Toward Habitable Planets: Evolutionary Studies of Planets Around Solar-Type Stars

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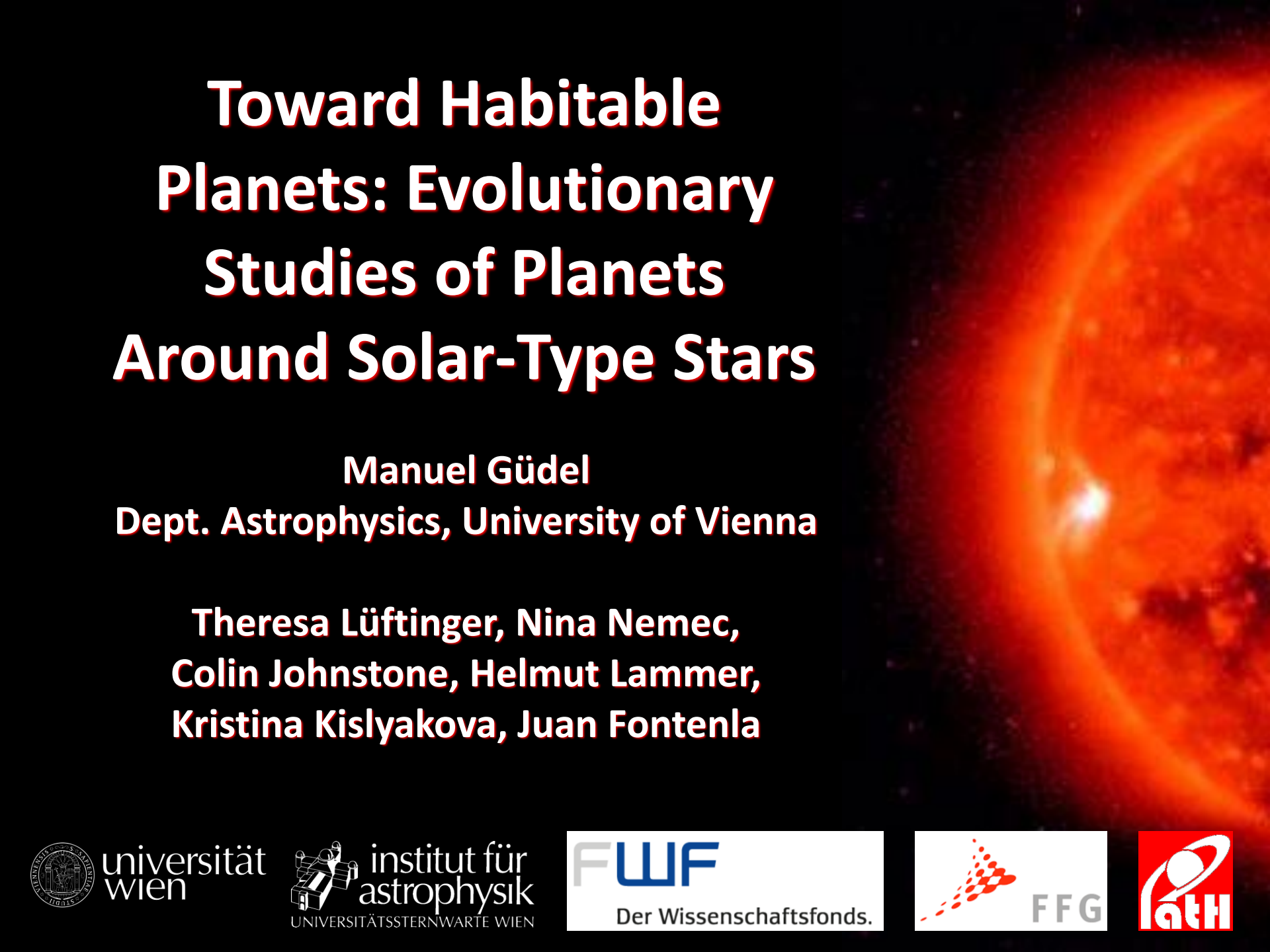

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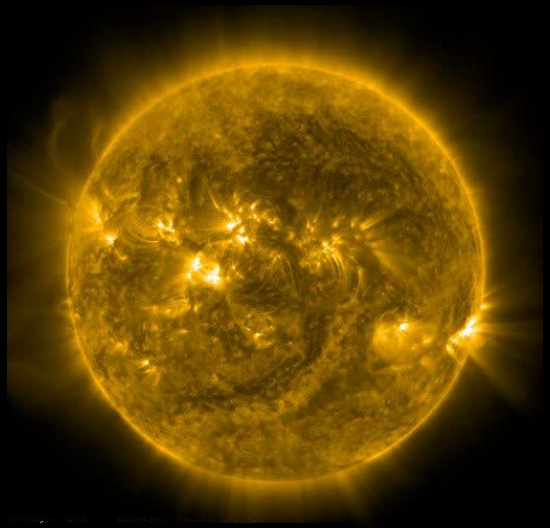
FWF Der Wissenschaftsfonds.

FFG

PATH

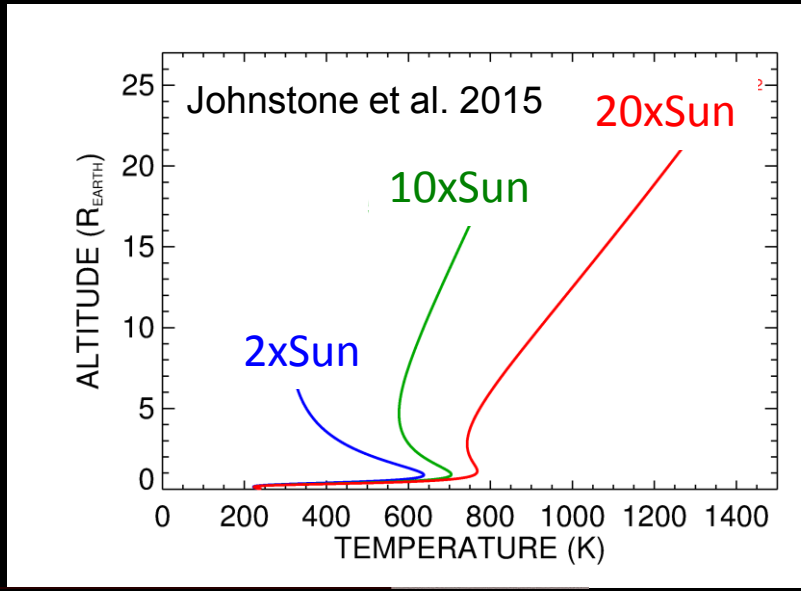
Motivation: Atmospheric Processing & Erosion



