EPSC Abstracts
Vol. 13, EPSC-DPS2019-2031, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Stability of mineral atmospheres on super-Earths against photo-evaporation

Yuichi Ito (1) and Masahiro Ikoma (2)
(1) Department of Physics and Astronomy, University College London, UK (yuichi.ito@ucl.ac.uk), (2) Department of Earth and Planetary Science, The Utniversity of Tokyo, Japan

Abstract

Some super-Earths such as CoRoT-7 b and Kepler-10 b are dense and hot enough that they are likely to be rocky planets with rocky vapor atmospheres on top of magma oceans. We call such an atmosphere a mineral atmosphere. An interesting question is whether mineral atmospheres are stable or not against photo-evaporation in strong stellar UV and X-ray (collectively called XUV, hereafter) environments. Here, we develop 1-D hydrodynamic model of the highly XUV-irradiated mineral atmosphere and, investigate the mass loss rate of its photo-evaporation from a super-Earth. Our model shows that the atmospheric escape occurs by a hydrodynamic/transonic wind. Almost all of the incident XUV energy is converted into the radiative emission of rocky vapors. Due to this, the mass loss rate is very low ($\sim 1 \times 10^{-2}$ $M_{\oplus}$/Gyr), but massive enough to remove completely the major species Na from the atmosphere. We suggest that photo-evaporation of mineral atmospheres affects the planetary mass only slightly, but changes the atmospheric major species on super-Earths.

1. Introduction

Until today, over 1000 exoplanets whose radii are less than 2 Earth radii have been discovered. About half of those planets have substellar equilibrium temperatures high enough to melt and vaporize rock. Thus, if rocky and dry, they likely have atmospheres composed of rocky vapor such as Na, O_2 and SiO [1, 2]. We call such an atmosphere a mineral atmosphere. Also, photo-evaporation would have played a key role in the evolution of the mass and composition of these planets since they are highly irradiated by stellar XUV. So far, hydrodynamic simulations of photo-evaporation have been done for hydrogen-rich and volatile-rich atmospheres [3], suggesting such atmospheres would be lost from close-in small planets. On the other hand, there have been no detailed theoretical studies of the escape of the mineral atmosphere, although a hot rocky exoplanet could evolve greatly through loss of planetary mass and atmospheric species if the mineral atmosphere undergoes massive escape [1, 4].

2. Model

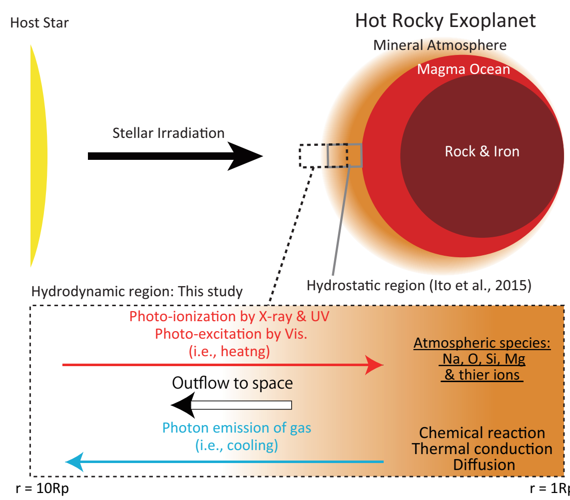

Figure 1: Schematic illustration of the hot rocky exoplanet (upper panel) and processes considered in this study (lower panel). Note that we explore only the hydrodynamic part of the mineral atmosphere and give the lower boundary conditions according to the hydrostatic model [2].

We have constructed an 1-D hydrodynamic model of the highly UV-irradiated mineral atmosphere at a sub-stellar point, including molecular diffusion, thermal conduction, photo-/thermo-chemistry, XUV heating and radiative line cooling. We assume Na, O, Si, Mg, their ion and electron as gas species in the model atmosphere and give the lower boundary conditions according to the hydrostatic model [2], as illustrated in Fig. 1. Using this model, we determine the outflow structure and mass loss rate of the mineral atmosphere on a hot rocky super-Earth with mass of 3 $M_\oplus$ and an orbit of 0.02 AU during the early stage of a host G-type star with a high UV flux.

3. Results and discussions

Our simulation shows that the atmospheric escape occurs by a hydrodynamic/transonic wind. Then, the atmospheric motion is driven by only 0.02 % of the incident XUV energy since the radiative emission of rocky vapors such as Na and Mg effectively releases the XUV energy into space. The corresponding mass loss rate is very low ($\sim 1 \times 10^{-2}$ $M_\oplus$/Gyr), indicating that such a planet survives photo-evaporation. The result is consistent with the detection of several hundred close-in exoplanets whose radii are less than 2 Earth radii.

On the other hand, the mass loss rate is massive enough to remove completely the major species Na and also K from the atmosphere. This is because Na and K are minor components in rocks (~ 0.1 wt% in bulk silicate Earth) but are the major species in mineral atmospheres [1]. Therefore, the detection of the presence or absence of Na and K in mineral atmospheres would give a chance toward characterizing hot rocky super-Earths and the escape processes of mineral atmospheres.

References

[1] Schaefer, Laura and Fegley, Bruce 2009, Astrophysical Journal, Vol 703, L113-L117

[2] Ito, Y. and Ikoma, M. and Kawahara, H. and Nagahara, H. and Kawashima, Y. and Nakamoto, T. 2015, Astrophysical Journal, Vol 801, 144

[3] Tian, Feng 2015, Annual Review of Earth and Planetary Sciences, Vol. 43, 459-476

[4] Valencia, D. and Ikoma, M. and Guillot, T. and Nettelmann, N. 2010, Astronomy & Astrophysics, Vol. 516, A20