X-Ray Spectroscopy of Cool Stars: Present View and Future Expectations

Coronal Structure, Heating, Accretion, Outflows, Circumstellar Disks

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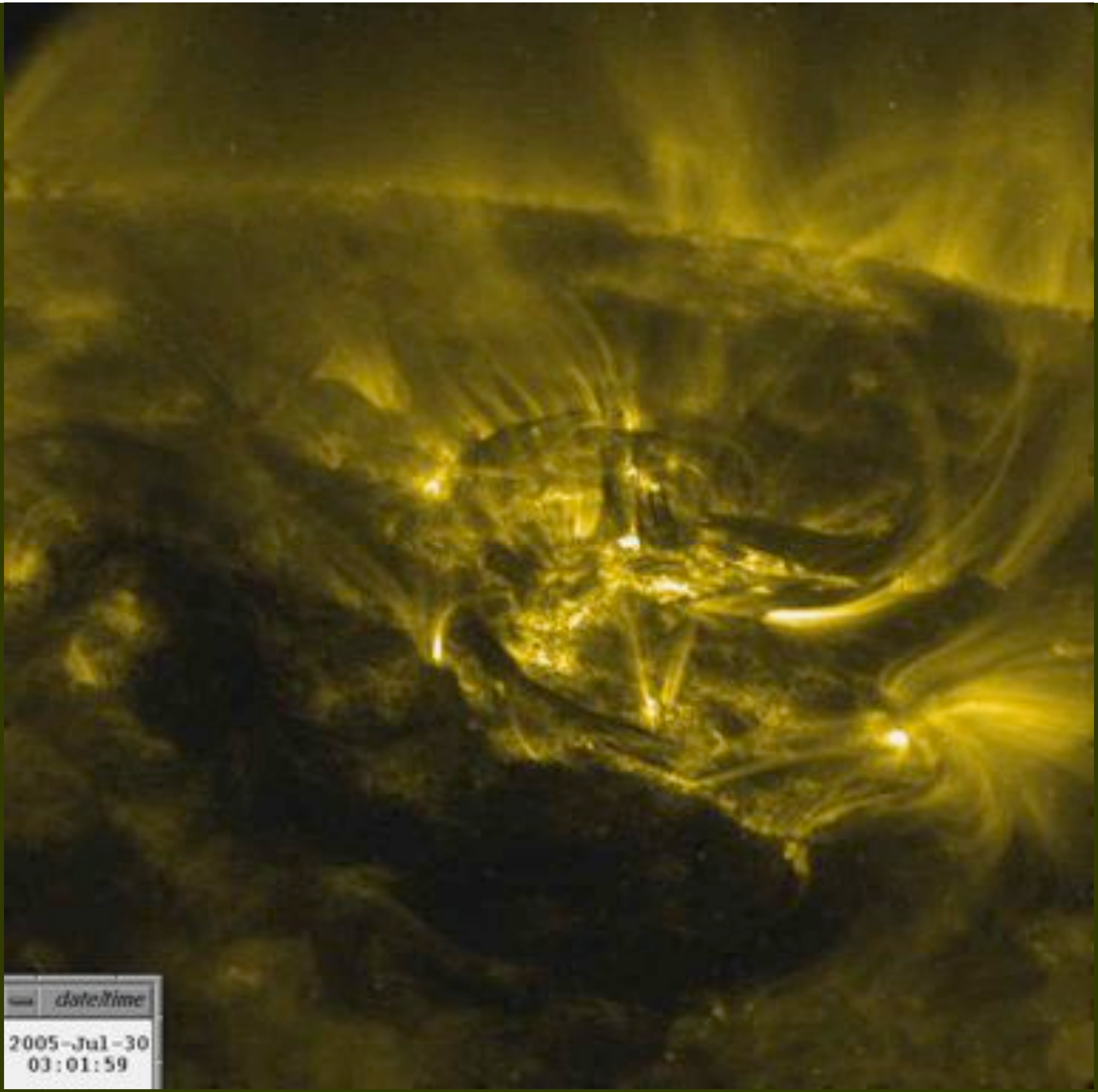
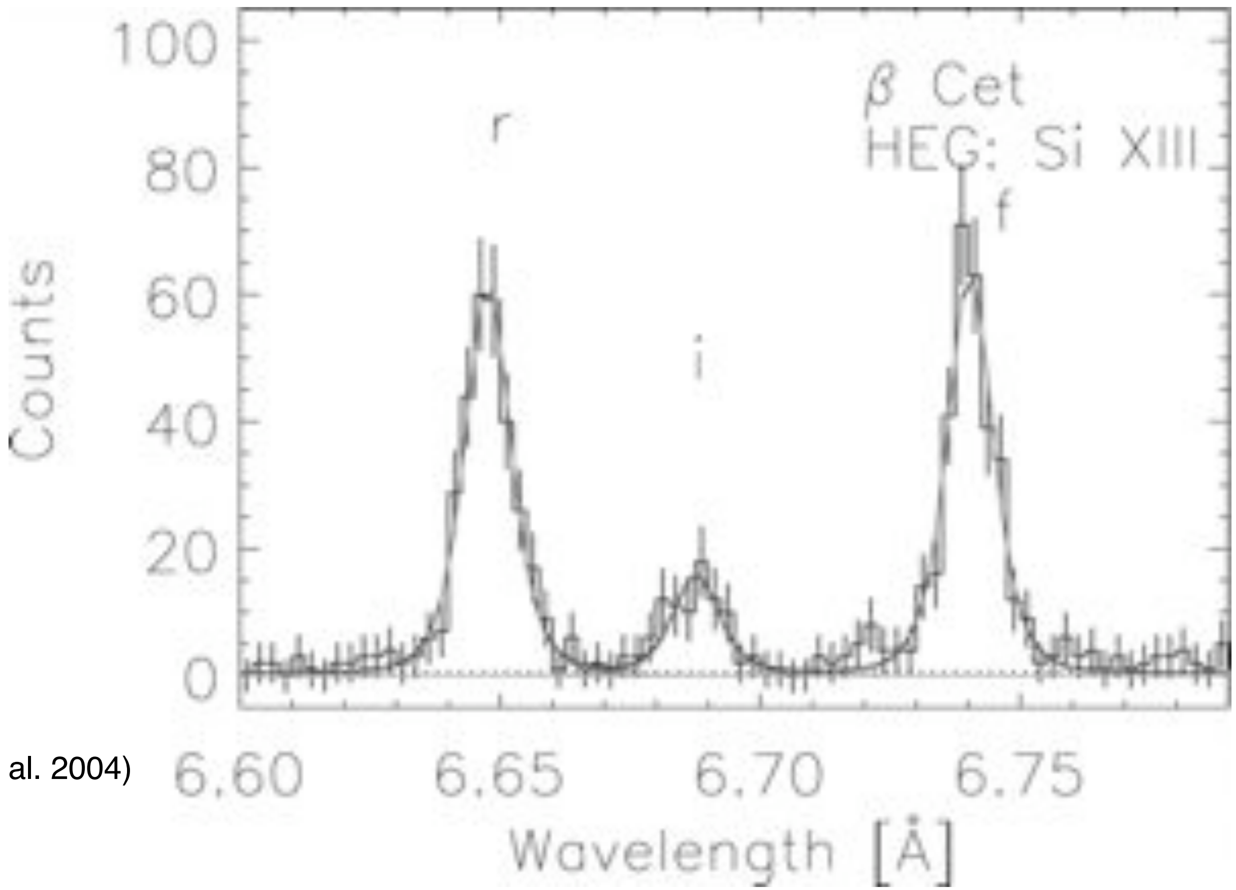


Coronal structure ↔ coronal heating and dynamics

First step toward coronal structure: densities and EM



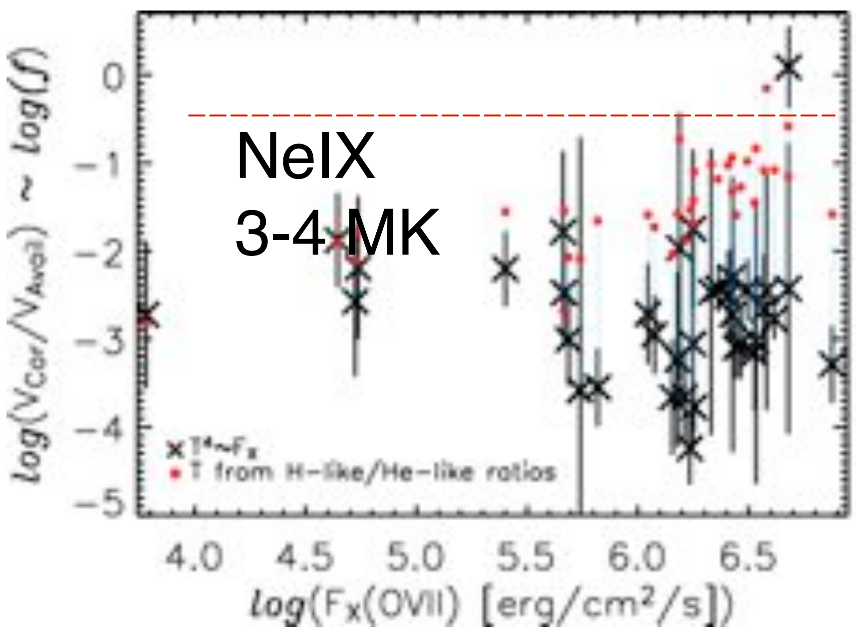
(Testa et al. 2004)

Typical for coronae: $n_e \approx \underbrace{10^9 \ - \ 10^{10}}_{\textit{inactive}} \underbrace{- \ 10^{11}}_{\textit{active}}$ cm^{-3} (for OVII)

