Stars Shaping their Planetary Environments

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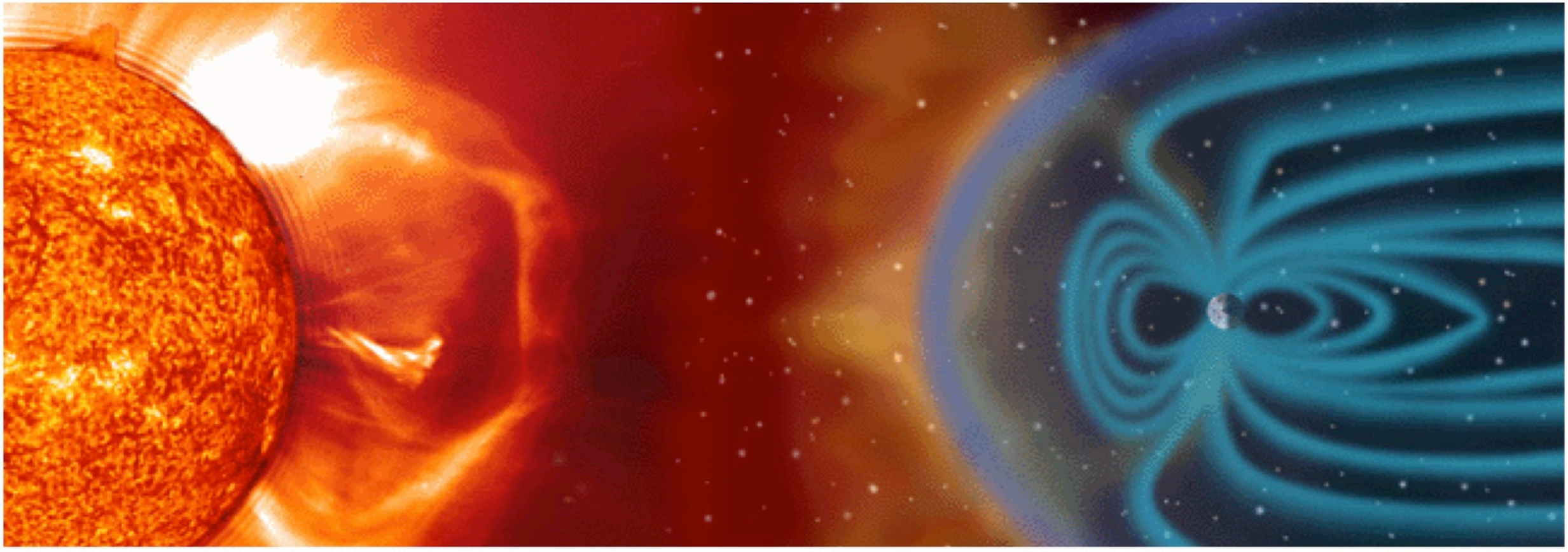
Stars – Shaping their Environments

Stellar activity

- Flares, Coronal Mass Ejections (CME's),
- High-energy radiation: UV, EUV, X-rays,
- Stellar Winds

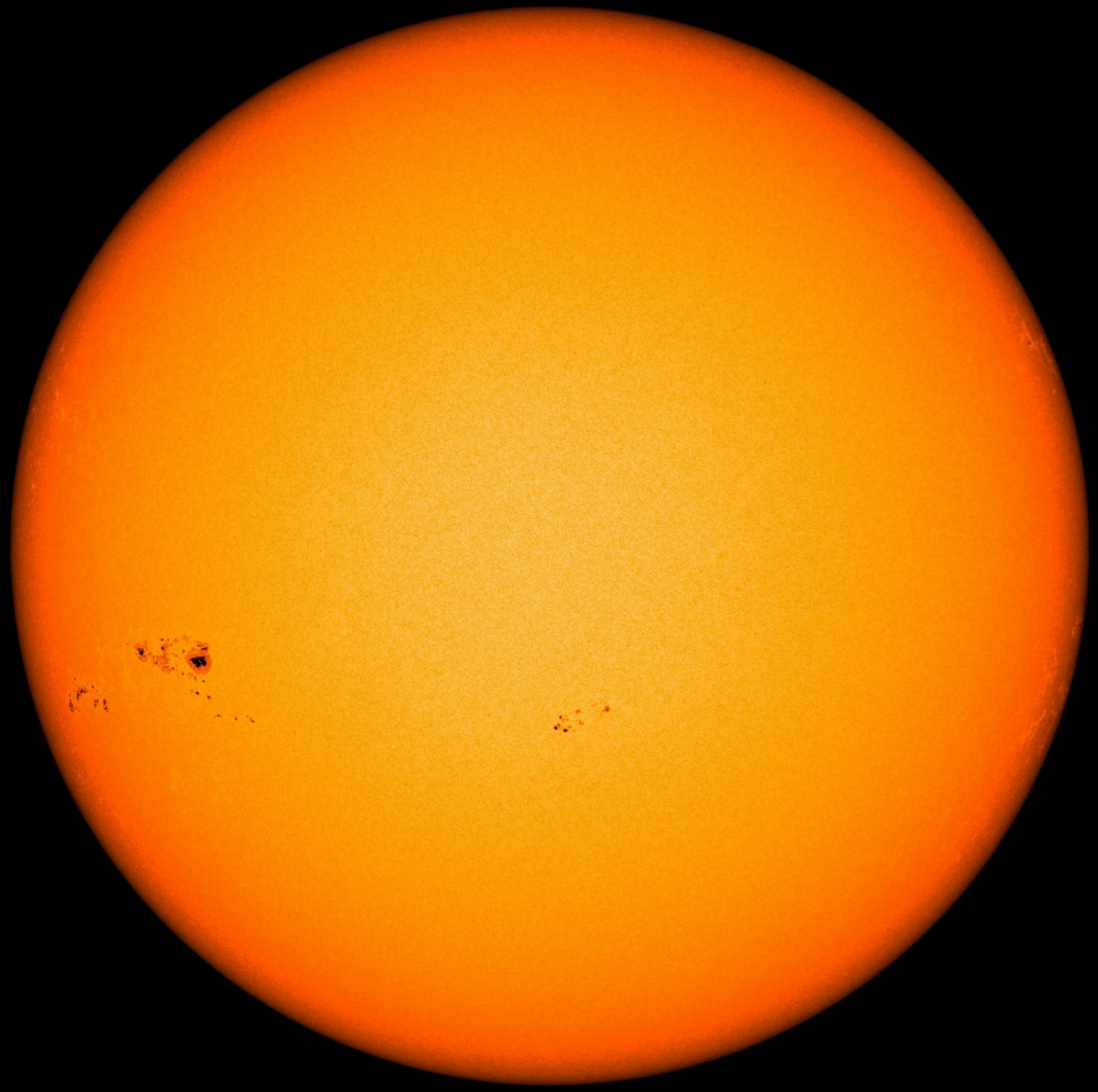
All triggered by the stellar magnetic field

- Radiation-atmosphere interaction
- Magnetosphere-wind interaction
- Magnetosphere-atmosphere system



