High-energy irradiances of Sun-like stars

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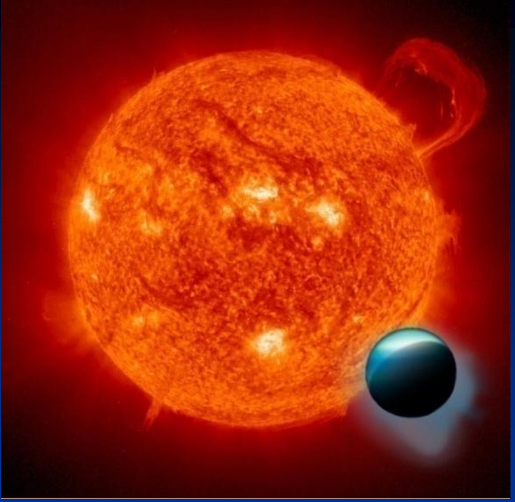
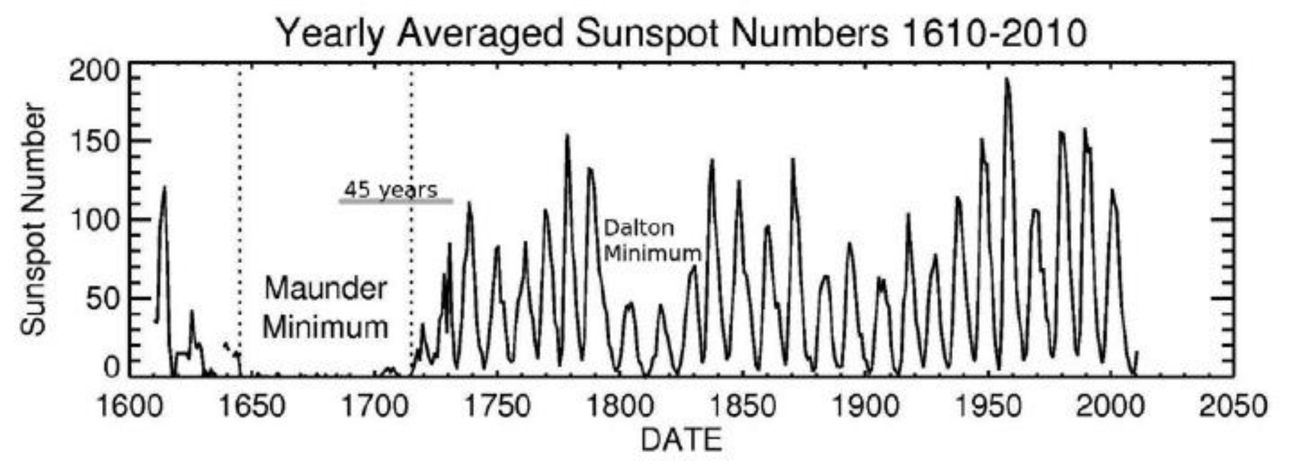
Outline

- Why should we care about XUV irradiation?
- Origin of XUV stellar radiation
- Stellar rotation, age and XUV
- How to know the XUV emission in other stars
- Watch out for stellar variability





Planetary climate

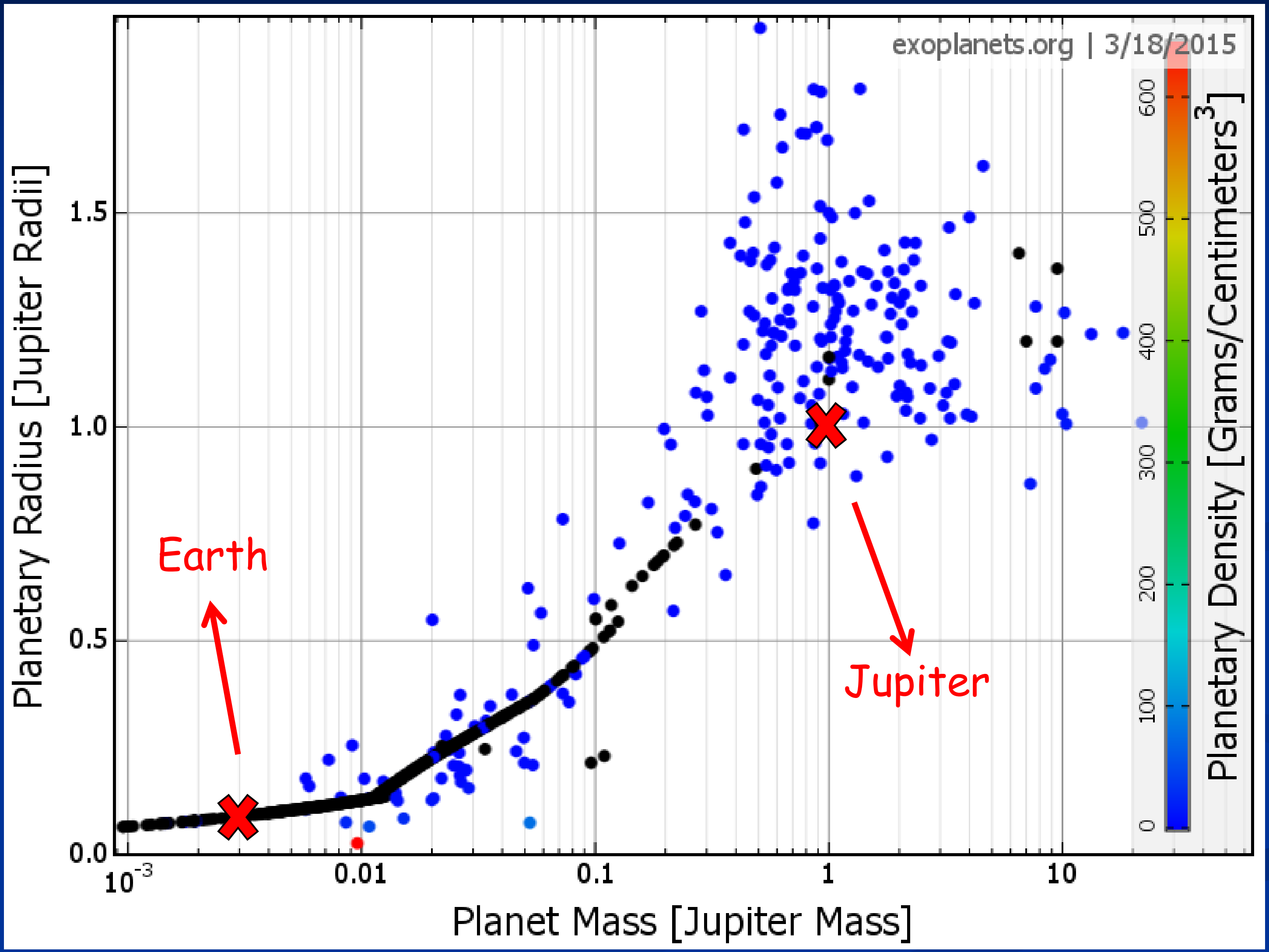
Atmospheric heating and evaporation

Atmospheric chemistry

Life evolution

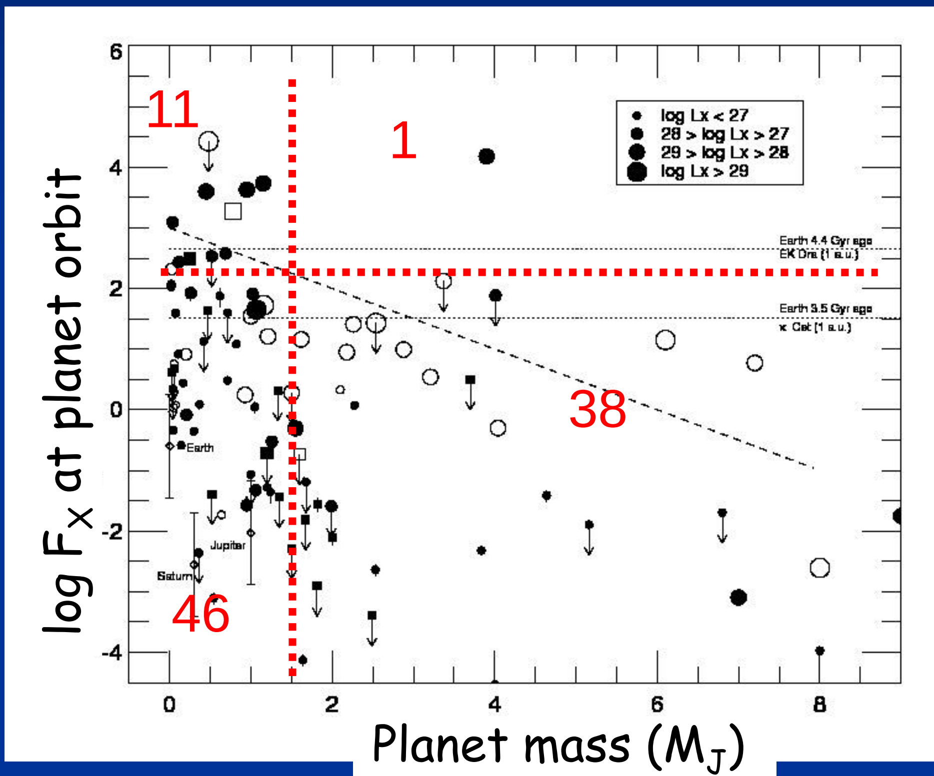
Aurorae

Transiting planets have short period orbits, thus they are very close to the star (bias)...



