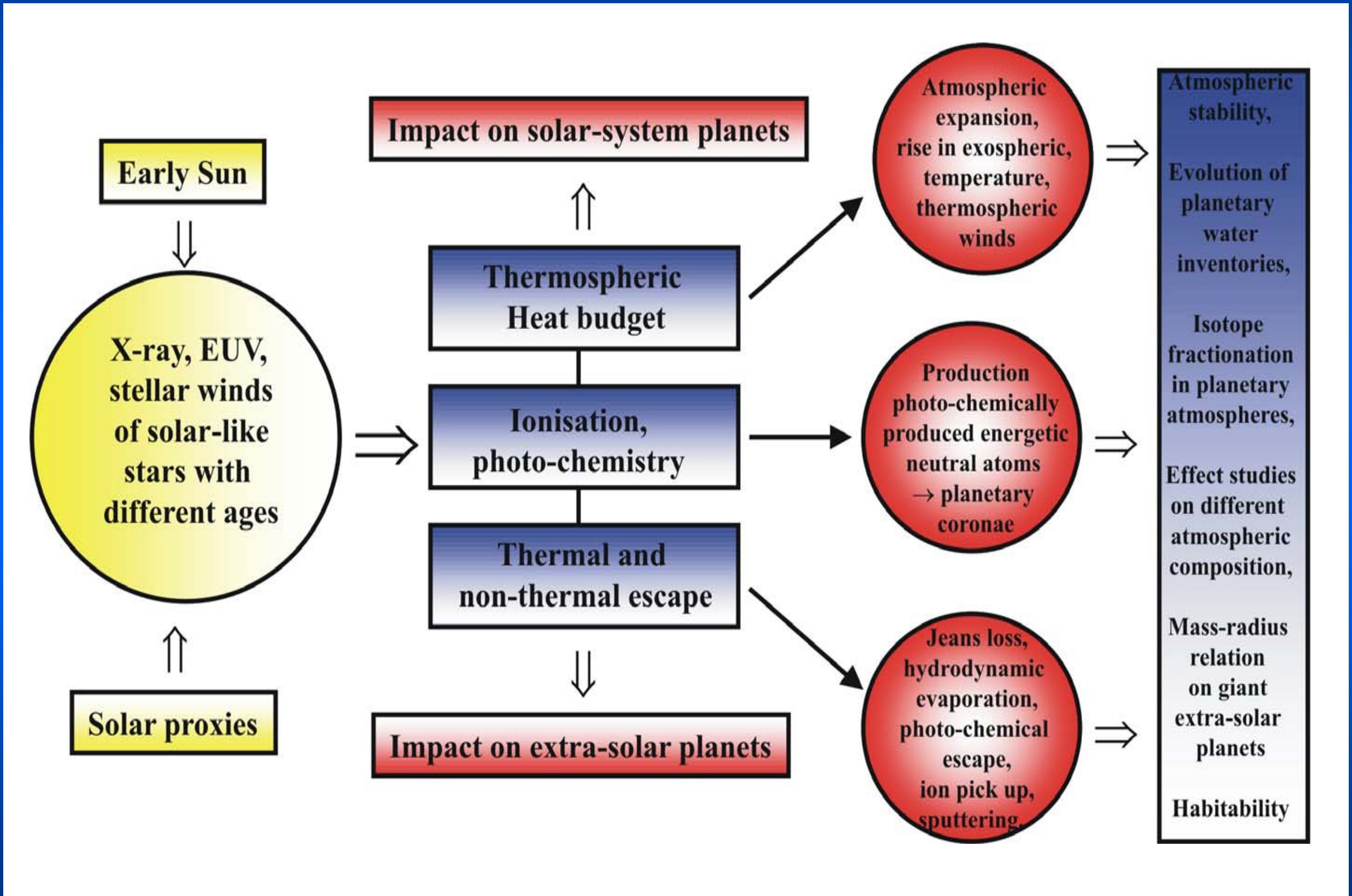