drive atmospheric chemistry and erosion

4500Å: 6000 K photosphere

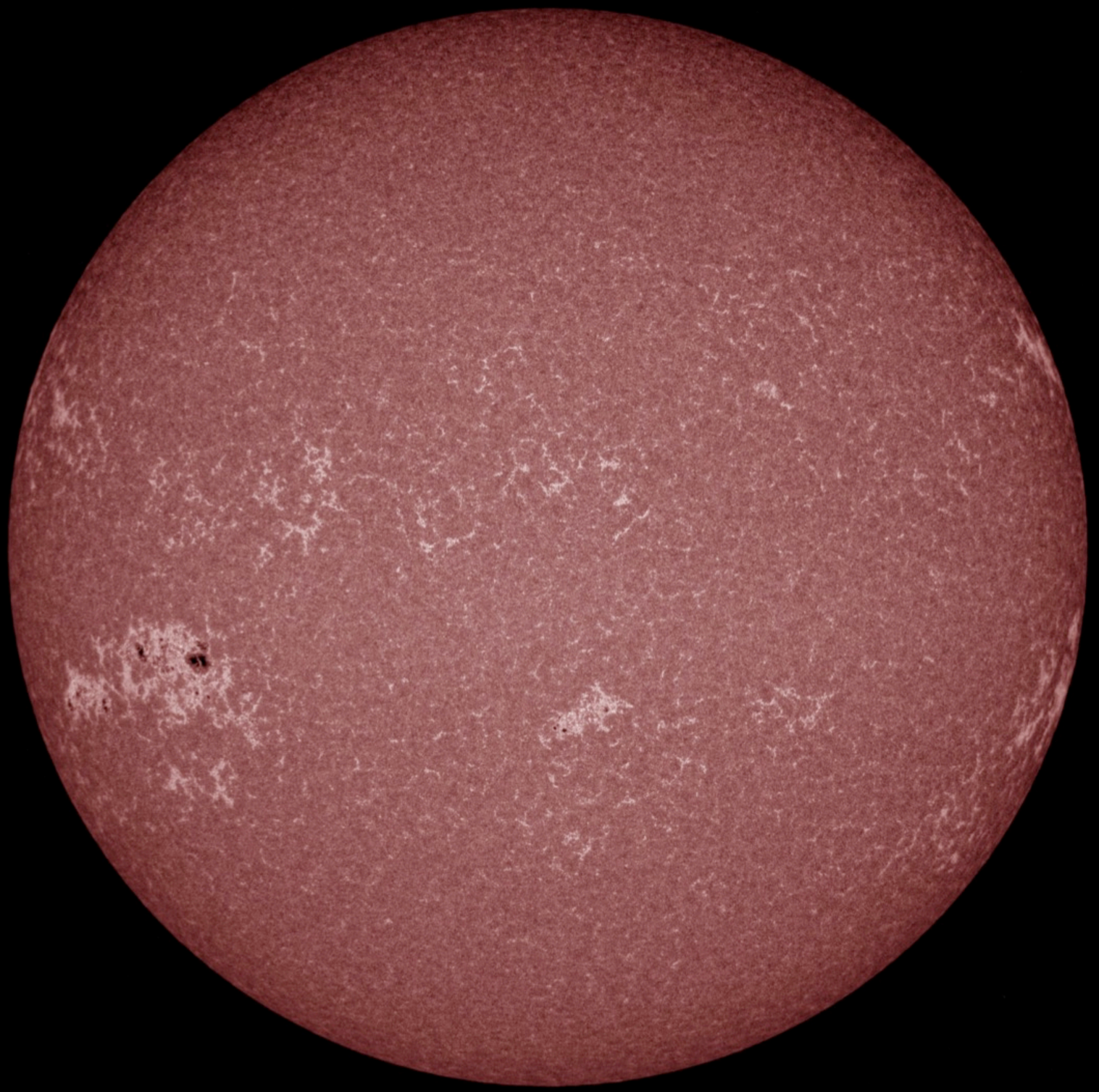


SDO/HMI Quick-Look Continuum: 20130704_150000

NASA/SDO/GSFC

The optical Sun

1700Å: 4500-10000 K chromosphere

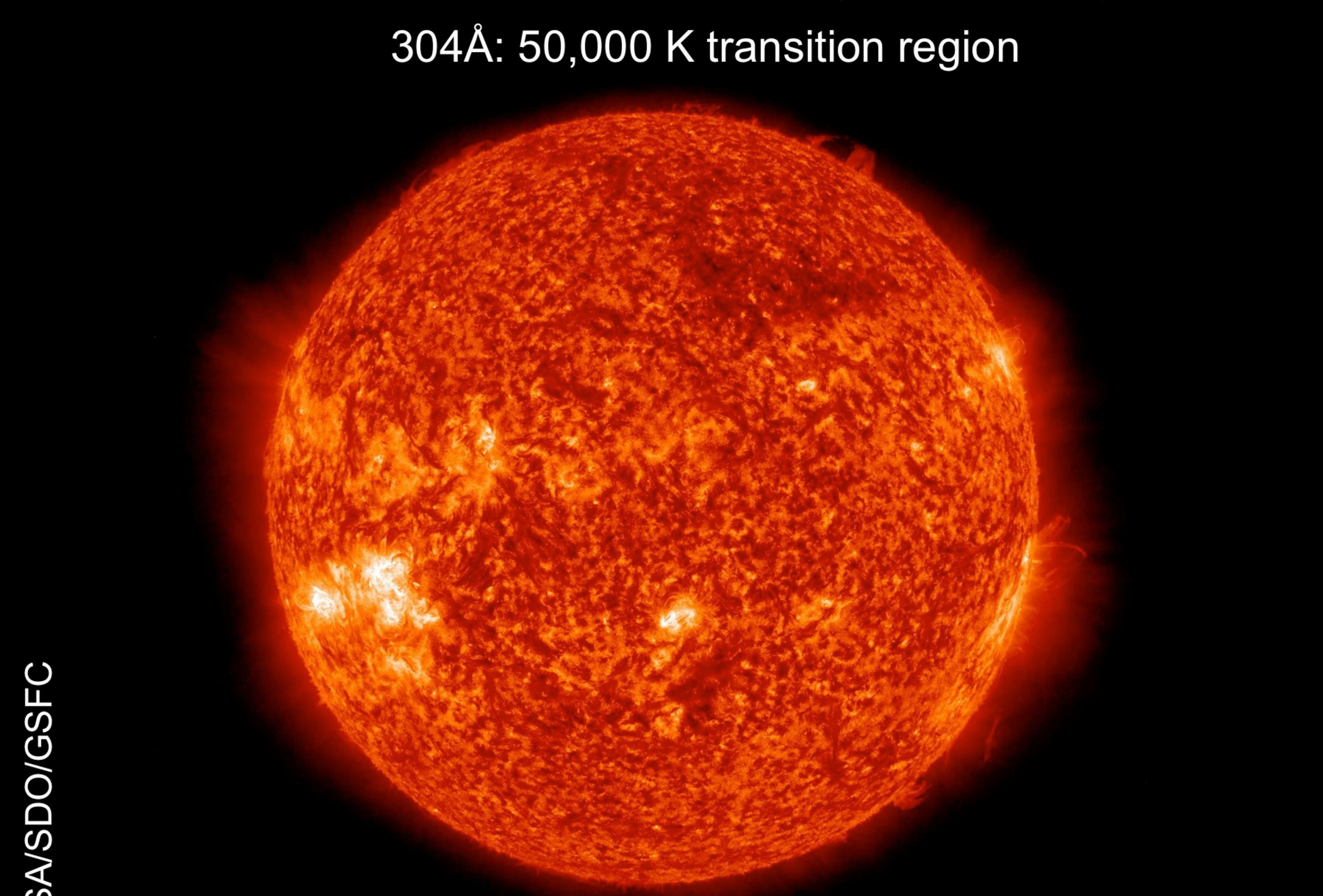


NASA/SDO/GSFC

The Ultraviolet Sun

SDO/AIA 1700 2013-07-04 15:17:19 UT

304Å: 50,000 K transition region

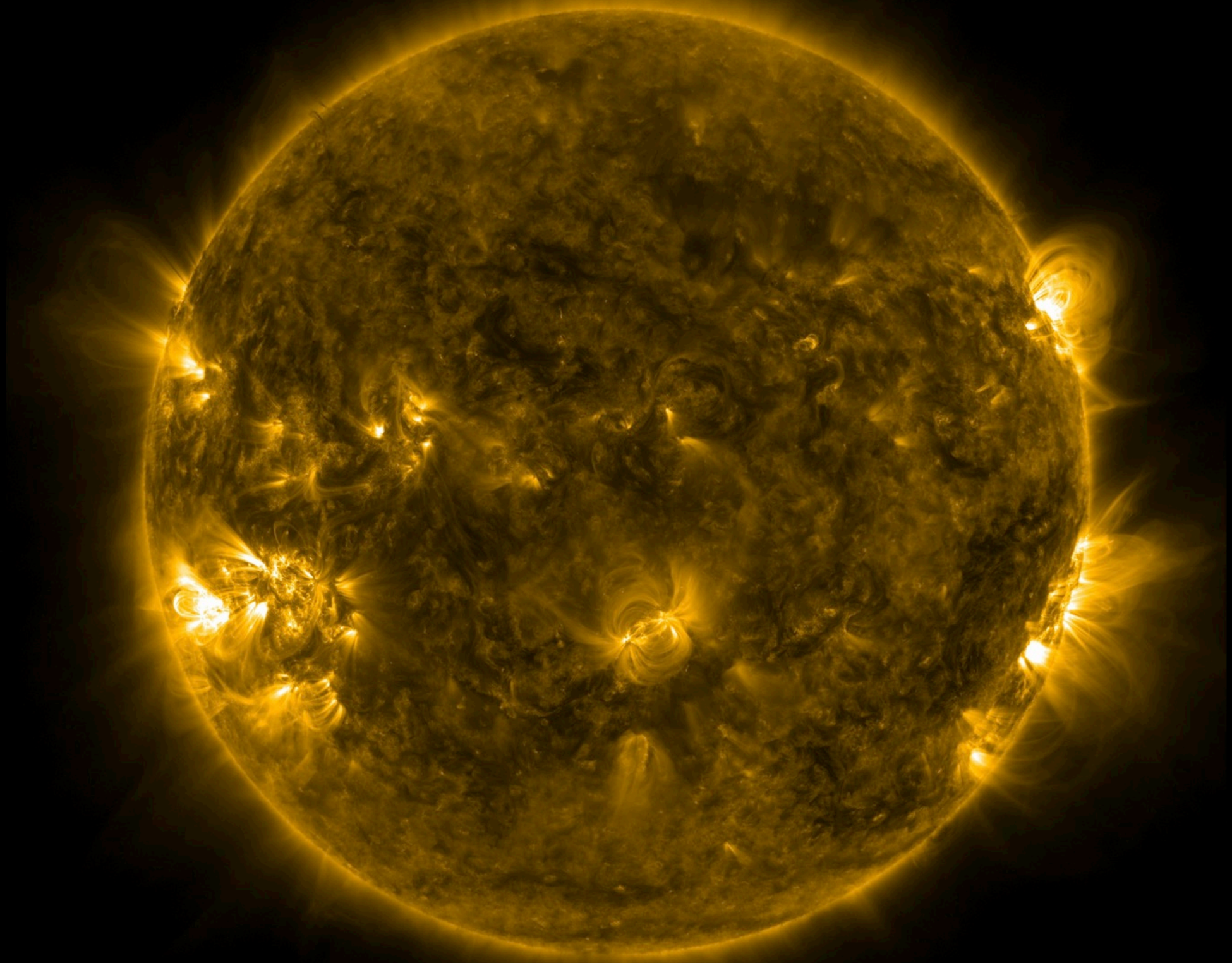


NASA/SDO/GSFC

The EUV Sun

SDO/AIA 304 2013-07-04 15:14:08 UT

171Å: 600,000 K transition region

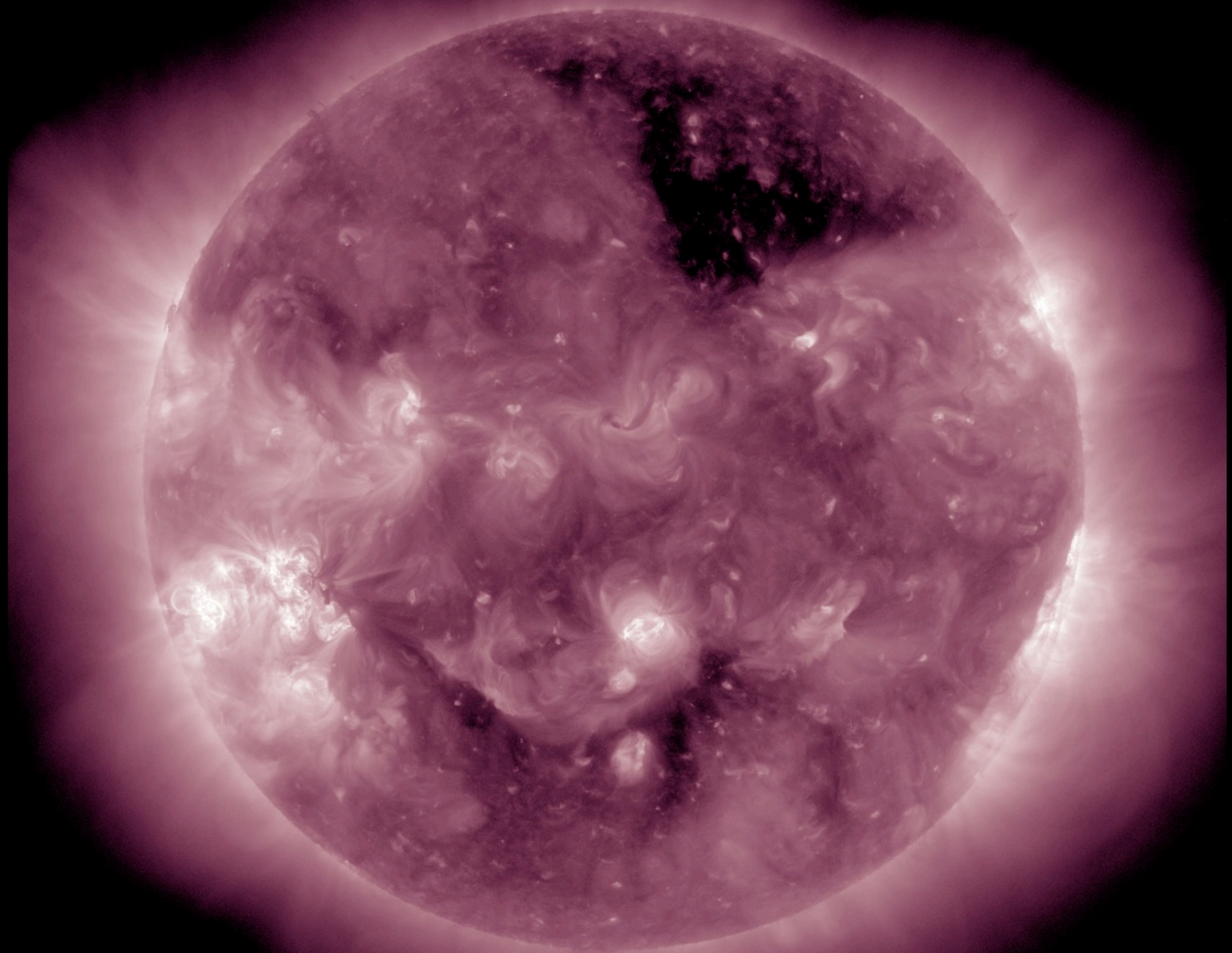


The EUV Sun

SDO/AIA 171 2013-07-04 15:14:12 UT

NASA/SDO/GSFC

211Å: 2,000,000 K corona

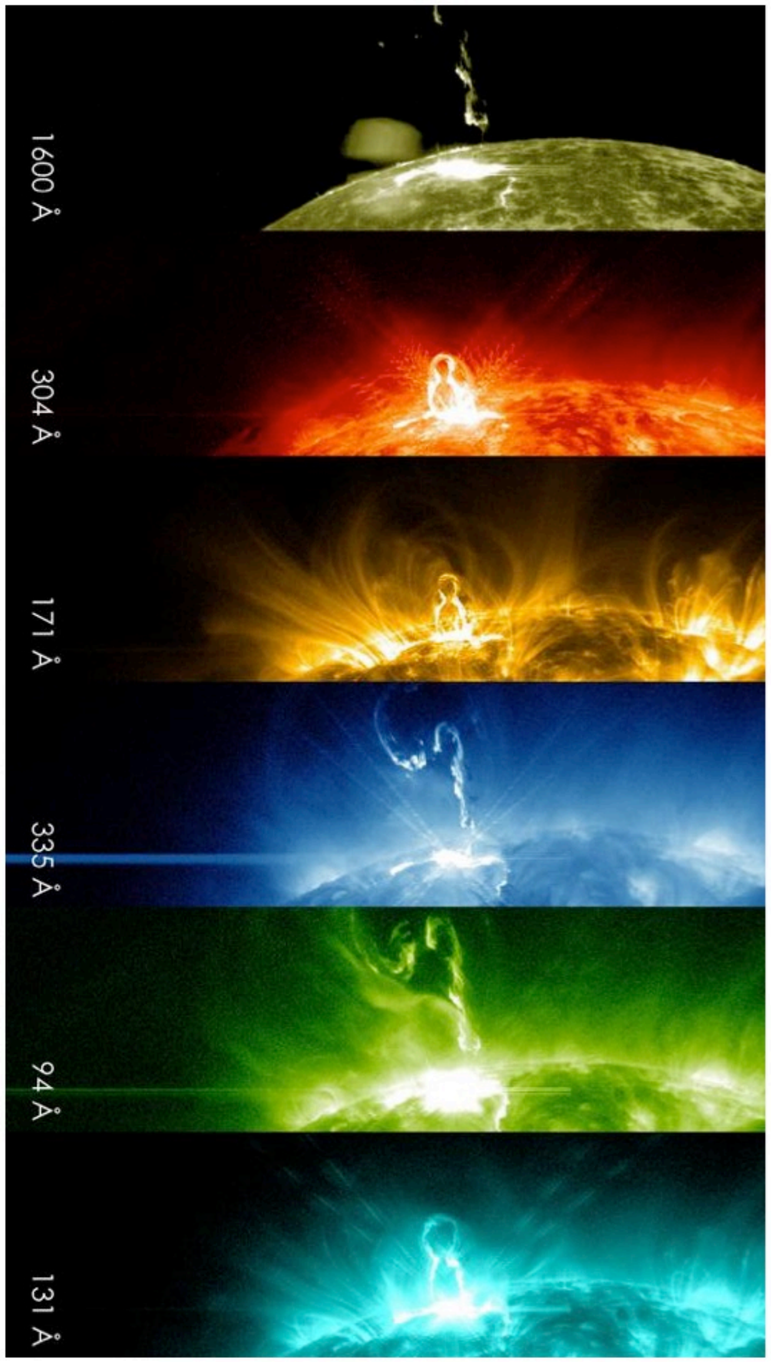


NASA/SDO/GSFC

The X-ray Sun

SDO/AIA 211 2013-07-04 15:16:13 UT

Flares, Superflares and CME's



SDO, Feb. 24, 2014: first moments of an X-class flare in different wavelengths (***NASA/SDO/)***

- Magnetic reconnection processes (Osten, 2015; Shibata 1999) - sudden release of magnetic energy stored near sunspots (10^{29} – 10^{32} *erg* within hours)

- Superflares, 10^{33} to 10^{39} *erg*, less frequent on solar-type stars (Maehara, 2012) - largest stellar flare 1mio. times more energetic than largest solar flares

- Maximum energy of flares not correlated with rotational period - but: superflares occur more frequently on faster rotating stars

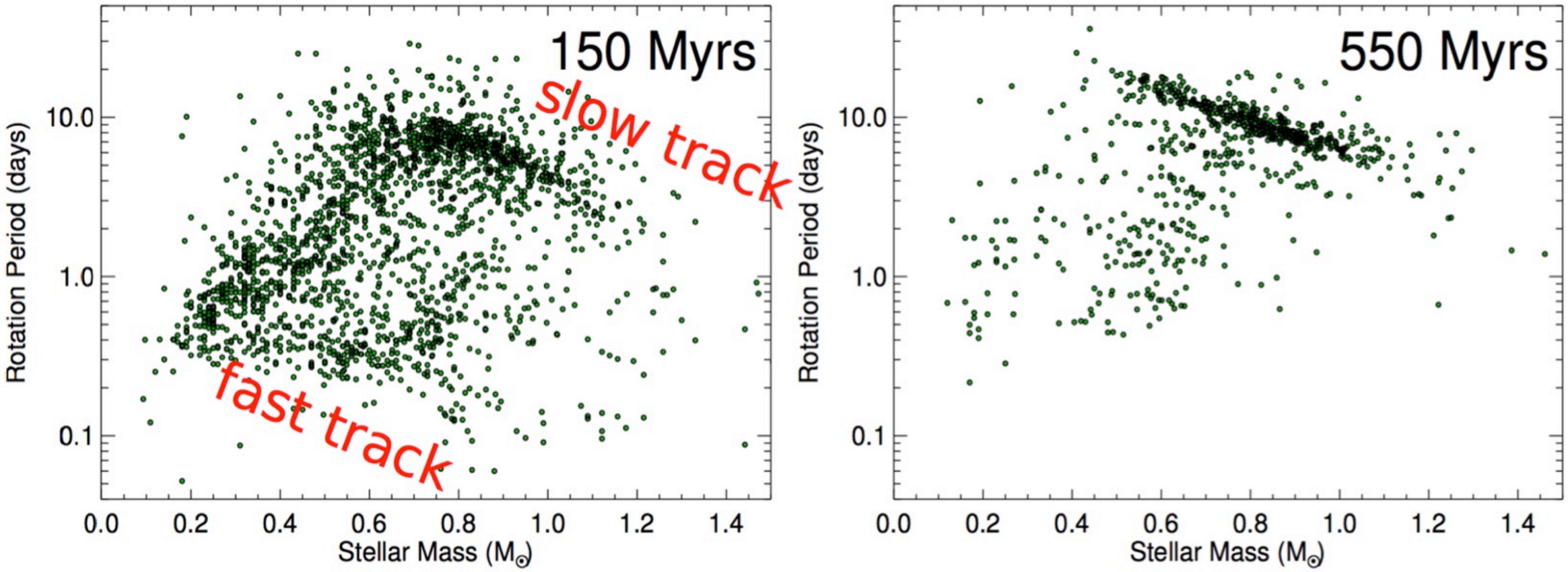
- Solar flares sometime associated with CME's – can cause geomagnetic storms

- Osten ApJ, 2015: detailed studies of stellar flare phenomena global agreement with processes occurring during solar flare events ➔ similar physical origin despite disparity in scale

CME's not detected on stars so far!

Evolution Matters - a lot!