... they receive much XUV radiation, they are inflated

X-ray flux vs planet mass

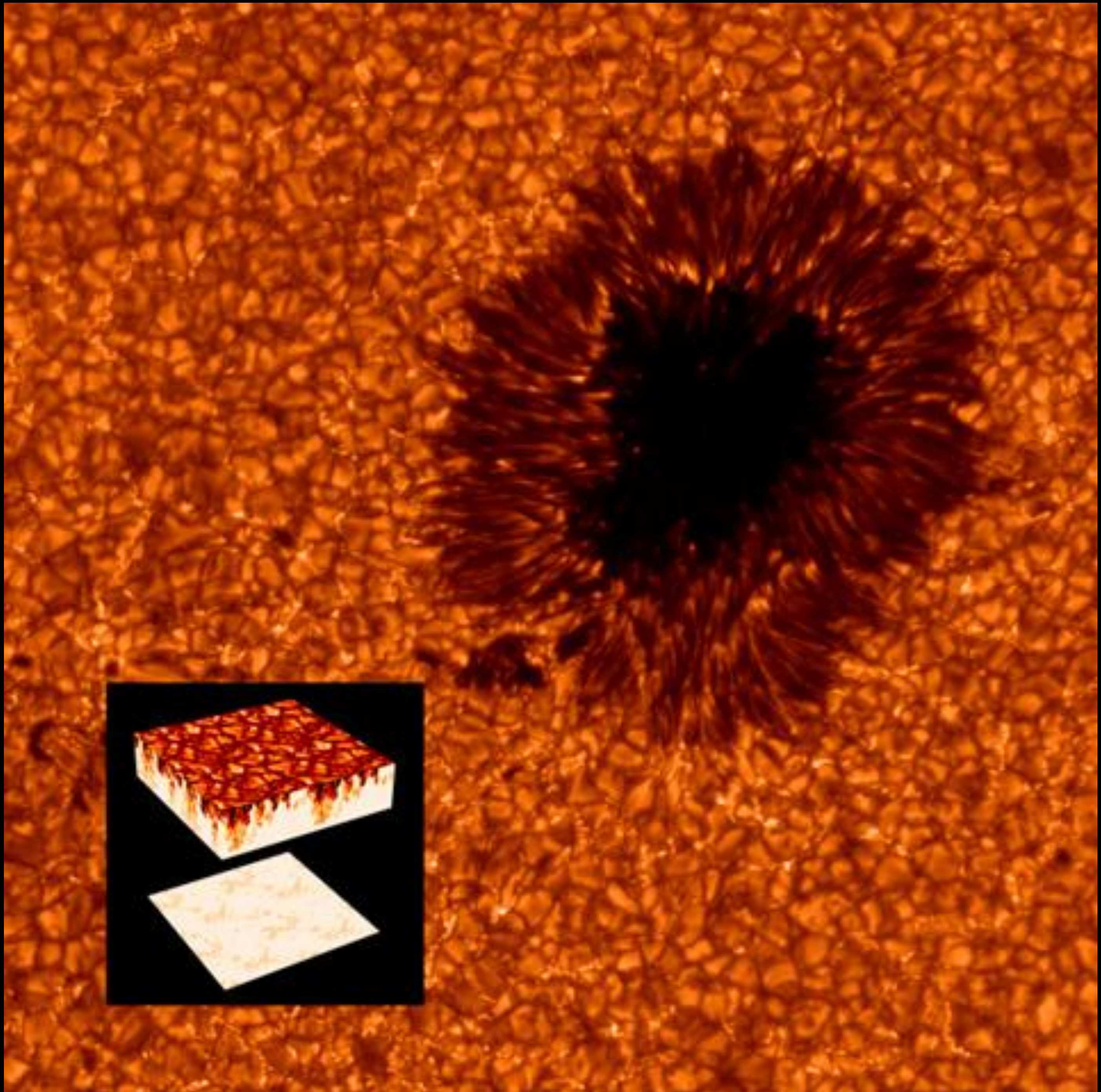


Sanz-Forcada et al. (2010, 2011)

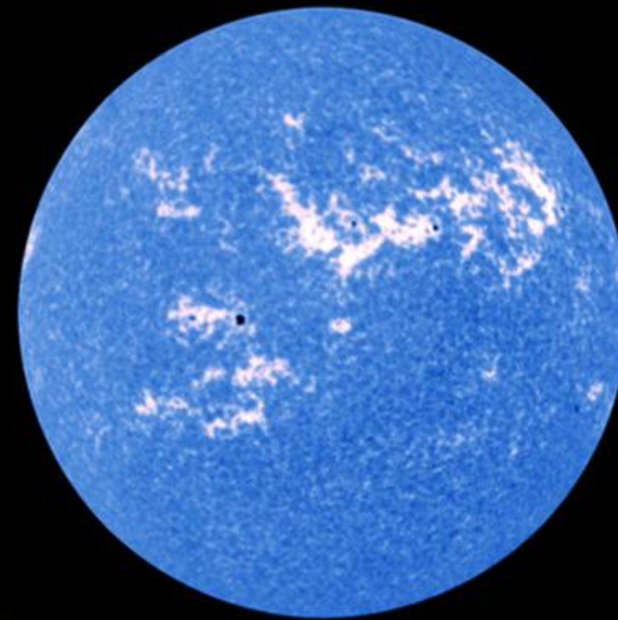
● Dwarfs ○ ROSAT ◊ Solar System
■ Subgiants ● XMM/Chandra

Lack of massive planets being irradiated.
Possible explanations:

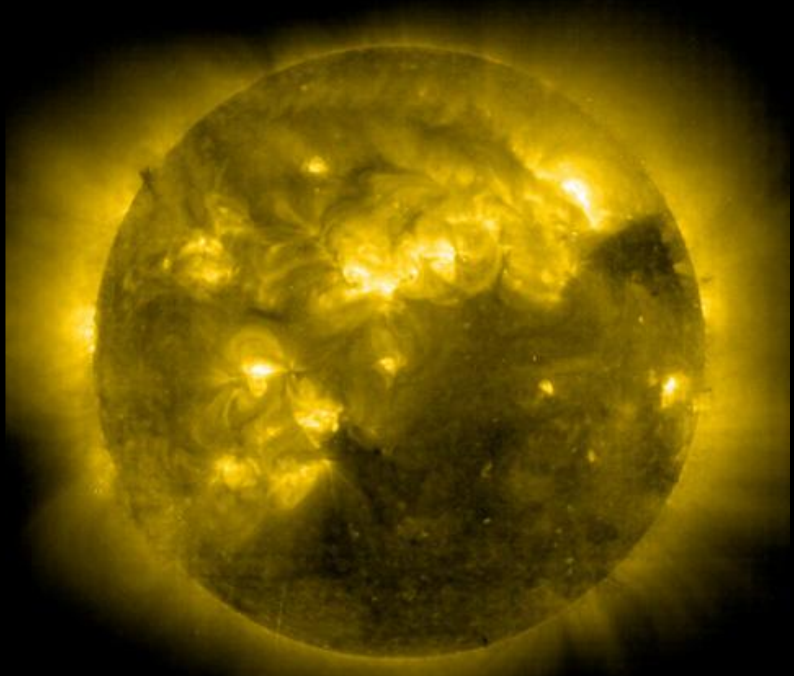
- Rapid mass loss during first Gyr
- Effects of planet formation
- A combination of both



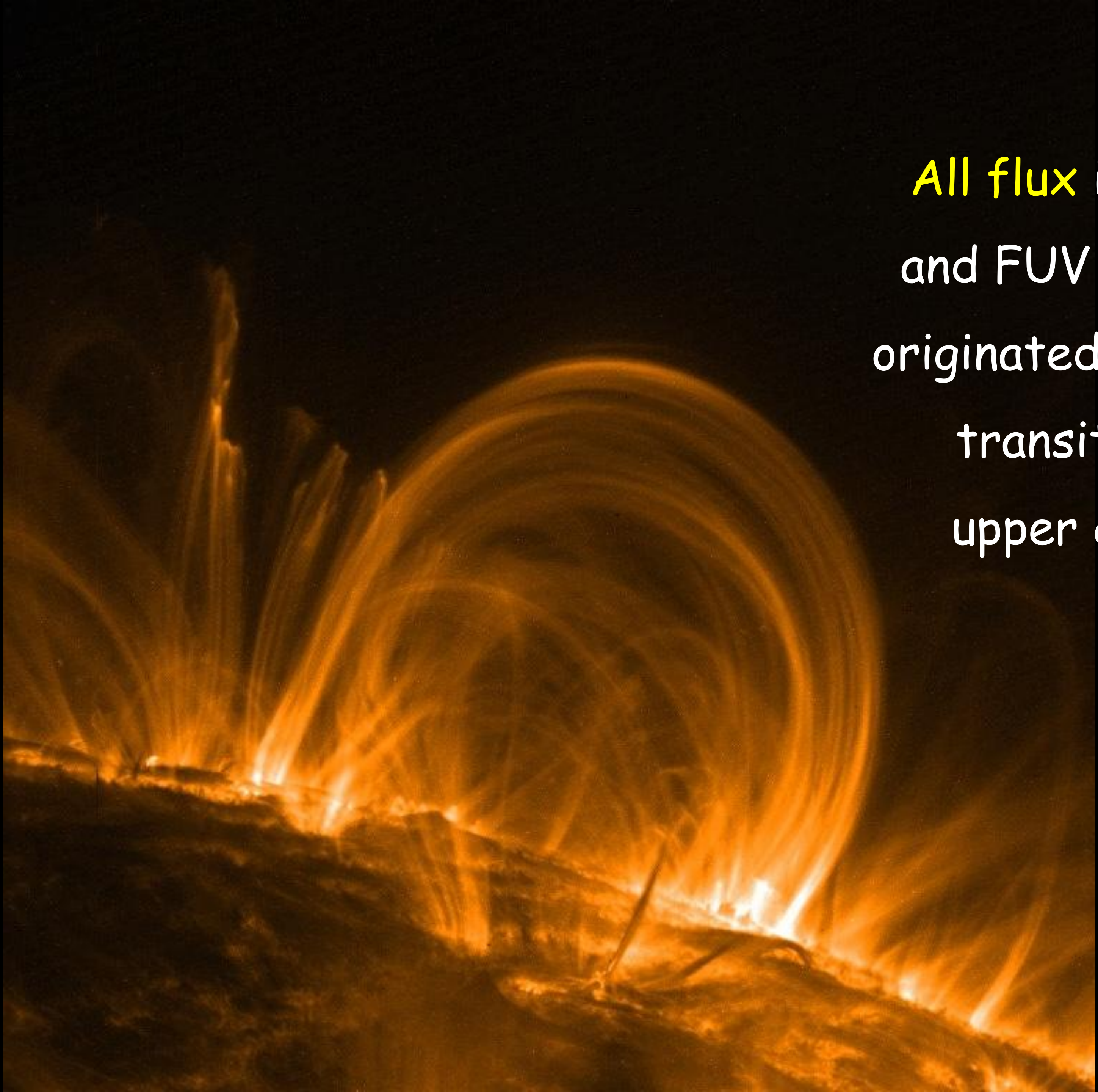
Photosphere
(visible, 5000 K)



Chromosphere
(H&K Ca II,
T~10,000 K)



