Coronal Activity in Non Solar-like Stars

PAOLA TESTA

larvard-Smithsonian Center for Astrophysic

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DECEMBER 5 2008 - EVERSHED MEETING, BANGALORE

Overview

General Issues:

- Solar-stellar connection (Jurgen Schmitt's talk)
- Exploring characteristic of dynamo in different regimes: dynamo activity in intermediate-mass stars in evolutionary phases when they have convective envelopes
- High spectral resolution X-ray observations: detailed plasma diagnostics

Chandra Observations of X-ray Active Intermediate-Mass Stars :

- post main sequence phase
- early pre-main sequence phase

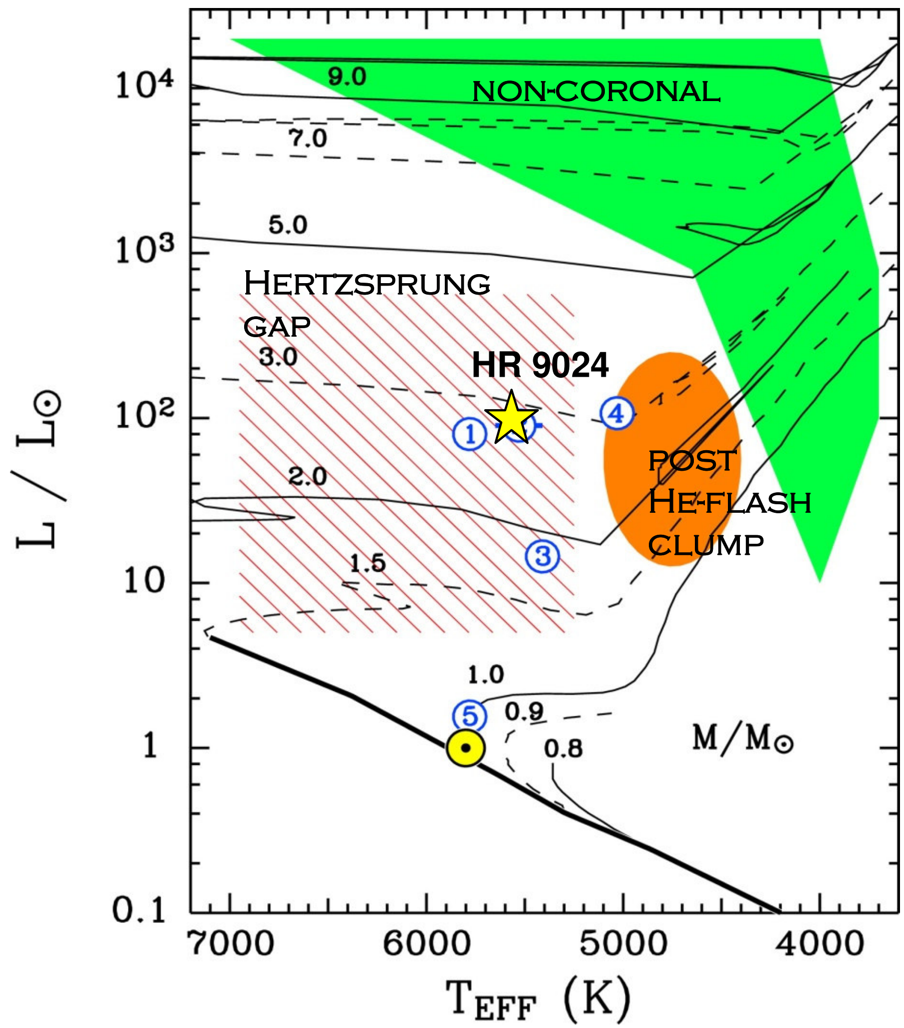
they present strong coronal activity:
what are the characteristics of spatial and thermal structuring, dynamic properties?

$\Rightarrow$ insights into characteristics of underlying magnetic dynamo

Coronal Activity in Intermediate-Mass Stars

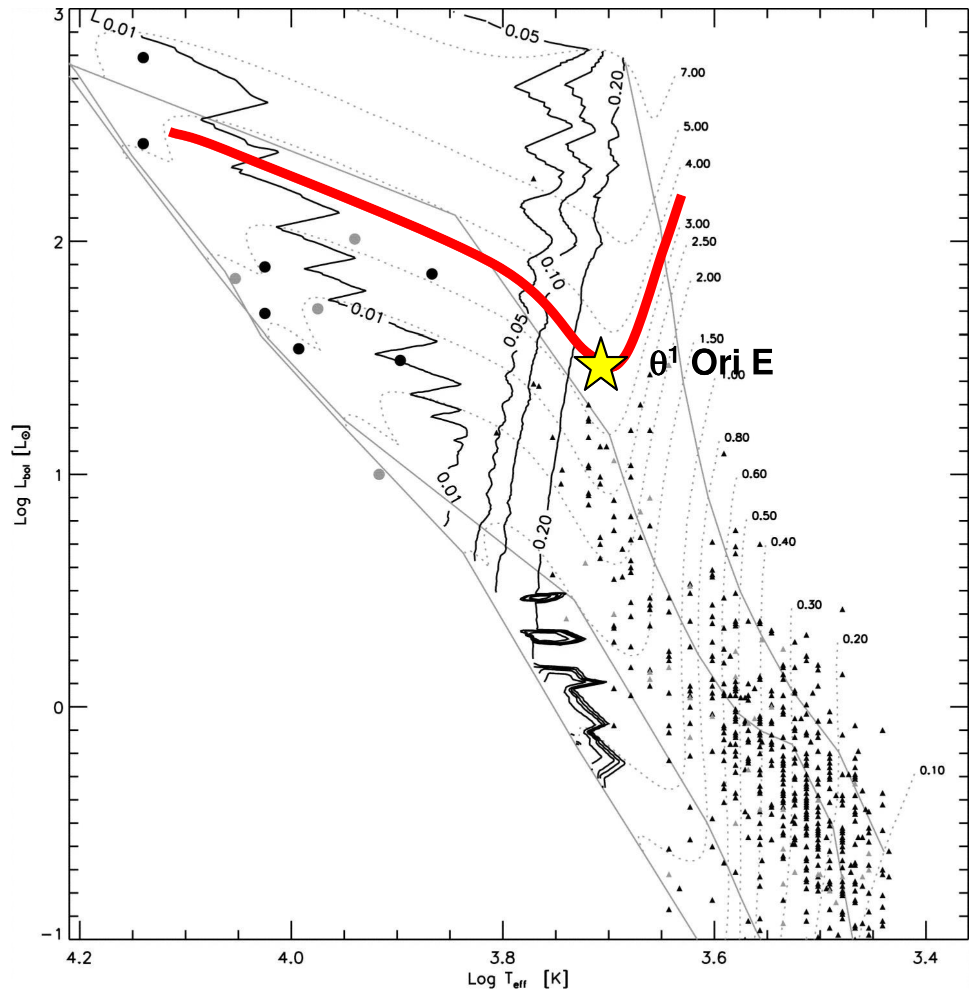
Post-Main Sequence Evolutionary Tracks

Ayres et al. (2007)