Rotational Evolution

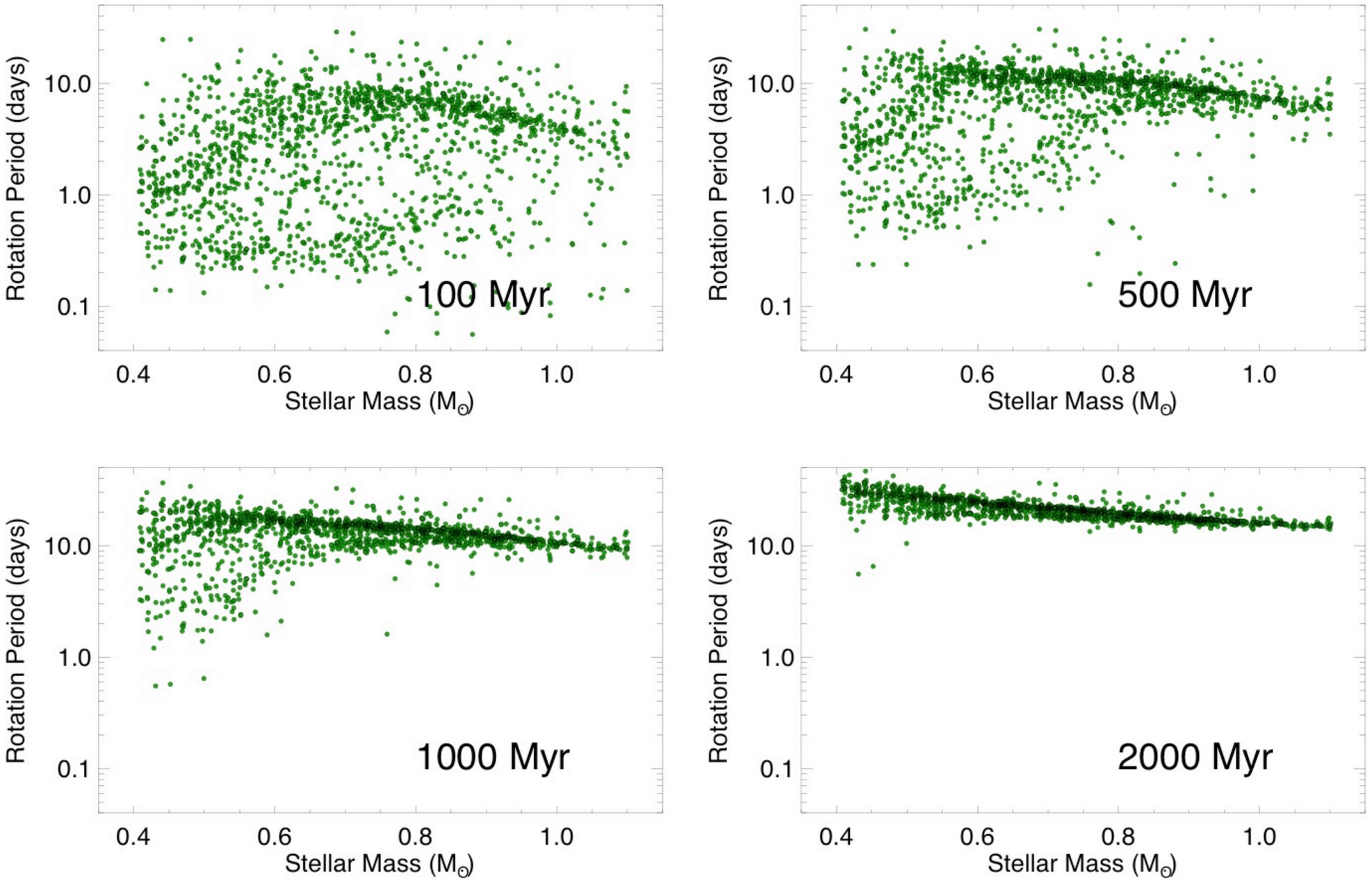


Johnstone et al., 2015

Distribution of stellar rotation rates at 150 Myrs and 550 Myrs. Left: combination of measurements in Pleiades, M50, M35, NGC 2516; Right: M37, Praesaepe

Evolution Matters - a lot!

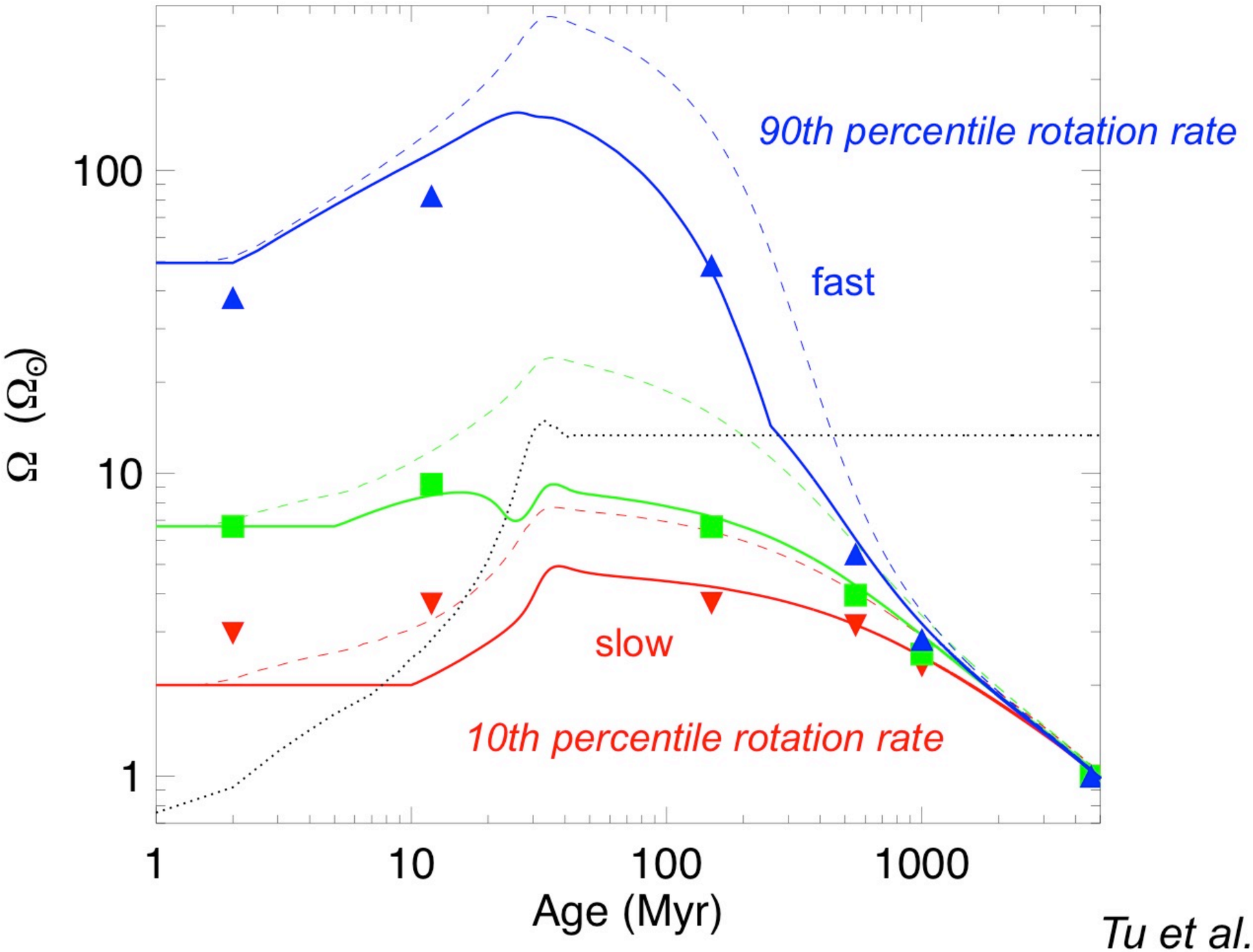
Rotational Evolution



Distribution of stellar rotation rates — *Johnstone et al., 2015*

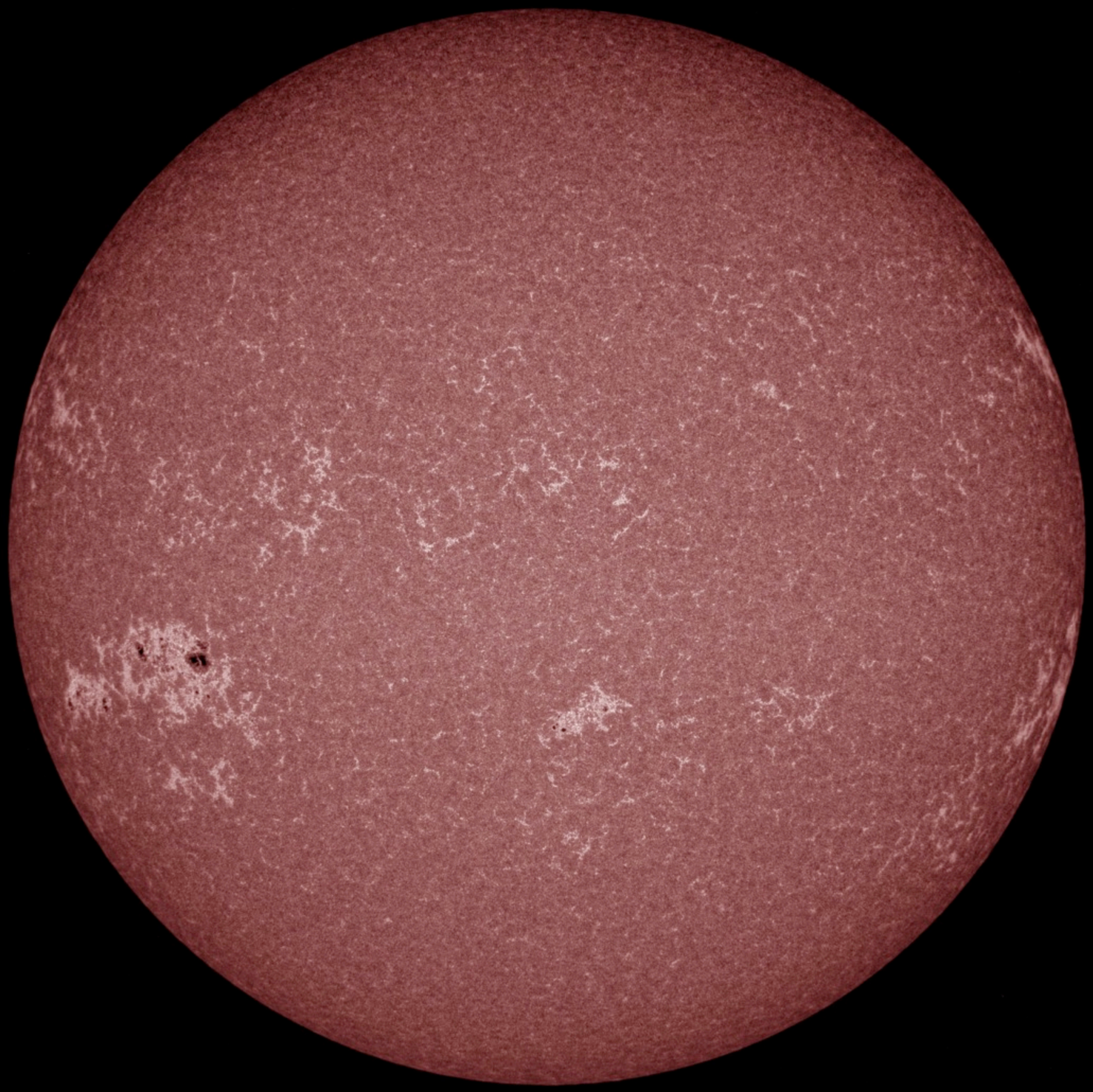
Evolutionary Aspects: Rotation

Stellar rotation rates evolution



Tu et al., 2015

1700Å: 4500-10000 K chromosphere



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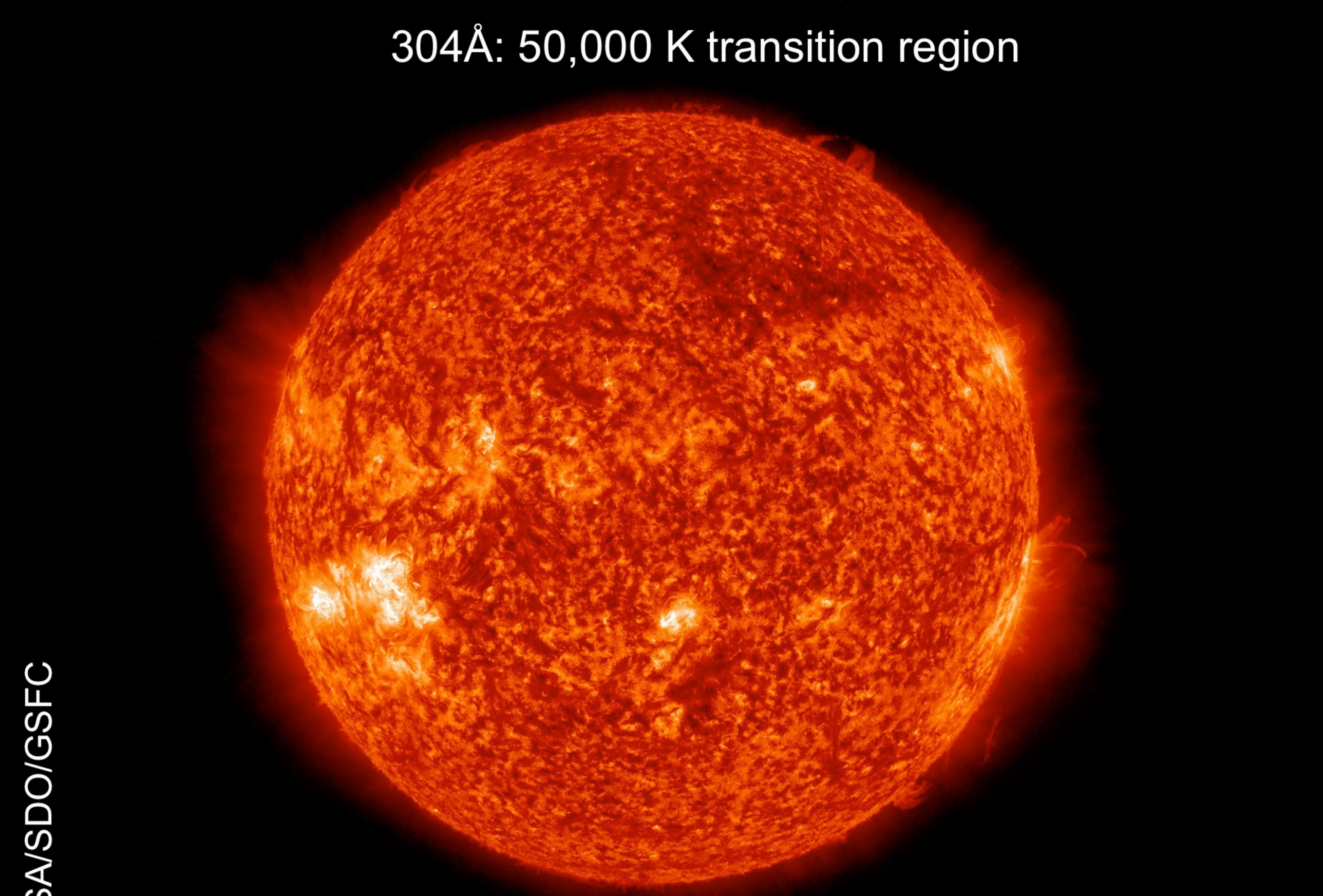

