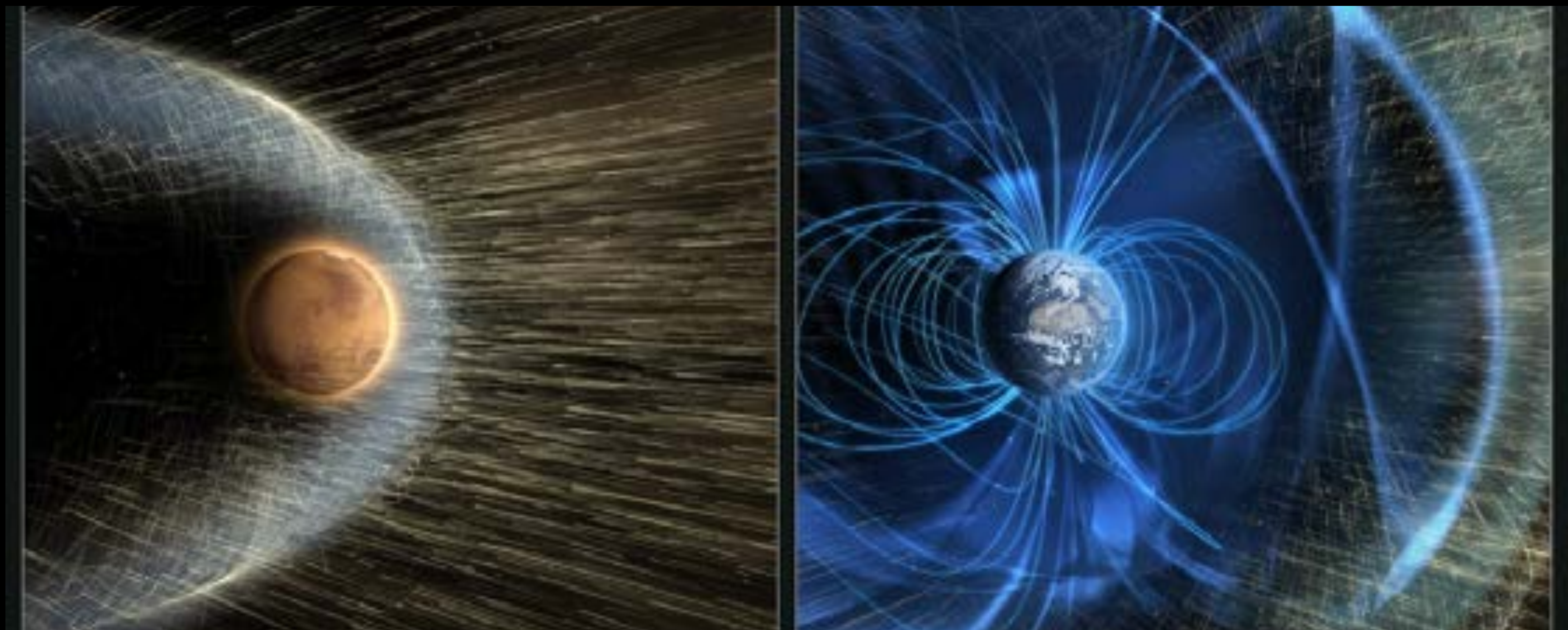
# Stars Shaping the Atmospheres of their Planets

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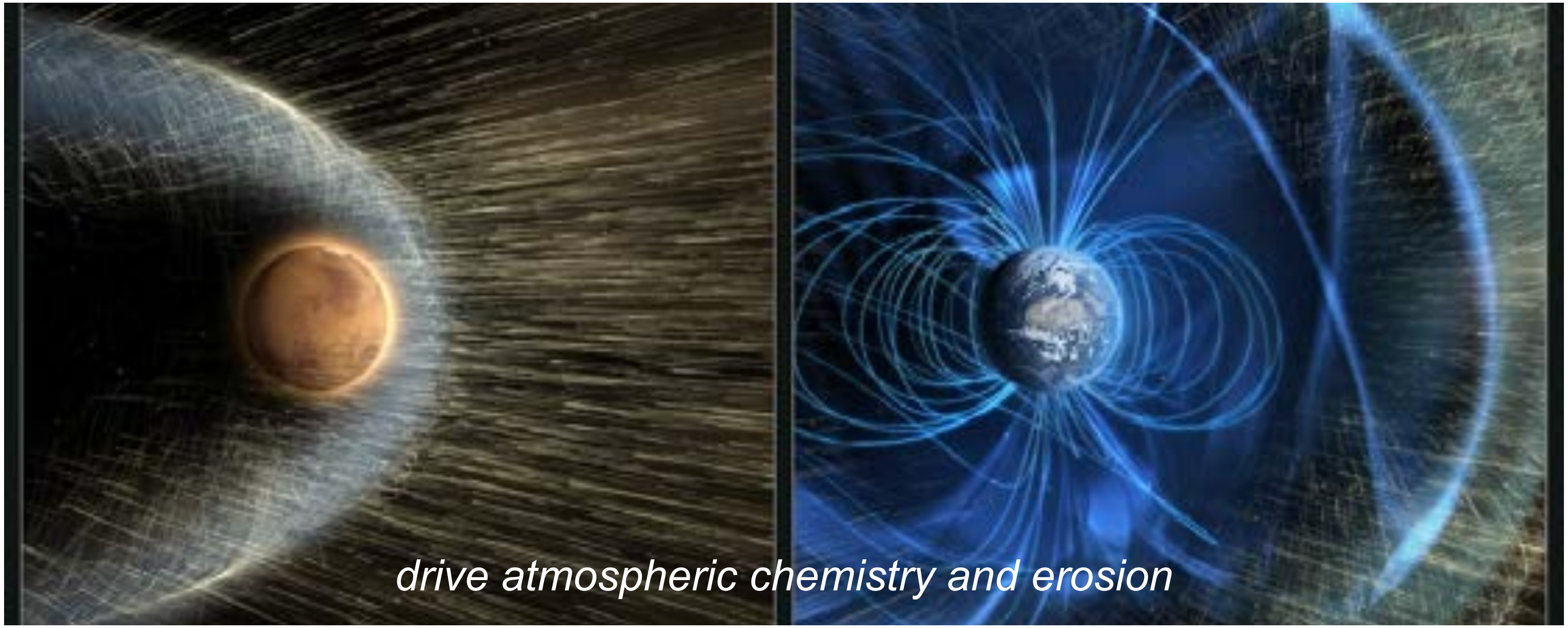
# *Stars – Shaping their planetary environments*

**Ingredients of Space Weather: G, K, M**

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

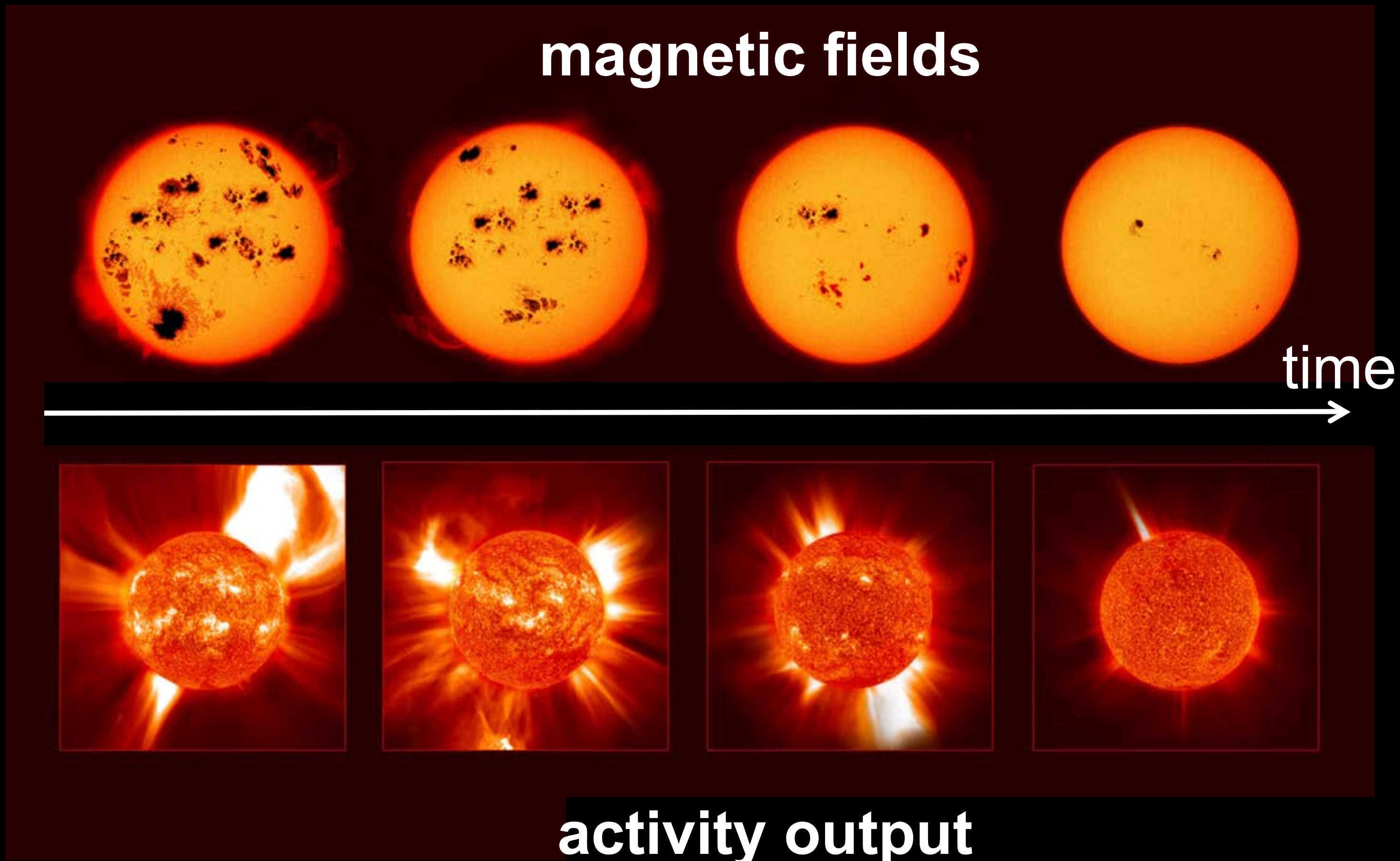
**All triggered by the stellar magnetic field**

