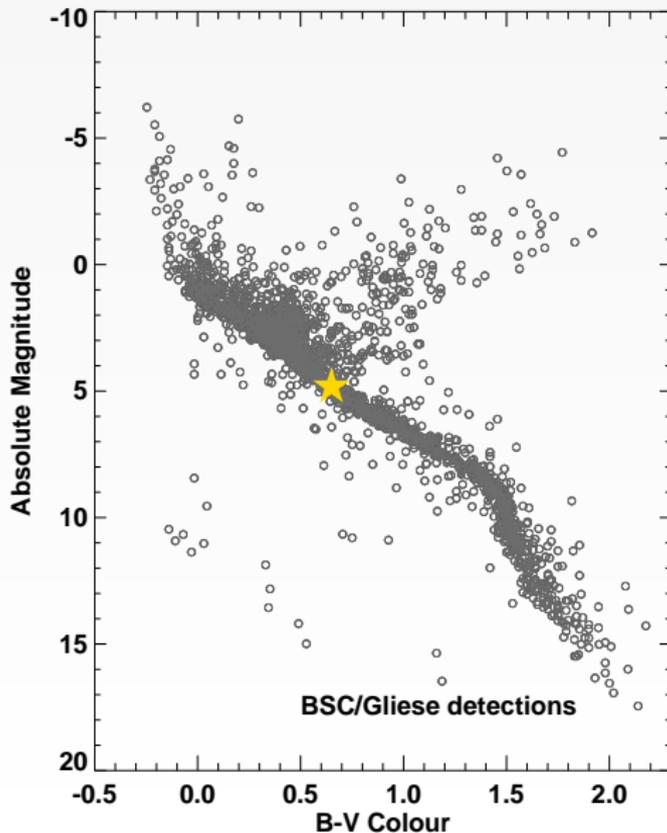


# X-RAYING THE STELLAR CORONAE

Lalitha Sairam  
Tata Institute of Fundamental Research

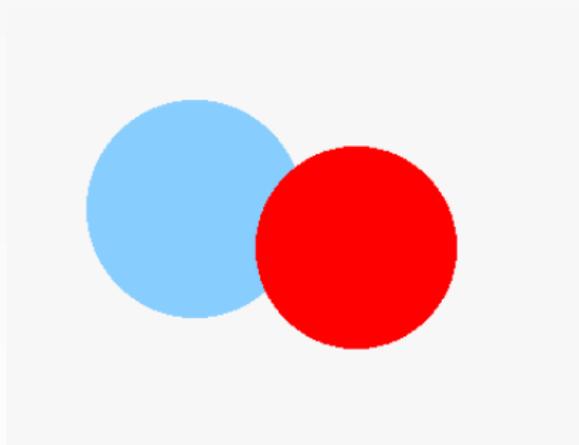
06 February 2014

# X-rays across the HR diagram



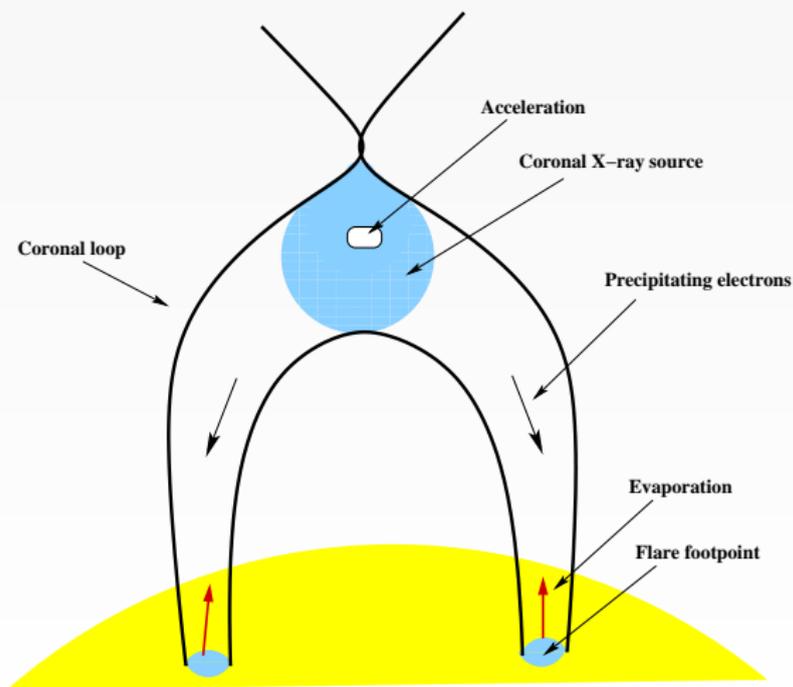
## Flaring star – Algol

- System – short period eclipsing binary

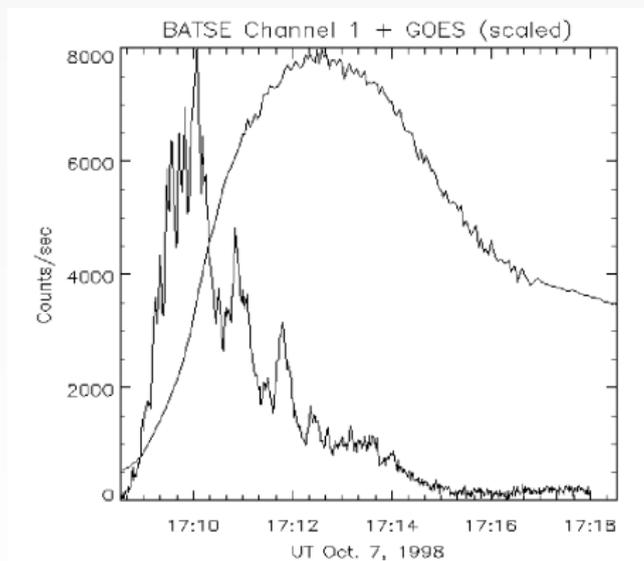