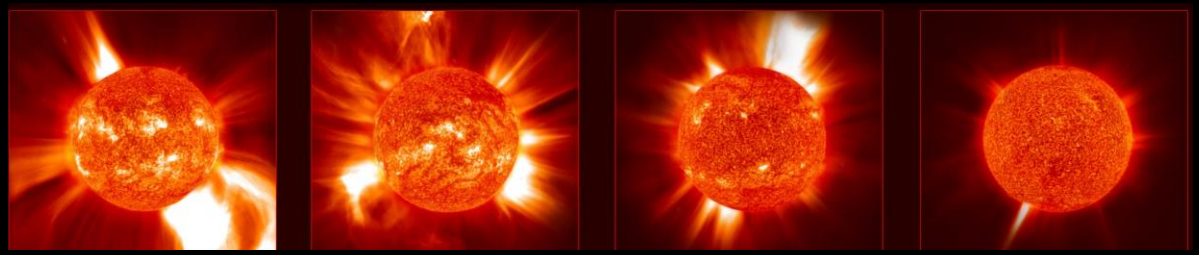
Extreme-UV & X-rays:

→

chemistry, thermal loss
(evaporation)

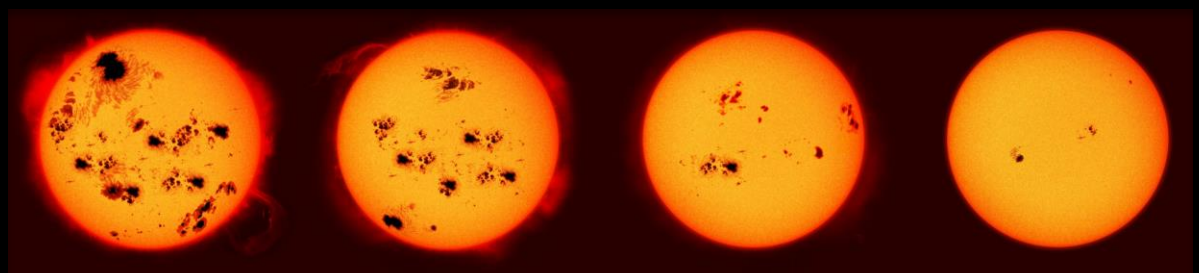


activity output

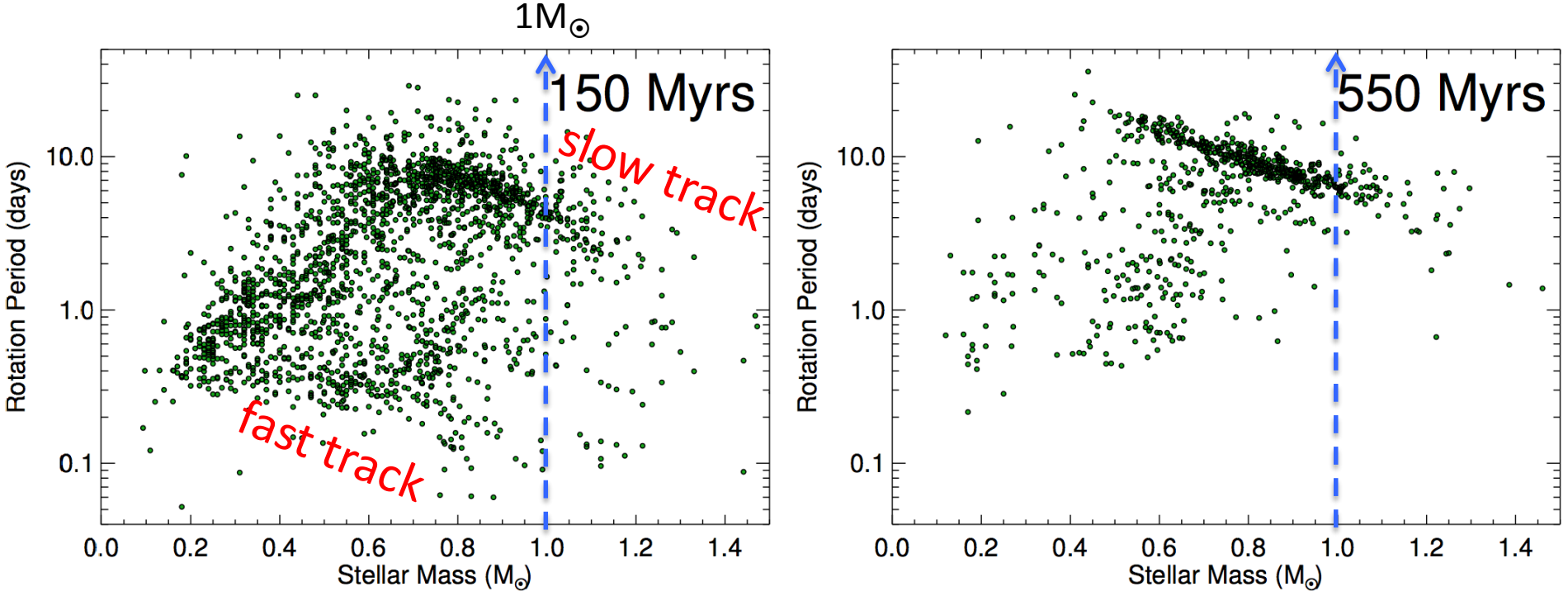


time

magnetic fields



Mass Loss and Rotation: Introducing Rotational Distributions



Johnstone et al. 2015

Constructing a *Physical* Rotational Evolution Model

Plan of attack:

1 torque = $f(B, \dot{M}, \Omega)$ *(Matt et al. 2012, 2015; Réville et al. 2015)*

1 $B = f(Ro)$ [Rossby number = $2\pi/\Omega\tau$, τ turnover time]