- Radiation-atmosphere interaction
- Magnetosphere-wind interaction
- Magnetosphere-atmosphere system (Rotation, Evolution, Dynamos)

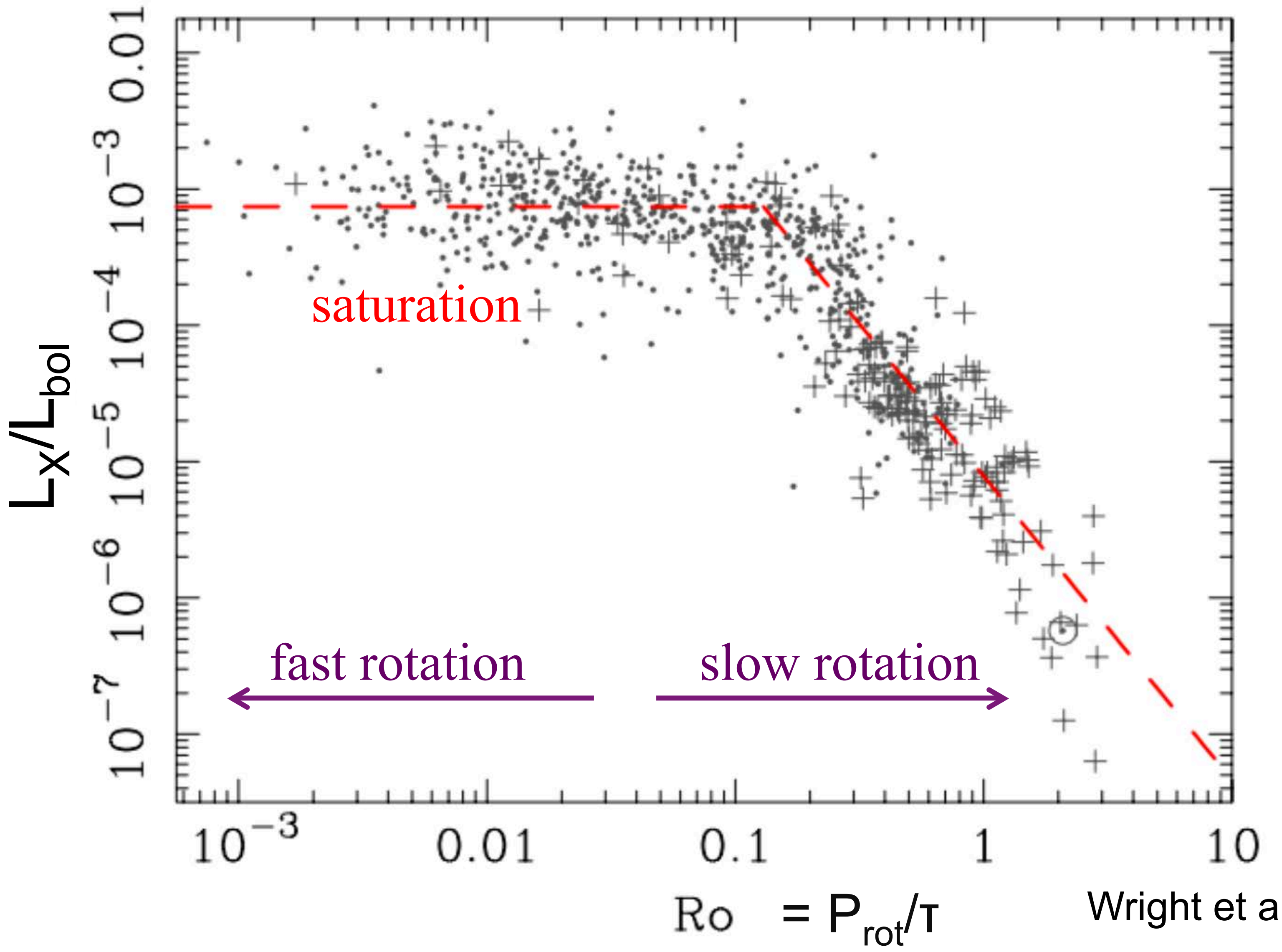


# *Stellar Activity Evolution*

Atmospheric escape history depends on stellar irradiation history



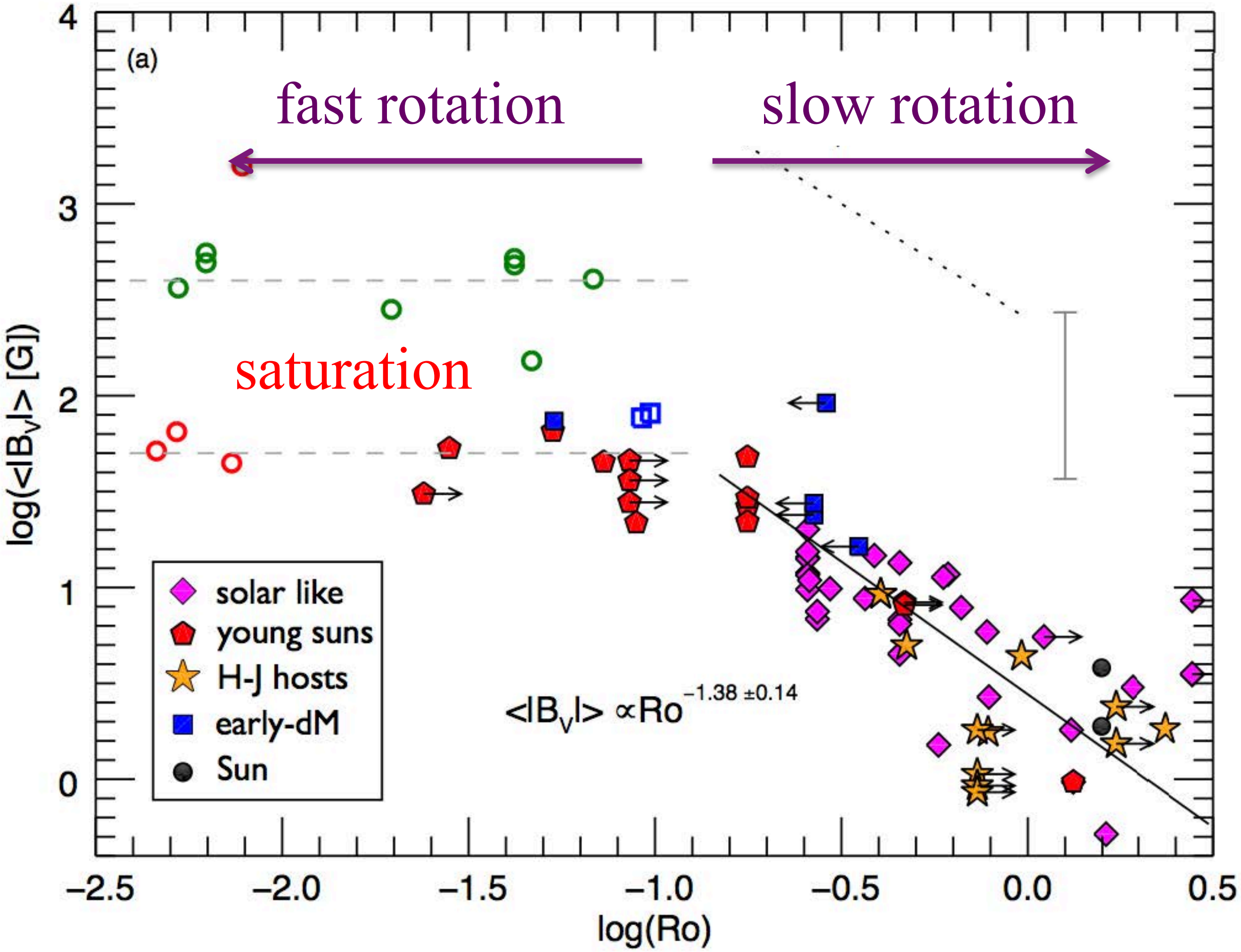
# *Dynamo on the MS: Activity vs Rotation*