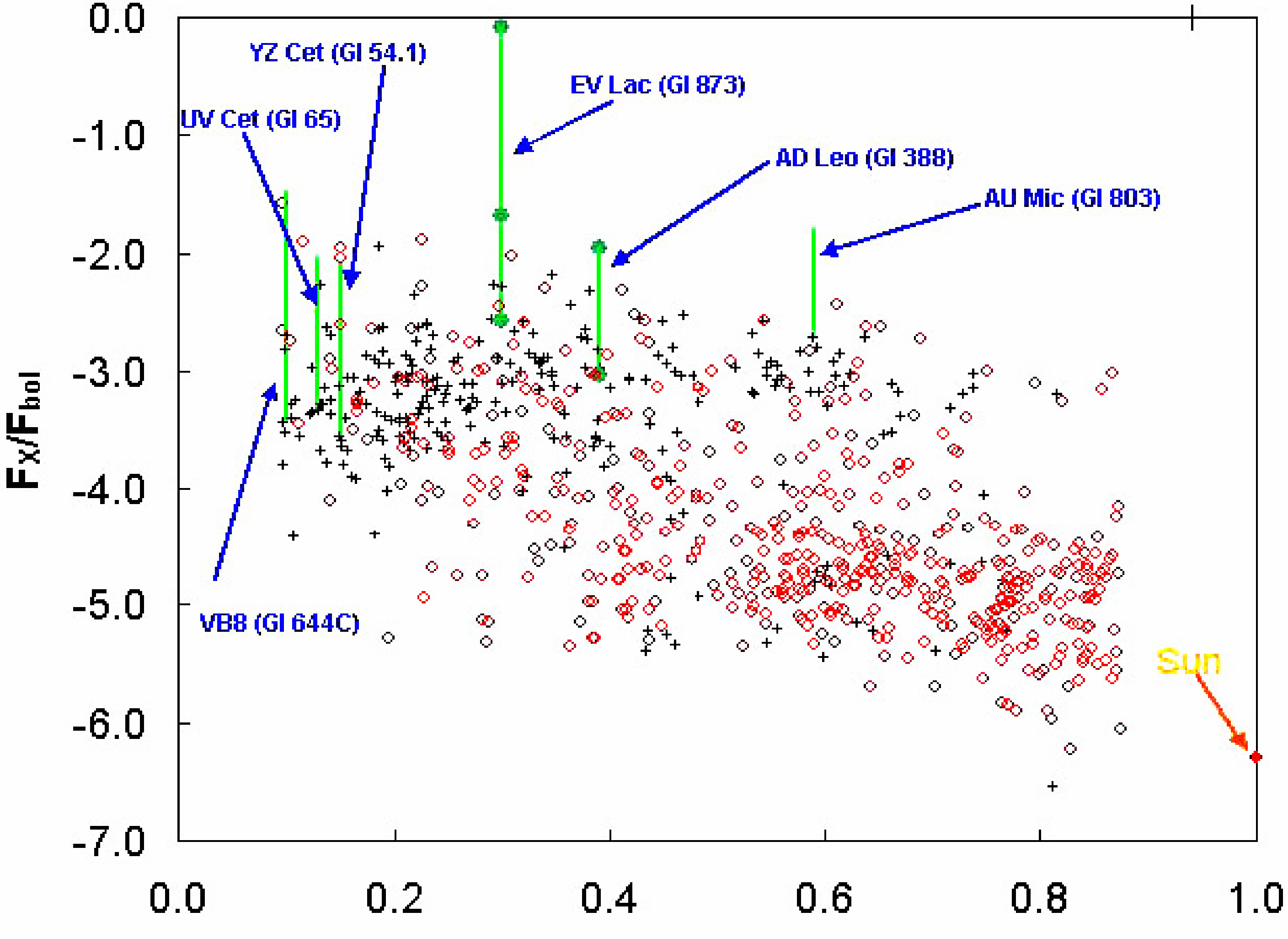
Radiation and plasma/particles



