Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS21-P07 Room:Convention Hall Time:May 22 17:15-18:30

Long-term Evolution of Surface Environment on Extrasolar Planets with Carbonate-Silicate Geochemical Cycle

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Surface environment of extrasolar terrestrial planets has been discussed in terms of presence of liquid water. Kasting et al. (1993), for example, estimated habitable zone (HZ) in which the planets are able to have liquid water on its surface. They found that the inner and outer limits of HZ are 0.95 and 1.37 AU, respectively. They also considered the change of HZ due to stellar evolution, and suggested that HZ moves outward and diminishes with time. In their study, sufficient amount of greenhouse gas is assumed, but it has not been verified quantitatively.

We investigate the conditions where planets hold liquid water, considering their surface temperature and the amount of greenhouse gas. Surface temperature is estimated with one-dimensional energy balance model (North et al. 1981; Williams & Kasting, 1997; etc.). The greenhouse gas is assumed to be CO_2, and its amount in the atmosphere is controlled by carbonate-silicate geochemical cycle, in which degassing rate is given and chemical weathering rate depends on surface temperature and partial pressure of CO_2.

The results show that, with the degassing rate as much as that at present Earth's value, planets can avoid snowball mode until 1.05 AU from the central star. This limit may be much narrower than the one estimated from previous studies. However, if the degassing rate of CO_2 is higher, the outer limit moves outward farther from the central star. Under such condition, a planet has higher partial pressure of CO_2, which makes meridional temperature distribution much uniform, resulting in shrink of partial ice cap.

The degassing rate of CO_2 becomes lower with time. In order to examine such effect, we consider thermal evolution of the planet (Tajika & Matsui, 1992) and consider on the long-term stability of surface climate.

Keywords: extrasolar planet, carbonate-silicate geochemcal cycle, EBM