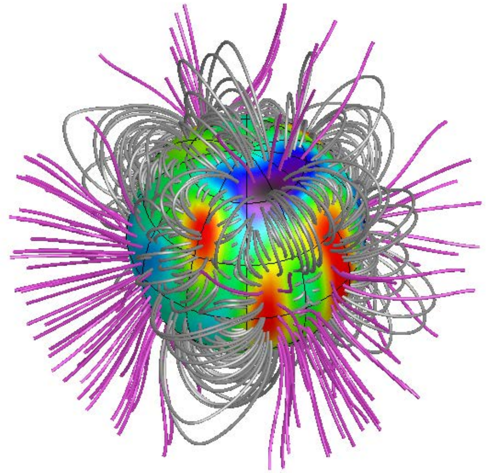



Wright et al. 2011

***Magnetic fields significantly affect stellar rotation (field-wind interaction)***

# *Stellar Magnetic Fields*



Lueftinger et al. 2018

large-scale (~dipole) field

$B_V \propto Ro^{-1.38}$

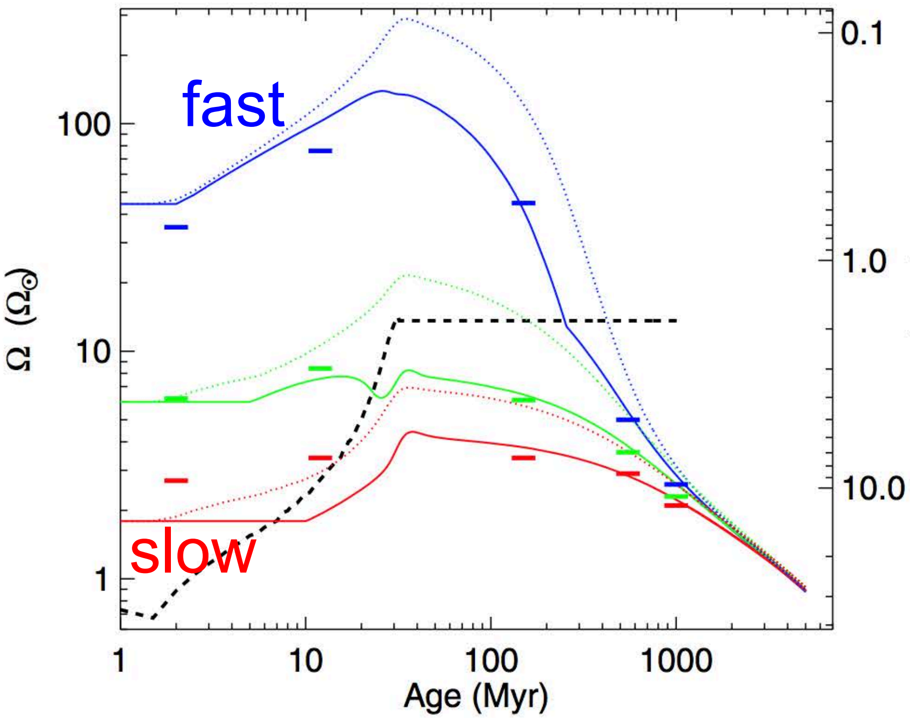
Vidotto et al. 2014

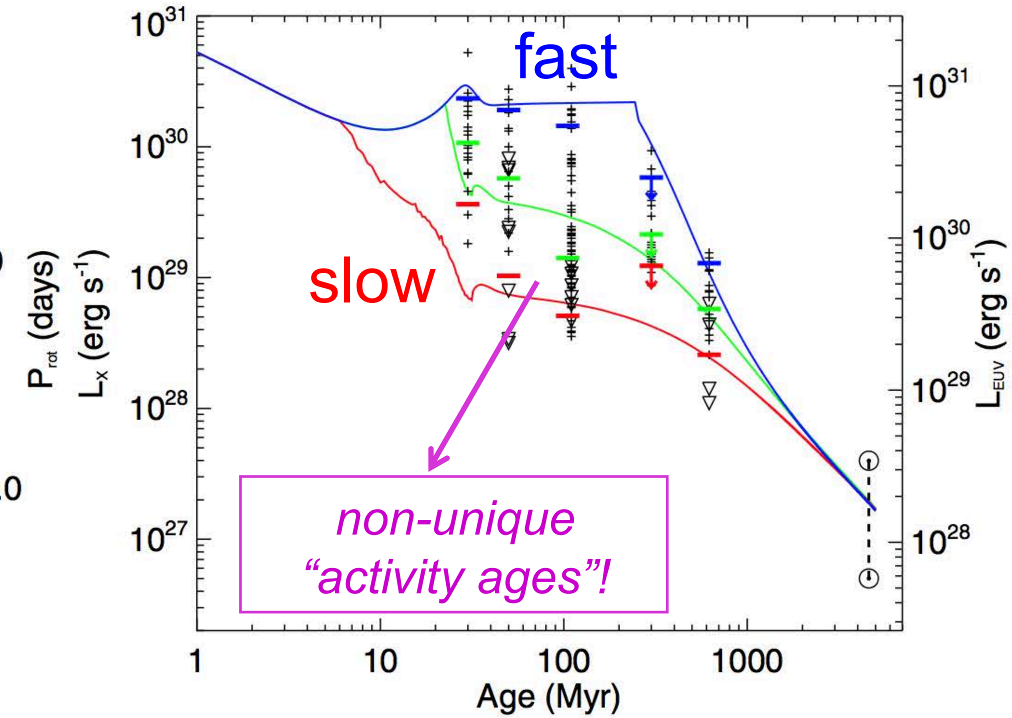
Large-scale magnetic flux correlates with rotation and shows saturation

# The High-Energy Sun in Time

Depending on initial rotation....

Rotation tracks → X-ray/UV radiation tracks

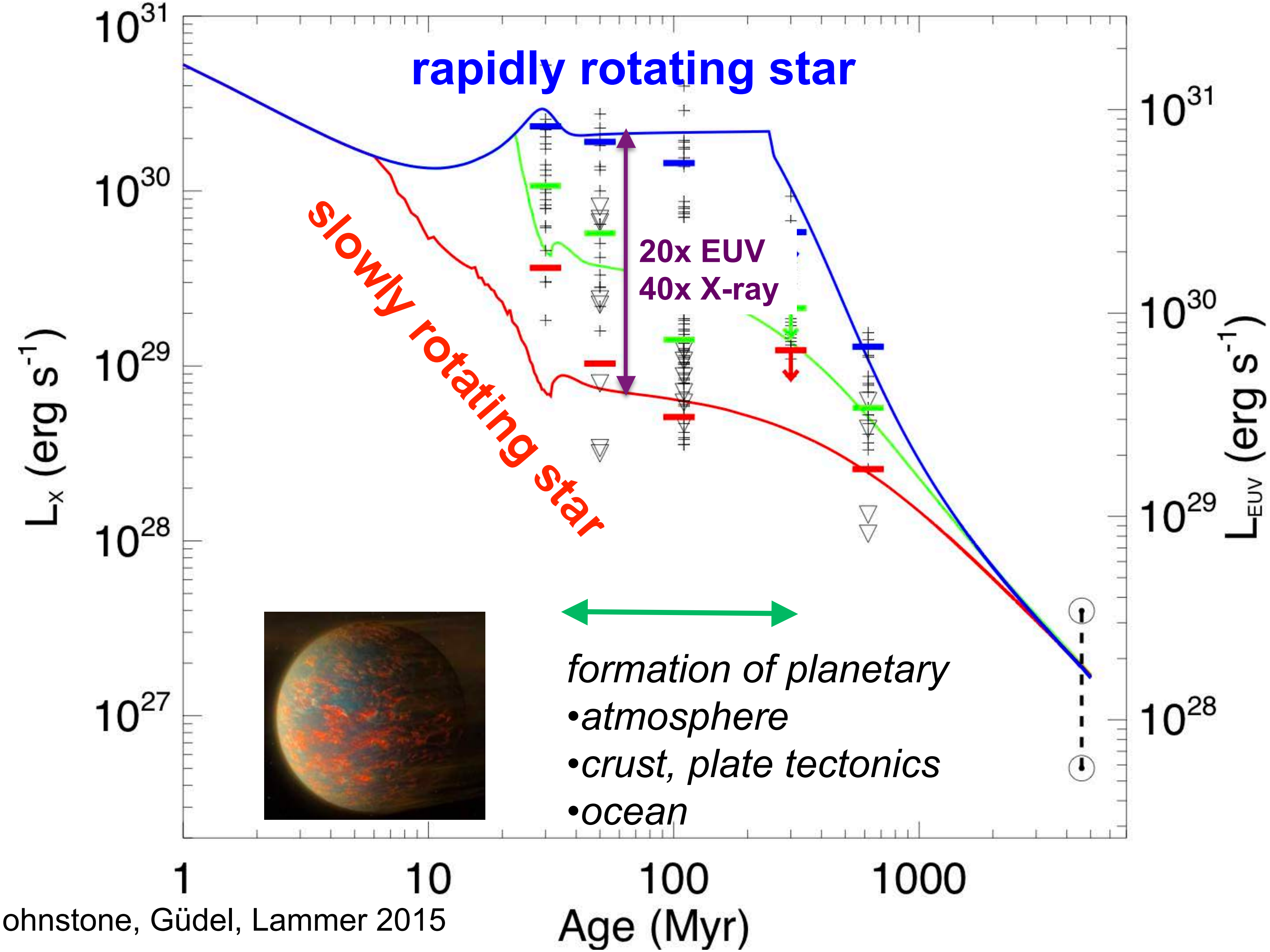



Tu, Johnstone, Güdel 2015

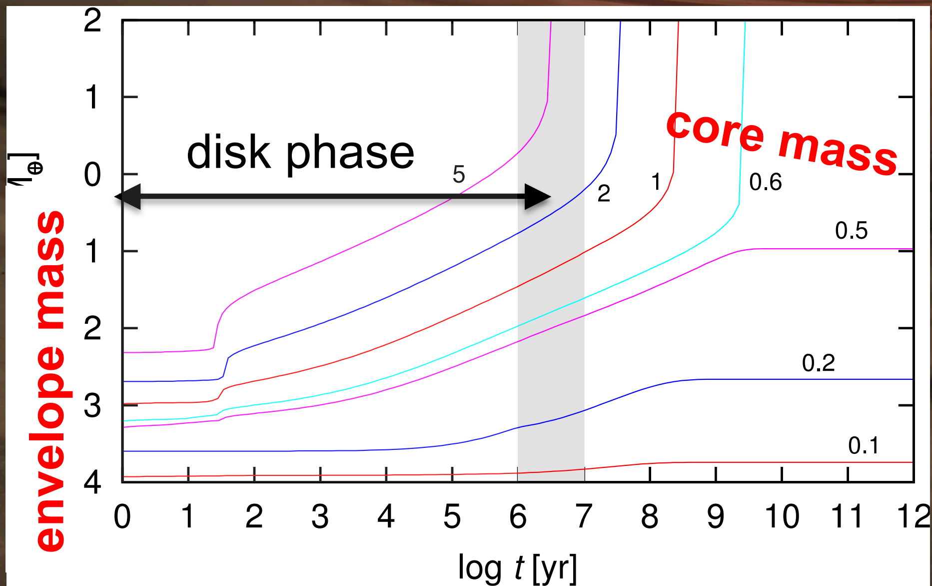
(see also Gallet & Bouvier 2013)

