GAS CAPTURE OF OUTER JOVIAN PLANETS – CRITICAL MASS FOR CORE INSTABILITY Sho Sasaki, Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ 85721, U.S.A.

The interior of Jovian planets consists of a central core of ice, silicate and metal (10–30M_E) and an outer envelope of hydrogen and helium (1–300M_E). The core was formed by accretion of planetesimals in the solar nebula and the growing core attracted ambient gas to form a primordial solar-type atmosphere. When the core mass exceeded a critical value above which no static solution of the atmosphere should exist, the atmosphere started to collapse onto the core because of its self-gravity [1,2,3]. This process is called core instability. Following rapid inflow of ambient gas would form the present Jupiter [4].

Mizuno [2], calculating the radiative structure of the atmosphere, showed that the critical core mass M_{CR} for the core instability is nearly independent of outer P-T condition and that its value is similar among Jovian planets ($\sim 10\ M_E$) so long as mass accretion rate is the same ($10\ M_E/10^7$yr). This was considered to explain the similar core masses of the present Jovian planets.

However, in Mizuno [2], mass ratio of atmosphere/core is about 0.6 at M_{CR} and much greater than the estimated present small gas ratio (6–11%) of Uranus or Neptune. Moreover, Voyager observation showed that Uranus envelope contains much ice species than expected from the solar abundance; icy materials must have accreted even after the gas capture unless the core material dissolved into the upper envelope efficiently. And a recent calculation of the Uranus structure suggests that the present core should contain hydrogen [5]. These are contradictory to the scenario that the envelope gas was captured after the core mass reached nearly the present size. Another suspect is that actual mass accretion rate $\dot{M}$ of Uranus or Neptune should be much smaller than that of Jupiter. The analytical theory predicts $\dot{M} \propto a^{-3}$ (a being heliocentric distance) [6]: the accretion of Neptune should be 200 times slower than that of Jupiter.

We here propose M_{CR} smaller than than the present core mass assuming slower mass accretion. The early core instability is also proposed on the basis of enhancement of gas molecular weight [7]. We calculated M_{CR} for various $\dot{M}$ using detailed formula of atmospheric opacity by gas species and dust [8]. The accretion rate determines energy flux outflowing through the atmosphere. When the energy flux supporting the atmosphere is small, the atmospheric mass should increase and result in decreasing the critical core mass. Thus, as seen in Figure, increase in typical accretion time τ should decrease M_{CR} . Obtained dependence $M_{CR} \propto \dot{M}^{\,0.20-0.25}$ is smaller than the analytically-estimated $M_{CR} \propto \dot{M}^{\,3/7}$ for constant atmospheric opacity. In the extreme of small $\dot{M}$, M_{CR} should converge at an isothermal result 0.034M_E[9].

The accretion time is restricted by the existence of nebular gas ($\sim 10^7$yr); the permitted area in Figure is the right-hand side of the long-dashed line. Intermittency of planetesimal collision could reduce the energy flux supporting the atmosphere [10] to be 0.1, assuming that released energy from gravitational fractionation between rocky and icy materials should determine the flux; the boundary of the permitted area should shift to be short-dotted line. As a result, the critical core mass becomes 0.5–1$M_E$when dust abundance f is as low as 10^{-4} (low dust abundance is probable at slow accretion since dust production rate is proportional to the mass accretion rate [11]).

The gas capture by Uranus and Neptune protoplanets would take place when their masses were about 0.1 of present planetary masses. The present Uranus and Neptune could be formed by mutual collisions of small gaseous protoplanets or accretion of planetesimals onto a gaseous protoplanet. Stirring of the planetary interior and mixsing with accreting materials at collision could form the present structure, where gas, ice and rocky component are not completely separated.

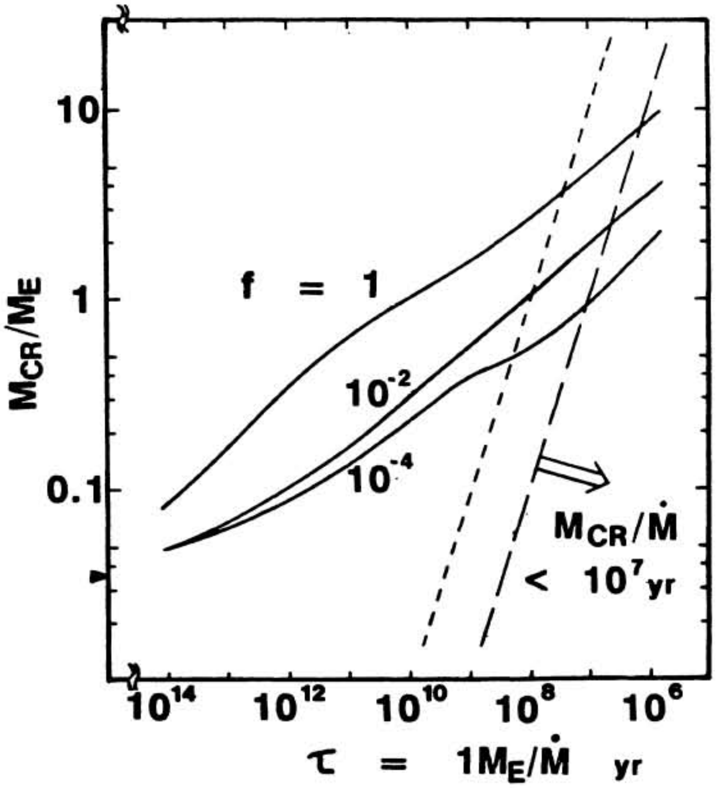

Figure The critical core mass for various timescale of accretion ($\tau = 1\mathrm{M_E}/\dot{\mathrm{M}}$). f is mass abundance of atmospheric dust to the interstellar value (3×10^{-3}[kg/kg]). Dust size is assumed to be 1×10^{-6}[m]. Outer boundary conditions are T=51.1K and $\rho = 1.2 \times 10^{-10}$kg m^{-3} (Neptune region [6]). The arrow on the left axis shows the critical core mass for the isothermal gas [9].

References: [1] Mizuno, H., Nakazawa, K., and Hayashi, C. (1978). *Prog. Theor. Phys.* **60**, 699-710; [2] Mizuno H. (1980). *Prog. Theor. Phys.* **64**, 544-557; [3] Bodenheimer, P. and Pollack, J. B. (1986). *Icarus* **67**, 391-408; [4] Sekiya, M., Miyama S. M., and Hayashi C. (1987). *Earth Moon Planets* **39**, 1-15; [5]. Hubbard W. B. and Marley, M. (1989). *Icarus*, in press; [6] Hayashi, C., Nakazawa, K., and Nakagawa, Y. (1985). in *Protostars and Planets II* pp.1100-1153. Univ. Arizona Press, Tucson; [7] Stevenson, D. J. (1984). in *Lunar Planet. Sci. XV*, 822-823; [8] Pollack, J. B., Mckay, C. P., and Christofferson, B. M. (1985). *Icarus* **64**, 471-492; [9] Sasaki, S. (1989). *Astron. Astrophys.* in press; [10] Sasaki, S. and Nakazawa, K. (1986). Proc. 19th ISAS Lunar Planet. Symp., pp.160-163; [11] Sasaki, S. (1987). Dortoral dissertation, Univ. Tokyo;