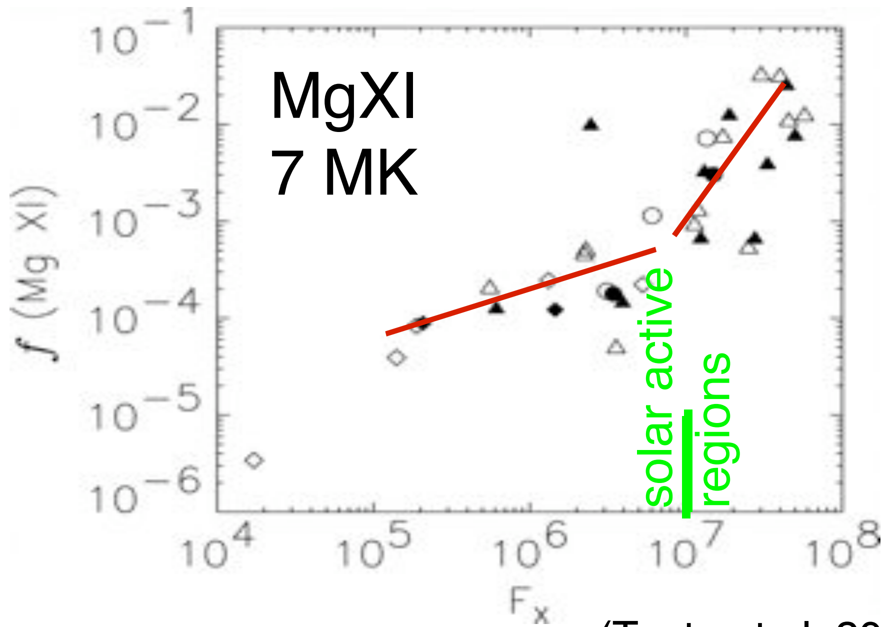
Combine

- density at T (homogenous assumption) & EM at T → V
- reasonable <u>scale height</u> at T (e.g., loop scaling laws)

→ *coronal filling factor for structures at T*



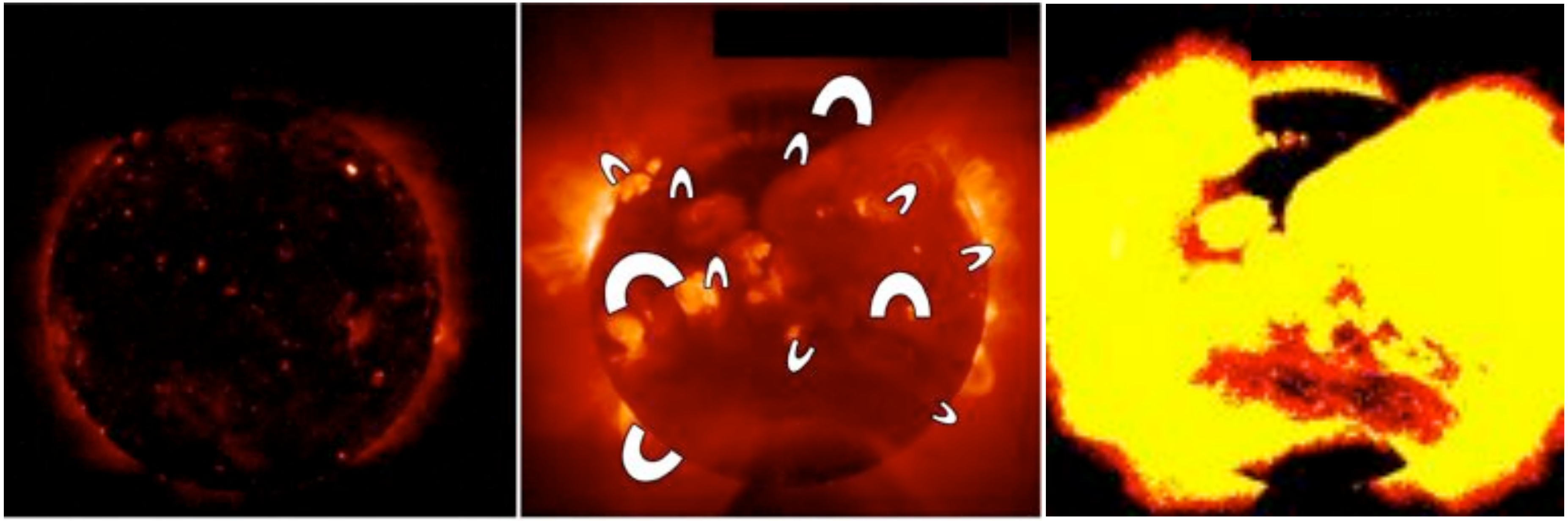
(Ness et al. 2004)



(Testa et al. 2004)

→ "activity" →

cool: fill up to 10% then: add hot plasma

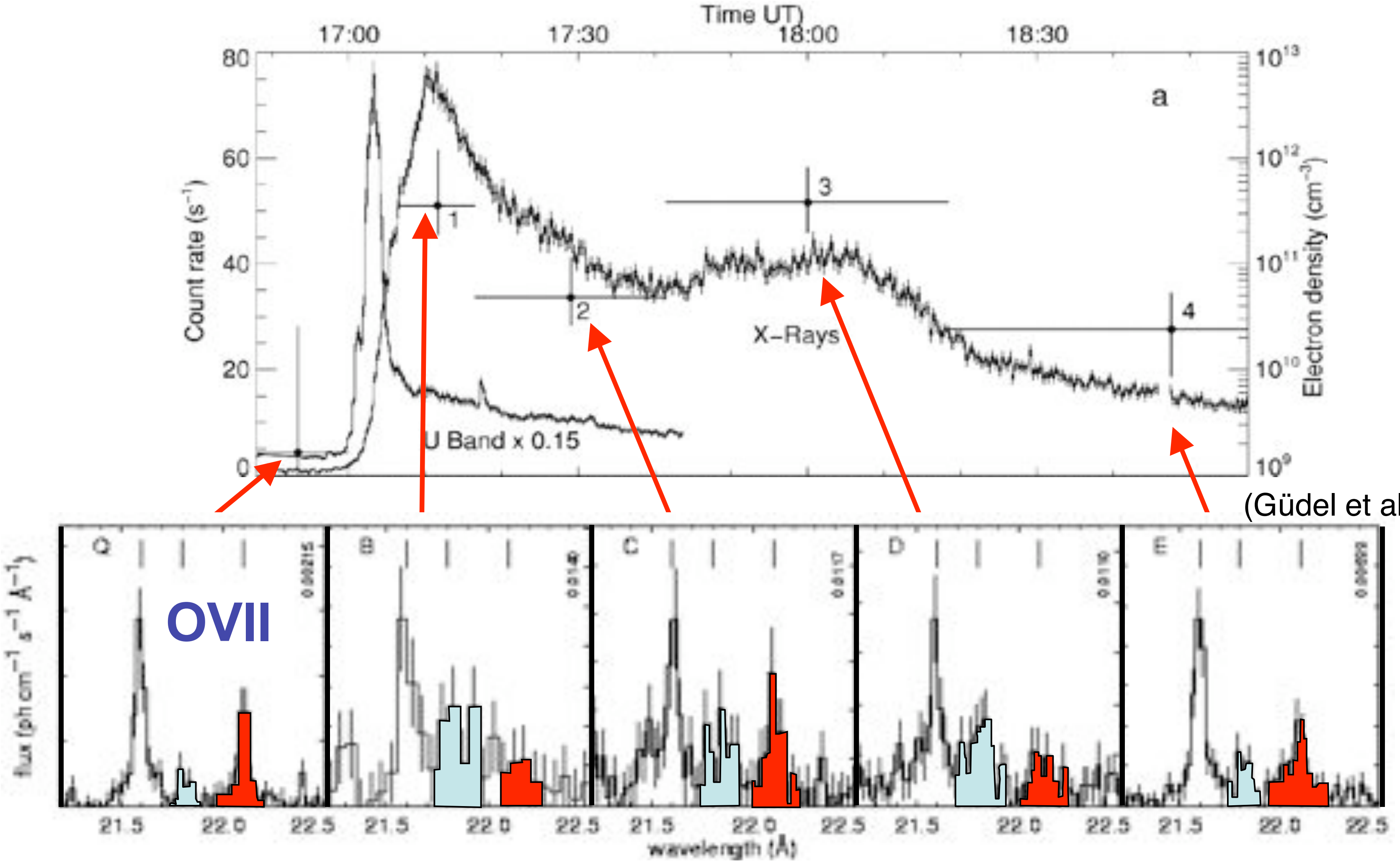


add cool plasma → interactions between active regions: flares → more heating, higher T, more plasma, higher n_e

Are <u>flares</u> heating active stellar coronae?

(e.g.,Güdel et al. 1997, Drake et al. 2000, Ness et al. 2004)

Density changes during a flare



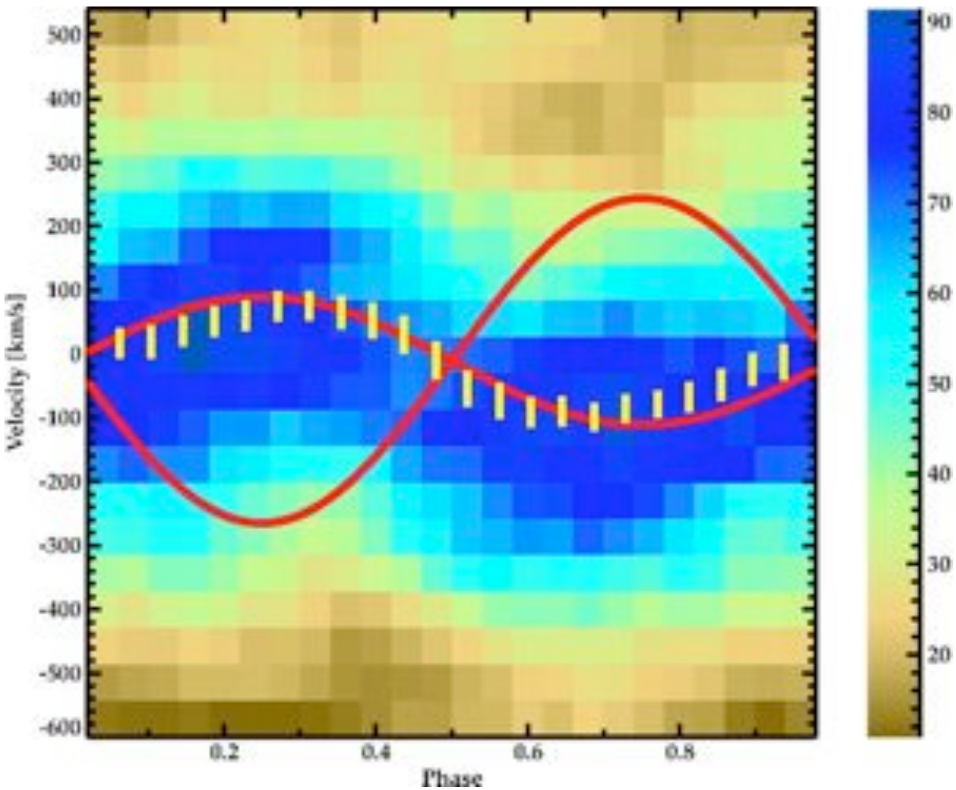
(Güdel et al. 2003)

