Evolution of Hydrogen-Rich Exospheres around Earth-like Exoplanets

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Context

The presence of hydrogen-rich atmospheres around Earth-like exoplanets could be a reliable tracer of **water** and other volatile elements near the planetary surface. If such exospheres are stable or not, strongly depends on the radiation, magnetic fields and particle flow coming from the host star, i.e. **stellar winds.**

What we know

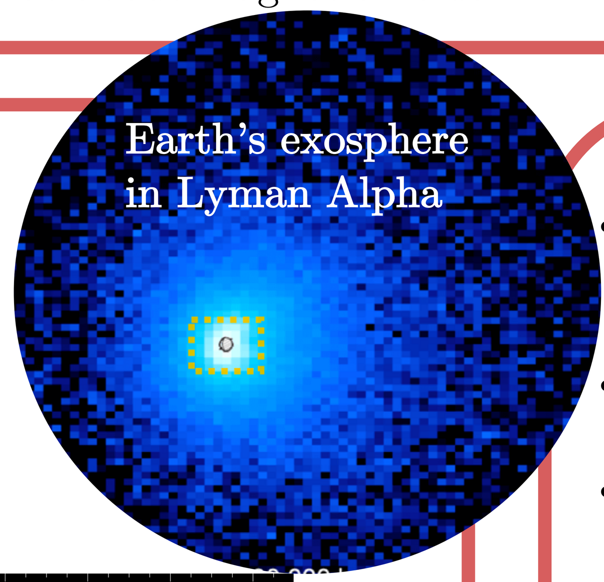
- UV observations of the Earth show an extended exosphere around our planet **[1]**: common feature in other exoplanets.
- Hydrogen extended exospheres have been widely modeled and detected **in giant, gaseous exoplanets** (e.g. HD209458b).
- Their detection around smaller, **rocky planets** is far from be achieved, and calls for a **more detailed modeling.**
- **HD** simulations have been carried out for Earth-like planets around M-dwarf stars [2]. What about magnetic fields?

Objectives

Numerical 2.5D MHD simulations of the interaction between stellar winds and Earth-like exospheres, using the PLUTO code [3], to show how the H-rich EE of an Earth-like planet evolves considering:

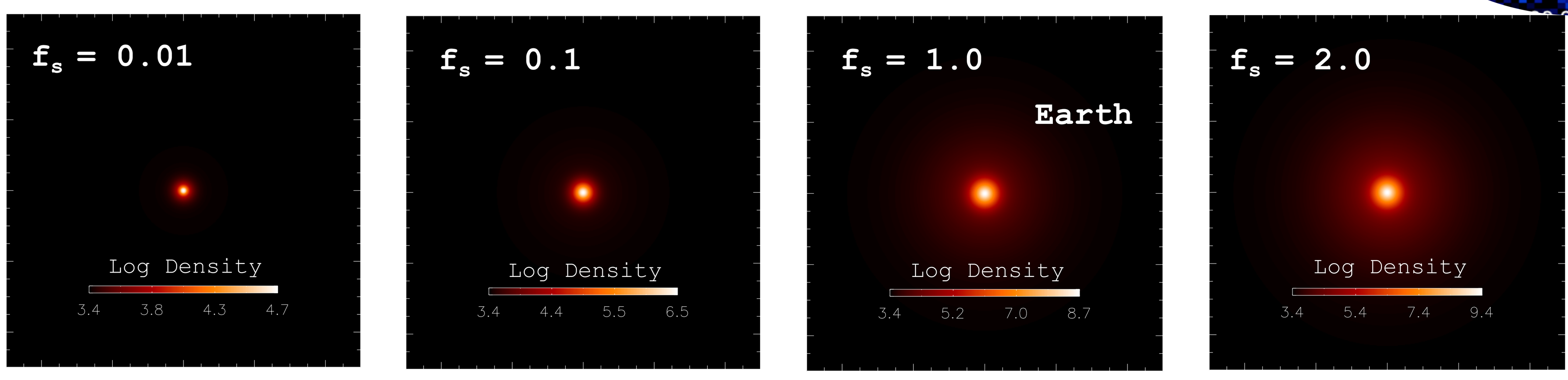
- The **stellar age** (from a very young, solar-like star of **0.1 Gyr** to a **5 Gyr** star).
- The **initial hydrogen density** present in the planet's EE.