2 $\dot{M} = f(\Omega)$ Mass loss rate relates to activity

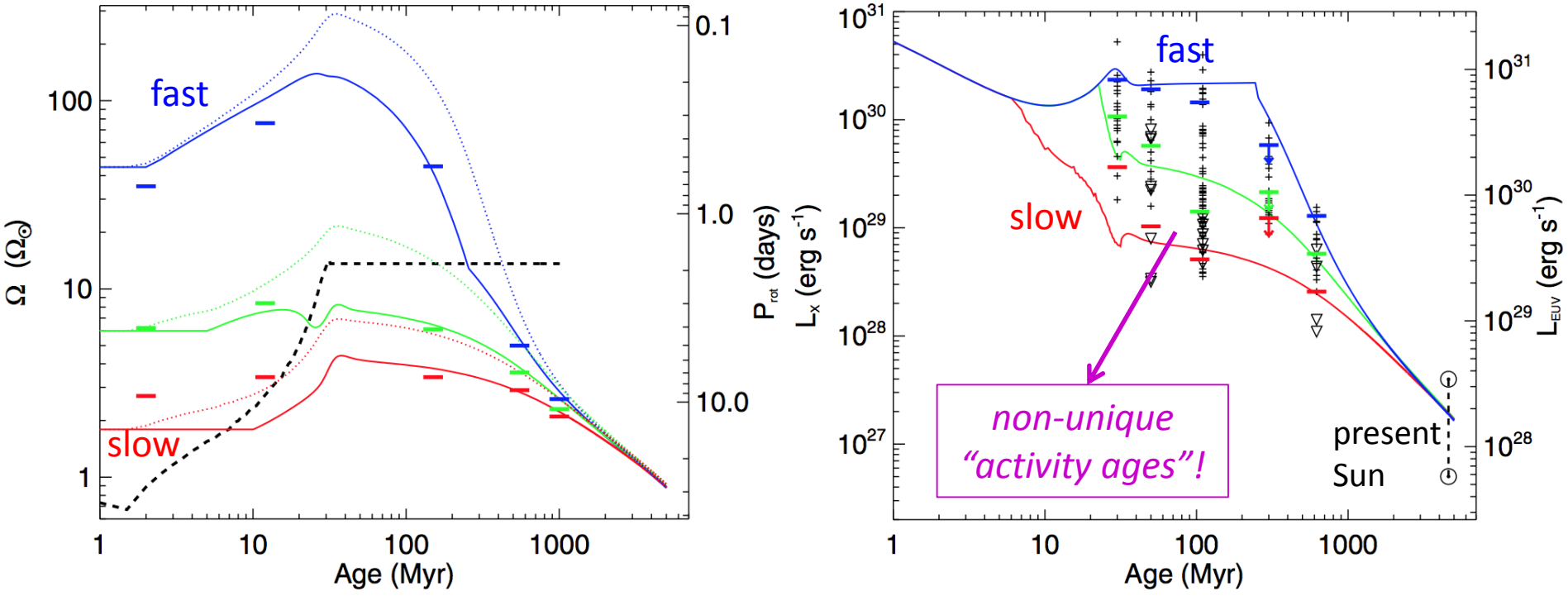
4 $d\Omega/dt$ = torque/moment of inertia spin-down rate (for MS)

Johnstone et al. 2015

The High-Energy Sun in Time

Depending on initial rotation....

Rotation tracks → X-ray/UV radiation tracks

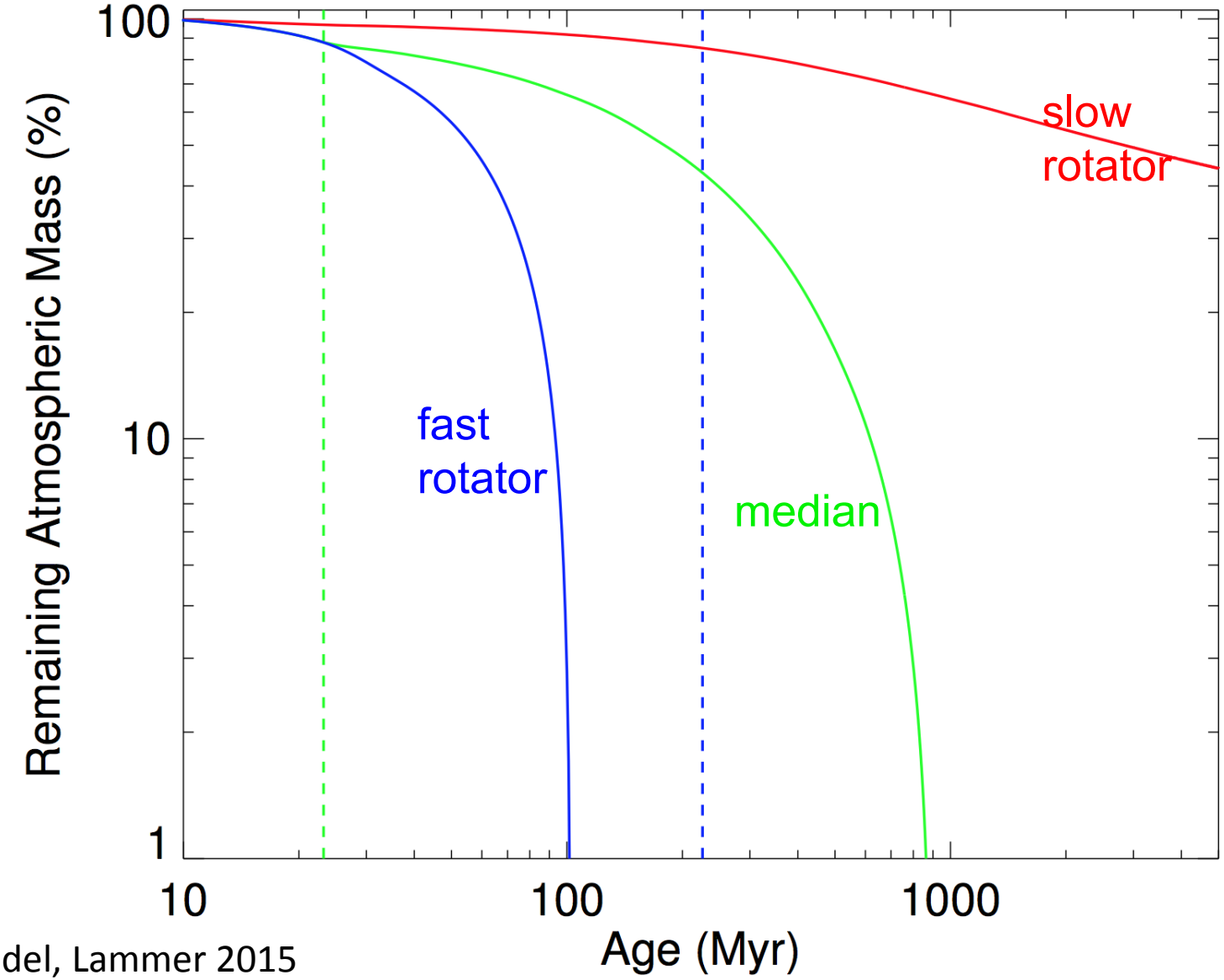


Tu, Johnstone, Güdel, Lammer 2015

(see also Gallet & Bouvier 2013)