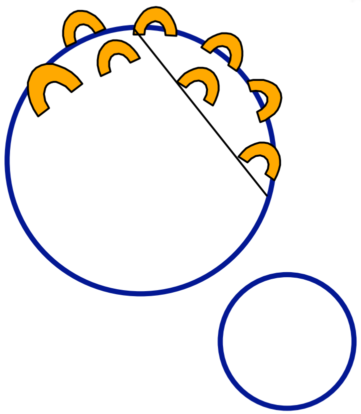
n_e 5×10^{9} 4×10^{11} 2×10^{10} 4×10^{11} 2×10^{10} cm^{-3}

average flare log n_e = 10.50 +/- 0.28
typical for active ("non-flaring") stars

Line-shift analysis: contact binary VV Cep

(composite, 15 lines in MEG)



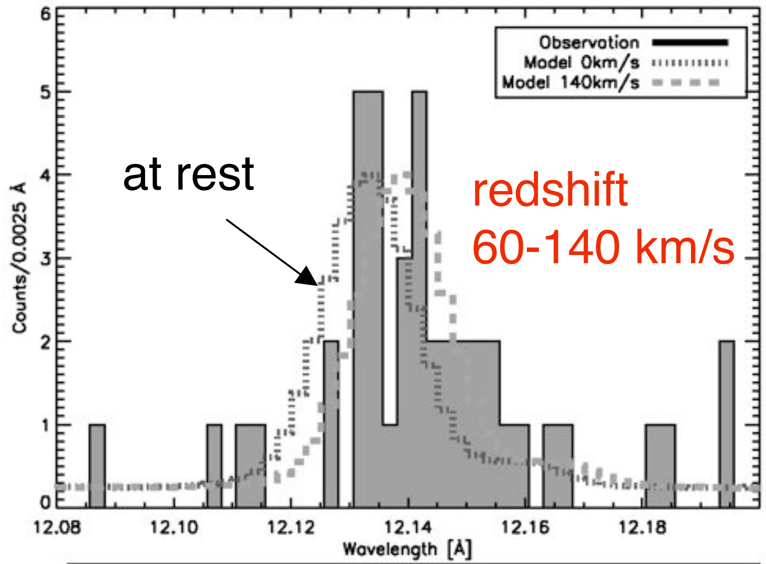


- no eclipse
- near-polar
- on primary
- height 0.06-0.2 R_*

(Huenemoerder et al 2006)

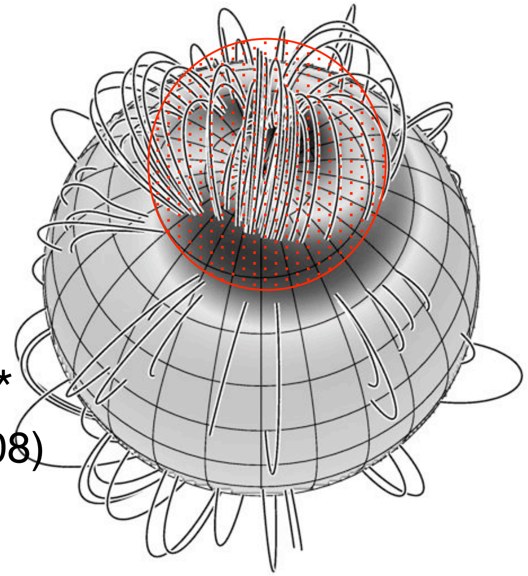
Rapidly rotating giant FK Com

(NeX 12..16A centroids, HEG)



(Drake et al 2008)

line shift,
broadening,
Doppler im.,
→near-polar
region, ≤ 1R*
(Drake et al 2008)

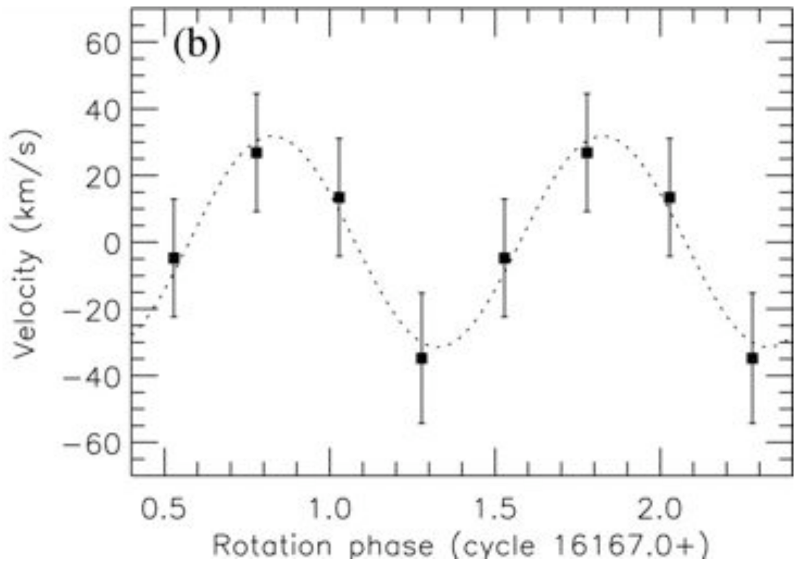


Requirements for spectral resolution

Centroiding at 10-30 km/s level possible for bright sources (Hussain et al. 2005)

Typical rotation speeds for active stars: few 10s km/s

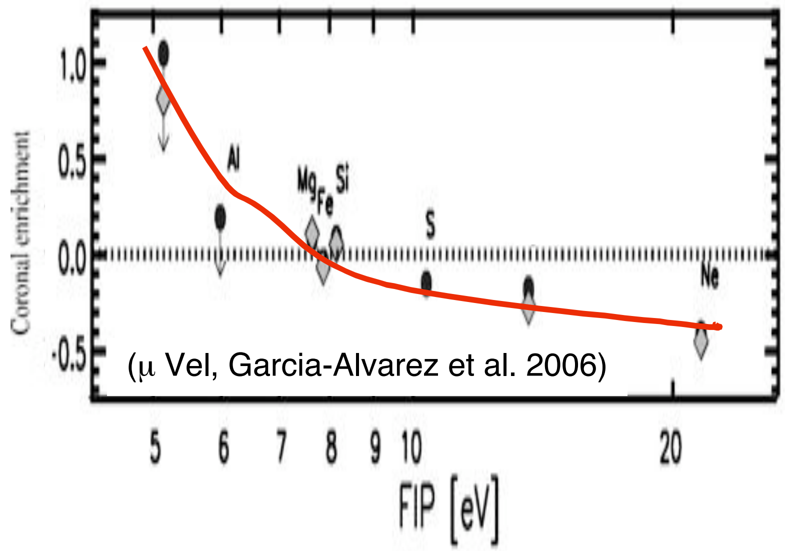
Separating two line systems important for *Doppler mapping*



(Hussain et al 2005)

Good to have: $\lambda/\Delta\lambda$ = 2000-5000

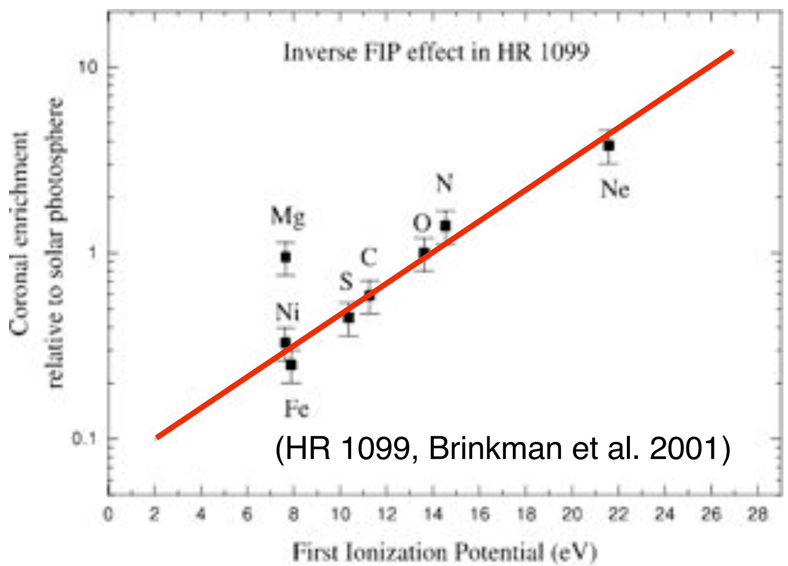
Composition of stellar coronae: Indicator of mass transport?



