EPSC Abstracts
Vol. 6, EPSC-DPS2011-277-1, 2011
EPSC-DPS Joint Meeting 2011
© Author(s) 2011

Dynamical Behaviour of Planetesimals Temporarily captured by a Planet

R. Suetsugu (1), K. Ohtsuki (1,2,3) and T. Tanigawa (2,4)
(1) Department of Earth and Planetary Sciences, Kobe University, Kobe 657-8501, Japan (ryo3088@stu.kobe-u.ac.jp) (2) Centre for Planetary Science, (3) Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392, USA (4) Institute of Low Temperature Science, Hokkaido University 060-0819, Japan

Abstract

Using three-body orbital integration (i.e. the Sun, a planet, and a planetesimal), we examine temporary capture of planetesimals initially on eccentric and inclined orbits about the Sun, and evaluate the rate of temporary capture.

1. Introduction

When planetesimals encounter with a planet, the typical duration of close encounter during which they pass within or near the planet's Hill sphere is smaller than or comparable to the planet's orbital period. However, in some cases, planetesimals are captured by the planet's gravity and orbit about the planet for an extended period of time, before they escape from the vicinity of the planet. This phenomenon is called temporary capture. Temporary capture may have played an important role in the origin and dynamical evolution of various kinds of small bodies in the Solar System, such as short-period comets and irregular satellites.

In most previous works on temporary capture or permanent capture with some energy dissipation, orbital stability of planetesimals in the vicinity of a planet was examined numerically [e.g. 1-3]. In these studies, orbital integration was started within or near the Hill sphere of a planet to study capture orbit. These studies show that orbits very close to the planet are stable, while they become unstable beyond a certain critical distance from the planet, and that the critical distance is larger in the case of retrograde orbits about the planet than in the case of prograde orbits. Although such orbital calculation started in the vicinity of a planet is suitable for the study of orbital stability around a planet, it is difficult to discuss relationship between temporary capture orbits and pre-capture heliocentric orbits based on such calculation. It is also difficult to evaluate the likelihood of such capture events from those numerical results.

Recently, temporary capture of planetesimals by a planet from heliocentric orbits has been investigated in detail using three-body orbital integration [4]. In the case of planetesimals initially on circular orbits, it was shown that planetesimals undergo a close encounter with the planet before they become temporarily captured. When planetesimals are scattered by the planet into the vicinity of one of periodic orbits around the planet, the duration of temporary capture tends to be extended. The rate of temporary capture was evaluated, and it was found that it increases with increasing semi-major axis of the planet, because the size of the planet's Hill sphere relative to its physical size increases with increasing distance from the sun. The rate of temporary capture in the case of low random velocity was also examined and shown to increase with increasing orbital eccentricity.

However, cases of large orbital eccentricities were not examined in detail. Moreover, the above calculations assumed that planetesimals and a planet were initially in the same orbital plane, and effects of orbital inclination were not studied. In the present work, we examine temporary capture of planetesimals initially on eccentric and inclined orbits about the Sun.

2. Numerical Method

We examine temporary capture using three-body orbital integration (i.e. the Sun, a planet, a planetesimal). When the masses of planetesimals and the planet are much smaller than the solar mass and their orbital eccentricities and inclinations are sufficiently small, the motion of planetesimal in the rotating coordinate system centered on the planet is represented by Hill's equation. We integrate Hill's equation for planetesimals with various initial orbital elements, using the eighth-order Runge-Kutta integrator as in the previous works [e.g. 4-6].

The initial azimuthal distance between planetesimals and the planet was taken to be large enough to neglect their mutual gravity. Planetesimals are uniformly distributed radially, and in the case of initially eccentric or inclined heliocentric orbits, their initial horizontal and vertical phase angles are also uniformly distributed. Orbital integration is terminated when the distance between the planetesimal and the planet becomes large enough again, or a collision between them is detected.