# *The High-Energy Sun in Time*

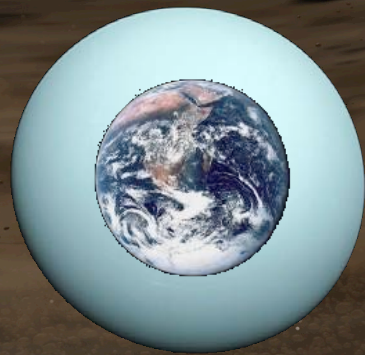



Tu, Johnstone, Güdel, Lammer 2015

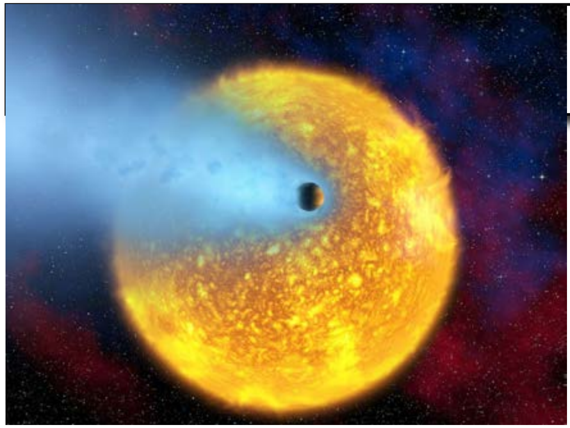
# Gas Envelope Accretion




Stökl et al. 2015ab



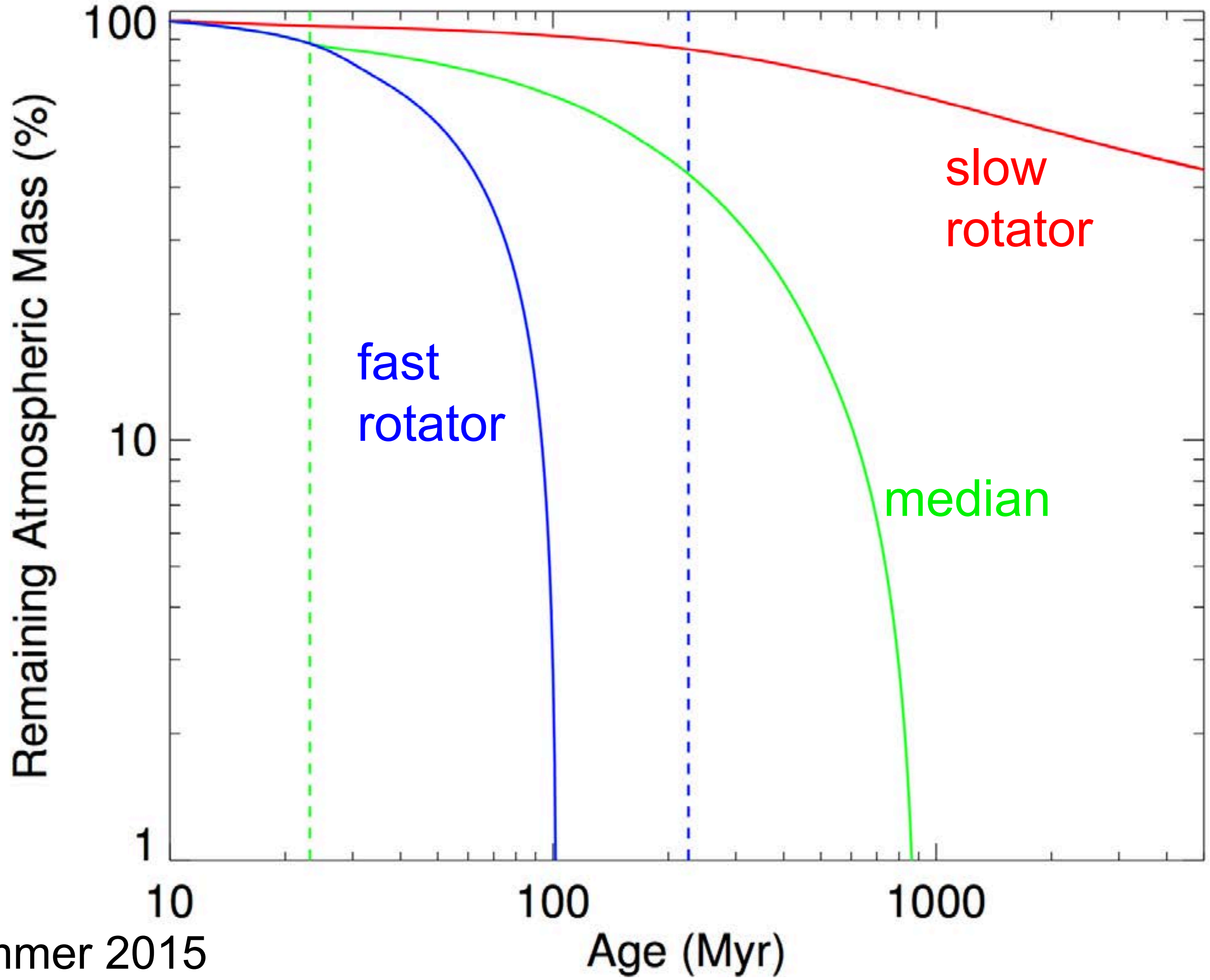
NASA



# .....And:

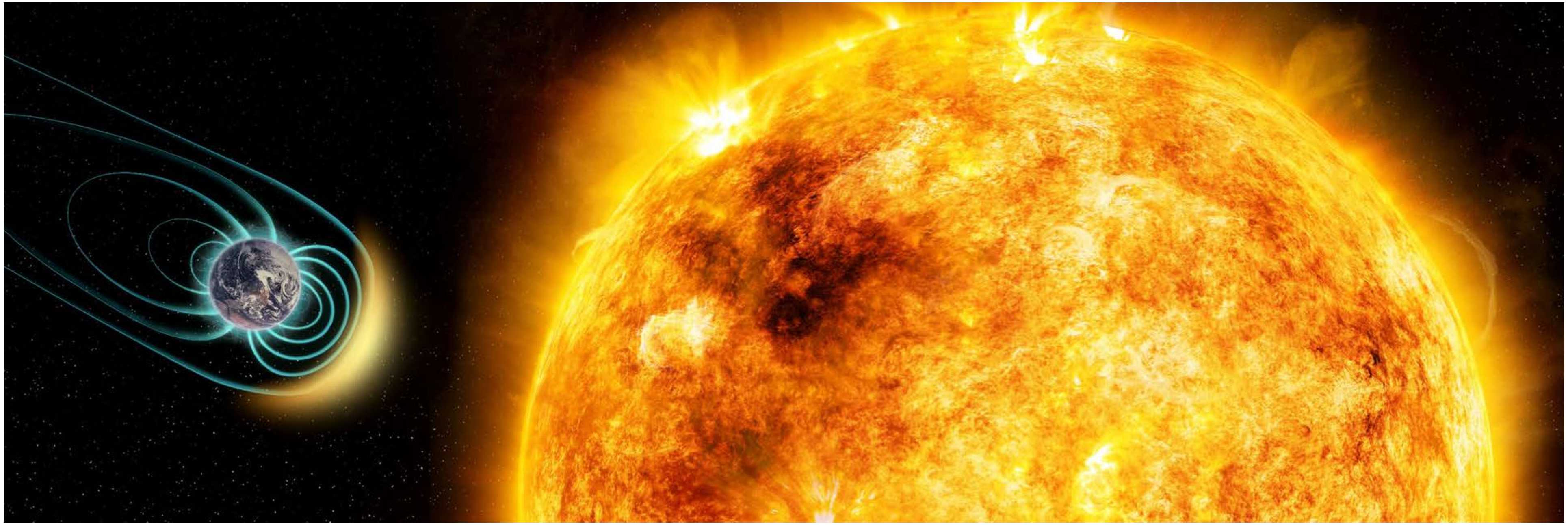
atmospheric evolution depends strongly on *initial atmospheric mass* and *initial stellar rotation!*

$1M_{Earth}$
1 AU
H atmosphere
$5x10^{-3}$ $M_{Earth}$




Tu, Johnstone, Güdel, Lammer 2015

***Age and the related rotational, magnetic field and activity evolution matter – a lot – for planetary atmospheres and their evolution!***

