Stellar Coronae, Flares and Winds As Seen by Suzaku: What Have We Learned?

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A Short Survey of the Stellar Menagerie

- FGKM-type Low-Mass Dwarfs (0.07-1.7 M_{sun})
  - Convective Outer Envelopes + Rotation (enhanced in Young or Binary Stars)
    => Magnetic Dynamo => Energy Input into Outer Layers => Heating and Particle Acceleration =>
  - Persistent Coronae with T ~ 1- 20 MK
  - Occasional Flares with T ~ 20 - 100 MK (+ Non-Thermal Hard X-ray Emission)
- BA-type Intermediate-Mass Stars (1.7-6 M_{sun})
  - Radiative Outer Envelopes + Weak Radiation-Driven Winds => Little or No X-ray Emission **(except in coronal pre- & post-main sequence phases)**
- WR & OB-type High-Mass Stars (6-100 M_{sun})
  - Strong Radiation-Driven Winds + Instabilities => Shocked Plasma with T ~ 1-6 MK
  - Subset of stars, e.g., Tau Sco, with some plasma at T up to >=30 MK: Magnetically Confined Wind Shocks?
- Pre-Main Sequence Stars ("T Tau Stars")
  - Magnetic Dynamo + Magnetically Channeled Accretion (T ~ few MK) + Star/Disk Magnetic Interactions (High-T and flares)=> Multi-component modeling needed

Stars and Suzaku

- XRS was clearly going to be the prime instrument for stellar observations because of their complex line-rich spectra
- Loss of XIS effective area makes observations of soft (T << 10 MK) stellar sources inefficient or problematic
- Most stars are not copious hard X-ray emitters, so HXD is likely only useful for hardest sources with T >> 20 MK or non-thermal emission, e.g, large flares
- XIS/HXD observations of hard stellar sources can nicely supplement Chandra and XMM-Newton CCD observations => XIS has more effective area in the 5-10 keV (Fe K) energy range

A Short Listing of Suzaku Pointings at Stars

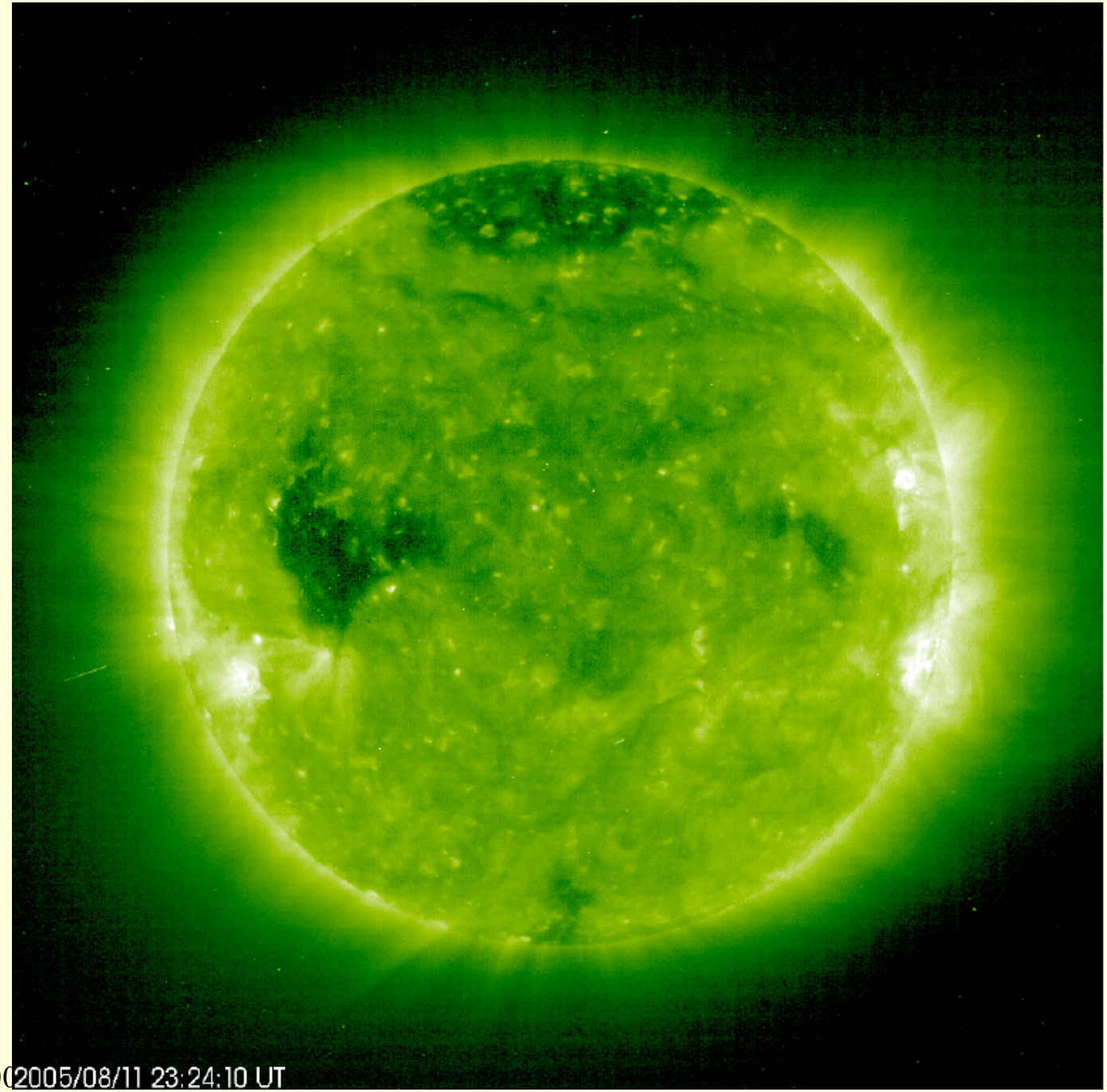
- 5 RS CVn and Algol-type Active Binaries: Sigma Gem, Algol, Beta Lyr, TZ CrB and GT Mus
- 1 Active M Dwarf: EV Lac
- 1 Active Young K Dwarf: AB Dor
- 1 Hertsprung Gap F Giant: Beta Cas
- 1 Rapidly Rotating G Giant: HR 9024
- 3 Classical T Tau Stars: V2129 Oph, TW Hya and SU Aur
- 2 OB Stars: Zeta Oph and Tau Sco