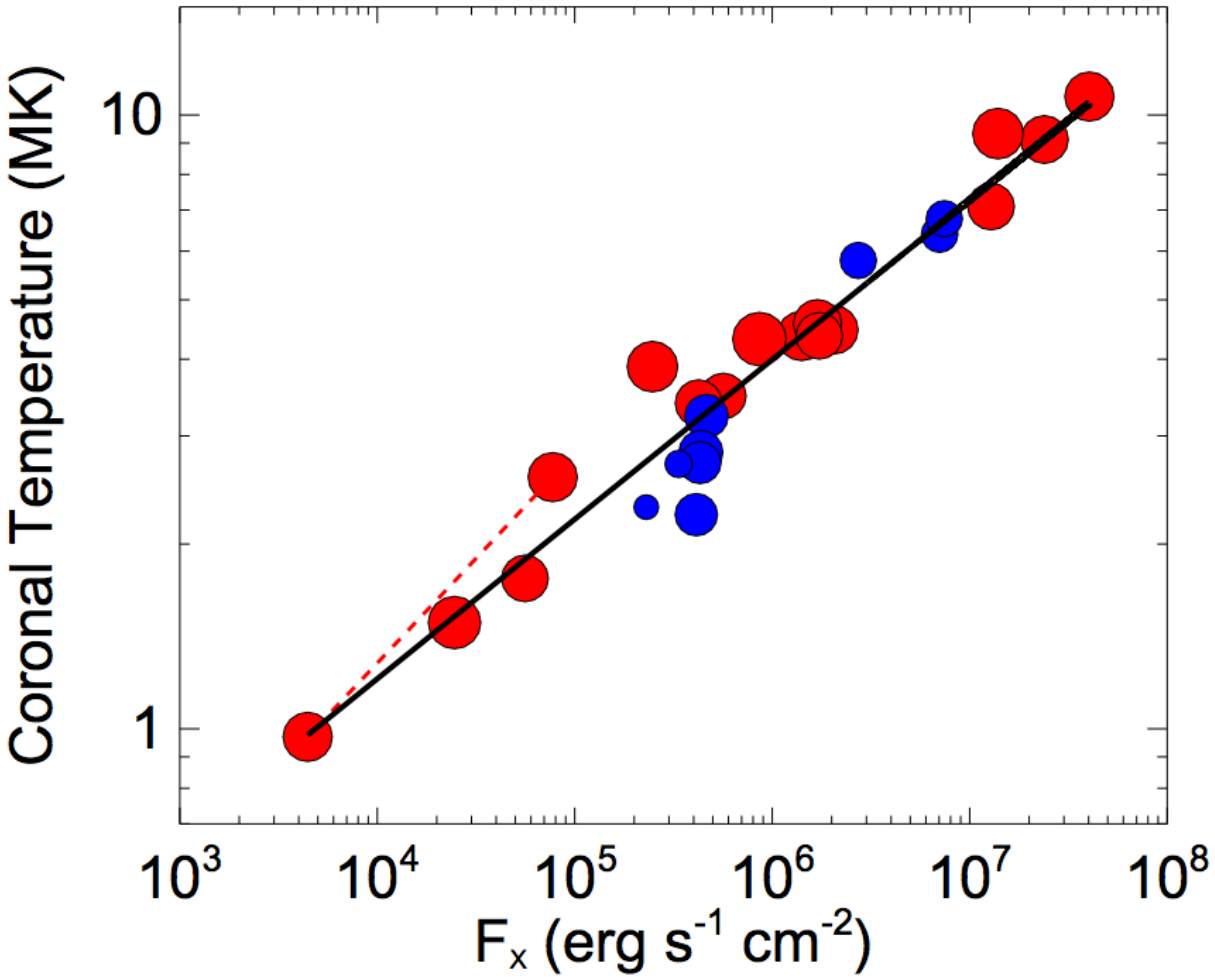
Hydrogen Envelope Erosion: Stellar Evolution Matters!