- B-type star – lack surface convective envelope
- Magnetically active secondary – major flares

# General picture



# Temporal variation



Hudson et al. (1998)

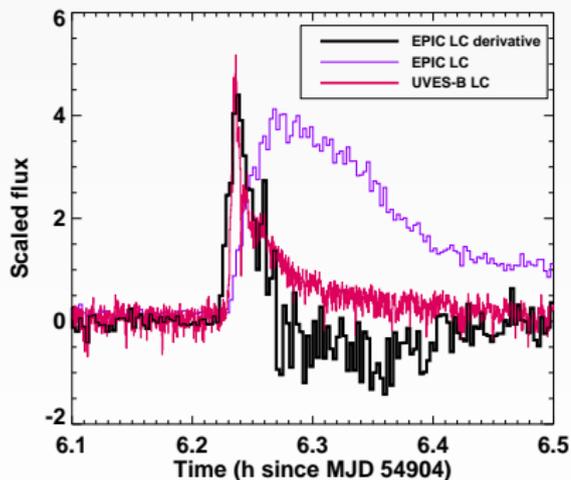
$$F_{SXR} \propto \int F_{HXR}(t) dt$$

or

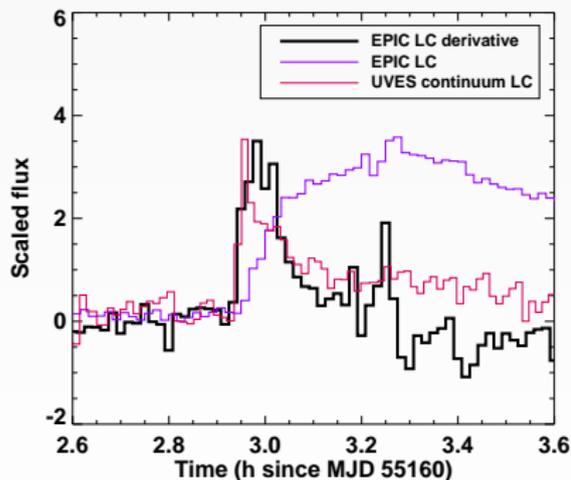
$$\frac{d}{dt} F_{SXR}(t) \propto F_{HXR}(t)$$