14 Stars Observed (about 1% of Total Number of Suzaku Observations)

- **What are Some of the Big Questions about Coronae, Winds and Flares?**

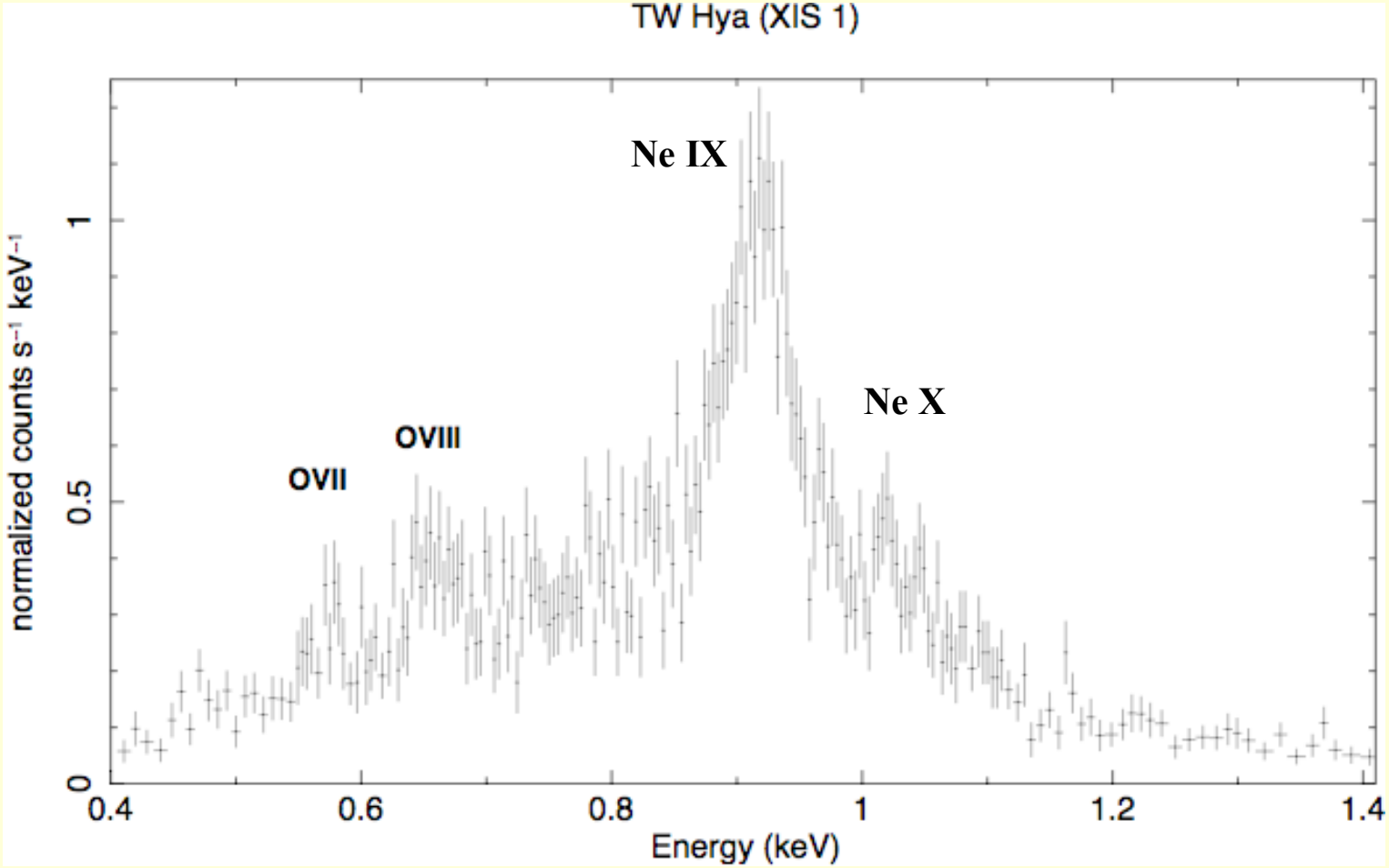
  - **What are the Actual Mechanism(s) that Heats Coronae and Trigger Flares?**
  - **How are Stellar Coronae/Flares/Winds Structured (Geometrically and Thermally, i.e., their DEMs)?**
  - **Why do Most Coronae Have `Funny' Non-Solar Abundances?**
  - **What are the Mass Loss Rates and Energy Inputs into the ISM of High- and Low-Mass Star Winds?**

