Coronal Dynamo Spectroscopy

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STScI

X-ray Vision Workshop
Oct. 8, 2015

From Simplicity to Complexity

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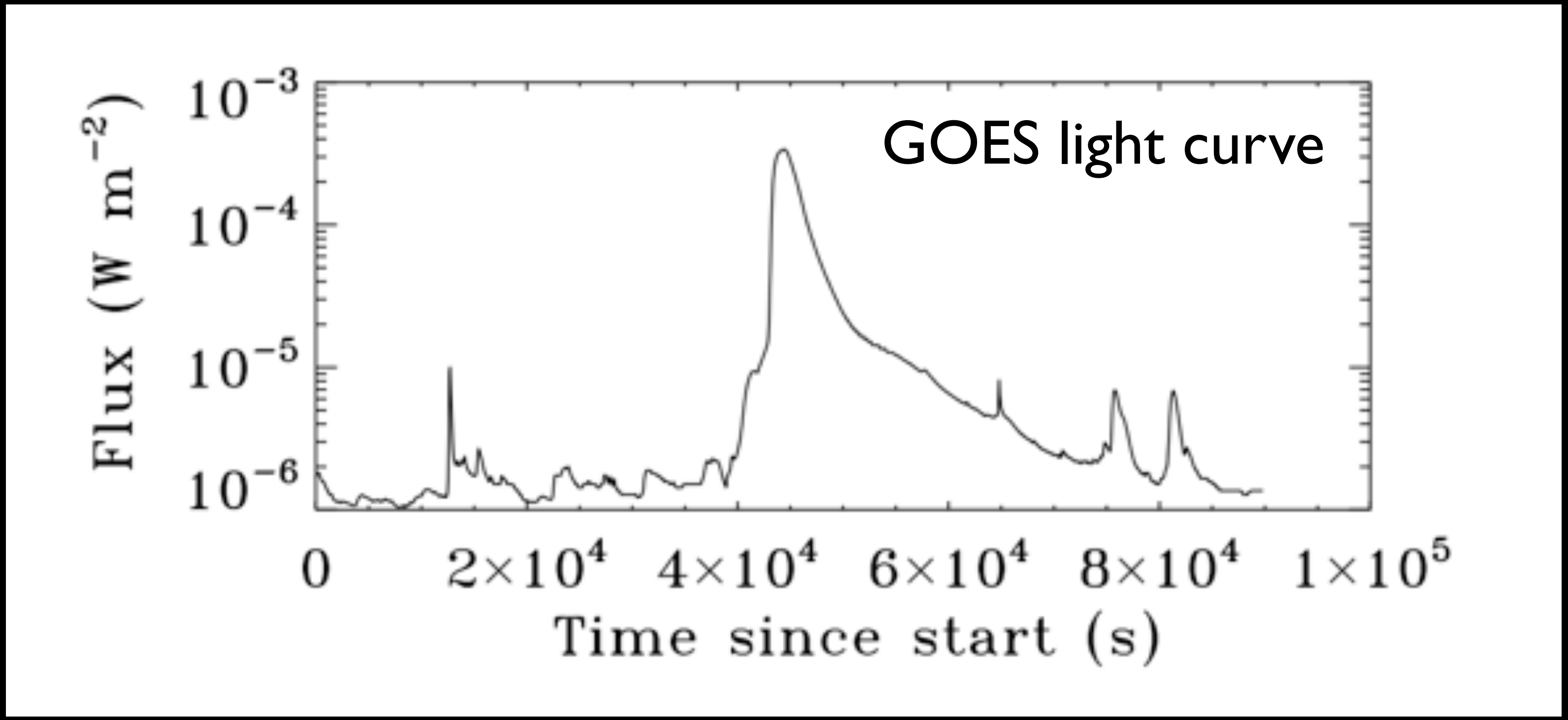
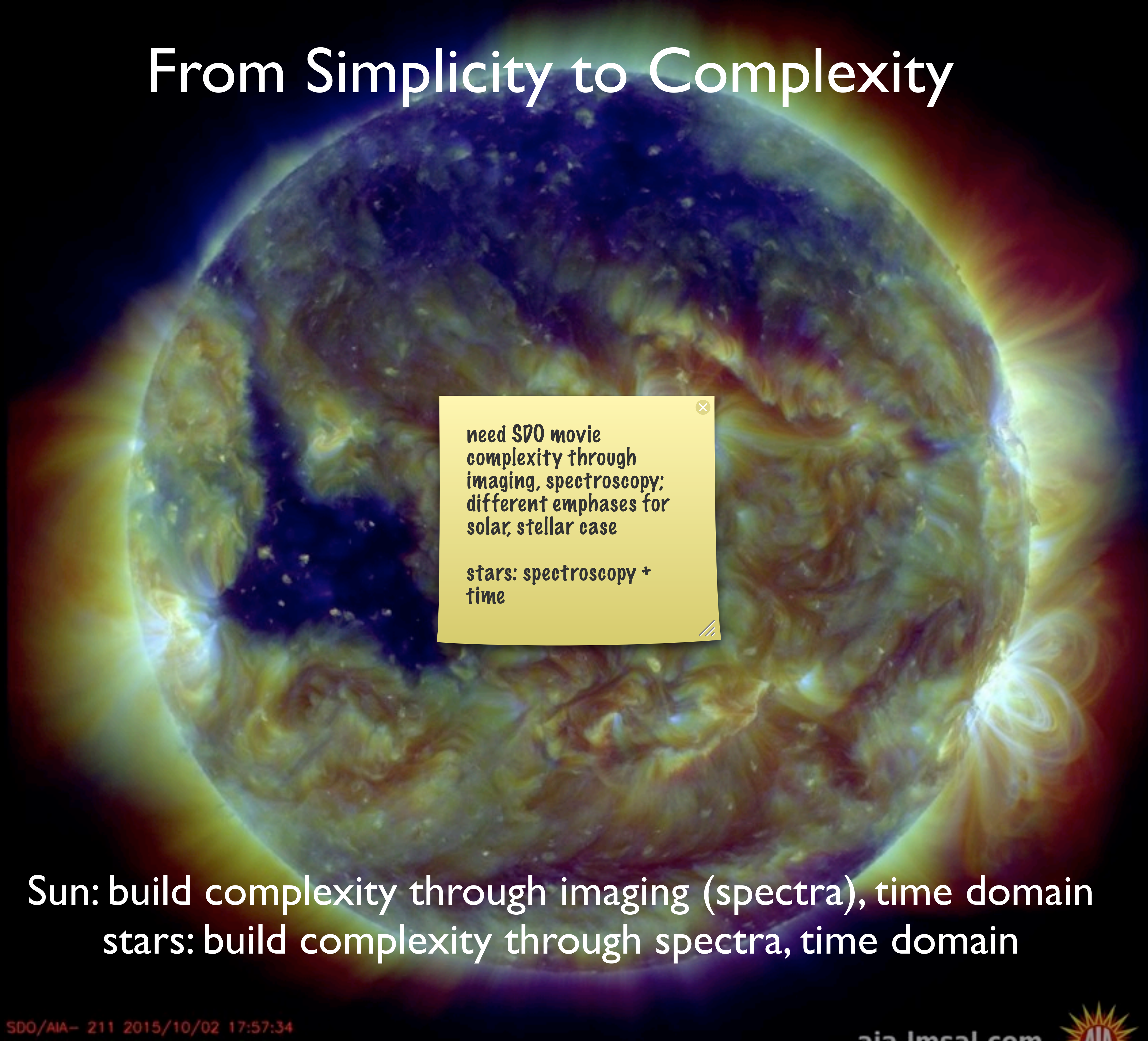


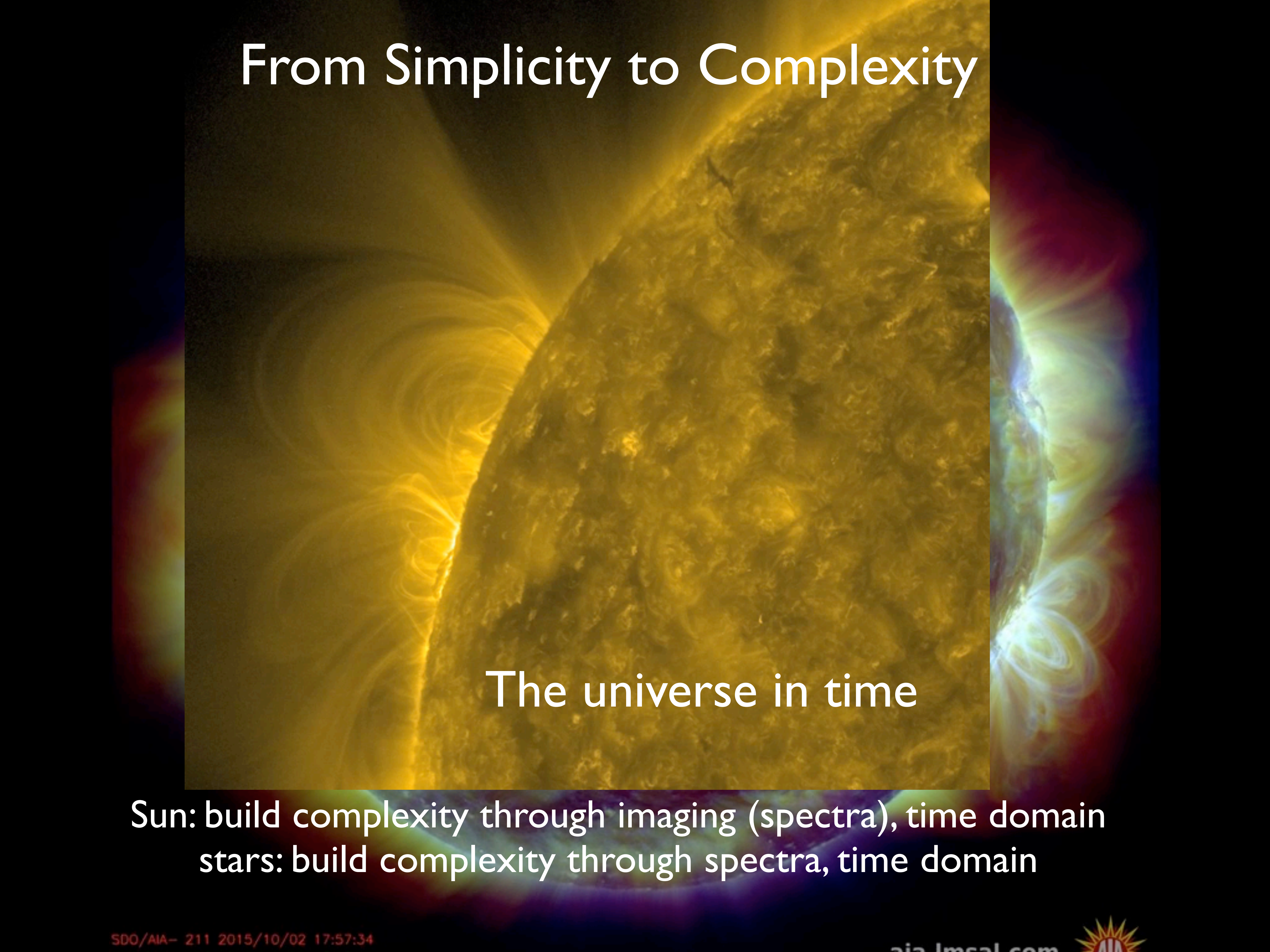
From Simplicity to Complexity



need SDO movie
complexity through imaging, spectroscopy; different emphases for solar, stellar case

stars: spectroscopy + time

Sun: build complexity through imaging (spectra), time domain
stars: build complexity through spectra, time domain


From Simplicity to Complexity
The universe in time
Sun: build complexity through imaging (spectra), time domain
stars: build complexity through spectra, time domain
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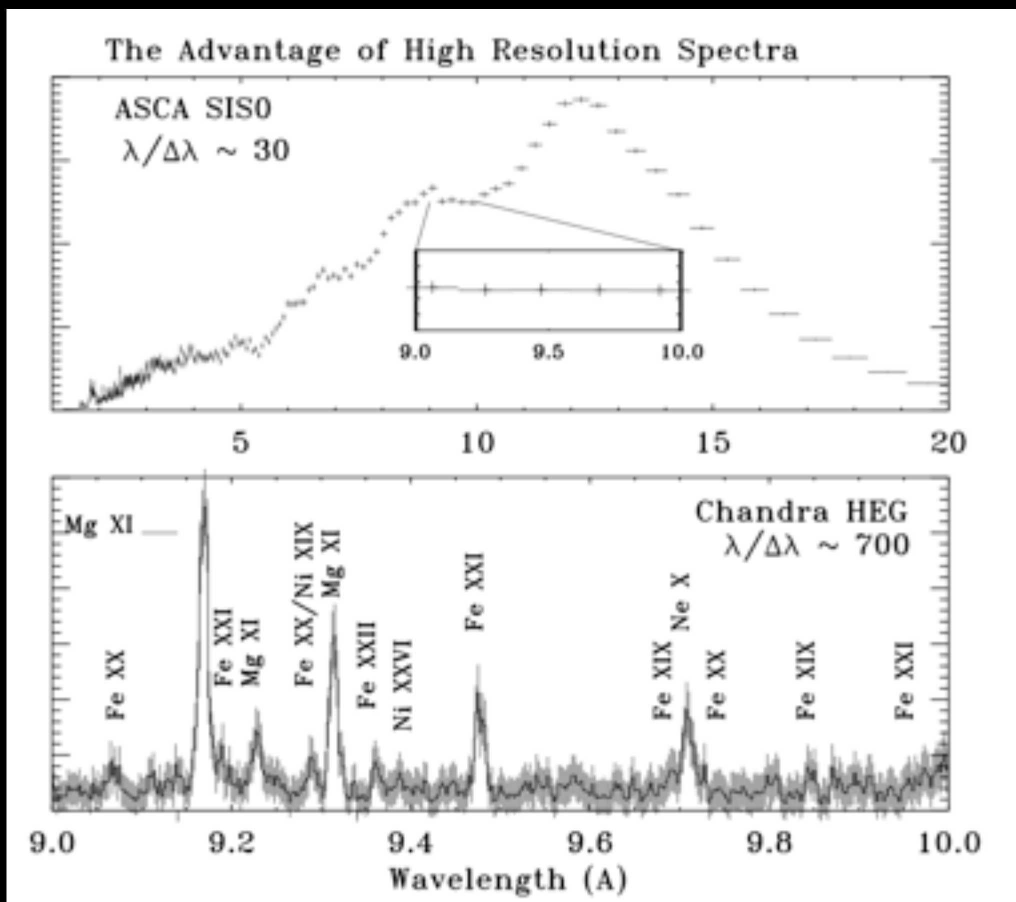
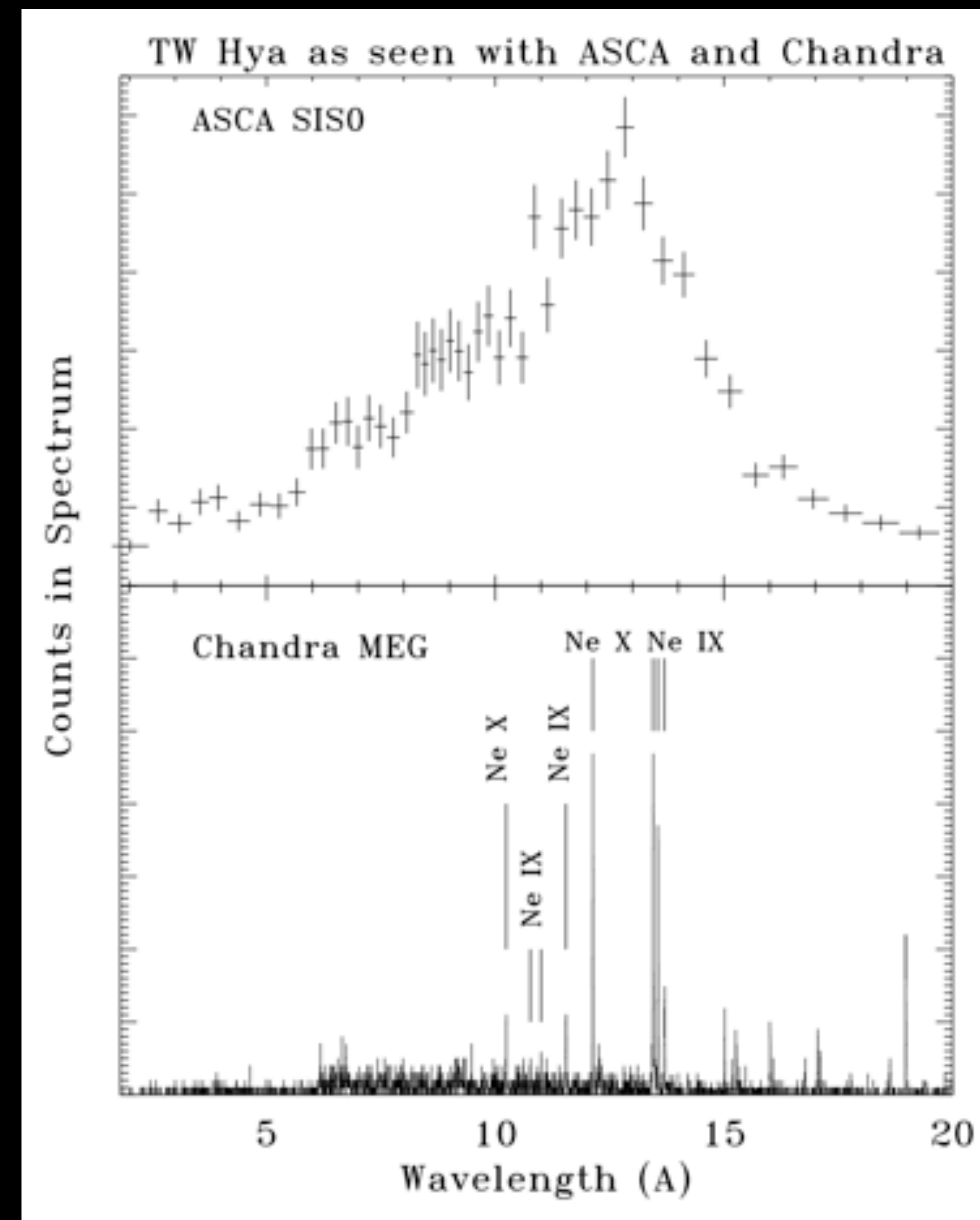
From Simplicity to Complexity: The Advantage of High Spectral Resolution





coronally active star (Osten et al. 2002) vs. corona+accretion shock + warm post-shock plasma (Brickhouse et al. 2010) revealed through high resolution spectroscopy

Big Questions*

- how do stars form?
- how do circumstellar disks evolve, form planetary systems?
- how diverse are planetary systems?
- do habitable worlds exist on other stars?
- how do rotation and magnetic fields affect stars?