(μ Vel, Garcia-Alvarez et al. 2006)

Sun and inactive stars (+Sun) enhanced low-FIP:

FIP effect

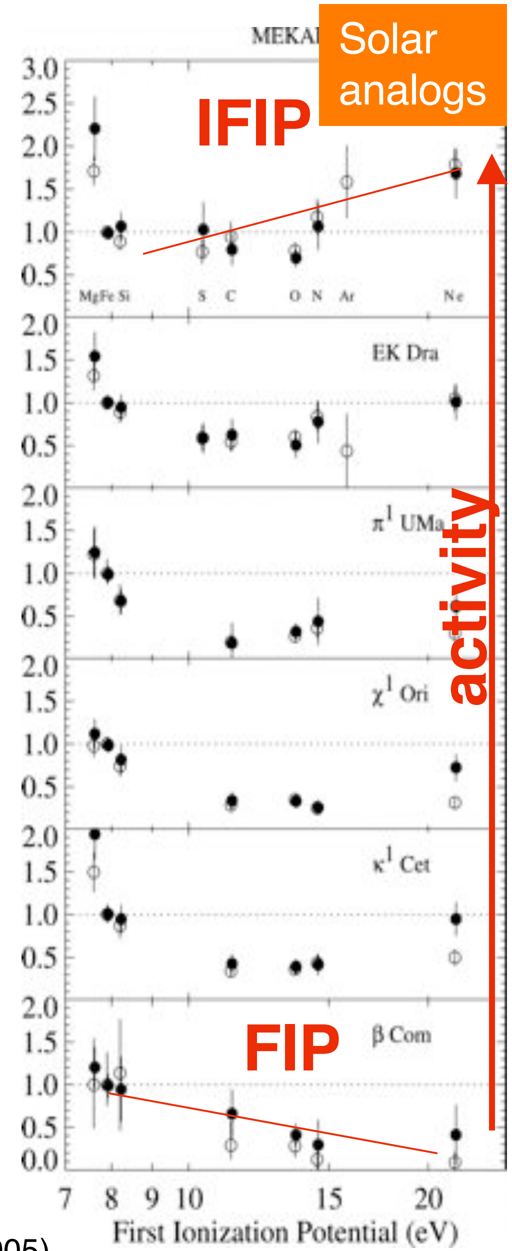


(HR 1099, Brinkman et al. 2001)

active stars enhanced high-FIP :

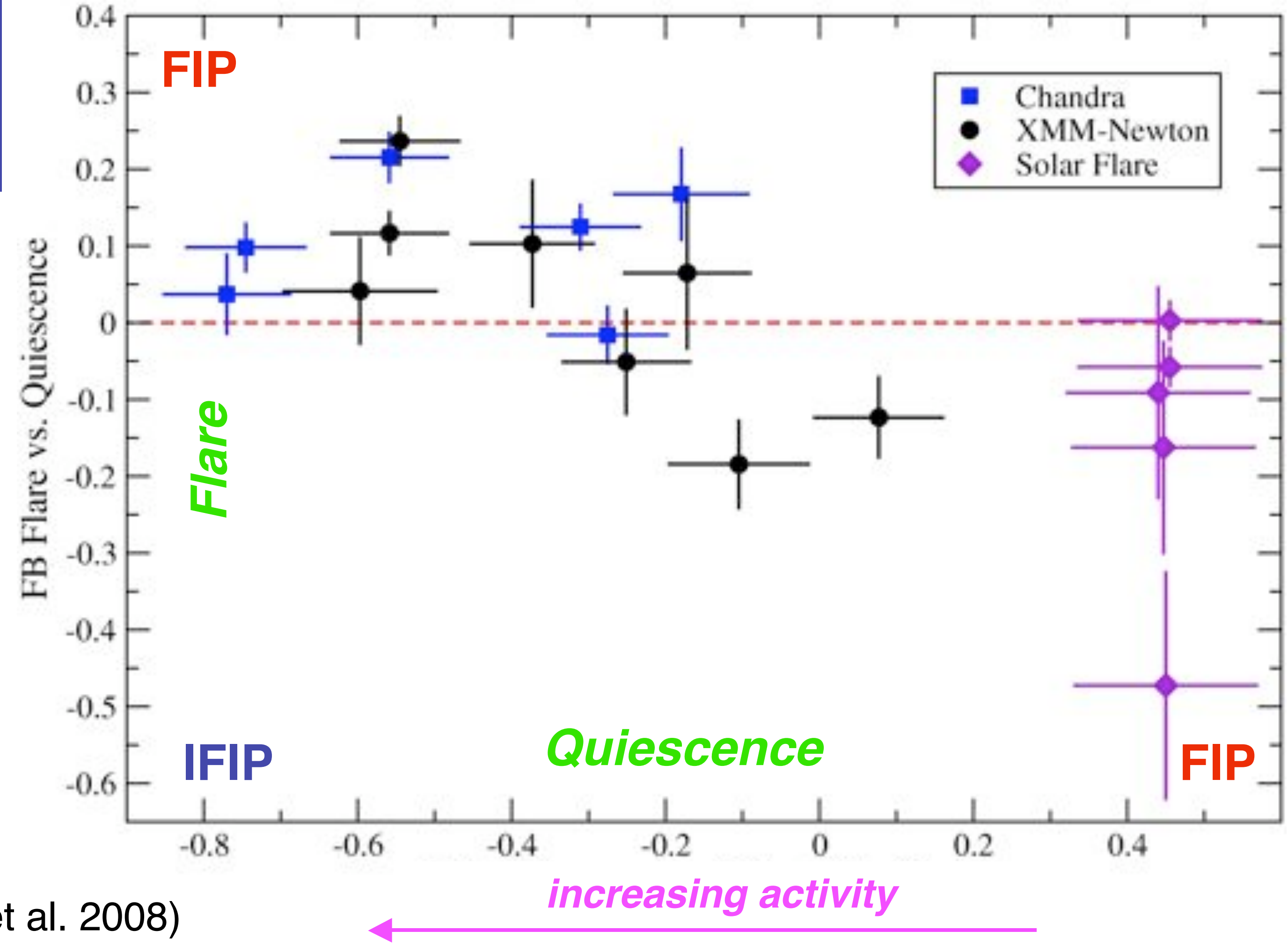
inverse FIP effect

Brinkman et al. 2001, Güdel et al. 2001)



(Telleschi et al. 2005)

FIP/IFIP and activity



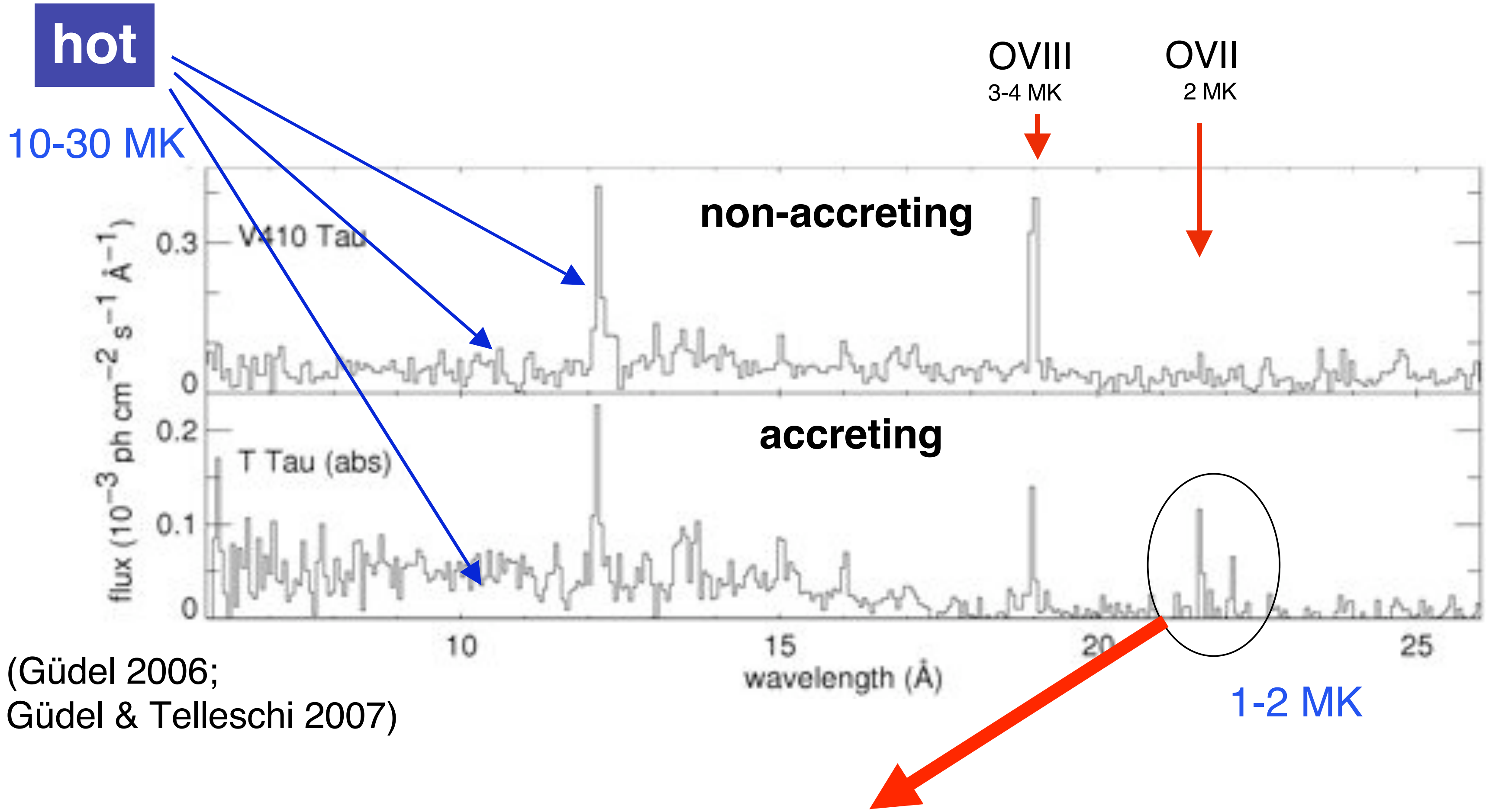
(Nordon et al. 2008)

