Geophysical Research Abstracts
Vol. 16, EGU2014-1165, 2014
EGU General Assembly 2014

Stellar wind interaction and pick-up ion escape of the Kepler-11 “super-Earths”

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We present the results of modeling of the interactions between stellar wind and the extended hydrogen-dominated upper atmospheres of planets and estimate the resulting escape of planetary pick-up ions from the 5 «super-Earths» in the compact Kepler-11 system. We compare the escape rates with the efficiency of the thermal escape of neutral hydrogen atoms. Assuming the stellar wind of Kepler-11 is similar to the solar wind, we used a polytropic 1D hydrodynamic wind model to estimate the wind properties at the planetary orbits. We applied a Direct Simulation Monte Carlo Model to model the hydrogen coronae and the stellar wind plasma interaction around Kepler-11b–f planets within a realistic expected heating efficiency range of 15–40%. The same model was used to estimate the ion pick-up escape from the XUV heated and hydrodynamically extended upper atmospheres of Kepler-11b–f. Modeling clarifies the influence of possible magnetic moments on escape processes and allows to estimate the charge exchange and photoionization production rates of planetary ions as well as the loss rates of pick-up H^+ ions for all five planets. This study presents also the comparison of the results between the five “super-Earths” and in a more general sense also with the thermal escape rates of the neutral planetary hydrogen atoms.

Our results show that for all Kepler-11b–f exoplanets, a huge neutral hydrogen corona is formed around the planet. The non-symmetric form of the corona changes from planet to planet and is defined mostly by radiation pressure, charge-exchange and gravitational effects. According to our estimates, nonthermal escape rates of pick-up ionized hydrogen atoms for Kepler-11 «super-Earths» vary between $\sim 6.4 \times 10^{30}$ s^{-1} and $\sim 4.1 \times 10^{31}$ s^{-1} depending on the planet’s orbital location and assumed heating efficiency. These values correspond to non-thermal mass loss rates of $\sim 1.07 \times 10^7$ $g{\cdot}s^{-1}$ and $\sim 6.8 \times 10^7$ $g{\cdot}s^{-1}$ respectively, which is a few percent of the thermal escape rates.