X-ray/EUV activity and stellar type and age



[Scalo et al., Astrobiology, submitted, 2006]

Modelling of thermospheric energy budgets

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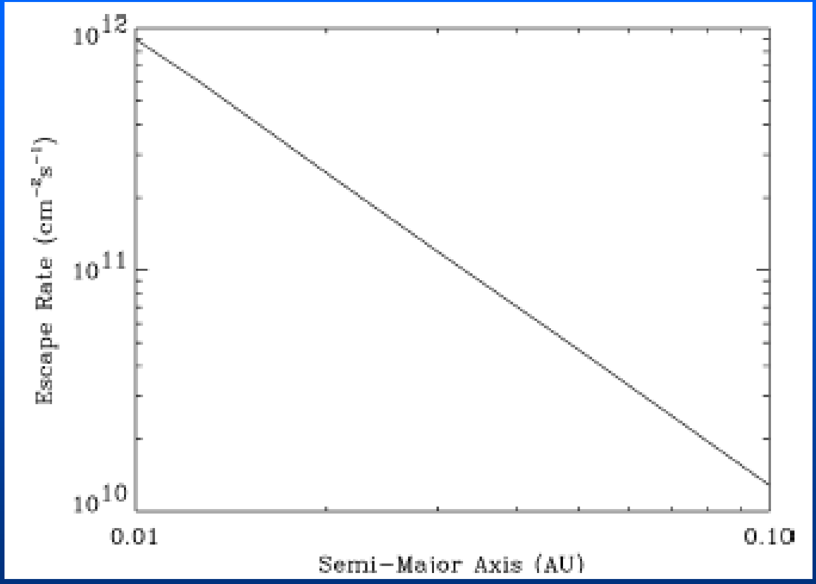
European Planetology Network

Hot Jupiter's

Reaction						Rate[a]
R1a	H_2	$+ h\nu$	$\rightarrow H_2^+$	$+ e$		2.68×10^{-5}
R1b			$\rightarrow H^+$	$+ H$	$+ e$	8.93×10^{-7}
R2	H	$+ h\nu$	$\rightarrow H^+$	$+ e$		4.76×10^{-5}
R3	He	$+ h\nu$	$\rightarrow He^+$	$+ e$		2.58×10^{-5}
R4	H_2	$+ M$	$\rightarrow H$	$+ H$	$+ M$	$1.5 \times 10^{-9} e^{-4.8E4/T}$
R5	H	$+ H + M$	$\rightarrow H_2$	$+ M$		$8.0 \times 10^{-33} (300/T)^{0.6}$
R6	H_2^+	$+ H_2$	$\rightarrow H_3^+$	$+ H$		2.0×10^{-9}
R7	H_3^+	$+ H$	$\rightarrow H_2^+$	$+ H_2$		2.0×10^{-9}
R8	H_2^+	$+ H$	$\rightarrow H^+$	$+ H_2$		6.4×10^{-10}
R9	H^+	$+ H_2(v \geqslant 4)$	$\rightarrow H_2^+$	$+ H$		$1.0 \times 10^{-9} e^{-2.19E4/T}$
R10a	He^+	$+ H_2$	$\rightarrow HeH^+$	$+ H$		4.2×10^{-13}
R10b			$\rightarrow H^+$	$+ H$	$+ He$	8.8×10^{-14}
R11	HeH^+	$+ H_2$	$\rightarrow H_3^+$	$+ He$		1.5×10^{-9}
R12	HeH^+	$+ H$	$\rightarrow H_2^+$	$+ He$		9.1×10^{-10}
R13	H^+	$+ e$	$\rightarrow H$	$+ h\nu$		$4.0 \times 10^{-12} (300/T_e)^{0.64}$
R14	He^+	$+ e$	$\rightarrow H$	$+ h\nu$		$4.6 \times 10^{-12} (300/T_e)^{0.64}$
R15	H_2^+	$+ e$	$\rightarrow H$	$+ H$		$2.3 \times 10^{-8} (300/T_e)^{0.4}$
R16a	H_3^+	$+ e$	$\rightarrow H_2$	$+ H$		$2.9 \times 10^{-8} (300/T_e)^{0.65}$
R16b			$\rightarrow H$	$+ H$	$+ H$	$8.6 \times 10^{-8} (300/T_e)^{0.65}$
R17	HeH^+	$+ e$	$\rightarrow He$	$+ H$		$1.0 \times 10^{-8} (300/T_e)^{0.6}$