Temporary capture of planetesimals is a rather rare event [4]. In order to study temporary capture of planetesimals quantitatively, we define the temporary capture time, T_{cap}. The temporary capture orbits we are to study here are those which allow planetesimals to stay in the vicinity of the planet for an extended period of time, as a result of gravitational interactions with the planet. If we define the duration of temporary capture by the period of time during which a planetesimal stays within a certain distance from the planet, the duration inevitably depends on the pre-assigned critical distance. Furthermore, if the pre-assigned distance is not large enough, we may miss large temporary capture orbits outside the given distance. In order to avoid such ambiguity, we define the duration of temporary capture by the time interval between a planetesimal's first passage of the *x*-axis and its last passage of the same axis during an encounter [4]. If a planetesimal crosses the *x*-axis only once, $T_{cap} = 0$. In addition to the temporary capture time, we also calculate the number of revolutions around the planet, which we call the winding number, N_w [4,7]. When a planetesimal crosses the *x*- or *y*-axis in the prograde direction around the planet, 1/4 is added to N_w, while the same amount is subtracted from N_w when it crosses the axes in the retrograde direction. Finally, after the planetesimal's last passage of the *x*-axis, N_w is re-defined by its integer part.

3. Results

We found that the rate of temporary capture increases with increasing eccentricity, in agreement with the previous calculation with a limited range of parameters [4]. In the case of low initial random velocity, temporary capture in the retrograde direction is common, and prograde capture is very rare [4]. On the other hand, both prograde and retrograde captures become possible for large initial eccentricities. Also, shapes of the orbits during temporary capture are different between cases of prograde and retrograde orbits about the planet (see, Fig. 1). In the cases of small eccentricities, planetesimals tend to orbit the planet within the planet's Hill sphere during temporary capture, while planetesimals initially on large eccentricities tend to orbit outside the Hill sphere during temporary capture. We also found that the long-lived temporary capture in the prograde direction is possible only with a limited range of initial orbital elements.

Summary

Using three-body orbital integration, we examined temporary capture of planetesimals by a planet in detail. We found that temporary capture orbits can be classified into four types, and that the rate of temporary capture increases with increasing eccentricity.

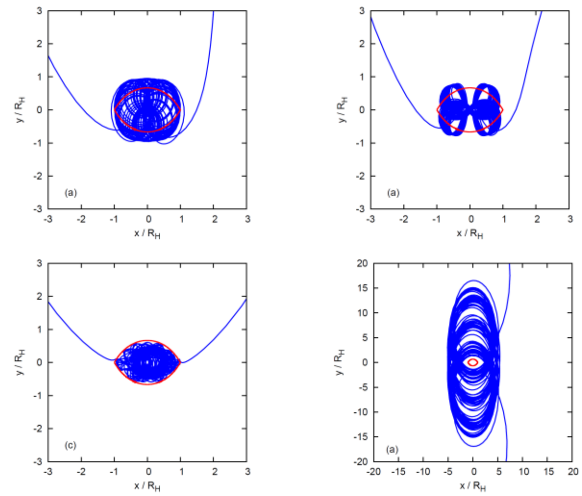

Figure 1: Examples of temporary capture from heliocentric eccentric orbits. These figures show planetesimals' orbits on the rotating coordinate system with a planet at the origin. Values of the coordinates are scaled by the planet's Hill radius.

Acknowledgement

This work was supported by JSPS and NASA's Origins of Solar Systems Program.

Reference

[1] Heppenheimer T. A., Porco C., 1977, Icarus, 30, 385;
[2] Nakazawa K. et al., 1983, Moon andPlanets, 28, 311;
[3] Hamilton D. P., Burns J. A., 1991, Icarus, 92, 118;
[4] Iwasaki K., Ohtsuki K., 2007, Mot. Not. R. Astron. Soc. 377, 1763;
[5] Ohtsuki K., 1993, Icarus, 106, 228;
[6] Ohtsuki K. et al., 2002, Icarus, 155, 436;
[7] Kary D. M., Dones L., 1996, Icarus, 121, 207