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On the transit Lyα observations of terrestrial planets in the habitable zones of M dwarfs

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Abstract

We study the transit signatures in the Lyman-alpha (Lyα) line of a putative Earth-sized planet orbiting in the habitable zone (HZ) of GJ 436. We estimate the transit depth in the Lyα line for an exo-Earth with three types of atmospheres: a hydrogen-dominated atmosphere, a nitrogen-dominated atmosphere, and a nitrogen-dominated atmosphere with an amount of hydrogen equal to the one of the Earth. We use out-of-transit observations of GJ 436 to study the calculated absorption.

1. Introduction

Lyα transit observations are a very important tool to study exoplanetary atmospheres. GJ 436 hosts a transiting Neptune-sized planet GJ 436b which has been observed in the Lyα line and revealed a very deep transit in this line, indicating a presence of a dense hydrogen envelope surrounding the planet [1]. Our aim is to check if a terrestrial planet in the HZ of an M star like GJ 436 can create observable signatures in the Lyα line in transit. To do so, we perform atmospheric modeling using Direct Simulation Monte Carlo (DSMC) code and then calculate Lyα absorption.

2. The model

We use a 3D DSMC code to model the extended atomic coronae of exoplanets. The code allows to track different species (up to 7 to date) as well as the interactions between species, and is able to handle different weights of the atomic metaparticles. The code is suitable for modeling of the rarefied planetary exospheres. The species are allowed to charge exchange with stellar wind protons as well as being photo- and electron impact ionized and collide with each other. The main processes and forces included for an exospheric atom are:

1. For hydrogen atoms: collision with a UV Lyα photon which defines the velocity-dependent radiation pressure. In this study, we consider relatively thin hydrogen envelopes. For this reason, self-shielding, i.e., optical depth in Lyα is not included. For non-hydrogen atoms, radiation pressure is not included.
2. Charge exchange with a stellar wind proton.
3. Elastic collision with another neutral atom.
4. Ionization by stellar photons or wind electrons. While being very important for hot Jupiters, in the HZ electron impact ionization is not significant due to a much less denser wind.
5. Gravity of the star and planet, centrifugal, Coriolis and tidal forces.

The code has been previously successfully applied to modeling of hydrogen-dominated atmospheres (e.g., [2]).

3. Modeling results

Fig. 1 presents our modeling of atomic coronae around a putative Earth-sized, Earth-mass planet orbiting in the HZ of GJ 436. The simulations are performed for three types of atmospheres: a hydrogen dominated atmosphere (left), a nitrogen dominated atmosphere with an additional hydrogen exospheric density equal to hydrogen density in the Earth's exosphere (center), and a fully nitrogen dominated atmosphere with no additional hydrogen content (right).

4. Summary and Conclusions

According to our results, only hydrogen-dominated atmospheres can be detected in the Lyα line for the quality of observations similar to out-of-transit observations of GJ 436. This indicates that secondary (non-

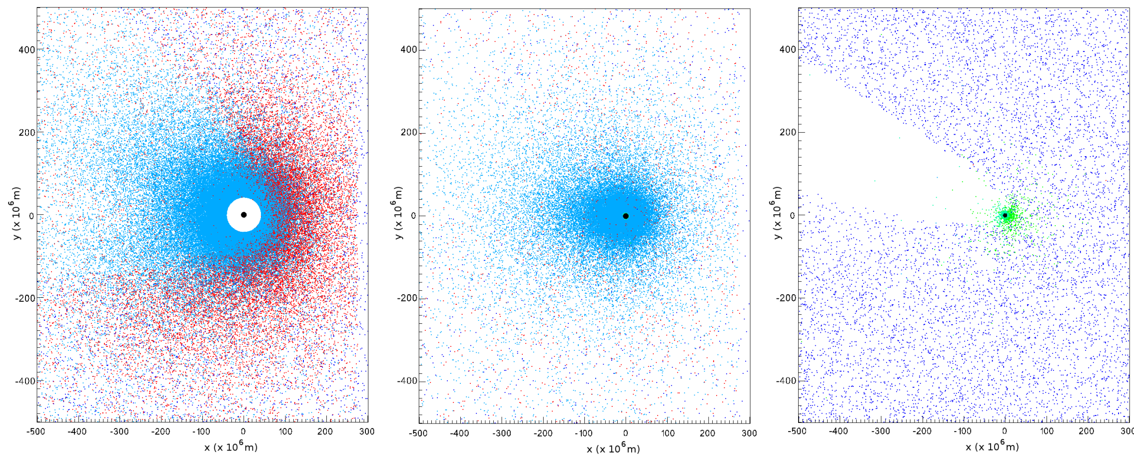

Figure 1: Illustration of modeled 3D atomic hydrogen coronae. Presented is a slice of modeled 3D domain for $-10^6 < z < 10^6$ m. Left: hydrogen-dominated atmosphere. Middle: nitrogen-dominated atmosphere with Earth-like hydrogen content. Right: fully nitrogen-dominated atmosphere. All dots show simulated metaparticles of the exosphere of a planet. The dark blue dots symbolize stellar wind protons, the light blue dots are the neutral atmospheric hydrogen particles, the green dots are neutral nitrogen atoms and ionized planetary N+. The red dots are ionized planetary hydrogen atoms (H+ of planetary origin). The black dot in the center of each plot is the planet, the white area around it is the lower atmosphere which is not simulated. For nitrogen-dominated atmospheres, the lower atmosphere is very close to the planetary surface, so that the white area is not visible on the plots due to scalings. The star is on the right, and the stellar wind is coming from the right side.

hydrogen dominated) atmospheres can be more effectively studied by other means. The results are being prepared for publication [3].

Acknowledgements

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References

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