Stellar and interplanetary ingredients for extreme habitability

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1. Short Summary

Planetary habitability crucially depends on the evolution of the host star, in particular its rotational evolution and the consequent long-term changes of its magnetic activity, wind, and high-energy radiation. We present calculations of this non-unique stellar evolution and present simulation results for atmospheric erosion on planets.

2. Evolution of Stellar Rotation, High-Energy Radiation and Winds

Planetary habitability requires conditions that are to a large extent determined by the stellar and planetary environments. A stable atmosphere and conditions allowing for the long-term presence of liquid water are among the most important prerequisites for habitability. Atmospheres are processed by a wide range of stellar radiative and particle output, many of them resulting from stellar magnetic activity which in turn is a result of a rotationally driven internal dynamo. To understand the pathways of a planet toward habitability, a full understanding of the co-evolution of the planetary atmosphere and stellar radiative output is required. In the early times of a planetary system, however, extreme conditions may prevail due to elevated stellar activity. This period coincides with the formation of planetary crusts, water oceans, and outgassed atmospheres, all setting the stage for future habitable conditions. Similar extreme conditions may prevail for long times in the habitable zones of lower-mass stars such as M dwarfs.

We present results from a large project devoted to the study of the long-term evolution of star-planet systems, with a focus on the early phases of planetary and stellar evolution. We first discuss the stellar spin-down behavior and the resulting - non-unique - stellar radiative and wind history in the pre-main sequence and the main-sequence phase; as Fig. 1 shows, different initial stellar rotation rates (after the disk phase) lead to dramatically different spin-down behavior and consequently largely different evolution of the crucial high-energy radiation (X-ray, extreme ultraviolet, ultraviolet; [1]).

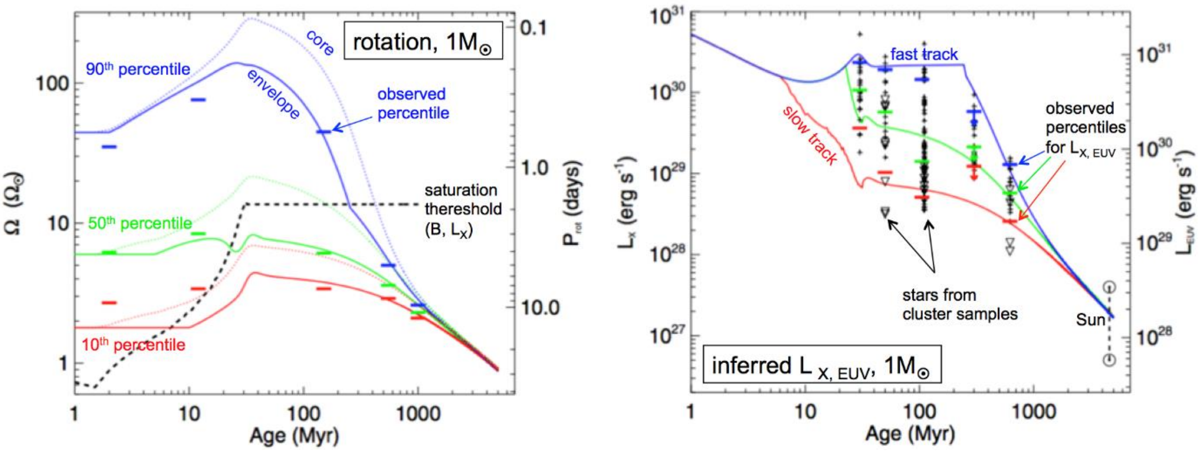

Figure 1: We show the non-unique evolution of the rotation rate Ω and inferred luminosities $L_{X,EUV}$ for a $1M_{\odot}$ star from the end of the disk phase to the end of the main-sequence life ($10^{th}/50^{th}/90^{th}$ percentiles of Ω), together with observed Ω from clusters. Between ~20 and 500 Myr, the X/EUV output scatters by ~an order of magnitude or more depending on the initial Ω [1].

We will show full reconstructions of the short-wavelength spectral irradiance resulting from this evolution. We then discuss the consequences for atmospheric processing, including thermal evaporation and non-thermal escape processes in young planets; results of hydrodynamic calculations for thermal escape ("evaporation") from planets around a solar-type star are shown in Fig. 2 below [2].

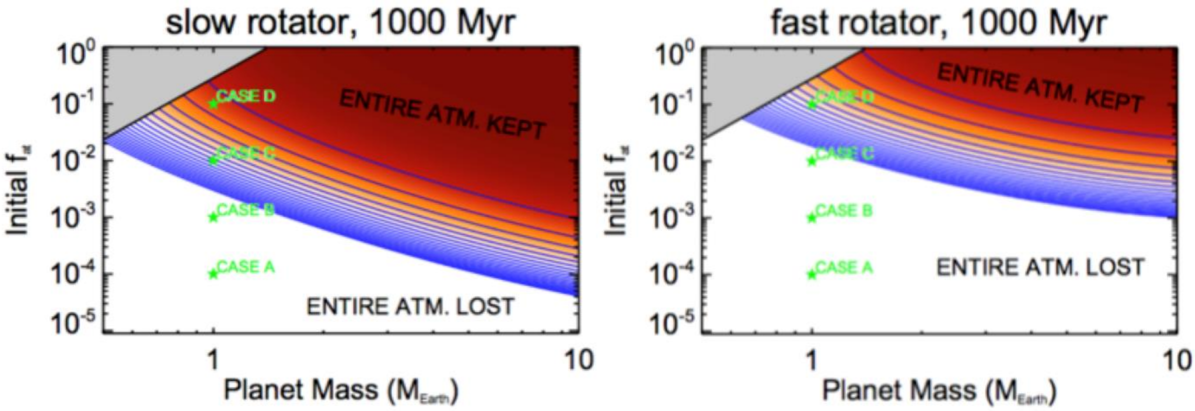

Figure 2: The figure illustrates the loss history of a hydrogen envelope of a planet in the habitable zone of a $1M_\odot$ star. It shows the remaining atmosphere (dark red = 100%) after 1Gyr of *thermal escape*, as a function of planetary and initial atmospheric mass (fraction f_{at} of M_{planet}), for a slowly and a rapidly rotating star in Fig. 1. Order-of-magnitude differences are evident [2].

In this context, we will also discuss the role of extreme conditions such as strong magnetic fields or winds in the early phases of evolution, or close to the host stars. We also mention applications to selected exoplanets and the possible early evolution of solar-system planets.

3. References

[1] Tu, L., Johnstone, C., Güdel, M., and Lammer, H.: The extreme ultraviolet and X-ray Sun in Time: High-energy evolutionary tracks of a solar-like star, A&A, 577, id. L3, 4pp, 2015.
[2] Johnstone, C. P., Güdel, M., Stökl, A., Lammer, H., Tu, L., Kislyakova, K.G., Lüftinger, T., Odert, P., Erkaev, N.V., and Dorfi, E.A.: The Evolution of Stellar Rotation and the Hydrogen Atmospheres of Habitable-Zone Terrestrial Planets, ApJ, 815, id L12, 6pp, 2015.

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