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Hydrodynamic escape from GJ 1214b atmosphere

WATANABE, Kensuke[1*] ; KURAMOTO, Kiyoshi[1]

[1]Department of Cosmosciences, Graduate School of Sciences, Hokkaido University

The extra-solar planet GJ 1214b discovered in 2009 has a radius 2.7 times the Earth's radius and a mass 6.5 times the Earth's mass, and its mean density is 1.9 g/cm^3 which is a value intermediate between those of rock and ice. Therefore, the GJ 1214b was possibly born as a giant ice planet, and might have acquired a hydrogen envelope during its formation like Neptune. On the other hand, a recent transit observation (i.e. Kreidberg et al., 2014) suggests that GJ 1214b has an atmosphere which consists of gas with high mean molecular weight. This implies that almost all hydrogen has been lost from this planet due to hydrodynamic escape driven by stellar EUV (Extreme Ultra Violet) radiation.

Recently, Lammer et al. (2013) numerically investigated the hydrodynamic escape from GJ 1214b assuming a hydrogen-rich atmosphere under the present EUV flux from the parent star. They obtained an escape rate smaller than 10 % of the observational estimation for HD 209458b, a hot Jupiter surrounded by expanding hydrogen gas (Vidal-Madjar et al., 2003). This result implies that the mass of GJ 1214b little changes through the planet history and the hydrogen envelope, if once acquired, would be maintained at present. However, their numerical solution shows significantly small escape flux compared with the energy-limit escape rate and its reason was unexplained. Their study has heating profile suggesting that incident EUV radiation is almost completely absorbed by the atmosphere before it reaches the bottom of calculation region. However, the total energy absorbed by the entire atmosphere per unit time is an order of magnitude smaller than the total EUV energy supplied to the planet. Thus this study might have a problem with radiative transfer calculation and underestimate the escape rate.

In order to obtain more accurate estimation of escape rate and discuss the effect of hydrodynamic escape on GJ 1214b, we apply a numerical model of the time-dependent, inviscid hydrodynamic equations for a pure atomic hydrogen atmosphere in spherical symmetric geometry with CIP & CIP-CSL2 methods that have high accuracy for mass and energy conservation (modify Kuramoto et al., 2013). We confirm that our model almost exactly satisfies uniformity of mass flux and energy conservation. Given basically the same boundary conditions with Lammer et al. (2013) (the temperature and density at lower boundary are 475 K and 1x10^{19} m^{-3}, respectively, and the incident EUV flux is 470 times the present solar), our model obtains hydrodynamic escape rates approximately 6-10 times larger than those by Lammer et al.'s study.

When we use the reevaluated hydrodynamic escape rate and the EUV flux dependent on the stellar age (Engle and Guinan 2011), the total mass of hydrogen escaped from GJ 1214b through the planet history is as large as approximately 15%-88% of the present planet mass. Therefore the hydrogen envelope of proto-GJ 1214b may have been almost completely lost, which is consistent with the observation suggesting hydrogen-depleted atmosphere. Furthermore, the initial mass of GJ 1214b is possibly as large as 1.15-1.9 times current mass (0.43-0.72 times the present Neptune mass), therefore this planet may have been more similar to Neptune in its mass and bulk composition in the past.

Keywords: Hydrodynamic escape, GJ 1214b