# Temporal variation

## Proxima Centauri

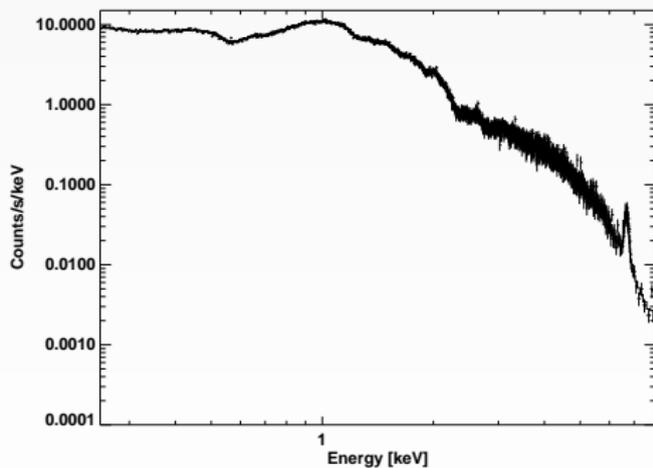


## AB Doradus A

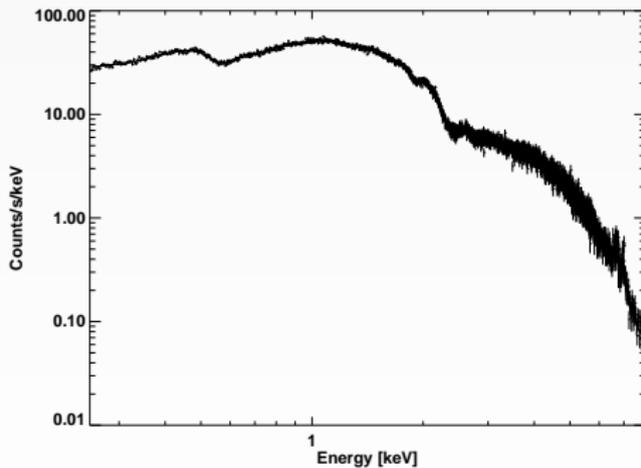


# Algol as observed with SXT

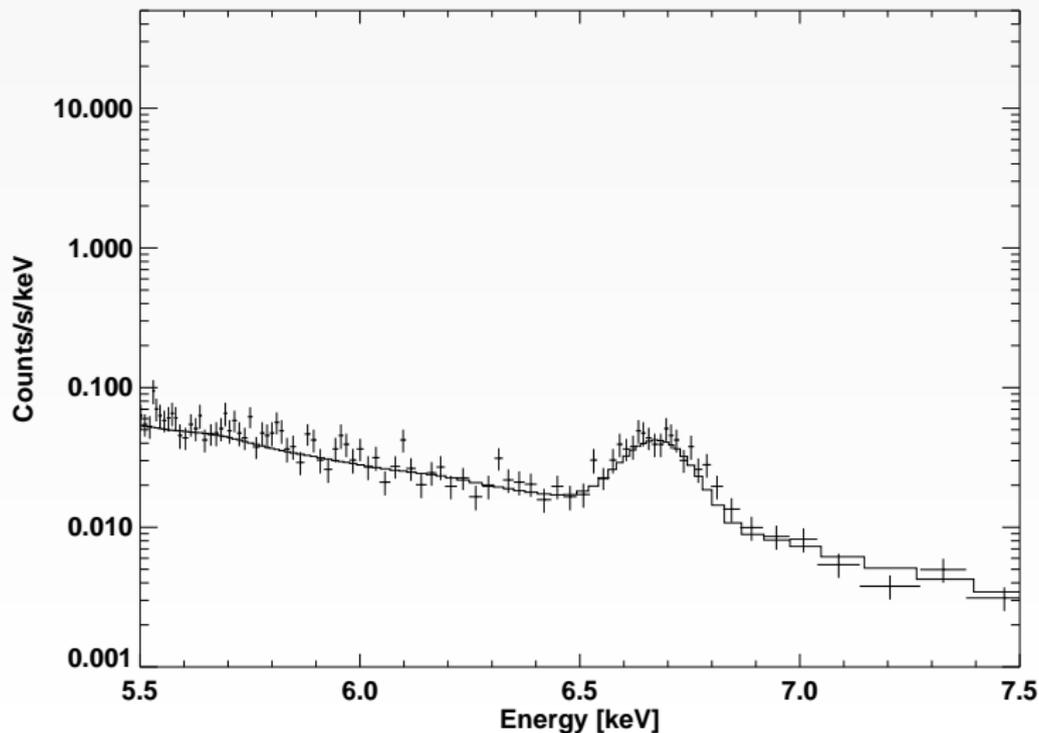