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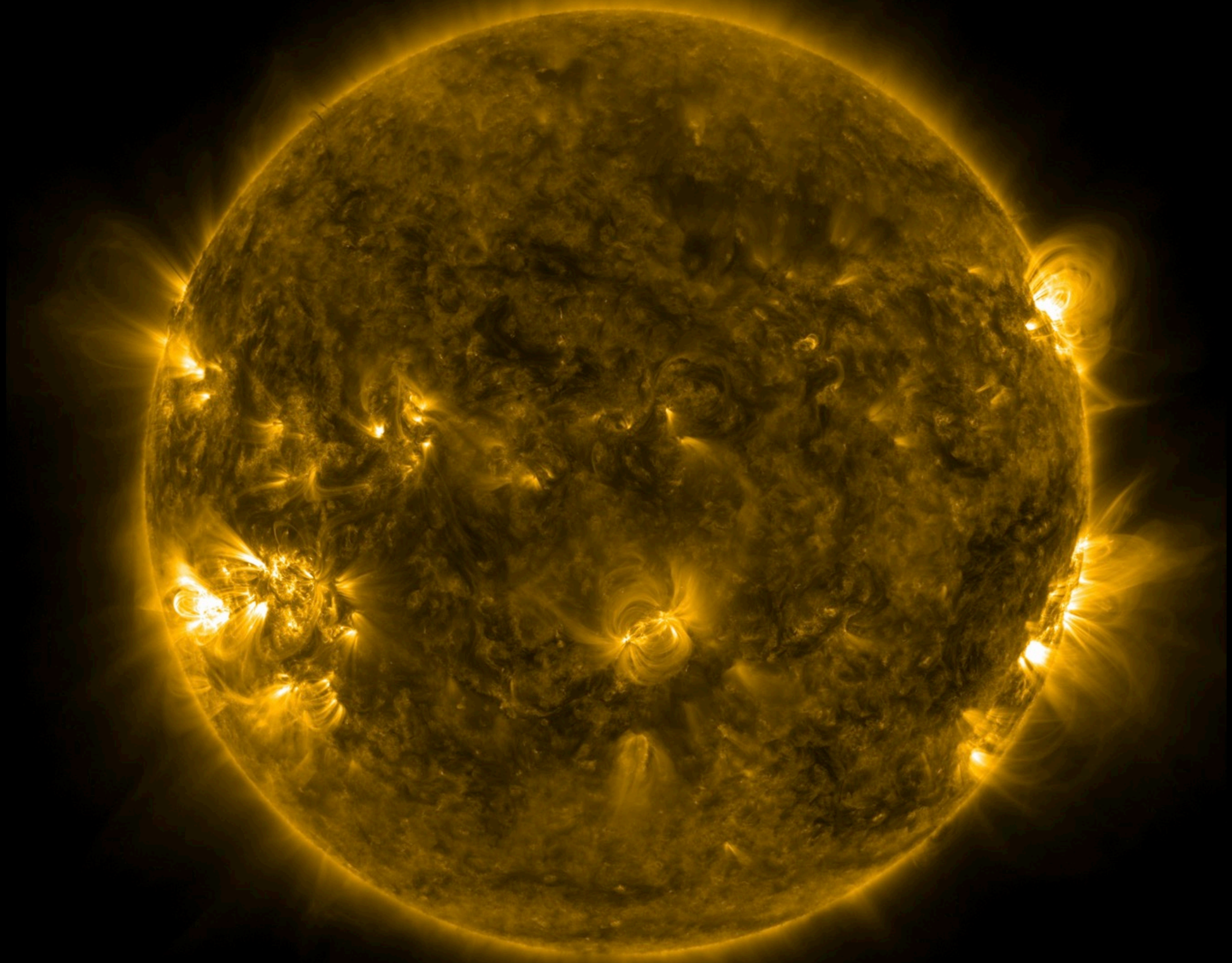

The EUV Sun

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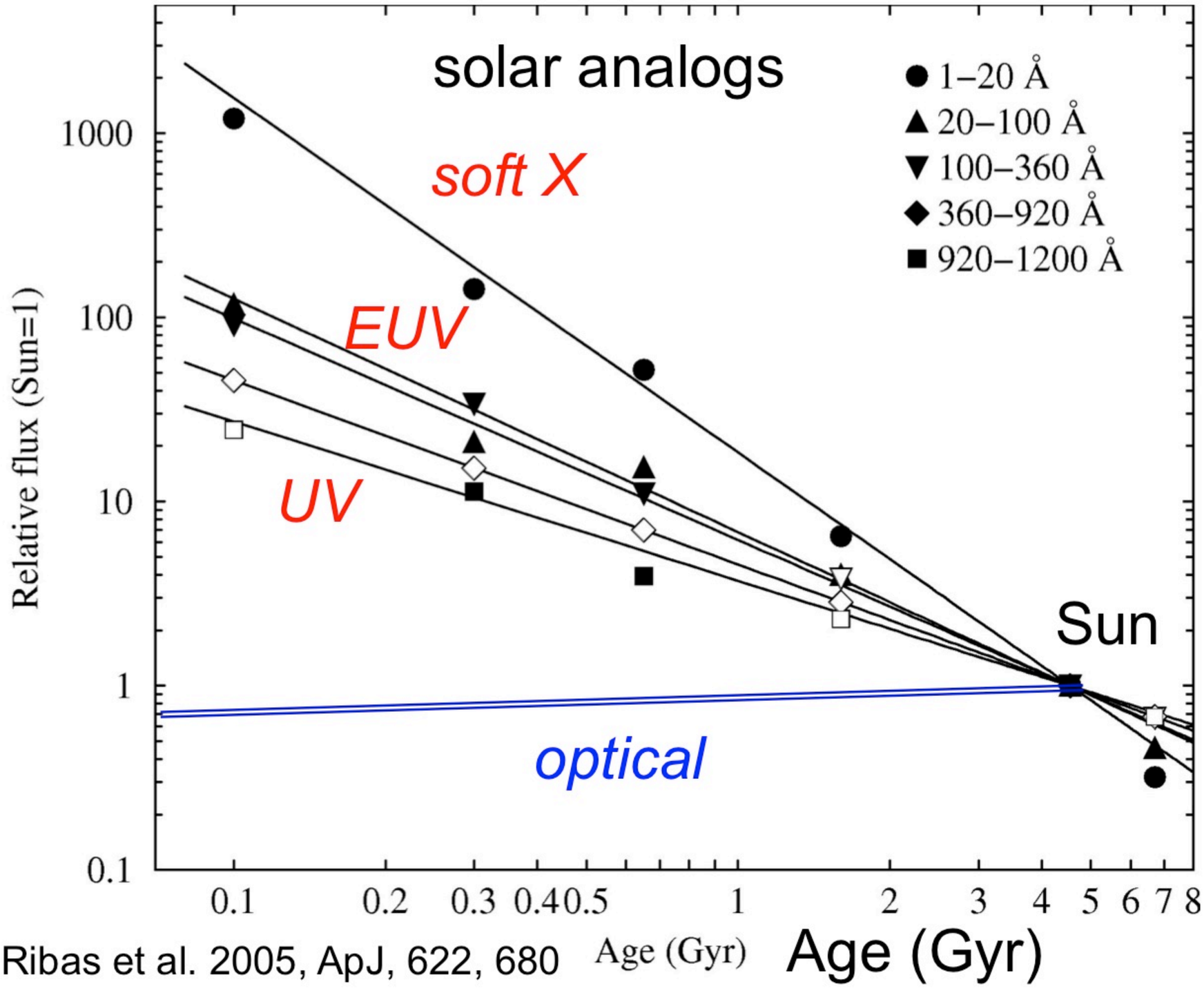
NASA/SDO/GSFC

Evolutionary Aspects

Magnetic Activity Decays

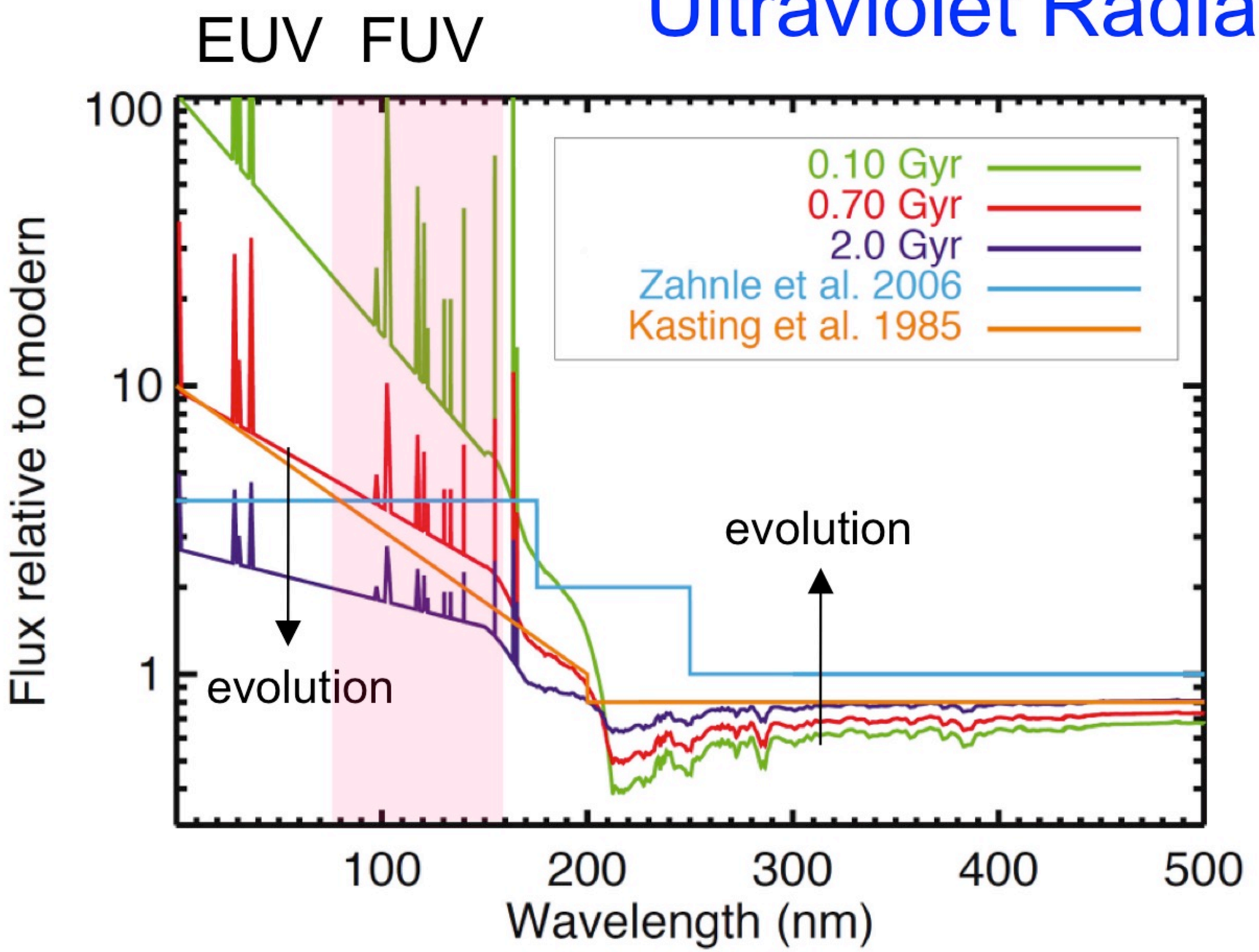


Ribas et al. 2005, ApJ, 622, 680

Luminosity decay larger and steeper at shorter wavelengths

Evolutionary Aspects

Ultraviolet Radiation



from Claire et al. 2012, ApJ, 757, 95

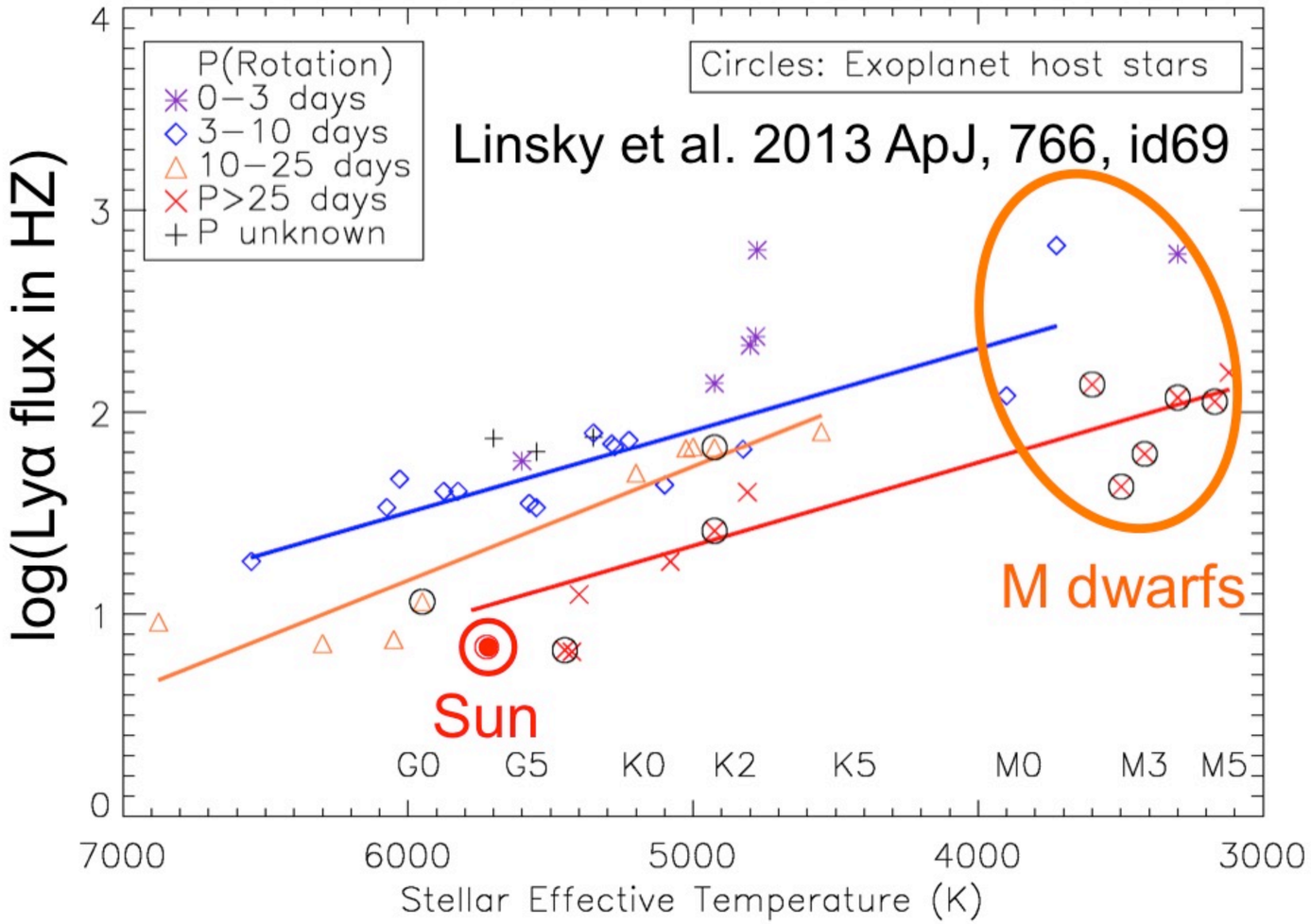
Young stars: stronger magnetic activity → more **FUV** active;
shorter wavelength → stronger evolutionary **decay**

