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Ion escape and energetic neutral atom production around EUV exposed, expanded hydrogen-rich upper atmospheres of Earth-like exoplanets

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Abstract

Different scenarios of the early Earth-type hydrogen-rich upper atmospheres and their expected evolution are discussed. Due to the higher EUV flux of the young Sun/stars exoplanets should experience non-hydrostatic states which manifest in an expansion of the dynamically outward flowing upper atmosphere. Outward flowing neutral atoms can interact with the stellar plasma flow. We show that extended hydrogen coronae and/or energetic neutral atoms (ENA) will be produced via charge exchange processes with the stellar wind. Finally we estimate the non-thermal ion loss rate and stellar wind erosion of the hydrogen envelopes.

1. Introduction

Recent studies [1, 2, 3, 4] showed that enhanced solar/stellar X-ray, SXR and EUV radiation in combination with plasma outflows will heat and expand the thermosphere-exosphere region of terrestrial planets to several planetary radii. Under such conditions the intrinsic magnetic field can not protect the upper atmosphere so that large erosion rates can be expected during the early phase of their evolution. In such a case, the upper atmosphere expands beyond the magnetopause where huge energetic neutral atom (ENA) hydrogen-clouds are produced via charge exchange with the incoming stellar plasma flow [5, 6]. In this study we present results of hydrogen-ENA cloud modeling around non-hydrostatic hydrogen-rich Earth-type planetary thermospehres, which are exposed to various EUV flux levels of their host stars. As a consequence of the stellar wind plasma interaction we discuss also the estimated atmospheric loss rates and the implication for atmosphere evolution and habitability.

2. Why H-rich thermospheres?

Terrestrial planets such as the Earth are formed via collisions between planetary embryos and by accumulation of planetesimals in the presence of the primordial solar/stellar nebula gases. At this early formation stage young terrestrial planets are surrounded by massive primordial gas envelopes which are mainly composed of hydrogen and helium [5]. Examples may be:

- dense hydrogen envelopes which remained from the primordial nebulae;
- hydrogen-rich thermospheres produced via dissociation of CH_4, NH_3 and H_2O molecules;
- ocean planets or planets which evaporate their initial H_2O reservoir;
- evaporation of H_2O oceans due to cometary or asteroid impacts.

The removal time of such hydrogen envelopes depends on the amount of available hydrogen, the SXR, EUV flux and plasma environment of the young host star. By considering these facts, one can expect that hydrogen-rich upper atmospheres may be a common scenario at younger terrestrial planets during tens or hundreds of Myr after their origin.

3. Model

For the simulation of extended hydrogen coronae around Earth-type test planets we apply the stellar wind-upper atmosphere test particle and Monte Carlo models, described in [5] and [6] to an assumed Earth-size test-planet around an orbits within a HZ at about 0.17 AU of an M-star (GJ 436-type) with 0.46 solar radii and 0.45 solar mass.

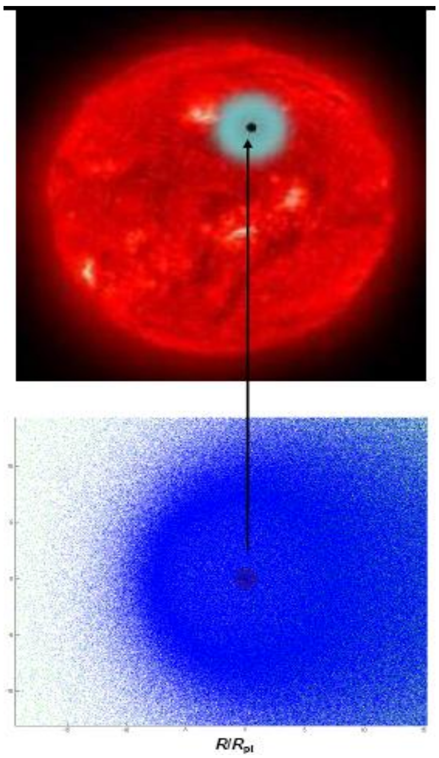

Figure 1: Transiting Earth-type exoplanet with an extended hydrogen atmosphere of $7R_{\mathrm{Earth}}$ and a simulation of an extended hydrogen corona around an Earth-size planet with an expanded (after [5])

6. Summary and Conclusions

Our study shows that the habitable zones of M-type stars are very close to their host stars, so that the influence of strong stellar plasma environments on non-hydrostatic dynamically expanding hydrogen-rich thermospheres of terrestrial planets results in larger stellar wind - atmosphere interaction areas, and no direct protection of intrinsic magnetospheres. Depending on the stellar EUV flux we found that the huge hydrogen ENA-clouds can be produced. Until these hydrogen envelopes are eroded by the stellar wind plasma flow heavier atoms and molecules which populate the atmosphere in deeper layers are protected from high non-thermal escape rates.

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References

[1] Tian, F., Toon, O. B., Pavlov, A. A., De Sterck, H., A.: Hydrogen-rich early Earth atmosphere, Science, 308, 1014–1017, 2005.

[2] Tian, F., Kasting, J.F., Liu, H., Roble, R.G.: Hydrodynamic planetary thermosphere model: 1. The response of the Earths thermosphere to extreme solar EUV conditions and the significance of adiabatic cooling, J. Geophys. Res., 113, doi:10.1029/2007JE002946, 2008.

[3] Lammer, H., Kasting, J.F., Chassefi`ere, E., Johnson, R. E., Kulikov, Yu. N., Tian, F.: Atmospheric escape and evolution of terrestrial planets and satellites, Space Sci. Rev., 139, 399-436, 2008.

[4] Lichtenegger, H. I. M., Lammer, H., Grießmeier, J.-M., Kulikov, Yu. N., von Paris, P., Hausleitner, W., Krauss, S., Rauer, H.: Aeronomical evidence for higher CO_2 levels during Earth’s Hadean epoch, Icarus, 210, 1–7, 2010.

[5] Lammer, H., Eybl, V., Kislyakova, K. G., Weingrill, J.,Holmström, M., Khodchenko, M. L., Kulikov, Yu. N., Reiners, A., Leitzinger, M., Odert, P., Xian Grüß, M., Dorner, B., Güdel, M., Hanslmeier, A.: UV transit observations of EUV-heated expanded thermospheres of Earth-like exoplanets around M-stars: Testing atmosphere evolution scenarios, Astrophys. Space Sci., DOI 10.1007/s10509-011-0646-5, 2011a.

[6] Lammer, H., Kislyakova, K. G.,Holmström, M., Khodachenko, M. L., Grießmeier, J.-M.: Hydrogen ENA-cloud observation and modeling as a tool to study star-exoplanet interaction, Astrophys. Space Sci., DOI 10.1007/s10509-011-0604-2, 2011b.