## Quiescence



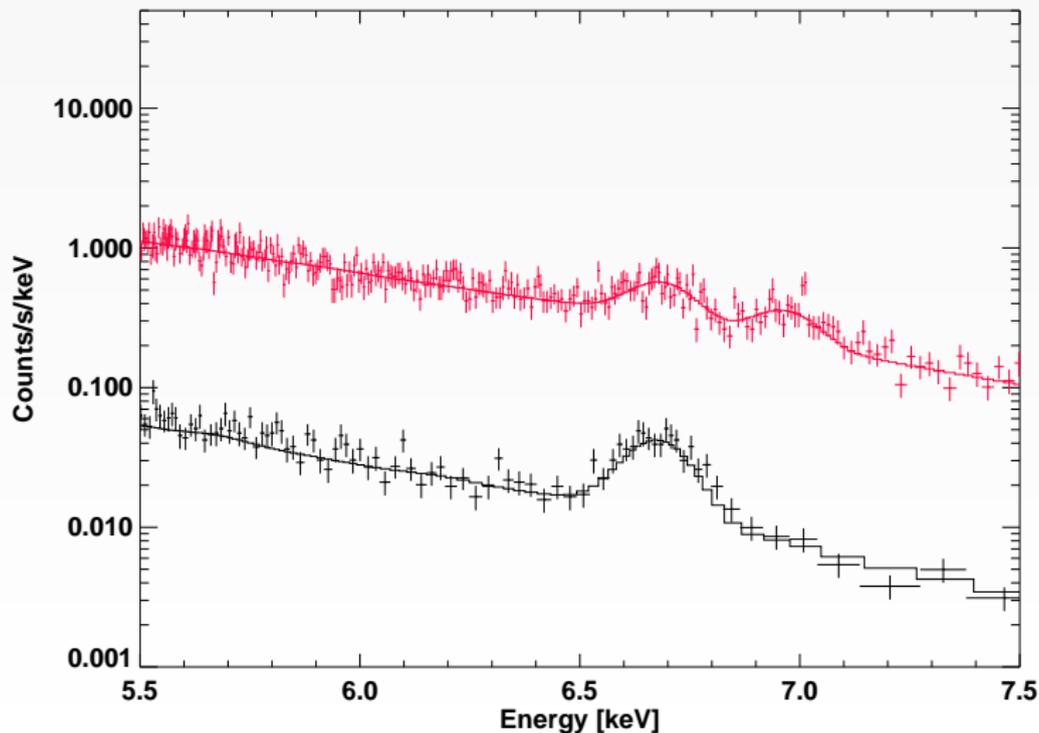
## Flare



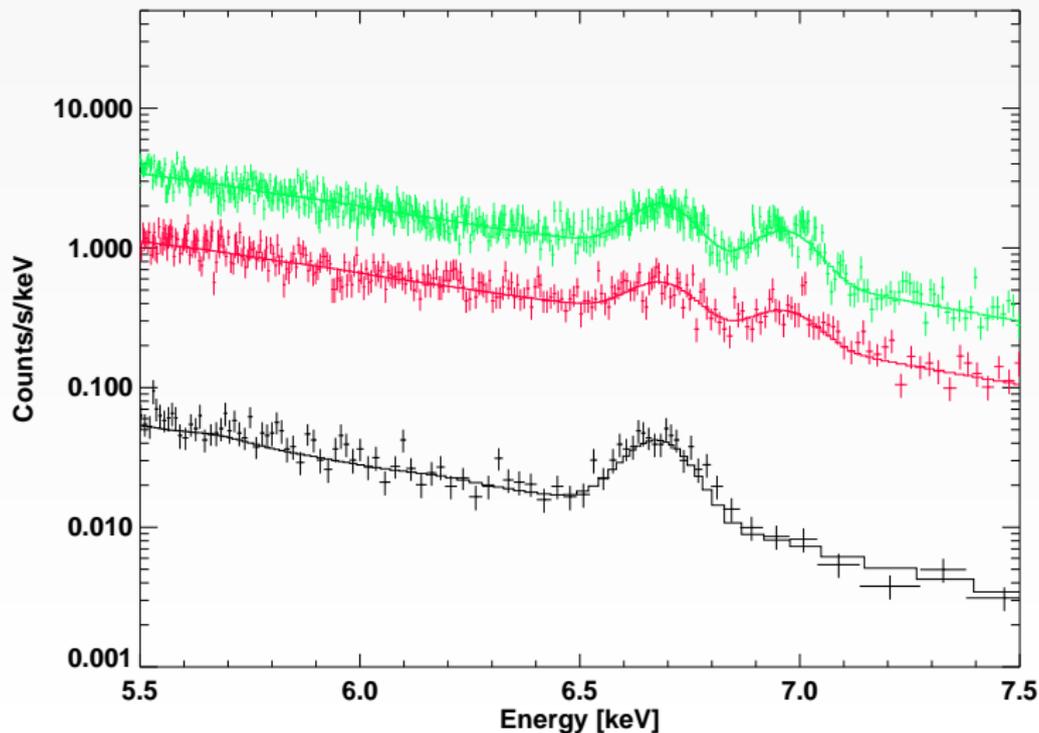
# Abundance variation – Fe K complex



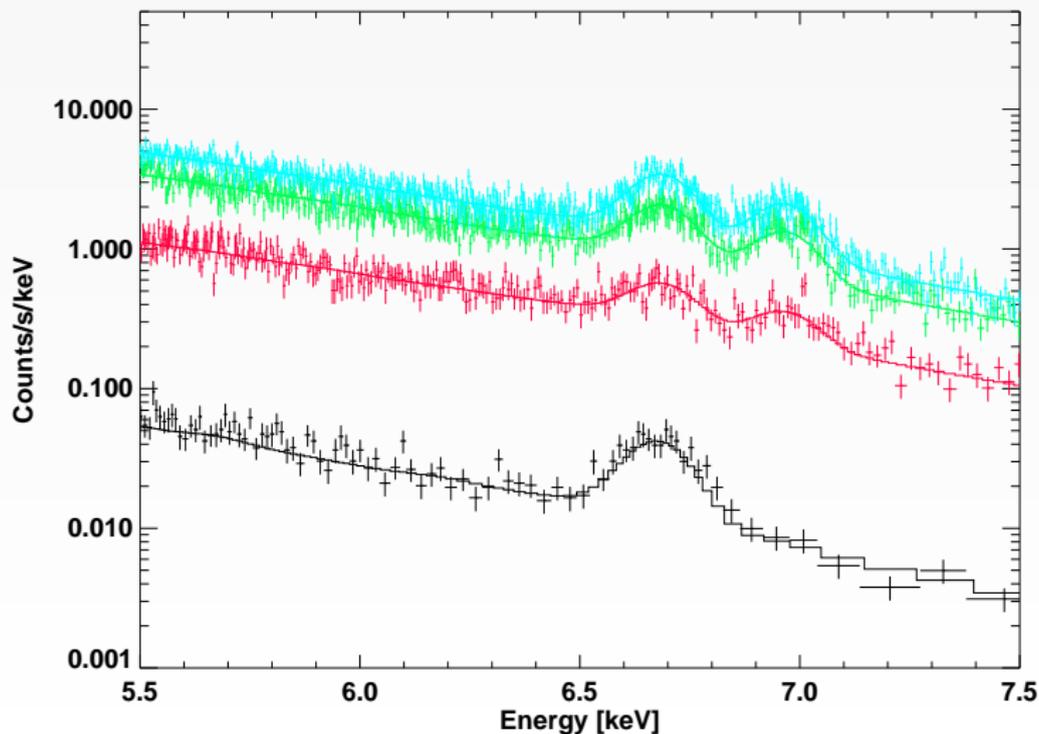
# Abundance variation – Fe K complex



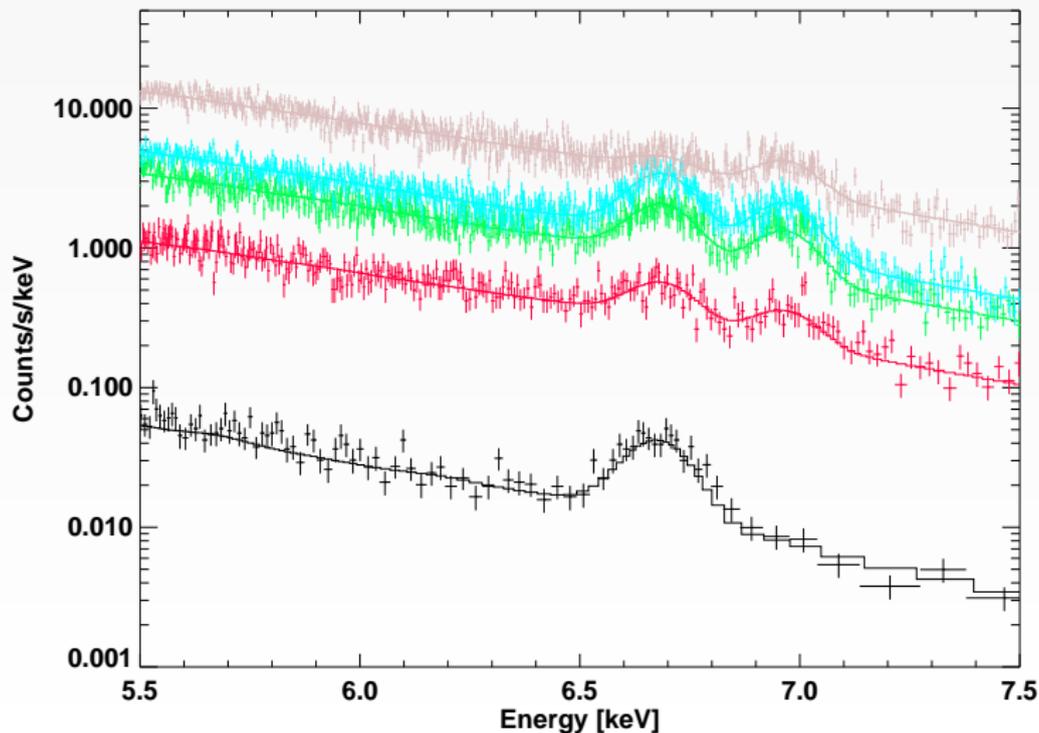