Evolutionary Aspects

Ultraviolet Matters: M Dwarfs

M dwarfs photospherically NUV faint, but magnetically FUV strong:

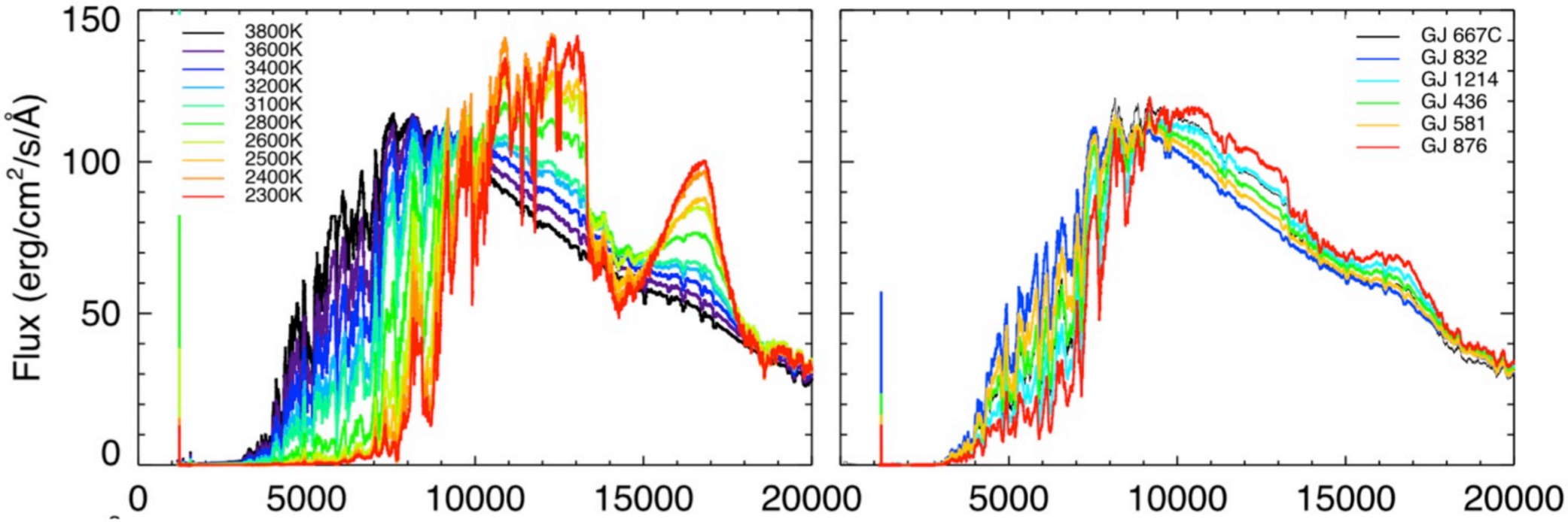
large f(FUV)/f(NUV) ratio (France et al., 2013), strong Lyα (Linsky et al., 2013)



M Dwarfs: strong FUV (photodissociates CO2 and H2O → ogygen) plus weak NUV (photodissociates O2 and O3) → abiotic path for producing significant oxygen in an exoplanet‘s atmosphere → France et al. (2013), Tian et al. (2014): detection of oxygen or ozone in an exoplanet‘s atmosphere not sufficient to constitute a valid biomarker

Ultraviolet Matters: M Dwarfs

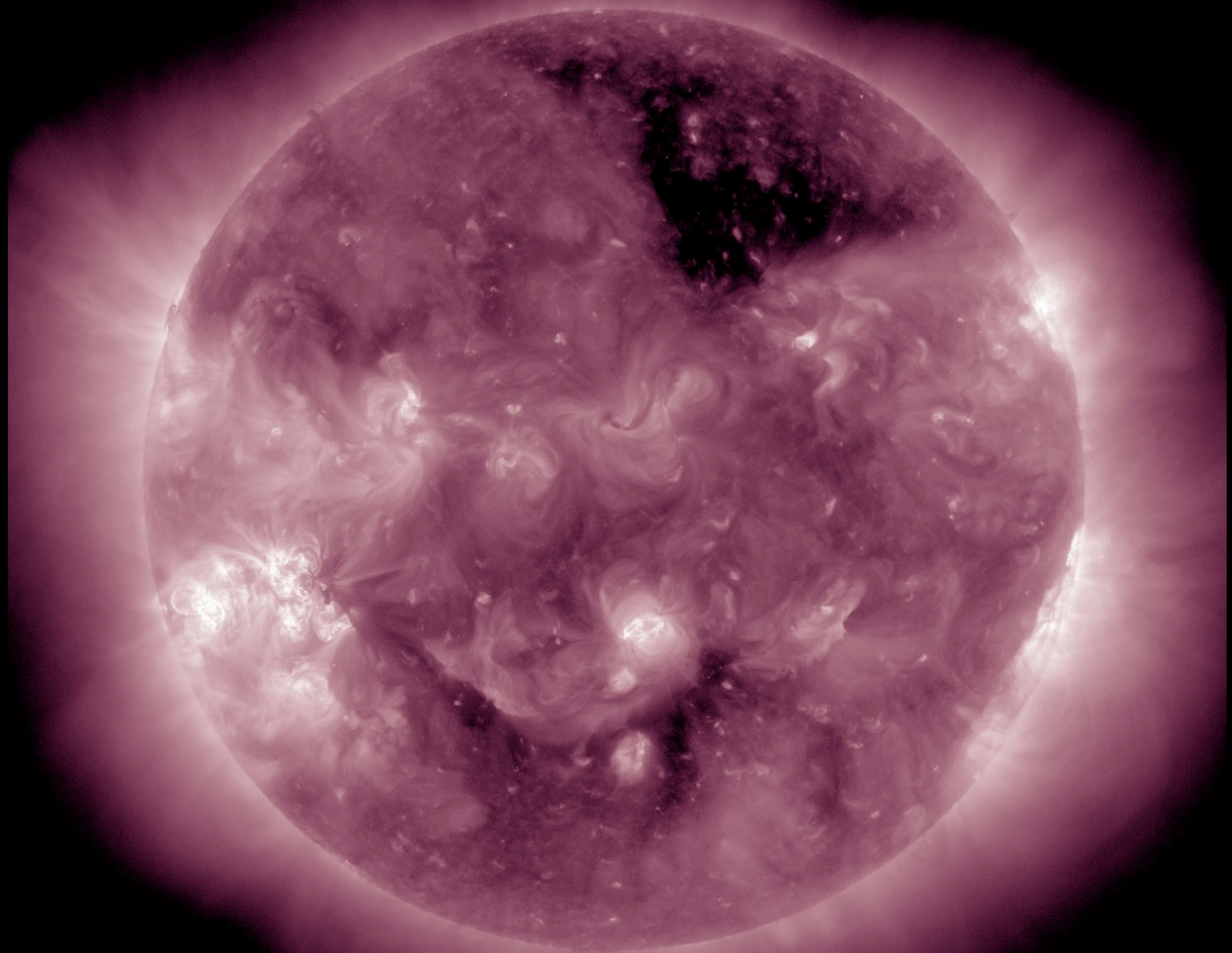
MUSCLES survey (P2.8)



Stellar input spectra for M0-M9 active grid stars, UV scaled by H_α and AD Leo UV flux (left) and MUSCLES stars with HST UV observations (right)

Rugheimer, Kaltenegger et al., 2015

211Å: 2,000,000 K corona



NASA/SDO/GSFC

The X-ray Sun

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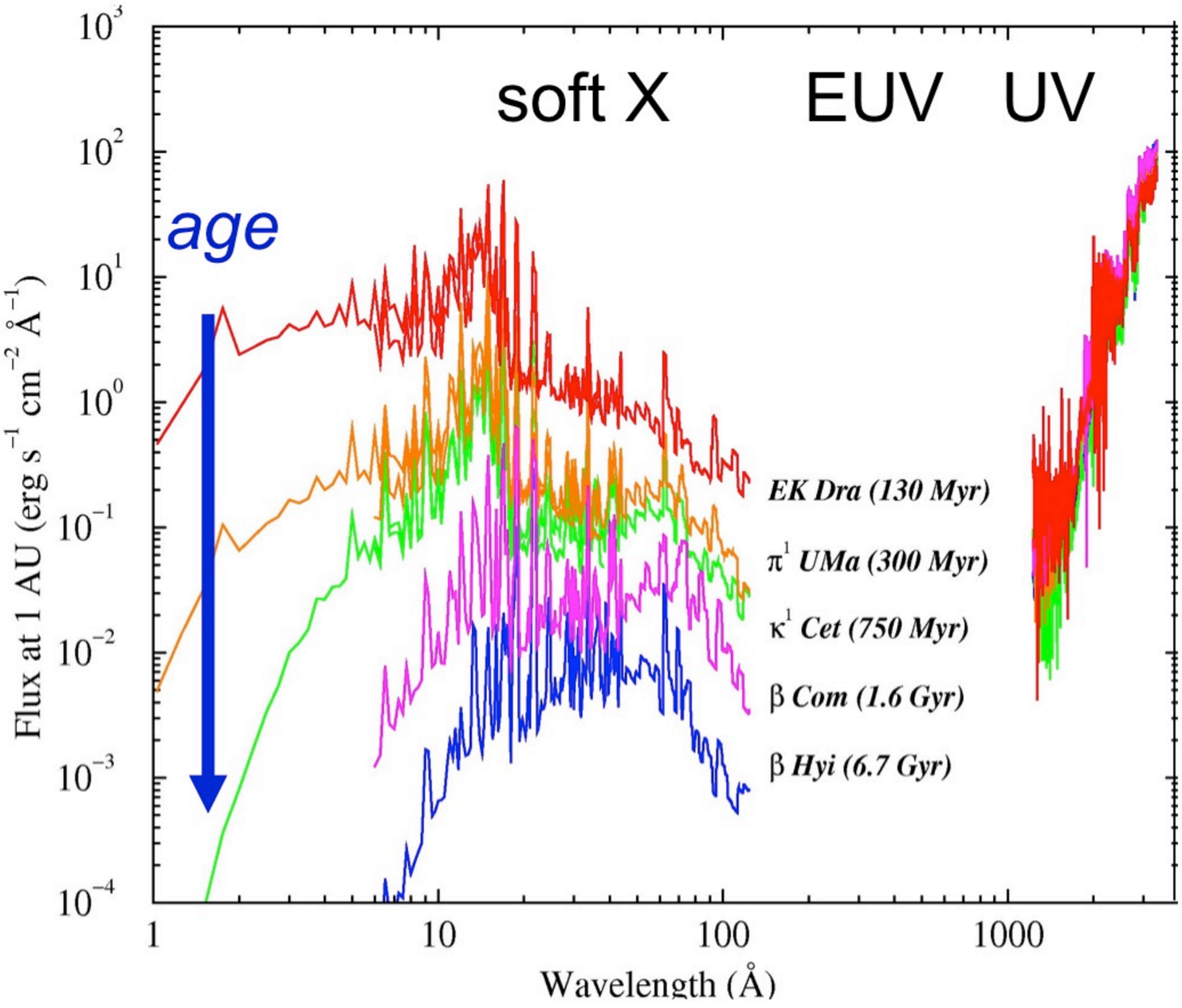
The EUV and X-Ray Sun in Time

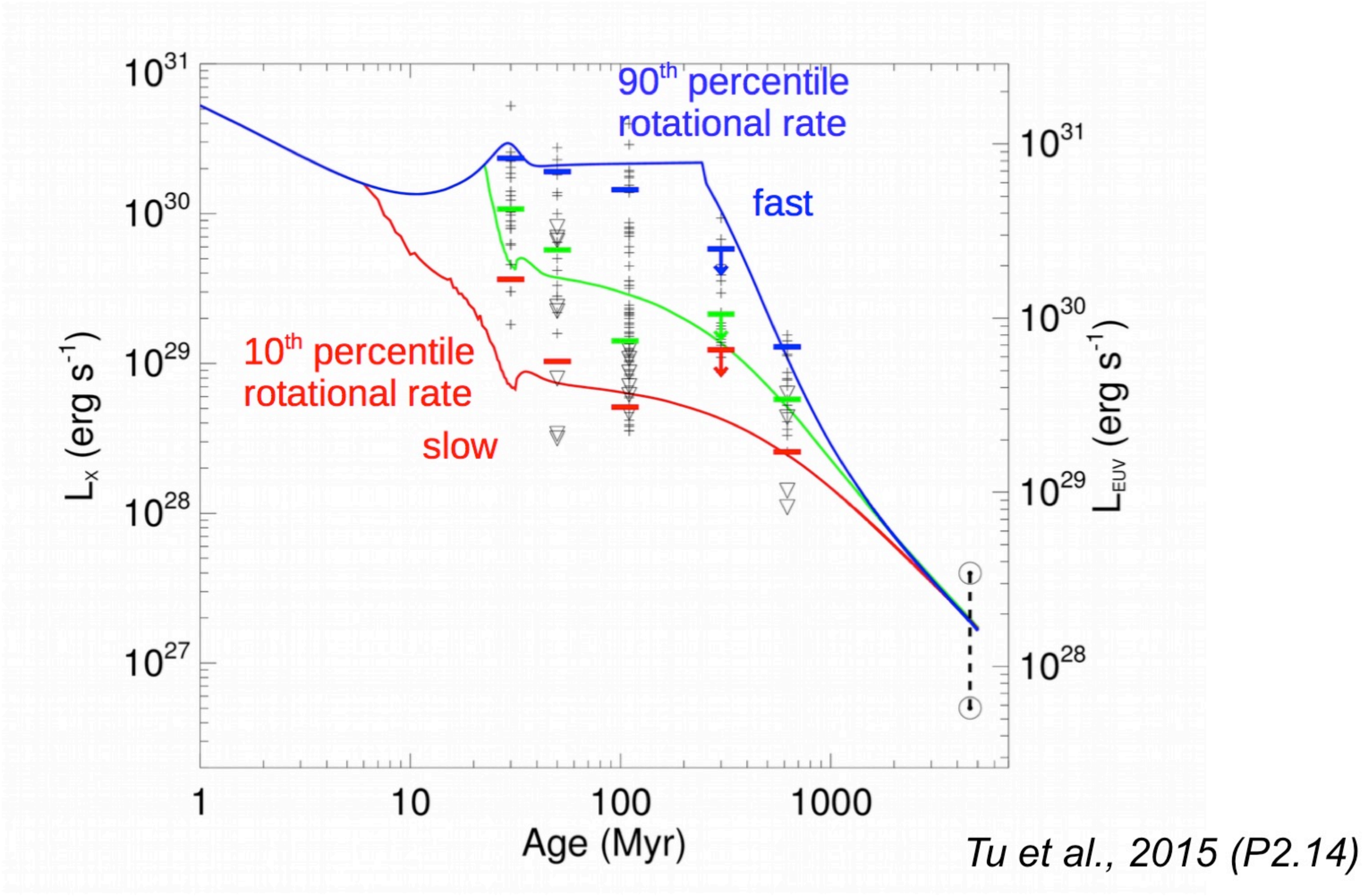


Guinan & Ribas 2002, ASP Conference Proceedings, Vol. 269, 85
Güdel 2004, A&A Review, 12, 71
Ribas et al. 2005, APJ, ApJ, 622, 680; Claire et al. 2012, ApJ, 757, 95