Pre-Main Sequence Evolutionary Tracks

Stelzer et al. (2005)



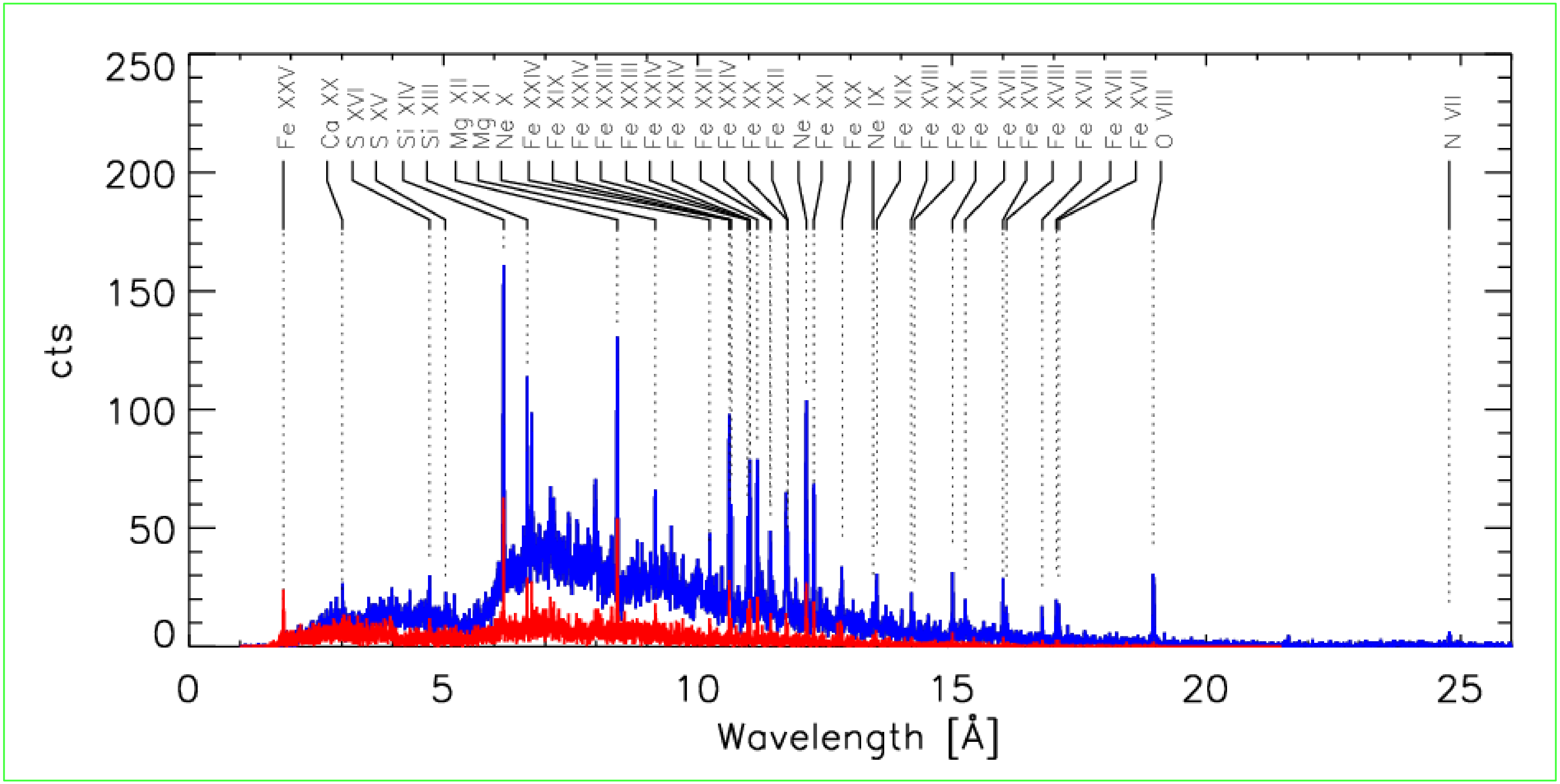
Coronal Activity in Intermediate-Mass Stars

X-ray emission of intermediate-mass stars outside of main sequence:

- evolved 2.9M⊙ giant HR 9024 (G1 III)
- pre-main sequence (<10^6 yr) binary system of 3.5M⊙ stars θ^1 Ori E (G5III)