# Abundance variation – Fe K complex



# Abundance variation – Fe K complex

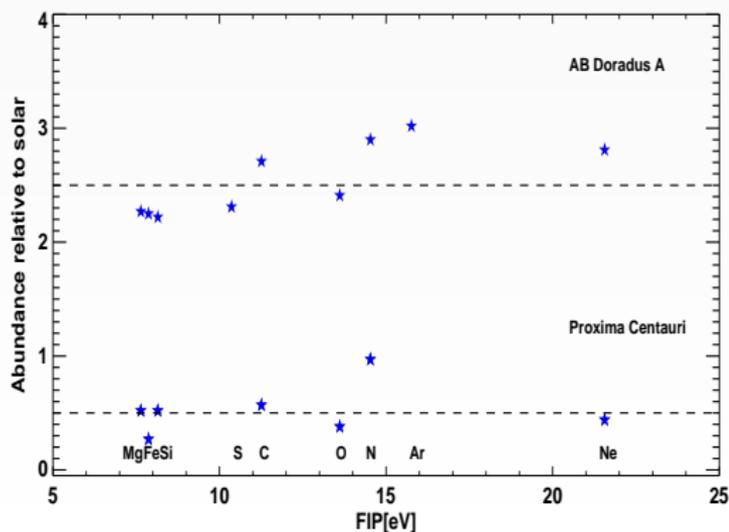


# Abundance variation – Fe K complex



# Abundance pattern

- Sun, inactive or low activity level stars - a normal FIP effect - elements with a low first ionization potential (FIP) are enhanced in the corona
- Active stars - inverse FIP effect - enhanced high-FIP elements and depleted low-FIP elements