Luminosity (and hardness!) decay
more rapidly over much larger scale in X-ray than in UV

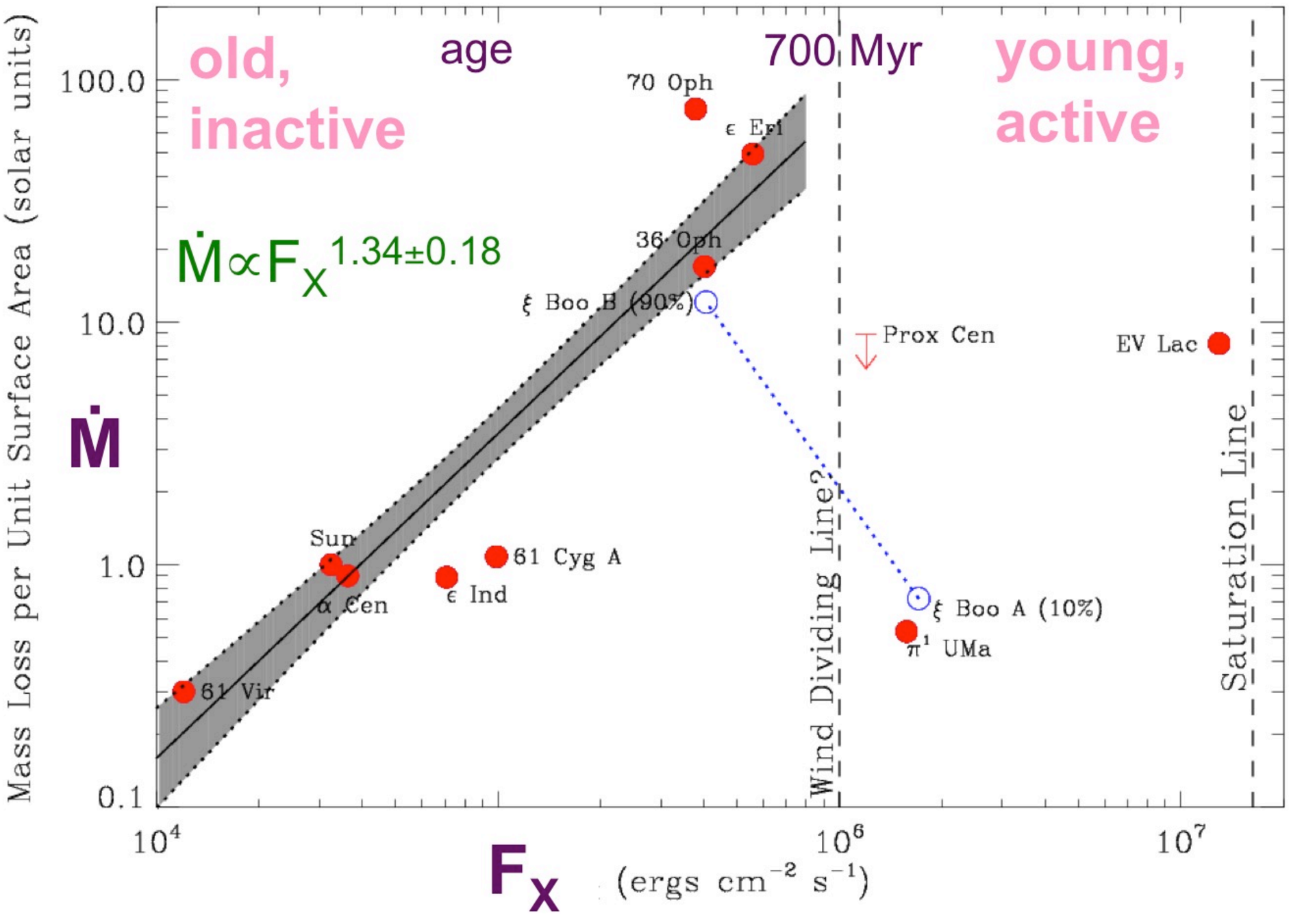
Evolutionary Aspects

Stellar radiation evolution



Tu et al., 2015 (P2.14)

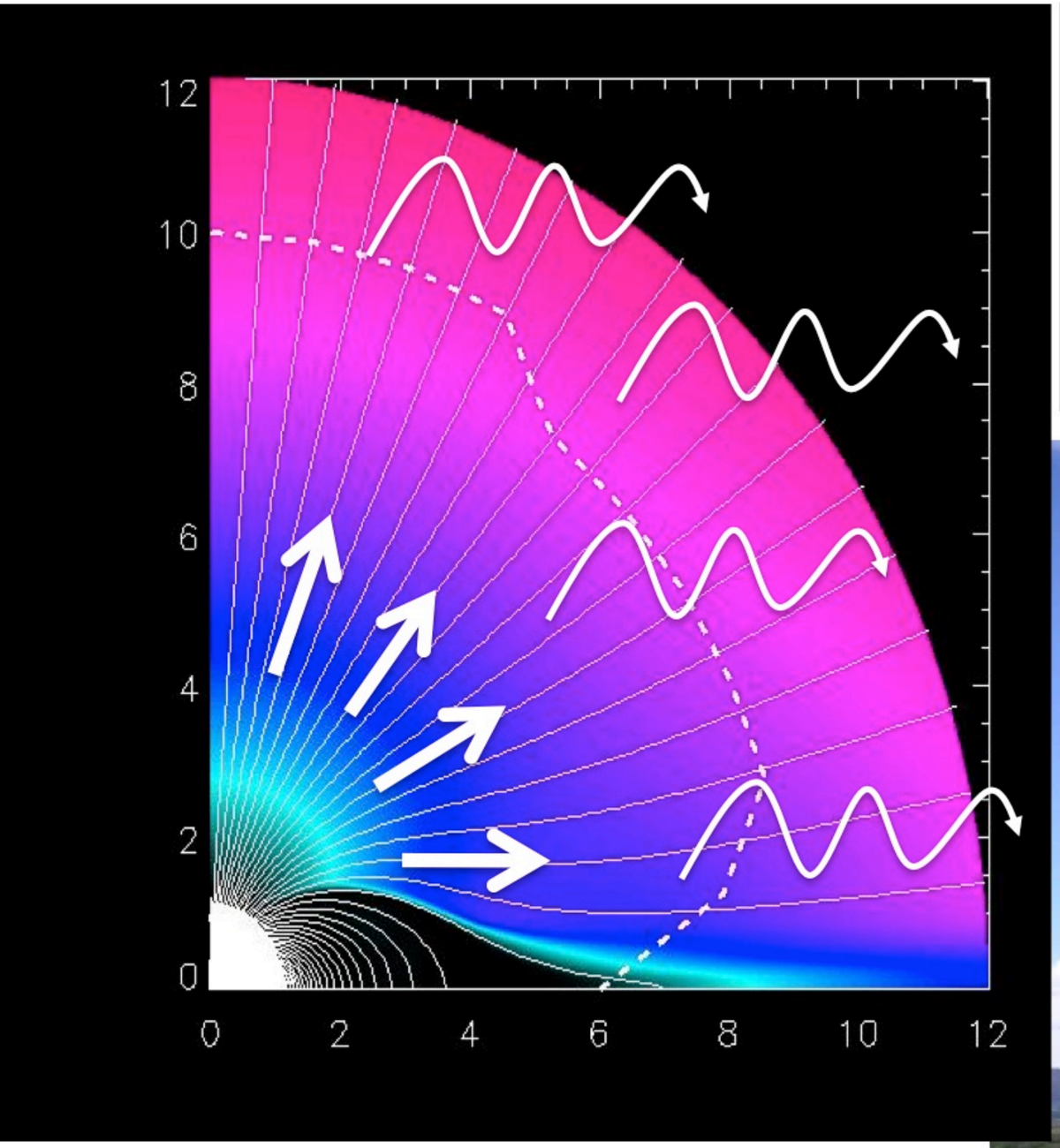
Evolutionary Aspects: Winds Decay in Time



Wood et al. 2005, ApJ, 628, L143; Wood et al. 2010, ApJ, 717, 1279

$\dot{M} \propto t^{-2.33\pm0.55}$ for ages > 700 Myr

Observing Stellar winds - indirectly



- attempts to directly detect thermal Bremsstrahlung radiation in radio from these winds: non-detections give important upper limits on the wind strengths

Mass loss rate estimates

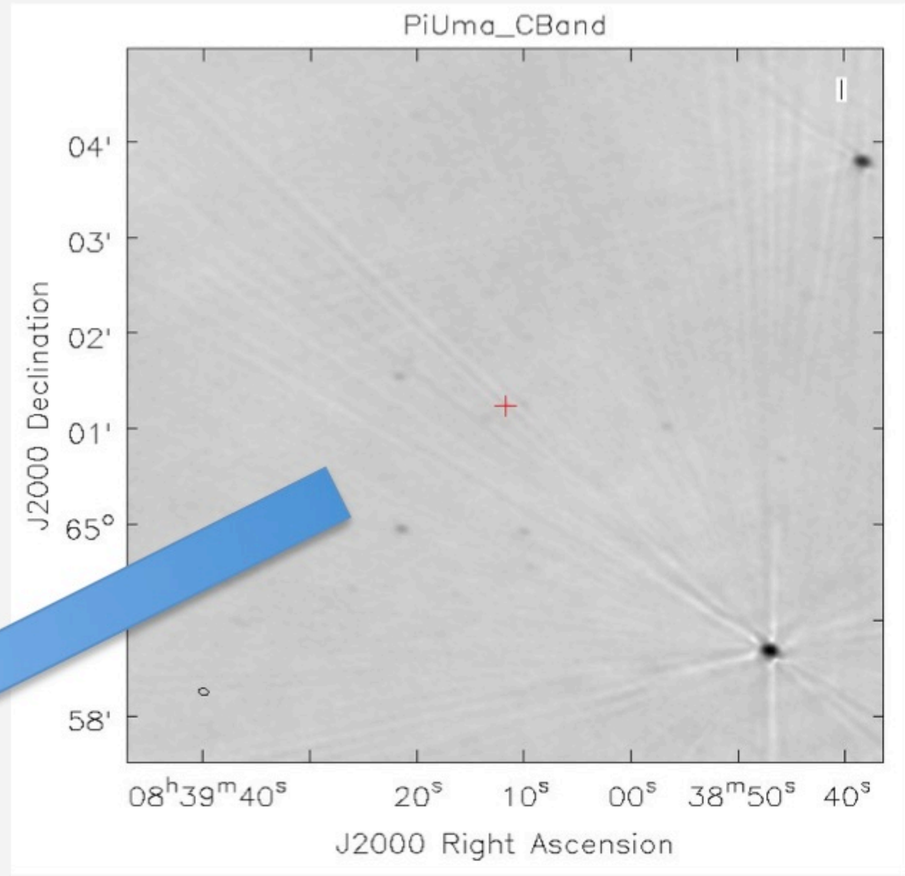
- kappa Cet:

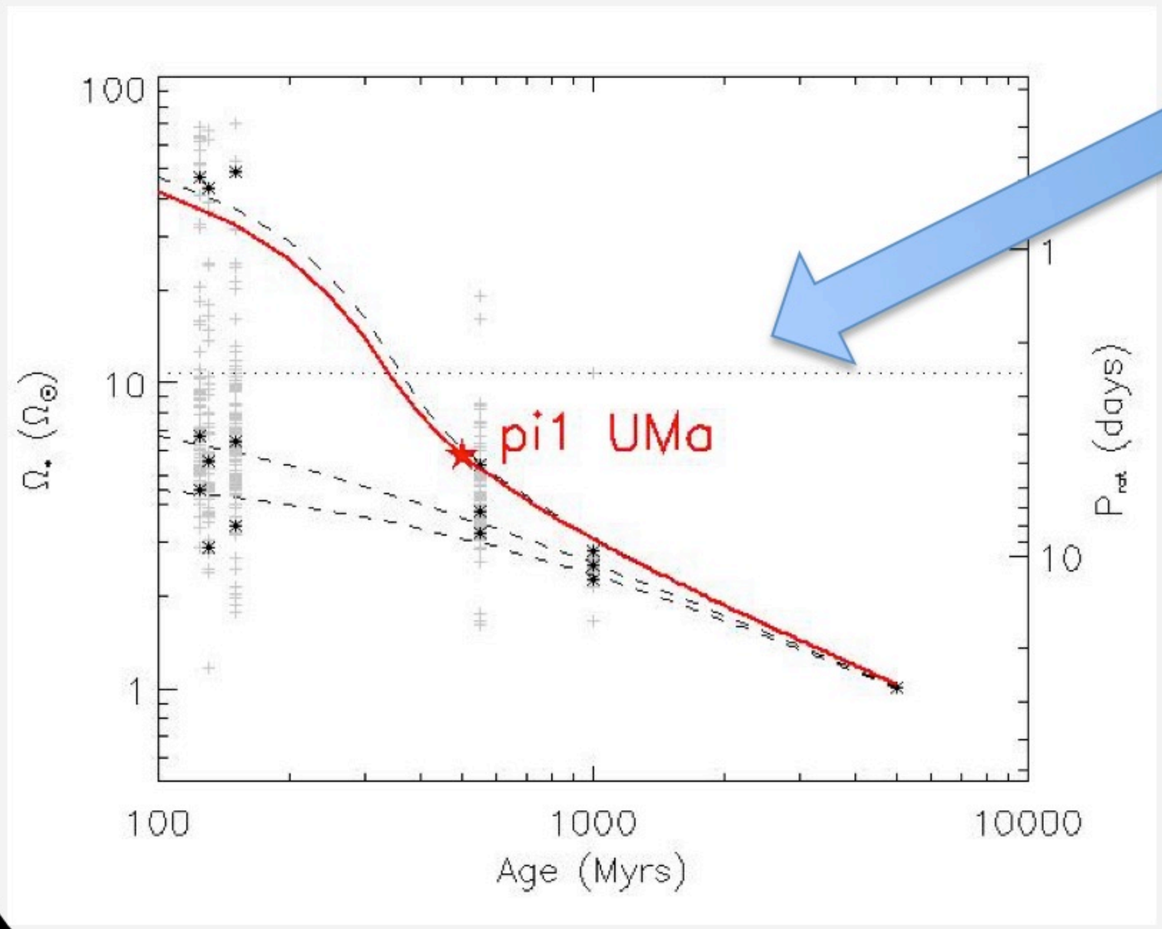
$$M_{dot} < 4.1 \times 10^{-12} M_{sun}/yr$$

