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Decay of Oort cloud comets by stellar encounters

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Abstract

The spherical structure of the Oort cloud and the nearly isotropic distribution of the Oort cloud comets are produced by the external forces such as the galactic tidal forces and perturbations from passing stars/giant molecular clouds. We have investigated Oort cloud formation by the external forces. These external forces also disrupt the Oort cloud. We present how the number of Oort cloud comets decays by stellar encounters using an impulse approximation. We obtained the semi-analytical expression that gives the decay curve of the Oort cloud comets by using the Kohlrausch's formula. We also show how the Galactic tide affects the results.

1. Introduction

It is generally accepted that the comets are residual planetesimals from planet formation and they are originally inside the planetary region with small eccentricities and inclinations. In the standard scenario of Oort cloud formation, at first, the eccentricities and semimajor axes of planetesimals are raised by planetary scattering. Such planetesimals with large aphelion distances are affected by external forces. The external forces pull the perihelion distances out of the planetary region and randomize all the orbital elements. The perturbation from passing stars is the only external force considered in the original Oort's scenario. Since then, many authors have studied the external forces and now we recognize that not only passing stars, but also the Galactic disk and giant molecular clouds are effective perturbers (e.g., [1]). Though the galactic tide causes oscillations of the orbital elements, the passing stars, due to its random-walk nature, may play an important role in the randomization of the inclination of planetesimals. Many authors have examined this effect, mainly by analytical approach (e.g., [3]). However, their main interest is in the production of long period comets from the Oort cloud by stellar encounters. Their initial conditions are the spherical Oort cloud. In contrast, we investigate the effect of stellar encounters and the galactic tide on the evolution of a planetesimal disk, from the point of view of the formation of the Oort cloud. We use the classical impulse approximation to calculate the velocity change of planetesimals induced by stellar encounters and the analytical formulae to derive the time evolution of the orbital elements due to the galactic tide [4]. We present one of our results, the decay curve of the number of Oort cloud comets.

2. Model and Method

2.1 Numerical calculation

We examine the effect of stellar encounters using the impulse approximation and clarify how much they prune the planetesimals from the solar system. We use 10 star sets generated by different random numbers for each stellar parameters using the method described in [5]. For the standard case, we use an identical mass and velocity. These values are given by averaging the values obtained from observations of the solar neighbourhood. We also use several realistic star sets; mixture of 13-types of stars. The initial planetesimals disks for the standard cases consist of mass-less particles with the identical semimajor axes. We set 20,000AU as the standard value. We also calculate the evolution of planetesimal disk with a broad distribution of the semimajor axes.

2.2 Kohlrausch's formula

To fit the decay curve of the Oort cloud comets, we use the Kohlrausch's formula defined as

$$P_{\mathrm{alive}} = \exp\left(-\left[\frac{t}{t_0}\right]^{\beta}\right) \qquad (1)$$

where P_{alive} is the survival rate of the planetesimals in the Oort cloud, beta is a parameter called stretching parameter, and t_0 is the *e*-folding time for beta=1[2]. When beta=1, equation (1) is a standard exponential function. When beta is not 1, the *e*-folding time is given by

$$t_e = \frac{t^{(1-\beta)} t_0^{\ \beta}}{\beta}. \qquad (2)$$

Using the least squares, we try to find the values of beta and t_0 as functions of stellar and planetesimals' parameters that reproduce the numerical results.

3. Results

We obtain

$$t_0 = 5.2\left(\frac{a_0}{2\times10^4\,\mathrm{AU}}\right)^{-1.4}\left(\frac{m_*}{0.5M_{\mathrm{Sun}}}\frac{20\mathrm{km/s}}{v_*}\right)^{-1.8}\left(\frac{f_{\mathrm{enc}}}{10/\mathrm{Myr}}\right)^{-1}\mathrm{Gyr} \qquad (3)$$

$$\beta = 0.3 P_{\mathrm{alive}}^{\ 0.4}. \qquad (4)$$

Figure 1 shows the fits expressed by equations. (1), (3), & (4) with the numerical results against time. The more detail and the application to the other models will be presented on the poster at the EPSC meeting 2012.

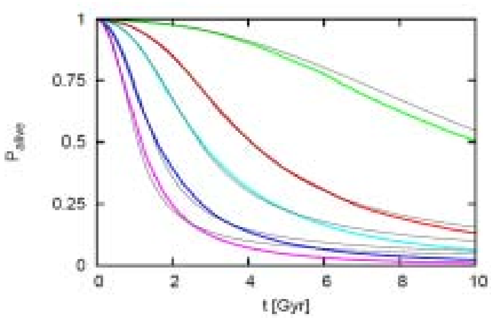

Figure 1: Decay curves for several parameters against time. Curves in colours are the numerical results. Curves in black are the fit expressed by equations (1), (3), and (4).

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