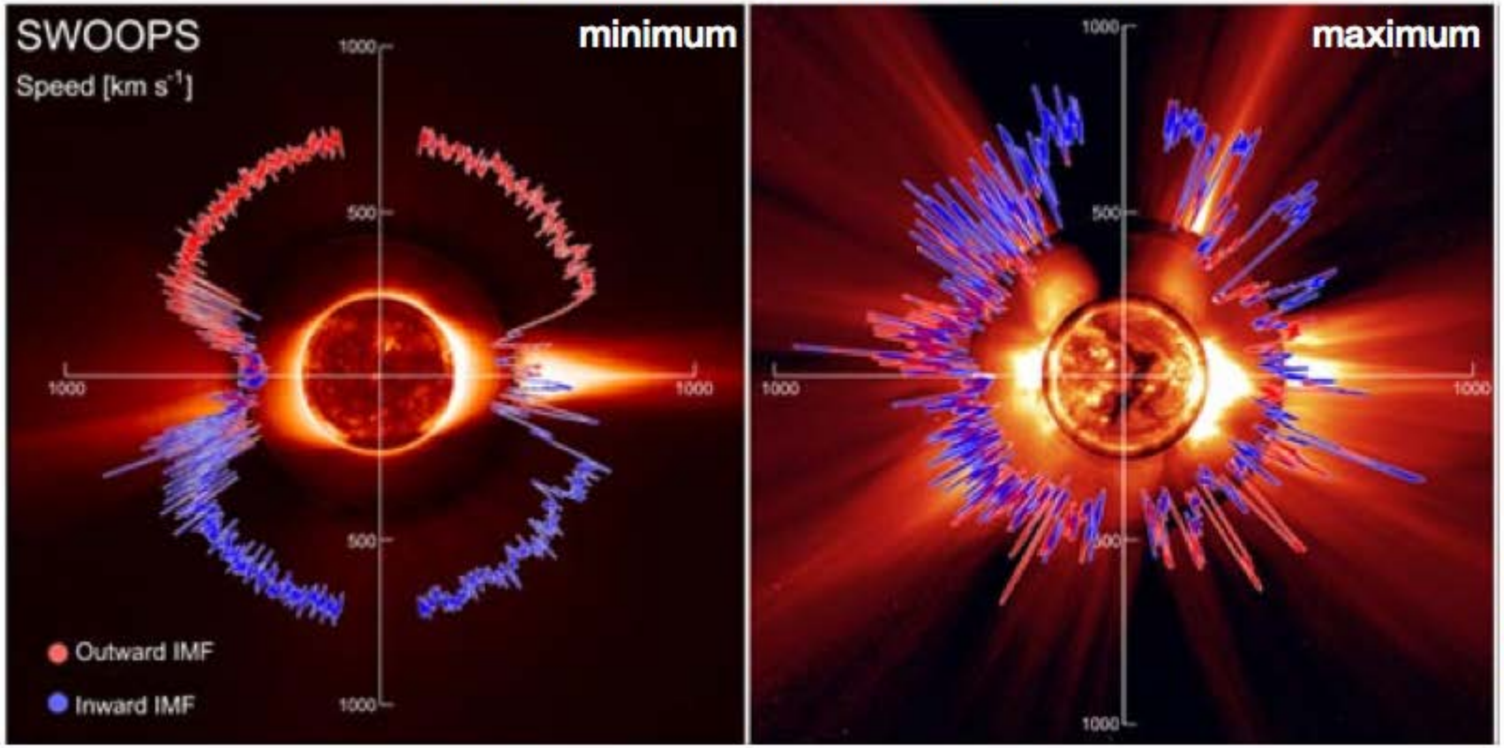


# Winds: Field Geometry Matters

## Effects of the field geometry on winds

- Stellar wind structure depends on the stellar magnetic field

Solar wind as measured by Ulysses

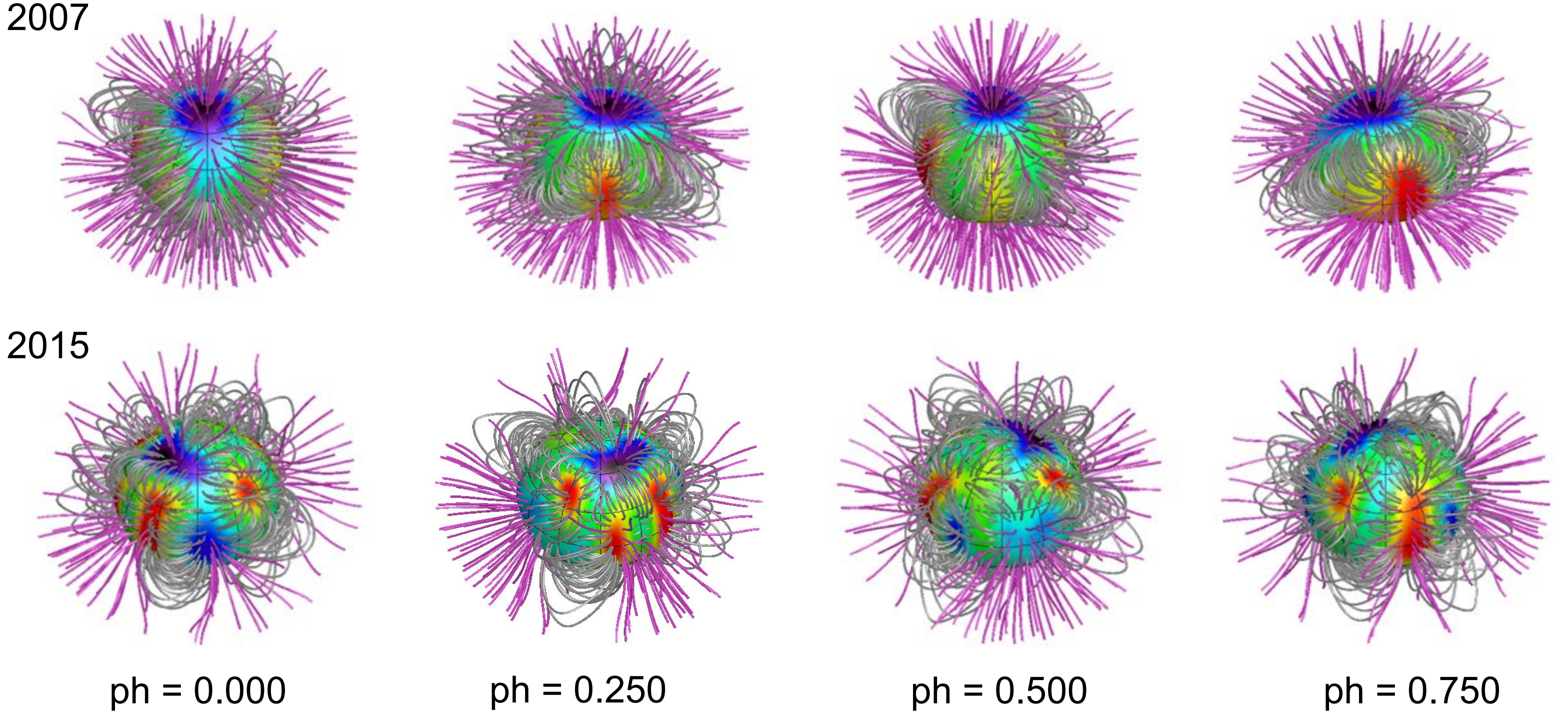



McComas+08

# Getting the Fields of Young Suns (ZDI)

Stellar surface magnetic field distribution: π¹ UMa

*Lüftinger et al. 2018, Rosén et al. 2016*




| Star name | $T_{\rm eff}$ ($K$) | Mass ($M_\odot$) | Radius ($R_\odot$) | $P_{\rm rot}$ ($d$) | Age (Myr) | Membership | No. obs. epochs |
|---|---|---|---|---|---|---|---|
| EK Dra | 5845[1] | 1.044[2] | 0.97[2] | 2.6[3] | 100 | Pleiades[4] | 2 |
| HN Peg | 5974[1] | 1.103[2] | 1.04[2] | 4.6[5] | 250 | Hercules-Lyra association[6] | 6 |
| $\pi^1$ UMa | 5873[7] | 1.00[7] | 0.96[8] | 4.9[9] | 300 | Ursa major stream[4] | 1 |
| $\chi^1$ Ori | 5882[1] | 1.028[2] | 1.05[2] | 5.08[8] | 300 | Ursa major stream[10] | 4 |
| BE Cet | 5837[1] | 1.062[2] | 1.00[2] | 7.65[8] | 600 | Hyades moving group[11] | 1 |
| $\kappa^1$ Cet | 5742[1] | 1.034[2] | 0.95[2] | 9.2[9] | 650 | - | 2 |

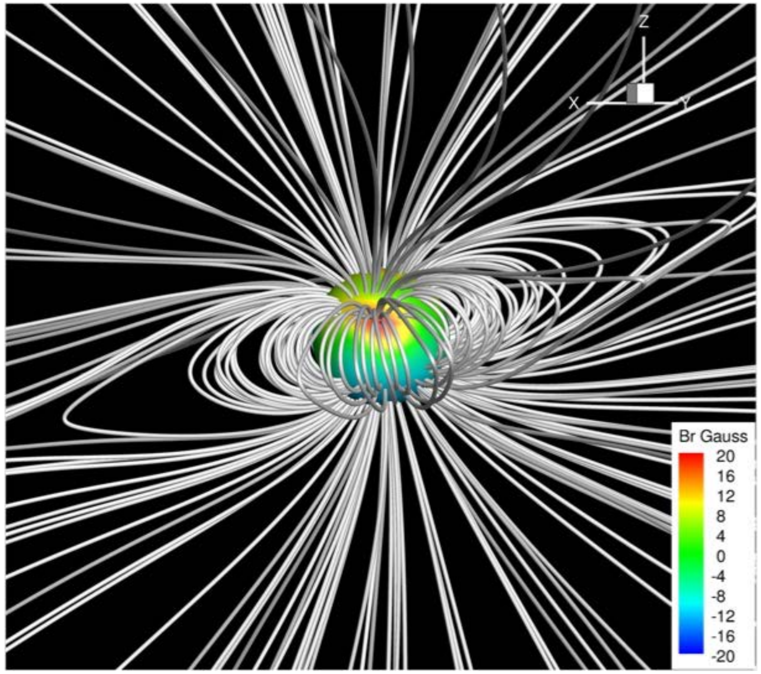
**References:** (1) Valenti & Fischer (2005); (2) Takeda et al. (2007); (3) Strassmeier & Rice (1998); (4) Montes et al. (2001a); (5) Boro Saikia et al. (2015b); (6) Eisenbeiss et al. (2013); (7) Gonzalez et al. (2010); (8) Güdel (2007); (9) Messina & Guinan (2003); (10) King et al. (2003); (11) Montes et al. (2001b).