Flare evaporation drives composition back toward photospheric mix

→Coronal FIP or IFIP is genuine, not reflecting photospheric composition

For further issues on coronal abundances, see presentation by J. Schmitt

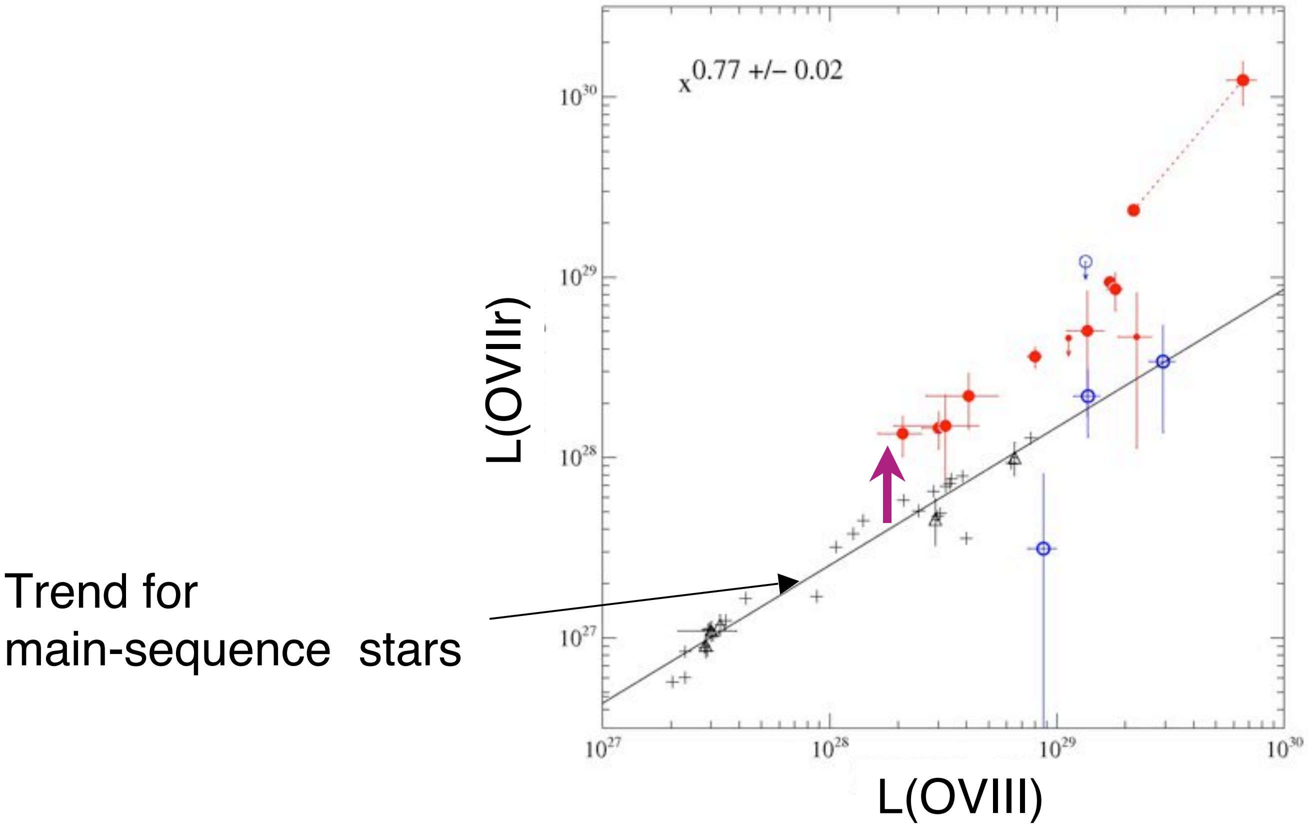
T Tauri stars: Accretion signatures?



(Güdel 2006;
Güdel & Telleschi 2007)

"SOFT EXCESS" *(Güdel 2006; Telleschi et al. 2007, G&T '07)*

The X-ray Soft Excess: Dependencies



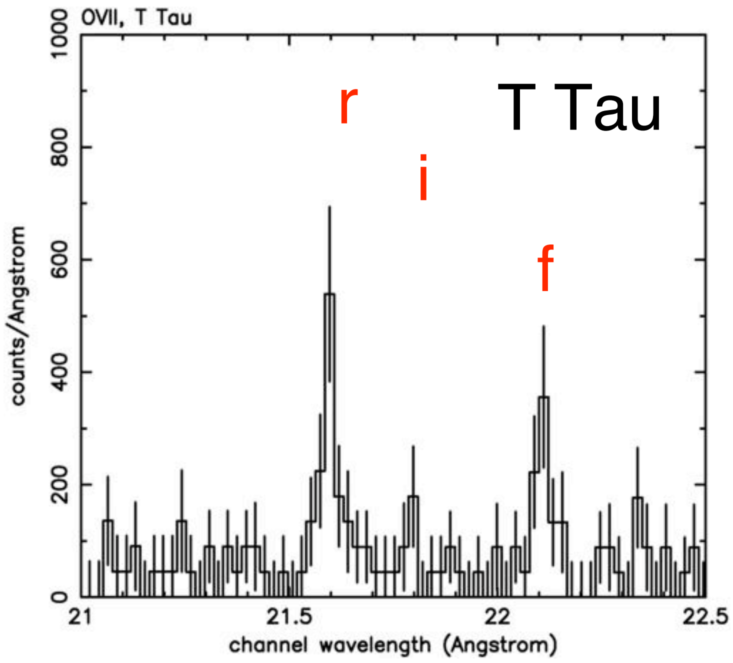
constant excess factors

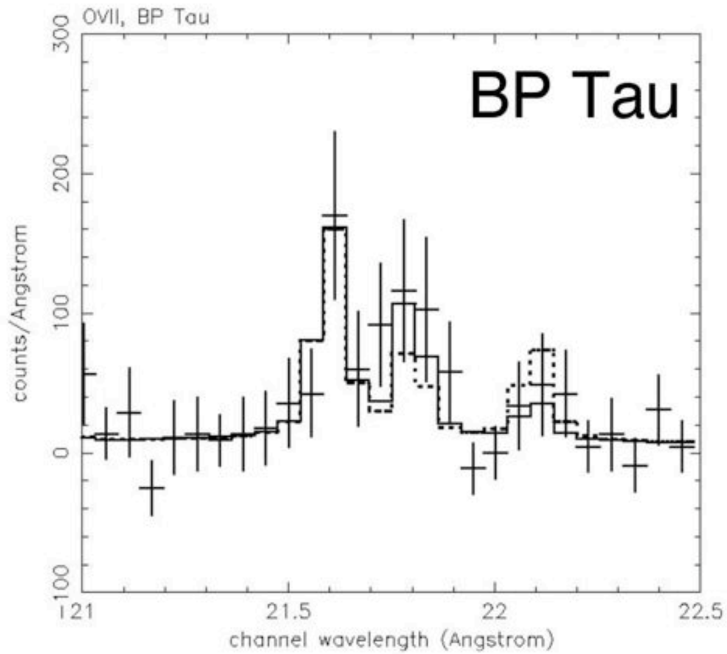
(Güdel & Telleschi 2007)

- *accretion required*
- *coronal activity matters as well*

Interaction between accretion flows and coronal magnetic field?

T Tauri stars: Electron densities





Exception (1): low-density

Norm (7): high density (≥ 10^{11} cm^{-3})

Dense, cool plasma in accretion shocks?

(Kastner et al. 2002, Stelzer & Schmitt 2004, Schmitt et al. 2005, Günther et al. 2006, Argiroffi et al. 2007, Robrade & Schmitt 2006/07, Günther et al. 2006, Huenemoerder et al. 2007)

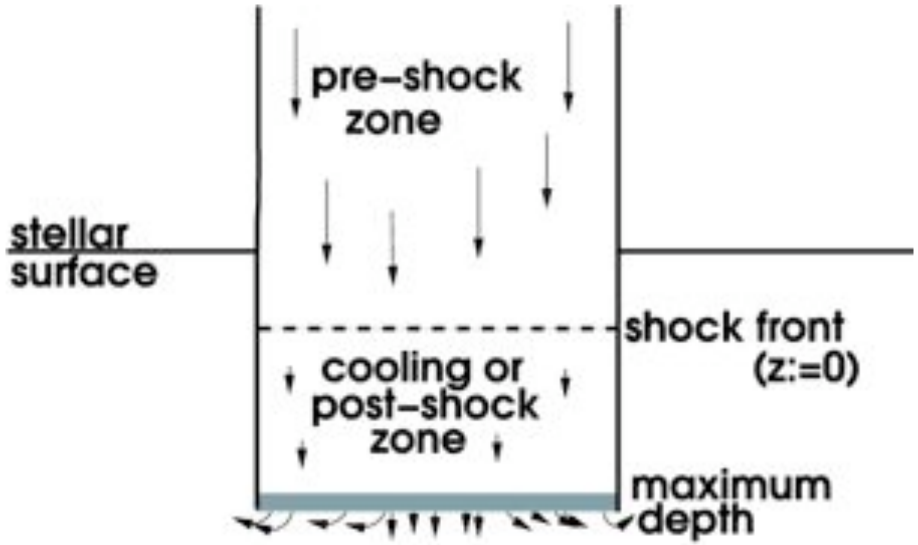
High densities in “cool” accretion shocks of CTTS

Shocks in accretion streams:

$T = 3\mu m_H v^2 / 16k$

$v \approx v_{ff} = (2GM/R)^{1/2}$

$\rightarrow T =$ a few MK   ($\ll 10$ MK)