Our Friend: The Sun



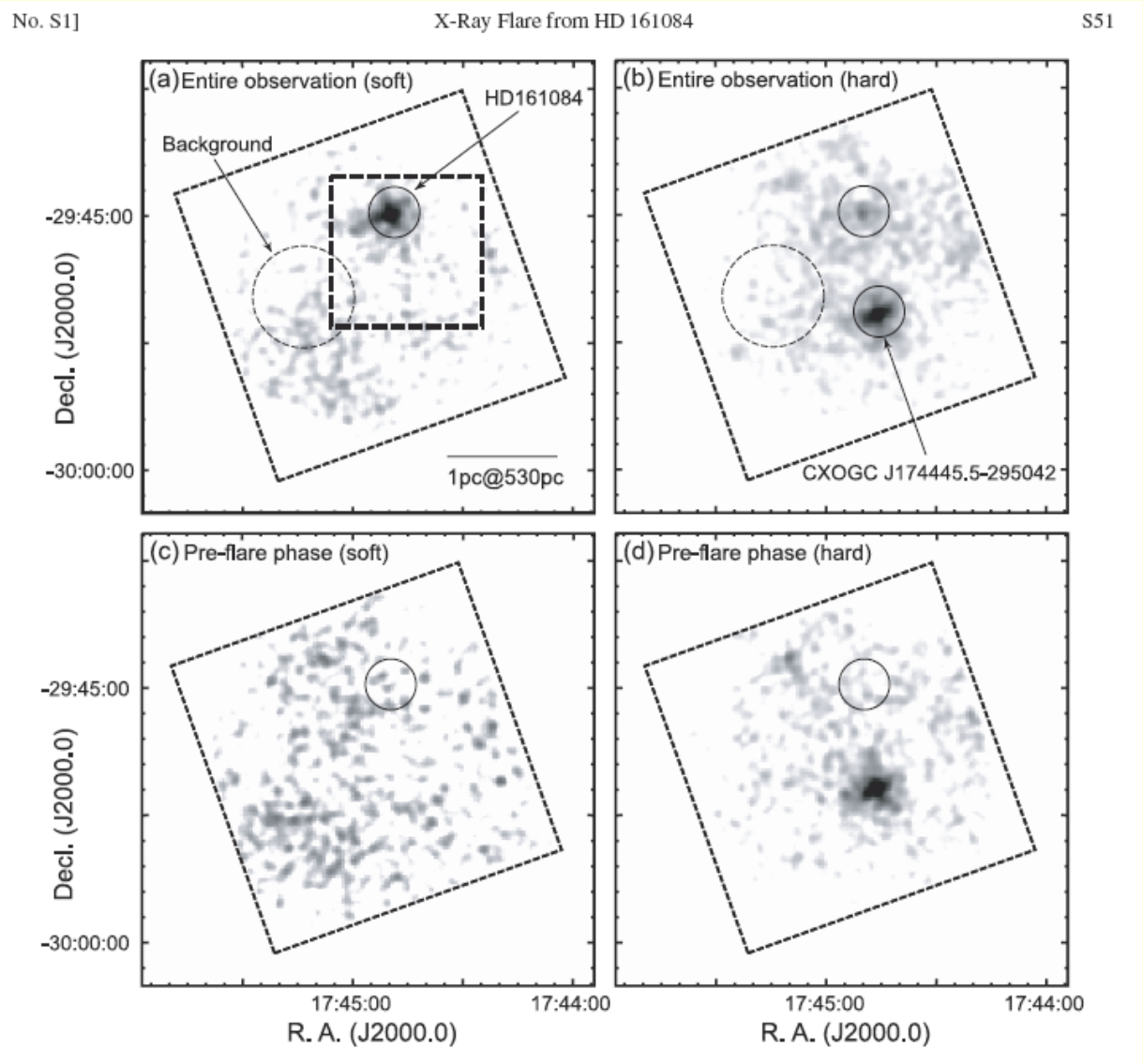
EIT: Fe XII line @ 195Å

Schmitt & Robrade (2008, unpub)



Goals were to (i) Search for and better characterize the soft X-ray excess and (ii) Detect