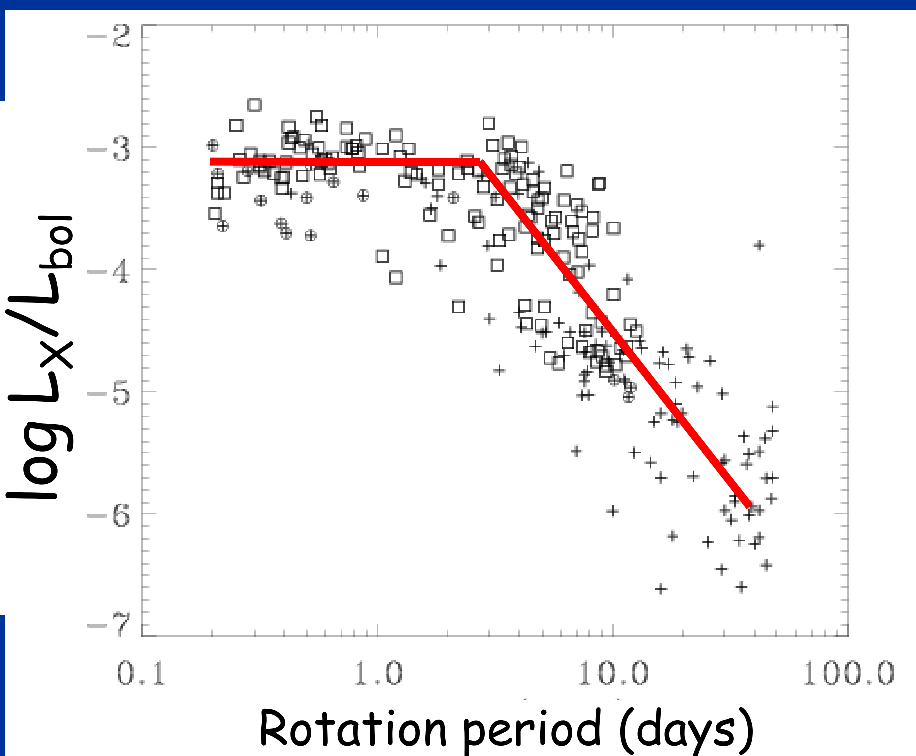
Corona
(Fe XIV, 2 MK)

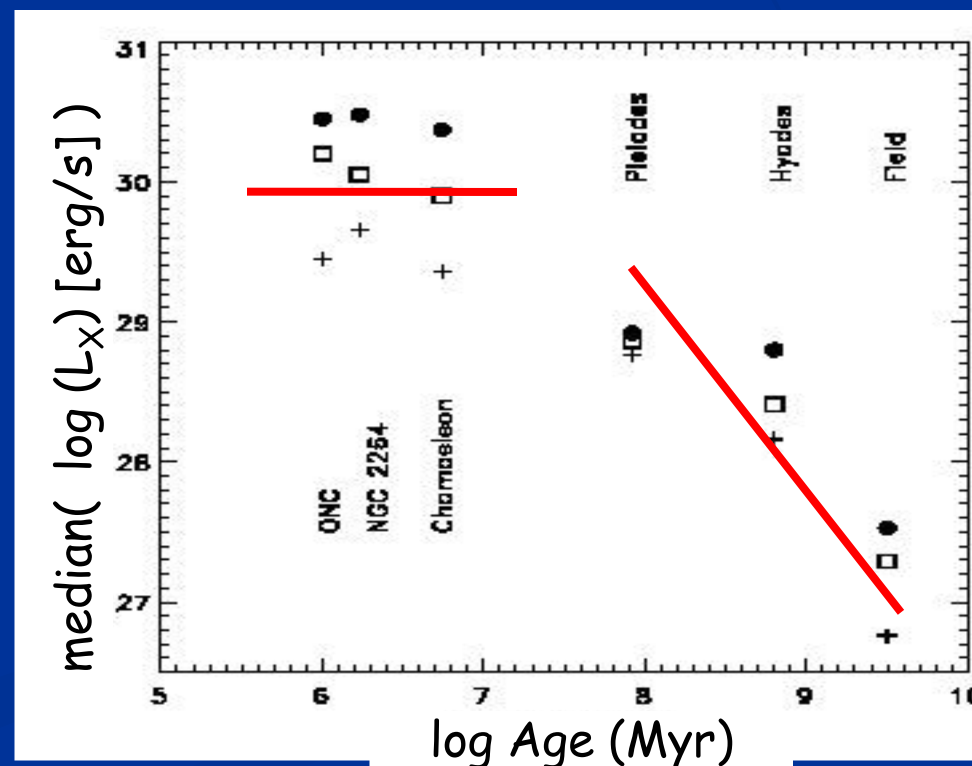


All flux in X-rays, EUV and FUV (≈1-1300 Å) is originated in the corona, transition region and upper chromosphere.

X-rays evolution with time

- Late type stars (F, G, K, M) have a corona.
- Activity depends on rotation. Rotation depends on age
- X-rays will decrease as star gets older (slower rotator)



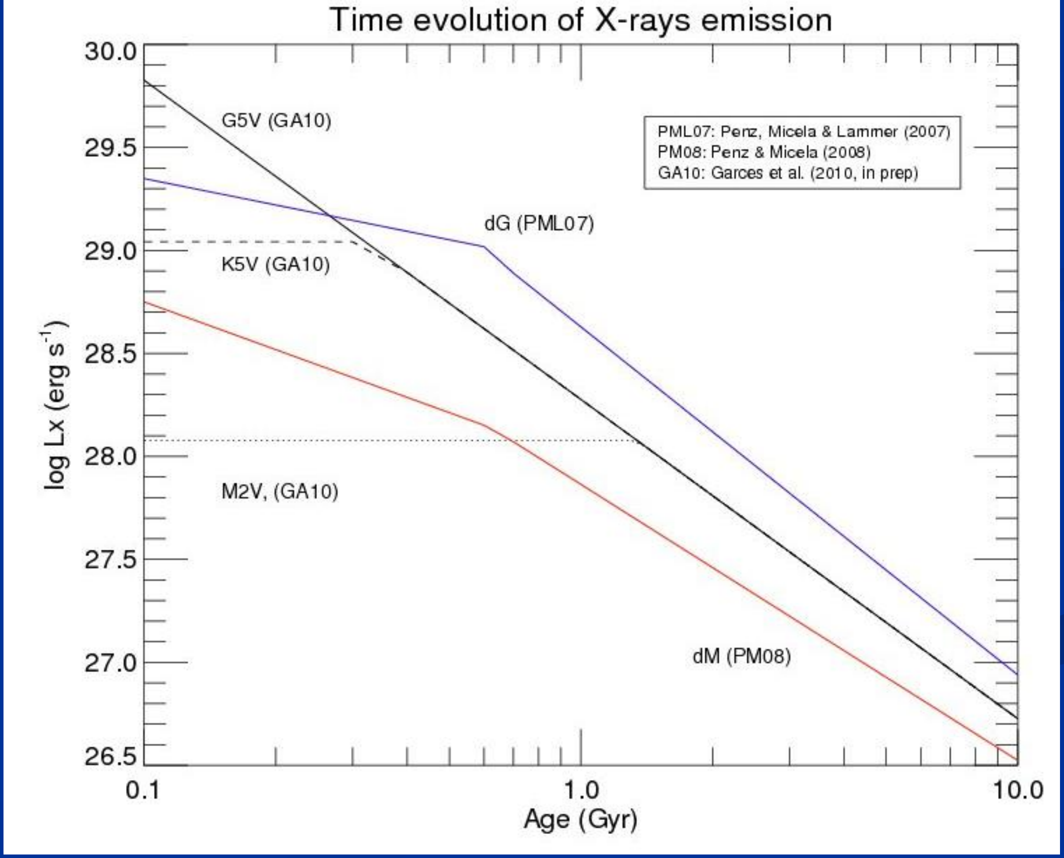


Time evolution of XUV

We should care about rotational age, rather than real age

Dependency log Lx vs log T:

- Maggio (1987): -1.5 (G)
- Ayres (1997): -1.74 (G2V)
- Ribas et al. (2005): -1.92 (1-20 Å), -1.27 (20-100 Å) (G2V)
- Penz et al. (2007): -1.69 (G)
- Penz & Micela (2008): -1.34 (M)
- Garcés et al. (2011): -1.55 (G-M)