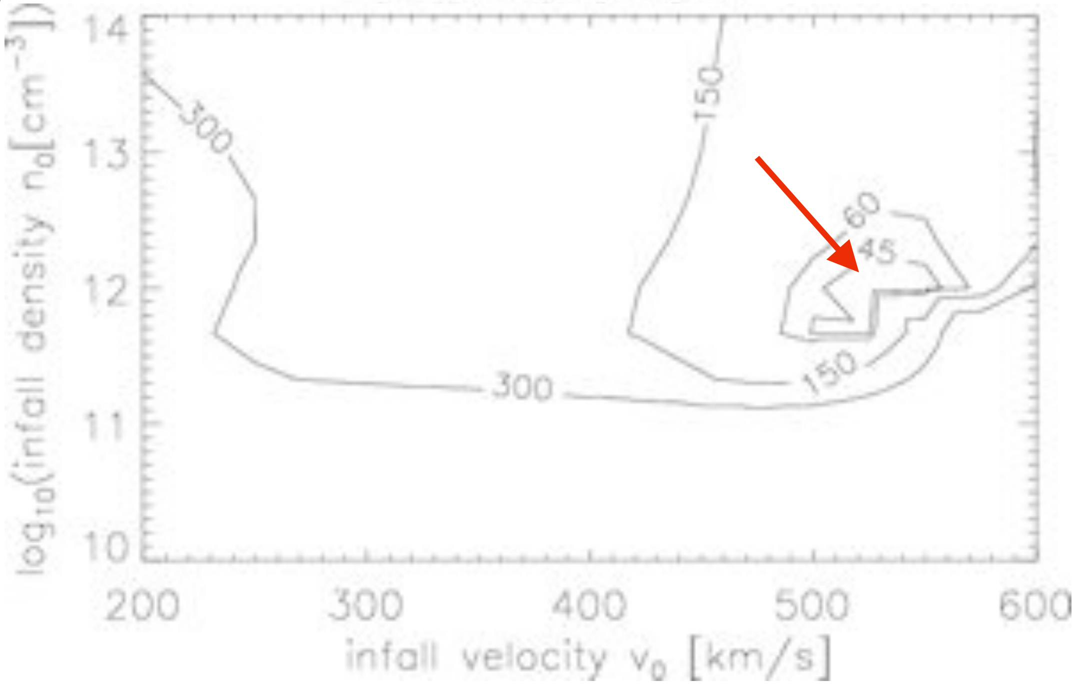


<u>Shock models for TW Hya:</u>

infall $n_e \approx 10^{12}$ cm^{-3}

$v = 530$ km s^{-1}

(Günther et al. 2007)



Requirements for sensitivity

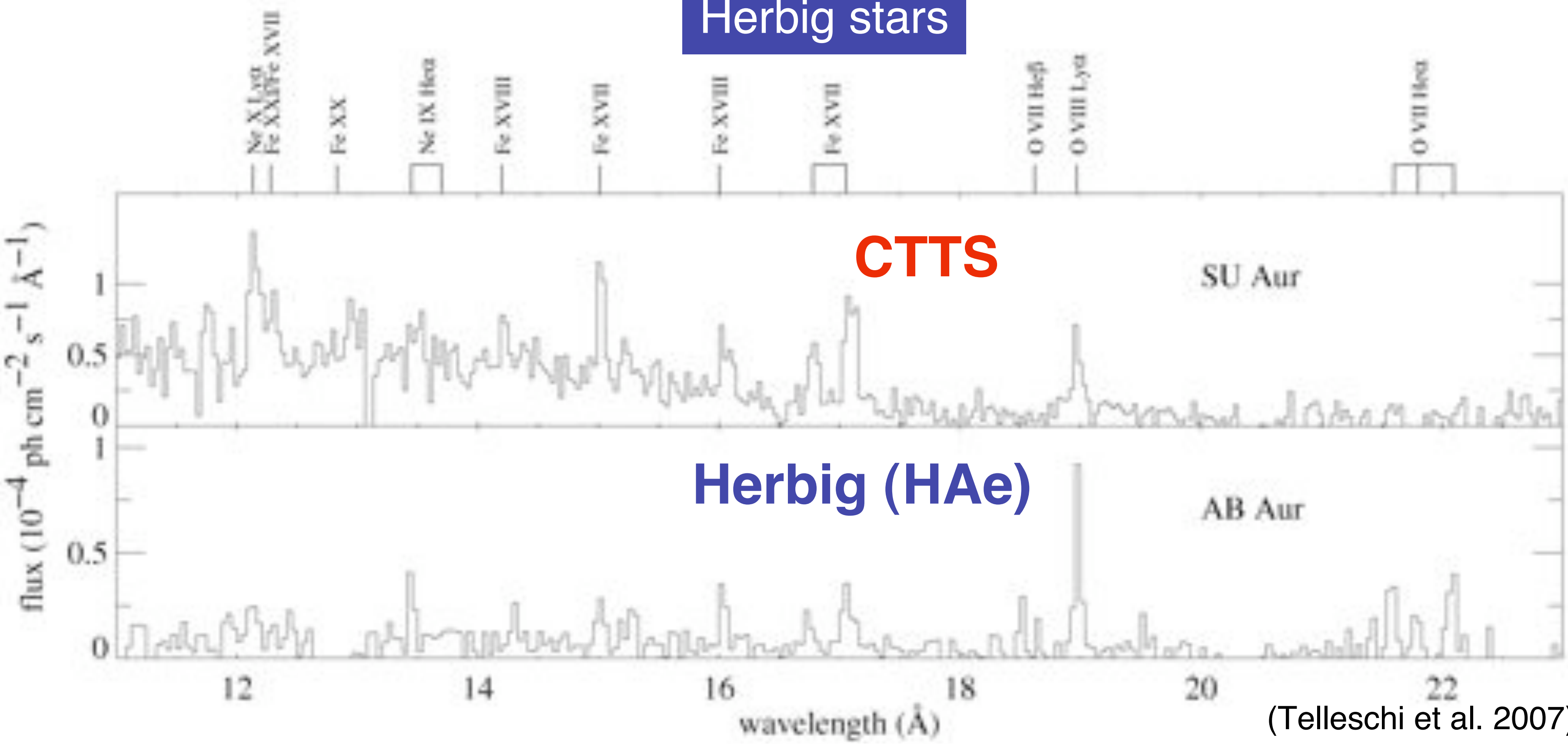
- So far, studied 8 CTTS at low S/N

- no accreting brown dwarfs

- no accreting “protostars” (1-2 keV)

Good to have: 10xA_{eff} now available: 2,000 cm^2 @ 0-5.1 keV

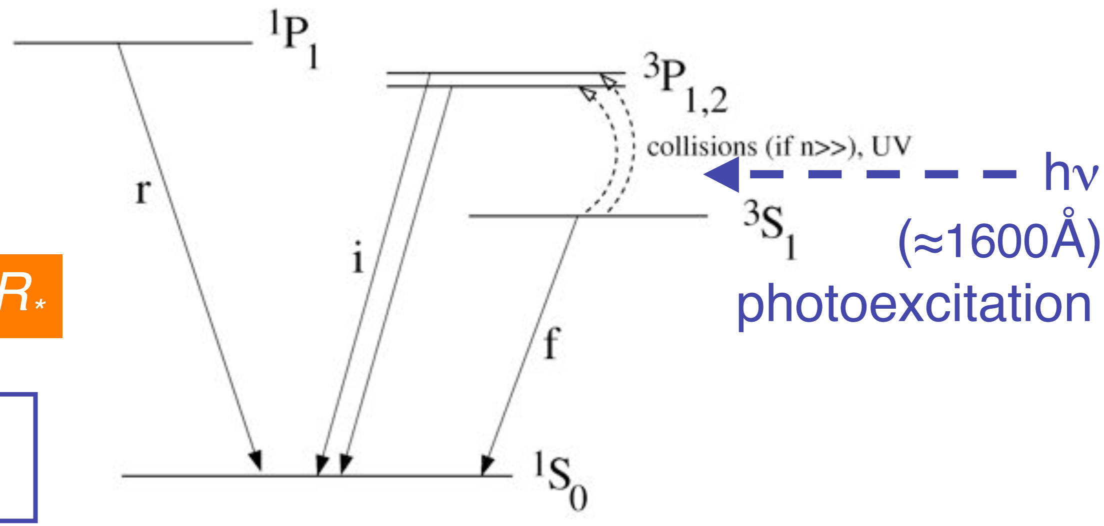
Herbig stars



(Telleschi et al. 2007)

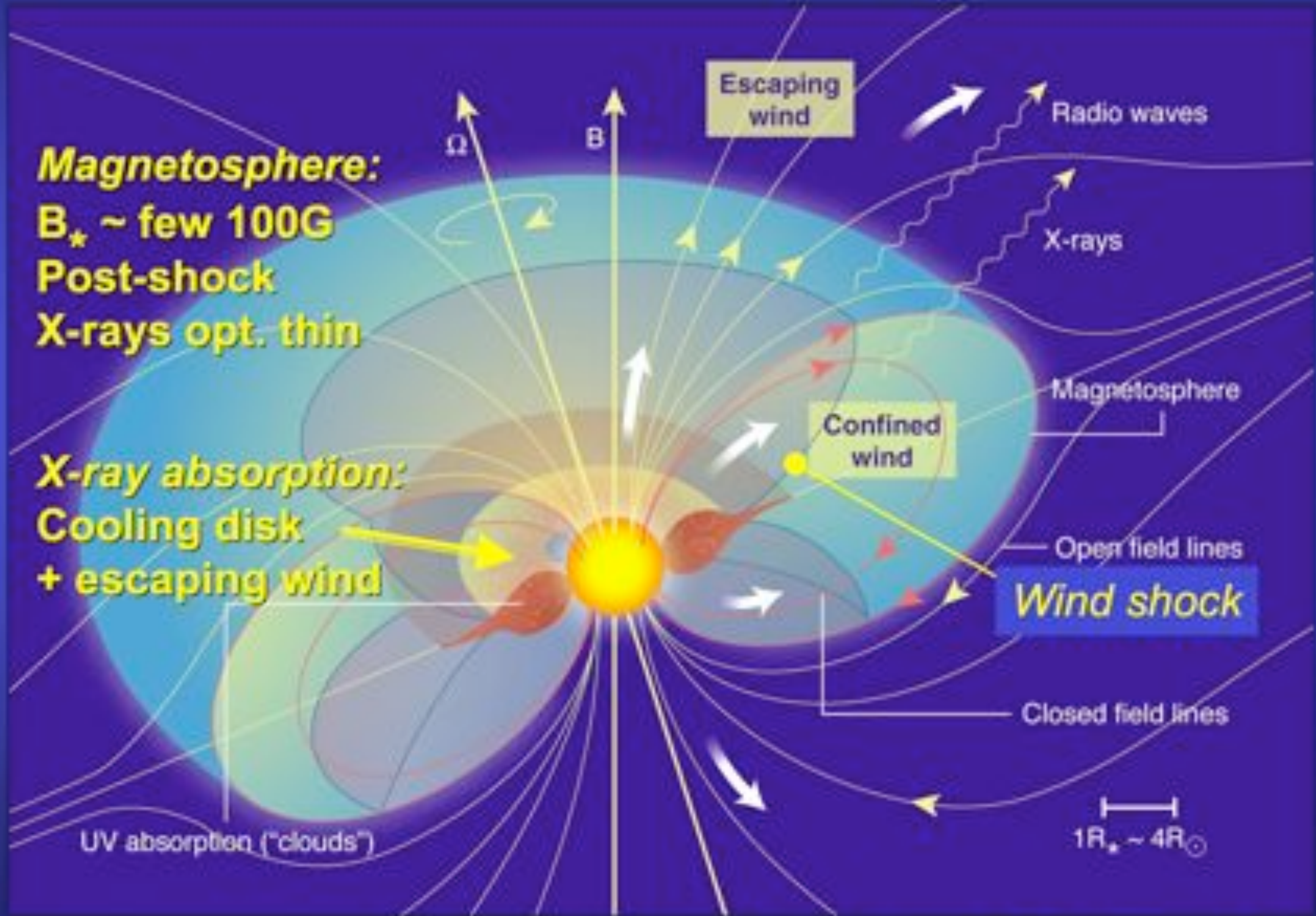
- *Soft spectrum*
- *low density*
- *high T_{eff} (10 kK)*