Chandra High Energy Transmission Grating

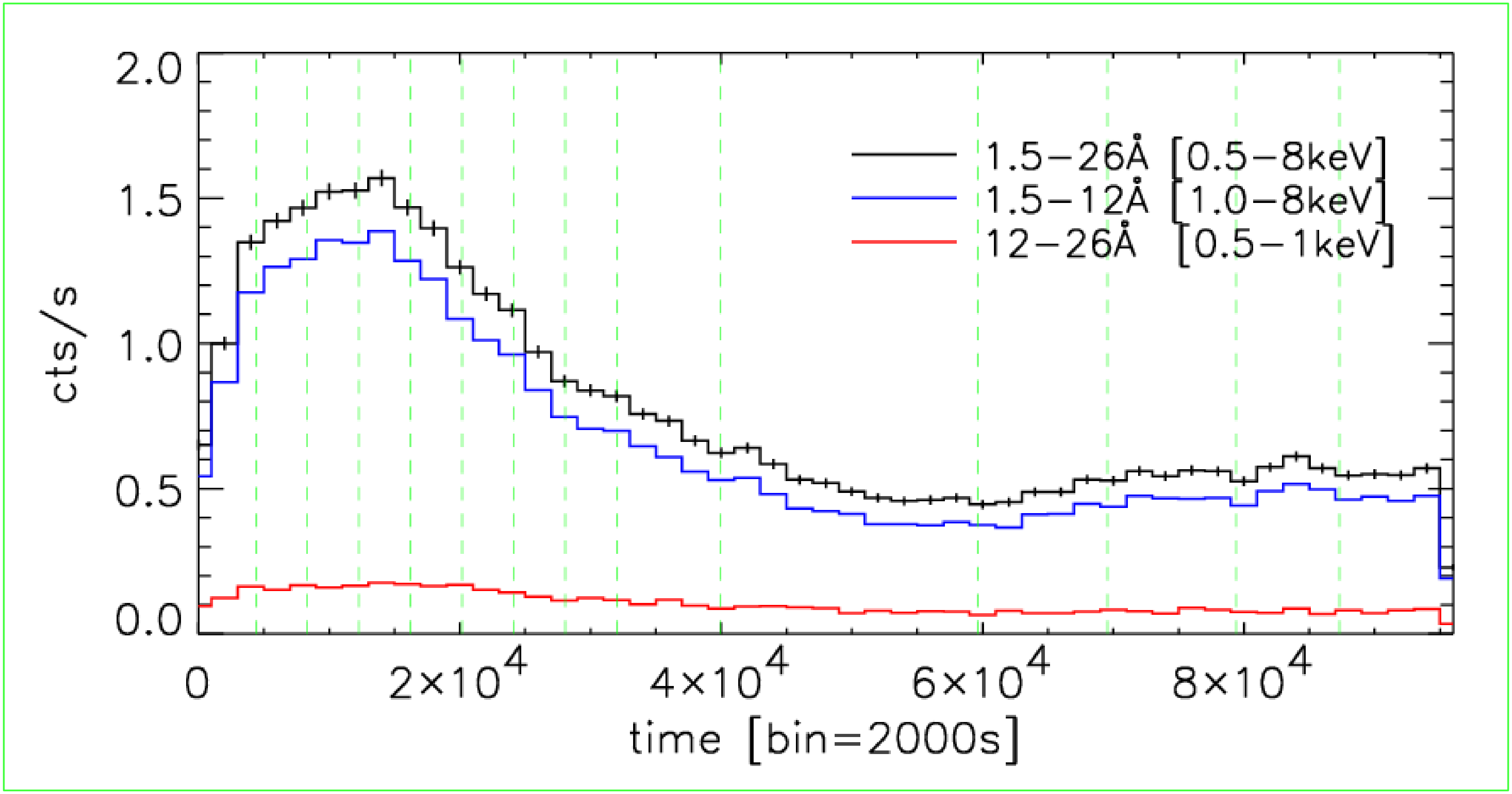
HR 9024: G1 giant, 3M⊙, 13R⊙, peak Lx~10^{32}ergs/s



MEG: 1.5-30Å, Δλ=0.02Å; HEG: 1.5-15Å, Δλ=0.01Å

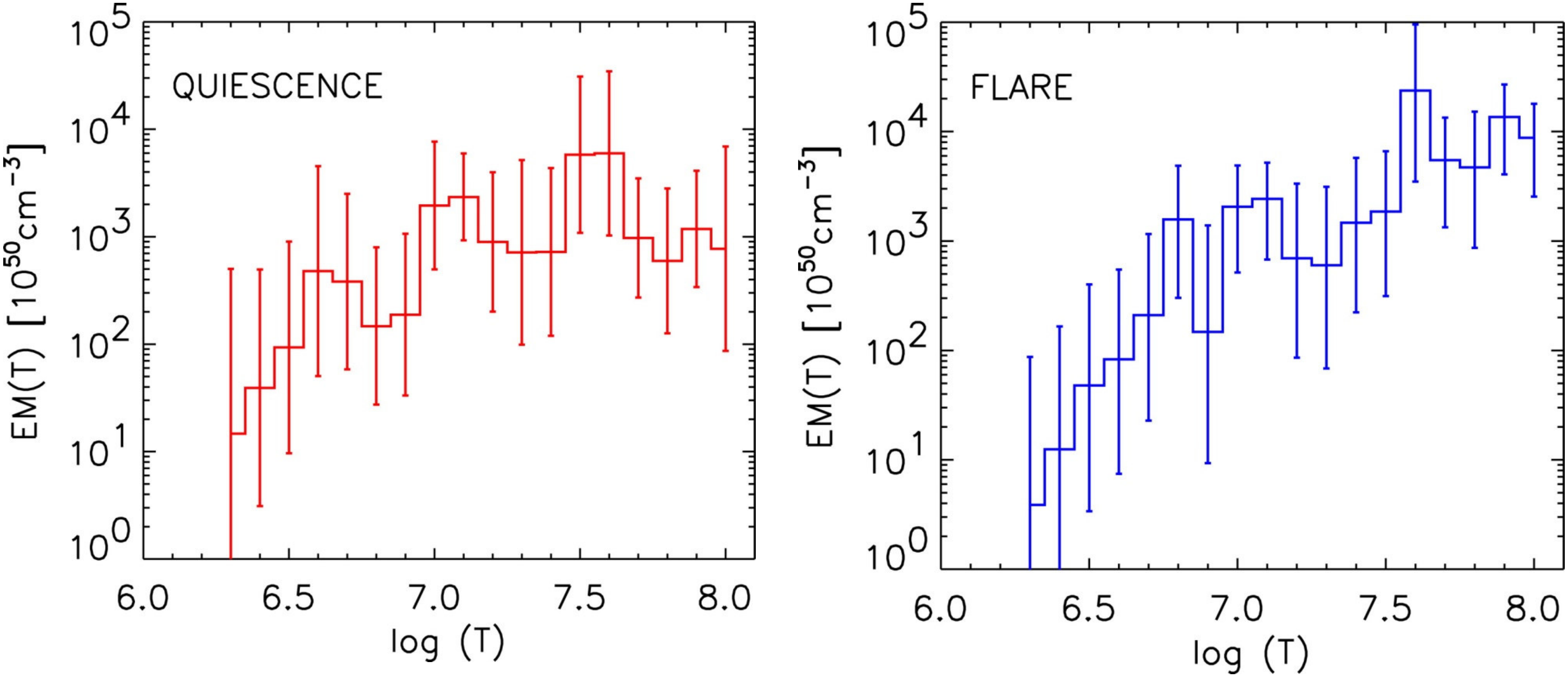
Lightcurve and Hardness Ratio

HR 9024: peak Lx~10^{32}ergs/s



Thermal Structuring

- very hot and high L_X corona



(Testa et al. 2007)