and resolve the O VII & O VIII lines **[Note weakness of Fe L complex]**

HD 161084



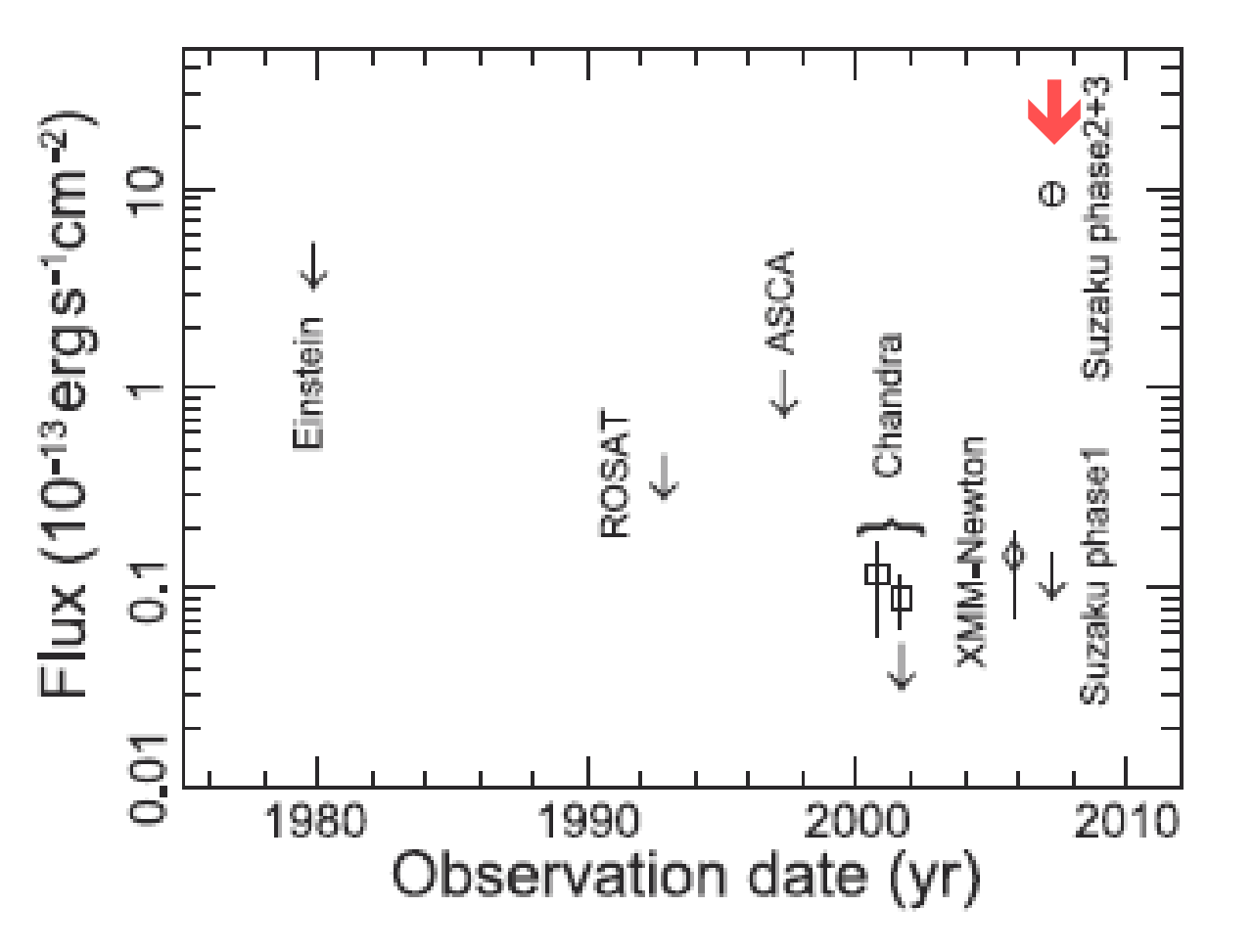
Miura et al. (2008, PASJ, 60, 49) observed a transient in a GC-ish pointing

