Dynamical lifetime of the new Oort Cloud comets under planetary perturbations

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Nearly-isotropic comets with very long orbital period are supposed to come from the Oort Cloud. Recent observational and theoretical studies have greatly revealed the dynamical nature of this cloud and its evolutional history, but many issues are yet to be known. Our goal is to trace the dynamical evolution of the Oort Cloud new comets (OCNCs) produced by an evolving comet cloud, hopefully estimating the fraction of OCNCs embedded in the current populations of the solar system small bodies. We combine two models to follow the dynamical evolution of OCNCs beginning from their production until their ejection out of the solar system, obtaining statistics of the dynamical lifetime of OCNCs: The first model is a semi-analytical one about the OCNC production in an evolving comet cloud under the perturbation of the galactic tide and stellar encounters. The second model numerically deals with planetary perturbation over OCNCs' dynamics in planetary region. The main results of the present study are: (1) Typical dynamical lifetime of OCNCs in our models turned out to be $O(10^7)$ years. Once entering into the planetary region, most OCNCs stay there just for this timespan, then get ejected out of the solar system on hyperbolic orbits. (2) While average orbital inclination of OCNCs is small, the so-called "planet barrier" works rather effectively, preventing some OCNCs from penetrating into the terrestrial planetary region.

Models. Recently a series of detailed dynamical studies with similar scientific objects to ours are published [1–3]. Our present study is an extension of our own independent project [4], using a pair of dynamical models. The first model is for the evolving Oort Cloud that produces OCNCs along its evolution [5,6]. The model initially starts from a planar planetesimal disk, which evolves into a three- dimensional, nearly isotropic shape over a timespan of Gyr under the perturbation by the galactic tide and stellar encounters. This model is largely analytical in order to reduce the amount of computation. The second one is a numerical model for incorporating planetary perturbation from the major seven planets except Mercury, similar to the framework of our previous studies [7,8]. It receives OCNCs from the first model, and traces the orbital evolution of the comets up to 500 Myr until they get ejected out of the solar system by being scattered away. The second model does not include the galactic tide or stellar perturbation. For further reduction of computation amount, we assume that OCNCs go along their Keplerian orbits beyond $r = 800$ au without any perturbations. The effect of the galactic tide that OCNCs would have during this period is separately evaluated using a perturbation function that includes the galactic tide used in the first model.

Results. We selected two different eras among the Oort Cloud history: (a) the initial 1 Gyr while the comet cloud is still nearly planar with a high OCNC production rate, and (b) the period $t = 4$–5 Gyr when the comet cloud is almost in an isotropic shape with nearly constant supply of OCNCs. It turned out that most of the OCNCs got scattered away by the four giant planets (*i.e.* being ejected out of the system with $r > 800$ au and $e > 1$, or aphelion distance becoming larger than $Q > 2 \times 10^5$ au) with a typical timespan of $O(10^7)$ years in the planetary region. This timescale is roughly consistent with an analytical estimate in [9]. Also, this timescale does not strongly dependent on which era we choose, as the range of OCNC's semimajor axis is similar to each other. To get an estimate as to which planet has the largest dynamical influence on the fate of OCNCs, we calculated the number of planetary encounters defined by OCNC's close approaches within 500 × scatter radius of planets, r_{s} (r_{s} is a typical distance when a massless body's orbit gets bent 90 degrees by scattering. It is proportional to (relative velocity)$^{-2}$). A simple analysis shows that Jupiter and Saturn play a dominant role on scattering OCNCs away from the system.

There has been a concept called the "Jupiter barrier" where giant planets such as Jupiter protect the Earth from cometary bombardments (*e.g.* [10,11]). Our study partially validates this hypothesis, showing that the planetary barrier actually works when the incoming OCNC flux is nearly planar as in the era (a). The main barrier is composed by Saturn with an aid by Jupiter, making OCNCs' perihelia stick around Saturn's orbit. Once the comet cloud has become isotropic as in the era (b), OCNCs come from almost any directions, and the barrier no longer works. This is just the situation in the current solar system.

References: [1] Fouchard et al. (2013) Icarus 222, 20–31. [2] Fouchard et al. (2014a) Icarus 231, 110–121. [3] Fouchard et al. (2014b) Icarus 231, 99–109. [4] Ito and Higuchi (2012) ACM 2012 abstract, LPI Contribution 1667, id. 6209. [5] Higuchi et al. (2006) Astron. J. 131, 1119–1129. [6] Higuchi et al. (2007) Astron. J. 134, 1693–1706. [7] Ito and Malhotra (2006) Adv. Space Res. 38, 817–825. [8] Ito and Malhotra (2010) Astron. Astrophys. 519, A63. [9] Tremaine (1993) ASP Conference Series 36, 335–344. [10] Everhart (1973) Astron. J. 78, 329–337. [11] Wetherill (1994) Astrophys. Space Sci. 212, 23–32.