Thermal Structuring

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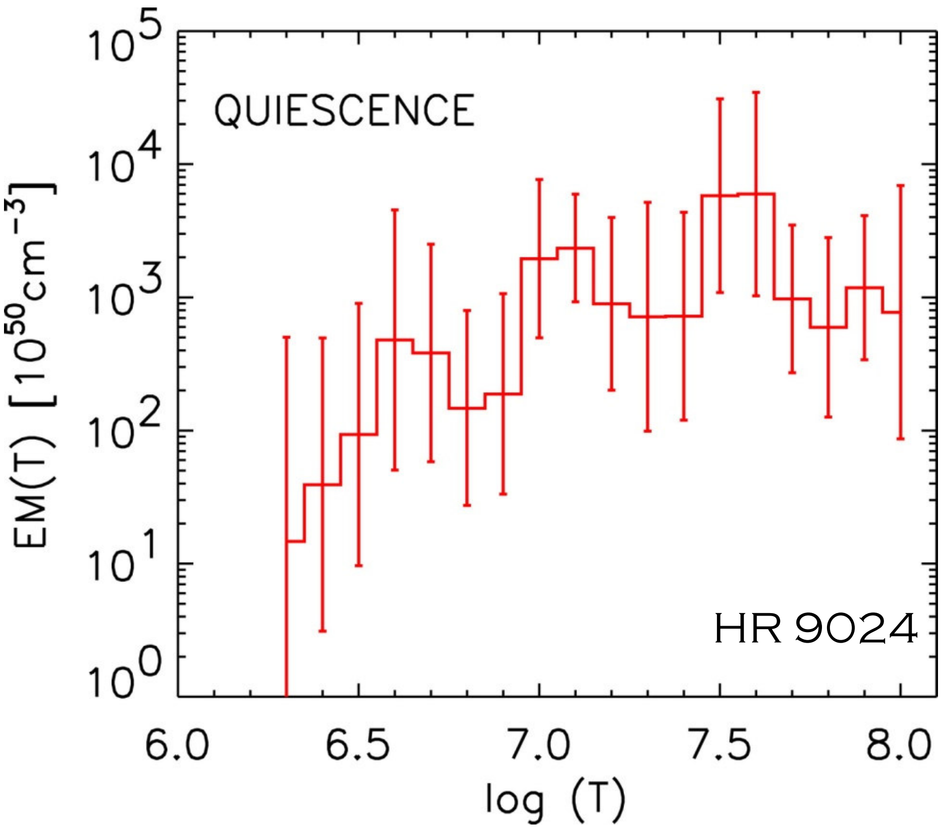
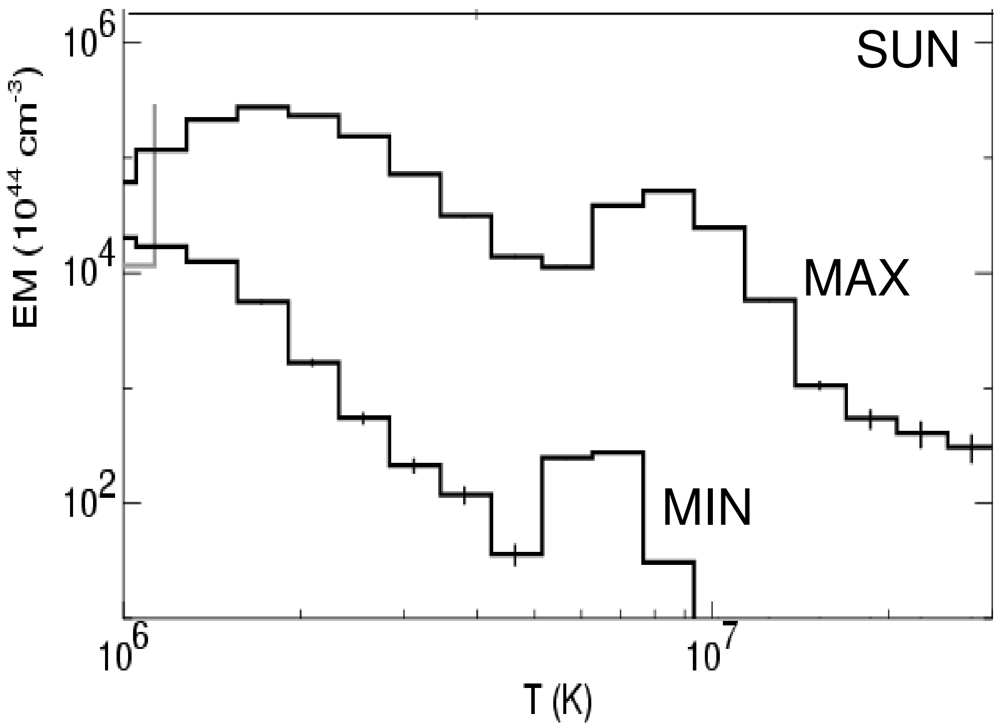


(Argiroffi et al. 2008)



Hydrodynamic Modeling of Flaring Plasma

1D loop hydrodynamic model

- solves time-dependent plasma equations with detailed energy balance (Peres et al. 1982; Betta et al. 1997), with a time-dependent heating defining the energy release that triggers the flare (see, e.g., Reale et al. 1997, 2004)
- constrained by light curve, evolution of temperature, and emission measure

⇒ provides information on geometry (loop length) and heating

Applied successfully to several solar (Peres et al. 1987; Betta et al. 2001), and stellar flares (e.g., Reale et al. 2004; Favata et al. 2005; Getman et al. 2008)

