The Capture of Satellites by Binary-Planet Encounters: A Computational Analysis of the Cases of Triton, Phobos and Deimos

Introduction

Conversely to regular satellites, irregular ones have been widely accepted to be foreign bodies originated elsewhere from their present location, that early in the Solar System history were somehow captured by planets. However, despite almost unanimous agreement about the what and when, the question about how such irregular satellites became gravitationally apprehended by planets remains wide open, as no model seems to satisfactory tie up all loose ends.

A promising capture mechanism has recently been proposed for Triton, the flag-ship of irregular satellites given its huge mass and inclined retrograde motion around Neptune. The key idea of this capture model is based on a three-body gravitational encounter, that is, two bound Kuiper belt objects would have adequately approached Neptune becoming finally disrupted, thus one member resulting captured by the planet – Triton – and the other one liberated.

The aim of this project will be to investigate by computational analysis the properness of the binary-planet encounter mechanism as a potentially flawless and very likely model for explaining not only Triton's weird existence – as already demonstrated by similar means – but even the capture of regular moons as well, like the potential case of both Martian satellites.

Background Science

Large, highly eccentric and/or highly inclined orbits of irregular satellites denote an improbable primordial formation process – circumplanetary disk accretion around current parent planets – as regular moons have certainly undergone. While capture is the obvious explanation for the existence of irregular satellites, to know which particular mechanism actually occurred becomes of major importance, since it constraints planet formation models (Jewitt and Sheppard, 2005).

In order to become captured, a passing object must lose a precise amount of its orbital energy so that it can result gravitationally bound to a new master – the largest dominating mass in the vicinity. This condition restraints permanent captures by planets to only take place inside their corresponding Hill sphere. However, none of the three "classical" mechanisms for explaining the required energy dissipation satisfactory answer all the interrogations.

Capture by gas drag (Pollack *et al*., 1979) has to do with the deceleration that an object would have experienced while passing through the gas and dust of a primordial circumplanetary nebula. In case such breaking down action resulted precisely enough – neither too low, nor too high – the object would have been finally captured by the planet in question. However, for a passing object to be transformed into satellite this model requires that it should have encountered about its own mass within the nebula, a hard condition to satisfy (Sheppard, 2005).

Pull-down capture (Heppenheimer & Porco, 1977) refers to the situation resulting from a "sudden" increase of the Hill sphere of a planet. If heliocentric bodies were moving at low velocities relative to the planet, their low energy could have made them unable to escape the enlarged Hill sphere, thus leading to permanent captures. Although plausible, this mechanism requires either mass changes of the Sun and/or the planets, or large planet migrations to happen over a few thousand years, a not very likely scenarios (Sheppard, 2005).

Considering that the number of irregular satellites measured to a given diameter is approximately constant for the four giant planets (Jewitt & Sheppard, 2005), neither gas drag, nor pull-down seem to have been the unique capture mechanism for all irregular satellites, since development conditions for Jupiter and Saturn were radically different compared to those for Uranus and Neptune.

Capture through three-body collisional or collisionless interactions (Colombo & Franklin, 1971) implies the right energy dissipation for one or both small interacting objects due to a close approximation within the Hill sphere of a planet. To work efficiently this mechanism requires a large number of passing bodies near the planets, orders of magnitude much larger than presently observed but possible for the early Solar System (Gomes et *al.*, 2005; Hahn, 2005).

The binary-planet gravitational encounter model for explaining moon's captures (Agnor & Hamilton, 2006) is a particular case of a three body collisionless interaction, where the required energy dissipation comes from slow speeds relative to the planet that each one of the binary objects transitorily experiment during part of their revolution around the common centre of mass. Given modern increasing percentage trend of binary systems in the Solar System constituted by small bodies (Stephens and Noll, 2006), binary-planet encounters appear as a very likely explanation for satellite captures (Morbidelli, 2006).

Description of the experiments

As the general case of three-body interactions can not be solved analytically, numerical analysis must be applied. The tool for studying the binary-planet capture mechanism in this project will be the Solar System Dynamics Simulator. It uses an integration software package called SWIFT, running at the Centre for Astrophysics and Supercomputing at Swinburne University of Technology (Melbourne, Australia).

The first case to be analyzed will be Triton, trying to verify and even expand the broad diversity of characteristics of the approaching binary bodies that, according to Agnor & Hamilton (2006), would have ended anyway with Triton captured. The objective of this study will be to test such model with the SWIFT tool, and determine as precise as possible the empirical boundaries of such binary parameters values – an outcome not clearly defined in Agnor & Hamilton's paper.

In particular, the range of the binary parameters to be tested will be: (a) encounter speed at infinity varying from 0.1 to 5 km/s, (b) mass of escaping companion varying from 0.05 to 1.5 Triton's mass, and (c) binary semi-major axis varying from 5 to 5,000 Triton's radius. Due to restrictions imposed by the simulator, the binary orbit inclination will be 0 degree.

In order to simulate Triton's capture, two scenarios will be applied. The simpler one will have Neptune as the central body, and just two massive objects approaching it – plus always required test particles. The more complex and realistic one will have the Sun as the central body, plus Neptune and two self-gravitating objects orbiting around it. After finding the appropriate initial conditions for both scenarios that make the two massive minor objects to really behave as an approaching binary system – a not at all trivial issue – comparison between positive capture outcomes from both models will be performed.

The second particular case to be attempted will be the Martian satellites. Although neither Phobos nor Deimos are irregular moons, it has been stated (Sheppard, 2005; Sheppard et *al*, 2004) that any of them could have previously been binary asteroids finally captured by Mars. The objective of simulating the binary-planet capture model for each of those satellites is to obtain any pertinent results that would either support or controvert Sheppard's idea.

As in Triton's case, the SWIFT tool will be applied for a wide range of binary incoming parameters, but this time for three different scenarios: (a) Considering just Mars and the binary asteroids, (b) the Sun, Mars and the binary asteroids, and (c) the Sun, Jupiter, Mars and the binary asteroids. Whatever results obtained from this experiment will be an interesting scientific contribution, as no published literature about this particular study could be found.

Project Schedule

The overall period to perform this project will span two months from early September, 2006. For a better time organization, the tasks planned to be performed have been arbitrarily distributed into three periods. The following table presents the corresponding timetable.

Period	***Date***	***Tasks to be performed***
# 1	Sep 11 – Sep 30	To run simulation tests that mimic the suggested Triton' capture. To find out proper initial values. To analyze respective influences due to broad parameter changes. To elaborate project diaries # 5, 6 & 7.
# 2	Oct 2 – Oct 21	To run simulations for testing plausibility of the binary-planet model to have been the origin of any of the two Martian regular satellites. To elaborate project diaries # 8, 9 & 10.
# 3	Oct 23 – Nov 4	To write the project report. To elaborate project diaries # 11 & 12.

Summary

Capture of irregular satellites is still one major topic in modern Solar System dynamics. However, the three-body binary-planet gravitational encounter model recently proposed for explaining some captures seems very promising, even to justify the presence of some regular ones. The outcome of the two experiments here proposed to be performed by computational analysis, whatever their conclusions could be, will have made some (modest) contribution towards the assessment of the binary-planet encounter model as the main Solar System satellite-capturing source.

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