[Yelle, Icarus, 170, 167–179, 2004]



⇔

Terrestrial planets

(i) heating due to the CO_2, N_2, O_2, CO and O photoionization by XUV-radiation ($\lambda \leqslant 102.7$ nm);
(ii) heating due to O_2 and O_3 photodissociation by solar UV-radiation;
(iii) chemical heating in exothermic three-body reactions

$$O + O + M \rightarrow O_2 + M, \quad (3)$$

$$O + CO + M \rightarrow CO_2 + M,$$

$$O + O_2 + M \rightarrow O_3 + M,$$

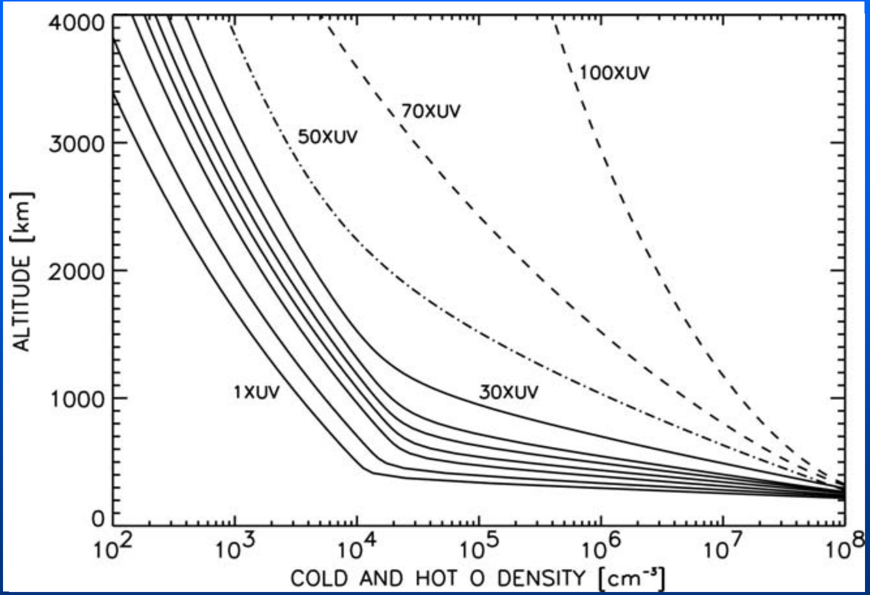
where M are CO_2, N_2 and CO molecules and O and He atoms. Further, the model includes:

(iv) neutral gas molecular heat conduction;
(v) IR-cooling in the vibrational–rotational bands of CO_2 (15 μm), CO, O_3 and in the 63 μm O line;
(vi) turbulent energy dissipation and heat conduction.