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



Tu, Johnstone, Güdel, Lammer 2015

Activity Level Determines Spectral Emission

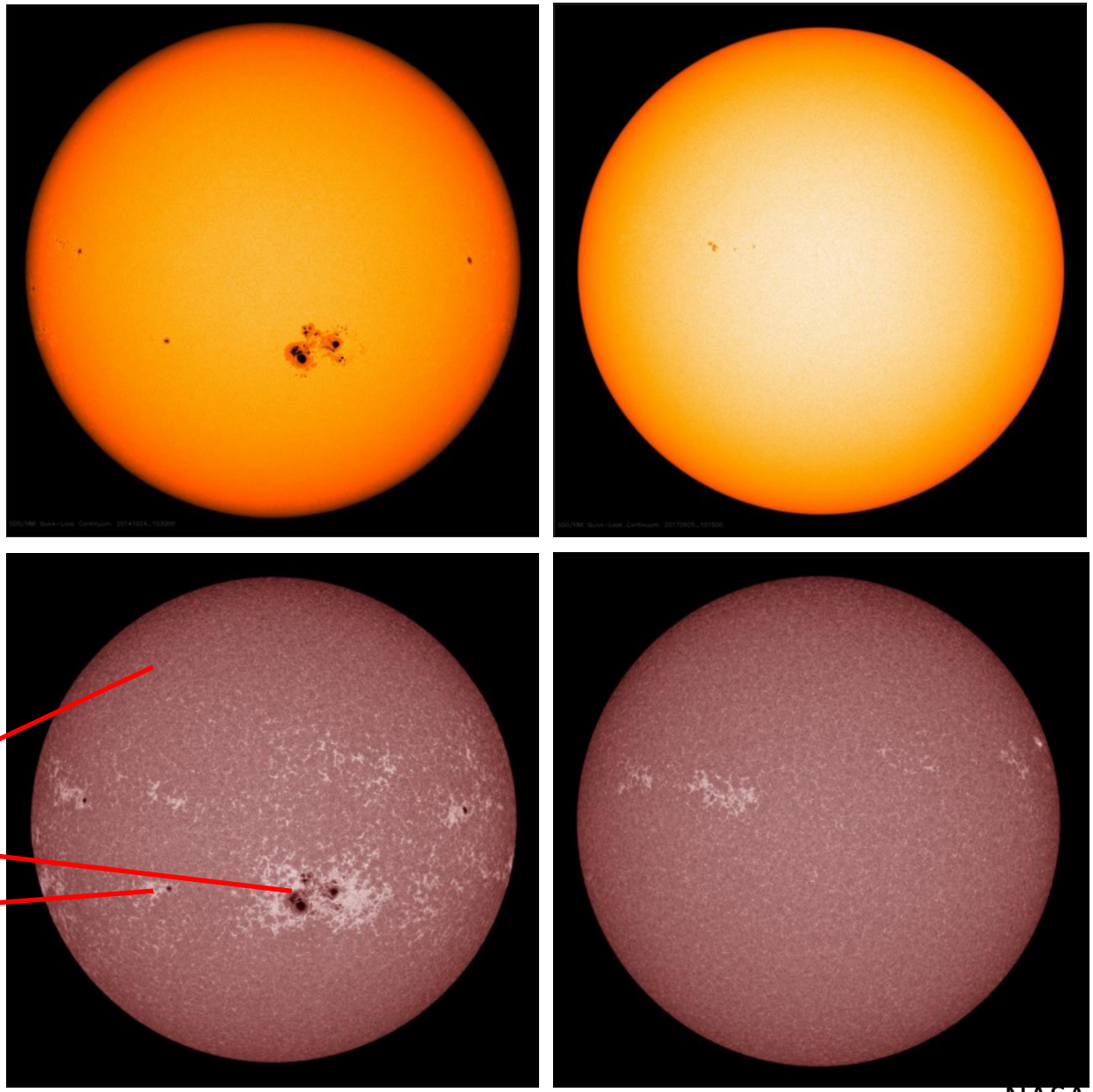


Johnstone & Güdel 2015

A Stellar Radiation Model From Solar Activity Components

optical/photosphere
SPOTS

Relative area scaling between components at different activity levels



spectrum A

spectrum B

spectrum C

UV/chromosphere
PLAGE

NASA/SDO

A Stellar Radiation Model From Solar Activity Components

- Dark-quiet-Sun inter-network
- Quiet-Sun inter-network
- Quiet-Sun network lane
- Enhanced network

- Plage
- Facula and Hot Facula
- Sunspot Umbra
- Sunspot Penumbra

Solar Spectral components:

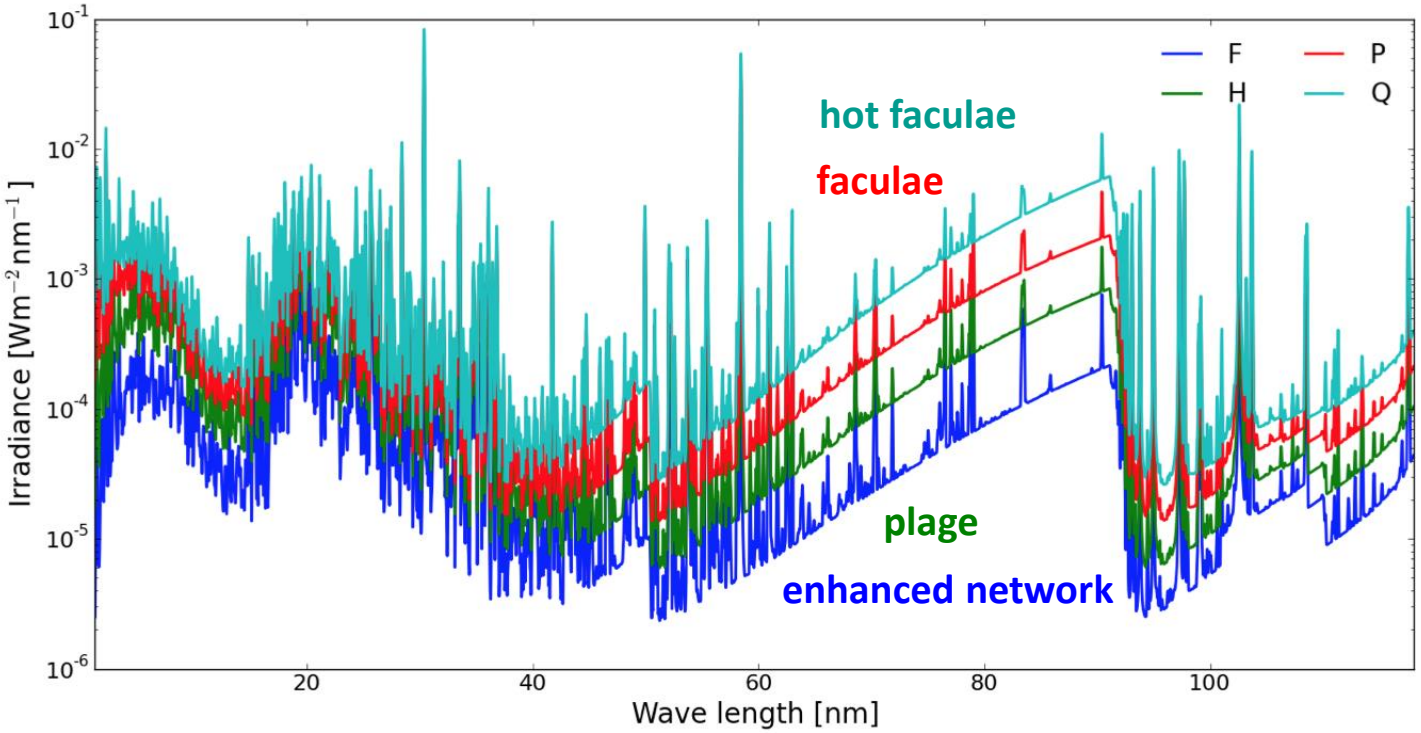


FIGURE 4.5: Components of the active Sun: enhanced network (F), plage (H), facula (P) and hot faculae (Q).

