Effect of Stellar Encounters on Comet Cloud Formation

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The Oort Cloud is a spherical comet reservoir surrounding the Solar system [1]. Observations and statistical studies estimate that it consists of more than 10^{12} comets and is on the order of 10^4–10^5 AU in size (e.g., [2]). Now it is generally accepted that the comets are residual planetesimals from planet formation and are originally inside the planetary region. In the standard scenario of the Oort cloud formation, passing stars randomize and eject planetesimals from the Solar system by giving velocity kicks. The perturbations from passing stars, due to their random-walk nature, may play an important role in the production of the nearly isotropic inclination distribution of planetesimals Many authors have examined this effect, however, their main interest is in the production of long-period comets from the spherical Oort cloud (e.g., [3]).

In the present paper we investigate the effect of stellar encounters on the evolution of a planetesimal disk, from the point of view of Oort Cloud formation. We calculate the evolution of a planetesimal disk into a spherical Oort cloud due to the perturbation from passing stars for 10 Gyr. We use the classical impulse approximation to calculate the perturbation from the passing stars. The stellar encounters are assumed to occur with random directions and follow the distribution $\mathrm{d}n_\mathrm{s}/\mathrm{d}b \propto b$, where n_s and $\mathbf{b}$ are a number of stellar encounters and the position vectors to the star from the Sun, respectively. The time interval to the next stellar encounter is given according to a Poisson distribution [3].

The number of planetesimals decreases while the distributions of the orbital elements approach the isotropic distribution. We fit the decay curve empirically using the standard exponential decay curve and the stretched exponential decay defined by the Kohlrausch formula [6]. Let P_bound denotes the survival rate of planetesimals in the Solar system. The empirical fit for P_bound for the standard exponential decay is

$$P_\mathrm{bound}^\mathrm{fit} = \exp\left(-\frac{t}{t_e^\mathrm{fit}}\right), \qquad (1)$$

$$t_e^\mathrm{fit} \simeq 5.6\left(\frac{a_0}{2\times 10^4\ \mathrm{AU}}\right)^{-1.4}\left(\frac{m_*}{0.5M_\odot}\frac{20\ \mathrm{kms}^{-1}}{v_*}\right)^{-1.7}\left(\frac{f_\mathrm{enc}}{10\ \mathrm{Myr}^{-1}}\right)^{-1}\mathrm{Gyr}, \qquad (2)$$

where a_0 is the initial semimajor axes of the planetesimals, m_* and v_* are the stellar mass and velocity, respectively, and f_enc is the encounter frequency per 1 Myr within 1 pc from the Sun.

We also show the radial variations of the e-folding times to the Oort cloud. We show that if the initial planetesimal disk has the semimajor axes distribution $\mathrm{d}n/\mathrm{d}a \propto a^{-2}$, which is produced by planetary scattering [7]. the e-folding time for planetesimals in the Oort cloud is ~10 Gyr at any heliocentric distance r (Fig. 1). This uniform e-folding time over the Oort cloud means that the supply of comets from the inner Oort cloud to the outer Oort cloud is sufficiently effective to keep the comet distribution as $\mathrm{d}n/\mathrm{d}r \propto r^{-2}$. We also show that the final distribution of the semimajor axes in the Oort cloud is approximately proportional to a^{-2} for any initial distribution [8].

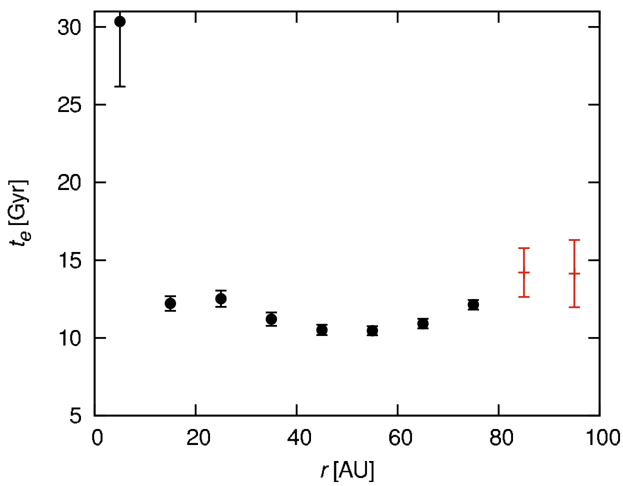

Figure 1: Standard e-folding time against r.

References

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