Flare-like morphology

At location of known A star (HD 161084)

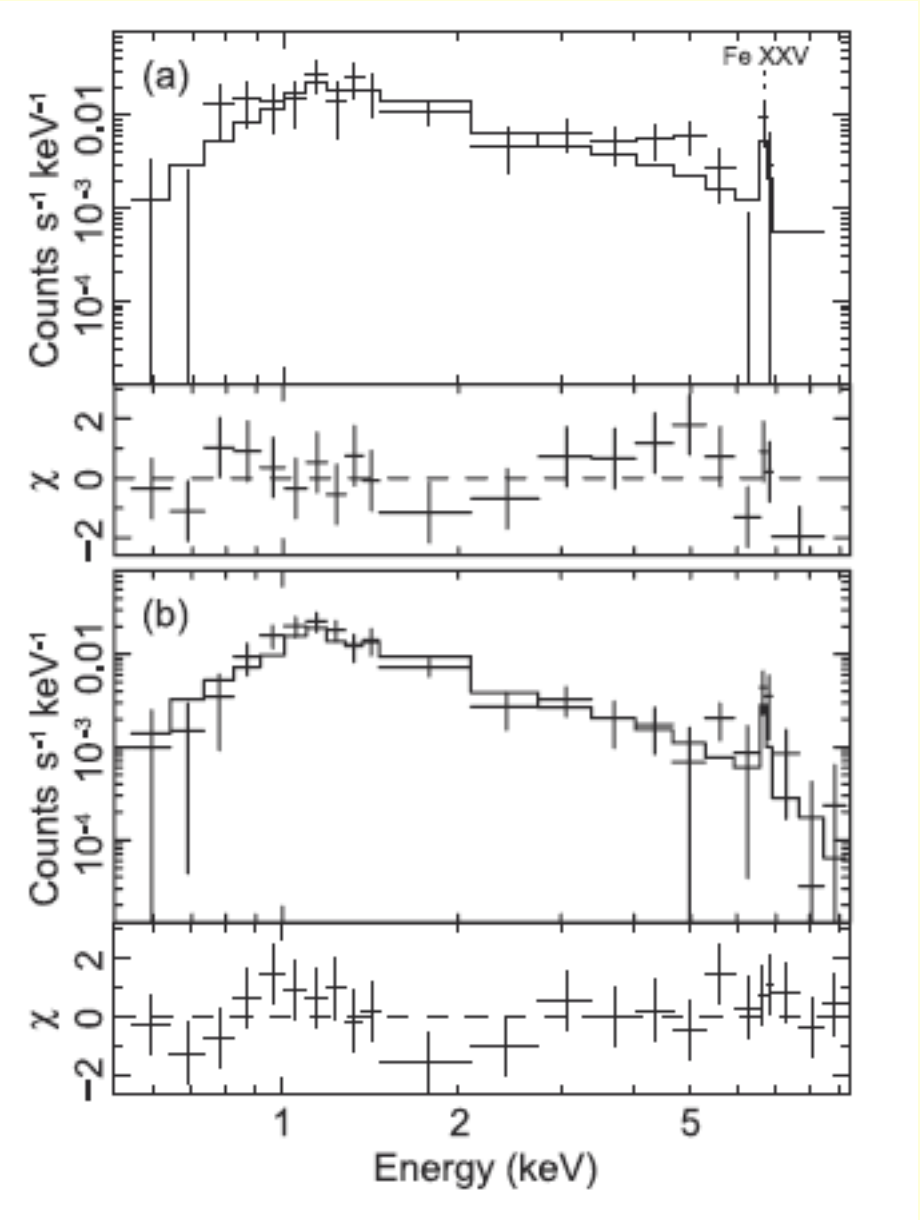
=> Large stellar flare

HD 161084