Earth-like Exospheres



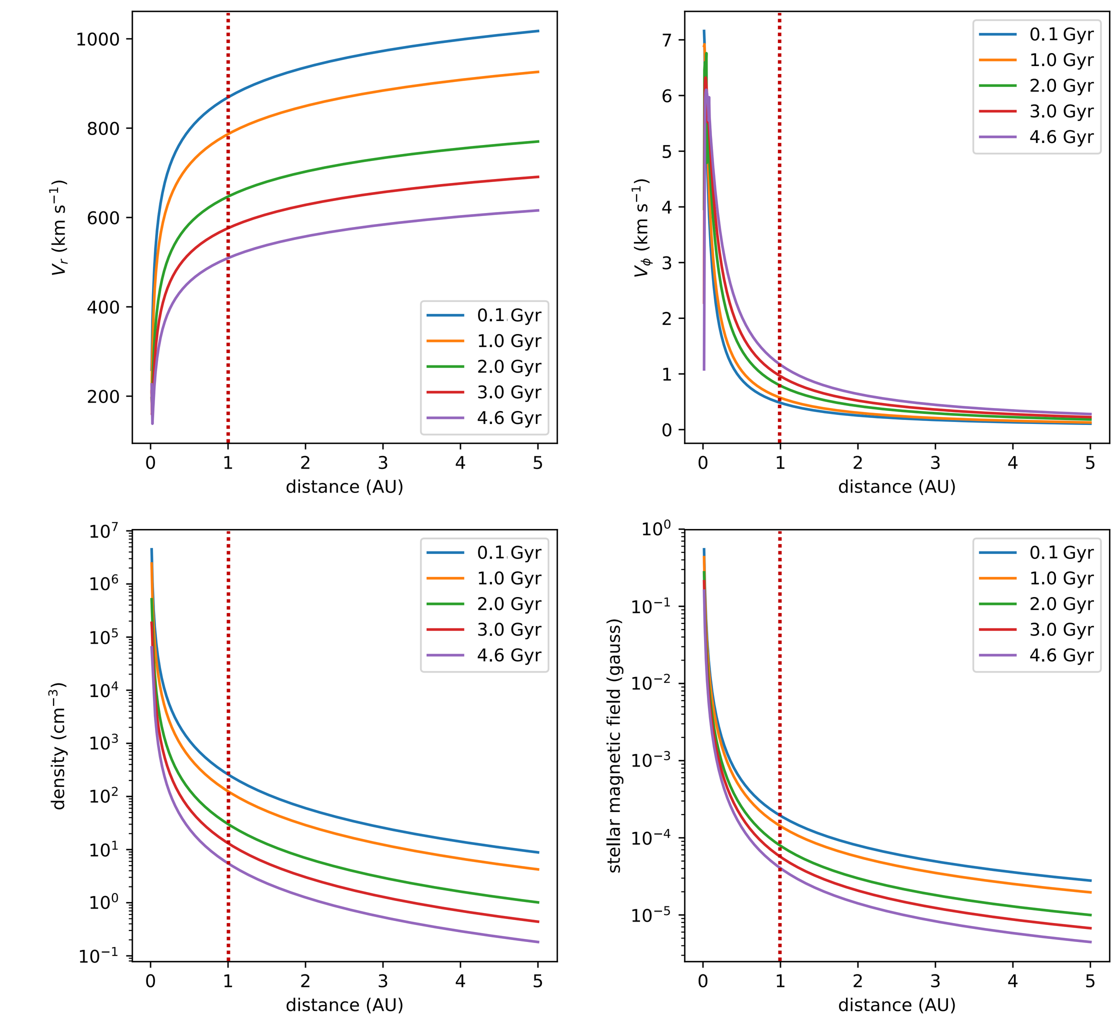
We use the classical Earth's exospheric model (Chamberlain (1963)) for the H particle distribution, including an extended component and a scale factor f_s:

$$n(r) = f_s \left[10^4 \, exp\left(\frac{-r}{1.02 R_\oplus} \right) + 70 \, exp\left(\frac{-r}{8.02 R_\oplus} \right) \right]$$