✔ X-rays inform each of these topics, are vital for understanding how stars work and how they interact with their environment

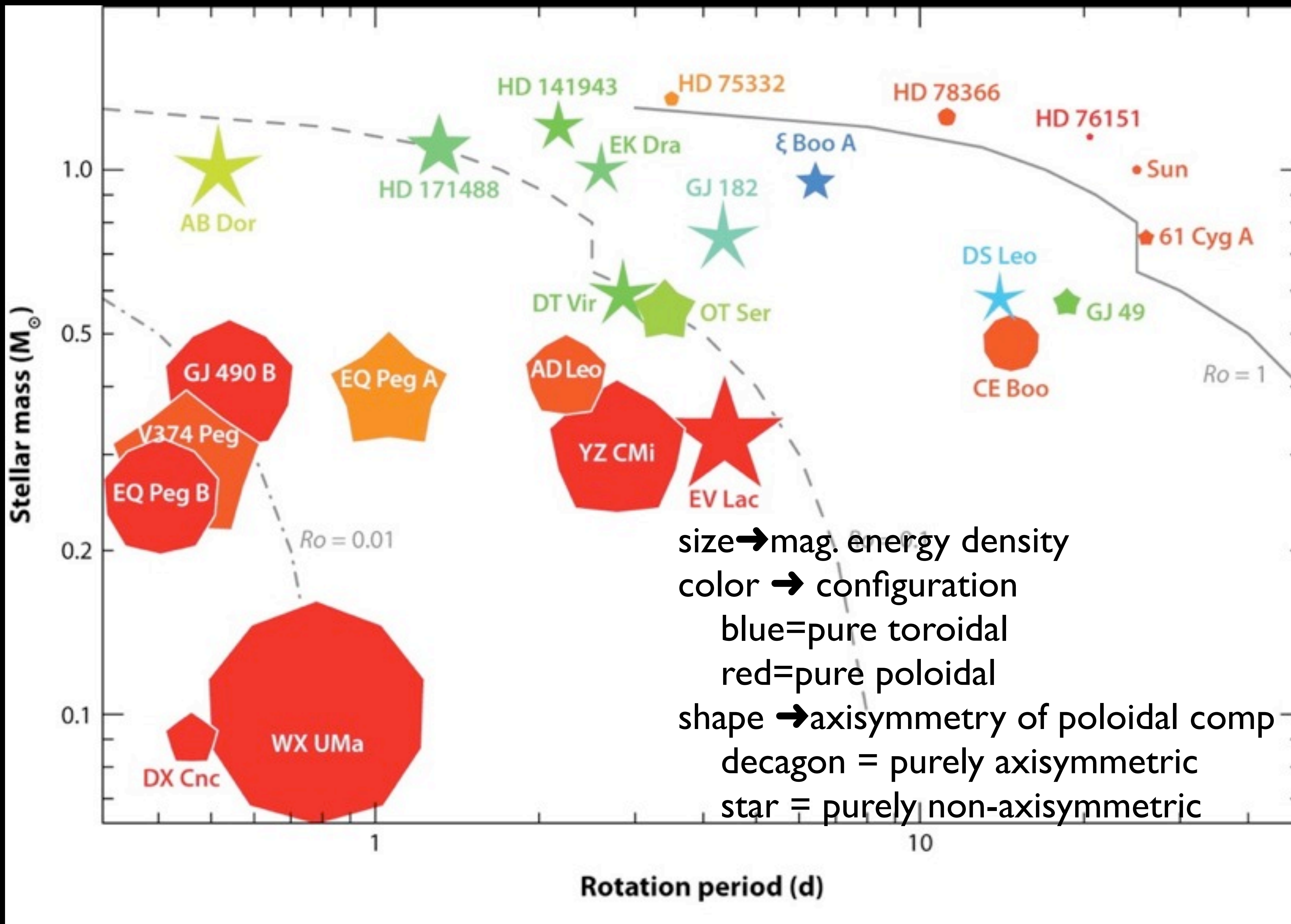
✔ Observations with X-ray Surveyor will be key to advancing these areas; require large collecting area coupled with high spectral, spatial resolution

*as informed by the Decadal Survey and more recent results

A (nonexhaustive) list of topics

- ***Magnetic fields dominate structuring and dynamics in a wide range of stellar exteriors and environments***
  - Stars with outer convection zone: young stars, solar-like stars, M dwarfs but also evolved cool stars
  - Current results based on high resolution spectroscopy have been biased towards the X-ray brightest objects due to the current sensitivity limits.
  - Increase in spectral resolution expands plasma diagnostics: flows, turbulence, length scales through opacity effects.
  - Important for understanding not just the star, but impact on environment (disks, planets)
- ***Revealing new physics in new sources***
  - Ultracool dwarfs extend studies of magnetic dynamo to the substellar regime. Beyond fluxes to temperatures, densities, abundances. Not possible now with tens of photons.
  - Relative contribution of coronal processes vs. accretion processes in youngest stellar objects

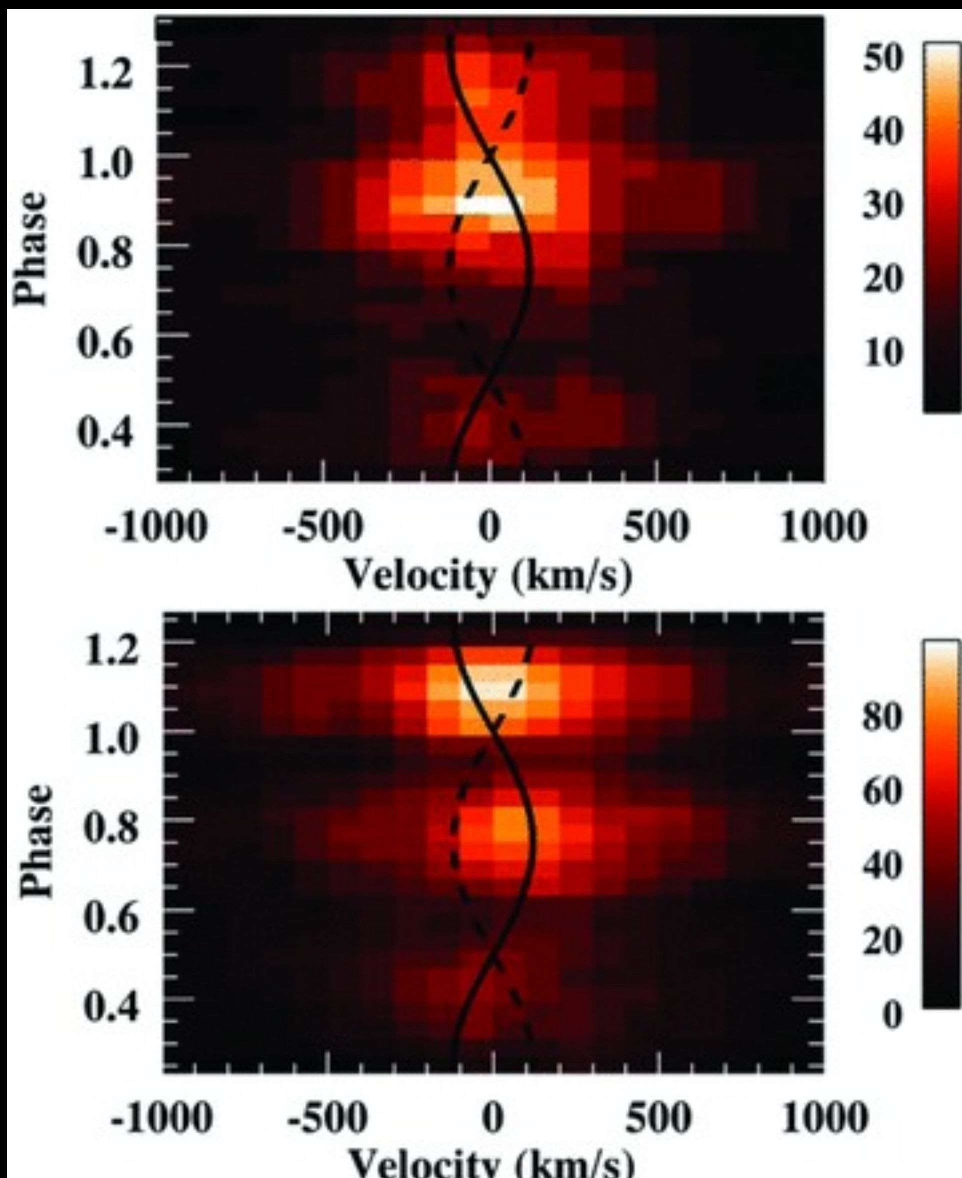
Magnetic Fields in Cool Stars



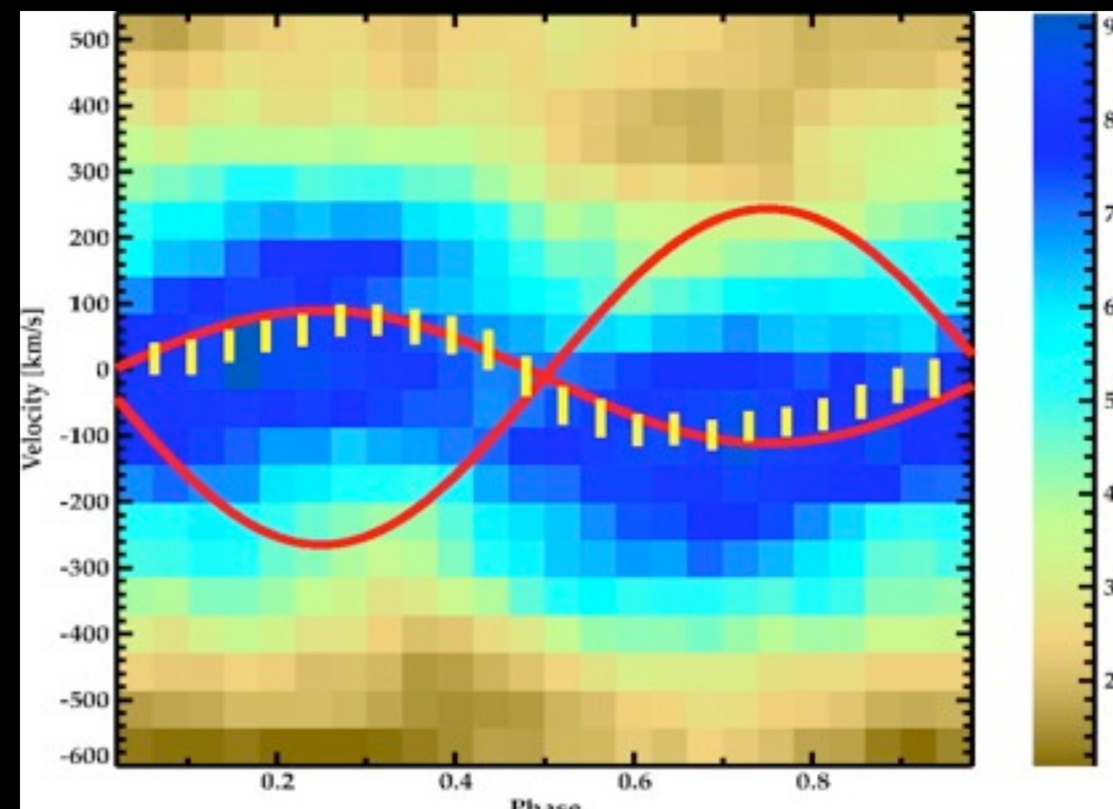
size➜mag. energy density
color ➜ configuration
blue=pure toroidal
red=pure poloidal
shape ➜axisymmetry of poloidal comp
decagon = purely axisymmetric
star = purely non-axisymmetric

Donati J.-F, Landstreet JD. 2009.

X-rays Trace Magnetic Structures



Hussain et al. (2012) looked at phase-folded Chanda/HETG spectra of the nearby eclipsing M dwarf binary YY Gem to investigate magnetic structure on cool stars



VW Cep; Huenemoerder et al. 2003

X-ray emission follows the more massive star in the binary

Hussain et al. (2012)

simulation | **FWHM=200 km/s, 300 cnts peak** | **FWHM=400 km/s, 500 cnts peak**

compact region on primary

primary: 2 ARs, secondary 1 AR

evenly distributed compact coronae (<0.05R_{star})

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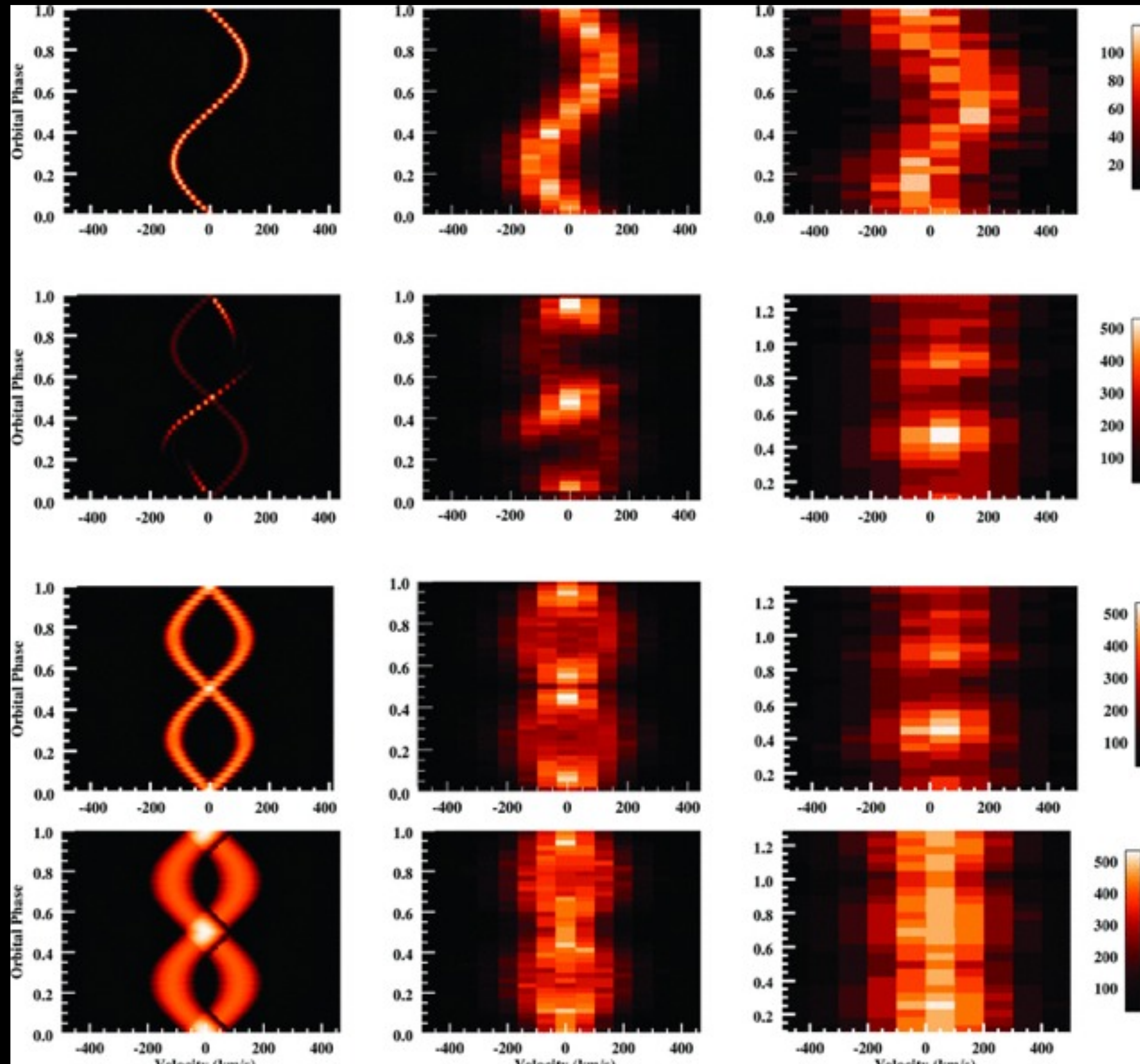
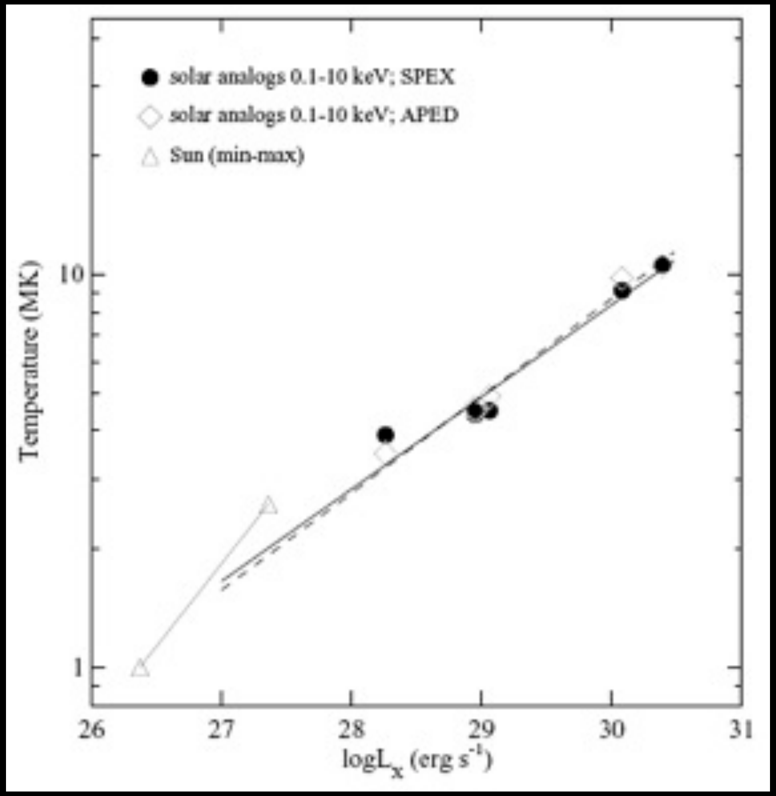


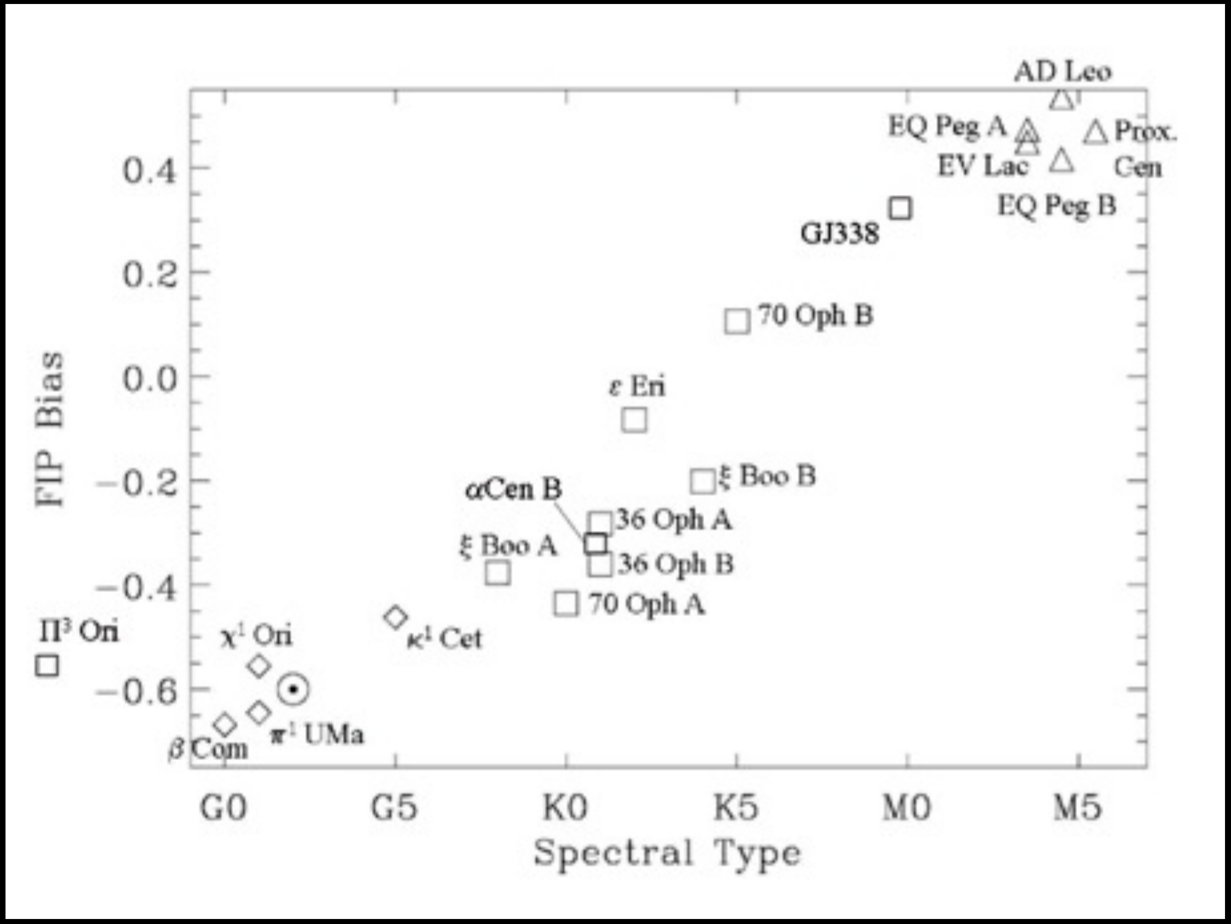
Turning Down the Dial on Activity

Because we've been challenged for photons, X-ray spectroscopic targets biased towards X-ray brightest: most active, hottest. Typical?

