Planets under Extreme Stellar/Solar Conditions SC 3.4

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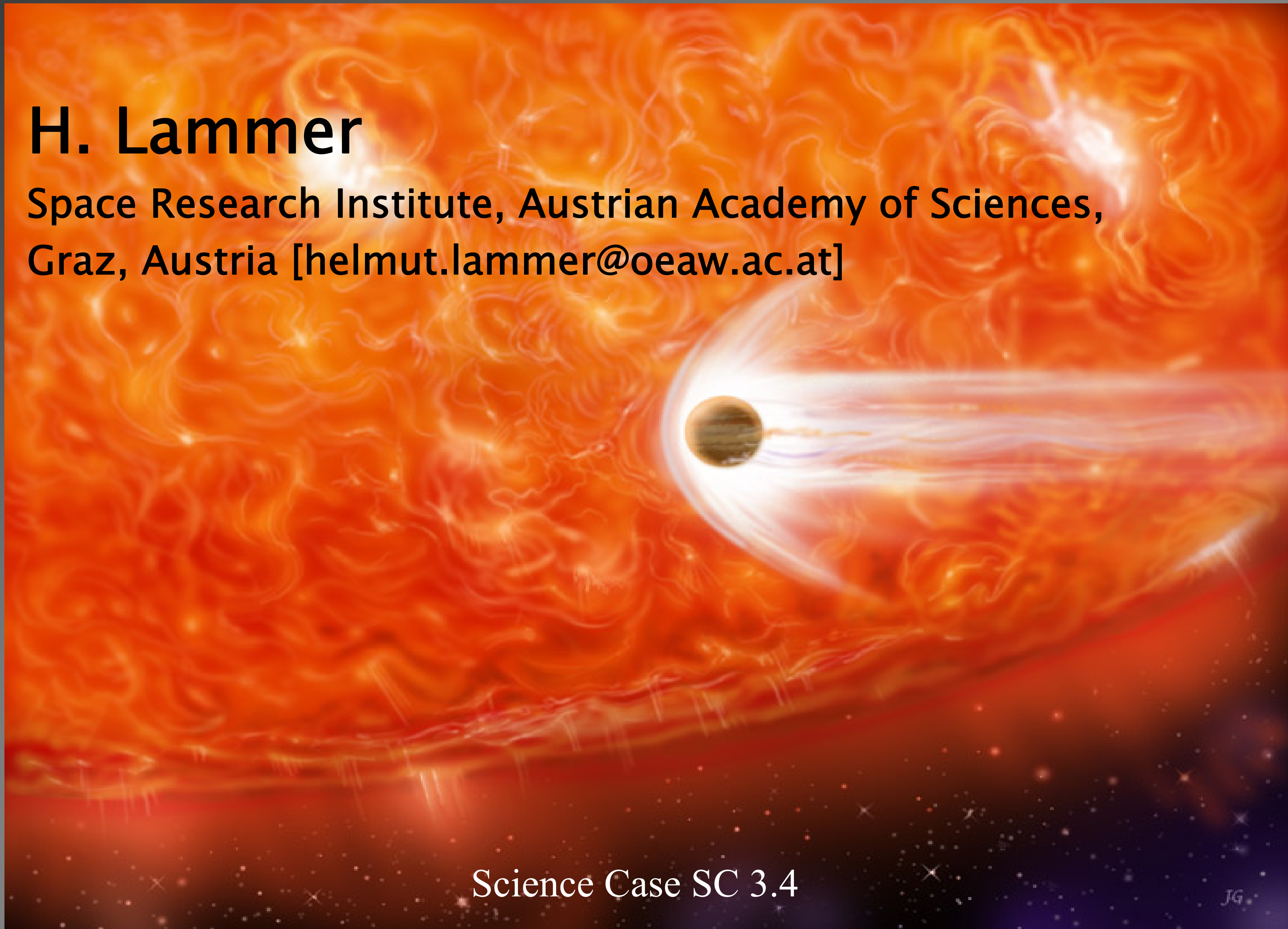
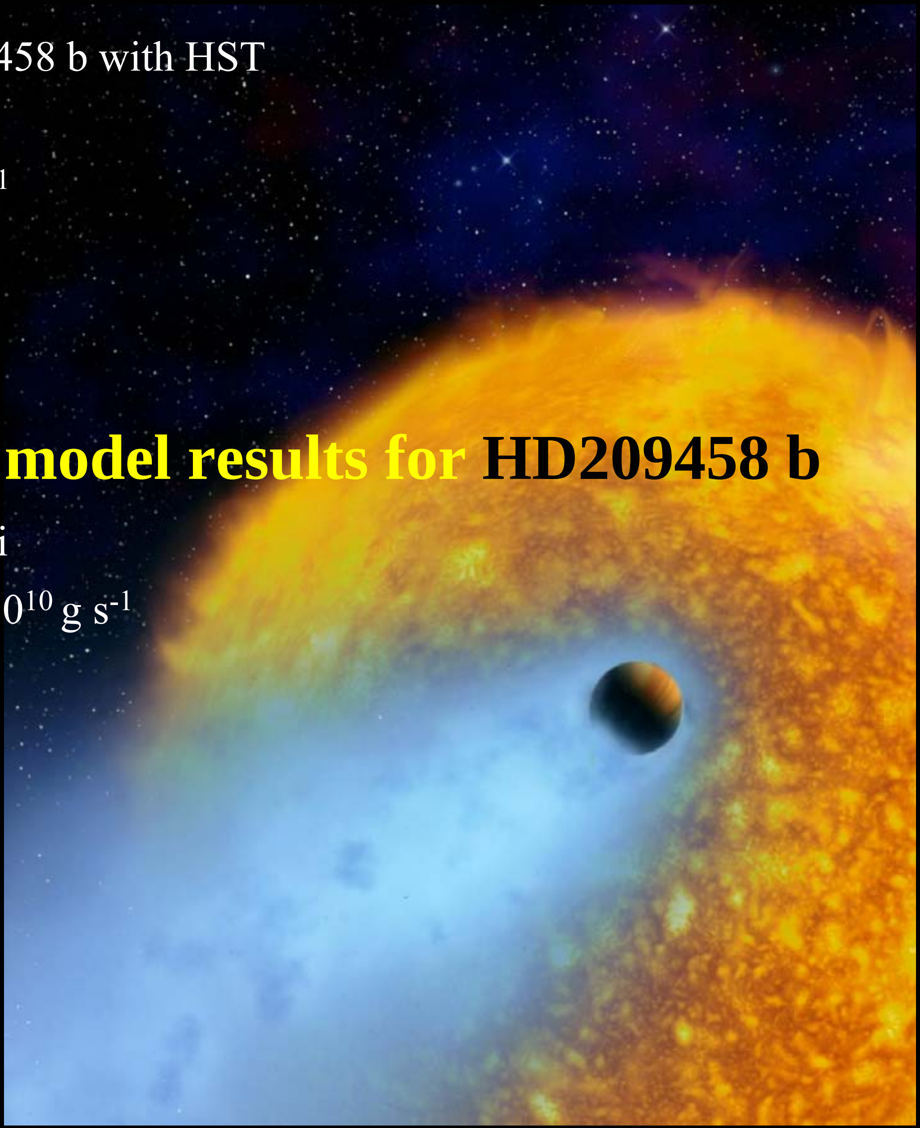


