P036-P012 Time: May 27 17:00-18:30

Orbital Evolution of Planetesimals and the Formation of Cometary Reservoir

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From observations of long-period comets, existence of comet reservoir in a region of 10^4-10^5 AU from the Sun is predicted (the Oort Cloud). It is estimated that the Oort Cloud is constructed spherically around the Sun with at least 10^11 comets. General scenario of formation of the Oort Cloud is that at the latter stage of planetary formation, the remained icy planetesimals change their eccentricities largely by a gravitational scattering by giant proto-planets, for example by proto-Jupiter. Consequently they enter the outer region of the solar system, and there their eccentricities of orbits decrease by external perturbations.

According to this scenario, Tremaine(1993) estimated analytically which proto-planets are responsible for the formation of the Oort Cloud and showed that Jupiter and Saturn are so massive to form the Oort Cloud that they would eject planetesimals out of solar system, but Uranus and Neptune would form it. On the other hand, Fernandez(1997) supposed that the local galactic density near the proto-solar nebula at the stage of the Oort Cloud formation was high from the observed evidence that the stars are formed within a molecular cloud and/or an open cluster, and he introduced the galactic tide, stronger than ever assumed, to affect the dynamical evolution of scattered planetesimals by the proto-planets. Moreover, using the result of numerical simulations showing that almost half of the planetesimals starting at Neptune's zone falls under the gravitational control of Jupiter or Saturn, he concluded that Jupiter and Saturn can form the Oort Cloud. Thus, there are some possible scenarios but a certain one hasn't been established.

In the latter stage of protoplanetary formation in which the Oort Cloud may be formed, it seems that a gas disk remained yet and the remained planetesimals in the outer region of planetary formation spiral inward the Sun according to the gas drag forces. So when we study the gravitational scattering of planetesimals by the proto-giant planet, it is necessary to take into account not only the planetesimals remained around the giant planets but also ones remained in the outer region and moved near the proto-planet by the gas drag forces.

We have examined the process of the transportation of icy planetesimals from the outer region to near the proto-giant planets by the gas drag and the possibility that they are thrown into the Oort Cloud after being perturbed by these planets. Observed results suggest that many of long-period comets contain volatile ice which can be frozen only at lower temperatures. These facts indicate that the comets were formed at beyond the Jupiter region and support our scenario where a part of comet nuclei were formed far away from the proto-giant planets. In our revised consideration of gravitational scattering of planetesimals by proto-planet, we take into account a time variation of the mass of proto-giant planets. Namely, Jupiter's mass may be less than present mass during the Oort Cloud formation because Jupiter's core which is 10 earth mass takes 10^7 years to grow up to present size. These aspects are not considered in the previous studies.

In this study, the time scale is calculated, in which icy planetesimals born in the heliocentric distance of 30-100AU reach the proto-giant planet region by the gas drag forces. In analytical results, we found that, for example, a planetesimal with a radius of 100m and a density of 100kg/m^3 located at 30 AU falls into the Sun after 2*10^6 years. To examine the dynamical evolution of icy planetesimals in the outer region of planetary formation in detail, we have performed the numerical simulation for the dynamical evolution of planetesimals, including their gravitational scattering by proto-giant planets. Probability of ejection of planetesimals after this process into the outer region of solar system is examined and the possibility of forming the Oort Cloud is discussed.