Nemec et al. 2017

Synthetic XUV Spectral Irradiance From Solar Components

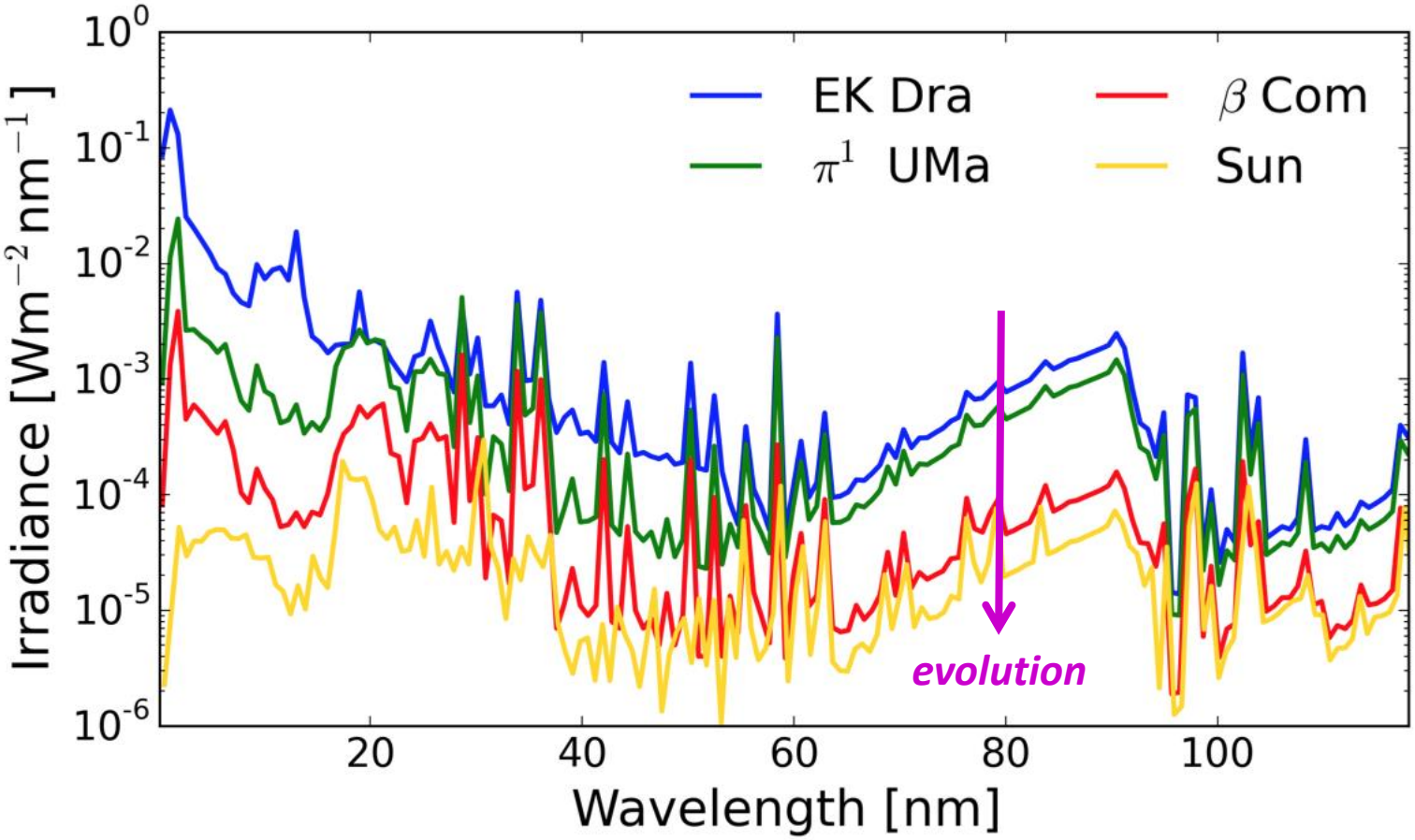


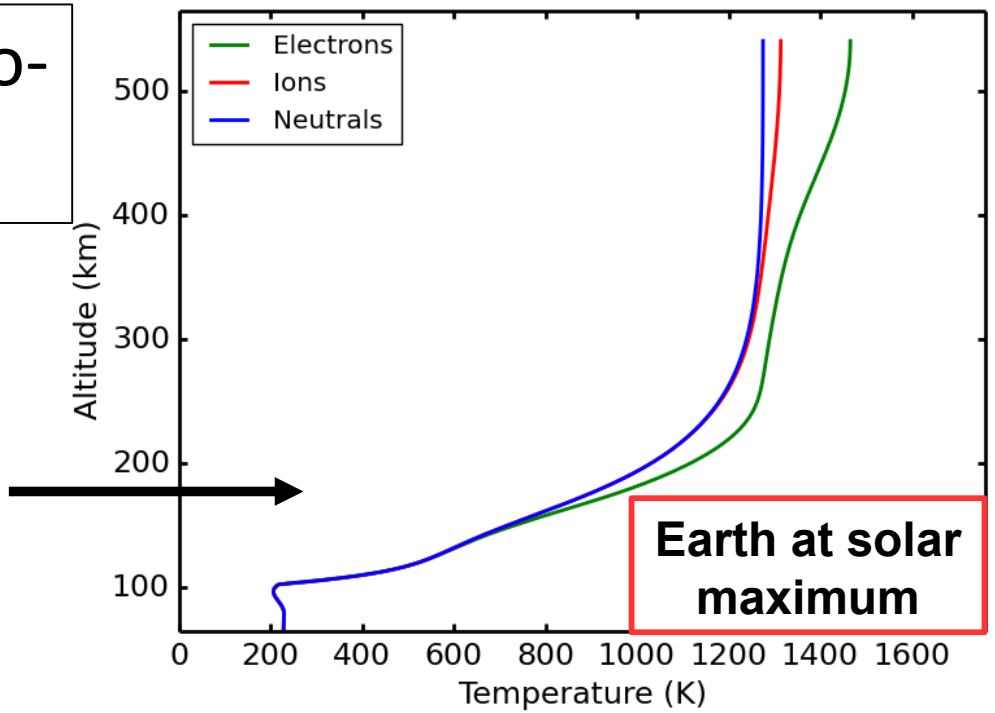
FIGURE 5.3: Spectra for the sample stars from 0.124 - 118 nm