Evaporation of close & H-rich gas giants

Observation

- Hydrogen-cloud observed around HD209458 b with HST
- Expanded atmosphere
- Estimated lower mass loss rate $\geq 10^{10}$ g s^{-1}

[Vidal-Madjar *et al.*, Nature, 2003]



Full hydrodynamic blow-off model results for HD209458 b

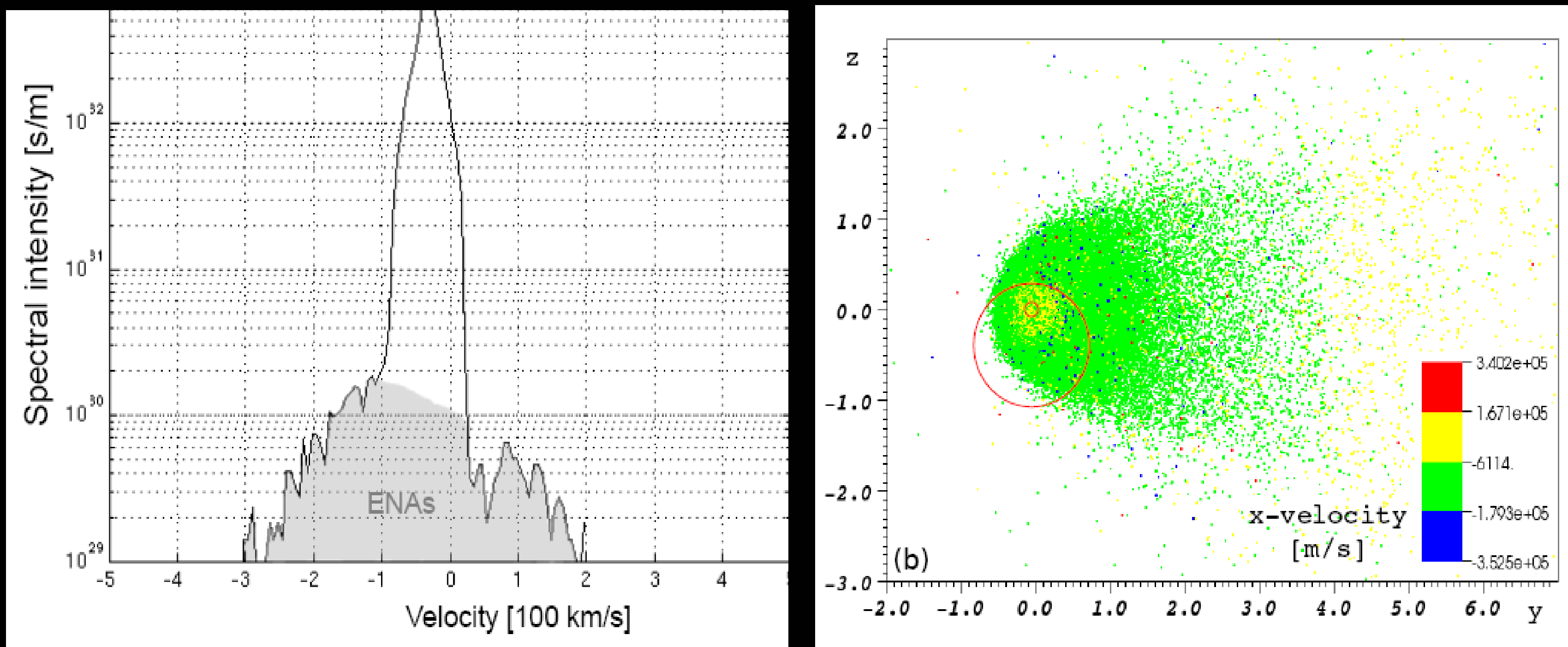
- Atmosphere expansion ≈ 3 planetary radii
- Estimated maximal mass loss rate $\approx 7 \times 10^{10}$ g s^{-1}

[e.g., Lammer *et al.*, 2003; Yelle 2004; Tian *et al.* 2005; Munoz 2007; Penz *et al.* 2007]

BUT !

Did they really observe the atmospheric hydrogen?