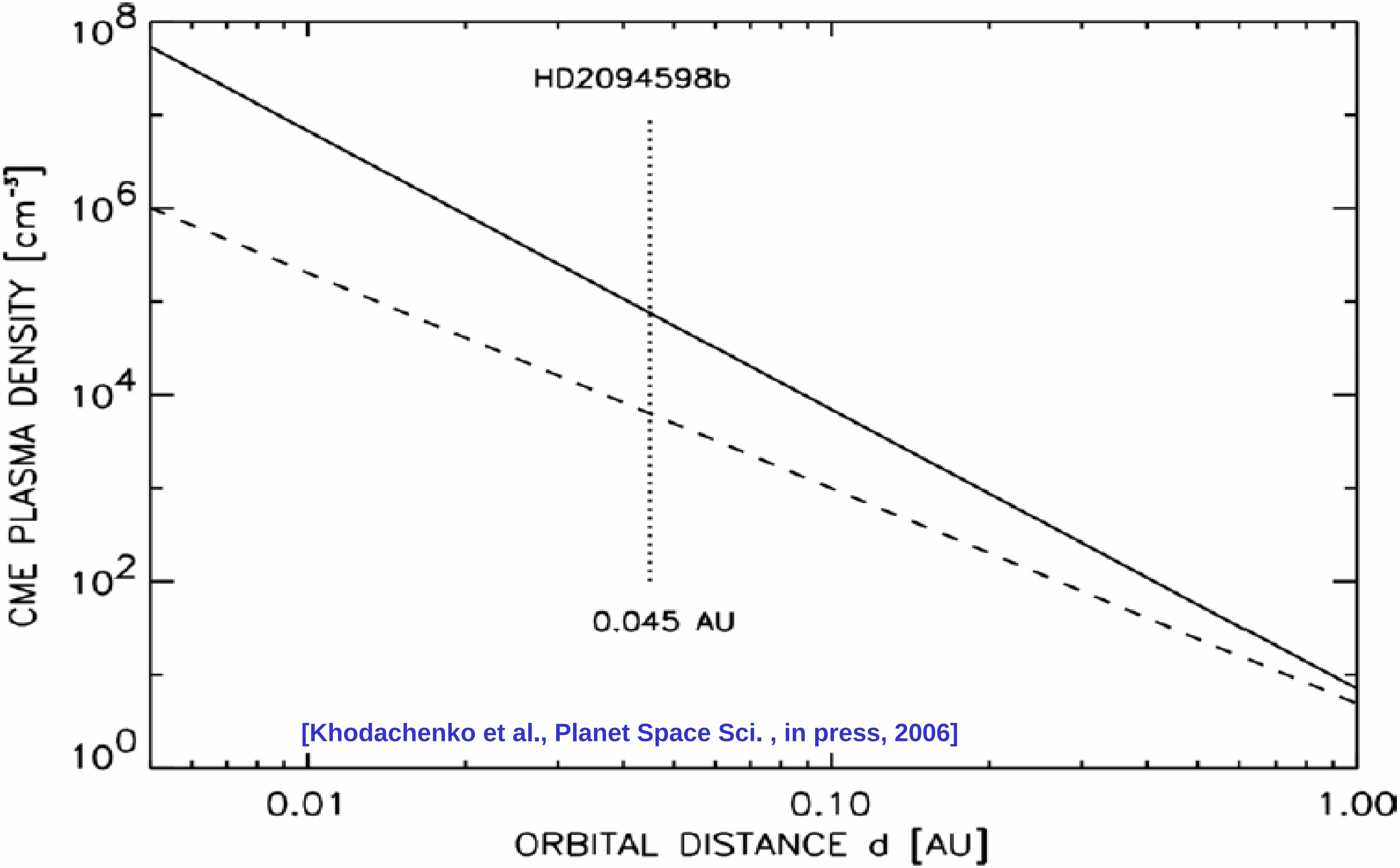
Expected consequences

- large thermal escape rates
- effect on planetary H_2O inventory
- fractionation of atmospheric species
- effect on bio-markers
- expanded atmospheres resulting in large interaction areas for solar/stellar plasma and non-thermal loss

[Kulikov et al., Planet. Space Sci., in press, 2006]



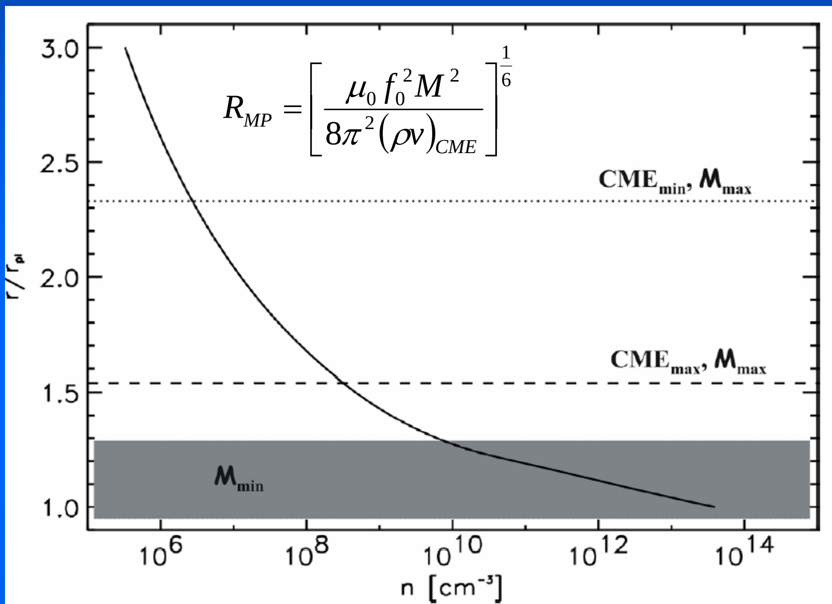
Extreme plasma-atmosphere interaction



[Khodachenko et al., Planet Space Sci. , in press, 2006]