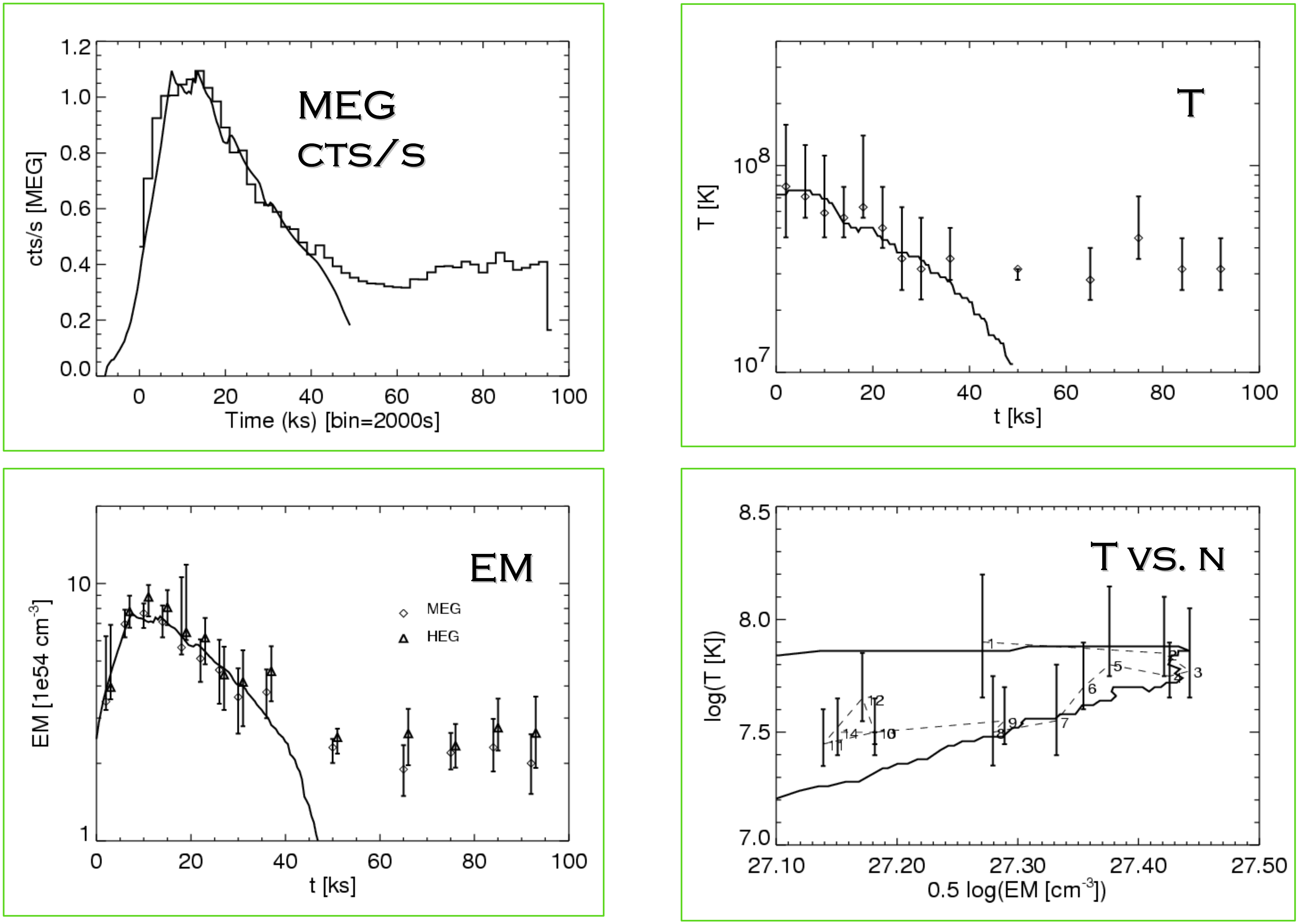
Hydrodynamic Modeling of Flaring Plasma

For the hydrodynamic modeling we use information mainly from the continuum that is strong, and it probes the hot flaring plasma

Loop Model:

1. start with an educated guess for the parameters
2. synthesize the HETG spectrum of the solution
3. repeat the analysis carried out on the observed spectrum and compare the same quantities
4. refine the model if needed

Hydrodynamic Modeling of Flaring Plasma



(Testa et al. 2007)

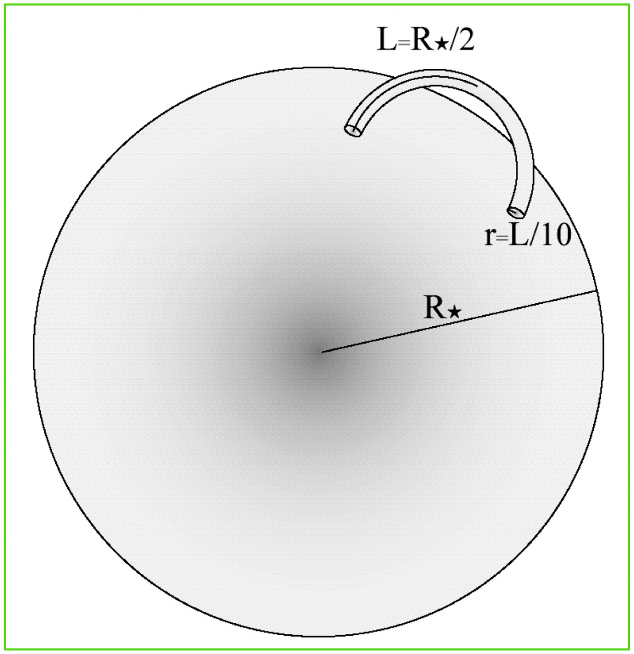
HYDRODYNAMIC MODELING OF FLARING PLASMA

MODEL PARAMETERS:

- loop semi-length $L = 5 \cdot 10^{11}$ cm~ R☞/2, as found for other active stellar coronae

- cross-section radius $r \sim 4.5 \cdot 10^{10}$ cm, i.e. aspect ratio r/L~0.1 as in typical solar loops