- pi^1 UMa:

$$M_{dot} < 5.0 \times 10^{-12} M_{sun}/yr$$

Fichtinger et al., 2016 (P2.4)



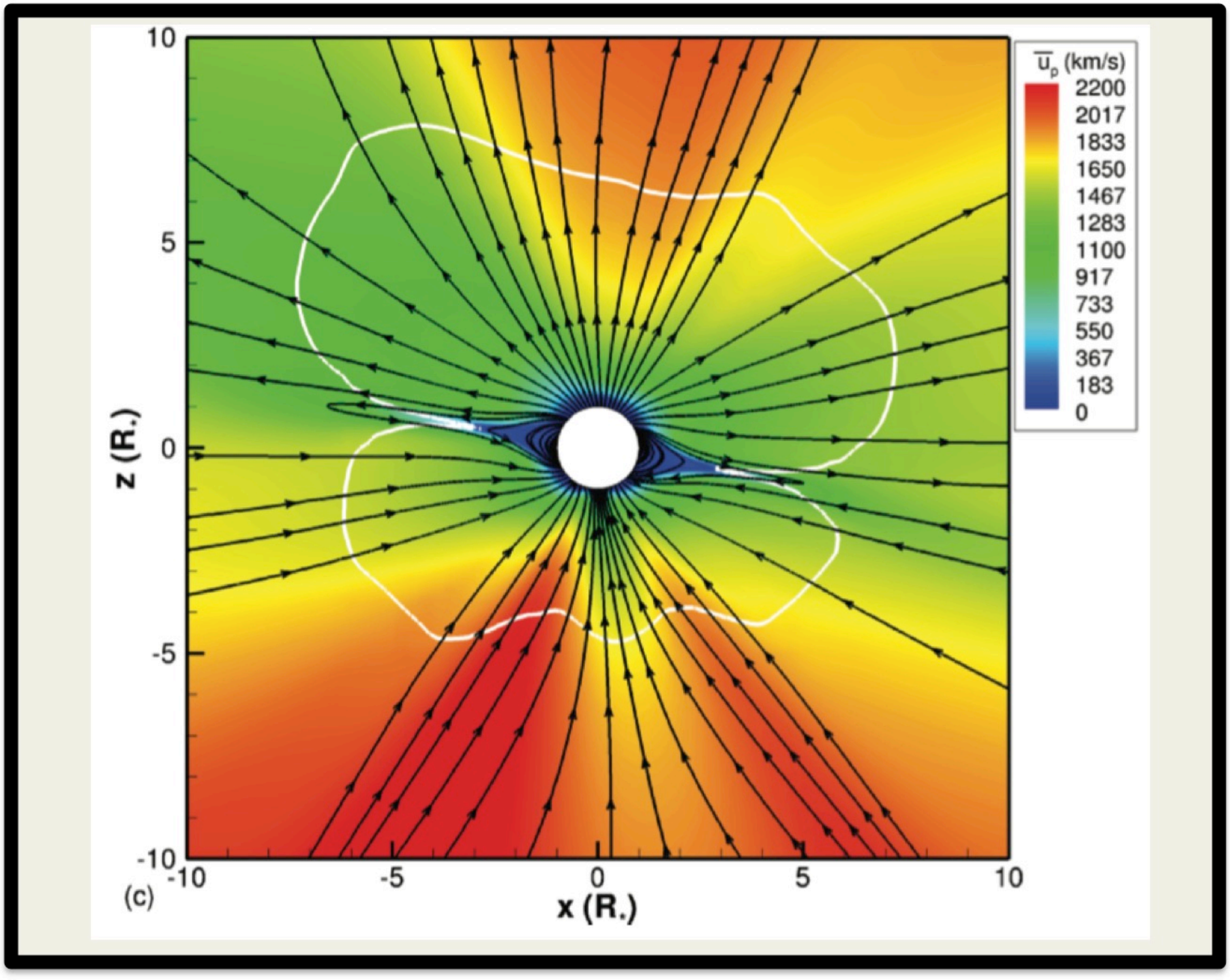


ESPaDOnS/NARVAL observations of:

EK Dra (100 Myr),
χ^1 Ori (300 Myr)
κ^1 Cet (700 Myr)
pi1 UMa, new set in 2015

➔ **ZDI**

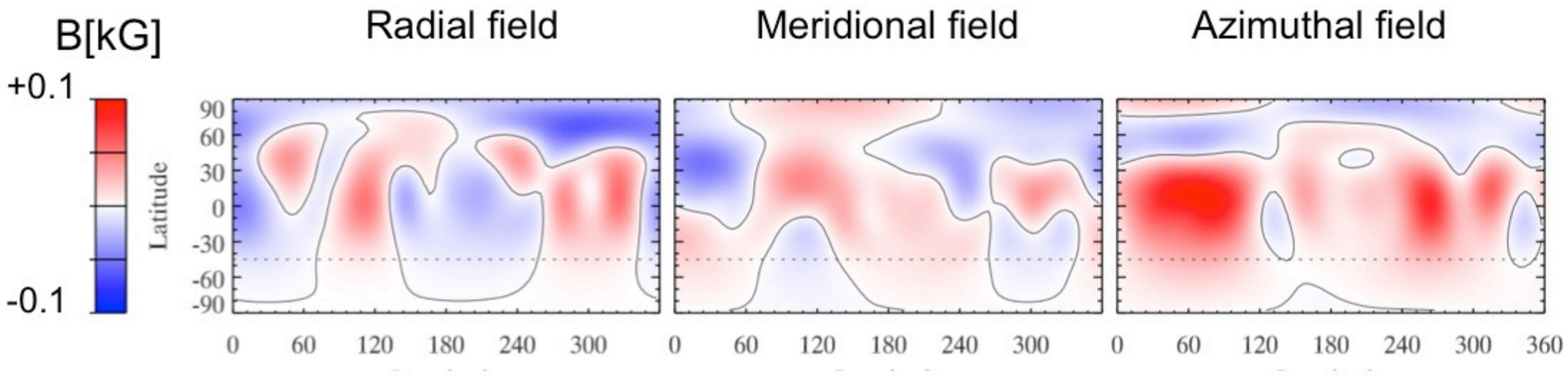
3D MHD Wind Models



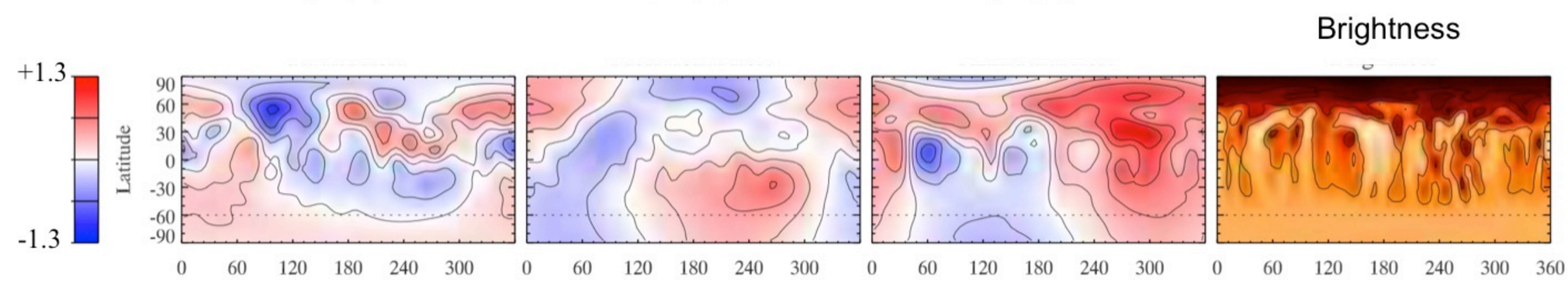
scaled poloidal wind velocity based on map of V374 Peg *Vidotto et al., 2011*

Further details: talks by C. Johnstone and A. Vidotto, this session

Getting the Fields: Zeeman Doppler Imaging



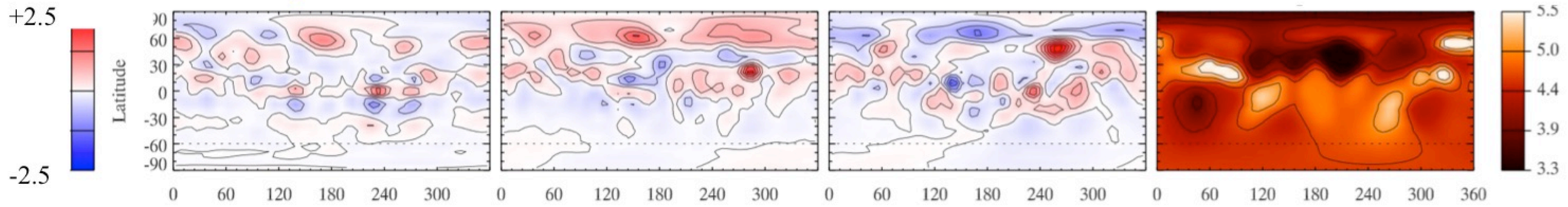
pi[1] UMa



V410 Tau

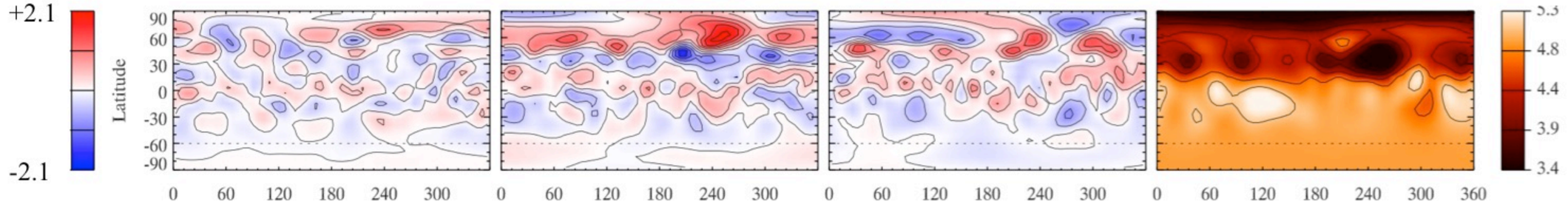
Lüftinger et al., 2016

25 Sep - 1 Oct 2012



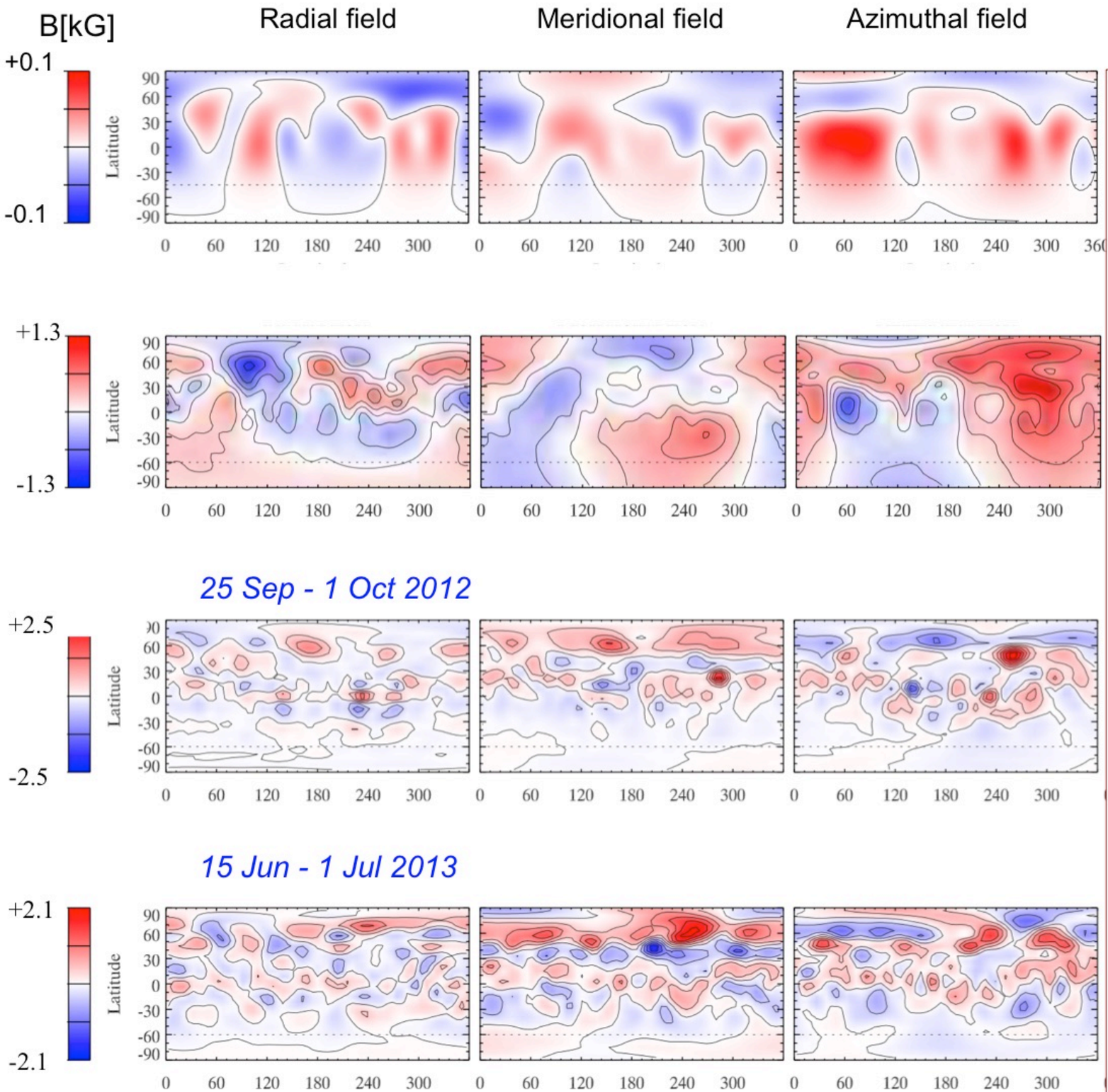
II Peg

15 Jun - 1 Jul 2013



Rosén et al., 2012

Getting the Fields: Zeeman Doppler Imaging



A lot has been done:

Donati et al.,

Folsom et al,

Kochukhov et al.,

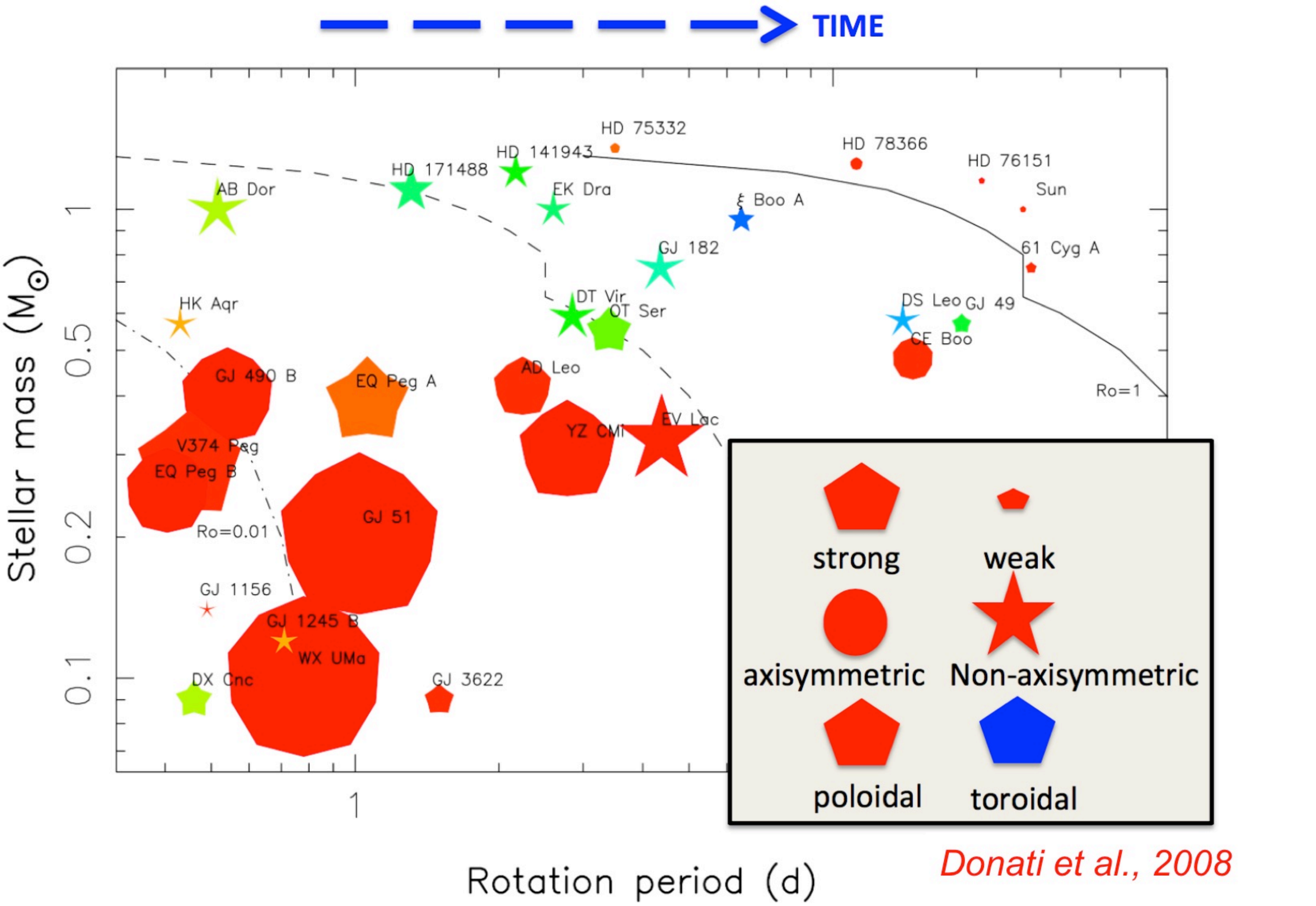
Lueftinger et al.,

Strassmeier et al.,

Piskunov et al.,

BCool, ...

Magnetic Fields – shaping the Stars and Planets



Donati et al., 2008

Evolution Matters (a lot!) - Magnetic fields

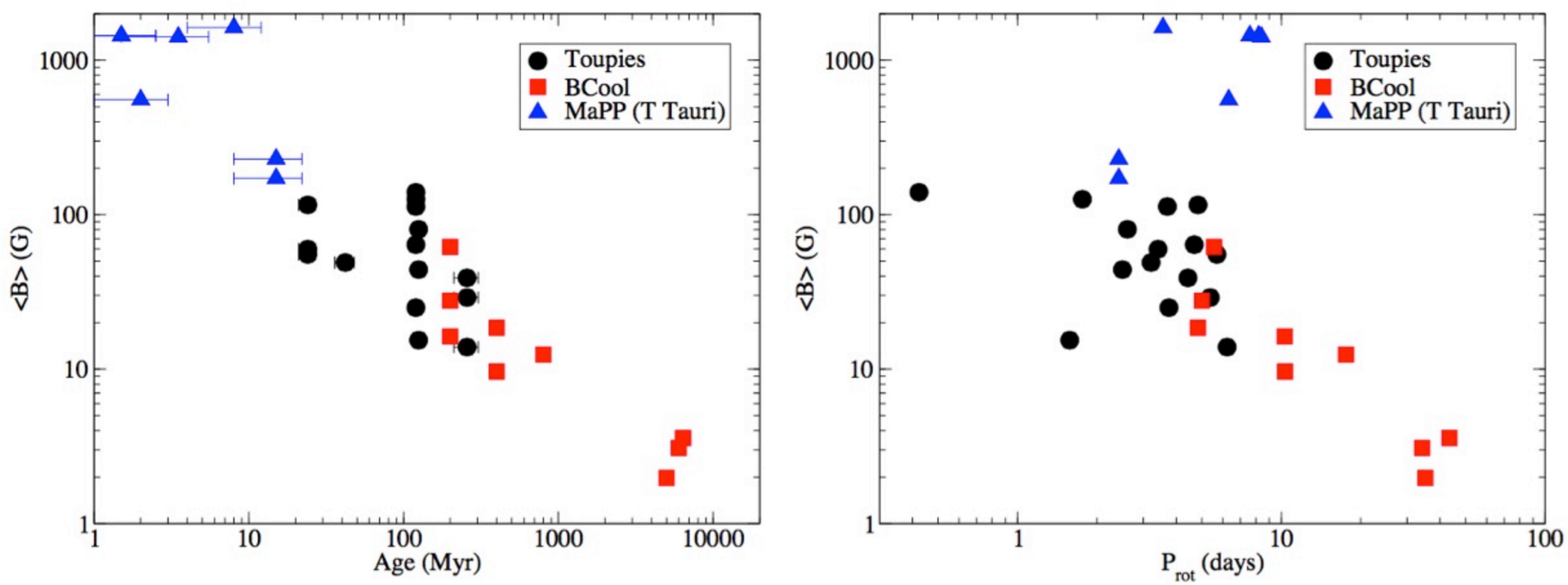
Maps of young suns suggest:

(Folsom et al., 2016)

- trend towards **decreasing complexity with increasing rotation period** (structures tend to be more small scale for faster rotators)

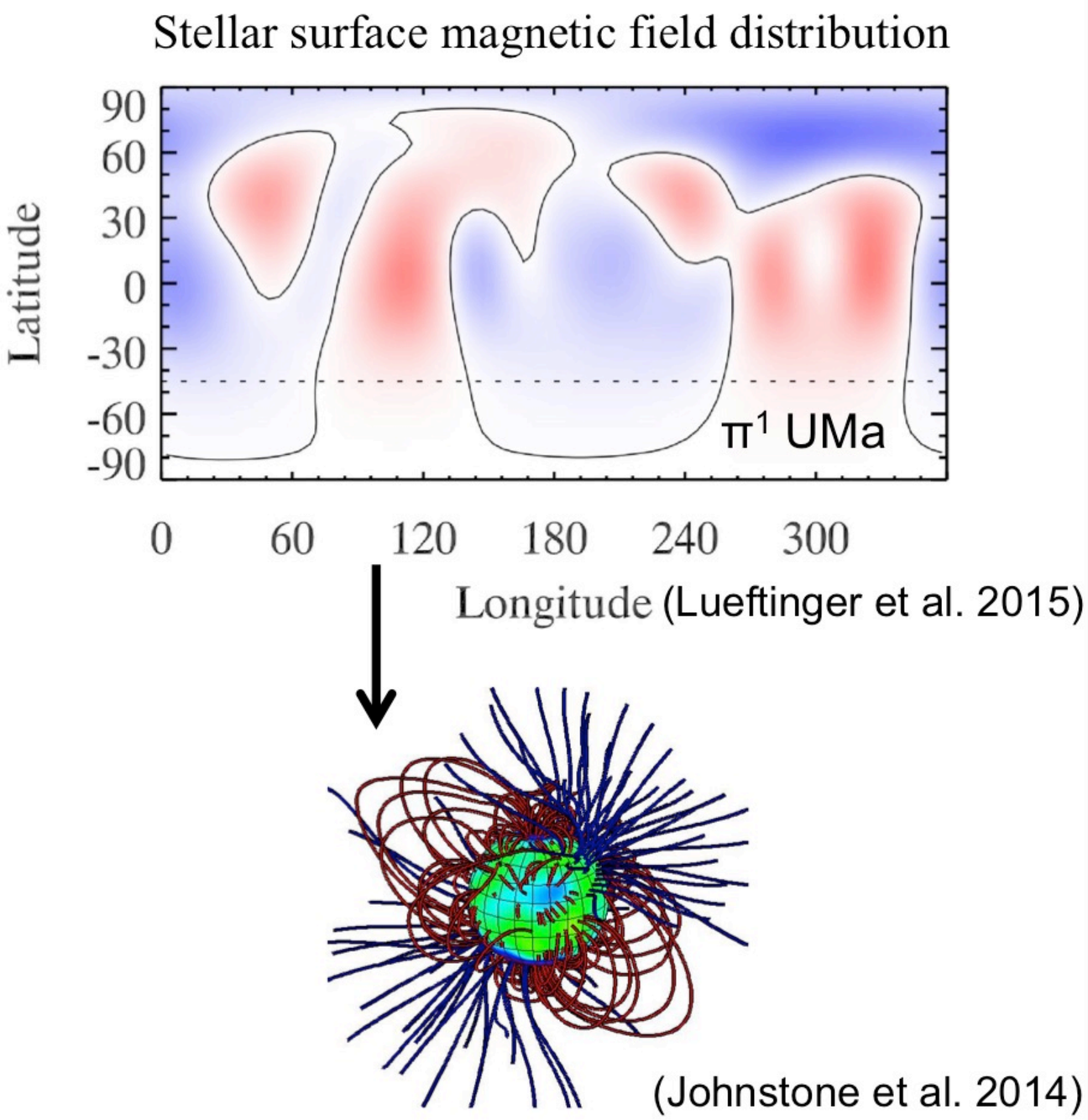
- similar trend with increasing Rossby number (ratio of rotation period to convective turnover time: $R_o = P_{rot}/\tau_{conv}$)

note: spatial resolution of ZDI a function of the vsini ➔ *potential systematic observational bias, although: correlation appears to be stronger with rotation period than vsini, and all stars should have maps with a resolution higher than an l order of 2* ➔ *trend appears to be real*



Couple the Whole System

Observations of magnetic fields

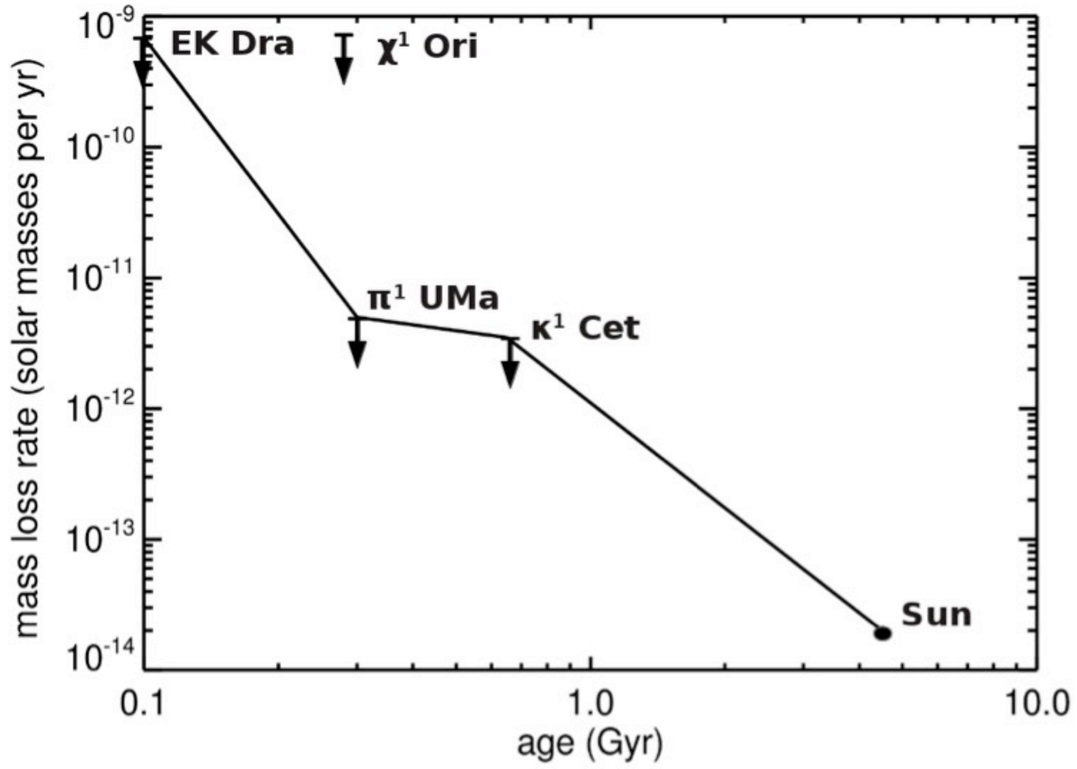


(Lueftinger et al. 2015)

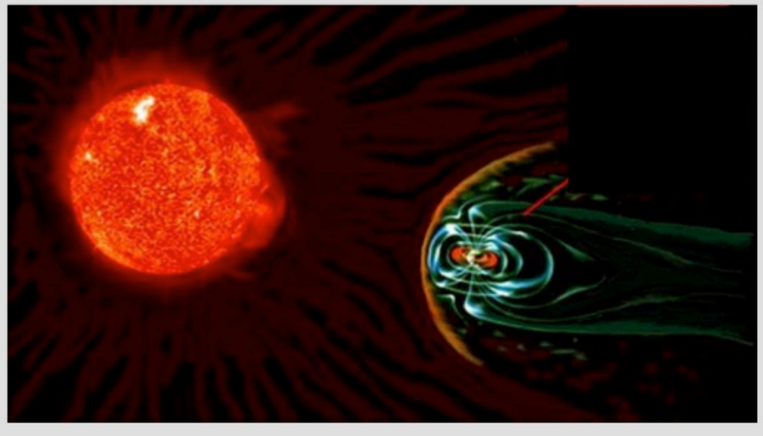
(Johnstone et al. 2014)

"Stellar magnetic fields and winds in time"

Observations of winds



Couple stellar wind to planetary magnetosphere and upper atmosphere



(Kislyakova et al. 2015, Khodachenko et al., 2015)

THANK YOU!