T_x decreases with decreasing L_x



Telleschi et al. (2005)



"inverse FIP"

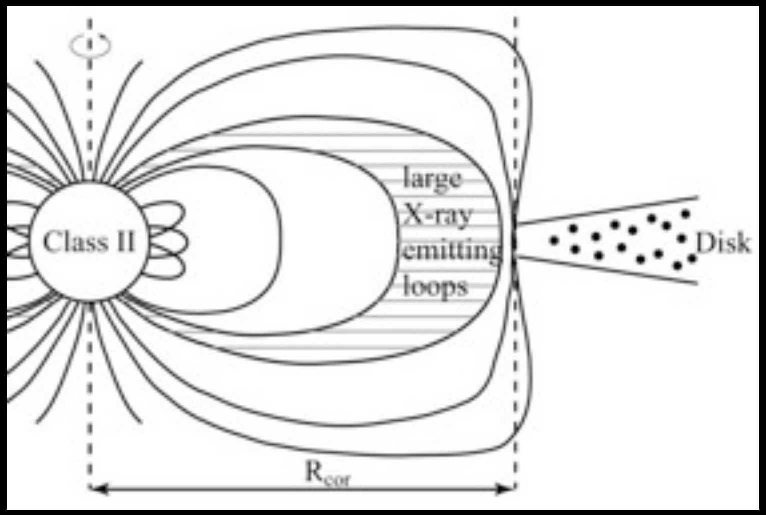
"FIP effect"

Laming et al. (2015) $L_x<10^{29}$ erg s^{-1}

Stellar Coronal Flares; Moving Beyond the Usual Suspects

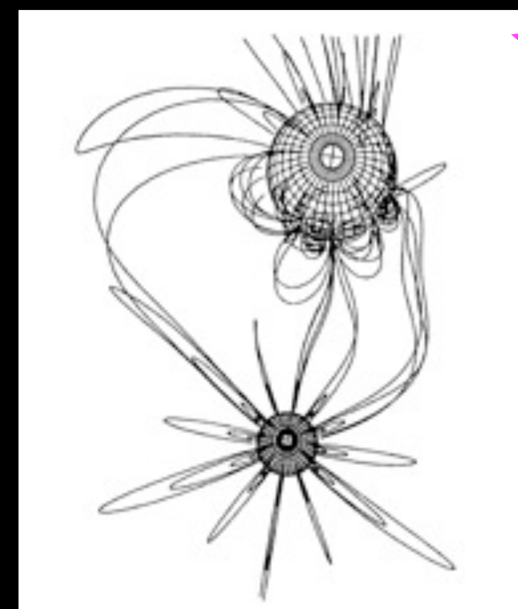
Stellar Coronal Flares; Moving Beyond the Usual Suspects

young stars

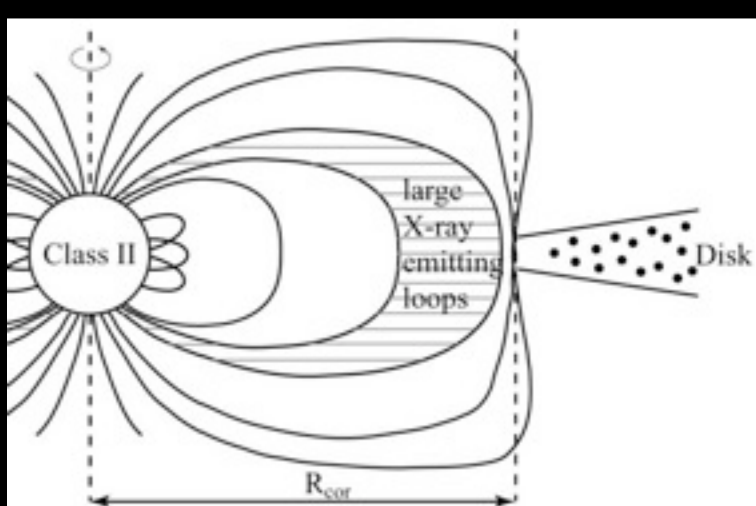


Stellar Coronal Flares; Moving Beyond the Usual Suspects

young stars

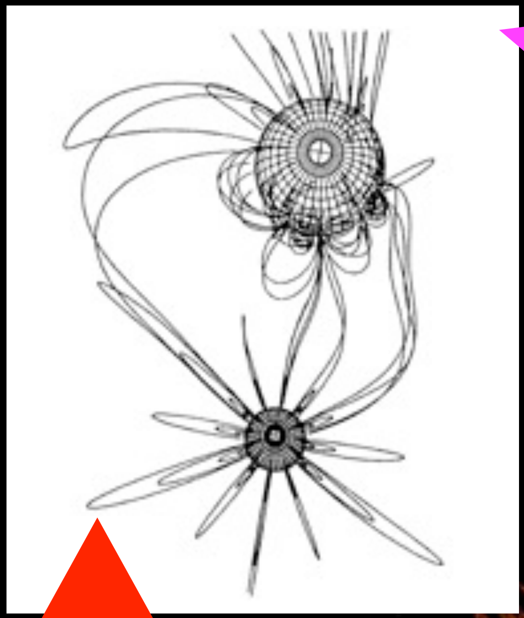


active binaries

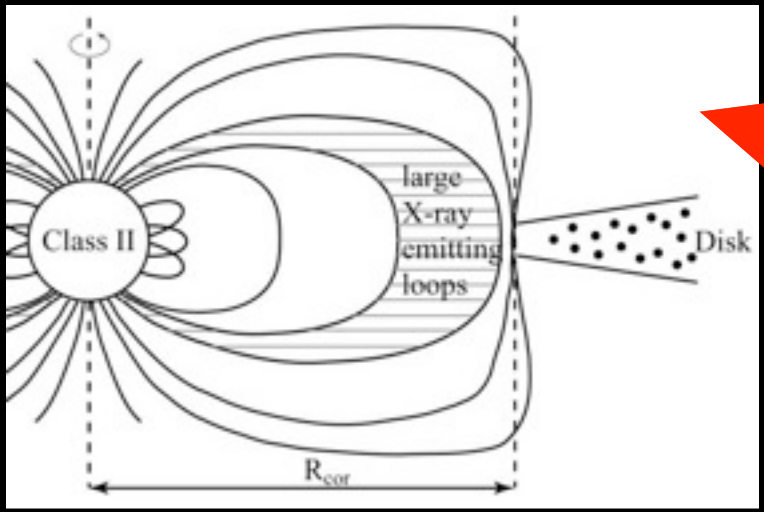


Stellar Coronal Flares; Moving Beyond the Usual Suspects

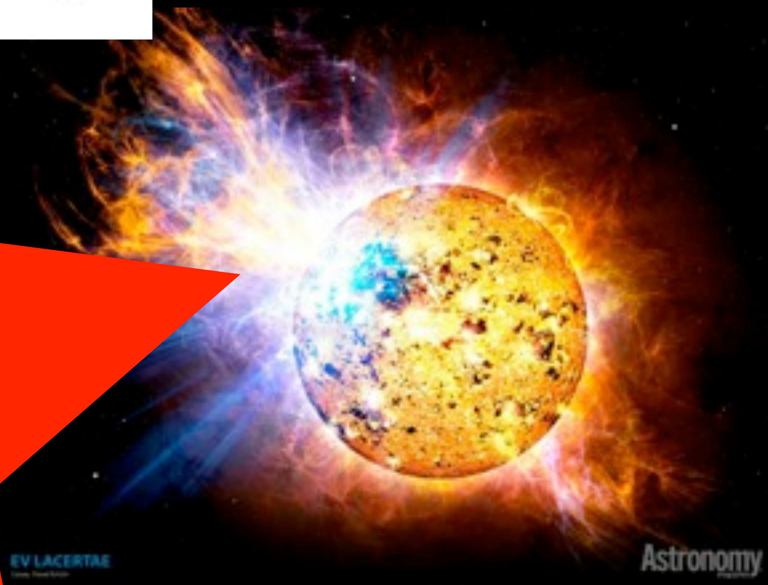
young stars



active binaries

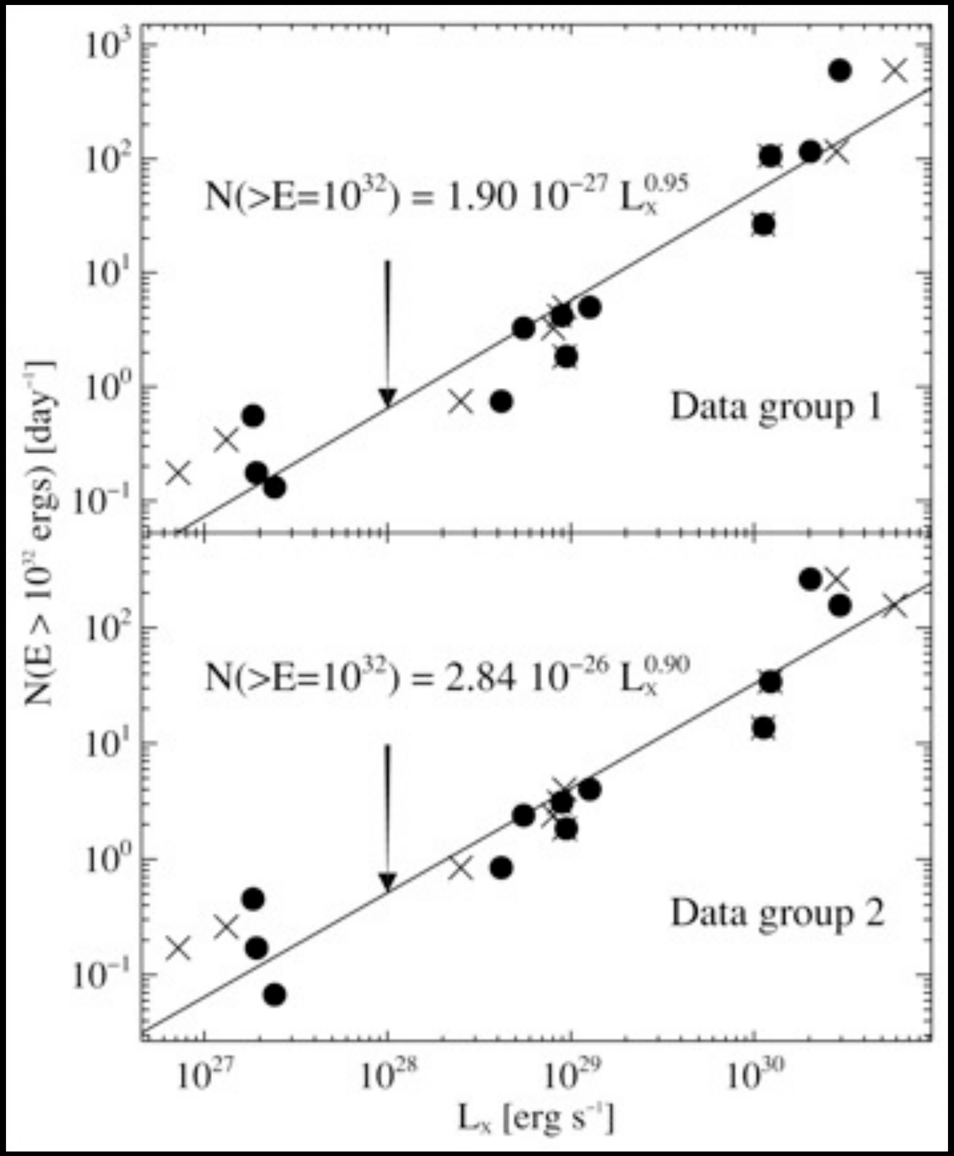


fully convective
(M dwarfs)

