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Evolution of terrestrial planets with water loss

KODAMA, Takanori[1*], GENDA, Hidenori[1], ABE, Yutaka[1], Zahnle, Kevin[2]

[1]The University of Tokyo, [2]NASA Ames Research Center

Liquid water on the planetary surface is thought to be important for the origin and evolution of life. The region from the central star where liquid water is stable in the planetary surface has been called the habitable zone (HZ). Kasting et al. (1993) [1] estimated the width of the HZ around various types of the main sequence stars for Earth-like planets (called aqua planet). The width of the HZ is located between 90% and 110% of the incident solar radiation that the present Earth receives.

Abe et al. (2011) [2] considered a hypothetical planet with very small amount of water (called land planet). On a land planet, the water circulation is limited in the atmospheric circulation. The distribution of ground water is determined by the local balance between precipitation and evaporation. Using the general circulation model (GCM), they estimated the inner and outer edges of the HZ. They found that the width of the HZ for a land planet is located between 77% and 170% of the incident solar radiation that the present Earth receives. This result means that the width of the HZ for land planets wider than that for aqua planets. They proposed a new planetary evolution pathway on their study. It is the evolution from the aqua planet to the land planet by water loss. However, this planetary evolution pathway has not been discussed in detail.

These two studies indicated that the amount of water on the planetary surface is important to habitability of the planet. We focus on the evolution of water content on the planet by considering the water loss and discuss the evolution from the aqua planet to the land planet.

Using numerical model, we calculate the evolution of water content on the planetary surface and discuss the evolution from the aqua planet to the land planet. We use the hydrodynamic escape model [3,4] as a water loss mechanism considering the time-dependent stellar evolution [5,6,7] and treat the initial amount of water, the distance from the central star, the mass of the central star and the mass of the planet as a parameter to offer suggestion to observations of extrasolar terrestrial planets.

There are two important timescales for the evolution from the aqua planet to the land planet. One is the timescale of loss of ocean by water loss and another is the timescale of increasing of radiations from the central star. If the former is shorter than the later, the aqua planet evolves to the land planet. When the aqua planet with the Earth mass around the star like Sun and its orbital radius is 0.75 [AU], the boundary of the initial amount of water is 0.15-ocean mass (1 ocean mass is the present ocean mass of Earth). The aqua planet evolves to the land planet if the initial amount of water is less than this boundary.

Extrasolar planets that have been observed have various masses and orbit around various types of stars. In general, stars with low mass relative to the Sun are dim and the evolution of them is slow. Planets with a mass higher than Earth have a strong gravity relative to Earth. It is mean that super-earths around stars with low mass hard to evolve from the aqua planet to the land planet. However, the habitable duration of a planet that evolved to the land planet is longer than that of a planet that was considered on the classical HZ. This result means that the number of sample of habitable extrasolar planet by observations increases.

Reference

[1] Kasting, J. F., Whitmire D. P., and Reynolds, R. T. (1993). Icarus, 101, 108-128.

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