Hydrogen ENAs → form the observed cloud

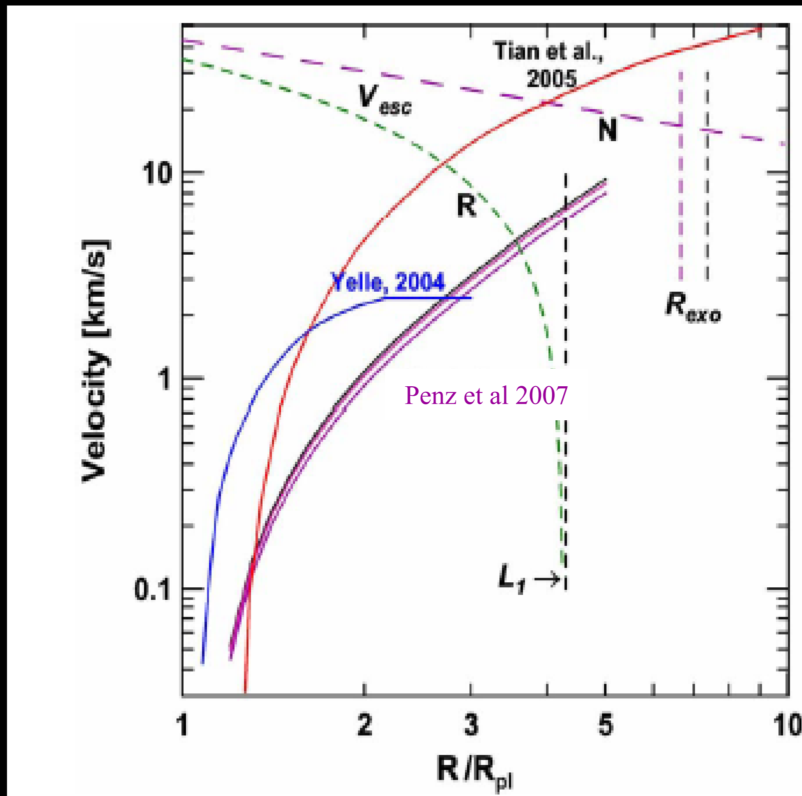


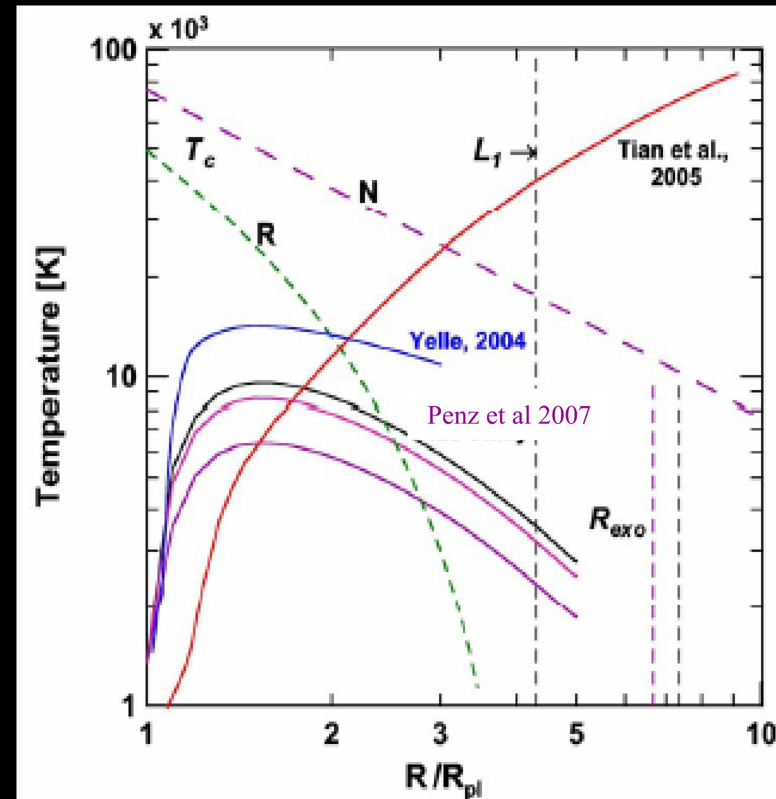
[Holmstroem *et al.*, Nature, 2008]

Stellar wind plasma interaction with an extended hydrogen atmosphere can explain the observations → information of the stellar wind around an other star at 0.045 AU!

A parameter study can give information about the magnetosphere and planetary exosphere

Evaporation of close-in H-rich gas giants





$$\frac{\partial n}{\partial t}+\frac{1}{r^2}\frac{\partial n v r^2}{\partial r}=0,$$

$$n\frac{\partial v}{\partial t}+nv\frac{\partial v}{\partial r}+\frac{1}{m}\frac{\partial p}{\partial r}=nF_{grav},$$

$$nm\left(\frac{\partial E}{\partial t}+v\frac{\partial E}{\partial r}\right)=q-p\frac{1}{r^2}\frac{\partial r^2 v}{\partial r}+\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\chi\frac{\partial T}{\partial r}\right)$$

$$F_{grav}=-\frac{GM_{pl}}{r^2}+\frac{GM_{st}}{(d-r)^2}-\frac{G(M_{st}-M_{pl})}{d^3}(s-r)$$

$$p=nkT,\quad E=\frac{1}{\gamma-1}\frac{p}{nm}$$

[Penz *et al.*, PSS, in press 2008]