→ X-ray source at $R > 1.7R_*$



More on Herbig stars: see presentation by J. Schmitt

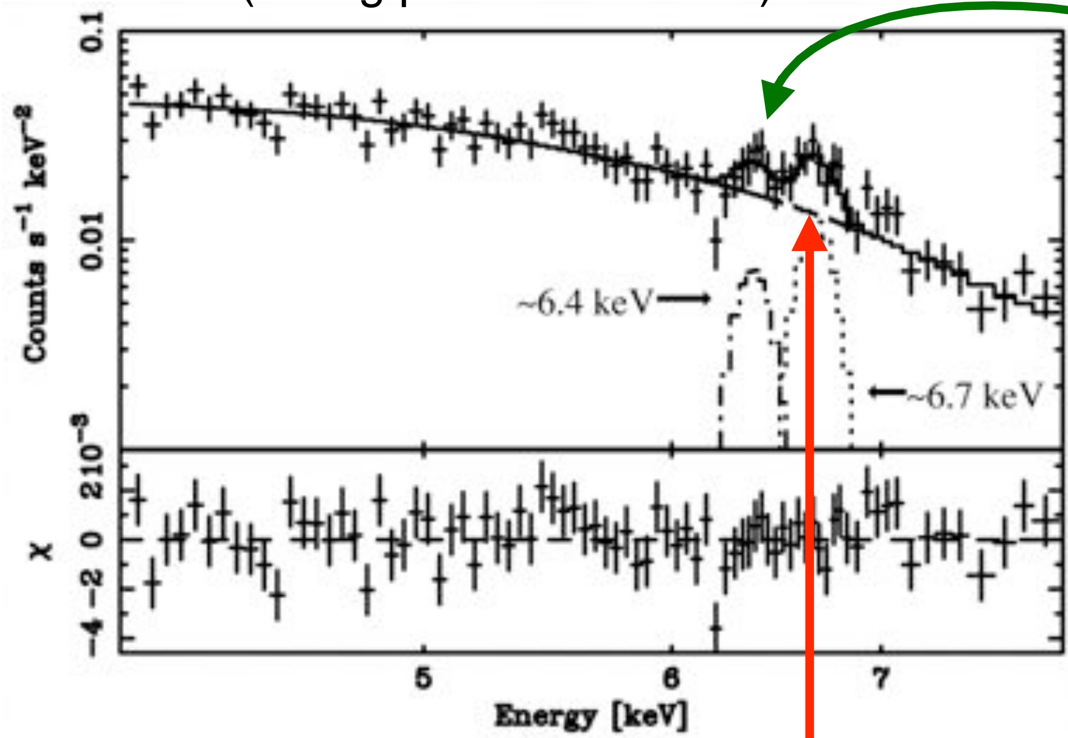
*The **Magnetically Channeled Wind Shock** (MCWS) model*



Montmerle 2001, Science (after Babel & Montmerle 1997)

Disk ionization by stellar X-rays? Fluorescence

(flaring protostar YLW15)

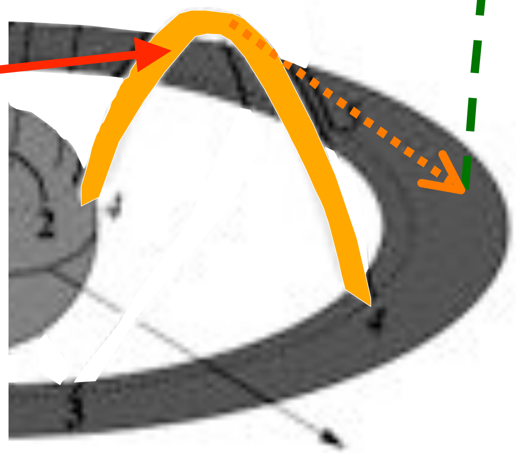


(Imanishi et al. 2001)

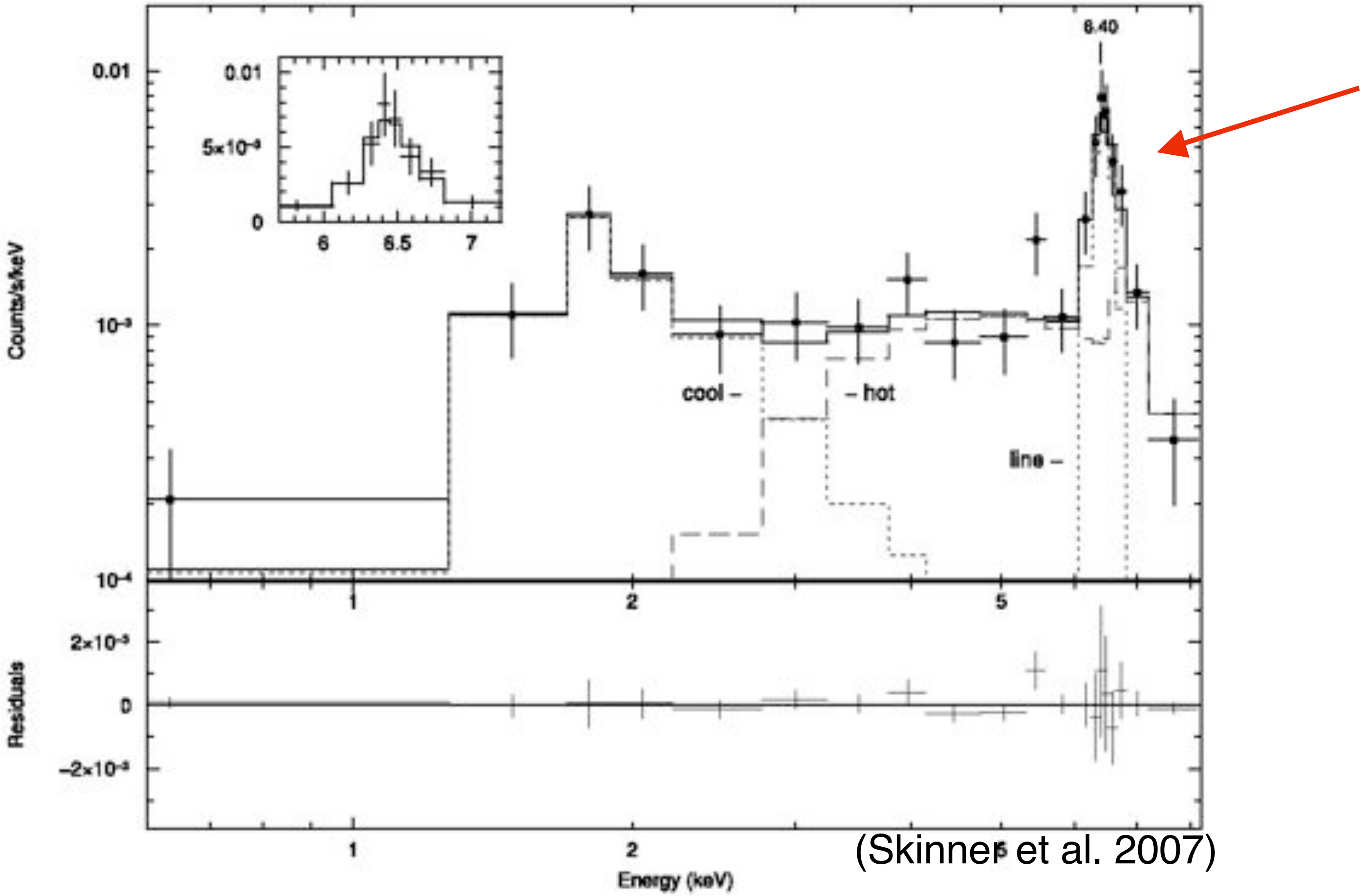
Fe Kα 6.4 keV

Fluorescence of cool material

Fe XXV 6.7 keV
(30 – 100 MK)



