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Predictions of stellar occultations of 9 irregular satellites of giant planets

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ABSTRACT

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1. Introduction

Irregular satellites, also known as outer satellites, of the giant planets are objects orbiting the planets from a distant, eccentric and highly inclined orbit, most of them are retrograde. Because of these peculiar orbits, it is largely accepted that these objects were captured by their planets in the early solar system (Sheppard 2005).

There is a number of capture mechanisms of objects by giant planets proposed in the literature. There is the Gas Drag in the primordial circumplanetary nebulae (Sheppard 2005) where the object would be affected by the gas drag and its velocity slowed down until it be captured by the planet. Another mechanism is called pull-down capture (Sheppard 2005), where the mass of the planet would increase while the object was temporarily captured.

A mechanism based in the Nice model (Morbidelli et al. 2005; Tsiganis et al. 2005; Gomes et al. 2005) was proposed by Nesvorný et al. (2007) and, in the specific case of Jupiter with the modern Nice model, by Nesvorný et al. 2014. During the early solar system instability, encounters between the outer planets occurred. These planetary encounters could exchange energy and angular momentum between planets and the objects nearby making it possible for the capture of irregular bodies by the giant planets. In this scenario, the survival rate of prior-LHB (Late Heavy Bombardment) satellites is very small.

Another important mechanism is the capture through collisional interactions (Sheppard 2005). A collision between two small bodies in the Hill's sphere of the planet could generate fragmented objects and the dissipated energy could be such that some of these objects could be captured.

Some of these objects are in dynamical groups with similar orbital elements, called families, similar to families found in the Main Asteroid Belt. These families may have been created by a parent body disrupted by collisions with comets or other satellites (Nesvorný et al. 2004). Collisions with comets are more likely to have occurred during the Late Heavy Bombardment (LHB) (Gomes et al. 2005).

Nesvorný et al. (2003) studied the collision rates between irregular satellites and concluded that some satellites could have been removed by collision with a bigger satellite. The rate collision between satellites of the Himalia Group (Himalia, Elara, Lysithea and Leda, mainly), for instance, was found to be more than one during the solar system age suggesting that their current structure was originated by satellite-satellite collision.

For Phoebe, ejected material from its surface caused by impacts could evolve due to Poynting-Robertson drag and collide with Iapetus causing the large variation in albedo observed on it (Nesvorný et al. 2003). Indeed, Cassini was able to detected in Phoebe an absorption feature at 2.42 μm (probably CN combinations) that was also detected in the dark side of Iapetus (Clark et al. 2005).

The region of origin of these object is not well known, Grav et al. (2003) and Grav & Bauer (2007) showed that the irregular satellites from the giant planest have their colors and spectral slopes similar to C-, D- and P-type asteroids, Centaurs and trans-neptunian objects (TNOs) suggesting that they have been originated from different locations in the early solar system.

In this work, we study these objects as possible representatives of the small TNOs population. TNOs are objects that due to their distance may be highly preserved having their properties similar to those they had when they were formed, then providing history and evolution of the outer solar system (Camargo et al. 2013). Due to their distance, the smaller objects from this region are more difficult to observe and study.

In the intent to obtain the physical parameters (size, shape, albedo, density, etc) of the irregular satellites and help identify their origin locations, we will make use of the stellar occultation technique. This technique is the best one to obtain these parameters of the solar system objects from ground-based observations providing more accurate results than other ground-based techniques (Sicardy et al. 2011; Ortiz et al. 2012; Braga-Ribas et al. 2014).

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Since their sizes are very small (see table **??** Ainda vou fazer a tabela), predict the exact location and instant where the shadow will cross the Earth demands a good precision. For instance, the bigger irregular satellite of Jupiter has an estimated size of 150 km (Porco 2003), which is equivalent to an apparent size of 40 mas, must have an error smaller than its size for being observable. For the other objects, smaller or farther than Himalia, the situation is more difficult.

As pointed out by Gomes-Júnior et al. (2015), the ephemeris of the irregular satellites have errors that may reach 200 mas for some satellites. For an object at the distance of Jupiter, this represents an error bigger than 700 km in the shadow path.

We present in this paper the stellar occultation predictions for the 7 major irregular satellites of Jupiter (Himalia, Elara, Pasiphae, Lysithea, Carme, Ananke and Sinope), Phoebe from Saturn and Nereid from Neptune. In the section 2 we explore the scientific rationale for study the irregular satellites and the possibility of having a common origin with TNOs. In section 3 we show the correction made to the ephemeris for better predict stellar occultations. In section 4, we present the predictions of the stellar occultations by irregular satellites and how they were made. Some test realized to confirm the predictions are presented in section 5 and the conclusion is given in section 6.

2. Scientific Rationale

As explicited in section 1

3. Correction of the ephemeris

Gomes-Júnior et al. (2015) showed from observations made at the Observatório do Pico dos Dias (OPD), Observatoire Haute-Provence (OHP) and European Southern Observatory (ESO) that the orbits of the irregular satellites of the giant planets have systematic errors. The offsets of the observations relative to the JPL ephemeris could be up to 200 mas for some satellites. These differences could be associated with errors in their orbital elements.

We utilize the offsets obtained by Gomes-Júnior et al. (2015) to identify a pattern in the error of the ephemeris. This pattern could be used to extrapolate an offset to the satellite by the time of the occultation predicted. Plots of the offsets over time and true anomaly (see Fig. **??** for ??) clearly show that these two parameters are the most important in the differences observed.

4. Prediction of occultations

5. Occultation tests

6. Conclusion

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