Mass-loss due to thermal loss of HD209458b

Loss rates in g
10%, and the

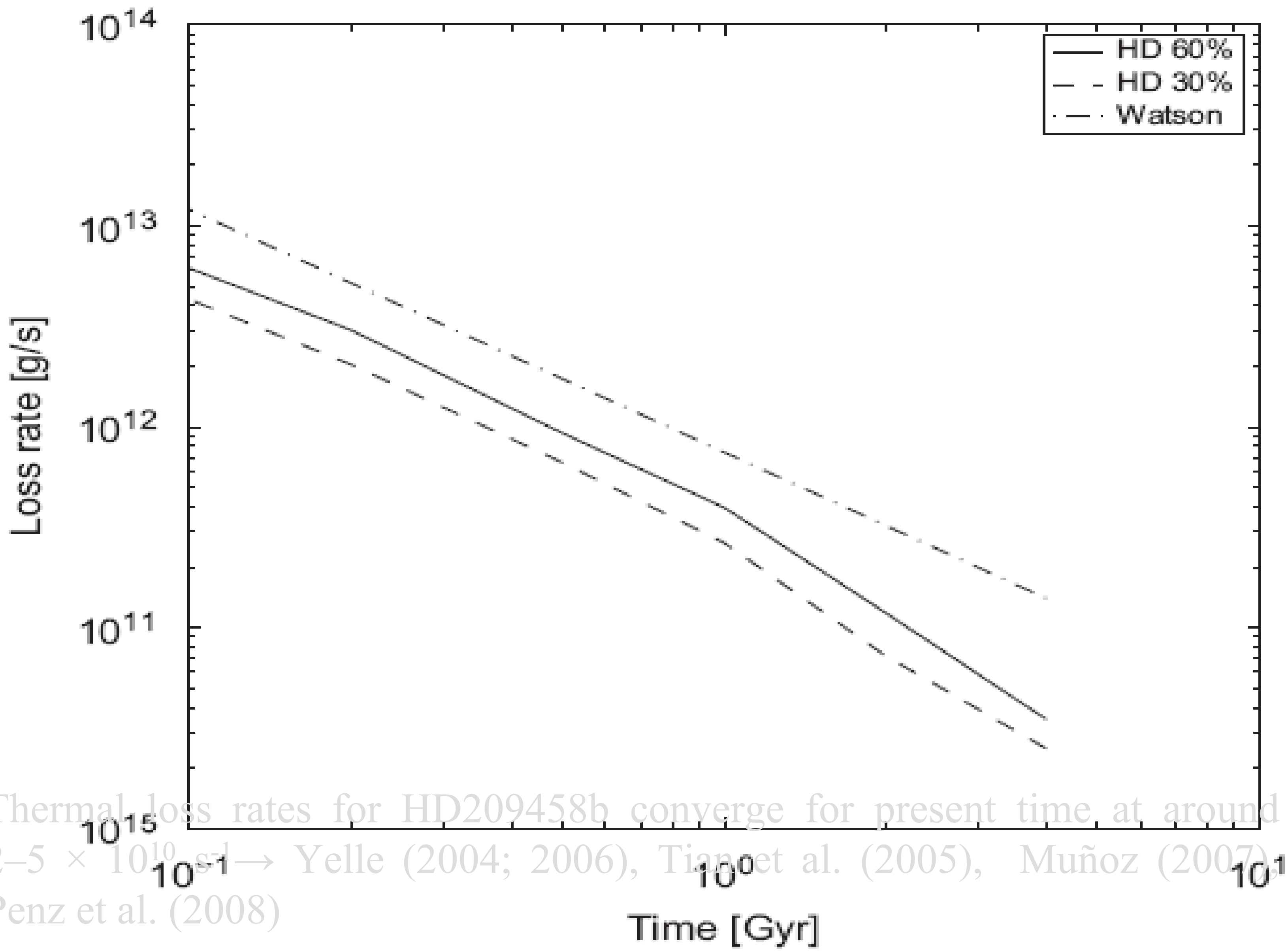
t (Gyr) (XUV

HD model $\eta =$
$\eta = 30\%$
$\eta = 10\%$
Energy limited

Similar to Tab

t (Gyr) (XUV

$\eta = 60\%$
Energy limited



Thermal loss rates for HD209458b converge for present time at around 2–5 × 10^{10} s^{-1} → Yelle (2004; 2006), Tian et al. (2005), Muñoz (2007), Penz et al. (2008)

Evaporation of close-in H-rich gas giants in orbits around solar-like stars

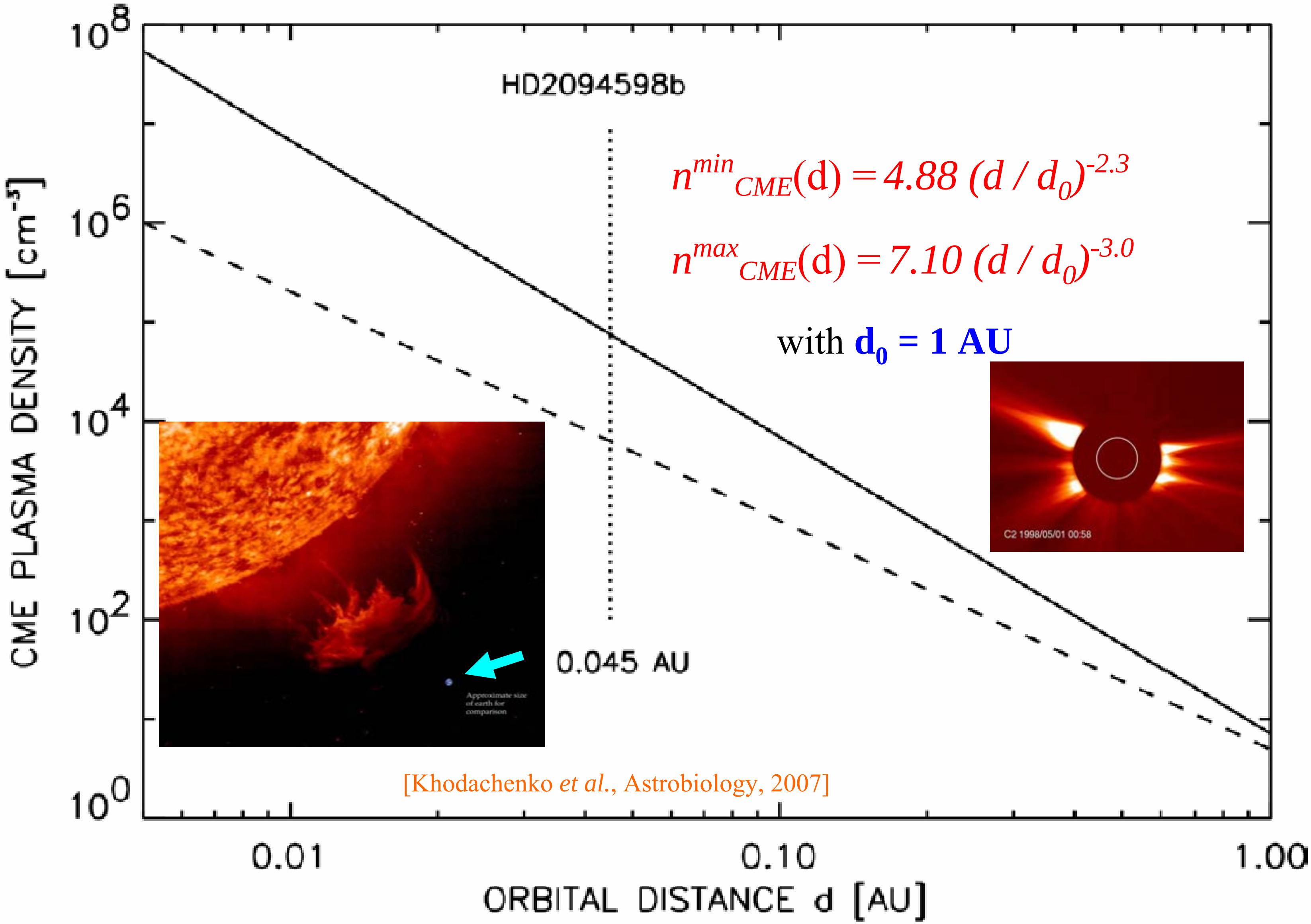
$t_{exo-form}$ [Myr]	d [AU]	P [d]	EGP I: L_{th} [%]	EGP II: L_{th} [%]
50	0.02	1	100 %	~19 %
50	0.05	4	~19 %	~2 %
50	0.13	16	~3 %	<1 %
100	0.02	1	100 %	~13 %
100	0.05	4	~13 %	~1 %
100	0.13	16	~2 %	<1 %
200	0.02	1	~89 %	~9 %
200	0.05	4	~9 %	~1 %
200	0.13	16	~1 %	< 1 %
300	0.02	1	~73 %	~7 %
300	0.05	4	~7 %	< 1 %
300	0.13	16	< 1 %	< 1 %