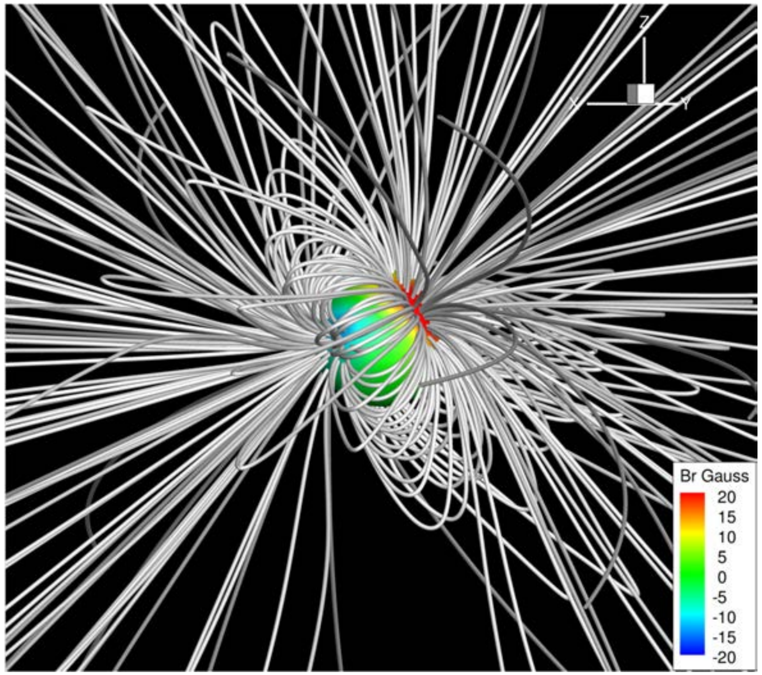
# *Stars – Shaping their planetary environments*

*Young Sun κ[1] Cet*

- Maps (ZDI)
- Reconstruct corona-wind systems: Winds, Flares, CME's (AWSoME)
- Couple to planetary upper atmospheres and magnetospheres

*κ[1] Cet:* *2012.8* *2013.7*

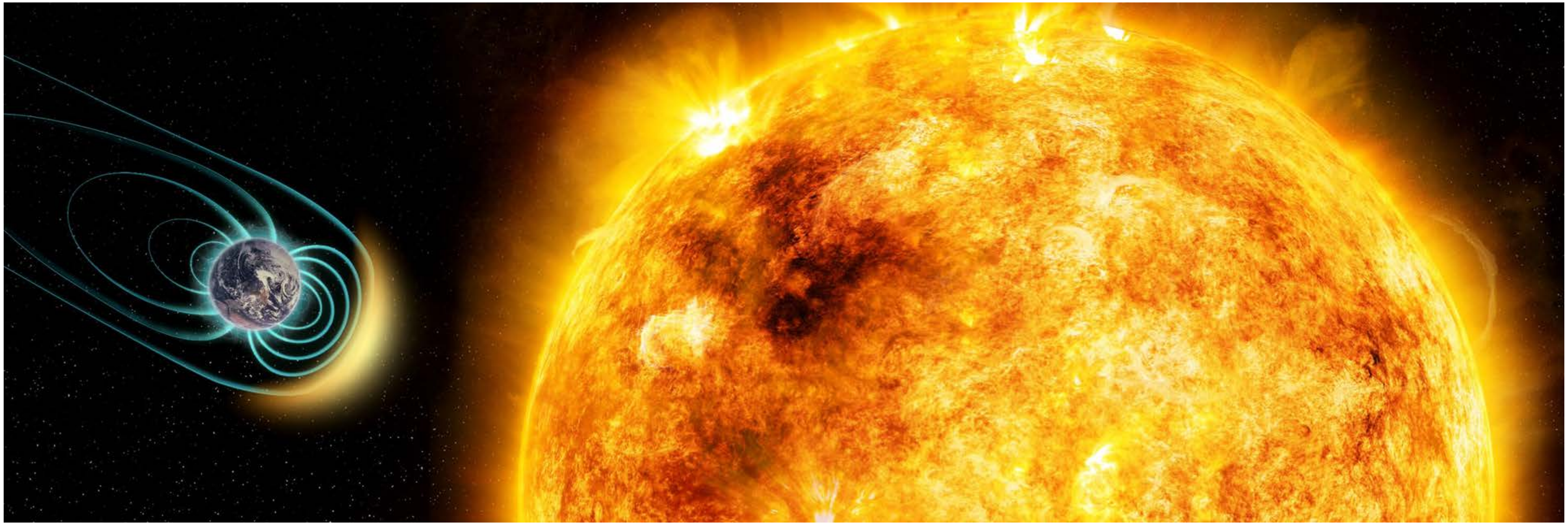


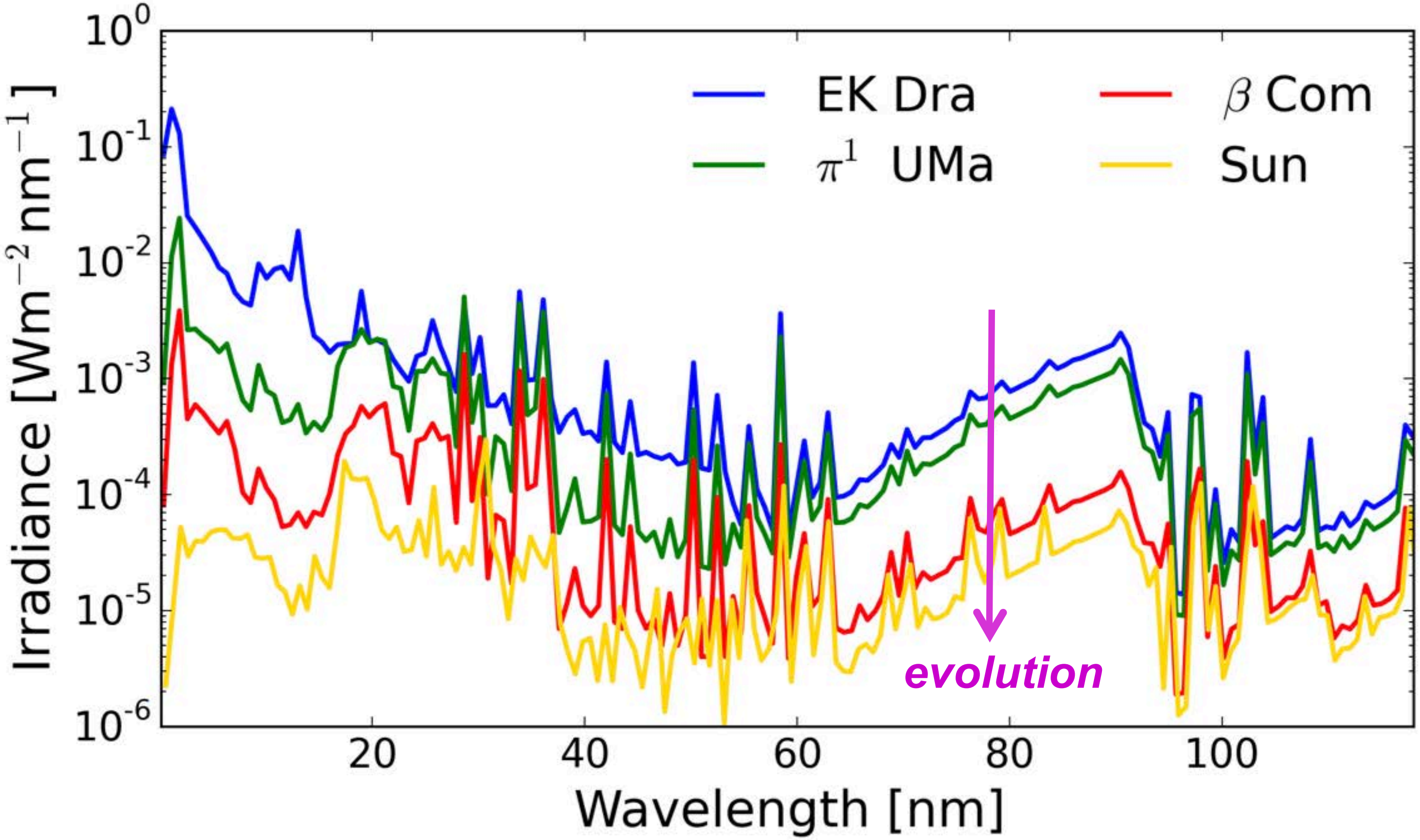

Lüftinger et al., 2018, Airapetian et al. 2018

Airapetian et al.: Large-scale 3D magnetic field embedded in the wind of the young Sun's proxy, *κ[1]Cet* based on 3D MHD simulations with the AWSoM code. The color map shows the radial component of the observationally derived stellar magnetic field (ZDI).