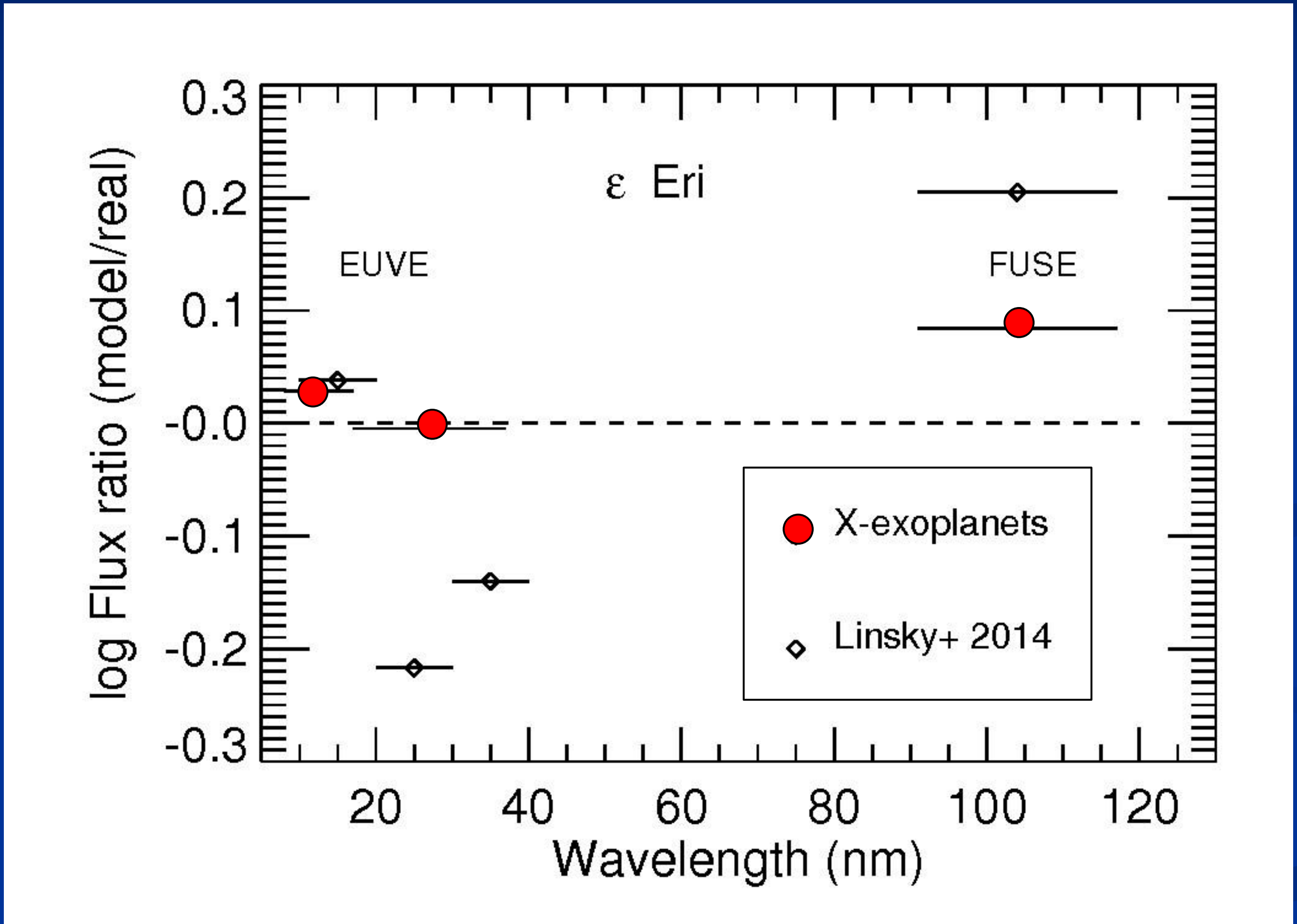


XUV emission in solar ancestors

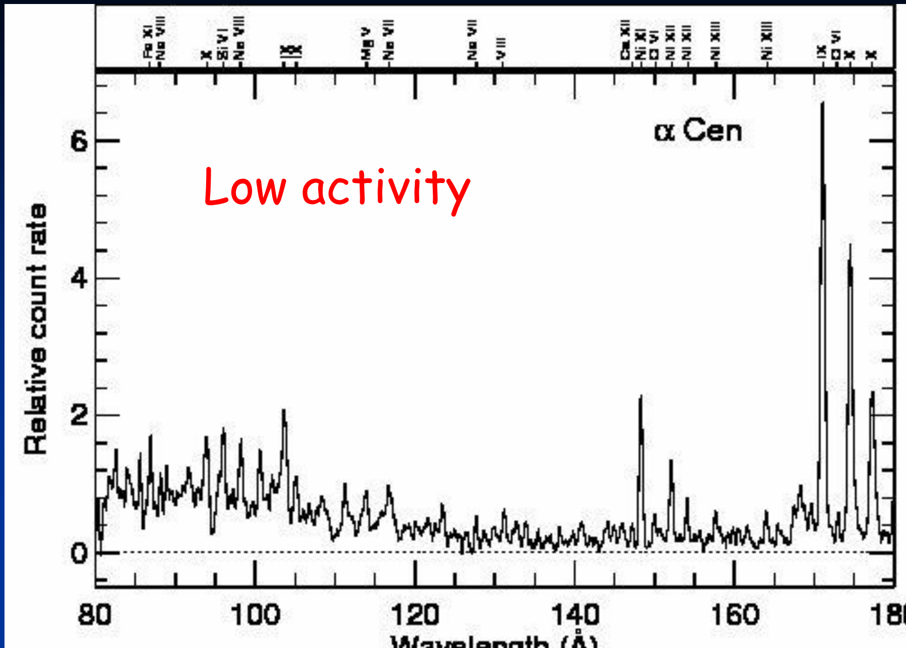
X-rays (1-100 Å) o.k. EUV (100-920 Å) absorbed by interstellar medium

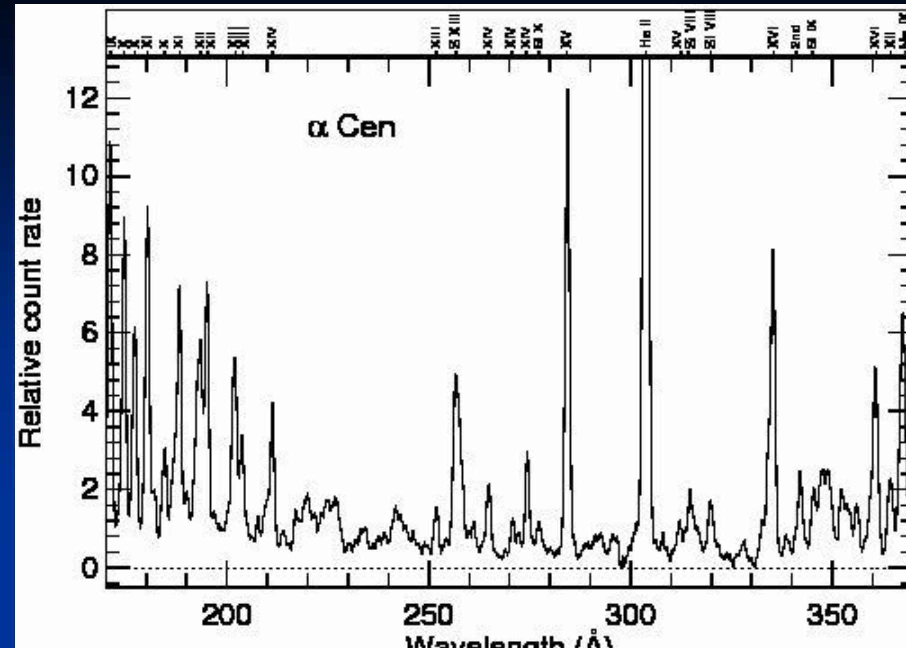
- Use solar spectrum to scale it by stellar size: only as first approximation
- Scale solar SED interpolating between X-rays and UV (e.g. Ribas+ 2005, Claire+ 2012): better approach, for broadband flux.
- Relate EUV flux and Lymann alpha (Linsky+ 2014): concerns on the calibration, and Ly a measurement. Broadband only (also solar models for 400-920 Å)
- Use coronal model to create a SED (Cnossen+ 2007, Sanz-Forcada+ 2011 – X-exoplanets): High spectral resolution SED. Best possible.

Comparison of EUV models of ε Eri (K2V intermediate activity) with measured broadband flux in EUVE and FUSE

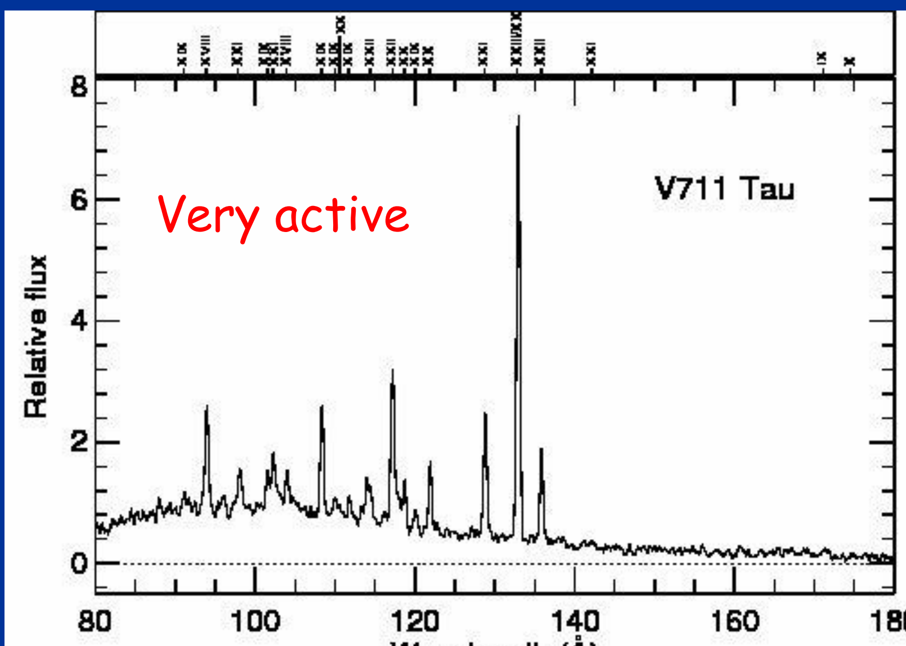


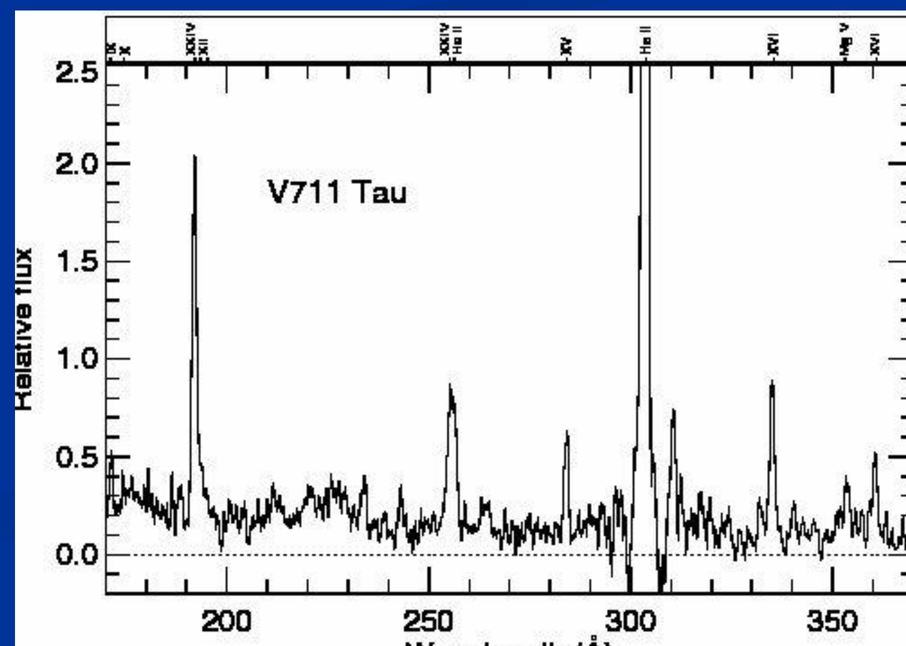
(*) Linsky+ 2014 uses the same star to calibrate the relation Ly α vs EUV



