P036-005 Room: C401 Time: May 27 14:18-14:30

Evolution of obliquity of a terrestrial planet due to gravitational perturbations by a giant planet

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We have numerically investigated time evolution of the obliquity (the angle of the spin axis relative to the orbital plane) of a terrestrial planet, considering a system of a central star, the terrestrial planet and a giant planet. We study the basic process of the obliquity change and also try to apply the results to extrasolar planetary systems as well as our Solar system.

The obliquity of the terrestrial planets in the Solar system could have experienced large, chaotic variation (Laskar & Robutel 1993). Laskar & Robutel (1993) investigated the evolution of the obliquity of planets through orbit-averaged equations for eight planets (except Pluto) in the Solar system and suggested that the chaotic variation of the obliquity is induced by the resonance between the precession of the spin axis and change in the orbital plane. The change of spin axis orientation of the planet would influence global climate of the planet through change in solar insolation.

In this study, in order to clarify the evolution process of the obliquity in more general, we study a system containing a central star, a hypothetical terrestrial planet and a hypothetical giant planet in wide parameter ranges, and calculate the evolution of the obliquity of the terrestrial planet. We perform three different calculations: (1) numerically integrating the Eular equation for a rigid body rotation with orbital evolution of the planets by N-body simulation, (2) numerically integrating the orbit-averaged Eular equation with secular perturbations of orbits that are derived by analytical formula, and (3) calculating the first order solution to the equation in (2) with the assumption of small orbital inclination. We compare the results of the calculations and discuss the limit of the approximate methods of (2) and (3). Furthermore, we investigate the behavior of the obliquity near a resonance in detail such as the resonance width and the amplitude of the obliquity oscillation.

Applying the above results to extrasolar planetary systems, we also discuss 'habitability' of terrestrial planets in the extrasolar planetary system. Many giant planets have been found around nearby solar-like stars outside our Solar System. In a system with a giant planet with relatively large semi major axis, Earth-like planets (small rocky planets) may exist inside the orbits of the giant planet. For life to exist in such a Earth-like planet, the planet may need to have not only H2O ocean but also obliquity with small variation to keep the climate stable. We discuss the mass and orbit of a giant planet that allows a planet with obliquity with small variation in a region where H2O ocean can exist.