## *Energy output from different activity components and in different wavelengths*



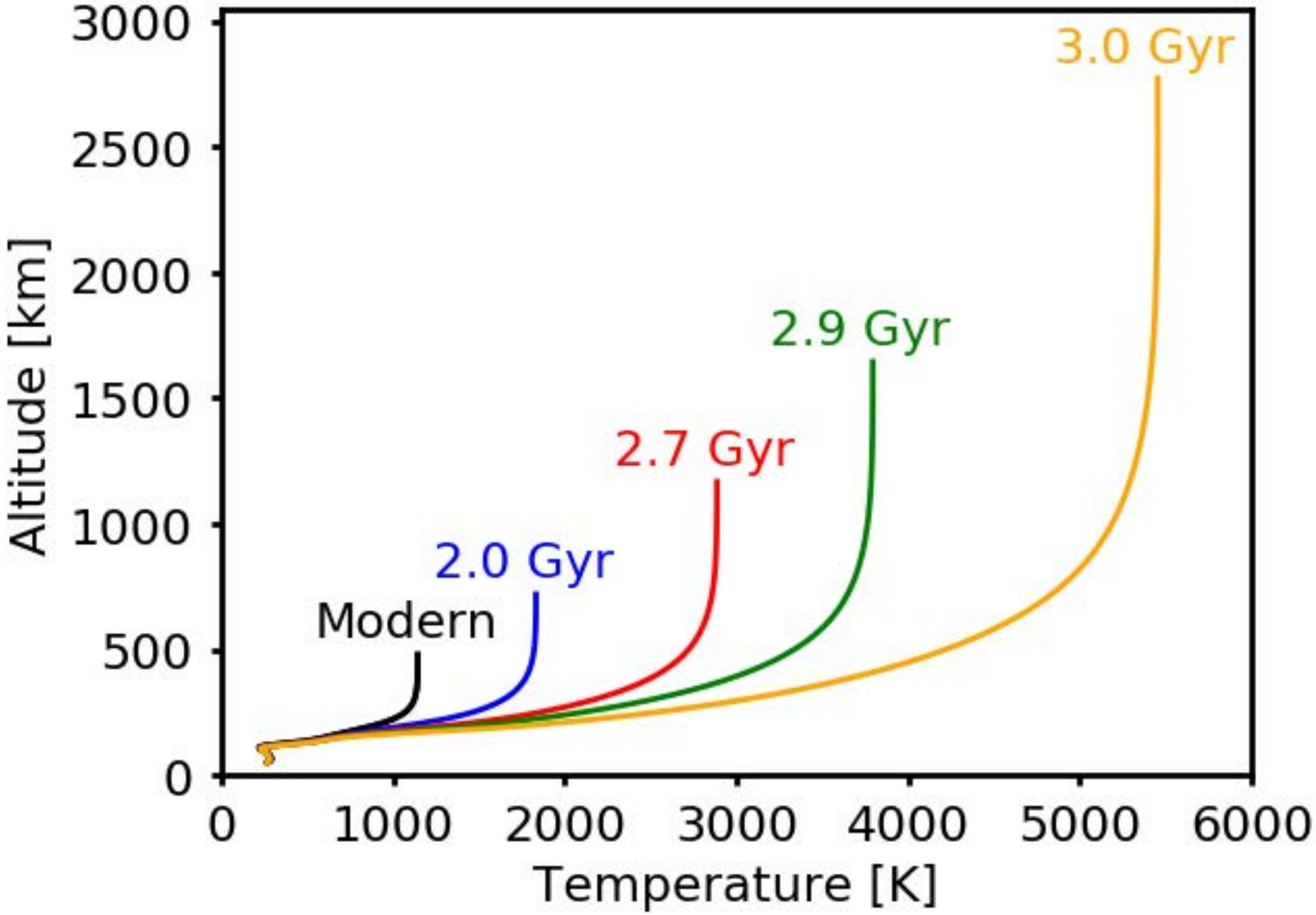
# Synthetic XUV Spectral Irradiance From Solar Components




Spectra for the sample stars from 0.124 - 118 nm

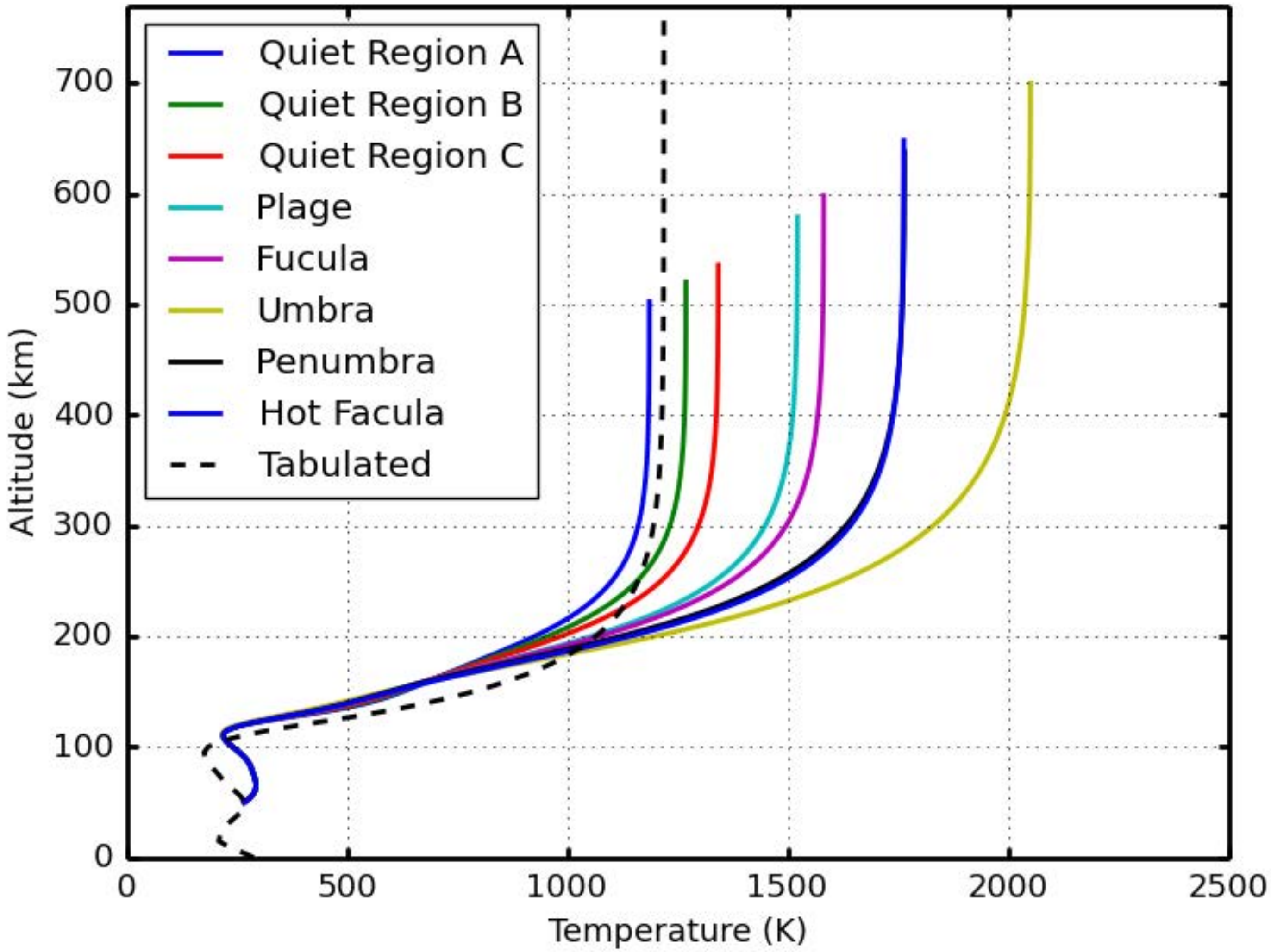
Making use of spectra of Fontenla et al. 2014, Nemec et al. 2018 in prep.

# *Earth Upper Atmosphere in Time*




Temperature response of the Earth's atmosphere to the evolving XUV spectrum of the Sun (Johnstone et al. 2018).

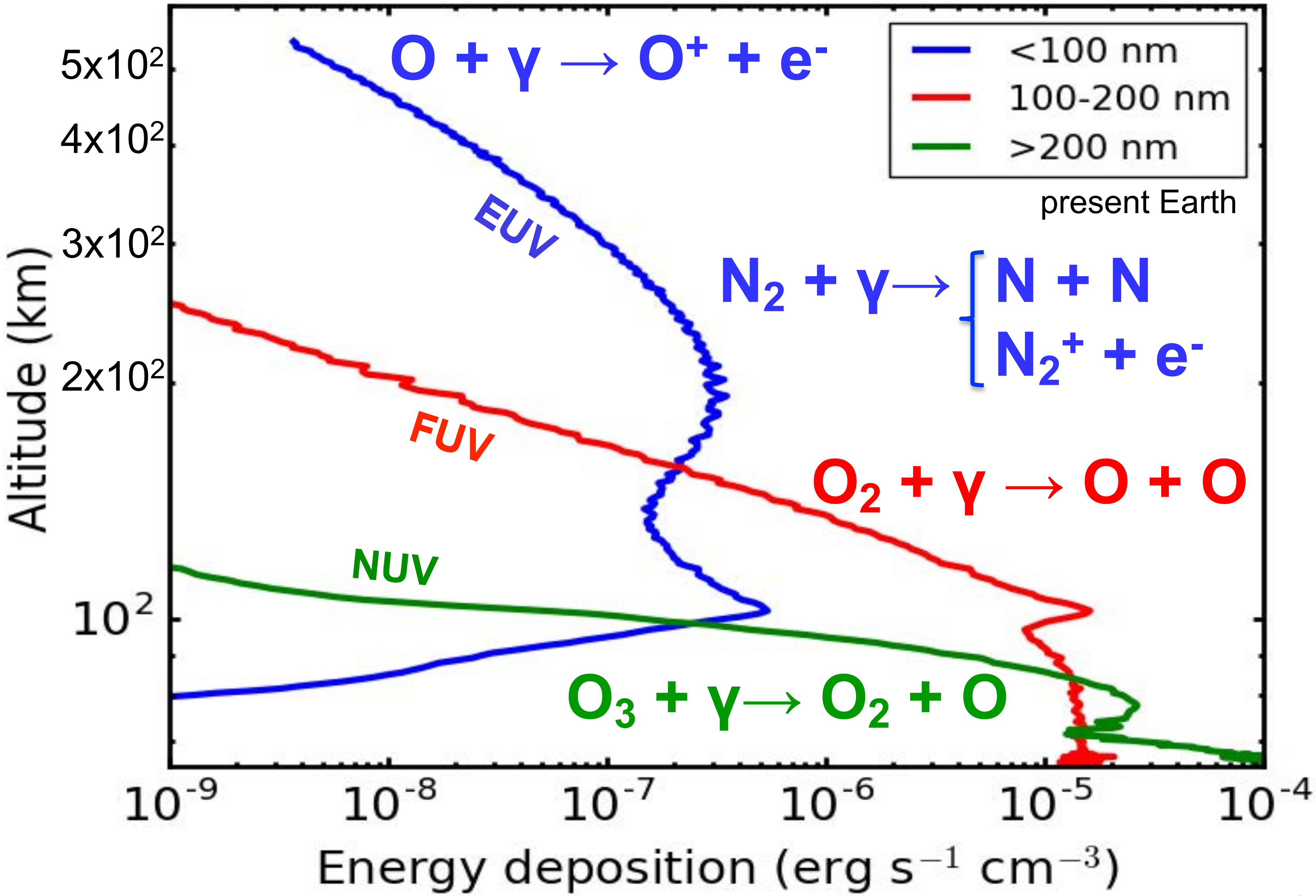
# *Stellar Components Affecting Thermospheric Heating*