Includes the X-ray/EUV evolution history

EGP I: $\rightarrow 10^{26}$ kg; EGP II: $\rightarrow 10^{27}$ kg

Transformation of hydrogen-rich Neptune-type planets to a kind of "Super Earth"

Solar-Stellar analogy → CME activity

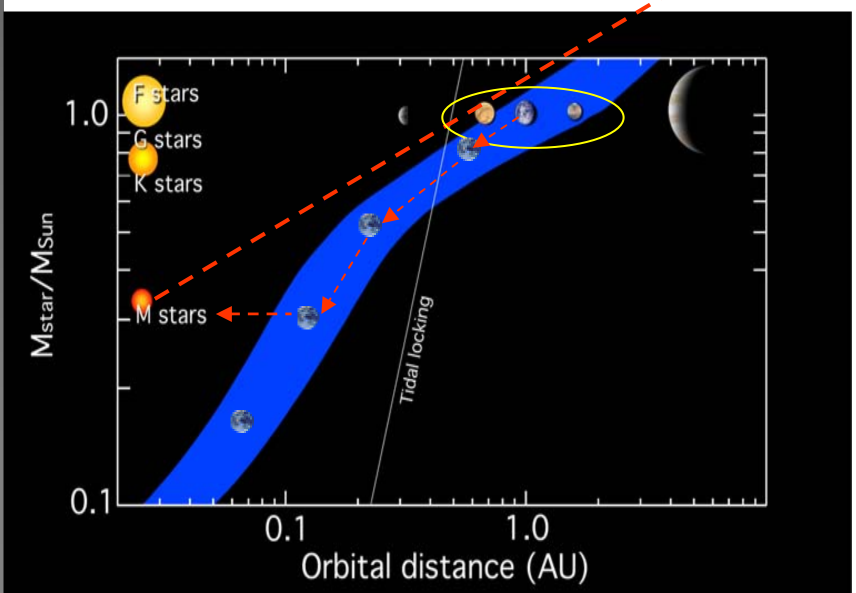


[Khodachenko *et al.*, Astrobiology, 2007]

No solar analogy for habitable zones of lower mass stars (K and M-types)

Atmospheric effects and habitability of Earth-like exoplanets within close-in habitable zones

- Enhanced EUV and X-rays
- Neutron fluxes
- Coronal mass ejections (CMEs)
- Intense solar proton/electron fluxes (e.g., SPEs)