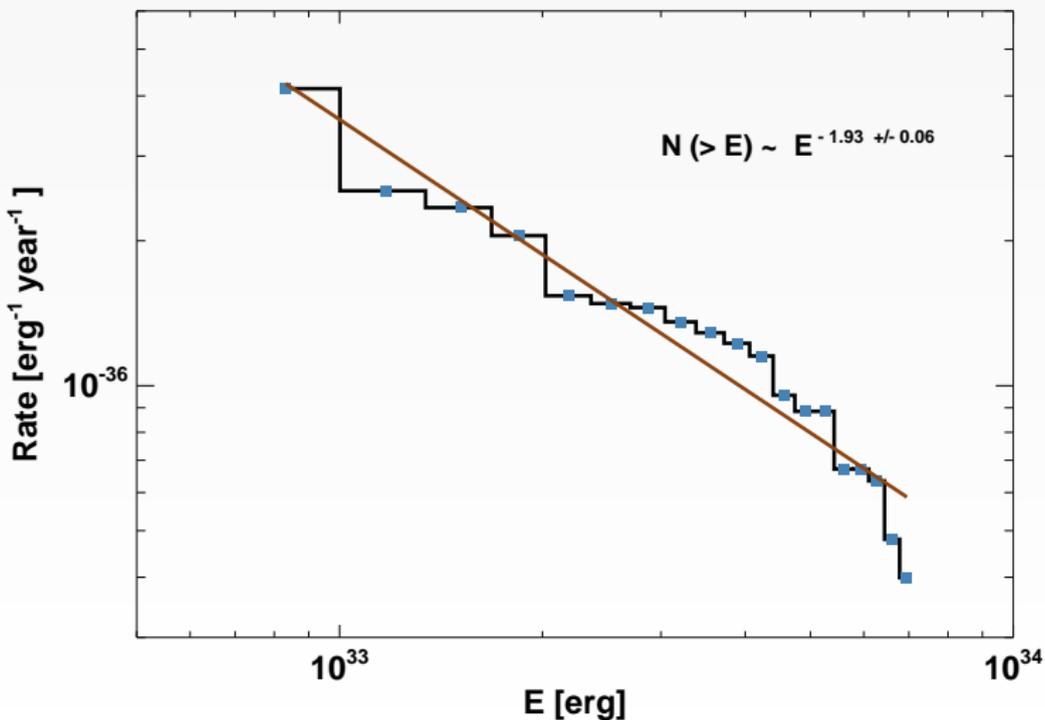
# Flare energy distribution

Parker model - nanoflare for the Sun -  $< 10^{27}$  erg

$$N(> E) = \int_E^\infty \frac{dN}{dE} dE = KE^{-\alpha+1}$$

- In Solar context
  - $\alpha = 1.5 - 1.6$  for a normal flare (Crosby et al. 1993)
  - $\alpha = 2.3 - 2.6$  for small events in the quiescent corona (Krucker et al. 1998)
- Solar analogs:
  - $\alpha = 2.2$  for solar analogs EK Dra and 47 Cas (Audard et al. 1999)
- M dwarfs:
  - $\alpha = 1.6$  for X-ray flares using EXOSAT observations (Collura et al. 1988)

# Flare energy distribution



# Summary

- overall picture of the atmosphere from the chromosphere to the corona - the X-ray and optical/UV light curves of active low mass stars during the flare onset
- abundances, emission measures, and temperatures of flaring plasma
- short term energy release and their role in heating of the atmosphere of active stars.

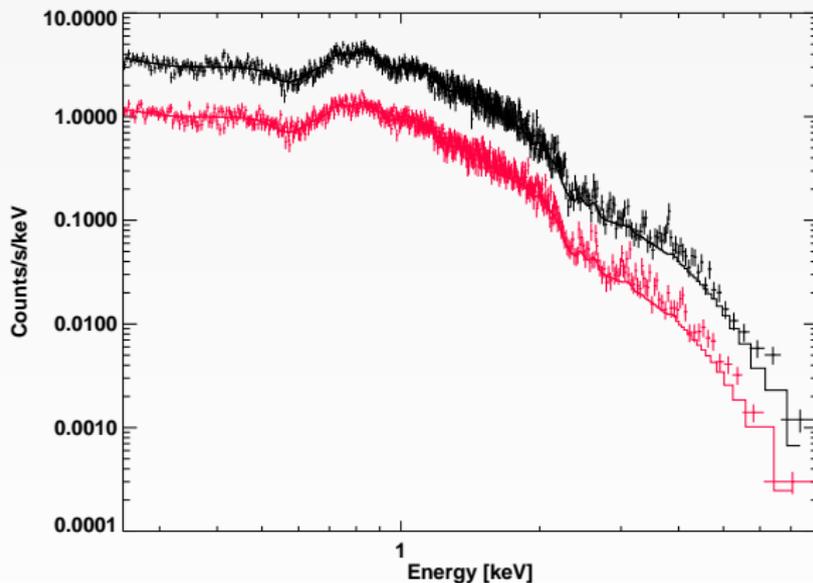
# Appendix

# X-raying stellar coronae with SXT

## 2T XSPEC model + APEC

- Case 1 – Bright coronal X-ray source
- Case 2 – RS CV<sub>n</sub> and dMe
- Case 3 – Sun-like stars
- Case 4 – Late-type stars

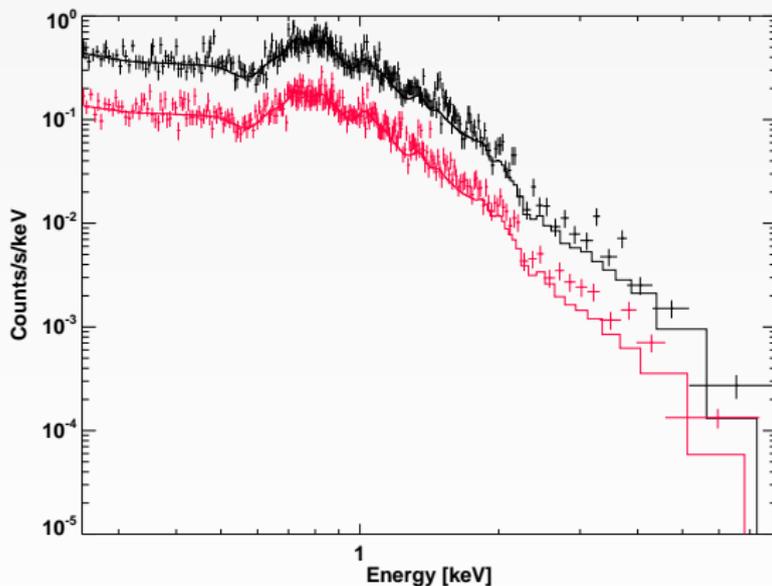
# Case 1 – Bright coronal X-ray source



$$F_x = 1 \times 10^{-10} \text{ ergs cm}^{-2} \text{ s}^{-1}, n_H = 6 \times 10^{18} \text{ cm}^{-2}$$

