EPSC Abstracts
Vol. 5, EPSC2010-749, 2010
European Planetary Science Congress 2010

Energetic Neutral Atoms in Planetary Systems

M. Holmström
Swedish Institute of Space Physics, Kiruna, Sweden (matsh@irf.se),

Abstract

We review observations of energetic neutral atoms (ENAs) in the Solar System. This is done with a focus on the populations that could be remotely observed in other stellar system, and we present how Lyman-alpha (Ly-a) observations of transiting extrasolar planets could detect ENAs near these planets. We also discuss the problems and uncertainties in interpreting such transit spectra. Finally, we conclude with an outlook to future observations, and possible directions in modeling.

1. Energetic Neutral Atoms

Energetic neutral atoms (ENAs) are produced wherever energetic ions meet a neutral atmosphere. By energetic we mean that the ions have a much greater velocity than the thermal velocities of the exospheric neutrals. During the charge exchange process, an electron is transferred from the neutral to the ion, resulting in a neutral atom and an ionized neutral. Due to the large relative velocities of the ions and the exospheric neutrals, the momenta of the individual atoms are preserved to a good approximation. Thus, the produced ENAs will have the same velocity distribution as the source population of ions [1]. This enables remote characterization of the interaction between planets and stellar winds.

2. Solar System ENAs

In particular, when the solar wind encounters the exospheres of the planets in the solar system, ENAs will be produced, and such solar wind ENAs have been observed in-situ at every planet in the solar system where detectors has been available — at Earth [2], at Mars [3], and at Venus [4]. Also, ENAs are produced in the heliosheet [5], and are present as the neutral component of the solar wind [6]. Recently it was discovered that also the Moon produces ENAs by reflecting solar wind protons as energetic neutral hydrogen atoms [7].

3. Planetary System ENAs

As solar wind ENAs have been observed at every planet in the solar system where ENA instrumentation has been available, the production of energetic neutral atoms from charge exchange between solar wind protons and neutral hydrogen should also occur at extrasolar planets. Since these hydrogen ENAs have velocities on the order of stellar wind velocities, up to a few 100 km/s, they will scatter Ly-a photons emitted by the parent star. This is the basis for using transits of extrasolar planets to remotely detect the presence of ENAs associated with the planets. The difference between the in-transit and out-of-transit Ly-a spectra will be due to scattering by ENAs. Additional information comes from the time variation of the absorption spectra. An advantage of such transit observations is that no modeling of the star's Ly-a spectrum, or of photon scattering, away from the planet is needed.

3.1. Ly-a Transit Observations

The only published high resolution Ly-a transit spectra are from HD 209458b [8], and there has been a debate in the literature on the interpretation of these spectra. It has been suggested that they show the thermal escape of hot hydrogen [8]. Another possibility is that natural broadening of the spectra is responsible, and the hydrogen is not escaping [9]. A third interpretation is that the observed hydrogen are ENAs [10] (see Fig. 1), and that the observation does not constrain the state of the exosphere, but can instead provide information on the stellar wind, and the magnetization of the extrasolar planet [11]

4. Summary and Conclusions

What is the way forward? Further Ly-a observations of transiting exoplanets are needed to resolve outstanding questions. Of particular importance is the time variation of the absorption spectra, during a transit, and between transits. Another key question is if the asymmetry between the red and blue part of the observed spectra is real, i.e. are there hydrogen atoms moving toward the star?

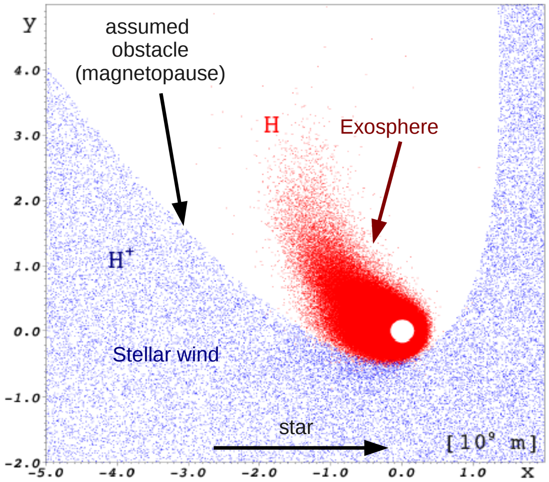

Figure 1: A model flow of solar wind protons and the hydrogen exosphere cloud seen from above in the direction of the negative z-axis (perpendicular to the orbital plane). Each point corresponds to a neutral hydrogen (red), or a proton (blue) meta particle. The circle without particles correspond to the inner boundary of the simulation, and the large area without protons corresponds to the assumed obstacle to the stellar wind. Part of the hydrogen cloud are ENAs. See [10, 11] for further details.

In terms of modeling, [12] argues that a multi-dimensional plasma model that self-consistently includes an ionosphere is needed to study the interaction of the stellar wind with the magnetosphere. However, apart from the modeling and computational complexity, it is not clear if such a model would contribute more knowledge than simply assuming an obstacle, due to the large number of unknown parameters in such a model. Maybe a three-dimensional coupled atmosphere-ionosphere model that includes charge-exchange would be sufficient to study the relative importance of atmospheric H and H-ENAs. Even a simple estimate of acceleration by radiation pressure can put constraints on the relative importance of atmospheric H and H-ENAs.

References

[1] Gruntman, M., 1997, *Rev. Sci. Instrum.*, 68, 3617

[2] Collier, M. R., et al., 2001, *JGR*, 106, 24893

[3] Futaana, Y., et al., 2006, *Icarus*, 182, 413

[4] Galli, A., et al., 2008, *PSS*, 56, 807

[5] Wood, B.E., et al., 2000, *ApJ*, 542, 493

[6] Gruntman, M.A., 1994, *JGR*, 99, 19213

[7] Wieser, M., et al. 2009, *PSS*, 57, 2132

[8] Vidal-Madjar, A., et al. 2003, *Nature*, 422, 143

[9] Ben-Jaffel, L. 2008, *ApJ*, 688, 1352

[10] Holmström, M., et al. 2008, *Nature*, 451, 970

[11] Ekenbäck, A., et al. 2010 *ApJ*, 709, 670

[12] Koskinen, T. T., et al. 2010 *ArXiv*, 1004.1396