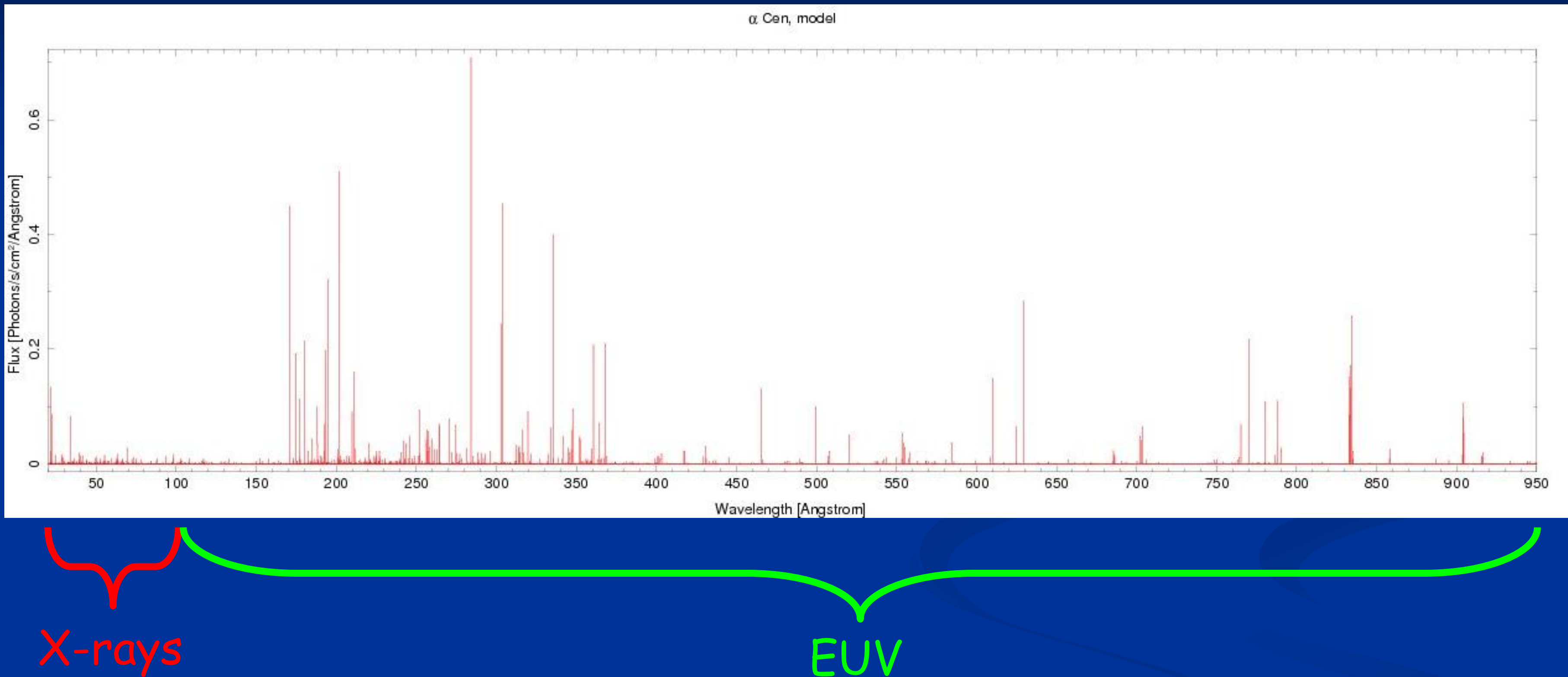


We can not simply scale the solar EUV



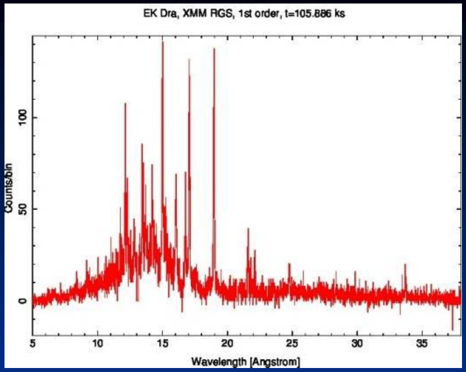


XUV = X + EUV



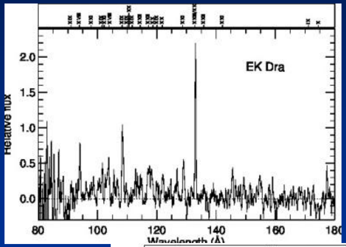
Total flux in X-rays+ EUV		Star (dG)	Activity level
11%	89%	β Hyi	Low (≈Sun)
48%	52%	κ^1 Cet	Medium
65%	35%	EK Dra	High

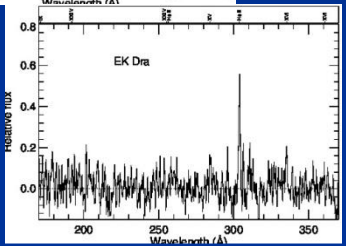
How to calculate a coronal model



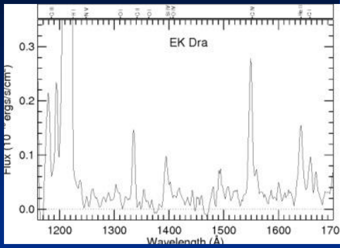
XMM
Chandra

1.5 - 175 Å

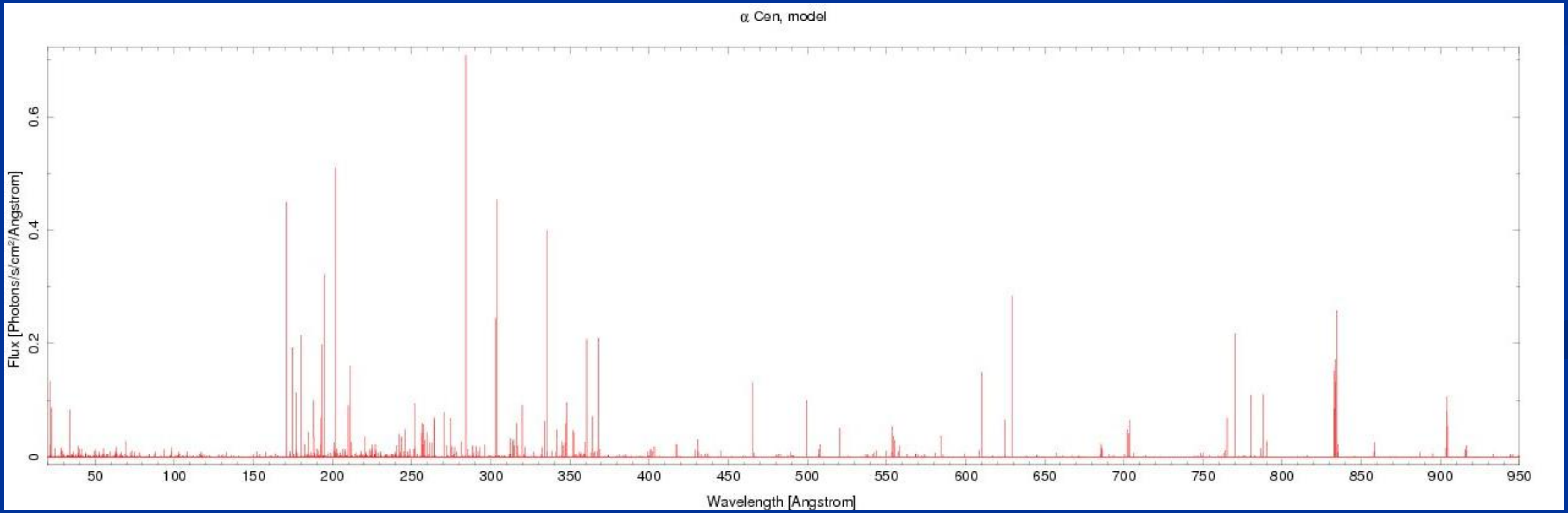




EUV: 90-400 Å
(ISM dependent)

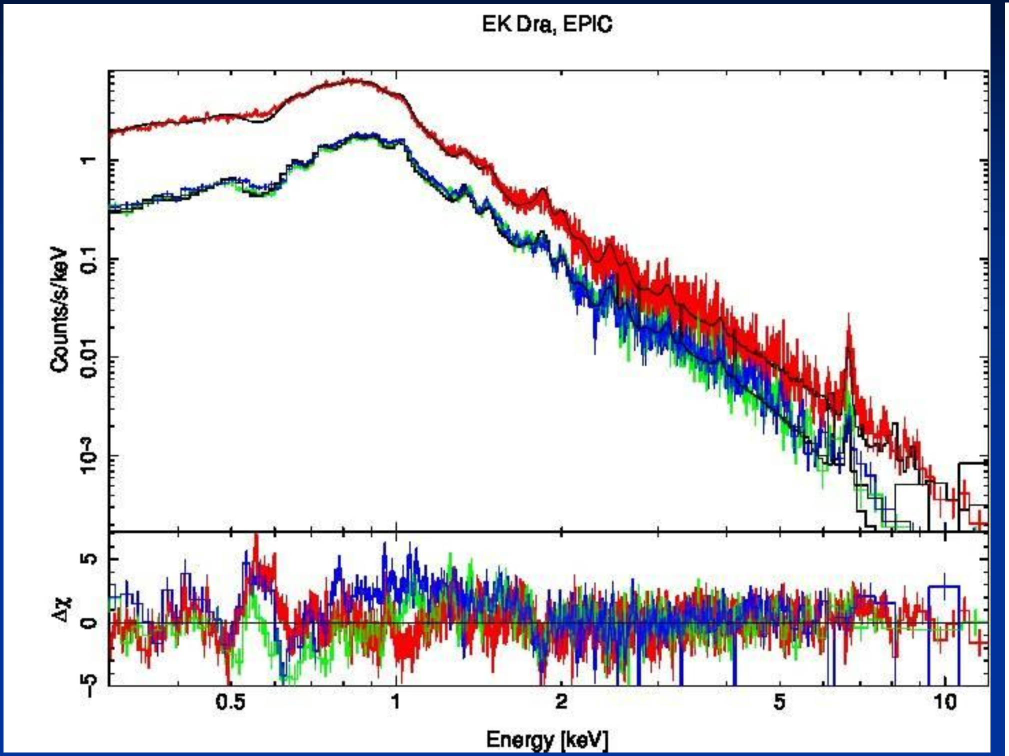


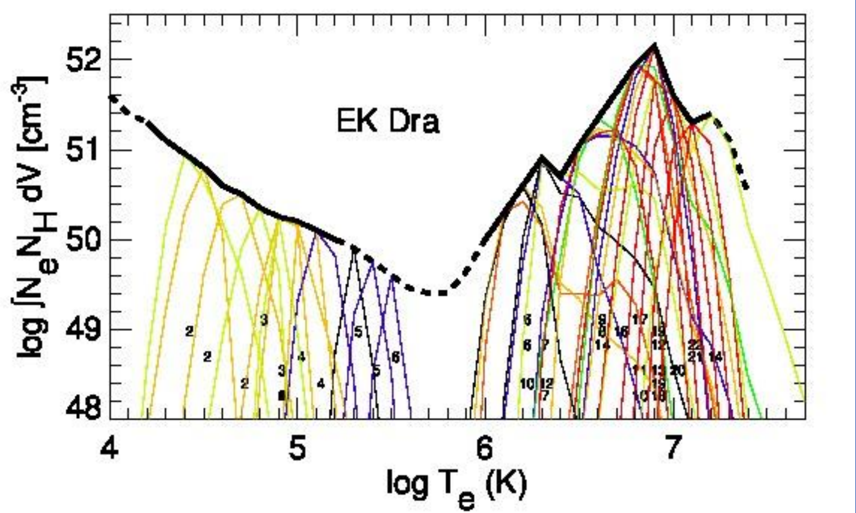
FUSE: 920-1180 Å
IUE: 1150-3000 Å
HST: 1200-3000 Å

