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Energetic neutral atom modeling as a tool for upper atmosphere structure characterization

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Abstract

For the analyzing stellar plasma flows around planetary magnetospheres Energetic Neutral Atom (ENA) imaging have become an important remote-sensing tool in planetary science. ENAs are produced whenever solar- or stellar wind protons interact via charge exchange with a neutral particle from an upper atmosphere of a planetary body. In this study we discuss how these observations together with numerical models can be used for the investigation of the upper atmosphere structure of exoplanets, the magnetospheric shape and stellar wind properties. In this study we focus on hydrogen-dominated upper atmospheres of the exoplanets of various types.

1. Introduction

Energetic neutral atoms can be produced due to following reaction:

$$H^+_{sw} + H_{pl} \rightarrow H^{ENA}_{sw} + H^+_{pl} \qquad (1)$$

Depending on the main upper atmospheric constituents, other reactions of the same type with another species may also take place. In this process an electron is transferred to the stellar wind proton turning it into a neutral hydrogen atom. After the transformation to an energetic neutral hydrogen atom, the particle will no longer be affected by electric or magnetic fields and will continue to travel along its path with the energy of the proton. A great advantage of ENAs is that their observation can provide global images of a stellar wind plasma flow around an exoplanet. ENA observations combined with modeling can thus provide information about the stellar wind plasma properties, non-thermal ion escape from the planet's exosphere and its magnetic field. For simulating the production of ENAs magnetohydrodynamic plasma flow models or particle flow models in combination with aeronomical models can be applied.

1.1. ENA observational possibilities

The observational method may be similar to that applied by [1] who observed the transiting hydrogen-rich gas giant HD 209458b with the HST STIS-instrument and discovered a several percent intensity drop in the stellar L-α line which was larger than for an atmosphere of a planet occulting only 1.5% of the star. From this observation one can suggest that the upper atmosphere of HD 209458b is expanded up to $\approx 4.3R_{Jup}$ (e.g., [1]). Similar transit observations of extended hydrogen atmospheres or non-hydrostatic upper atmospheres in general around terrestrial exoplanets should be observable if the planet orbits around M-type dwarf stars [2].

2. ENA modeling

The main modeling parameters used in simulations are summarized in Table 1 where D is the orbital distance, R_{pl} the planetary radius, M_{pl} the planetary mass, T_{exo} and d_{exo} the exobase temperature and density respectively, v_{sw}, d_{sw} and T_{sw} are stellar wind velocity, density and temperature. R_{ib} stands for inner boundary radius where the simulation starts. The details about the code used for modeling can be found in [3], [4] and [2]. Fig.1 illustrates the modeling results for the «Hot Jupiter» HD 209458b.

Result of ENA cloud modeling of stellar wind plasma interaction around an Earth-like planet with a H-rich thermosphere is presented in Fig.2. The planet is exposed to a 10 times larger EUV flux compared to that of the Sun and is located inside the habitable zone (HZ) at 0.24 AU of an M-star with a mass of 0.45 solar masses. On both Fig.1 and Fig.2 the yellow points represent the slow planetary neutral hydrogen atoms moving with the velocities < 10 km/s, green points represent the stellar wind protons while the blue and red points represent ENAs moving away and towards the star, respectively. The dashed line shows the mag-

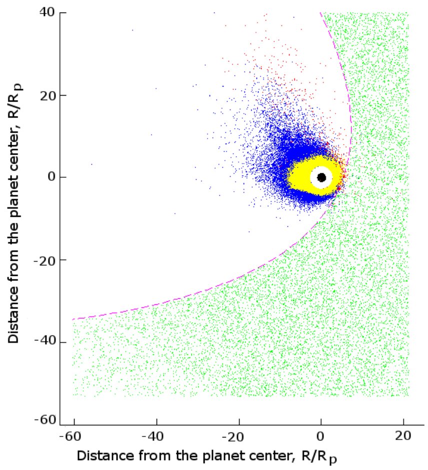

Figure 1: Resuls of ENA cloud modeling around the «Hot Jupiter» HD 209458b.

netic obstacle. As one may see, in the case of an terrestrial planet as well as in the case of the «Hot Jupiter» HD 209458b a corona conisisting of energetic neutral hydrogen forms around the planet.

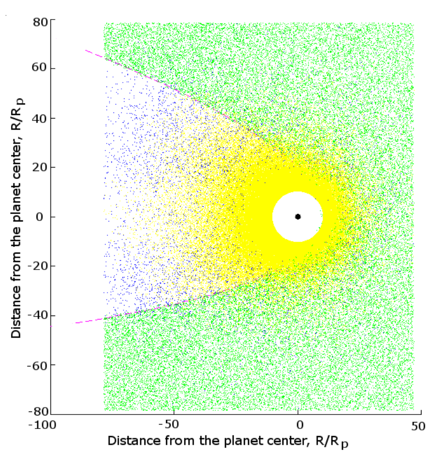

Figure 2: Resuls of ENA cloud modeling around an Earth-like H-rich planet orbiting an M-star.

3. Summary and Conclusions

It is expected that terrestrial planets with huge hydrogen envelopes orbiting dwarf stars should be observable during the transits by space telescopes in the L-α line. Observations of Earth-size bodies or super-Earths with this type of upper atmosphere would be strong evidence that hydrogen coronae which may have remained from the protoatmospheres of the particular planet may play a significant role in the protection of the lower atmosphere and species like nitrogen from enhanced EUV fluxes and stellar wind erosion.

Table 1: Modeling parameters used in the simulations shown in Fig. 1 and 2.

Parameter	HD 209458b	M-star, 10 EUV
D	0.047 a.u.	0.24 a.u. (HZ)
R_{pl}, m	9.54×10^7	6.37×10^6
M_{pl}, kg	1.21×10^{27}	5.97×10^{24}
R_{ib}, m	2.7×10^8	6.6×10^7
T_{exo}, K	8000	485
d_{exo}, m^{-3}	4.0×10^{13}	4.85×10^{10}
v_{sw}, km/s	140	330
d_{sw}, m^{-3}	3.0×10^9	2.5×10^8
T_{sw}, K	10^6	10^6

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