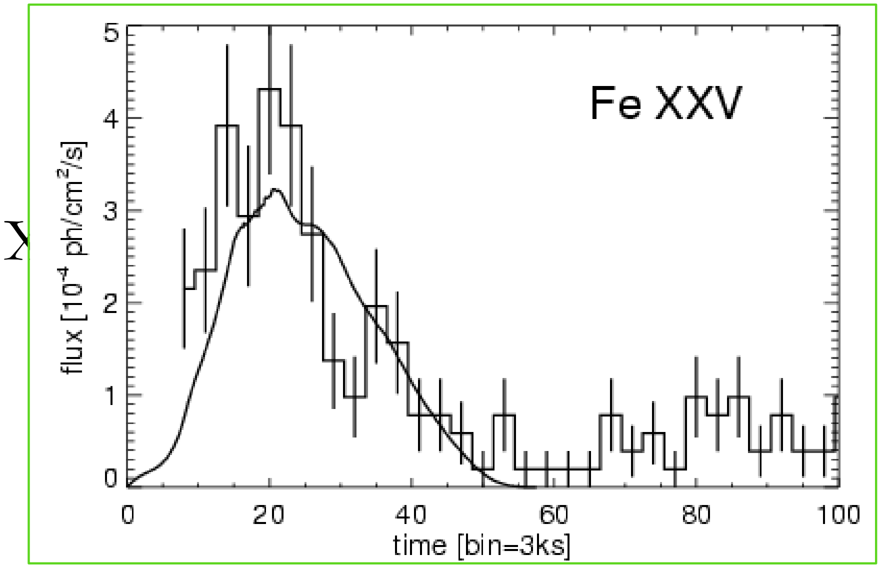
- impulsive heating (15 ks) at the footpoints; heating rate ~ 10^{33} erg/s



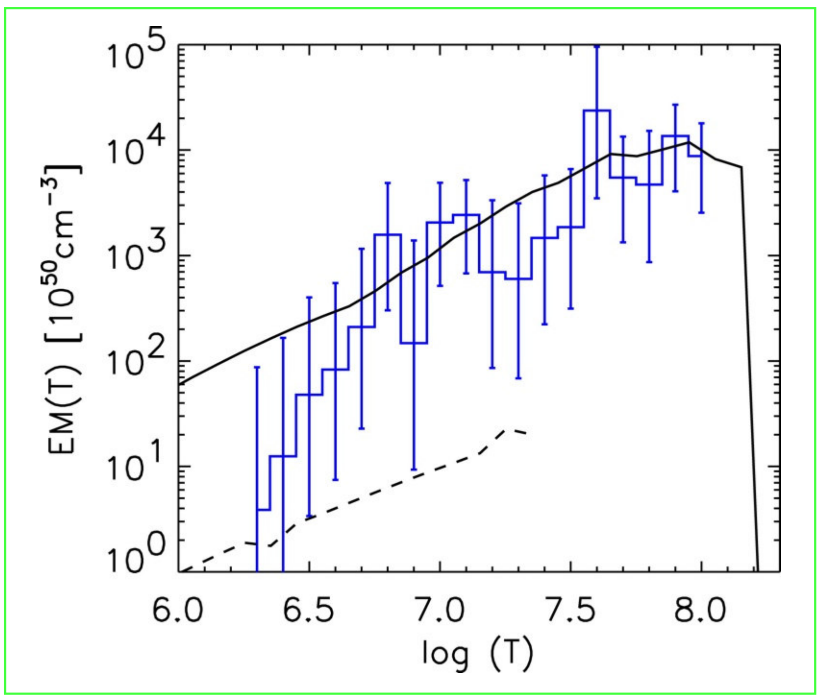
Hydrodynamic Modeling of Flaring Plasma

Cross-check of results:

- light curves in strong spectral features: **Fe XXV**, Si XIV, Mg X



- DEM



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Chandra Observations of ORION

Chandra Orion Ultradeep Project (COUP)

~13 days (~1Ms) almost continuous observation of the Orion star forming region

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

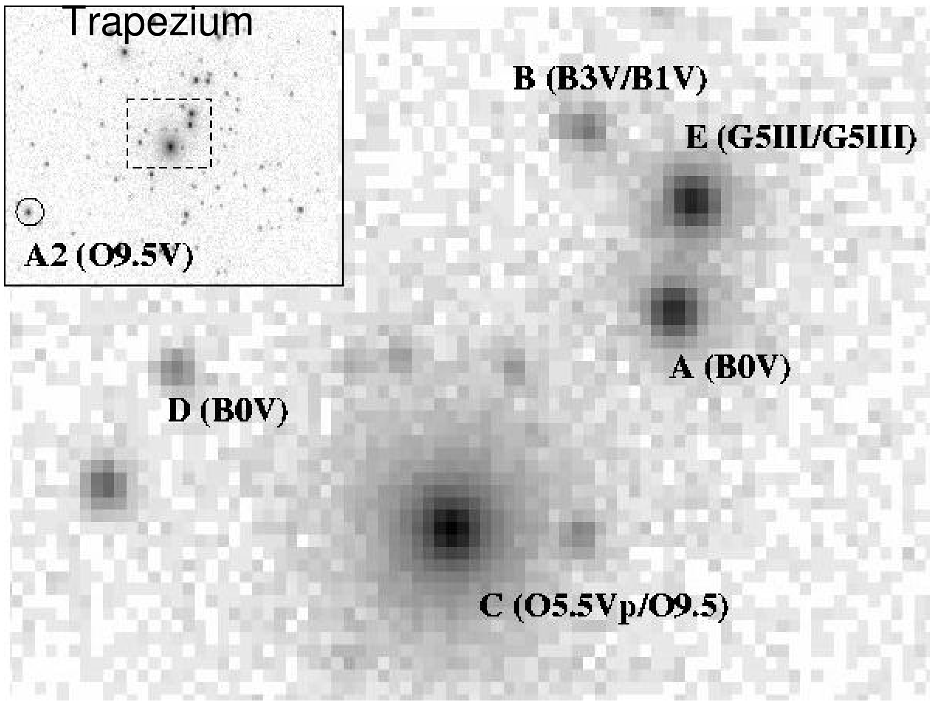
Colors indicate hardness of the X-ray source:

HARD
SOFT

(http://www.astro.psu.edu/coup/)