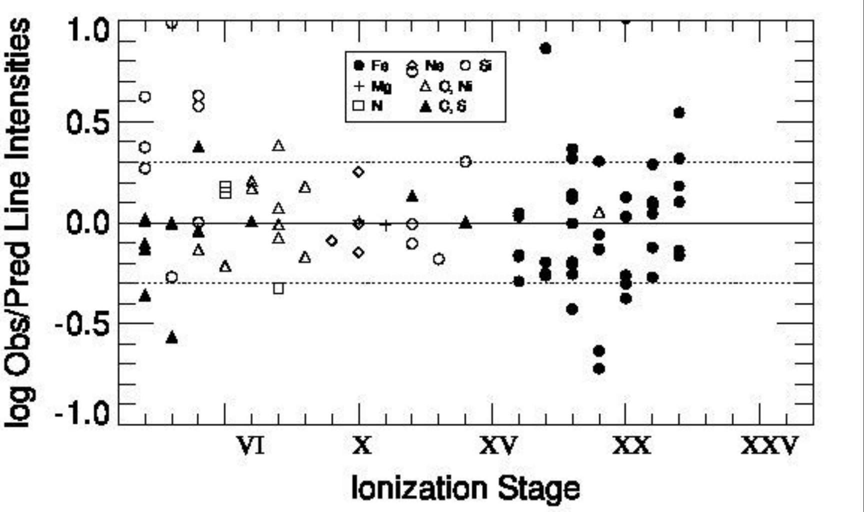


Global fitting to a low-res. spectrum

Fluxes line-based fit





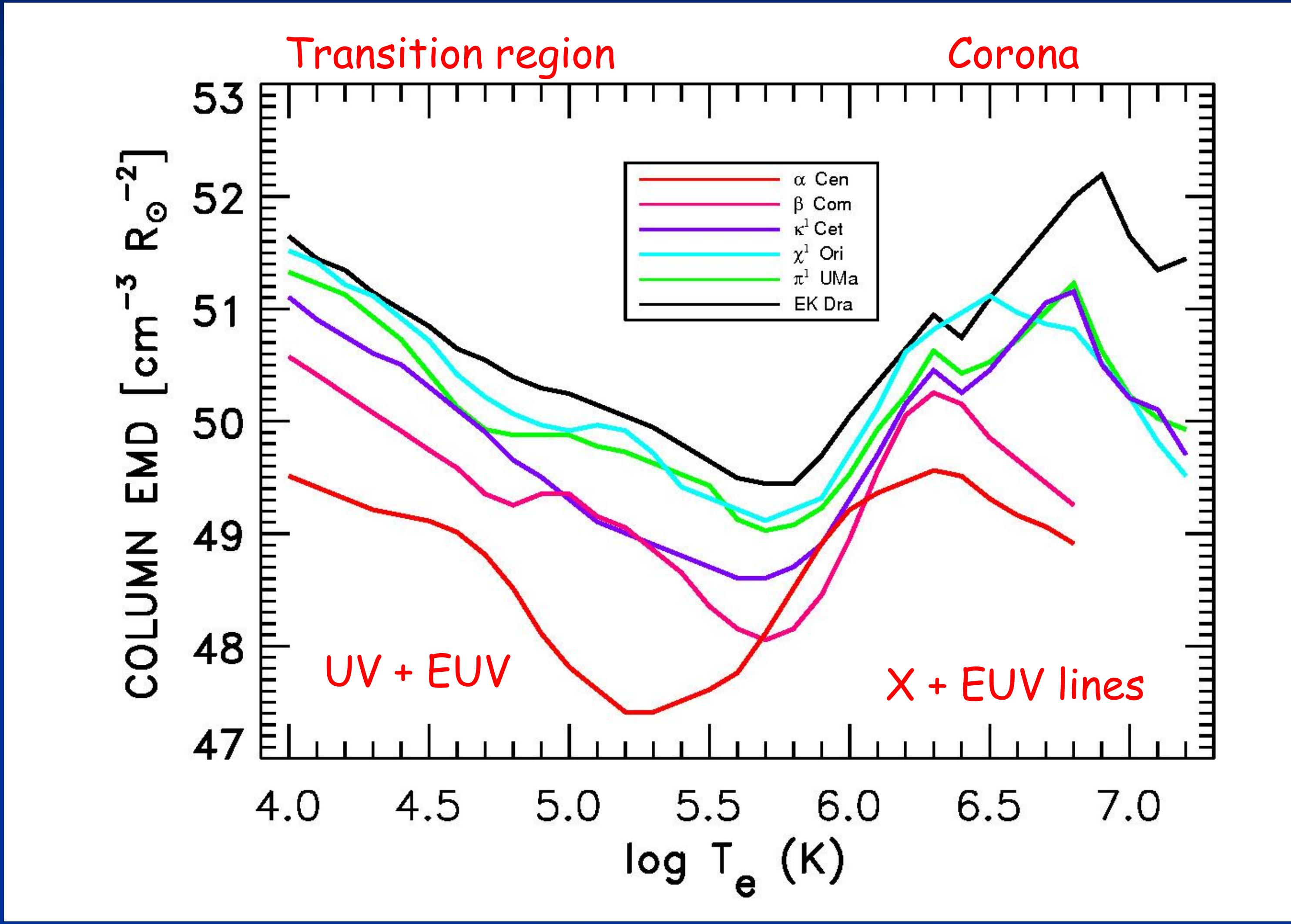


Only 2 or 3 values of temperature

Currently using ATOMDB v3.0.2 (APEC)

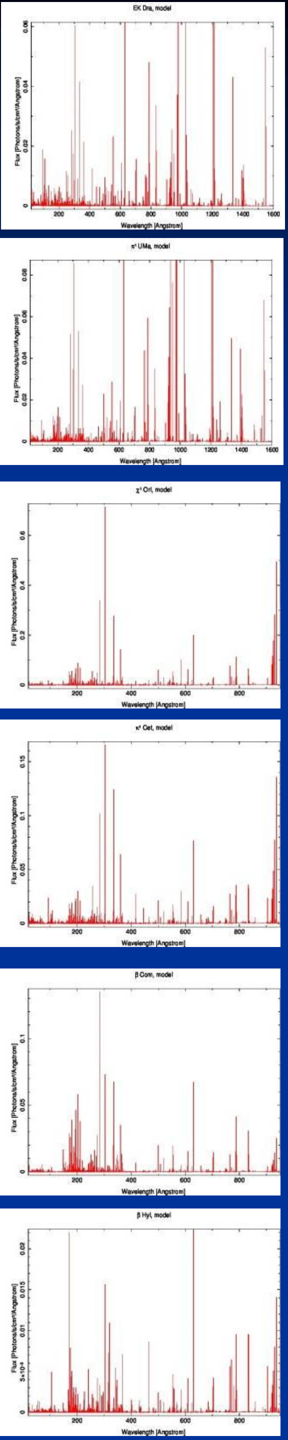
More than 30 temperature components

A coronal model requires information on both transition region and corona



Sanz-Forcada & Ribas (in prep.)