Exomagnetospheres and non-thermal loss processes

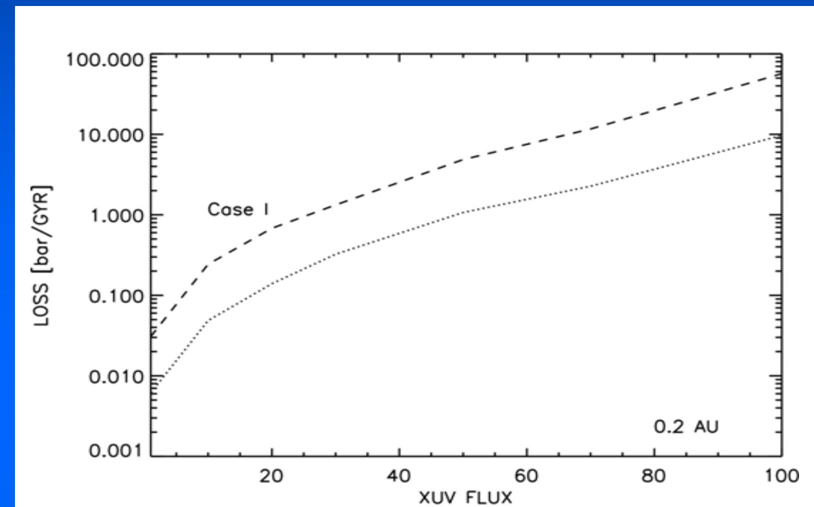
Hot Jupiter's [0.045 AU]

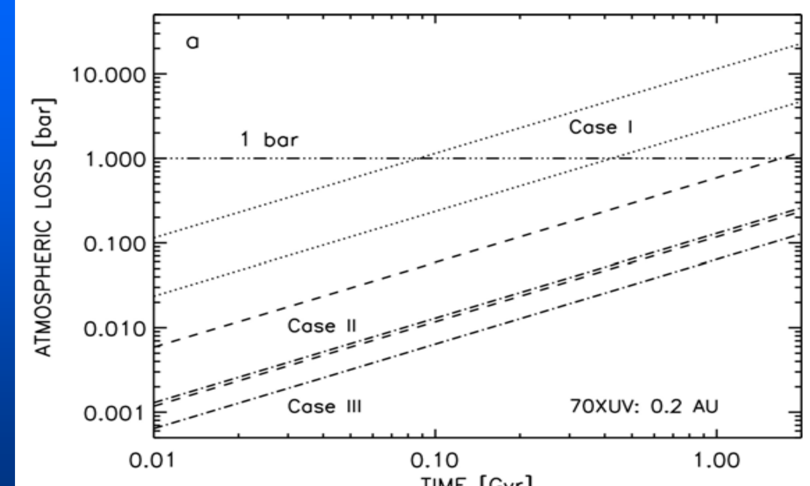


[Khodachenko et al., Planet Space Sci. , in press, 2006]

Conditions	S [s^{-1}]	L [g s^{-1}]	$\mathcal{M}$ [$\mathcal{M}_{Jup}$]	n_{CME} [cm^{-3}]	r_s [r_{pl}]	Γ [M_{pl}]
CME$_{min}$, $\mathcal{M}_{max}$	9×10^{34}	1.5×10^{11}	0.1	6300.0	2.33	1.56×10^{-2}
CME$_{max}$, $\mathcal{M}_{max}$	7×10^{37}	2×10^{13}	0.1	7.5×10^4	1.54	0.2
CME$_{min}$	7.2×10^{36}	1.2×10^{13}	0.017	6300.0	1.3	0.12
CME$_{max}$	8.2×10^{37}	1.37×10^{14}	0.059	7.5×10^4	1.3	1.43
CME$_{min}$	8.4×10^{37}	1.4×10^{14}	0.012	6300.0	1.15	1.46