Stellar Winds in Time

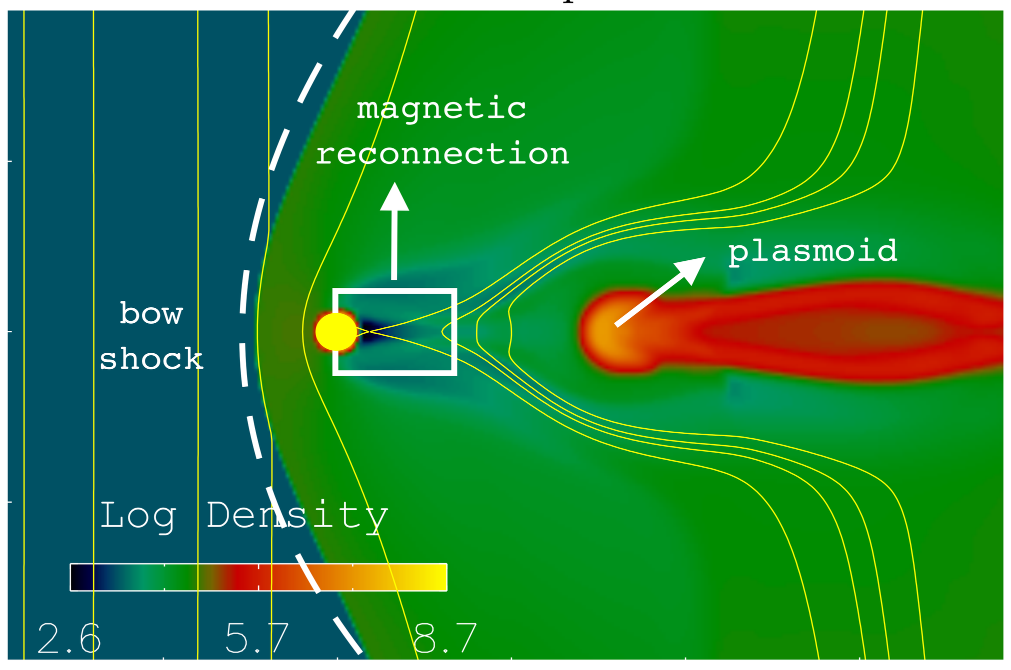
- Prediction of the characteristic stellar wind parameters for cool, solar-like stars of 0.1, 1.0, 3.0 and 5.0 Gyr at 1 AU.
- Taking into account the magnetic fields: Weber and Davis solutions for the solar wind (1967).
- Stellar age-dependent scale relations for other stars.