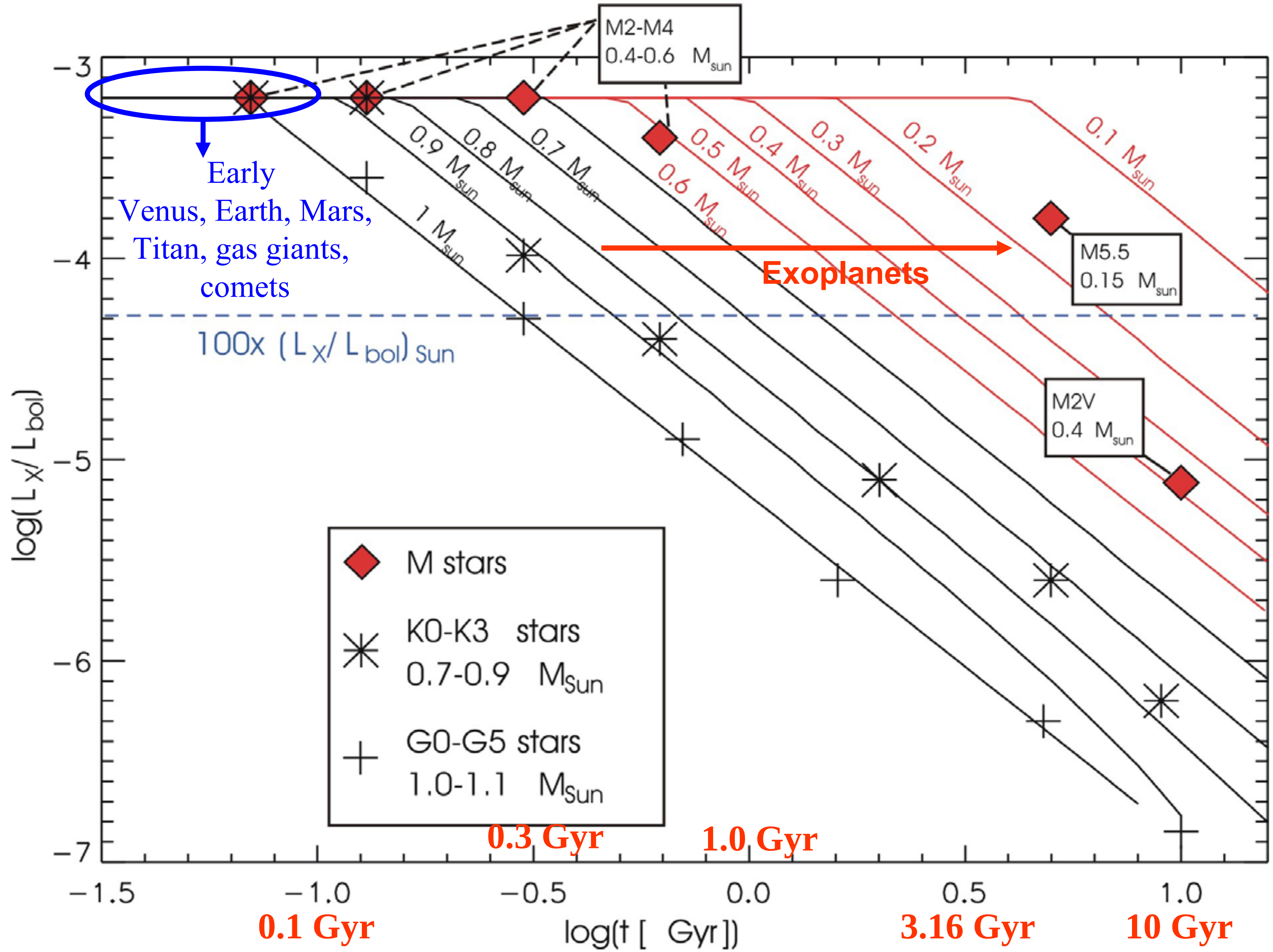
Solar – stellar analogy

- Data from Sun + Stars

Space and ground-based data

- Correlated analysis of events
- Establishing an extreme event data-base (Venus, Earth, Mars, exoplanets)
- Input for models