Solar evolution



EK Dra

π^1 UMa

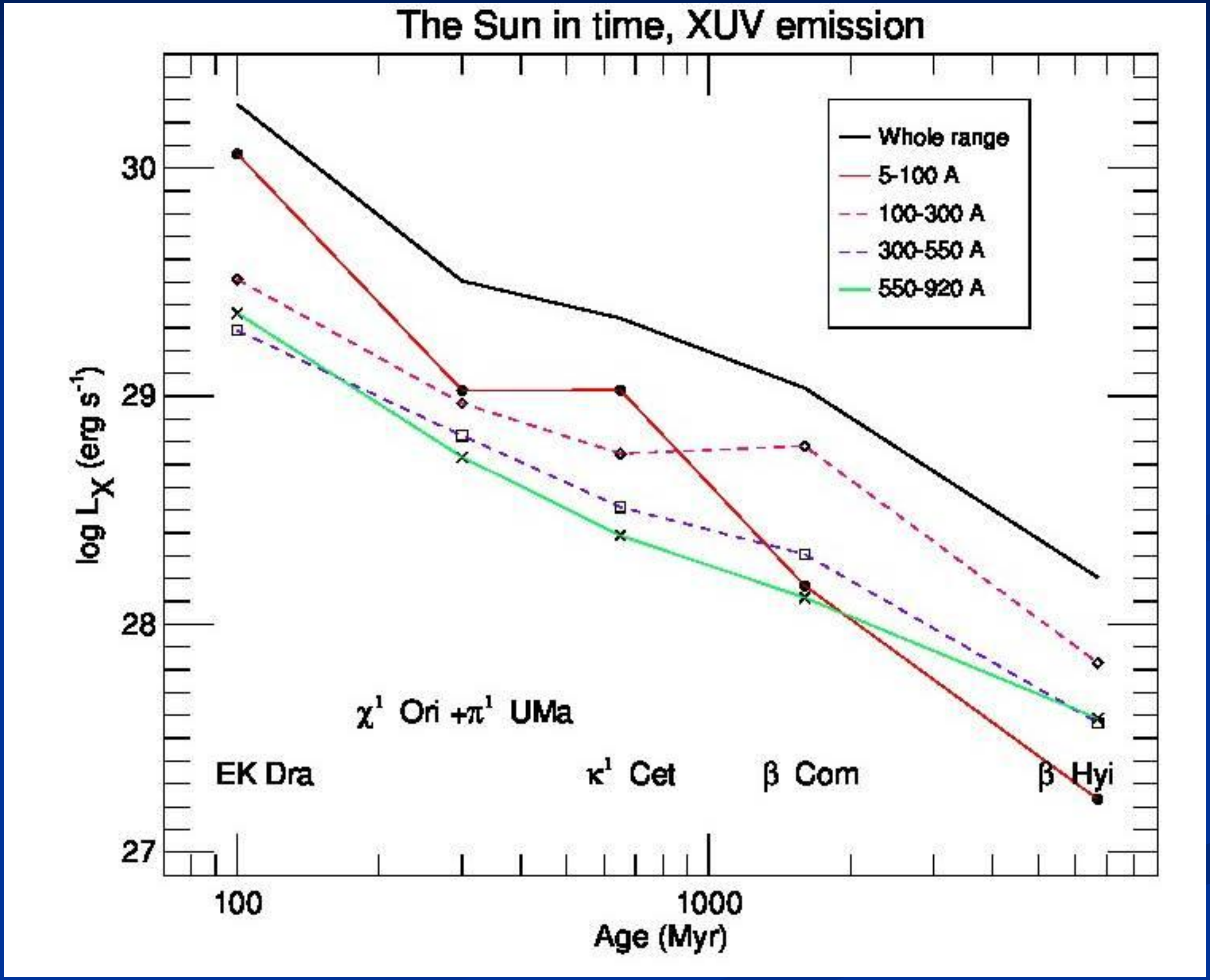
χ^1 Ori

t

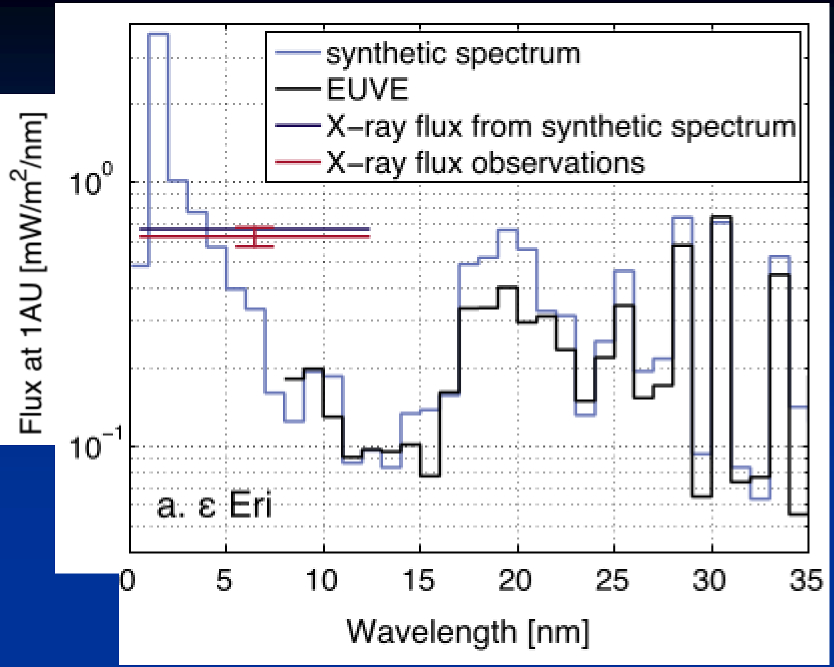
κ^1 Cet

β Com

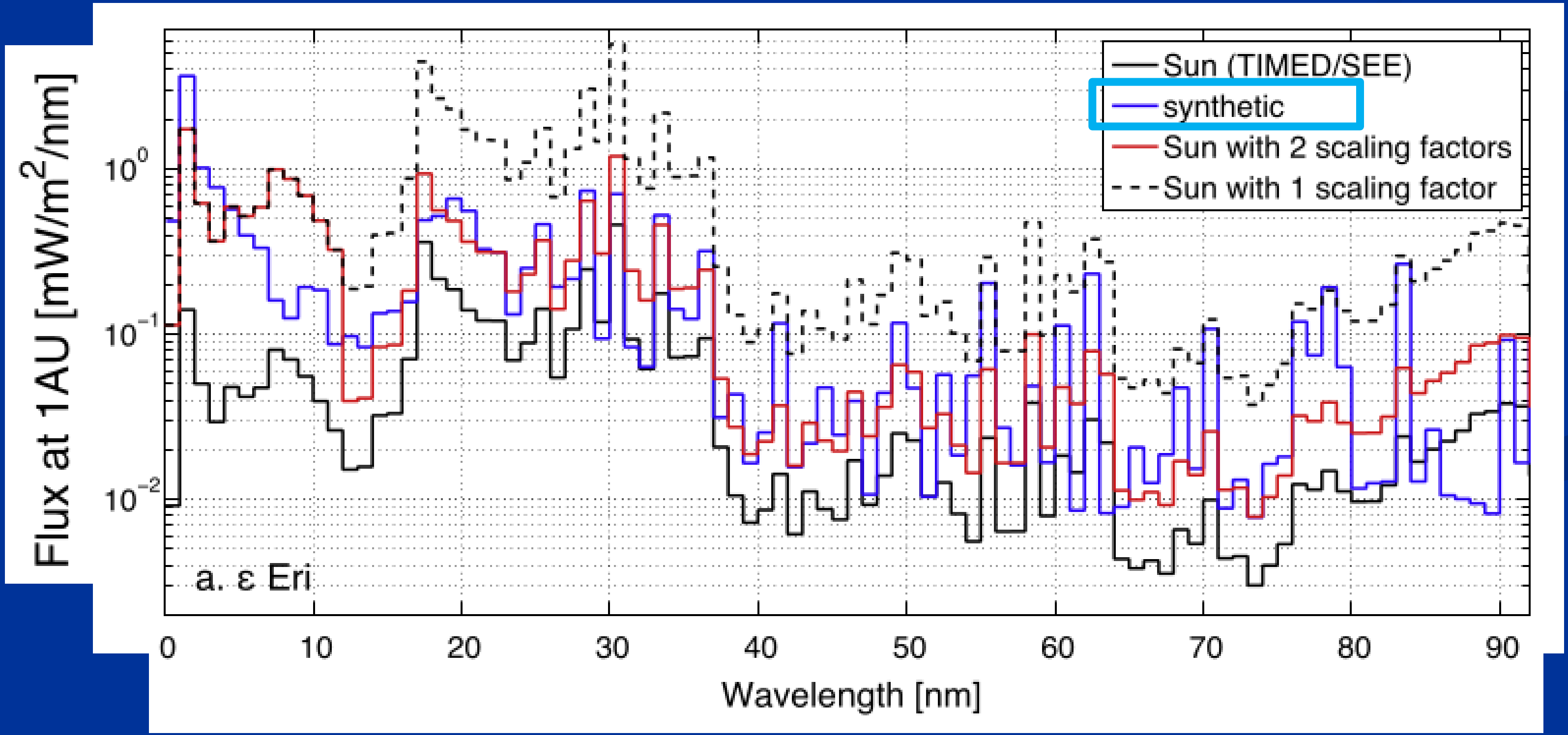
β Hyi



Model of ε Eri based on Chandra + IUE data. EUVE spectrum of different epoch (lowered resolution for display)

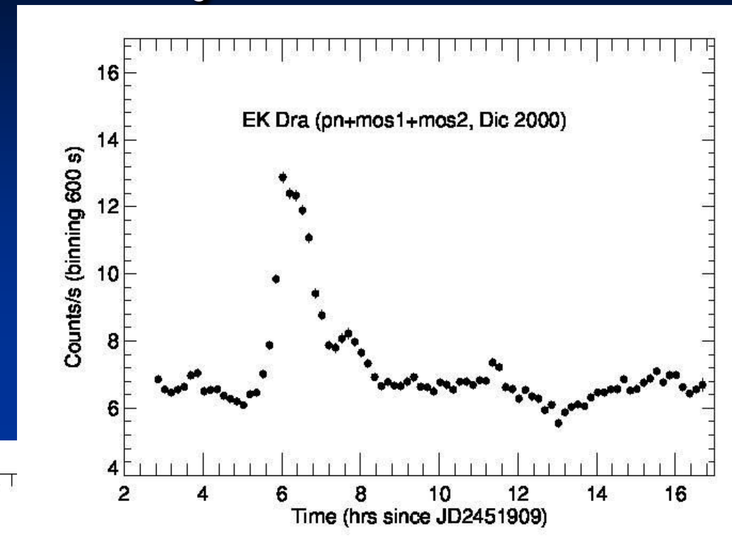


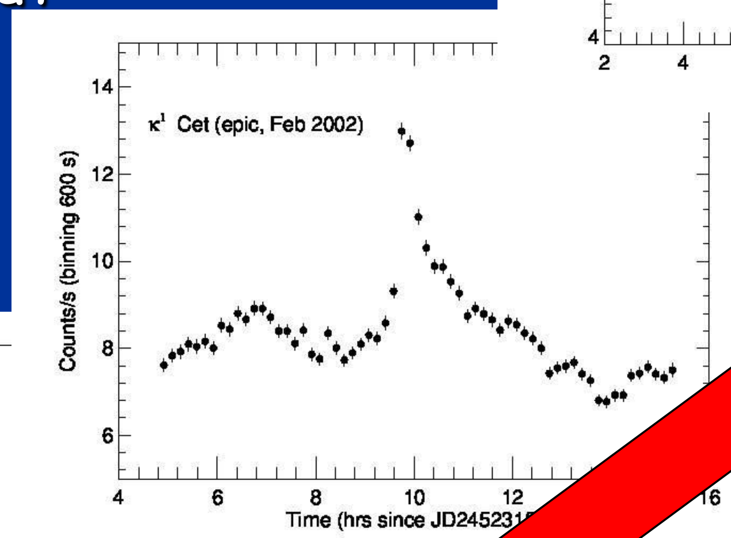
Chadney et al. (2015)

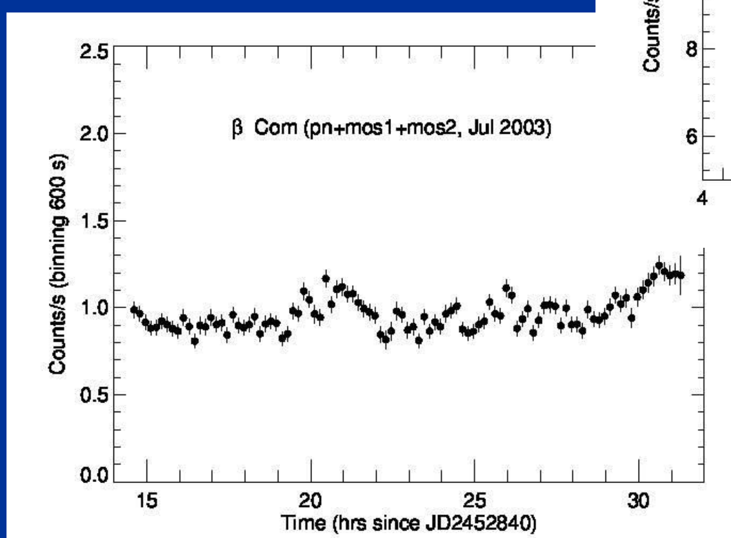


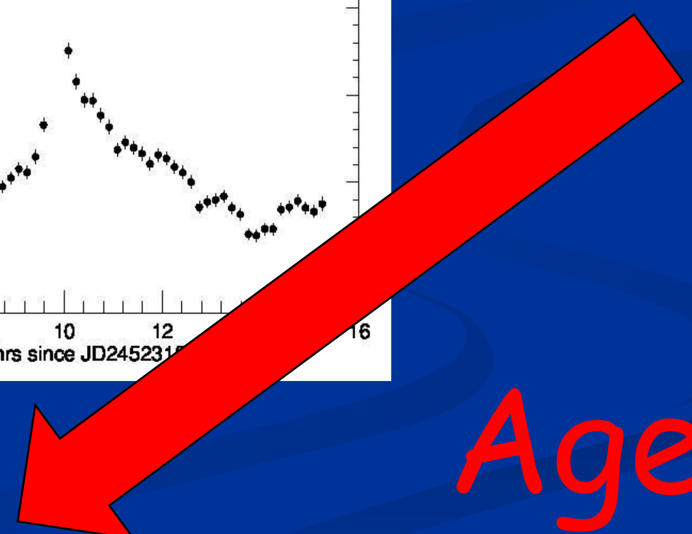
Variability (flares, cycles)