X-rays from Young I-M Stars: θ^1 Ori E

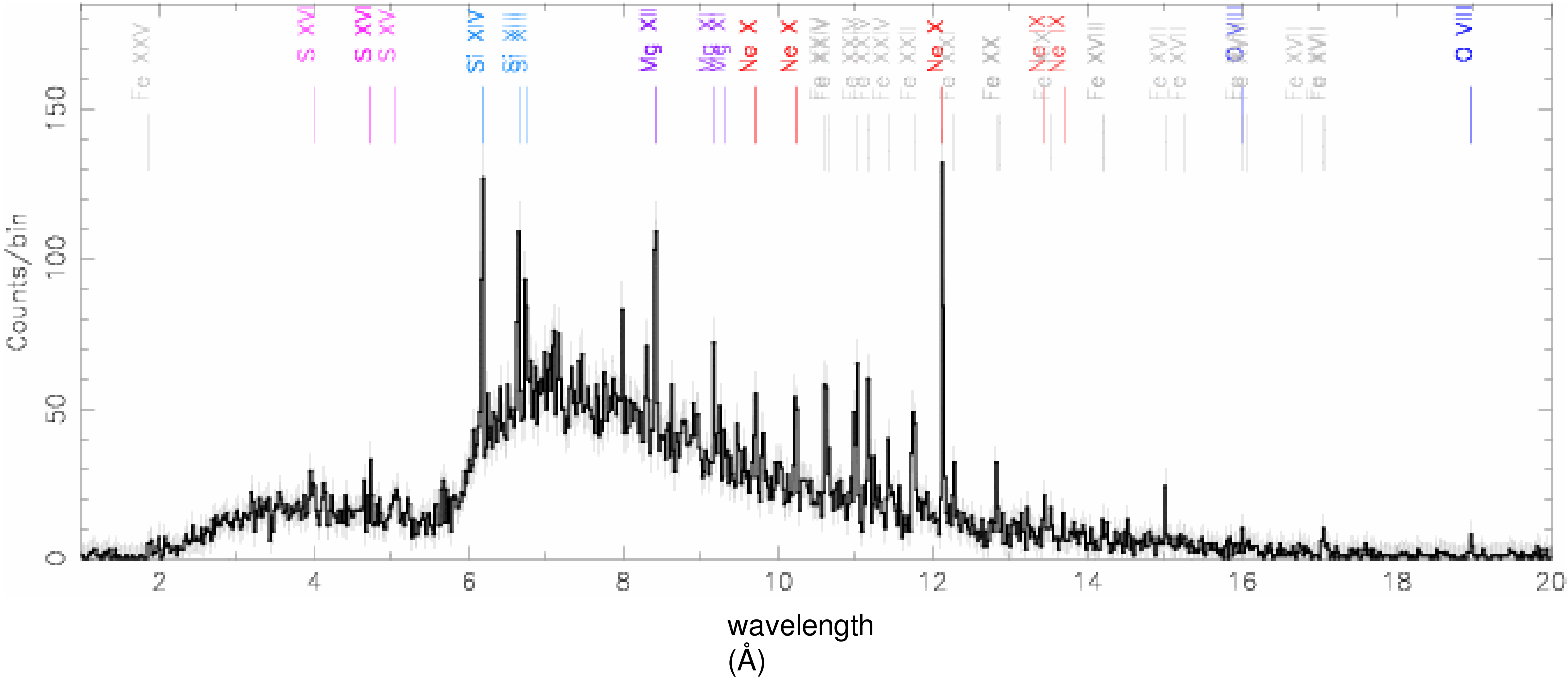
Chandra X-ray observations of Orion Trapezium



- G5III+G5III
- $M_{*} = 3.5M_{\odot}$
- $R_{*} = 7R_{\odot}$
- orbital radius ~2.5-3R_{*}
- P_{orb} = 9.89 days
- no signatures of powerful chromospheric and disk-accretion phenomena typical of young solar mass stars (T Tauri stars)