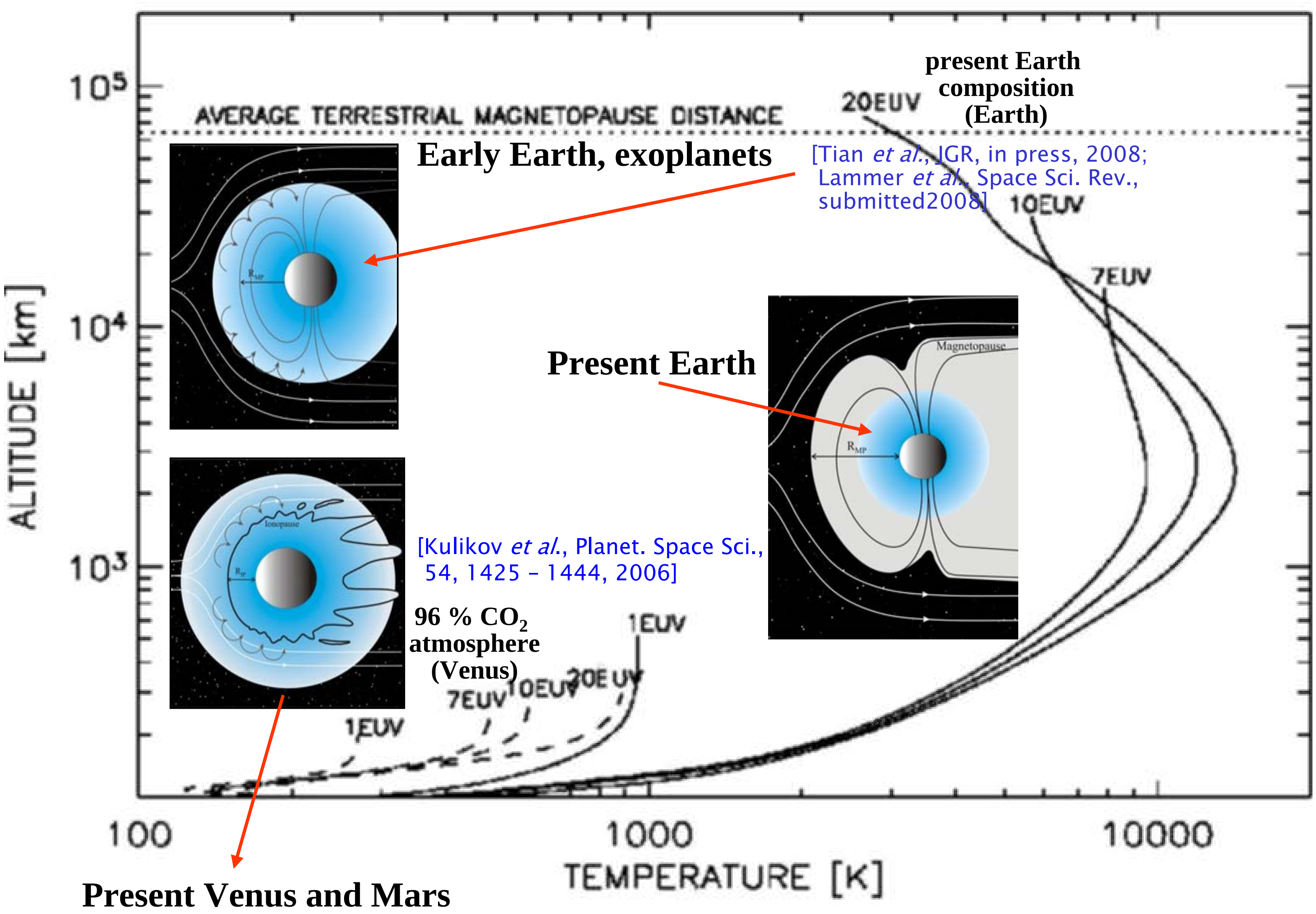
X-ray/EUV activity of low mass stars



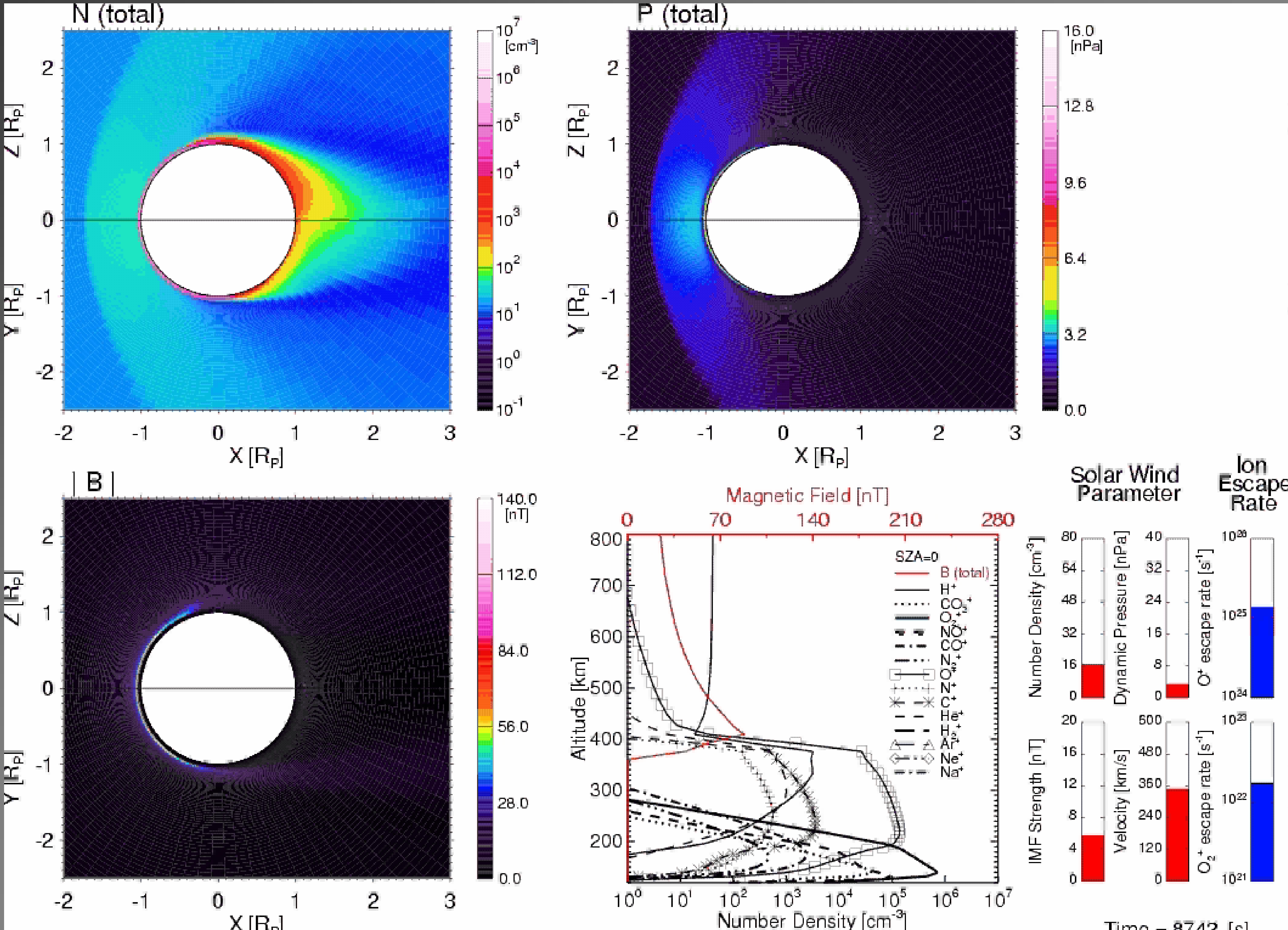
[Scalo *et al* 2007]

Expected scenarios of atmosphere responses during the young Sun active star epochs

IWF Graz ...



O^+ pick up loss rates of present Venus at 0.7 AU



Exo-Venus (M-star habitable zone) studies: parameter study for early Venus modelling

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$$\int \Phi dt = \pi\left[\left(r_{pl}+\delta_i\right)^2 - r_{pl}^2\right] n_{O+} v_{O+} \Delta t,$$

LETTERS

The loss of ions from Venus through the plasma wake

S. Barabash[1], A. Fedorov[2], J. J. Sauvaud[2], R. Lundin[1], C. T. Russell[3], Y. Futaana[1], T. L. Zhang[4], H. Andersson[1], K. Brinkfeldt[1], A. Grigoriev[1], M. Holmström[1], M. Yamauchi[1], K. Asamura[5], W. Baumjohann[4], H. Lammer[4], A. J. Coates[6], D. O. Kataria[6], D. R. Linder[6], C. C. Curtis[7], K. C. Hsieh[7], B. R. Sandel[7], M. Grande[8], H. Gunell[9], H. E. J. Koskinen[10,11], E. Kallio[11], P. Riihelä[11], T. Säles[11], W. Schmidt[11], J. Kozyra[12], N. Krupp[13], M. Fränz[13], J. Woch[13], J. Luhmann[14], S. McKenna-Lawlor[15], C. Mazelle[2], J.-J. Thocaven[2], S. Orsini[16], R. Cerulli-Irelli[16], M. Mura[16], M. Milillo[16], M. Maggi[16], E. Roelof[17], P. Brandt[17], K. Szego[18], J. D. Winningham[19], R. A. Frahm[19], J. Scherrer[19], J. R. Sharber[19], P. Wurz[20] & P. Bochsler[20]

By using modelled O^+ ion densities corresponding to Venus-type CO_2 atmospheres and planets over the terminator and by assuming that only about 20 % of the circular area over the polar terminator areas one can estimate the ion loss into the tail which is a factor of 10 higher compared to ion pick up loss:

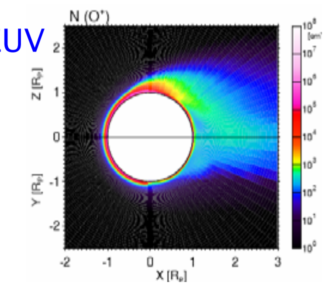
[Terada *et al.*, in preparation for Astron. & Astrophys., 2008]

Exo-Venus (30 EUV): at HZ 0.3 AU → 5×10^{28} s^{-1};
< 2 bar during 150 Myr

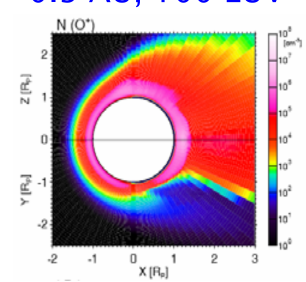
Exo-Venus (100 EUV): at HZ 0.3 AU → 8×10^{29} s^{-1};
~ 20 bar during 150 Myr

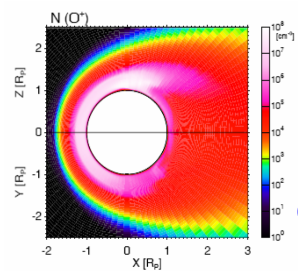
Exo-Venus (100 EUV): at HZ 0.05 AU → 10^{31} s^{-1};
~ 500 bar during 150 Myr