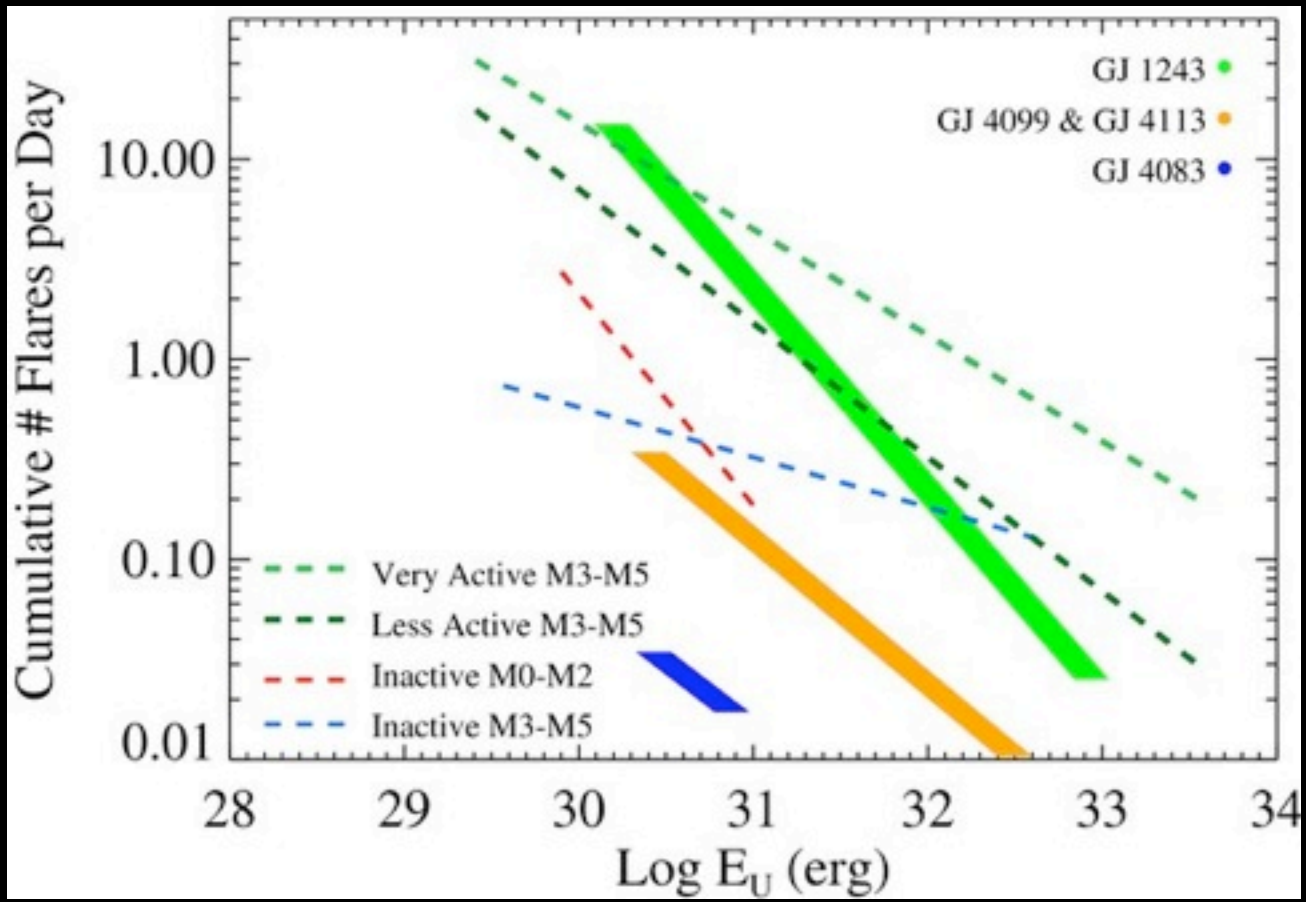


Still have to contend with flaring at low magnetic activity stars

flare rate $\propto L_X$



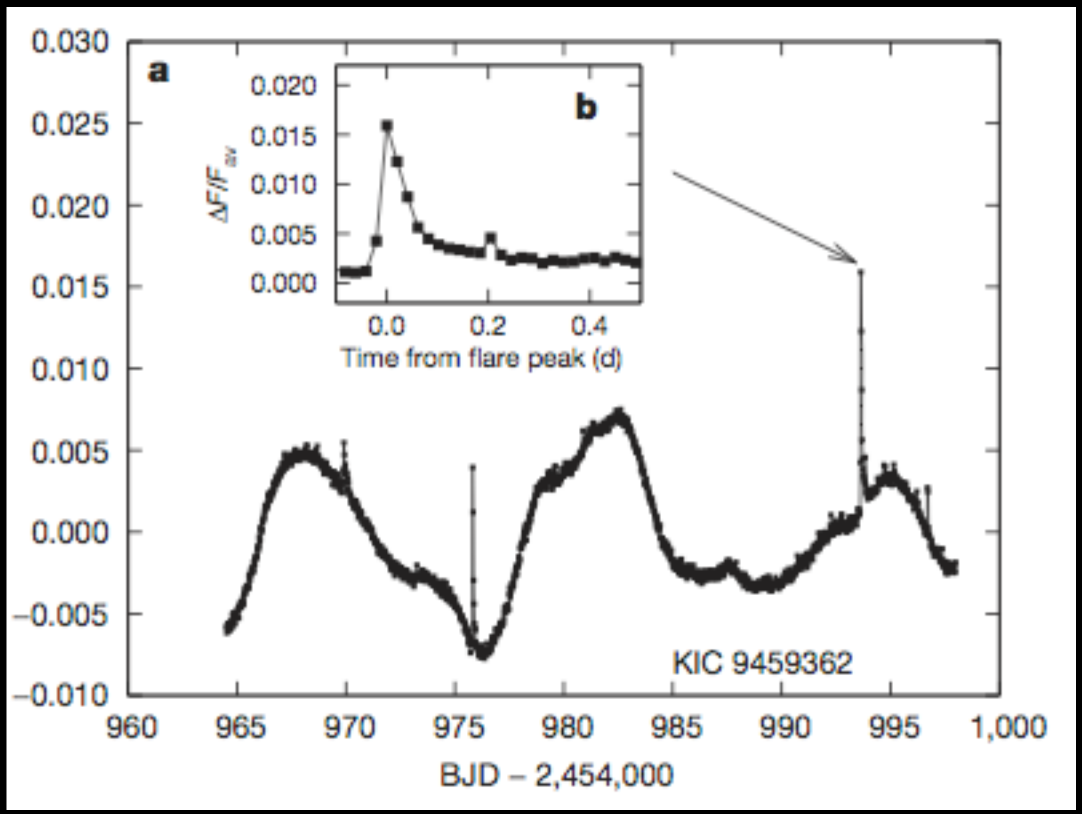
Audard et al. 2000

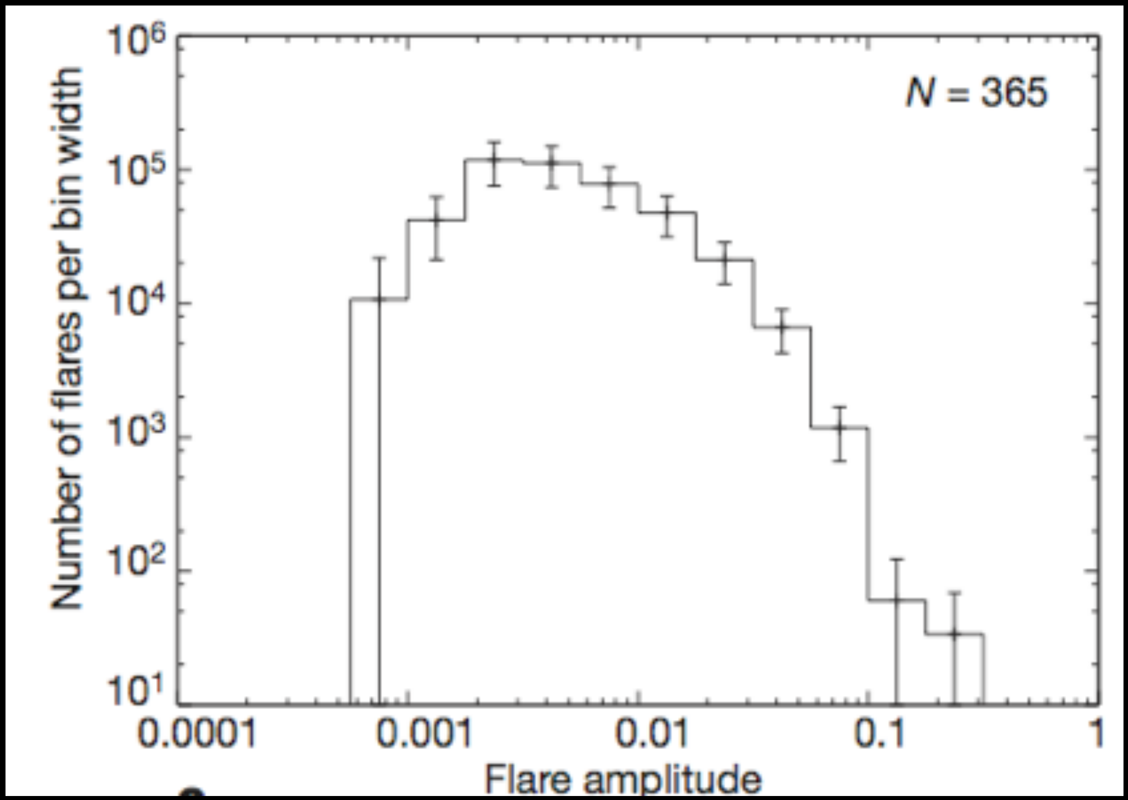


Hawley et al. (2014)

Inactive ≠ not active

Don’t need the X-rays to see flares

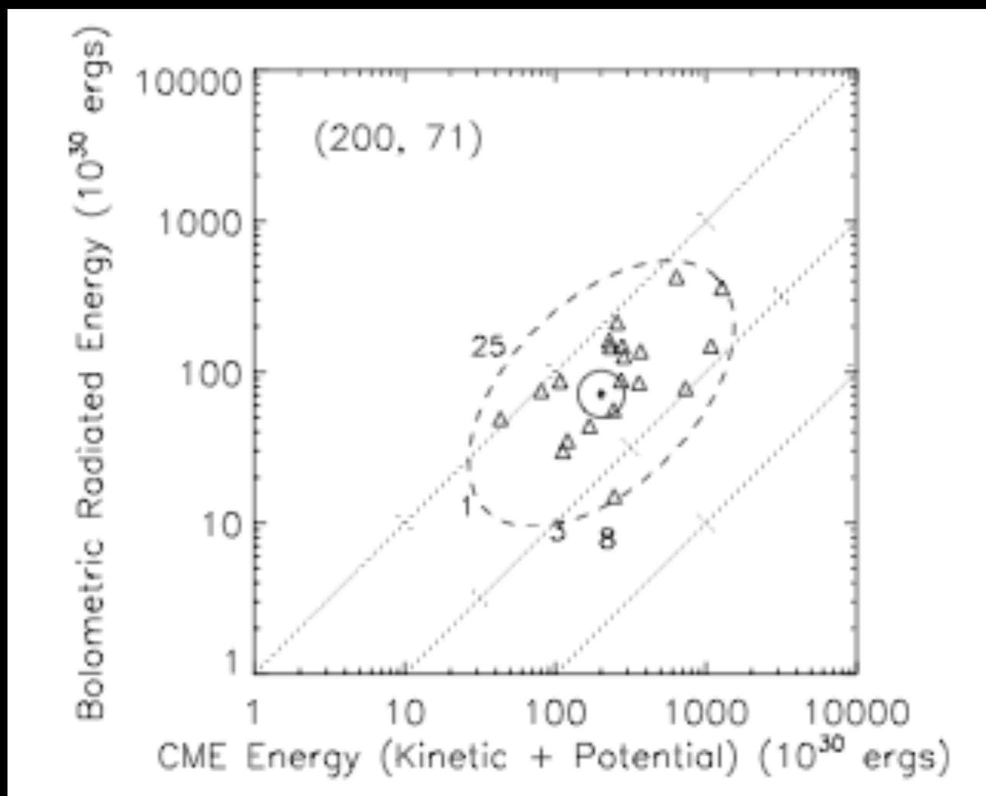


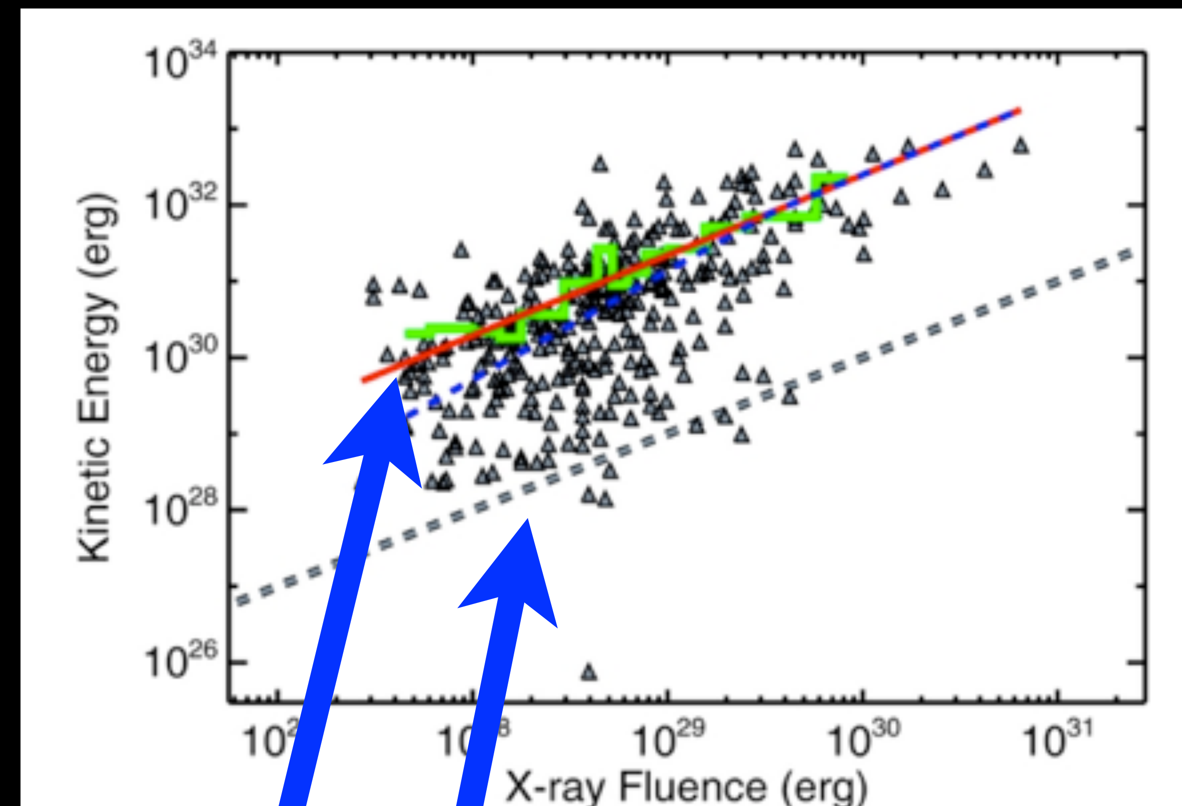


Maehara et al. (2012) superflares seen on apparently single, even slowly rotating, G stars in the Kepler field; Kepler, K2, TESS will see an abundance of stellar flares

Osten & Wolk (2015) energy partition in solar & stellar flares is similar

Using the flares to find the coronal mass ejections





Drake et al. (2013)

Emslie et al. (2012)

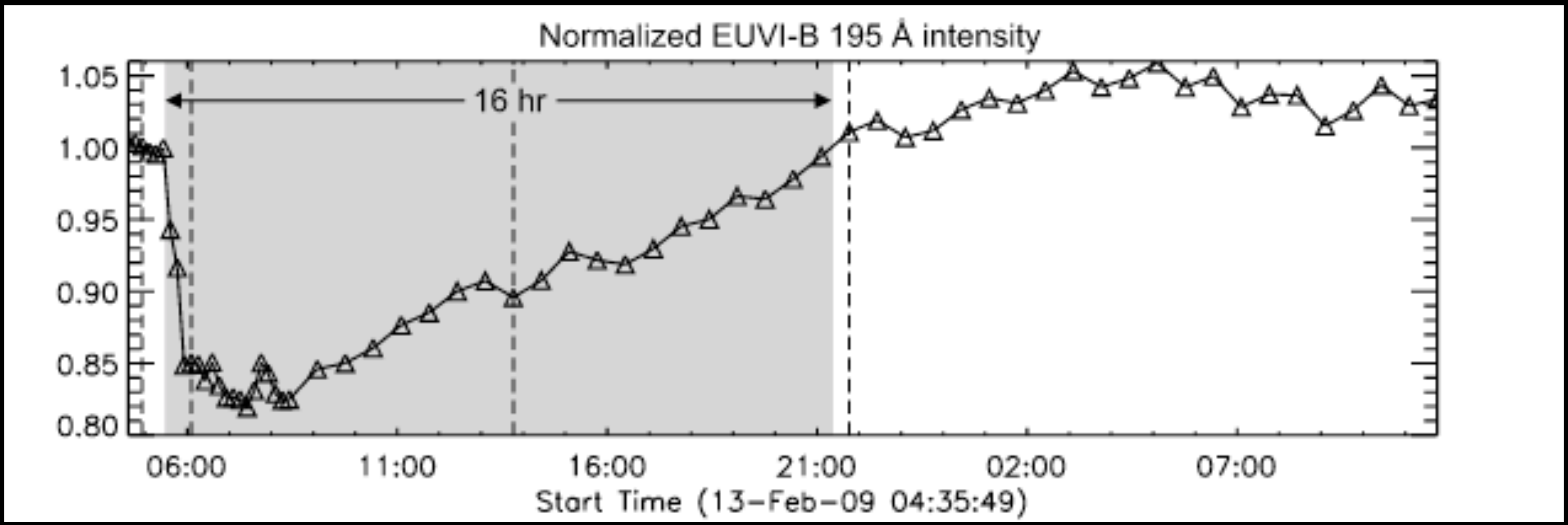
$E_{CME} \sim 3\ E_{bol}$

line of equality between X-ray flare energy and CME KE

see Osten & Wolk (2015) for another approach

with $E_{GOES}/E_{bol} \sim 0.01$, $E_{CME} \sim 2\ E_{bol}$

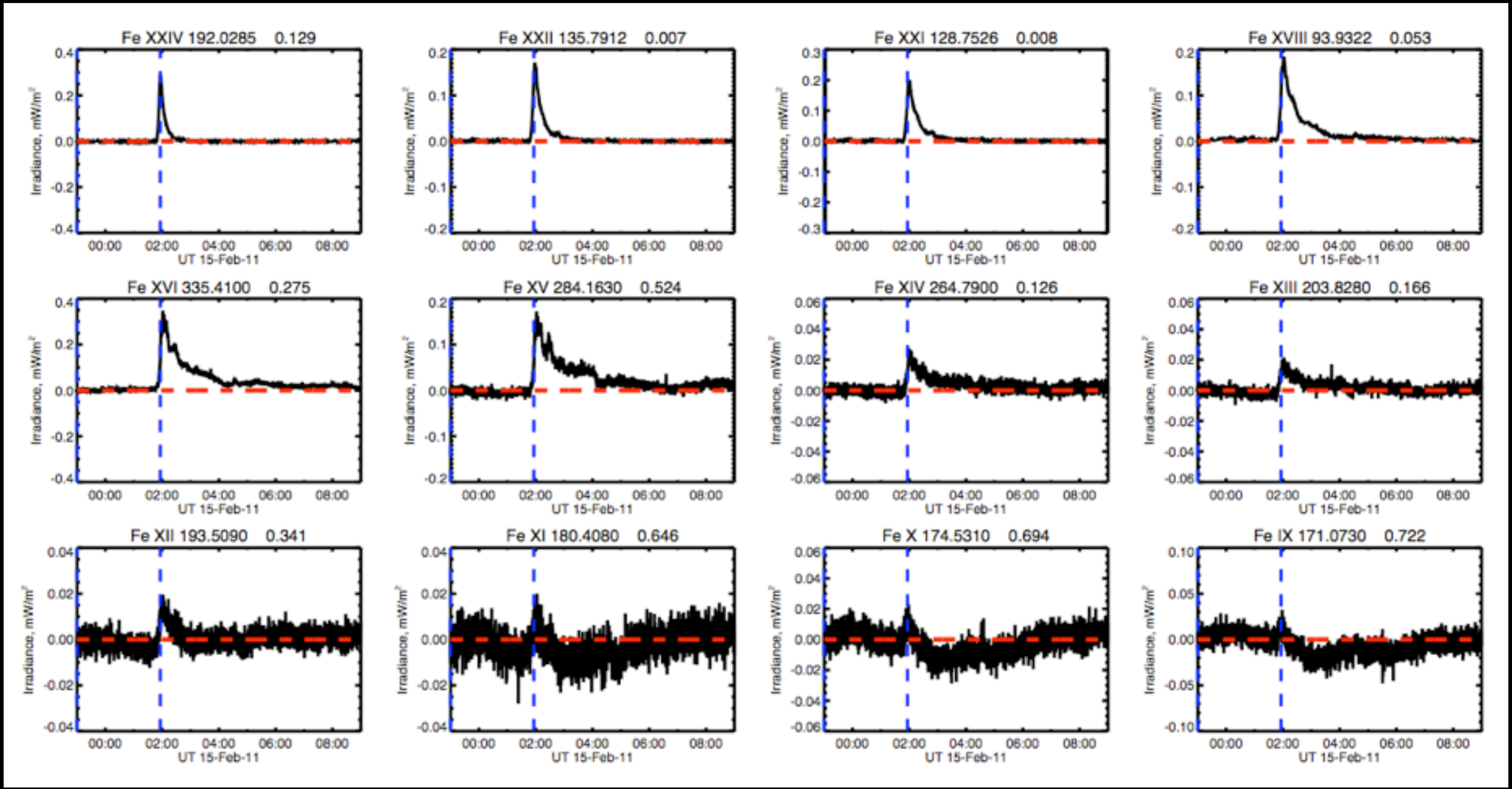
Coronal Signatures of Coronal Mass Ejections?



