Small hypothetical satellites and dust particles near Nix and Hydra: implications for the New Horizons mission

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Abstract: *Pluto and Charon form a binary system and, along with the recent discovered satellites Nix and Hydra, will be imaged by the New Horizons spacecraft in 2015. By analyzing the effects of hypothetical satellites on the orbital evolution of Nix and Hydra we verified that some of them can be present in this system, at specific locations, without provoking any significant gravitational effects on Nix and Hydra. The orbital dynamics of micron-sized dust particles (1-30* µ*m) under the effects of the radiation pressure force (a component of the Solar radiation force) was analysed. The results show that this effect is important for small particles located in the Pluto system.*

Keywords: *Orbital dynamics, New Horizons mission, numerical simulations, gravitational effects, solar radiation force.*

1 Introduction

The discovery of Pluto's two satellites Nix and Hydra raised questions about the existence of other small satellites and rings in this system. The New Horizons Spacecraft (the NASA's First Mission to Pluto and the Kuiper Belt) launched in 2006 to the Pluto system will make its closest approach to Pluto in July 2015. This closest approach will help the scientists to characterize the geology of Pluto and Charon, the Pluto's atmospheric composition, to study the small moons Nix and Hydra for months. The entire Hill sphere will be searched for additional rings and satellites during the approach phase.

[1] through an analysis of the spatial elliptic restricted three-body problem for a time-span of 10^4 orbital periods of the binary, generated stability maps for the (a–e) and (a–I) orbital element spaces near Nix and Hydra (taken as massless bodies). Their results showed an unstable zone larger than the unstable zone derived from the circular restricted three-body problem.

[2] proposed the possibility of rings in the Pluto system with a characteristic ring optical depth of $\tau = 5 \times 10^{-6}$ between Nix and Hydra. [3] analysed the ejecta exchange between objetcs in the Pluto system, the ejecta would be produced by collisions between the objects of this system and Kuiper Belt debris. The encounter between the New Horizons mission and the Pluto system in 2015 will help to check the existence of a ring system.

One of the goals of this work is to analyse the effects of hypothetical satellites on the orbital evolution of Nix and Hydra in order to constrain an upper limit size. A dust grain in orbit around a planet are affected by the gravitational field of the massive bodies and the solar radiation force. Therefore, we also analysed the importance of the solar radiation pressure on hypothetical dust particles located in this system.

In Section 2 we numerically simulate the system and determined a constraint on the upper limit size of unknown satellites. Section 3 contains a numerical analysis of the effects of the radiation pressure force combined with the gravitational interaction with Pluto and its satellites, on a sample of micrometer-sized dust particles in orbits around the barycentre of the system. In the last section we present the conclusions. All the numerical integrations in this work have been carried out using the variable time-step Bulirsch–Stoer algorithm from the Mercury package [4].

2. Hypothetical satellites

We performed an analysis of the gravitational effects of a sample of hypothetical satellites (moonlets) on the orbits of Nix and Hydra. The analysis was carried out in order to constrain the size and position of an additional satellite in the system, without inducing any eccentricity in the orbits of Nix or Hydra larger than 10^{-3}. The moonlets were initially in circular, coplanar and prograde orbits around the barycentre of the system. The range of sizes of the hypothetical satellites were chosen based on the results presented by [5].

The initial semimajor axis (barycentric) of the hypothetical satellites were distributed from $2d$ to $5d$, with a = $0.005d$. The diameters of the hypothetical satellites were assumed to be between 2 km (m = 6.8×10^{12} kg) and 50 km (m = 1.06×10^{17} kg) for those satellites interior to Hydra's orbit, and between 2 and 36 km (m = 3.9×10^{16} kg) for those satellites exterior to Hydra's orbit, by assuming a density equals to 1.63 g cm^{-3}. The orbital parameters of Pluto, Charon, Nix and Hydra used in the numerical simulations were taken from [6].

During the numerical simulations most of the moonlets initially located interior to Hydra's orbit collided with Charon, Nix or Hydra, or were ejected from the system. However, most of the satellites coorbital to Nix and Hydra and about 33% of those satellites located between their orbits survived during the whole time of the integration (650 000 days).

Fig. 1 shows the location and size (in radius) of those hypothetical satellites that cause only a small increase (less than 10^{-3}) in the eccentricities of Nix and Hydra ([7]). Therefore hypothetical satellites can reside coorbital to Nix and Hydra, in a small region between their orbits and beyond Hydra's orbit. During the closest approach phase the New Horizons spacecraft will be able to help the scientists to refine the nominal parameters (radii, masses, densities) of the bodies in the Pluto system.

