on FR Cnc.
- ✓ Long term variation is likely to be absent in FR Cnc but appears to be present in CC Eri and AB Dor.

References

Agrawal, P. C. 2017, JapA, 38, 27
Jardine, M., & Unruh, Y. C. 1999, A&A, 346, 883
Pandey et al. 2020, arXiv:201215062
Pizzolato, N., et al., 2003, A&A, 397, 147
Savanov, I. S., et al., Astrophysical Bulletin, 73, 344
Singh, K. P. et al., 2016, SPIE, 99051E
Vilhu, O. 1984, A&A, 133, 117
Vilhu, O., & Walter, F. M. 1987, ApJ, 321, 958

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