Nemec et al. 2017 in prep

Upper-Atmosphere Thermo-Chemical Hydro Model

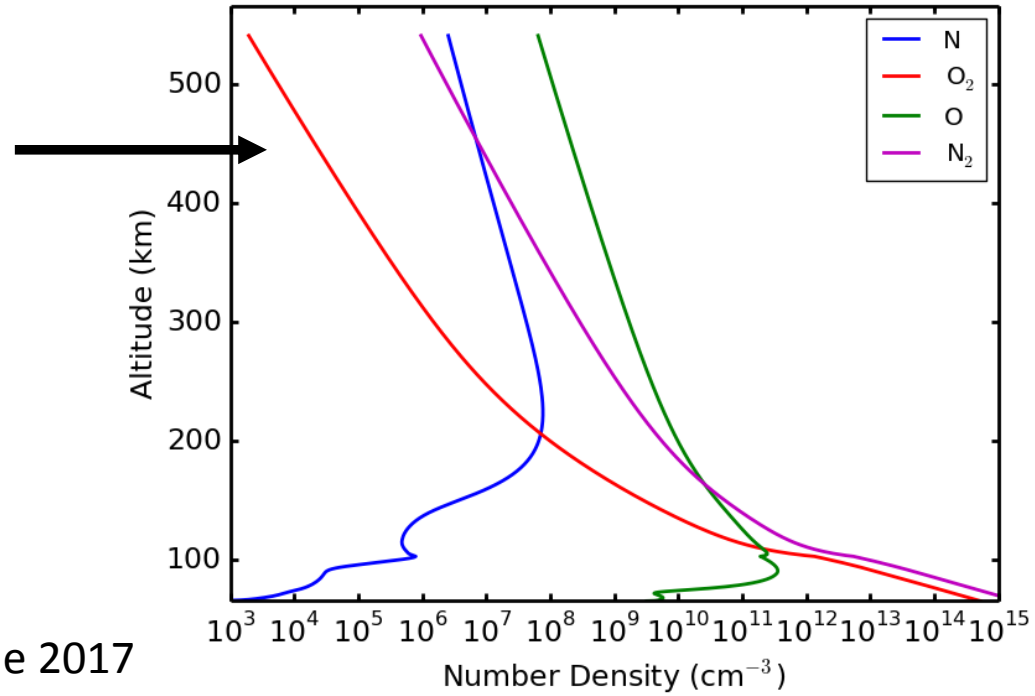
THERMAL STRUCTURE

- heating (XUV, IR, Joule,...)
- cooling (IR emission)
- conduction



CHEMICAL STRUCTURE

- chemistry
- photochemistry
- diffusion

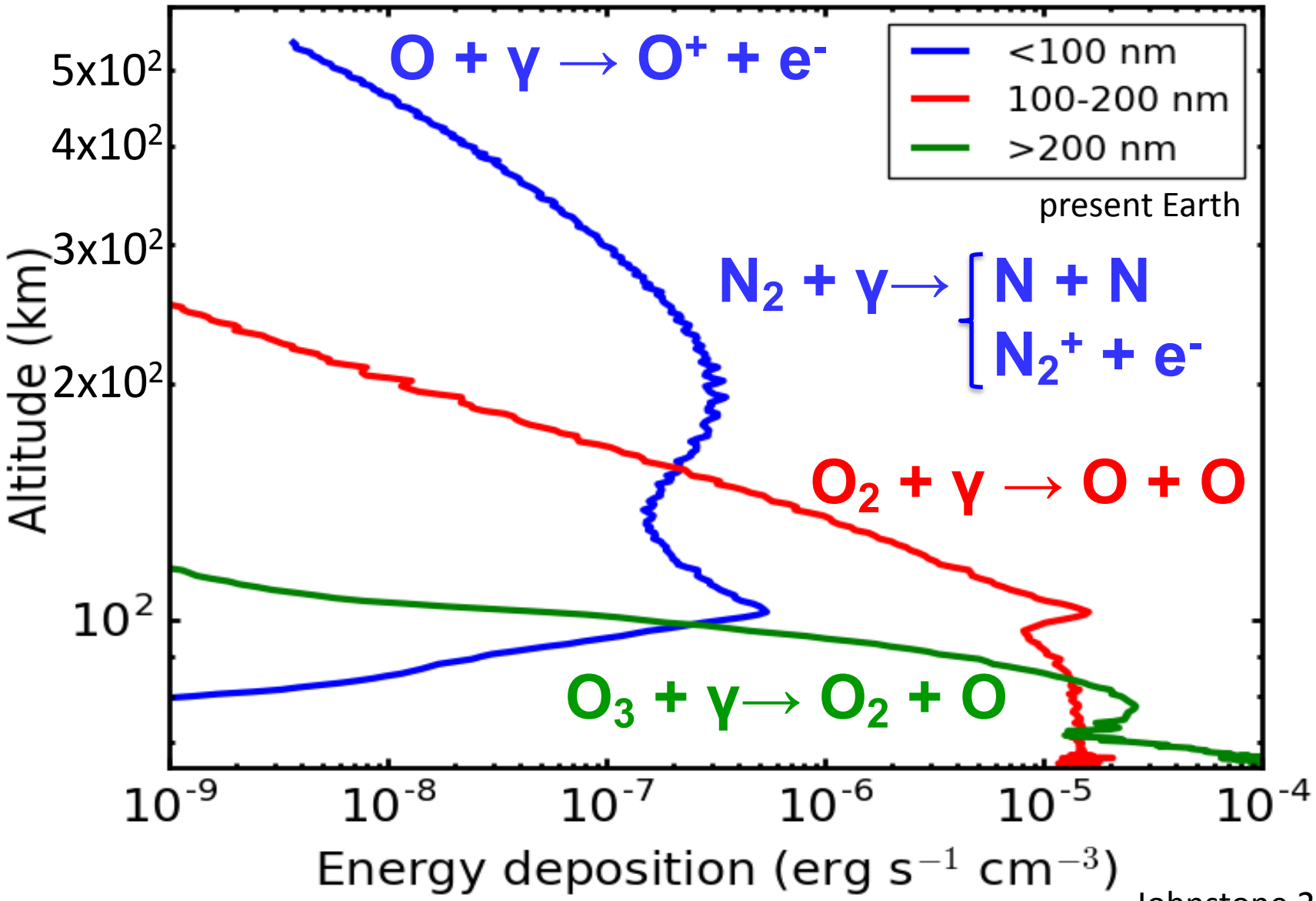


+ FULL HYDRODYNAMICS

- flows
- thermal escape

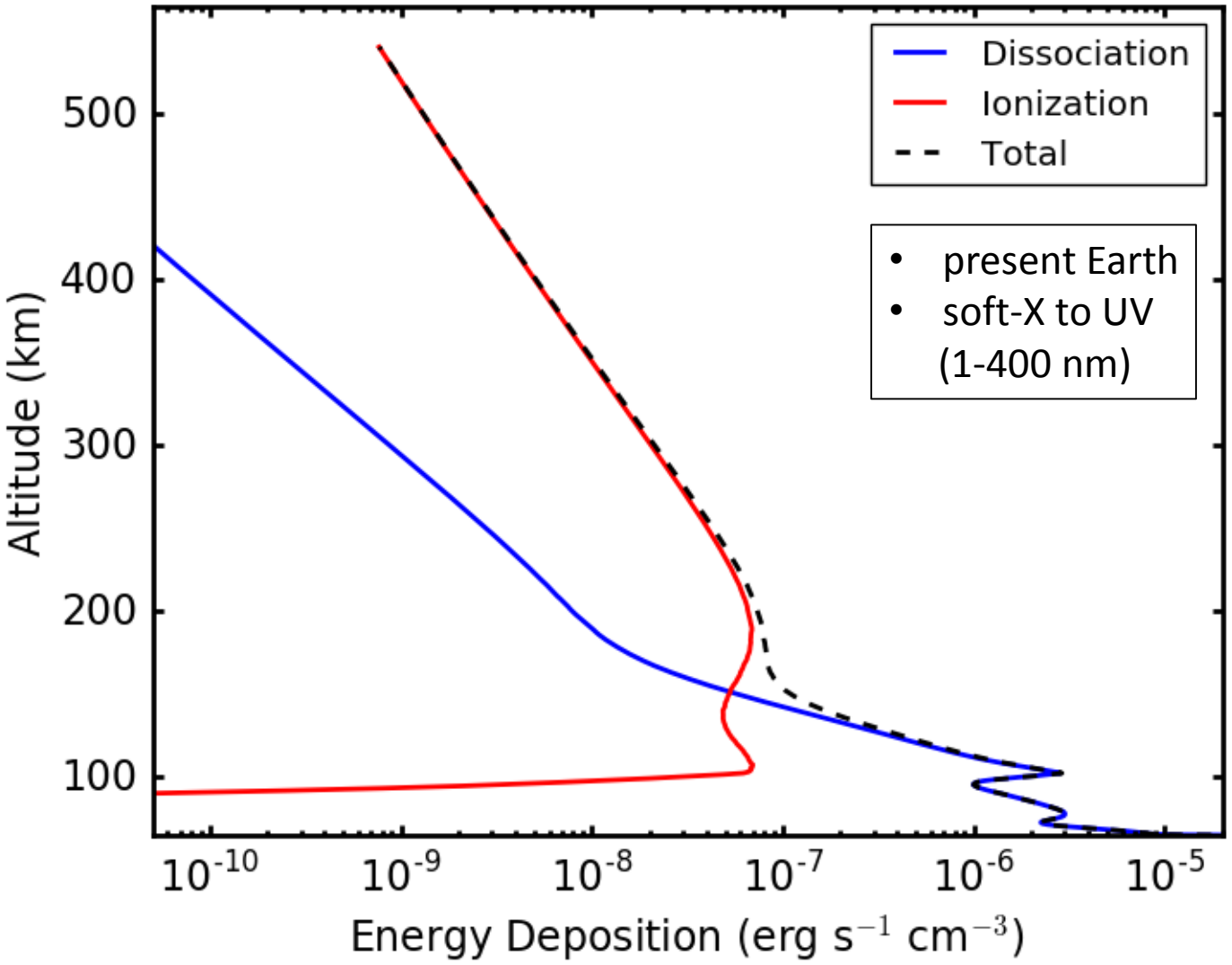
Johnstone 2017

Spectral dependence: ionisation/dissociation for species



Johnstone 2017