Miklenic et al. (2011)

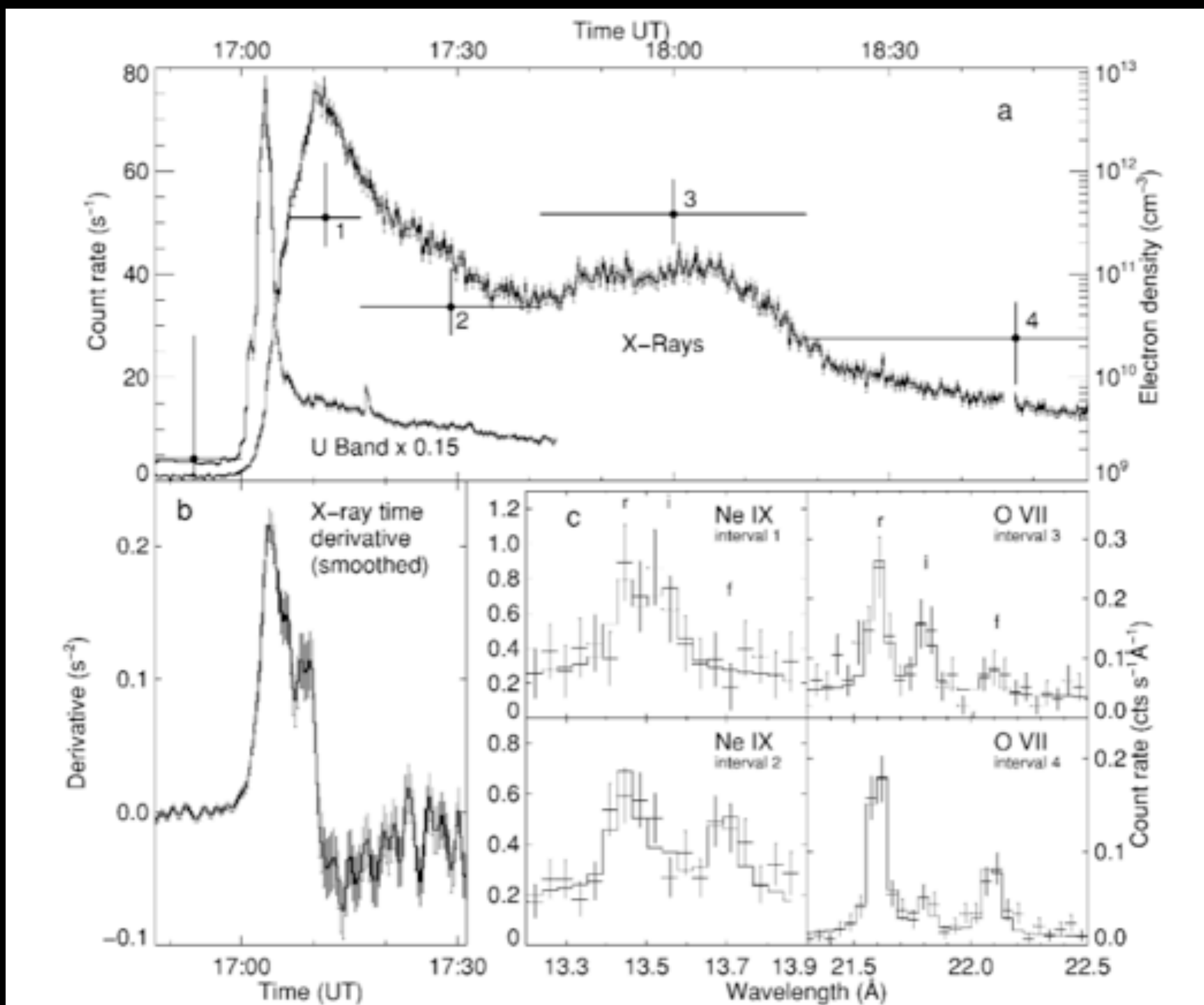
coronal dimmings, or "EUV dimmings" occur during solar flares; good correspondence with CMEs (Reinard & Beisecker 2008)

Coronal Signatures of Coronal Mass Ejections?



but they primarily manifest in *cooler* solar coronal plasma (Harra et al. 2015)

You DO Need X-rays to Characterize Dynamic Coronal Plasma



Güdel et al. (2002)

with R=5000: red/blue shifts of ~100 km/s

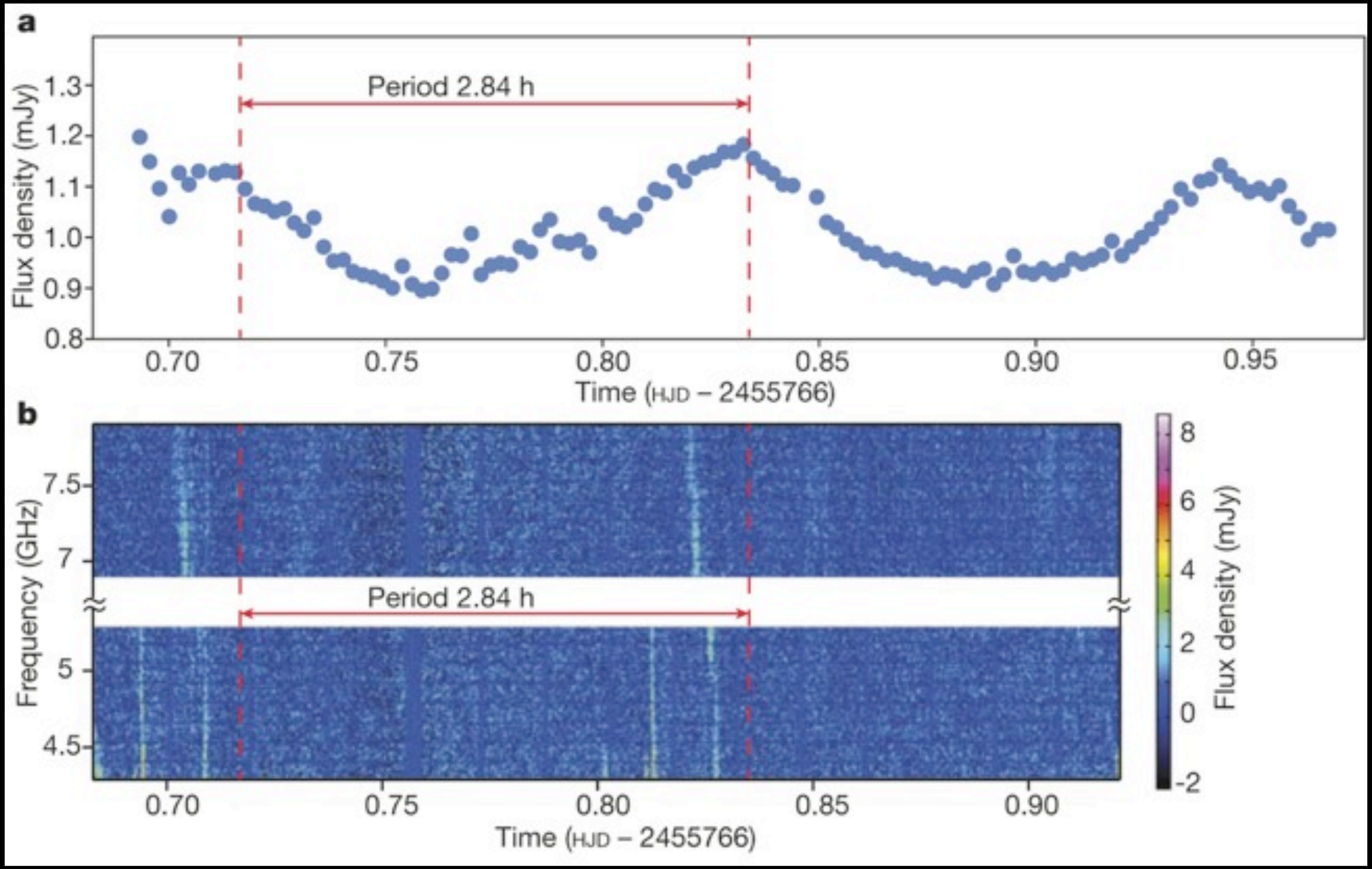
would confirm chromospheric evaporation scenario inferred from time relation between soft X-ray and radio/optical tracers of particle acceleration. Solar studies saw blueshifted plus stationary component.

need signal on short timescales (minutes) which may still be hard

Dynamos at the End of the Main Sequence

New physics!

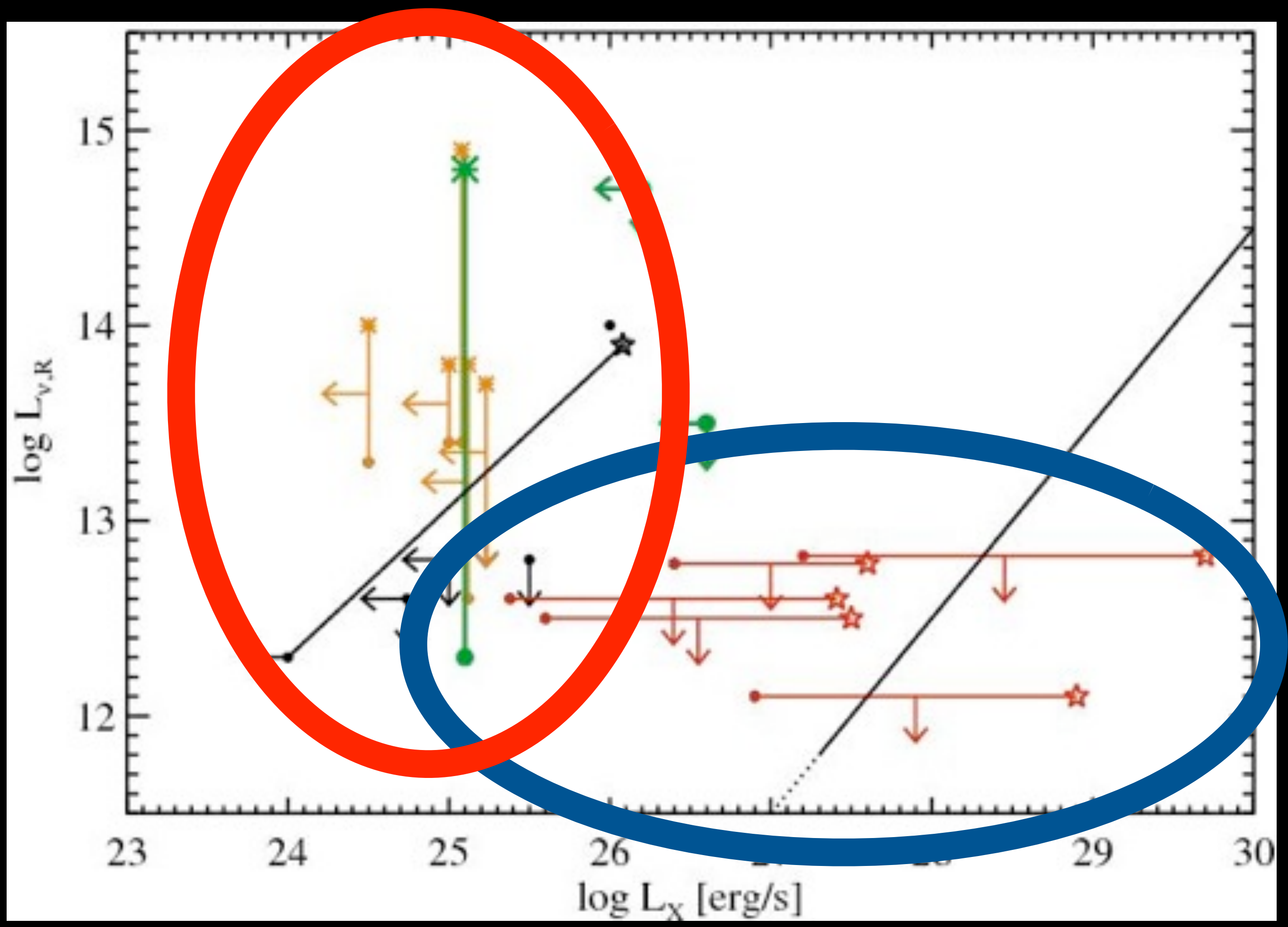
Radio observations suggest transition from stellar coronal behavior to rotation-powered magnetospheres



Hallinan et al. (2015) Nature

Dynamos at the End of the Main Sequence

bimodality of L_x, L_r may indicate two different magnetic processes at work



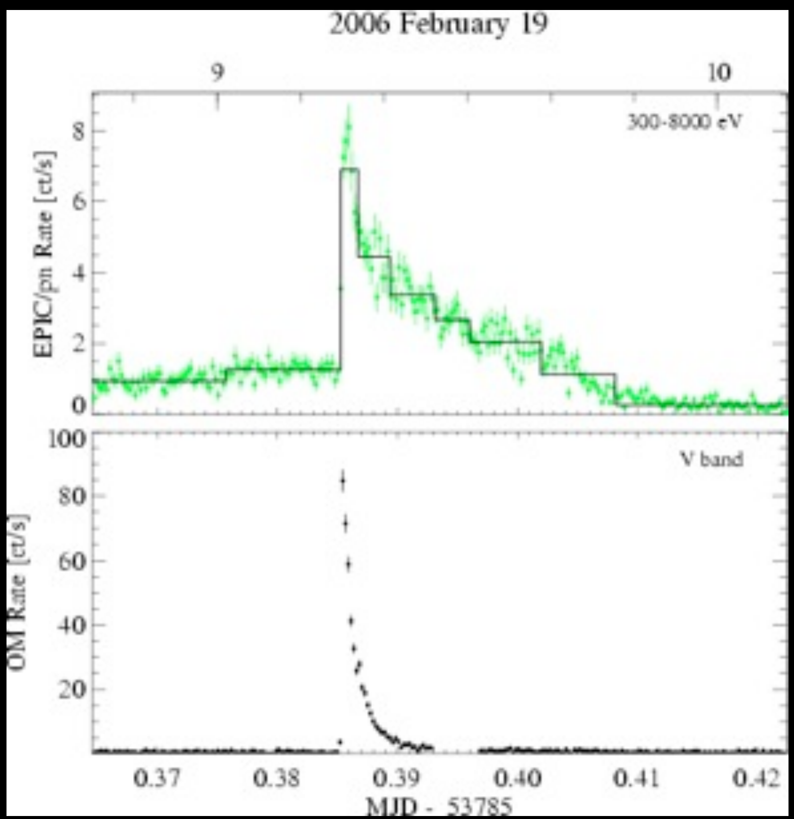
Gudel-Benz relation for solar flares, active stars

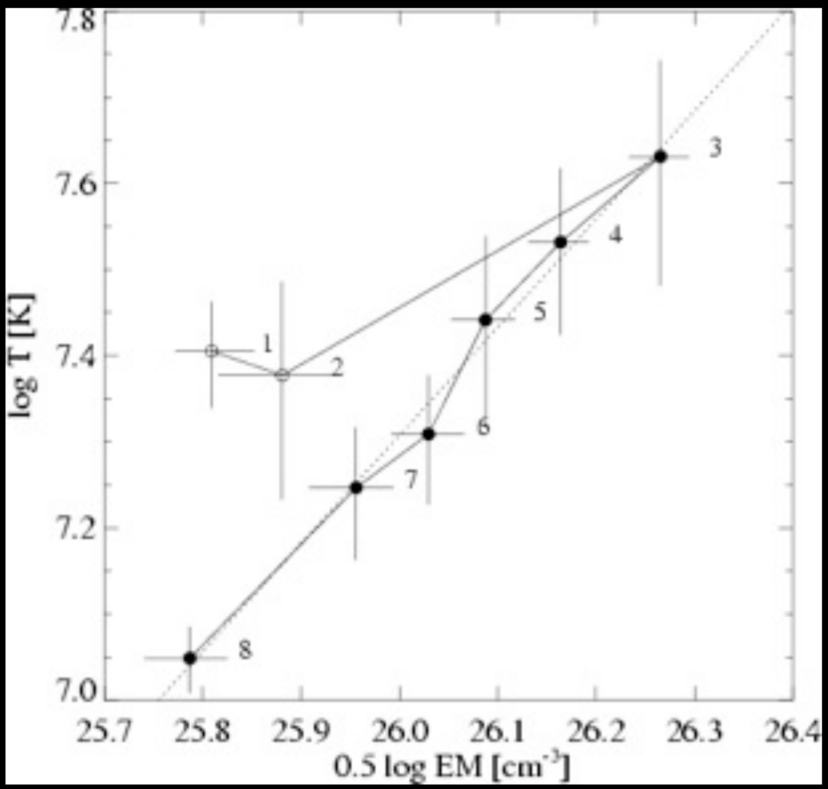
"radio-loud/X-ray quiet"
and
"X-ray-loud/radio quiet"

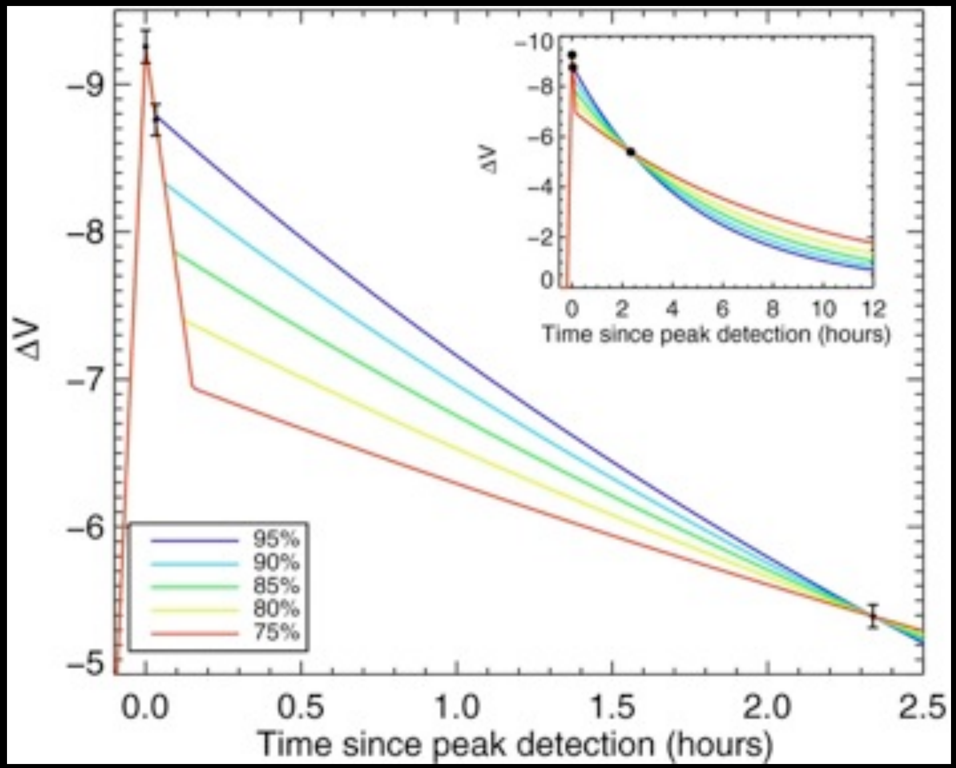
Stelzer et al. (2012)

Dynamos at the End of the Main Sequence

coronal flaring, spectacular optical flaring







ΔV=6 magnitudes in the optical!

