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On the stability of nitrogen-rich atmospheres of terrestrial exoplanets

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Abstract

The escape of atmospheric constituents from a planetary atmosphere is strongly connected to the radiation and particle environment of the host star and its evolution. At Earth, the most efficient heating processes in the thermosphere are the collisions between electrons and ions that are created by photoionization of atmospheric neutrals. Therefore, the most important wavelength range relevant for heating is the EUV radiation at wavelengths $\leq$ 90 nm which can ionize CO_2, CO, N_2, and O.

According to recent simulations of the Earth's nitrogen-rich thermosphere [1] , the temperature of the upper atmosphere is not expected to rise above 7000 - 8000 K even under extreme solar EUV conditions. When the solar EUV flux exceeds some critical value, the upper thermosphere starts cooling due to adiabatic expansion which results in a decrease of the exobase temperature. Under these extreme solar conditions, which may have prevailed in our solar system during the first billion year after the formation of the Earth, the exobase may expand above the magnetopause and the magnetosphere will not be able to protect the upper atmosphere against strong non-thermal erosion by the solar wind.

At dwarf stars (like M-stars) the period of extreme stellar wind and radiation may have lasted even longer. We therefore discuss whether a terrestrial exoplanet orbiting about an active dwarf star can maintain an earth-like nitrogen-rich atmosphere. Our results suggest that even a substantial amount of cooling species like CO2 being present in the thermosphere over the entire periode of extreme stellar conditions might not be sufficient to prevent the nitrogen from being completely lost.

Figure 1 displays the subsolar/substellar magnetopause distance for two different magnetic moment evolution scenarios (grey and dotted area) as a function of the stellar EUV flux. The short-dashed, dashed and dashed-dotted lines represent the exobase altitude for three different amounts of CO2 in the atmosphere. As can be seen, even for a CO2-rich atmosphere (96% CO2) the exobase will extend beyond the magnetopause for EUV fluxes 30-40 times the present one and will thus be subject to strong stellar wind erosion.

We therefore conclude that the likelihood for the existence of earth-like planets orbiting M-stars with an atmospheric composition similar to that of the present-day Earth may be greatly reduced. This will have important consequences for the habitability of earth-like exoplanets in M-star systems.

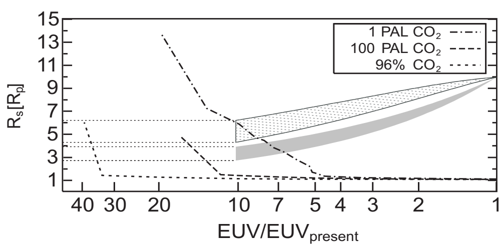

Figure 1: Subsolar magnetopause distance for two different evolution models (dotted and grey area) of the planetary magnetic moment. The width of the areas arises from uncertainties in the evolution of the solar wind density. The short-dashed line represents the extension of the planetary exosphere for a CO_2-dominated atmosphere, the dashed line corresponds to a present-day atmosphere with 100 Present Atmospheric Level (PAL) CO_2, and the dashed-dotted line represents the exobase altitude for a present-day (1 PAL) atmosphere [2]. The values are given in planetary radii from the planetary center.

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References

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

[2] Kulikov, Yu.N., Lammer, H., Lichtenegger, H.I.M., Penz, T., Breuer, D., Spohn, T., Lundin, R., Biernat, H.K.: A comparative study of the influence of the active young Sun on the early atmospheres of Earth, Venus and Mars, Space Sci. Rev. 129, 207–243, doi:10.1007/s11214-007-9192-4, 2007.