Johnstone+ 2018

**The Kompot Code -** *Upper-Atmosphere Thermo-Chemical Hydro Model*

*Spectral dependence*: ionization/dissociation for species



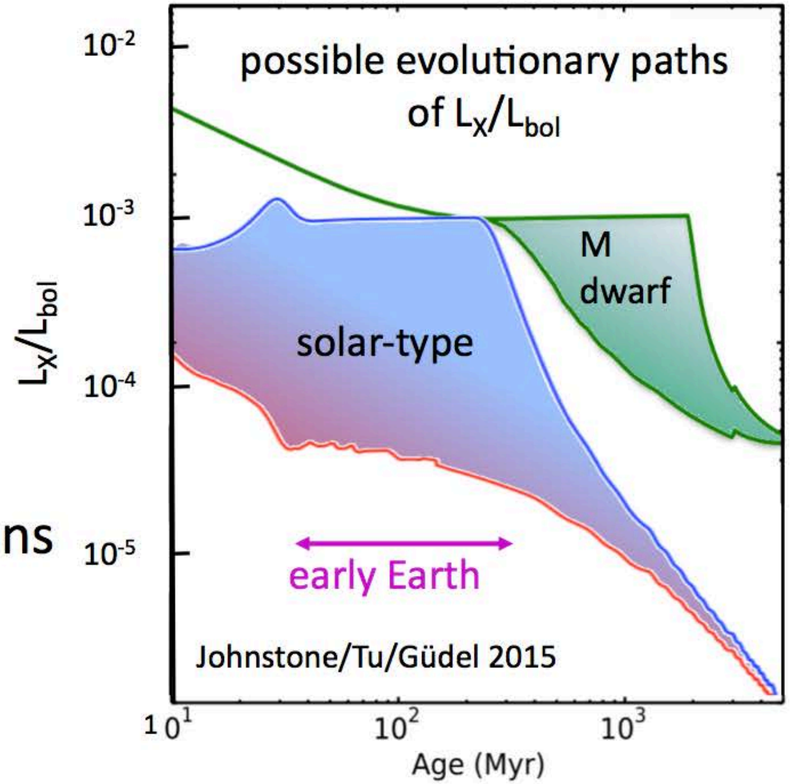

Johnstone et al. 2018

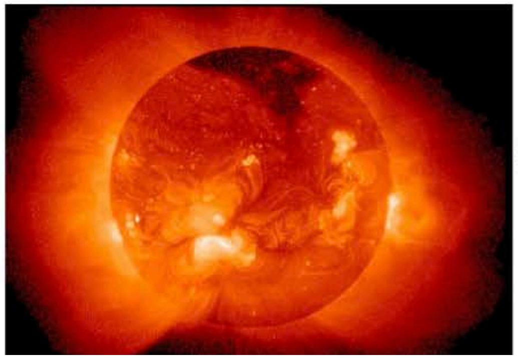
# *M dwarfs*

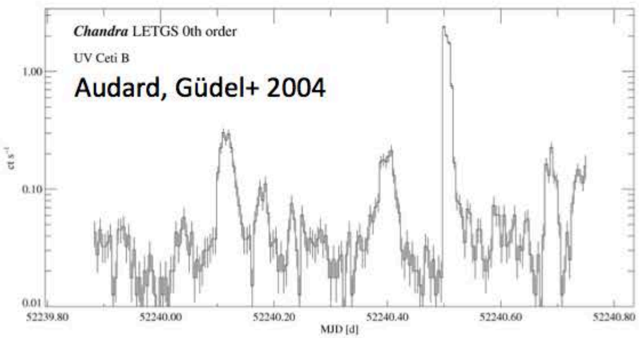
**(late) M dwarfs:**

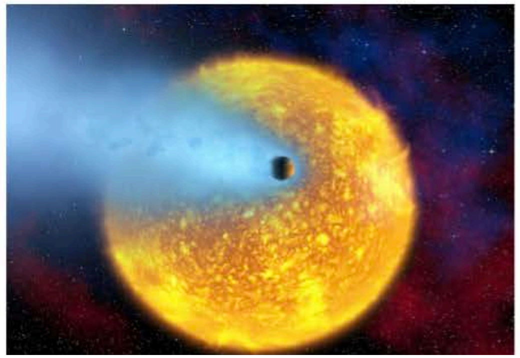
- considerably different magnetic field structures and strengths

- High magnetic activity level during first billion years
- Strong flares/coronal mass ejections erode atmospheres for long time





**Cannot** treat them just like solar-like stars with longer/higher activity levels (flare contrasts, magnetic fields, etc.)

# Successful Observing Program ongoing at Pic du Midi, F

So far 160h of spectropolarimetry, currently ground based follow-up of TESS and ARIEL targets plus H2020 project

(G. Tinetti, Piere-Olivier Lagage, J. Pye, S. Brun, M. Guedel, etc.)

## Plus:

HST-XMM data to model stellar activity and winds

*ARIEL-Targets observed already in spectropolarimetry:*

*HD 189733, HD 149026, 55 Cnc!*

*Other planet-hosts:*

*HD 219828, eps Eri*

*ARIEL Observations for potential ground-based studies:*

119 brighter than Star V Mag 09.0

269 brighter than Star V Mag 10.0

628 if we go to Star V Mag up to 11.0

ESA

# ARIEL

**ESA: UK, France, Italy, Germany, the Netherlands, Poland, Spain, Belgium, Austria, Denmark, Ireland and Portugal**

## Observing Campaigns

M4: 2028

*Target selection (C. Danielski) and ARIEL-Spot modelling for ExoSIM (S. Sarkar)*

- *Get representative filling factors for various rotational velocities (solar-type stars)*
- *Fully convective M-dwarfs: anything possible – also model different scenarios*

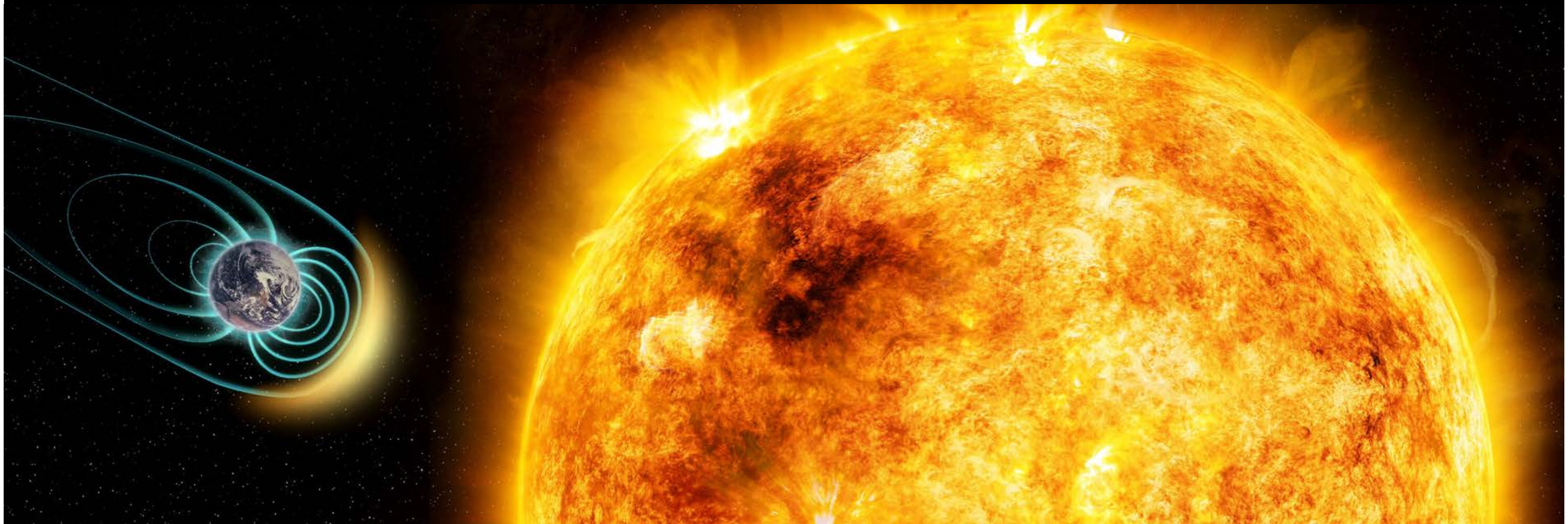
*Propose:*

- *Spectroscopic, photometric and spectropolarimetric follow up of host stars – suggest focus on TIER 3&4 - with neoNARVAL, SPIROU, CRIRES+, HARPSpol*

*-> continue and extend spectropolarimetric observing campaigns – Stokes I,V on specific selected targets*

*TESS, PLATO light-curves*
*S/R-indices, Ca H&K „for free“*

# *THANK YOU!!!*



Theresa Lueftinger & the ARIEL-TEAM

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