$E_x=10^{32}$ ergs, equivalent to the largest solar flares

M8V caught in a giant X-ray/optical flare:

Stelzer et al. (2006)

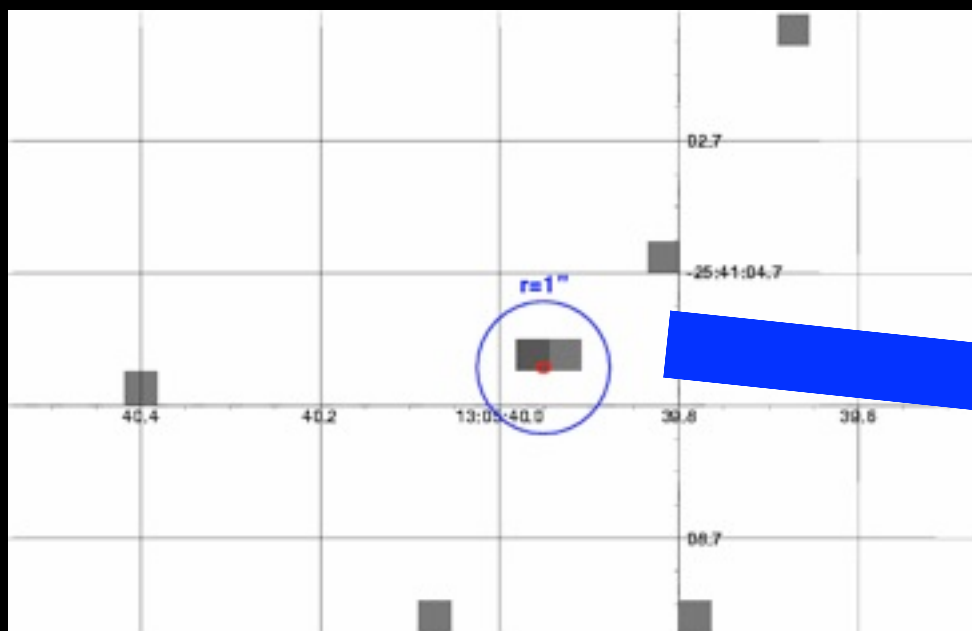
temperature, VEM evolution suggests coronal flare activity, with loop length scale ~R_*

Schmidt et al. (2014)

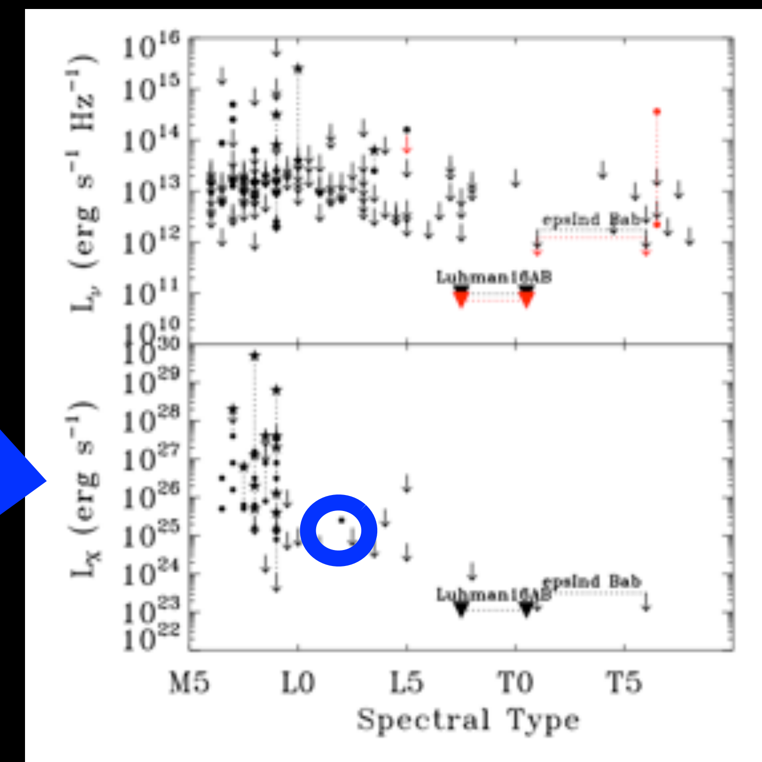
M8V caught by ASAS-SN survey; ΔV=9.25

Dynamos at the End of the Main Sequence

need sensitivity and spatial resolution



4 photons= detection!
Audard et al. (2007)

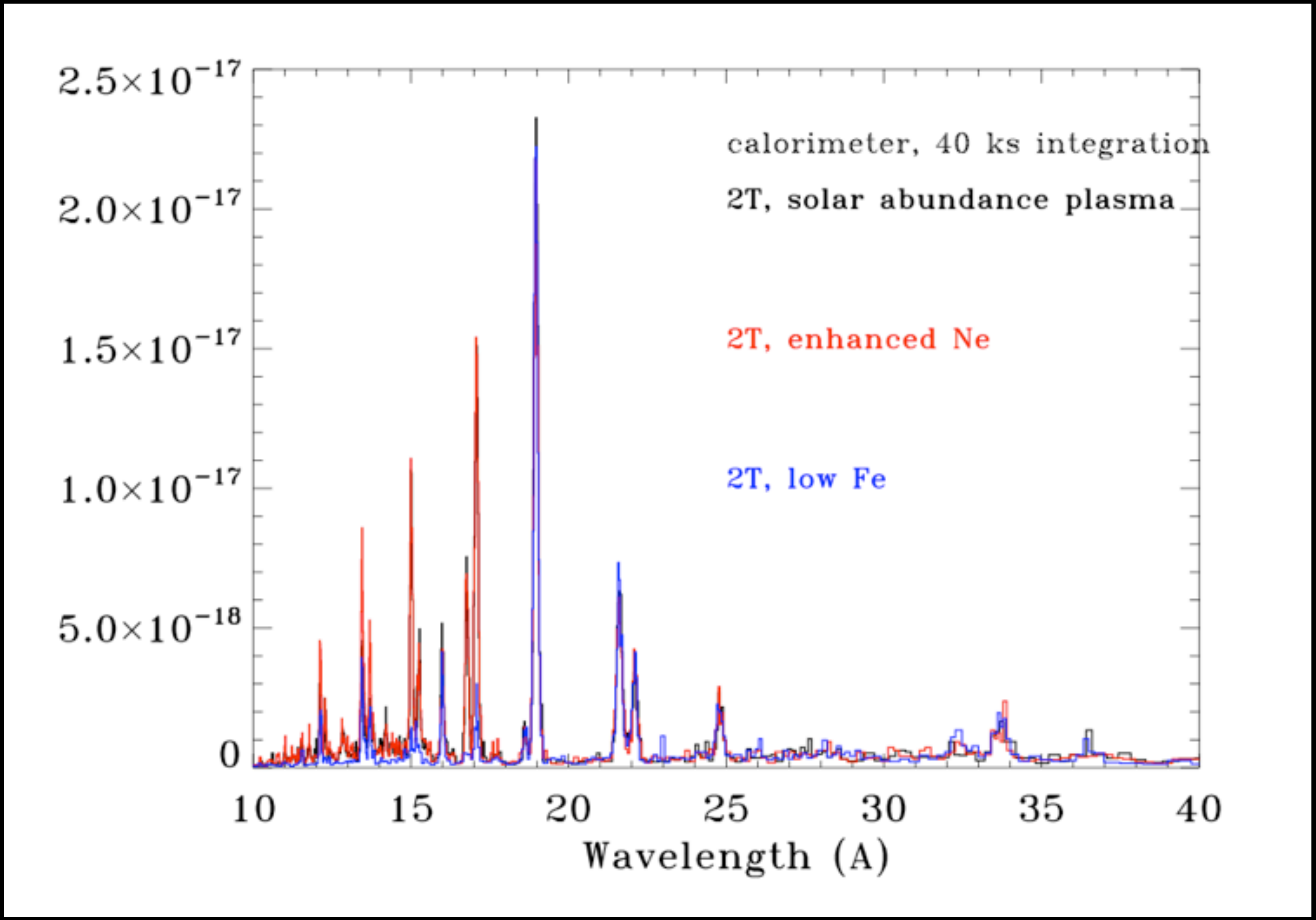


Osten et al. (2015)

Stelzer et al. (2005)

Dynamos at the End of the Main Sequence

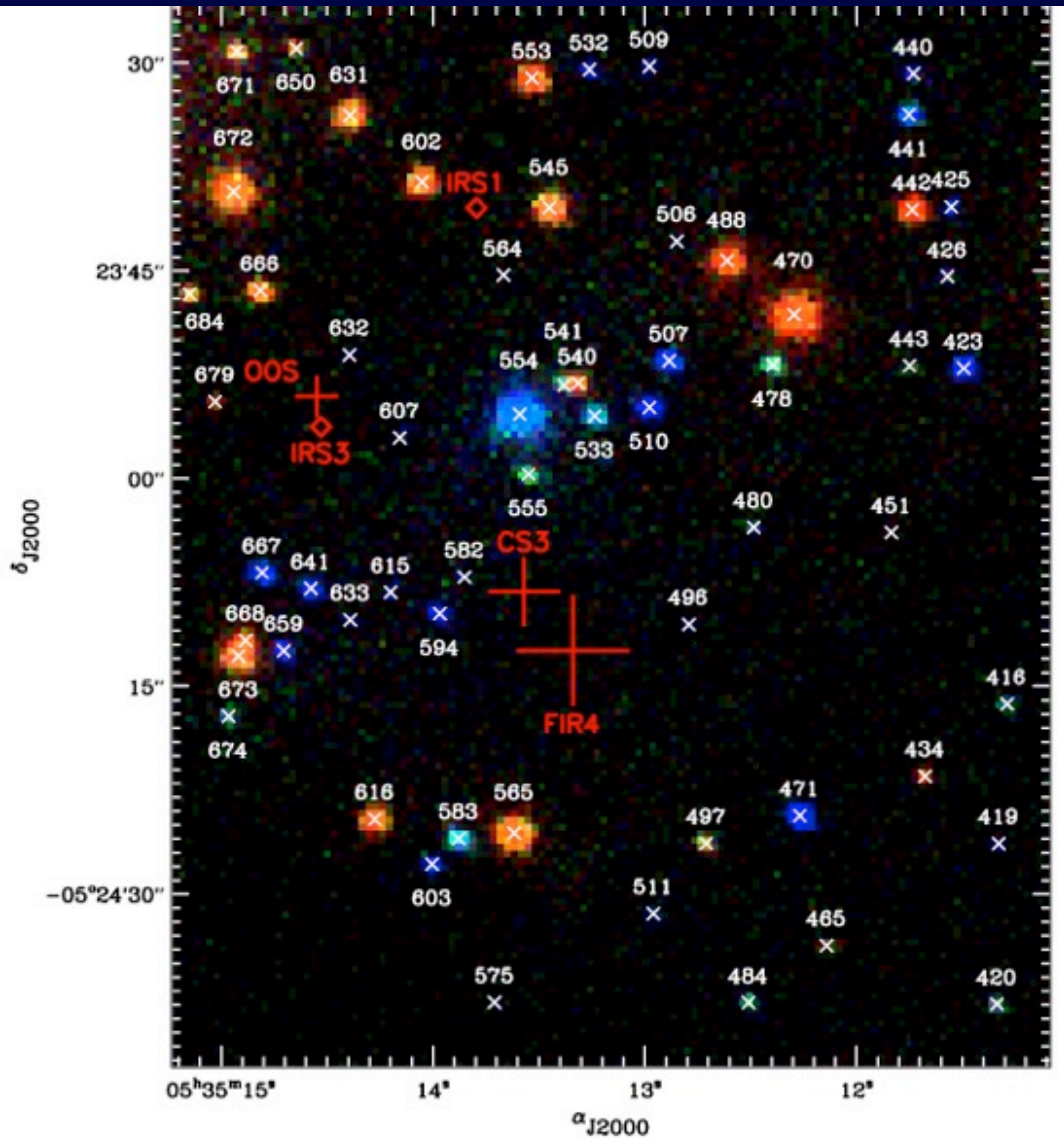
need sensitivity and spatial resolution



X-rays & star, planet formation

- finding the young stars through their X-ray emission
- impact of XEFUV radiation on disk lifetimes through irradiation
- processes controlling X-ray emission: magnetic reconnection, shocks and associated plasma

X-rays & star, planet formation: finding the young stars



COUP; Feigelson et al. 2005

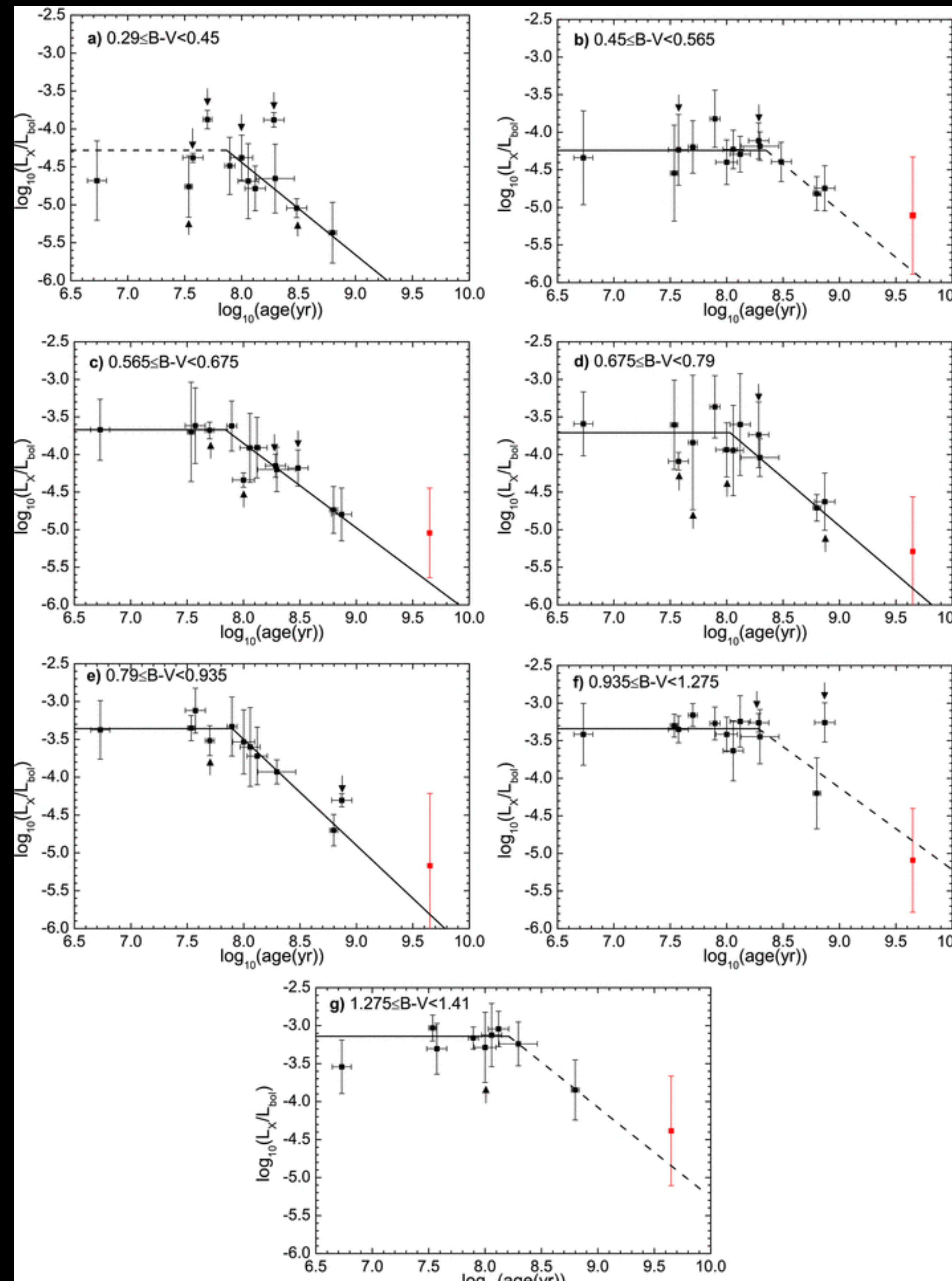
McCaughrean 2005

X-rays & star, planet formation

at early times, $L_x \propto$ mass
once in unsaturated regime,
$L_x \propto P_{rot}$, $P_{rot} \propto$ age

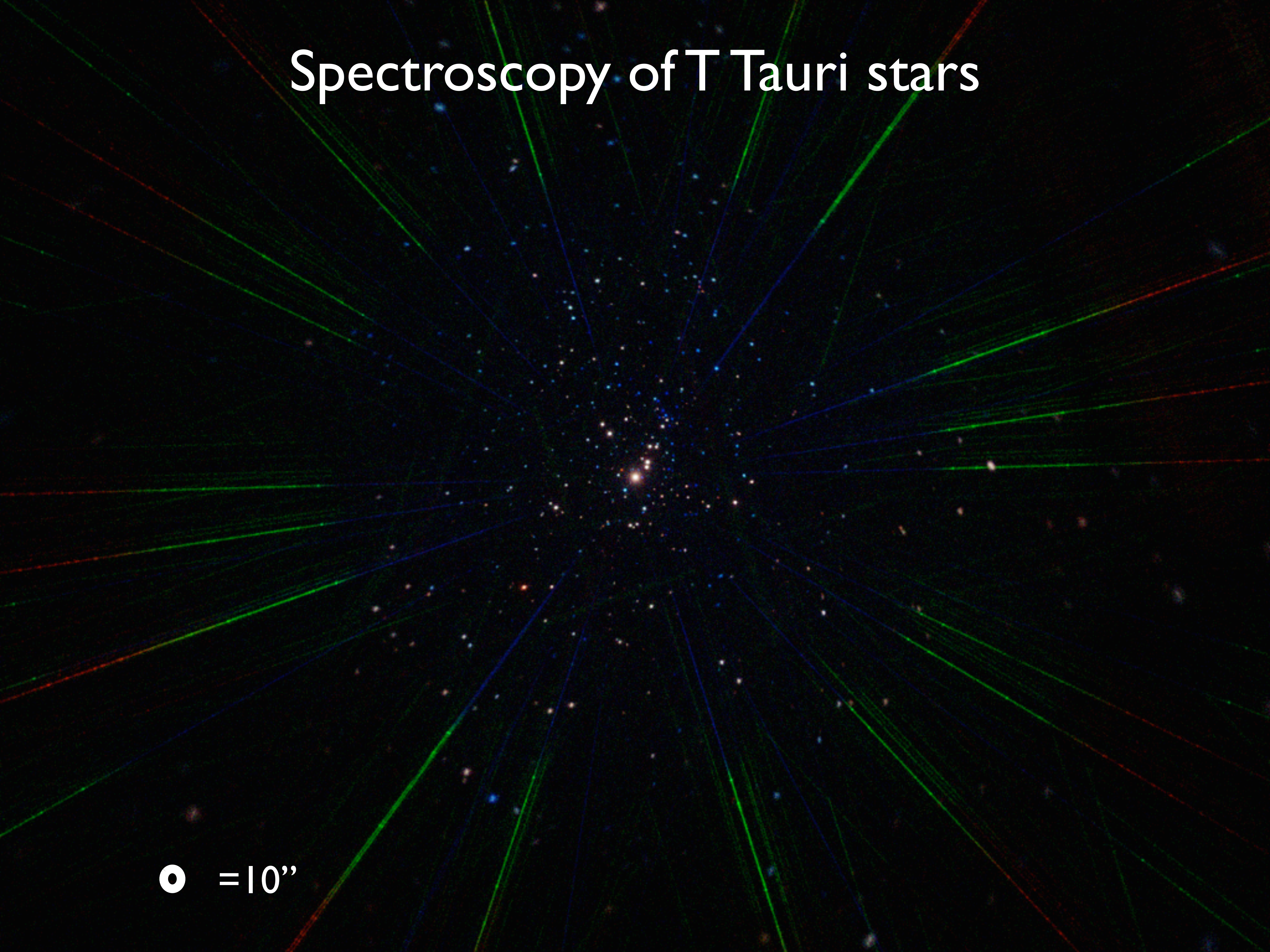
XUV flux of stars as a function of time is important for investigating photo-evaporation of exoplanet atmospheres: can remove large amounts of H, He from highly irradiated planets through hydrodynamic mass loss