Terrestrial planets [0.2 AU]





[Lammer et al., Astrobiology, submitted, 2006]

Open problems

- Extended atmospheres where the exobase is above the ionopause
  → it is not the case with Venus or Mars but there is a similarity with Titan

- Solar/stellar wind/plasma interacts within the collision dominated atmosphere
  → at which altitude does the planetary obstacle form?
  → how large are induced magnetic fields of dense ionospheres due to high XUV radiation and how do they contribute to atmosphere protection
  → essential for non-thermal loss studies

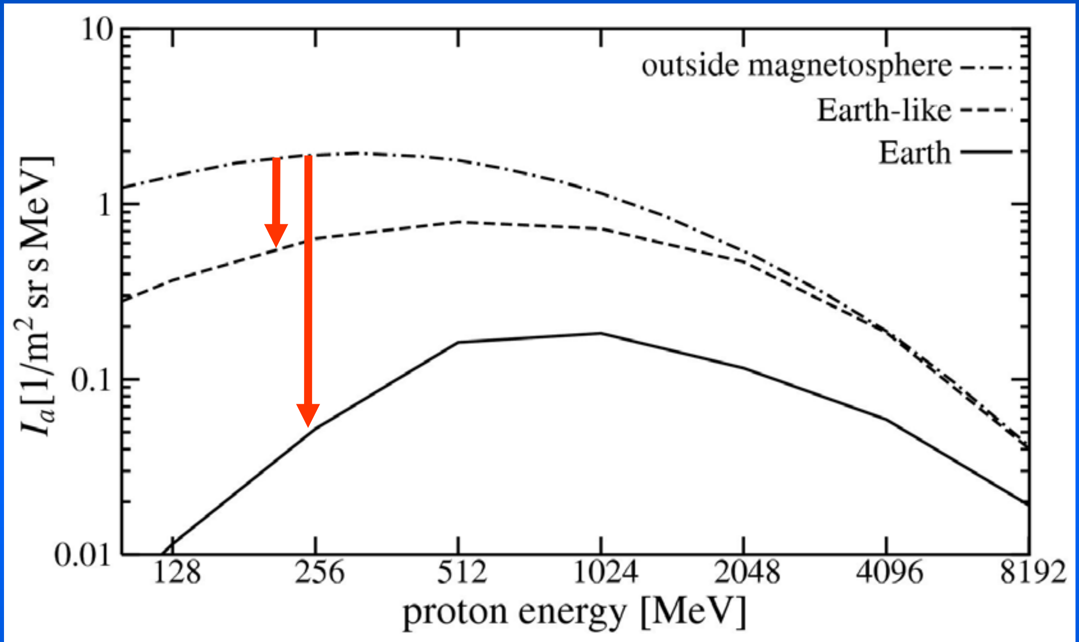
- In some cases the dense stellar wind close to its star is subsonic
  → similar with Titan's atmosphere-Saturn-magnetosphere interaction

- What is the heat input of CMEs to the atmospheres of planets at close orbital distances

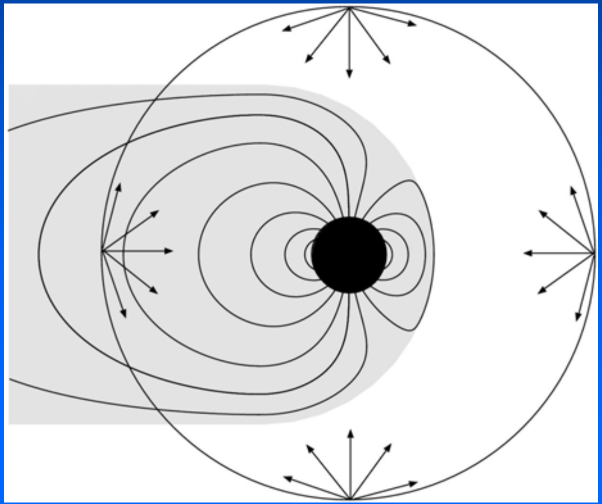
- Fractionation of atmospheric species over long time periods
  → effect and change in bio-markers and atmospheric stability and water inventories in general