$$T_1 = 0.6 \text{ keV}, T_2 = 2.5 \text{ keV}, EM_2 = 2EM_1$$

Exposure – 10 ks

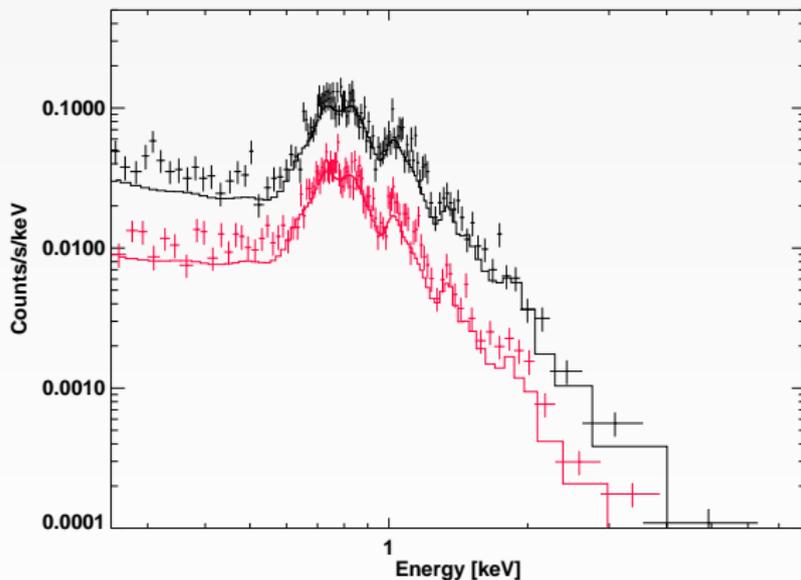
Case 2 – RS CV<sub>n</sub> and dMe

$$F_x = 1 \times 10^{-11} \text{ ergs cm}^{-2} \text{ s}^{-1}, n_H = 1 \times 10^{19} \text{ cm}^{-2}$$

$$T_1 = 0.5 \text{ keV}, T_2 = 2.0 \text{ keV}, EM_2 = EM_1$$

Exposure – 20 ks

## Case 3 – Sun-like stars

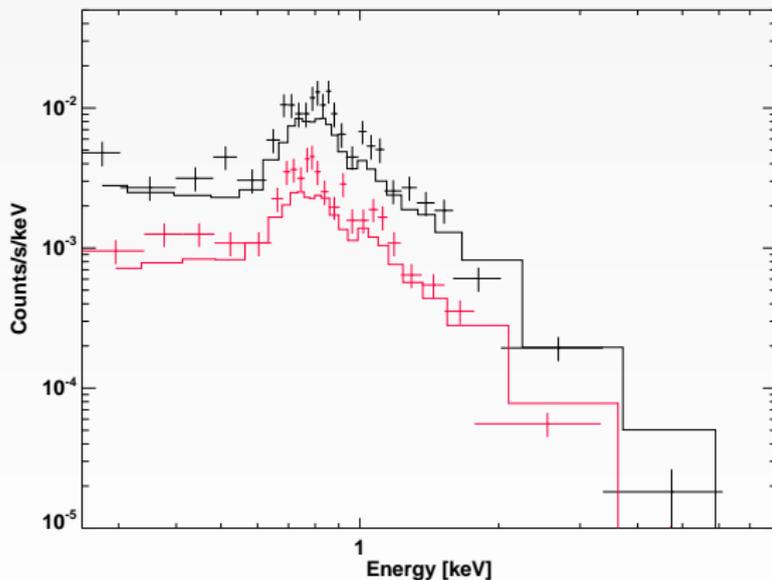


$$F_x = 1 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}, n_H = 1 \times 10^{19} \text{ cm}^{-2}$$

$$T_1 = 0.5 \text{ keV}, T_2 = 2.0 \text{ keV}, EM_2 = EM_1$$

Exposure – 50 ks

## Case 4 – Late-type stars



$$F_x = 1 \times 10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1}, n_H = 3 \times 10^{19} \text{ cm}^{-2}$$

$$T_1 = 0.5 \text{ keV}, T_2 = 2.0 \text{ keV}, EM_2 = EM_1$$

Exposure – 100 ks

# Temperature and emission measure variation