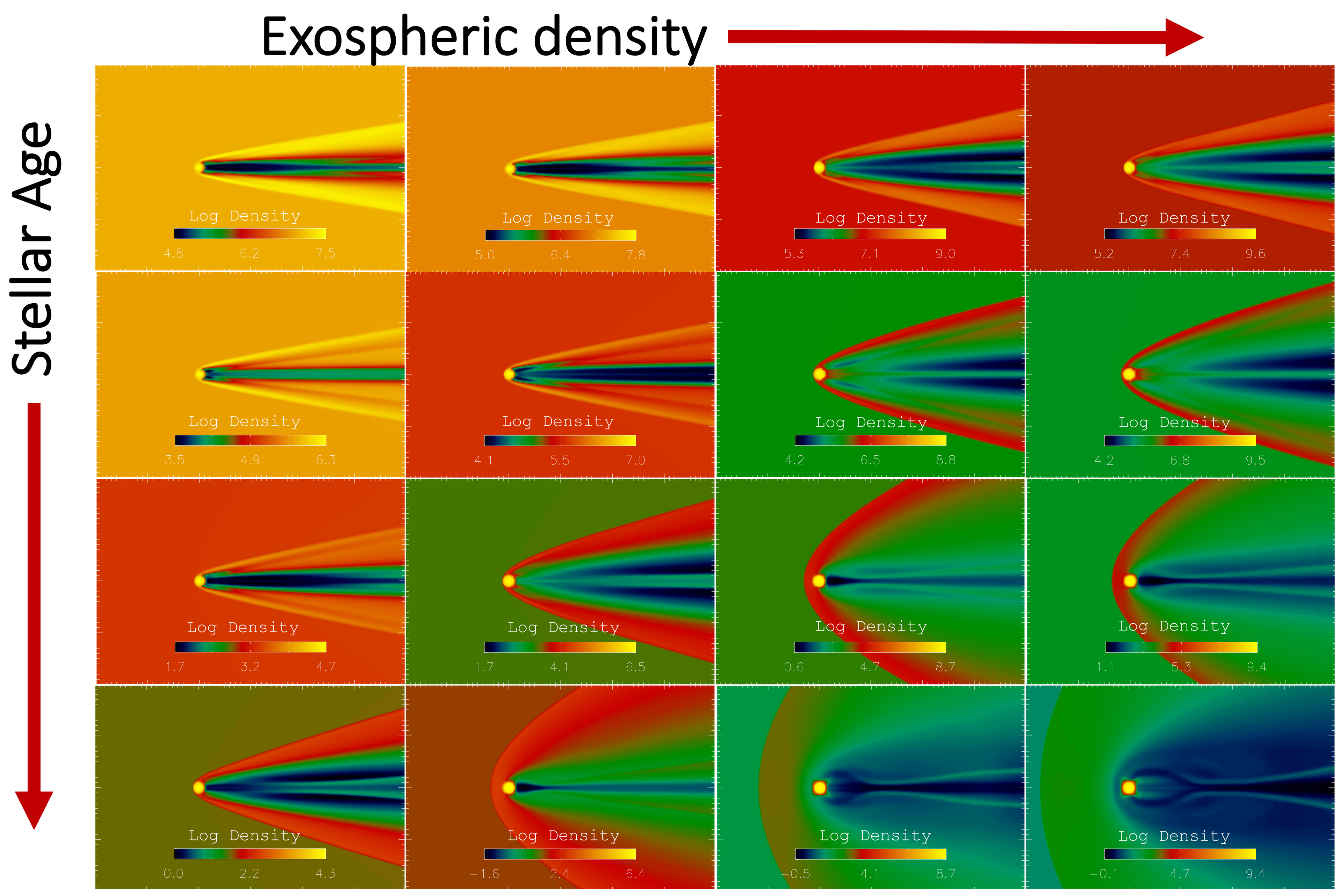


MHD Numerical Simulations

Numerical MHD simulations of the interaction between the ionized component of the H-rich exosphere of an Earth-like rocky planet, and the stellar wind coming from a cool, solar like star, of 0.1, 1.0, 3.0 and 5.0 Gyr at 1 AU.