detailed X-ray studies move from description to explanation



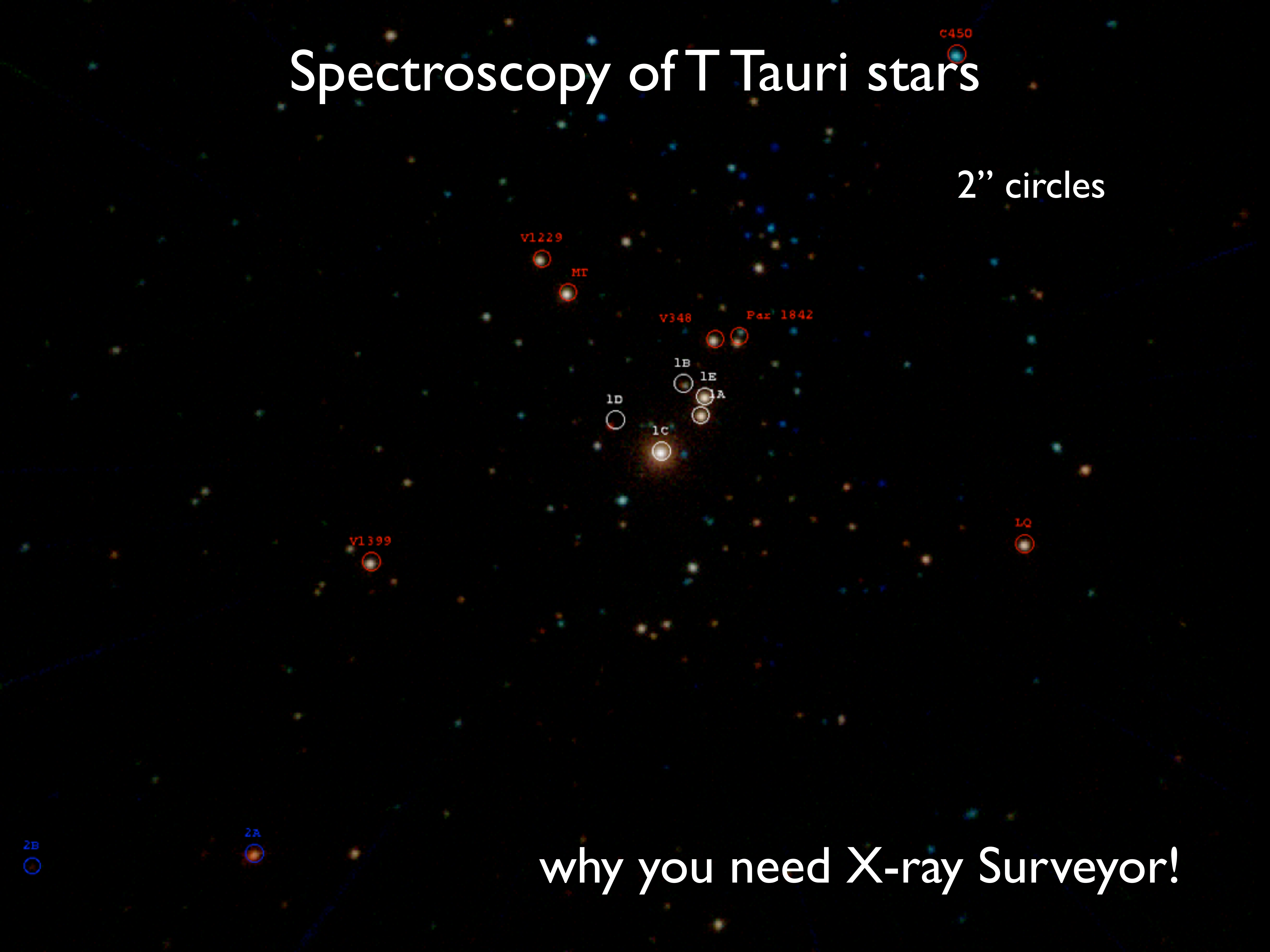
Jackson et al. 2012

Spectroscopy of T Tauri stars



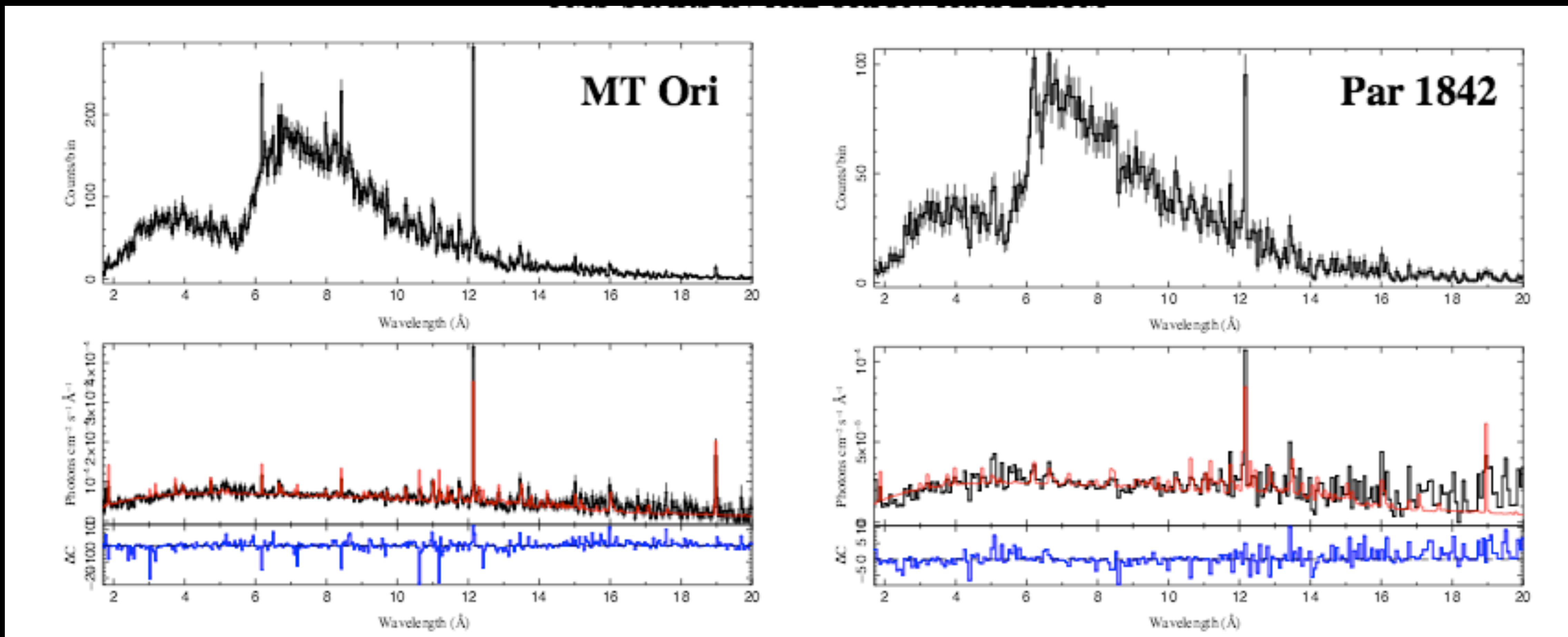
Spectroscopy of T Tauri stars

2” circles



why you need X-ray Surveyor!

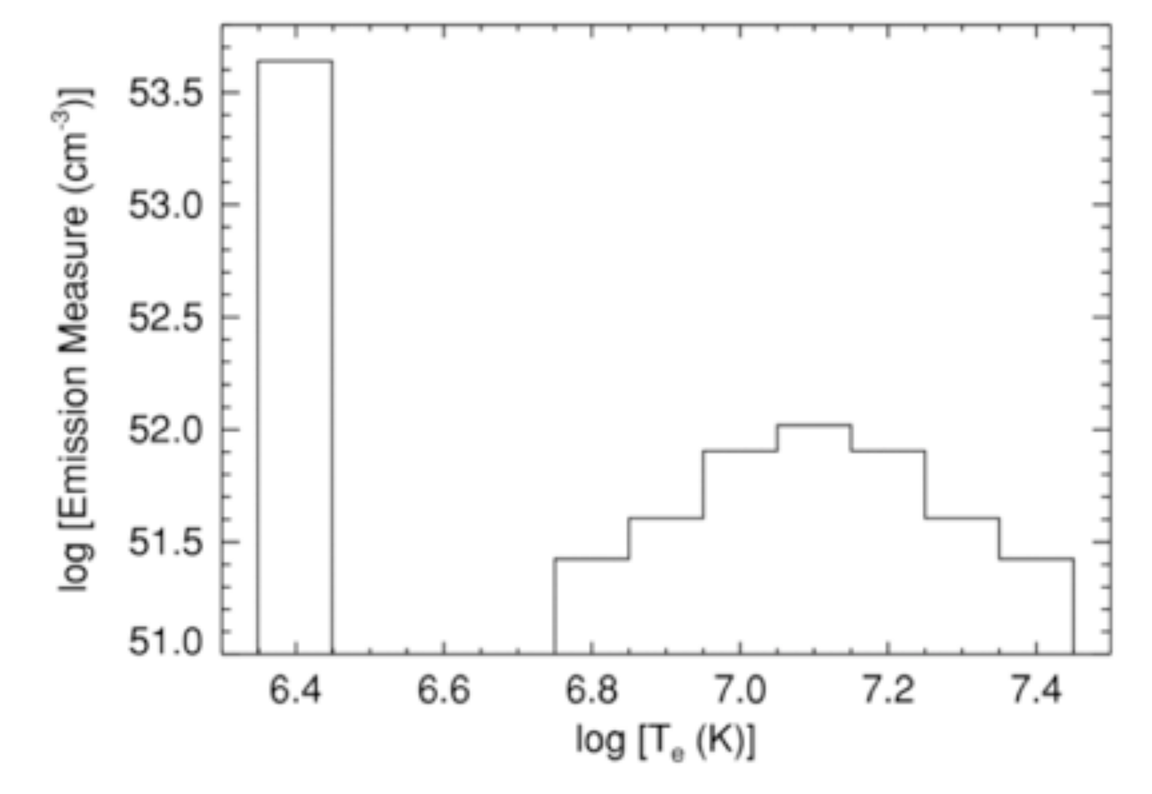
Spectroscopy of T Tauri stars

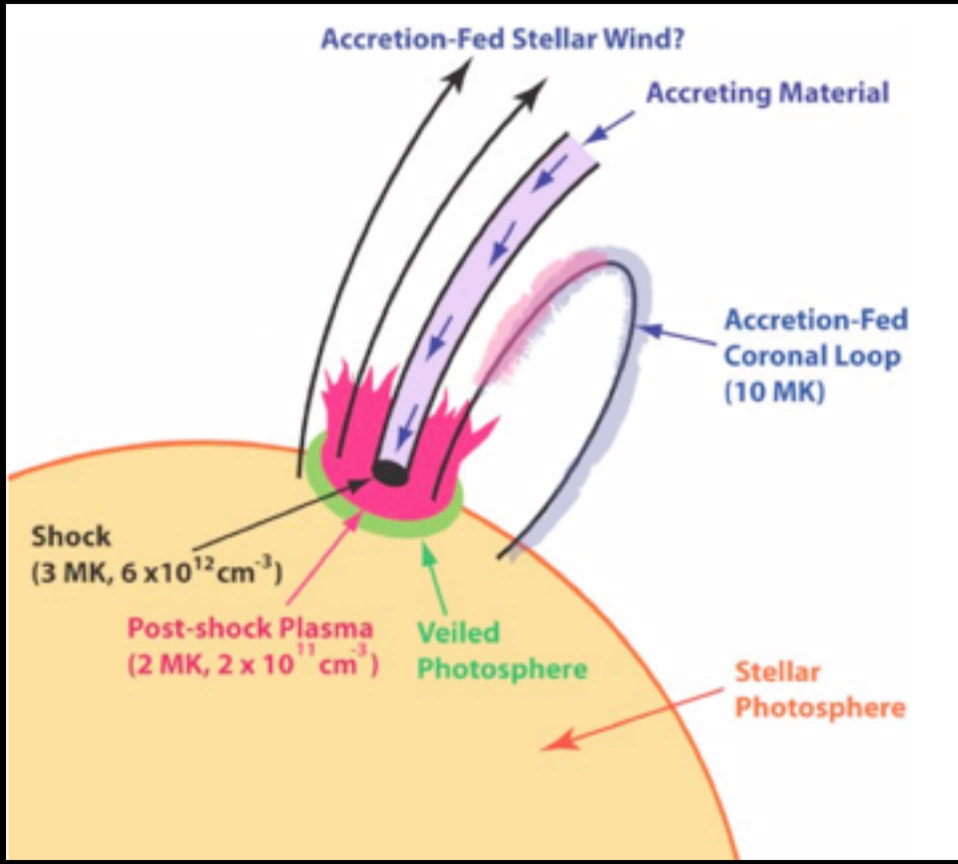


Schulz et al. (2015)

see also poster by Gunther, Huenemoerder, Schulz

Accretion spectral diagnostics

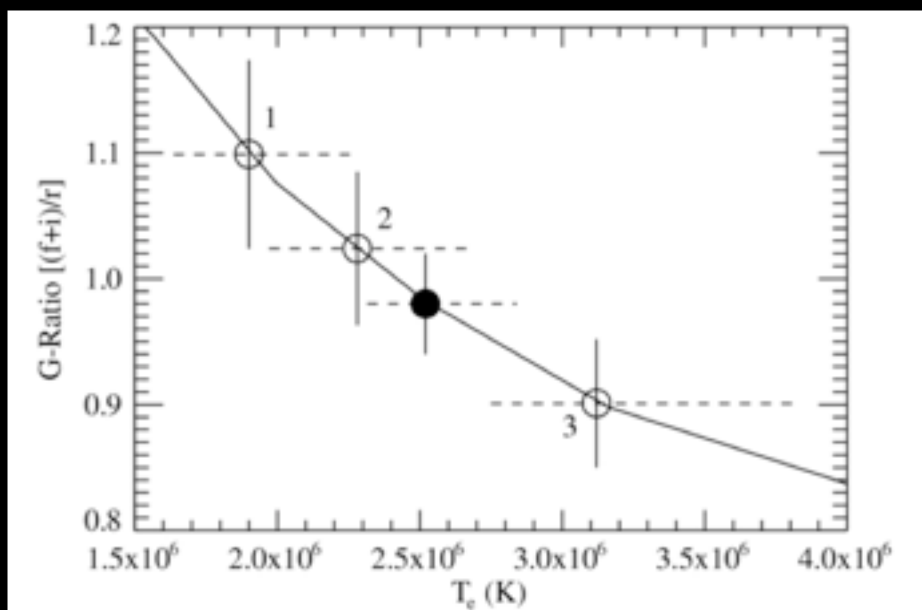


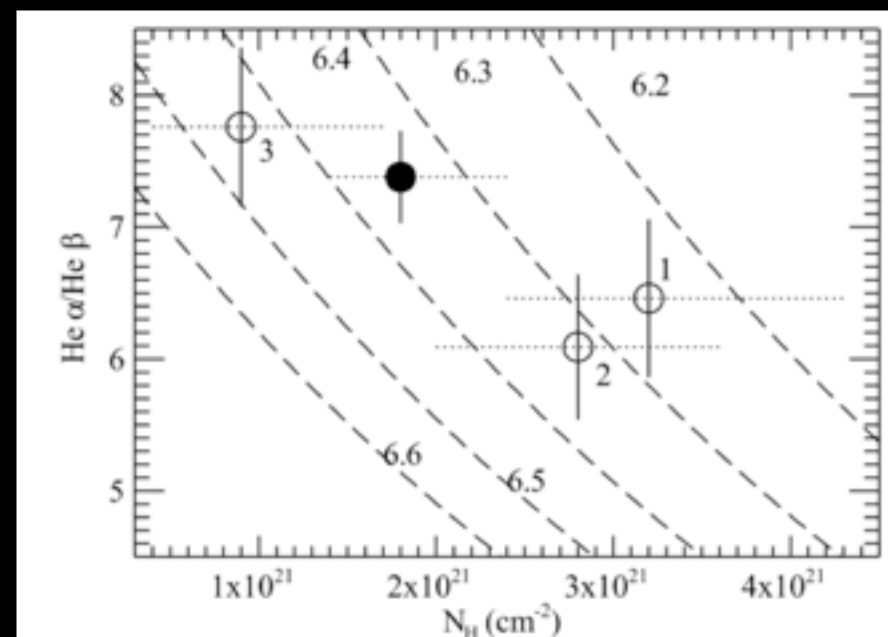


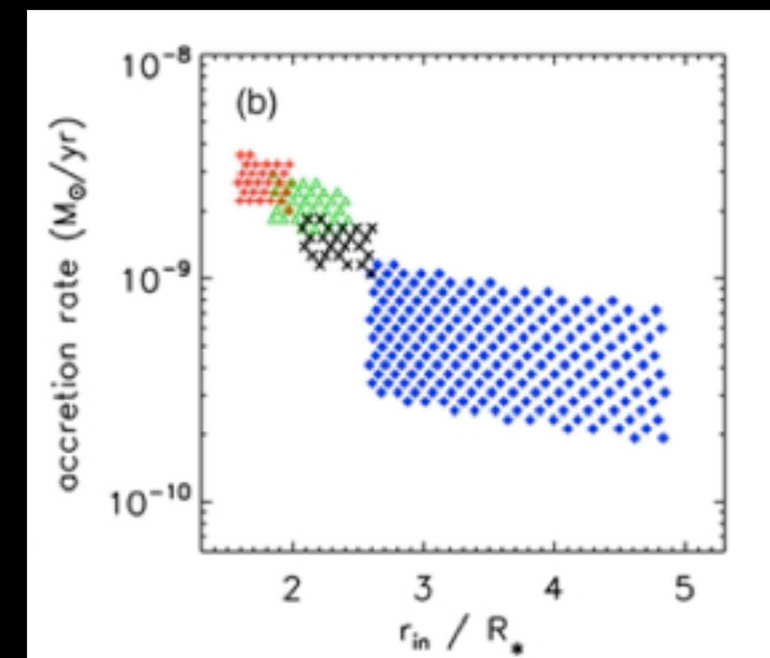
Brickhouse et al. (2010)

The impact of a high quality X-ray spectrum: need more than accretion source + coronal source to explain all the miriad diagnostics (electron density, electron temperature, absorbing column)

