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Notes to the capture irregular satellites in four body problem

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Abstract

Number irregular satellites were captured from heliocentric orbits. However, traditional factors, like tidal friction and gas drag cannot explain all observed orbits. Some recent works consider interaction binary minor body with planet. It is possible to consider binaries capture and capture due to close encounters with large regular satellites by the similar way. In result, we found, that encounter with regular satellite is more effective capture mechanism.

1. Introduction

More than 90 irregular moons of the Jovian planets have recently been discovered. Their origin, which is intimately linked with the origin of the planets themselves, has yet to be adequately explained. Most adequate way of their origin is capture, but detailed mechanism is unknown. A few possibilities are discussed: collisions, gas drag, tidal destruction. In [1] authors investigate the possibility that satellite families formed via collisions between large parent moons and stray planetesimals. A new theory of the origin of the irregular satellites of the giant planets: capture of one member of a ~100-km binary asteroid after tidal disruption is investigated in [2]. Authors of [3] reports that a three-body gravitational encounter between a binary system (of 10^3-kilometre-sized bodies) and Neptune is a far more likely explanation for Triton's capture. This model predicts that Triton was once a member of a binary with a range of plausible characteristics, including ones similar to the Pluto–Charon pair [3].

In approach of the three body problem, only temporary capture has significant possibility. Temporary captured objects are really observed. Two asteroids 2001 QQ199 and 2004 AE9 and two comets P/LINEAR-Catalina and P/LINEAR are found to be quasi-satellites of Jupiter at present time. [4] It is evident, that permanent capture may take place in vicinity of orbit of temporary capture. The way to change temporary capture into permanent is required. The close encounter with regular satellite is a possible way to make capture permanent.

2. Model

Using the results of simulated binary–planet encounters as a guide, we find that a simple model, which assumes that the binary is impulsively disrupted, provides an effective description of the gravitationally focused encounters with Neptune considered in [5]. As the binary approaches the planet on a hyperbolic trajectory, m_1 and m_2 orbit their mutual centre of mass. On disruption, the smaller body (m_2) experiences a change in speed of the order of its orbital speed about the binary centre of mass [5,6]:

$$\Delta v \approx \pm \frac{m_1}{m_1 + m_2}\sqrt{\frac{G(m_1 + m_2)}{a_b}} \qquad (1)$$

Here a_b is a distance between components of binary.

We use the Gauss equations to relate the size of a satellite family in the mean orbital elements space (δa, δe) with a selected velocity impulse (δV) [2]:

$$\frac{\delta a}{a} = \frac{2}{na(1-e^2)^{1/2}}\left[(1 + e\cos f)\Delta V_T + (e\sin f)\Delta V_R\right] \qquad (2)$$

$$\delta e = \frac{(1-e^2)^{1/2}}{na}\left[\frac{e + 2\cos f + e\cos^2 f}{1 + e\cos f}\Delta V_T + \sin f \Delta V_R\right] \qquad (3)$$

Here *a, e,* and *i* are the semimajor axis, eccentricity, and orbital inclination of a satellite prior to an impact; δa, and δe are the changes in these elements due to the impact; *n* is the orbital frequency of a satellite; and δV_T, δV_R, and δV_W are components of δV along the direction of the orbital motion, in the radial direction, and perpendicular to the orbital plane, respectively.

As it followed for equation for angular momentum [7], an orbital frequency may be estimated:

$$n = V_n r / a^2 \approx \sqrt{\frac{GM(1-e^2)}{a^3}} \qquad (4)$$

For tangential splitting:

$$\delta e \approx \frac{2(1-e^2)^{1/2}}{na}\Delta V_T \approx \frac{2m_1}{m_1+m_2}\sqrt{\frac{(m_1+m_2)a}{Ma_b}} \qquad (5)$$

Let $m_1 >> m_2$, δe =0.7 radius of main component of binary r_1=200 km, $m_1=10^{20}$. It means, that minimal distance for capture of one component of binary exists.

$$a_{Limit} \geq 0.125\frac{M}{m_1}a_b \qquad (6)$$

For giant planets, the ratio M/m is very large, about (10^7) and a_{Limit} is about $3*10^8$km. It is evident, that this mechanism is more effective for case martian satellites an maybe for Moon. Direct capture of irregular satellites of Jupiter and Saturn, at their present orbits, by destruction of binary is impossible.
Capture of Triton, by destruction of binary, is possible, if a second component of binary is large. It is easy to satisfy, due to number of massive objects in Koiper belt.
Capture of Moon, by destruction of binary, is possible, even in case small companion. Moon can be captured from heliocentric orbit as a component of binary even when another component has mass equal 1/fifth Moon mass. In this case radius of post capture orbit is about 3 time large then modern lunar orbit.
By the similar way it is possible to consider capture due to close encounters (interaction) with large regular satellites (table 1). The ratio M/m in this case is about 10^5 and a_{Limit} is smaller (about $1*10^7$ km). In addition, interaction with regular satellites is effective for change temporary capture to permanent. In this case δe may be smaller. Some another factors, like tides and tidal splitting of fast rotating minor body, can increase capture probability.

3. Summary and Conclusions

Number irregular satellites were captured from heliocentric orbits. However, traditional factors, like tidal friction and gas drag cannot explain all observed orbits. Some recent works consider interaction binary minor body with planet. It is possible to consider binaries capture and capture due to close encounters with large regular satellites by the similar way. In result, we found, that encounter with regular satellite is more effective capture mechanism. All irregular satellites of Jupiter can be captured by this way. However, destruction of binary can make capture more probable for some cases, for example, for Moon.

Table 1: Minimal semimajor axis of object, captured at encounter with regular satellite

Satellite	M/m	a_{Limit}, km
Moon	81.3	$5.2*10^5$
Io	21270	$9.4*10^6$
Europa	39554	$1.5*10^7$
Ganimed	12809	$8.3*10^6$
Callisto	17645	$1.0*10^7$
Titan	4224	$2.7*10^6$

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