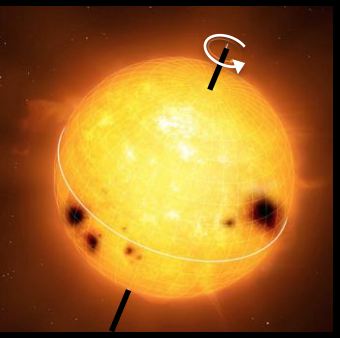
Ionisation versus dissociation



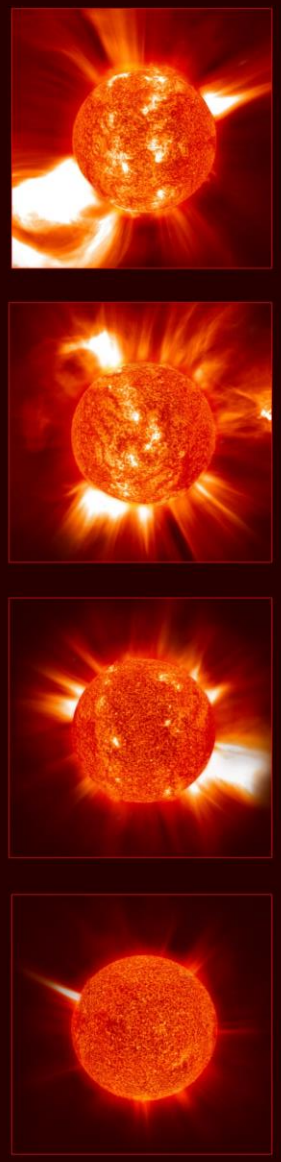
Johnstone 2017

SUMMARY: To understand a planet and its habitability, study entire evolution of the stellar/planetary environment!

stellar

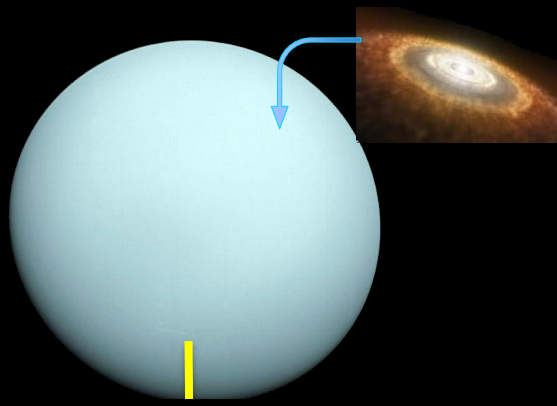


rotation



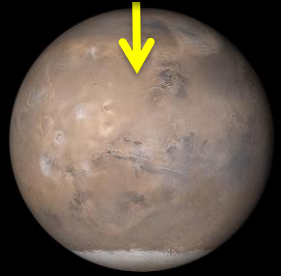
activity output

time



primordial envelope removal?

loss of secondary atmosphere?



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