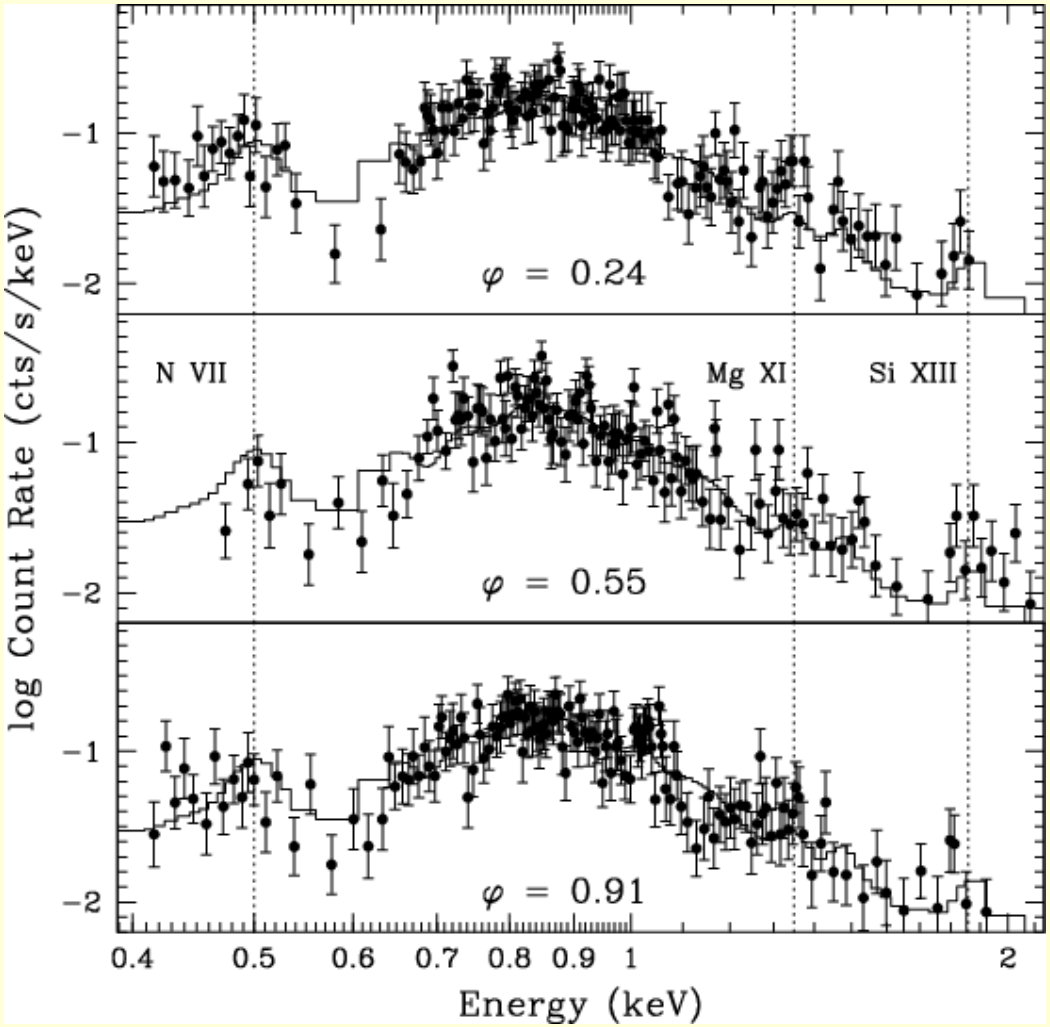
X-ray level is 100x previously observed (and pre-flare) strength => One of the largest ever flare enhancements