0.3 AU, 30 EUV



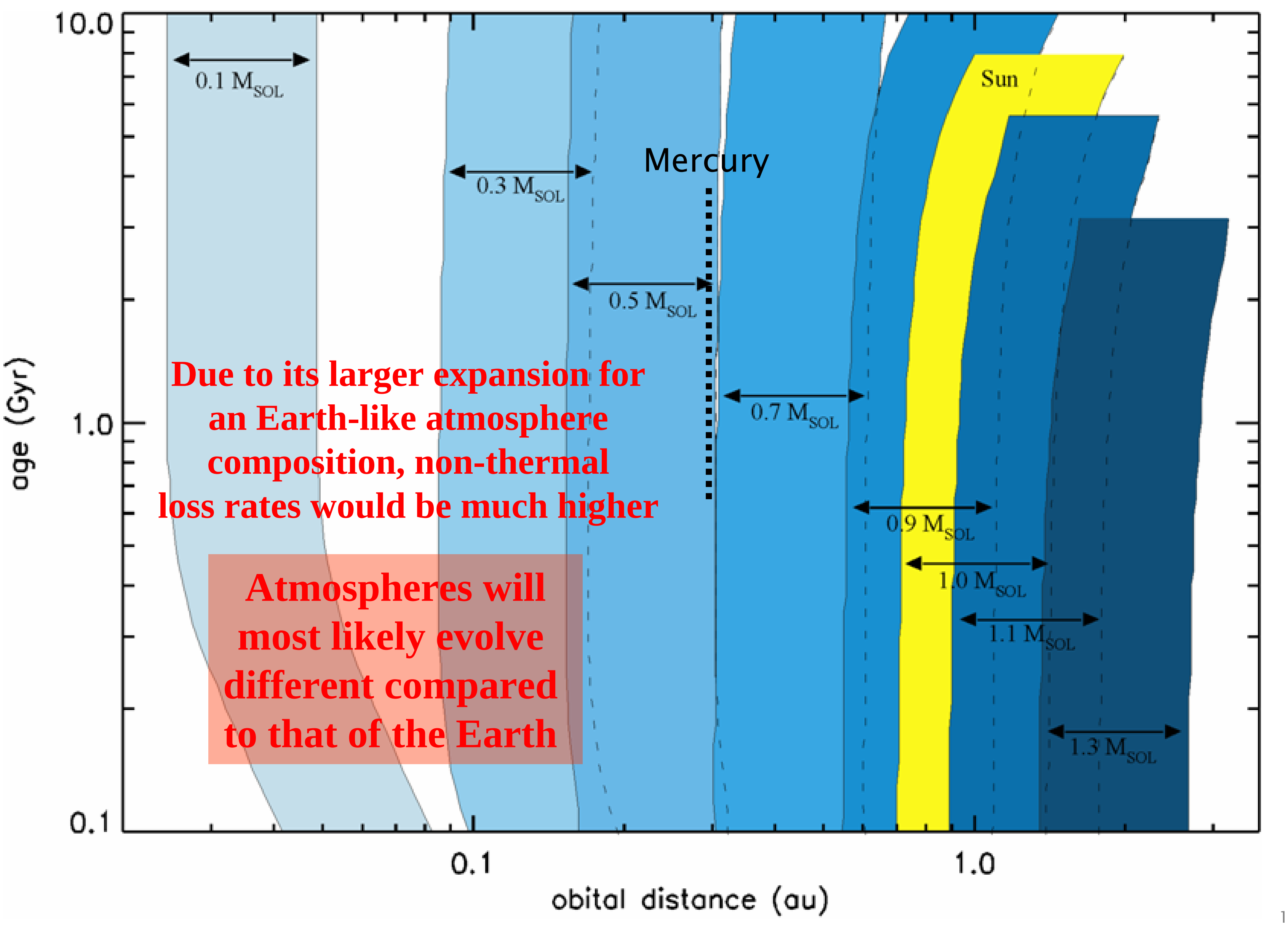
0.3 AU, 100 EUV





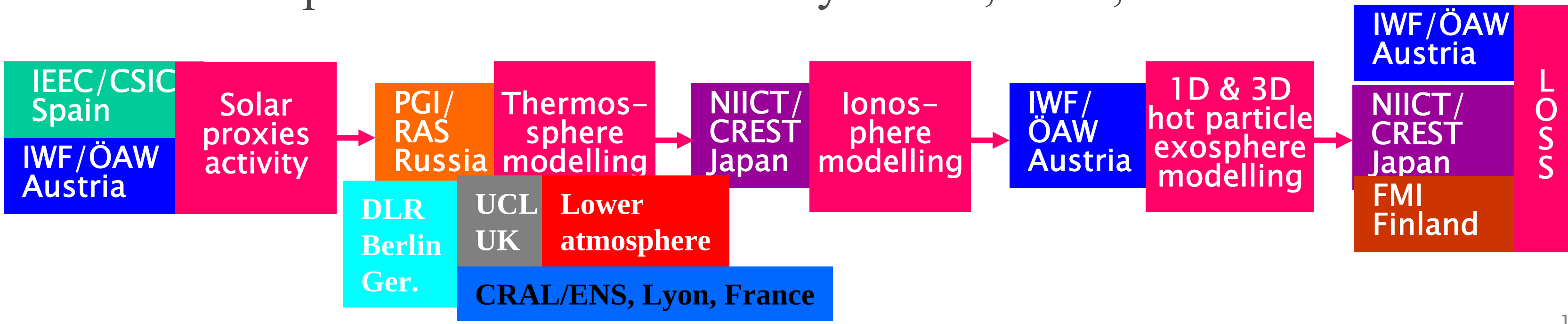
0.05 AU, 100 EUV

Water inventories and atmospheres are strongly effected due to non-thermal loss processes



Ongoing activities and future outlook

- Solar/stellar drivers for thermal and non-thermal escape processes
- Thermosphere - ionosphere – exosphere → escape
- Recent and preliminary modelling efforts for extreme solar/stellar conditions
  - 1D diffusive-gravitational equilibrium and thermal balance modelling of Venus and Martian-type CO_2 atmospheres under extreme XUV conditions → early Venus, early Mars & CO_2-rich terrestrial exoplanets
  - ionosphere and 1D and 3D hot particle and exosphere modelling
  - application of test particle and 3D MHD and 3D hybrid models
  - for upper atmosphere – solar wind interaction under extreme
  - radiation/plasma conditions → early Venus, Mars, etc.



SC 3.4 Implementation in the Plasma node (atmosphere node)

Planets under Extreme conditions