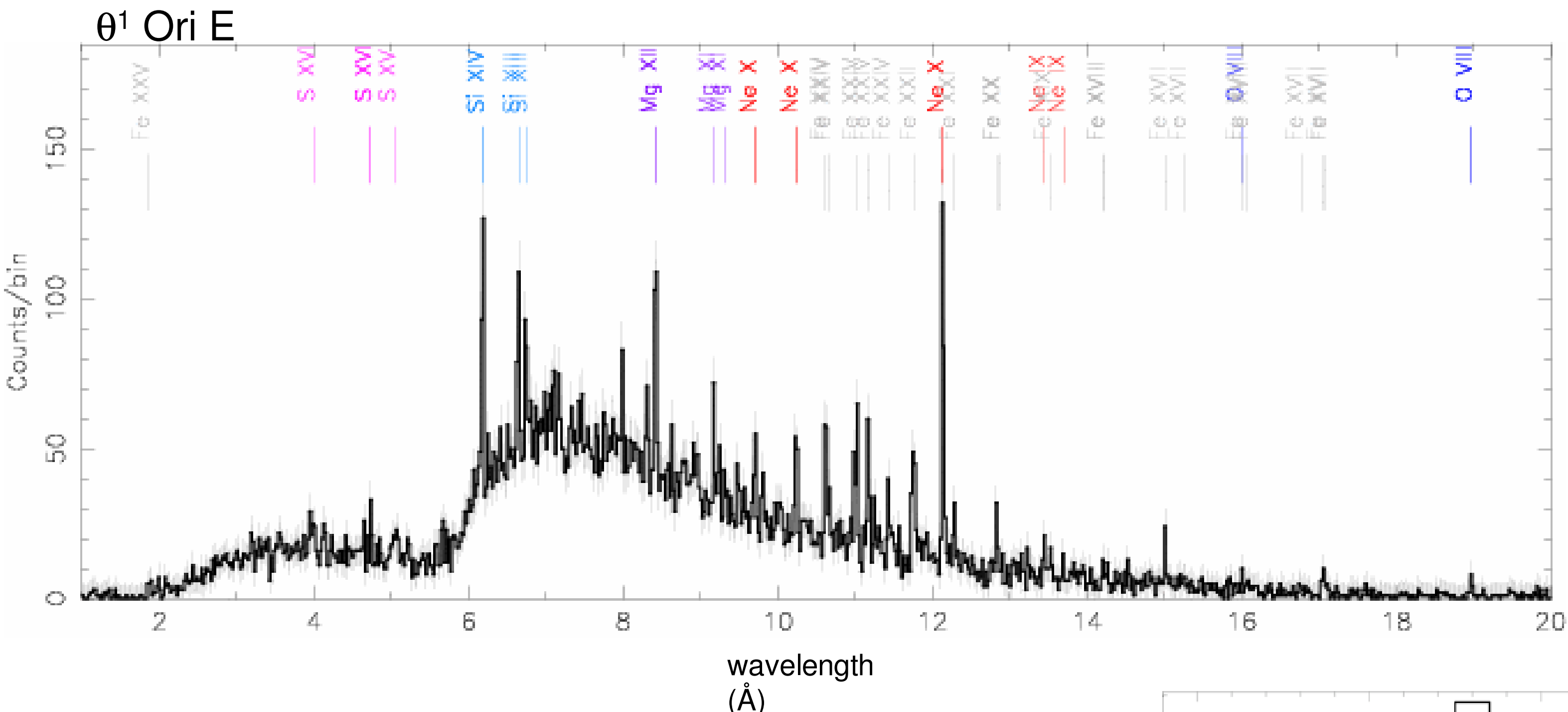
X-RAYS FROM YOUNG I-M STARS: θ^1 ORI E

θ^1 Ori E HETGS spectrum

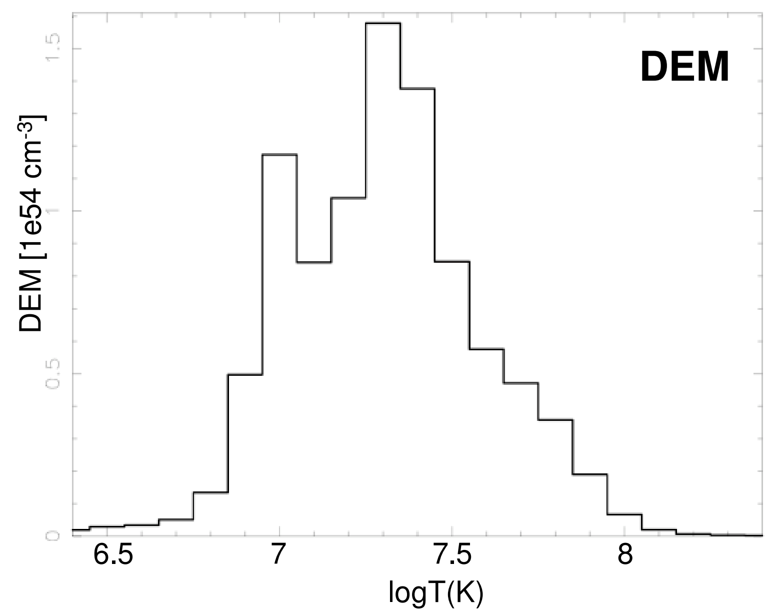


- ~3.5 days total integration time where spectrum is reliably free from contamination by other X-ray sources
- only moderate variability level
- coronal spectrum

X-rays from Young I-M Stars: θ^1 Ori E



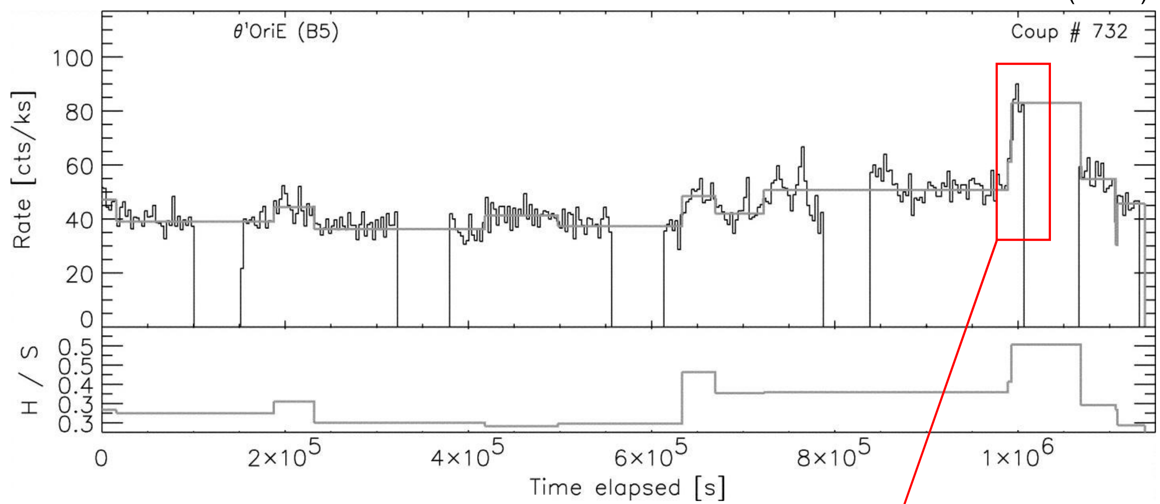
- ~3.5 days total integration time where spectrum is reliably free from contamination by other X-ray sources
- only moderate variability level
- coronal spectrum
- very hot spectrum
- activity indicator $\log(L_X/L_{bol}) \sim -3$, i.e. at highest observed levels for stellar coronae



X-rays from Young I-M Stars: θ^1 Ori E

Stelzer et al. (2006)

lightcurve for θ^1 Ori E from the *Chandra* Orion Ultradeep Project



- some flaring activity is observed
- geometry diagnostic from flare modeling is usually based on analysis of the **decay** phase, but Reale (2007) provides diagnostics based on the **rise** phase:

$$L_9 \sim 3\,(T_{0,7}/T_M)^2\ T_{0,7} \cdot \tau_{M,3} \sim 10\ \tau_{M,3}$$

applying it to the COUP θ^1 Ori E flare we estimate $\mathbf{L \sim 2 \cdot 10^{11} cm \sim R_{\odot}/2}$

Conclusions

- the X-ray characteristics of HR 9024 and θ^1 Ori E are typical of solar corona and active coronae but scaled up
    - coronal structures geometric properties (loop length ~ $R_{\odot}/2$, and aspect ratio ~ 0.1)
    - dynamic events: solar-like flares, that can be interpreted satisfactorily with 1D hydrodynamic loop models
- low level of variability for their activity level : active dwarfs at the highest activity range ($\log(L_X/L_{bol}) \sim -3$) flare all the time
- extreme conditions: **hot, high L_X coronae**
- dynamo processes seem to be at work in these intermediate mass stars in transitory phases of their evolution
- dynamo processes seem to operate close to or at the maximum observed efficiency