NGC 2071 IRS1

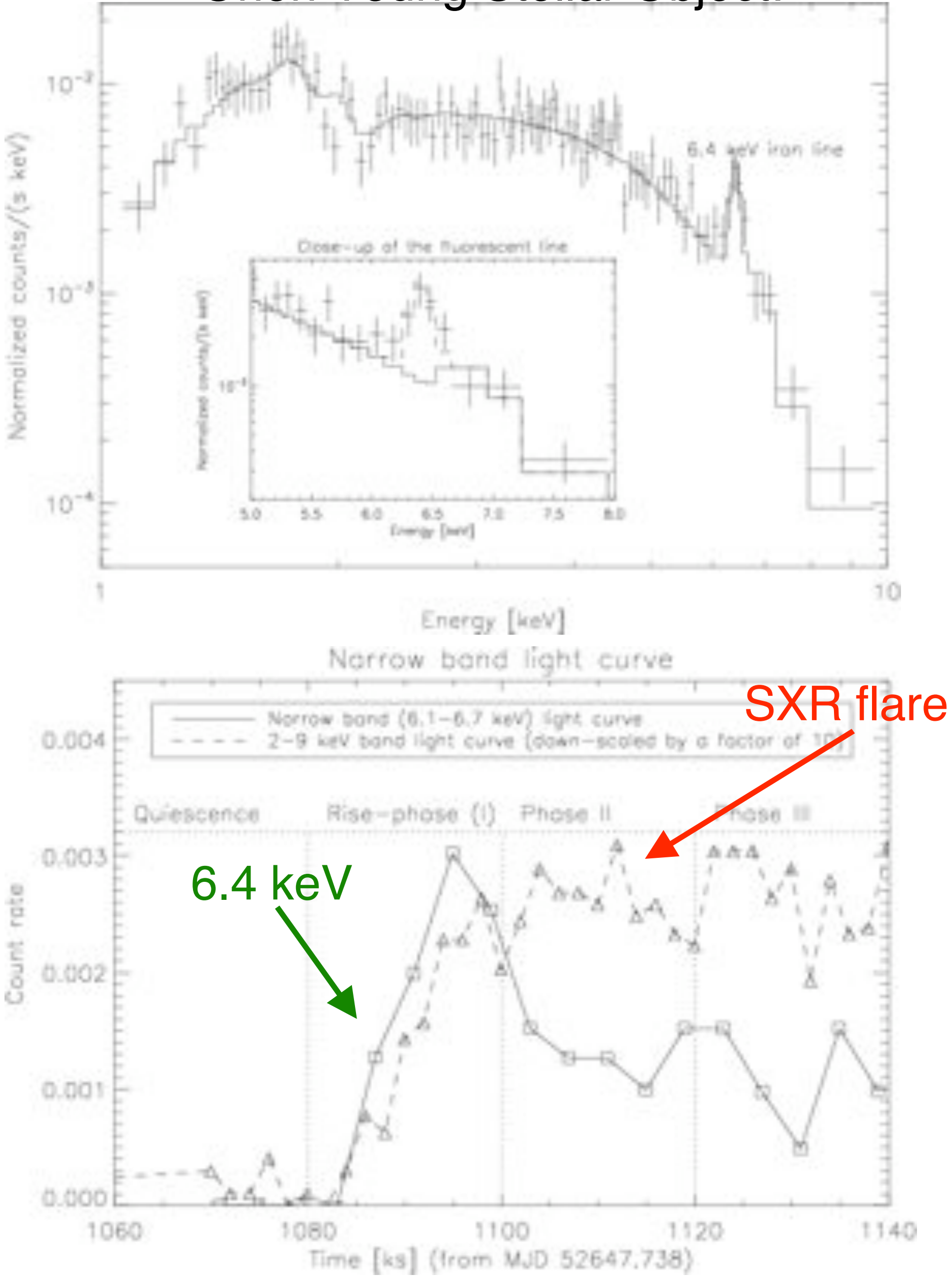


(Skinner et al. 2007)

- *only 6.4 keV line*
- *steady*
- *broadened: 160 eV FWHM*
- *EW = **2.4 keV**! theoretical disks: <150 eV* (*George & Fabian '91, Drake et al. '08*)

X-ray source hidden? EW requires $N_H = 10^{24}$ cm^{-2}

Orion Young Stellar Object:



(Czesla & Schmitt 2007)

Fluorescence

6.4 keV line during impulsive phase like HXR or radio (Osten et al. 2007, Czesla & Schmitt 2007):

K shell electron ejection by nonthermal electrons?

(challenged by Drake et al. 2008)

Need hard X-rays to unambiguously decide.

Requirements for spectral resolution

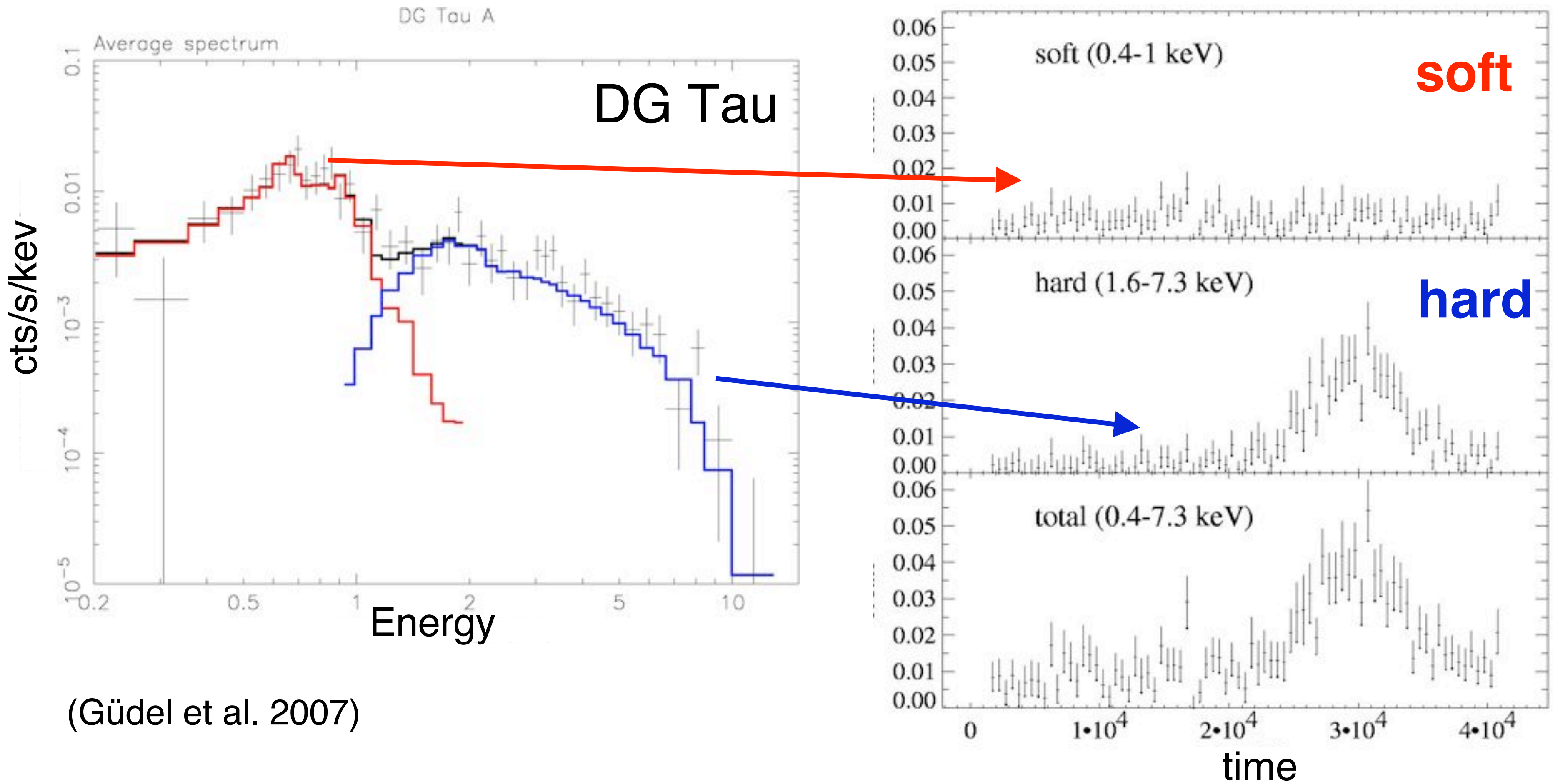
- localisation of fluorescence on (inner) circumstellar disks:

centroiding to 10 km/s at least

- reverberation mapping using Fe Kα

Good to have: $\lambda/\Delta\lambda = 3000$

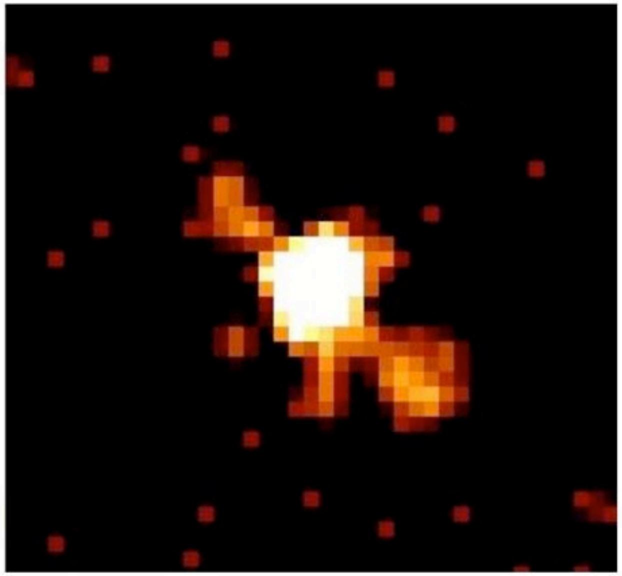
Spectroscopic evidence for stellar jets



(Güdel et al. 2007)

soft/cool component: low N_H, constant
hard/hot component: high N_H, flaring

Chandra high-resolution image of DG Tau



(Chandra, Güdel et al. 2008)

soft image of DG Tau (< 1.7 keV): essentially all due to jets (including central PSF, as suggested from spectrum)

R = 5000 & higher sensitivity: measure flows in jets!

Summary

New insights into magnetic structure and physical mechanisms from spectroscopy related to

densities (also resonant scattering), fluorescence, Doppler shifts

Still many open questions, among them:

- *Detailed magnetic structure:* *need higher spectral resolution & models from Sun*
- *Abundance anomalies:* *new theoretical developments needed*
- *Accretion disks:* *high resolution and sensitivity at 6.4 keV*