Habitability-Biomarkers

Magnetospheric shielding → important!



cosmic ray energy spectrum



$$d = 0.2\,\mathrm{AU}$$
$$M_* = 0.5\,M_{\mathrm{sun}}$$
$$\mathcal{M} = 0.15\,\mathcal{M}_E$$

vs.

$$\mathcal{M} = 1.0\,\mathcal{M}_E$$

→ **biological effects** [Grießmeier et al., Astrobiology 5, 591, 2005]

→ **change in atmospheric chemistry**

- bio-markers (O_3) [Grenfell et al., Astrobiology submitted, 2006]

Revisit the concept of the habitable zone (M,K,-G-,F stars)

Global circulation modelling

- atmospheric circulation, climate and atmospheric stability of slow rotating planets → what can we learn from Venus and Titan ?
- how does the atmosphere of an habitable planet reacts to increasing stellar luminosity (i.e. decreasing orbital distance) ?
- how far can habitability be sustained assuming a silicate-carbonate control of the atmospheric CO_2 content ?

Application of sophisticated sw-plasma magnetospheric/ atmospheric/ionospheric models (hybrid, etc.) to exoplanets with X-ray and EUV heated and extended upper atmospheres

→ Synergy with early Solar System planets
→ Experience from Titan, Mars/Venus/Mercury/Earth observations/modelling

Connecting thermal/non-thermal loss modelling to bio-marker studies → fractionation of species → habitability

Europlanet
European Planetology Network

Future outlook

"Physics of Auroral Phenomena", Proc. XXVIII Annual Seminar, Apatity, pp. 182- 185 , 2005

Polar Geophysical Institute

OBSERVATIONS OF THE IONOSPHERIC EFFECTS IN THE HIGH LATITUDE D-REGION DURING SOLAR FLARES IN APRIL, 2004

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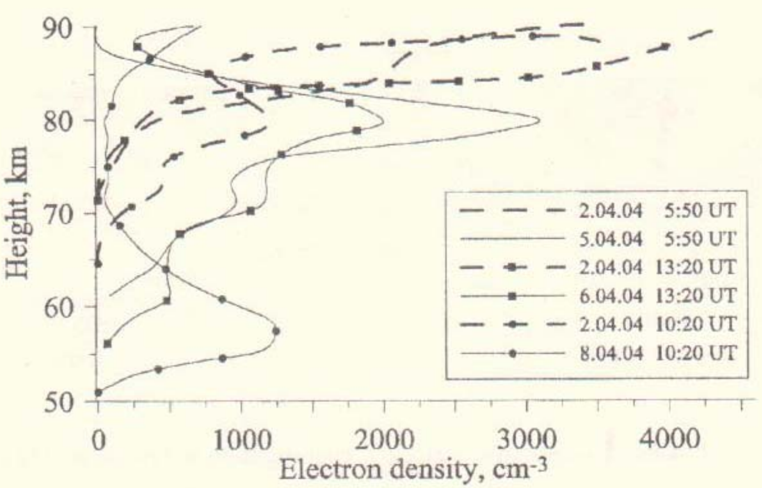
E-mail: vladter@pgi.ru)

Observations of the ionospheric effects in the high latitude D-region during solar flares in April, 2004



<u>Example</u> → X-ray effects on Earth's ionosphere during flare events

Extreme events can be used for in-situ studies which are usual conditions on exoplanets or early Earth during the active young Sun

- **Collect atmospheric/ionospheric/magnetospheric/chemical data correlated to extreme solar events available from various institutes → data base (IDIS)**
- **Establish a data base related to loss modelling (applied models and input data used - planet, atmosphere, XUV, plasma, etc., LOSS RATES) → (IDIS)**
- **Similar data bases could be established to topics related to GCMs, bio-markers**