Accretion spectral diagnostics



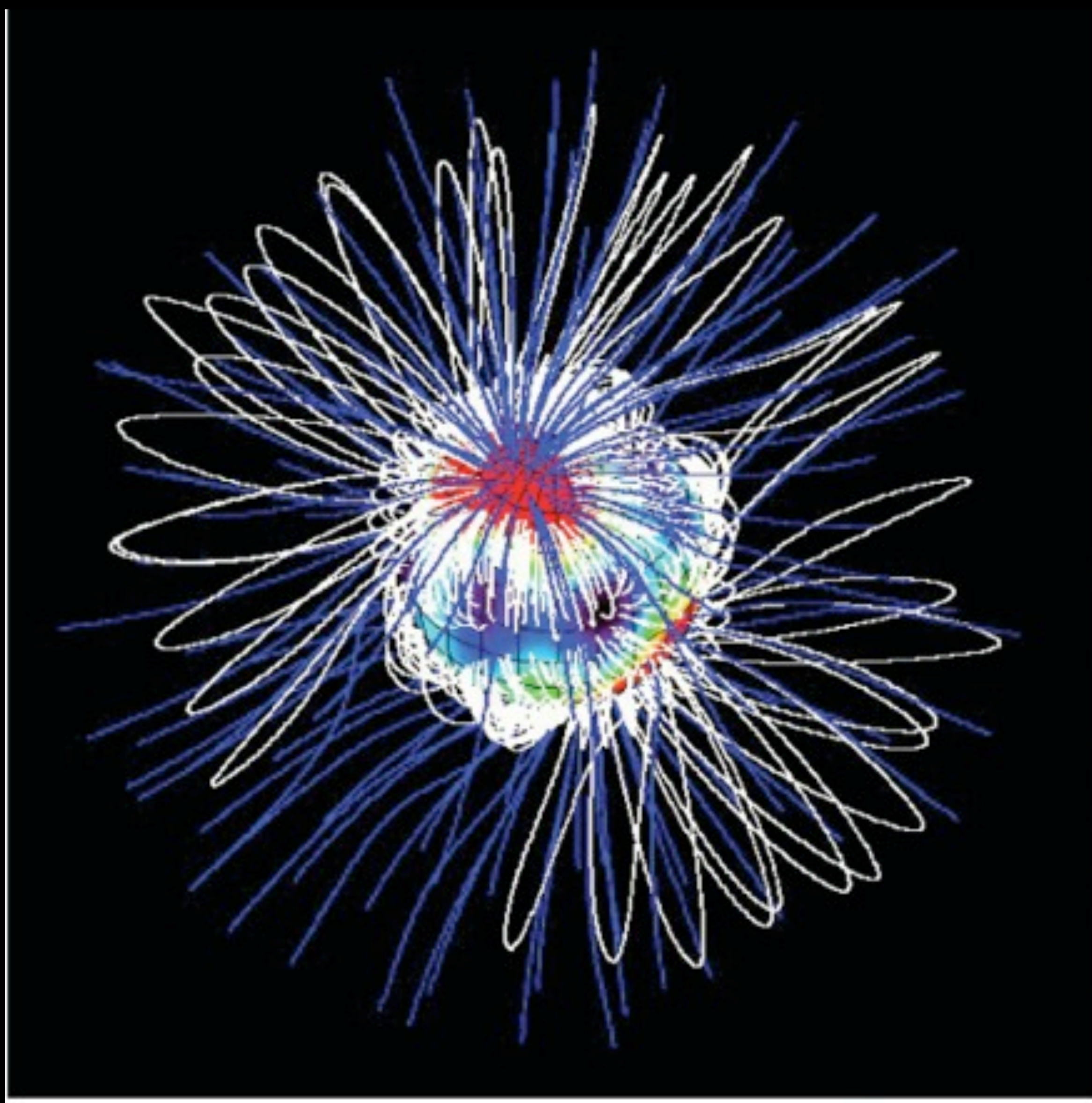




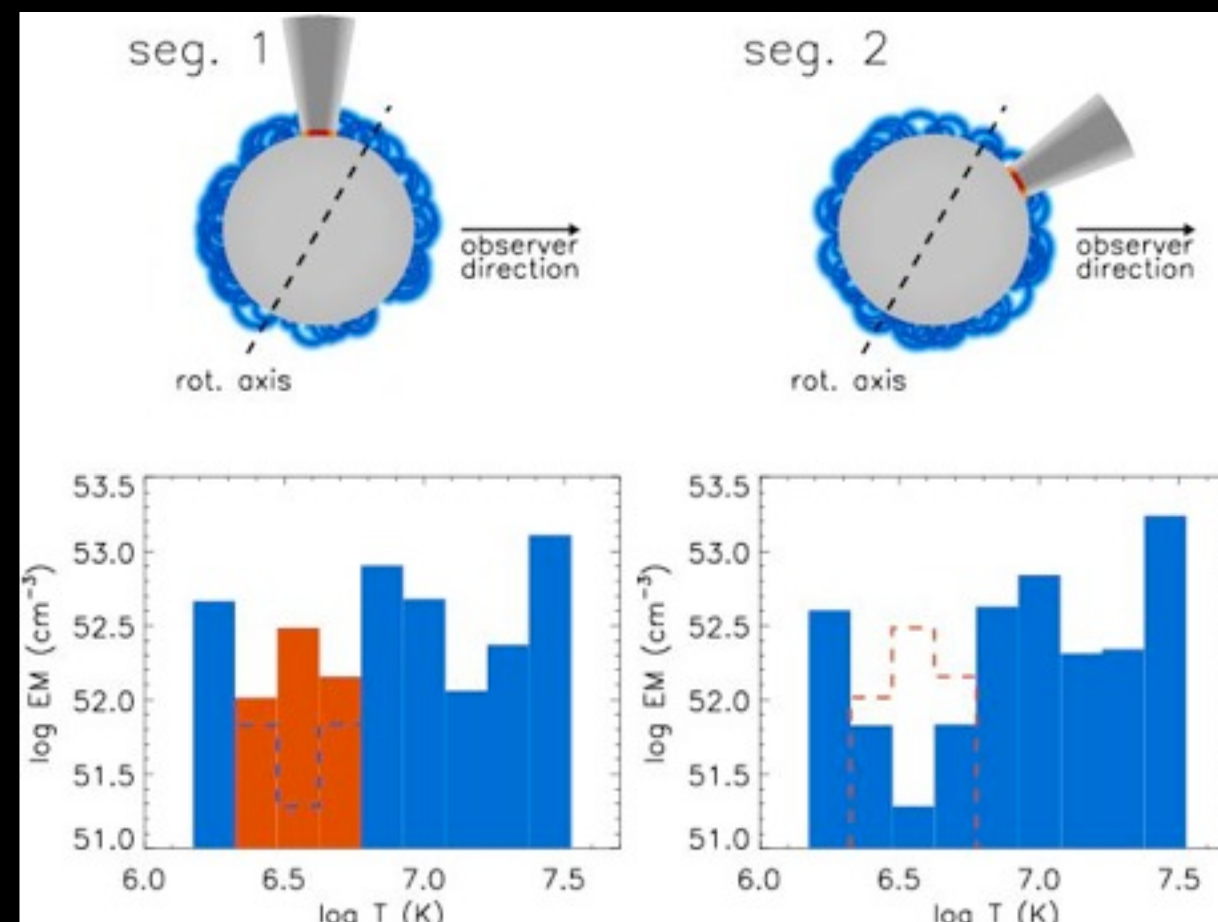
Brickhouse et al. (2012)
X-ray diagnostics for determination of accretion rate

photon-starved science: of ~120 nondegenerate targets of grating observations in Chandra archive, only ~10 have been T Tauri stars

Connecting photospheric structures to coronal structures



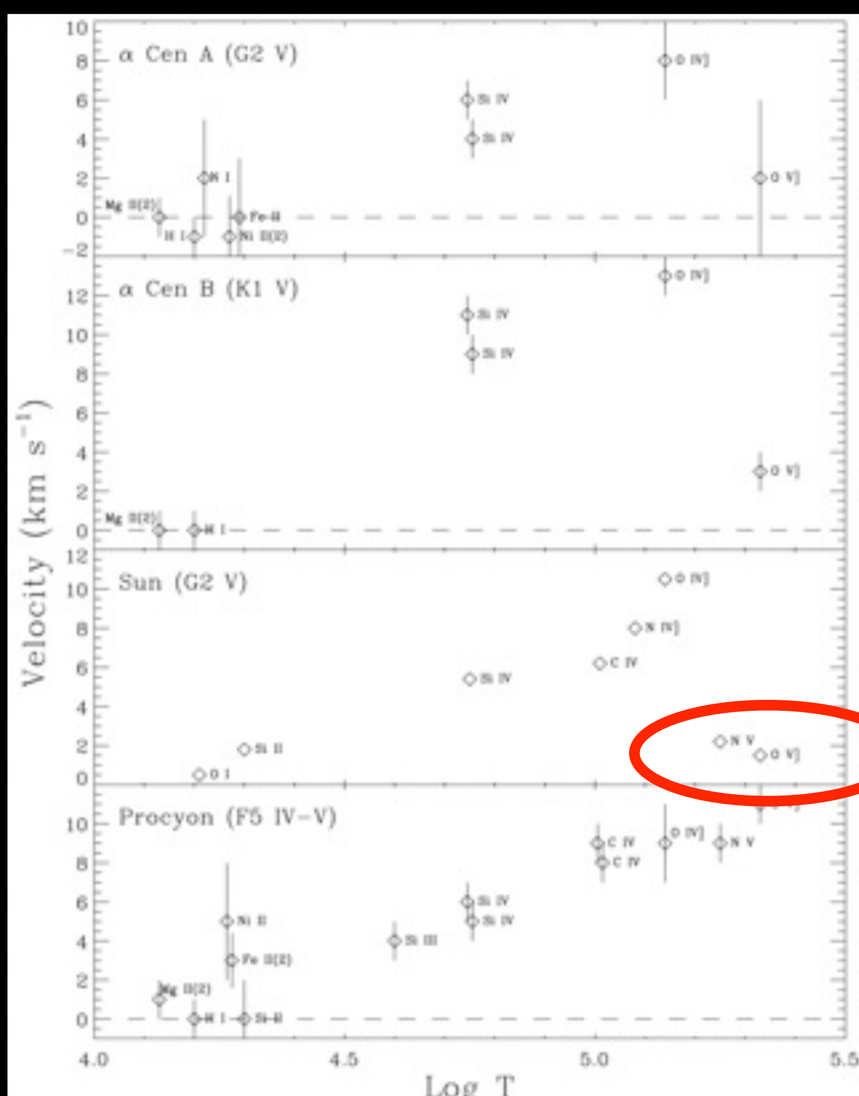
Donati J.-F, Landstreet JD. 2009.
Annu. Rev. Astron. Astrophys. 47:333–70



cTTS V2129 Oph
Argiroffi et al. (2011)
blue=coronal emission
orange=accretion

Taking a Cue from Stellar UV High Resolution Studies

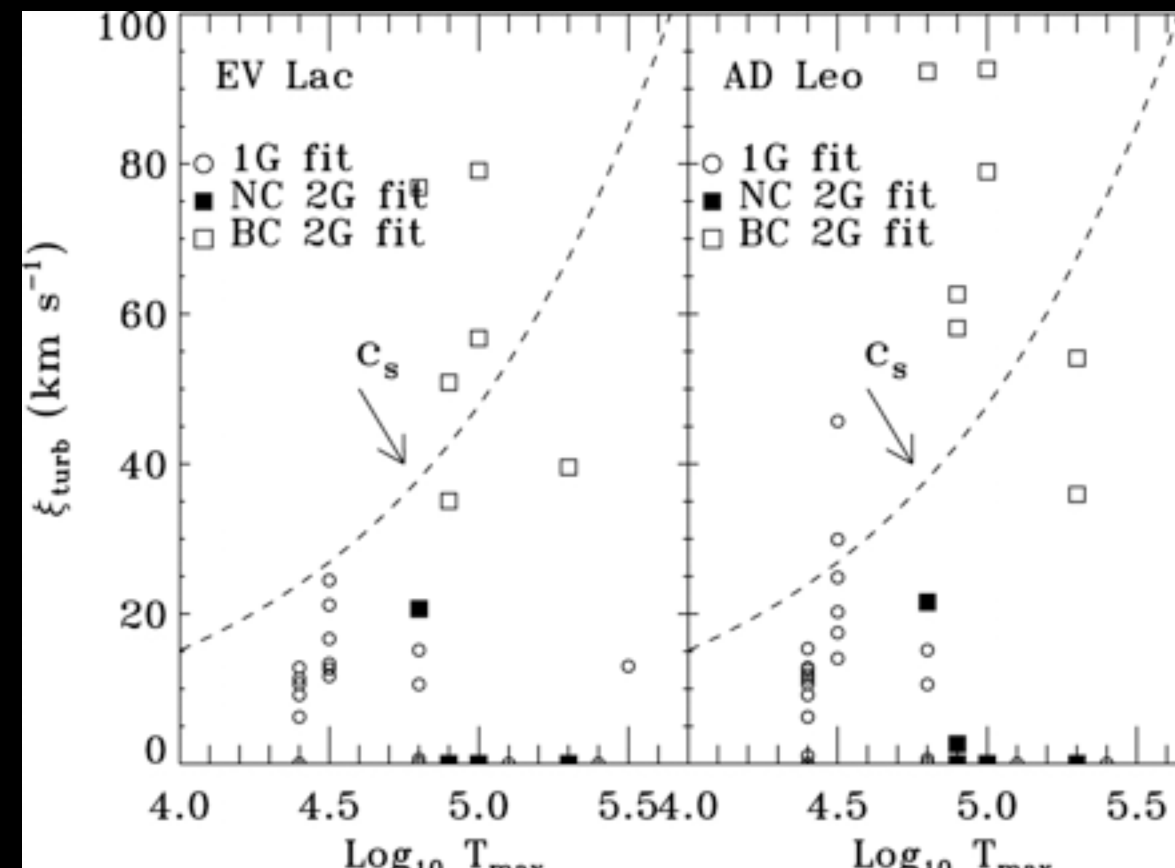
redshift vs formation temperature: constraints on flows, waves



Wood et al. (1997)

R=5000➔ 60 km/s

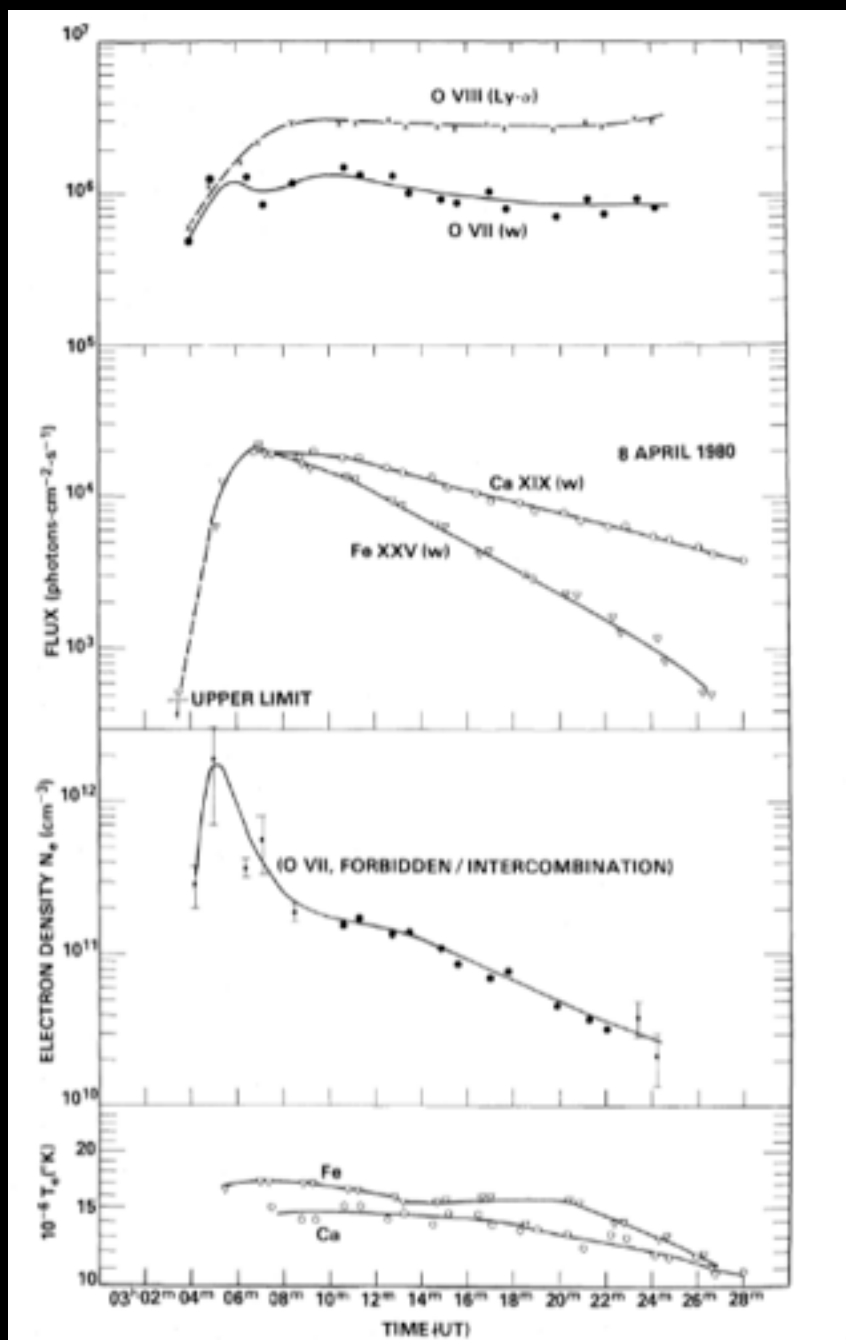
changes to **blueshifts** in solar corona



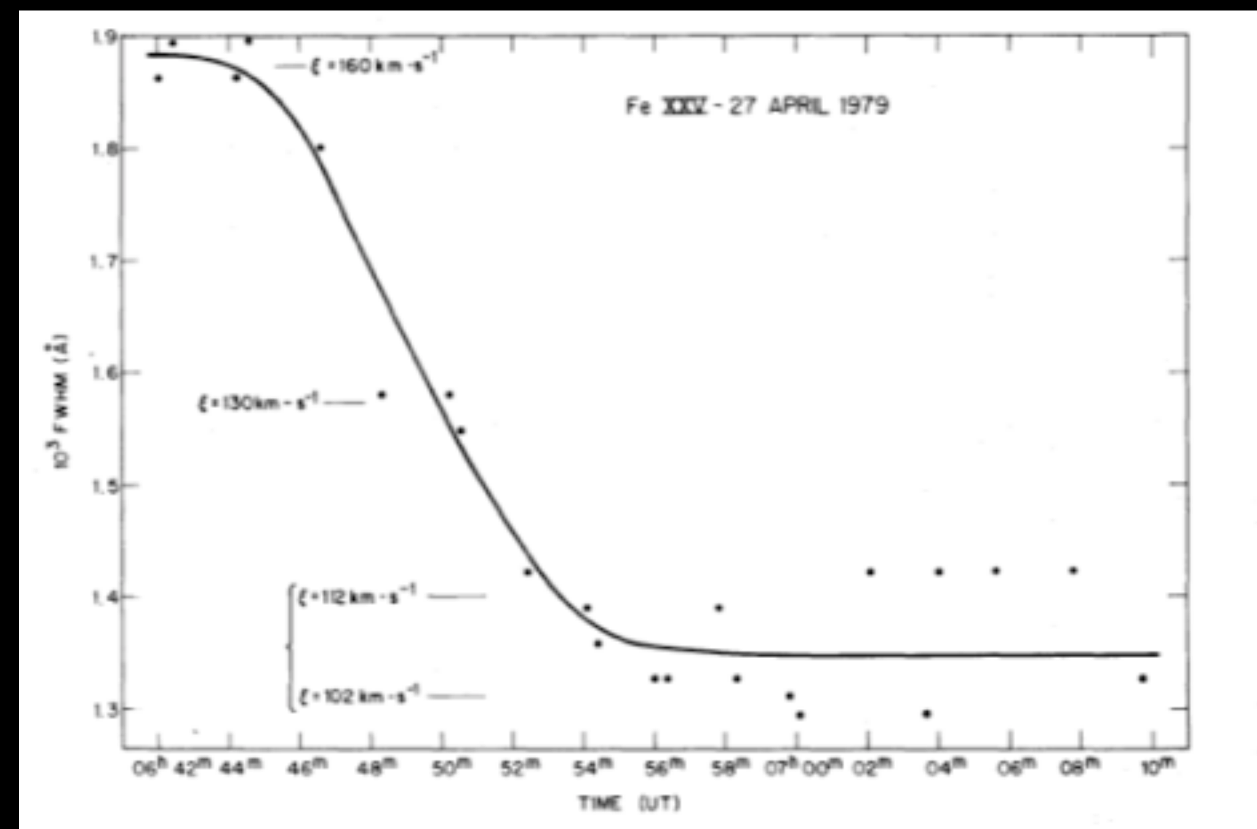
excess broadening in line profiles: turbulence in atmospheres

Osten et al. (2006)

Perspective: High Spectral Resolution Solar Studies



Doschek et al. (1981)



Doschek et al. (1980)

density changes with time during flare
blueshifts during impulsive phase of flare

Why is this important?

- Connection to the Sun; get around extrapolating by >3 orders of magnitude in L_X, energy
- Connecting stars and planets
  - Stars as planetary hosts, environments they create
  - Continuity/discontinuity of magnetic processes