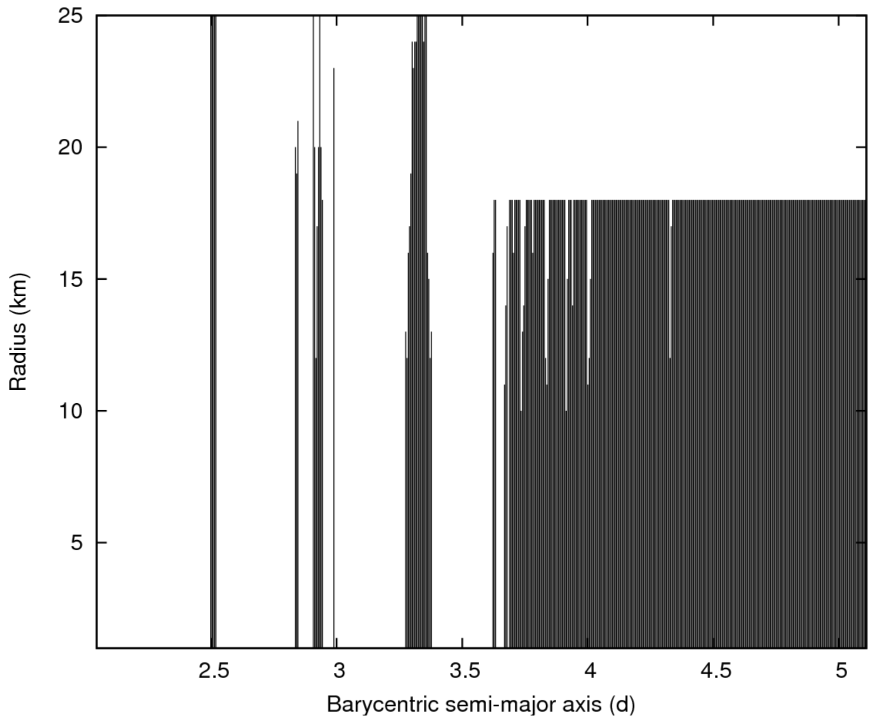

Figure 1. Barycentric semimajor axis as function of the radius (in km) of the survived hypotetical satellites which cause only a negligible variation in the eccentricities of Nix and Hydra (less than 10^{-3}).

3. Solar Radiation Pressure

In this section we present a numerical analysis of the effects of the radiation pressure component combined with the gravitational interaction with Pluto and its satellites, on a sample of micrometer-sized dust particles (spherical dust particles with uniform density) in orbit around the barycentre of the system. The Poynting-Robertson effect is unimportant effect on short timescales (~1000 years), therefore it was not taken into account.

The parameters of the four massive bodies are the same used in the simulations described in section 2. The planetary shadow and the light reflected from the planet were neglected. The Yarkovsky effect was also neglected since it is important for particles in the meter to kilometer range ([8]).

We assumed dust particles with radius ranging from 1 to 30µm and density of 1 g cm^{-3}. A set of 1 000 particles of each size were radially distributed relative to the barycentre of the system. The particles were in circular and equatorial orbits about the planet. The adopted ejection distance is $100a_0$ (a_0 is the Charon's semimajor axis). The numerical integration was performed for a time span of 1000 years.

Table 1 shows the collision and ejection data obtained in the numerical simulations. The radiation pressure component causes a large variation in the eccentricities of the particles leading them to collisions with the massive bodies or ejections. In this dynamical system, the majority of the particles did not remain during the whole time of integration, only those particles larger than 10µm remained in the system, although in small quantities, about 17% of the 30µm sized particles survived after 1000 years.

Table 1. Percentage of collision, ejection and surviving particles

Particle's radius (µm)	Collisions (%)	Ejection (%)	Number of surviving particles (%)
1	29	71	0
5	41	59	0
10	66	34	0
15	72	25	3
20	68	23	9
25	67	19	13
30	66	17	17

4. Conclusions

Small undetected satellites can exist in this system without inducing an eccentricity in the orbits of Nix and Hydra larger than 10^{-3}. These hypothetical satellites can be localized in the coorbital regions of Nix and Hydra, between their orbits and beyond Hydra's orbit.

The radiation pressure component provokes an increasing in the eccentricities of the dust particles, making them cross the orbits of the satellites, even in this further region of the solar system. Dust particles with radius less or equal to 10µm did not survived after 1000 years. The radiation pressure component causes an increasing in the eccentricities of the particles, reaching values of about 0.9. The solar radiation force is expected to have a smaller effect due to the large distance from the Sun, however its effects become important compared to the small gravitational field of Pluto.

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