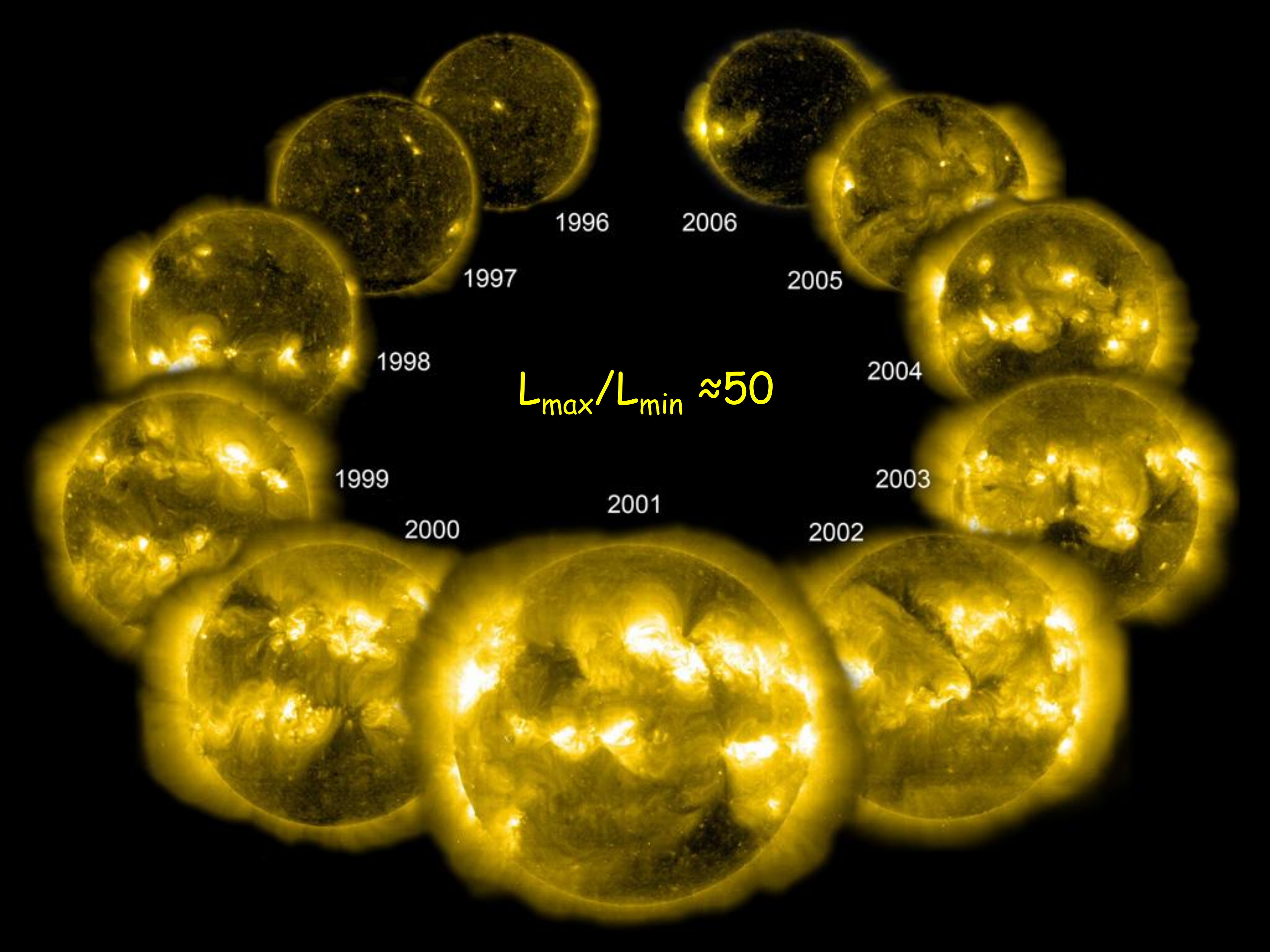
- Flares are episodic
- More frequent in young stars
- CMEs associated, but highly direction-dependent



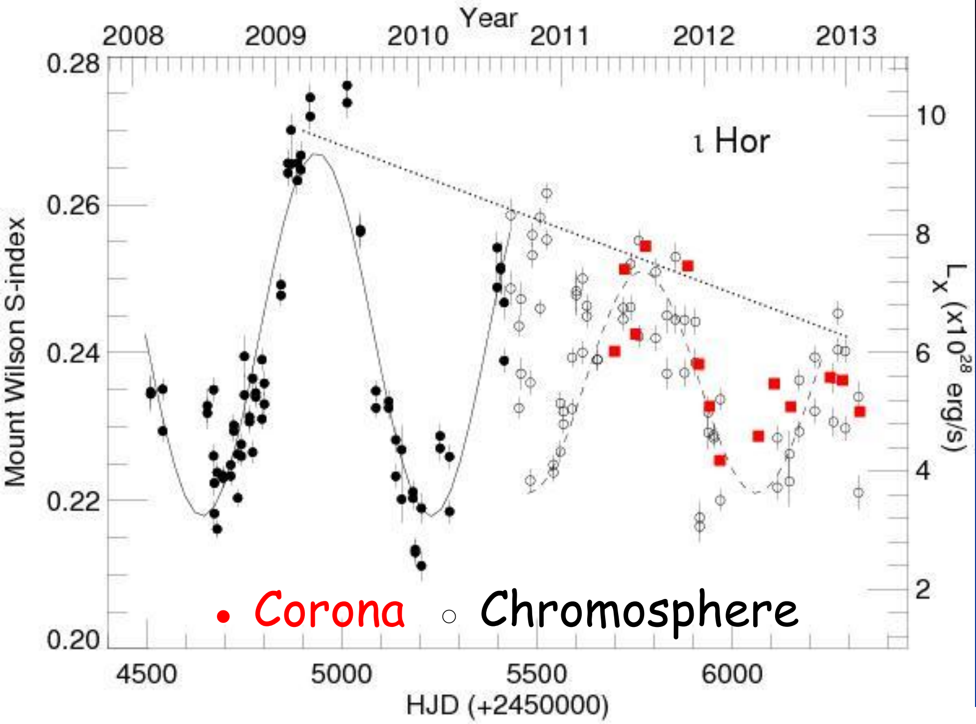








1996
2006
1997
2005
1998
2004
$L_{max}/L_{min} \approx 50$
1999
2003
2001
2000
2002



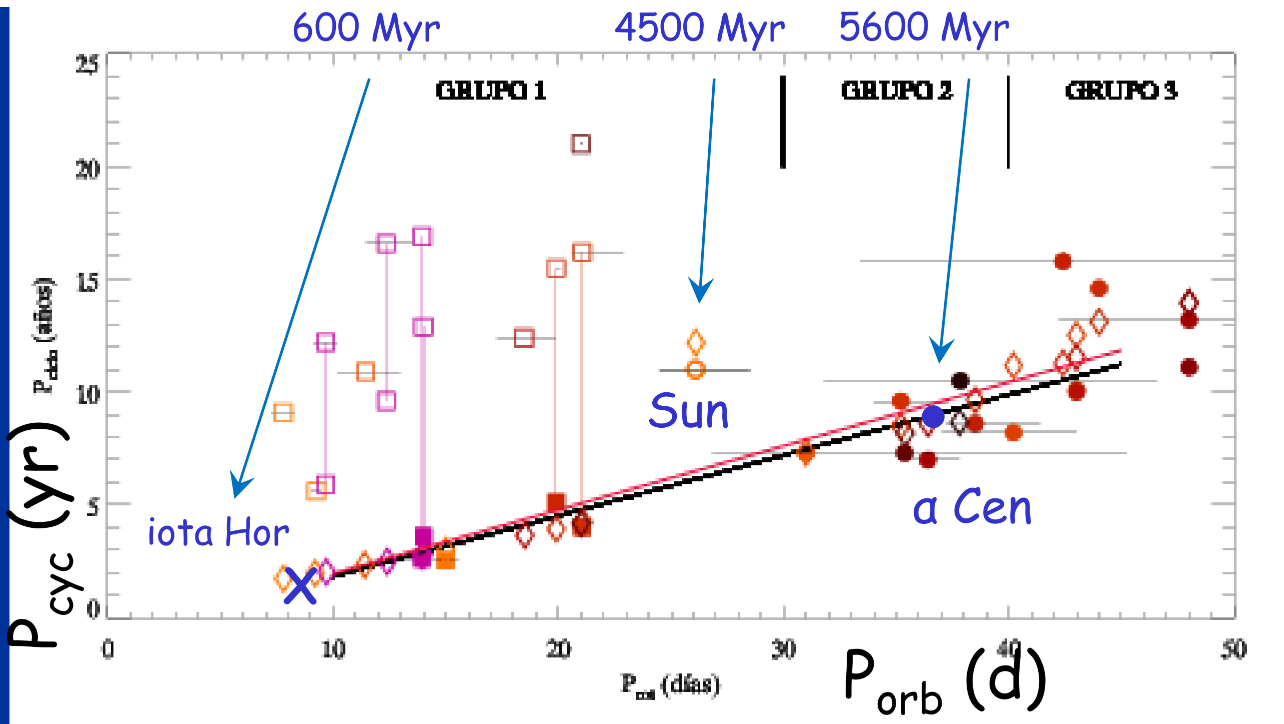
Sanz-Forcada, Stelzer & Metcalfe (2013)

iota Hor (age similar to κ Cet): earliest coronal cycles observed, amplitude factor ~2

Amplitude increases with age

- G0V, age 600 Myr
- Cycle of 1.6 yr
- ι Hor b: 1.9 M_J / 0.9 a.u.
- L_{max}/L_{min} ≈2 (‹‹ 50)

Lorente & Montesinos (2005)



Conclusions

- Stellar high energy radiation has strong influence in planet atmosphere
- XUV radiation decreases with age. Still high at 500-1000 Myr (life developed on Earth)
- Coronal models needed for detailed SED in the EUV range.
- UV and X-rays needed for coronal models. Tests show good fits to real data.
- Short term variability frequent at young ages
- Watch out for long term variability (at least factor ~2)