HD 161084



- Spectrum of HD 161084 flare is well-fit by 50 MK coronal plasma
- Implied Peak $L_x \sim 10^{32}$ erg/s
- Likely Algol binary system

Beta Lyr

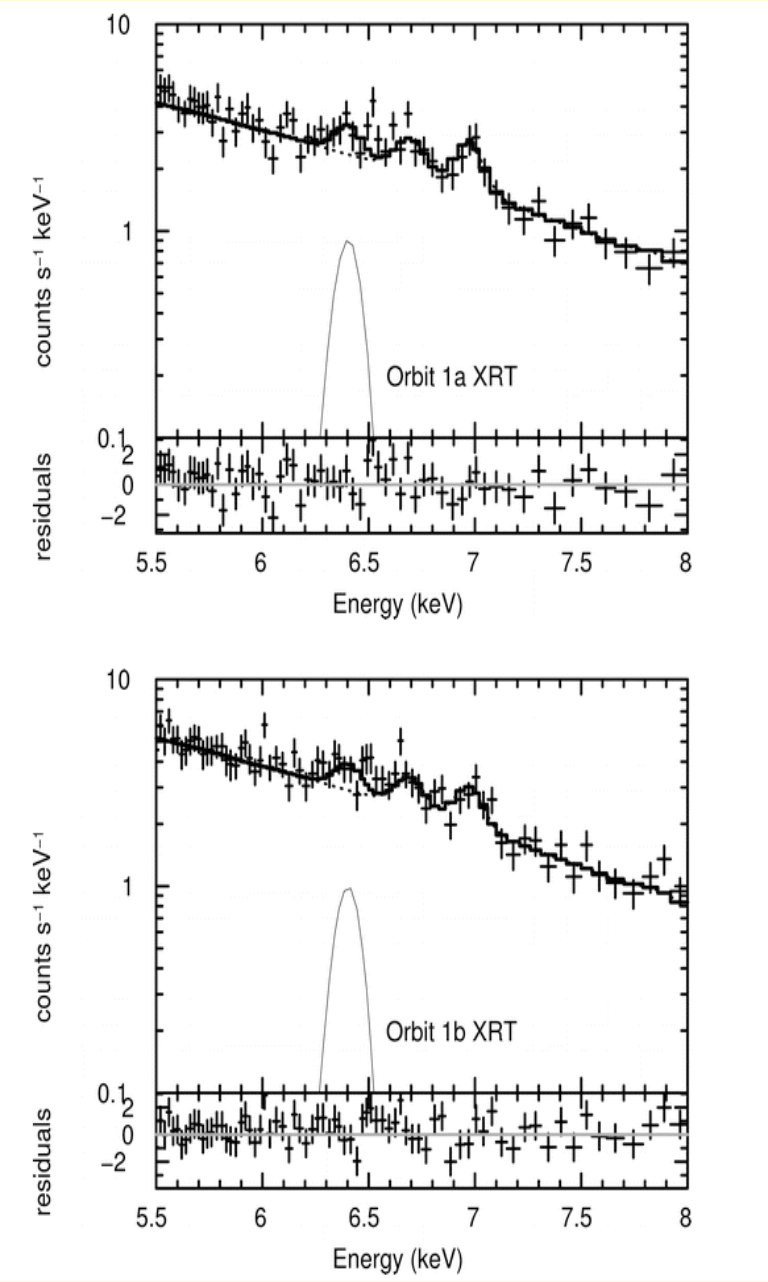


Ignace et al. (2008, A&A, 477, L37) observed Beta Lyr, a peculiar early-type binary system at 3 orbital phases:

- No X-ray variability observed
- Softness (6 MK thermal plasma) and Luminosity (7 x 10^{30} erg/s) => 'normal' OB star X-ray emission
- Inferred N abundance of 10x solar
- Claim for detection by HXD PIN of 10-60 keV emission at phase 0.55 needs confirmation