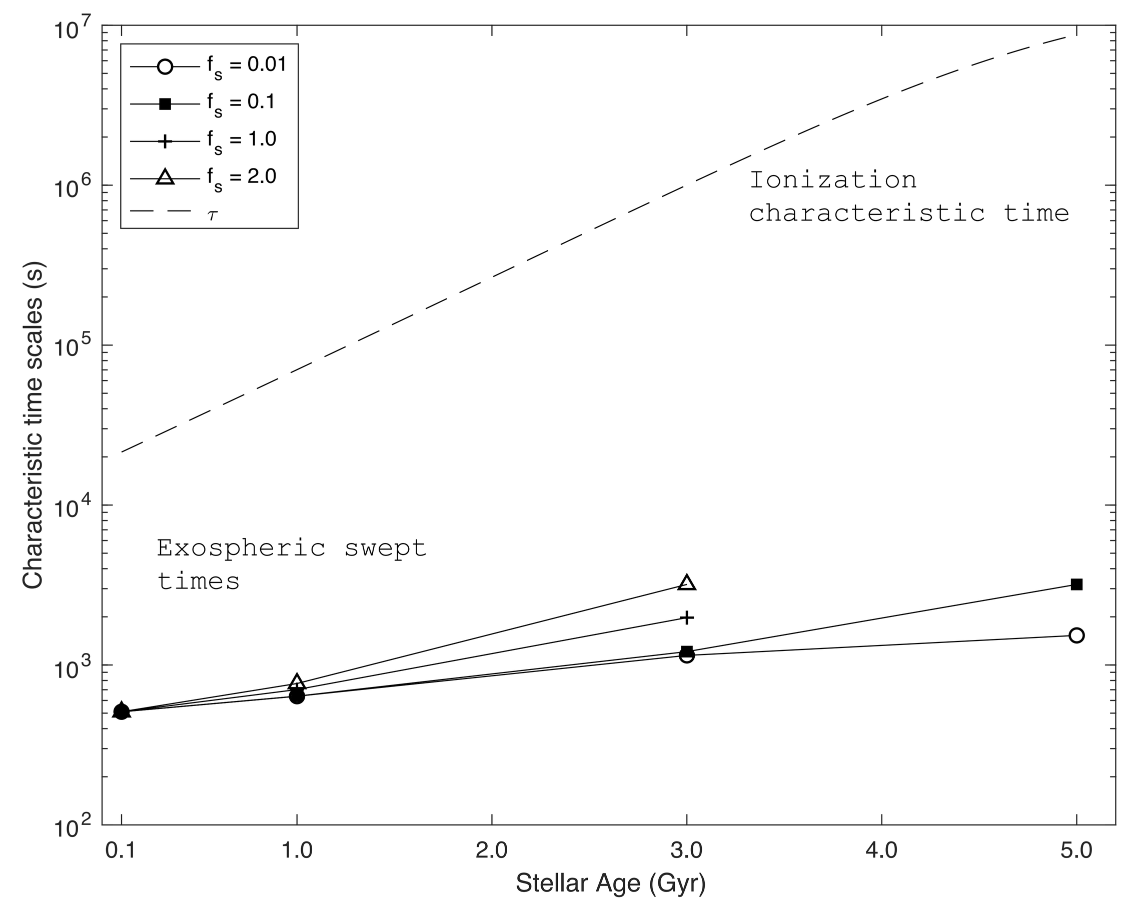
Characteristic magnetic/dynamical structures around the planet:





Conclusions

- Earth-like exospheres are swept in very short timescales, below the characteristic time of ionization τ.
- For planets orbiting very young stars, the ionized material of the exosphere is completely lost independently of the initial H density.
- Planets around more evolved stars, where ionization of the exosphere is not complete, lose their exospheres in longer timescales, showing a dependence with the initial H density.
- The latter will constitute the most promising targets for the **detection of neutral atomic hydrogen**, those being possible cansidates to host water in the lower atmosphere.



References:
[1] Kameda S., Ikezawa S., Sato M., et al. 2017, Geophys. Res. Lett., 44, 11.
[2] Kislyakova K.G., Johnstone C.P., Odert P., Erkaev N.V., Lammer H., et al. 2014. Stellar wind interaction and pick-up ion escape of the Kepler-11 "super-Earths." *Astron. Astrophys.* 562:A116.
[3] Mignone A., Bodo G., Massaglia S., et al. 2007. Pluto: A numerical code for computational astrophysics. *The Astrophysical Journal Supplement Series*, 170:228– 242.

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