- Suzaku results on stars are still mostly unpublished
- There are still many unsolved questions about stellar coronae, winds and flares!
- Long observations are essential - coronae and flares are dynamic and unpredictable.
- Loss of XIS sensitivity at softer energies has compromised some types of stellar science, e.g., of accreting stars
- Best science results will likely come from observations of nearby active stars, known to be (a) relatively hard and (b) to produce large flares, e.g., II Peg, AR Lac, HR 1099

II Peg



Swift Observation of `Superflare' of II Peg (Osten et al. 2007, ApJ, 654, 1052)

Peak flare temperature of ~100 MK observed

Fluorescent cold Fe emission at 6.4 keV detected

Peak X-ray luminosity of ~ 10^{33} erg/s near the bolometric luminosity

Hard X-ray nonthermal emission most likely detected

Suzaku can complement Swift by observing less luminous but more frequent large flares and determining non-flare spectral properties

Simulated 100-ksec XIS Spectrum of YY Men

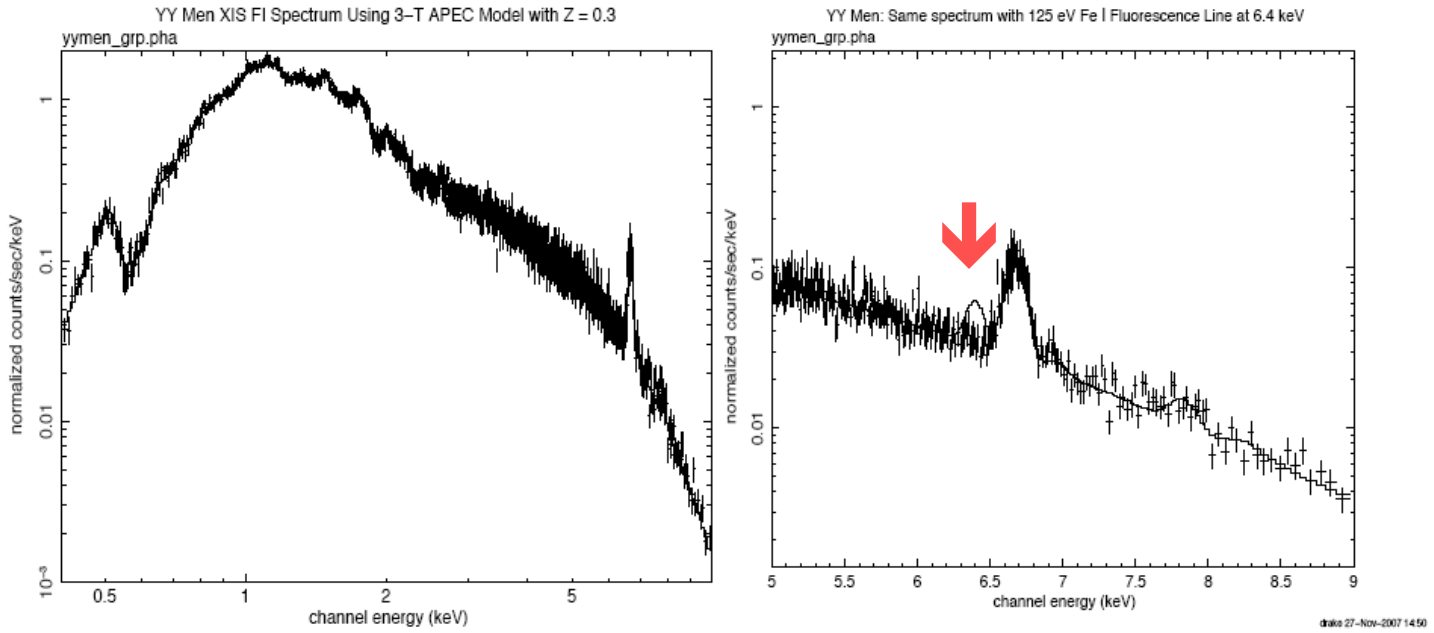


Figure 2: **(Left)** The predicted total 2-FI XIS spectrum of YY Men in 100 ksec. Both the simulated data and the model are based on a 3-component 0.3 solar abundance APEC model similar to that inferred from the Chandra spectrum by Audard et al. 2004. **(Right)** The simulated 2-FI 100-ksec XIS spectrum of YY Men in the Fe K region of the spectrum, using the same simulated data and model as in Fig 2, except that a 125 eV equivalent width 6.4 keV Fe fluorescence feature has been added to the model.