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Phoebe and the evolution of the outer Saturnian system

D. Turrini, F. Tosi and A. Coradini
Institute for Physics of Interplanetary Space IFSI-INAF, Rome, Italy (diego.turrini@ifsi-roma.inaf.it)

Abstract

The irregular satellites of Saturn are an important laboratory not only to investigate the dynamical and collisional evolution of the satellite systems of the giant planets but also to improve our comprehension of the mass transfer processes taking place between different bodies in the Solar System. Here we review the results of a series of investigations we performed on the origin and evolution of the Saturnian irregular satellites. In particular, we discuss the role of Phoebe in shaping the dynamical and collisional evolution of the outer Saturnian system and the origin of the orbital feature we labelled as Phoebe's Gap. Taking advantage of the data and the results from ground-based observations and the Cassini mission, we also discuss the origin and the formation region of these bodies and their link to the dark material coating the leading hemisphere of Iapetus and the recently discovered Saturnian ring spanning the orbital region of the irregular satellites.

1. Introduction

The outer Saturnian system is presently populated by 37 irregular satellites. The orbits of these captured objects are strongly affected by the perturbations of other bodies in the Solar and the Saturnian systems, making them an important laboratory for the study of N-Body dynamics. Phoebe is the innermost retrograde Saturnian irregular satellite: it is the most massive member of this population, its orbit is located in the middle of the region populated by the prograde irregular satellites and it is the only irregular satellite visited by a spacecraft to date. These facts pose Phoebe in a particular position from the perspective of the study of the origin and the evolution of the outer Saturnian system, as reviewed in [1, 3] and discussed in the following.

2. Dynamical and collisional evolution of the irregular satellites

We simulated the dynamical evolution of a population of 35 Saturnian irregular satellites under the influence of the giant planets and that of the outermost regular satellites of Saturn, Titan and Iapetus [5]. About two thirds of the irregular satellites showed resonant or chaotic features in their dynamical evolution (ibid). Solar and Jovian perturbations mainly shaped the evolution of the system, yet Titan and Iapetus had either stabilizing or destabilizing effects on the outer satellites, preventing or causing resonant of chaotic behaviors (ibid). The secular effects of the dynamical perturbations of the Sun, Jupiter and the major satellites tend to mask the dynamical families possibly existing in the outer Saturnian system (ibid). In particular, the effects of the Jovian perturbations counteract those of the Solar ones and prevent the onsetting of the Kozai resonance in most satellites, yet some satellites showed a temporal evolution of the eccentricity which was inclination-dependent (ibid). The present orbital structure of the outer Saturnian system is stable against collisions on a Ga-long time-scale [2, 5]. The only pairs of irregular satellites characterised by significative collisional probabilities are those having Phoebe as one of the members [5]. Over the considered timespan, Phoebe would erode about one sixth of the present satellites in the outer Saturnian System (ibid), suggesting the original population of irregular satellites was more abundant. Observing the radial distribution of the irregular satellites, we noted a gap centered on the orbital position of Phoebe and extending from about 11.22 to about 14.96 millions of km from Saturn [5]. Located between the pair Kiviuq-Ijiraq and Paaliaq, the gap coincides with the orbital region were the sweeping efficiency of Phoebe is higher [5]. We suggest that Phoebe's Gap formed due to Phoebe collisionally removing prograde satellites once existing in that orbital region. The irregular satellites presently nearest to Phoebe are located in regions characterized by low impact probabilities (ibid).

3. Phoebe's Gap, Phoebe's Ring and Iapetus

Dust grains produced by the impacts responsible for the formation of Phoebe's Gap would suffer a different fate depending on their size. Grains lower than a few microns would be injected on high eccentricity orbits by radiation pressure and would either impact the planet or be ejected from the system. Bigger grains (ten microns or more) would migrate inward due to Poynting-Robertson drag and cross the orbit of Iapetus. Due to its high orbital inclination, Iapetus is extremely efficient in capturing retrograde dust grains for their typical orbital features [4]. On the contrary, dust grains ejected from prograde satellites would occupy a region of phase space where the sweeping efficiency of Iapetus is greatly diminished (ibid). We took advantage of the data supplied by Cassini mission on Phoebe, Hyperion and Iapetus to explore the origin of the dark material. In the VIS range, the comparison was driven by the spectral continuum. The color indexes of the dark side of Iapetus, Phoebe and Hyperion were confirmed significantly different from each other [4]. Hyperion is spectrally red at visible wavelengths and the reddening is higher than that of the dark material of Iapetus (ibid). Phoebe instead shows no reddening (ibid). The comparison of IR data was based both on the spectral continuum and on the signatures of water at 1.51 and 2.05 microns, combined to a number of spectral features diagnostic for volatiles [4]. In the IR range the correlation is generally stronger between Iapetus and Phoebe (ibid). We observed a correlation of most non-ice features with water ice in the case of Hyperion, which suggests trapping into water ice (ibid). The same kind of correlation is not present in the data on Iapetus and Phoebe (ibid). Furthermore, the spectra of Hyperion in the near infrared show a continuum profile significantly different from those of Iapetus and Phoebe (ibid). It must also be noted that the low density value of Hyperion, measured by Cassini, make dynamical scenarios linking the dark material to this satellite extremely unlikely (ibid). The discovery of a new ring around Saturn located in the outer Saturnian system [7] represents the first direct evidence that dust production and transport processes acted and are likely still acting in the Saturnian system (ibid). We argue that the formation of this new Phoebe's Ring is connected to the collisional history of Phoebe and in particular to existence of Phoebe's gap [4, 5, 6].

4. Origins of the irregular satellites

Jason crater (D = 100 km) could be related to the orbital capture of Phoebe if it was generated by nearly grazing, low relative velocity impact with a body whose size was a significant fraction of that of Phoebe [6]. While the described event would be characterized by a very low probability, we argued that the present orbit of Phoebe could be the result of the intense collisional history of the satellite and that a multi-collision scenario would likely relax the dynamical constrains (ibid). We investigated the formation regions of the parent bodies of the Saturnian irregular satellites under the assumption they were captured through collisional processes [6]. We identified the small bodies of the outer Solar System dynamically compatible with capture as irregular satellites and compared their photometric color indexes with those of the Saturnian irregular satellites [6]. We observed a good match in both the infrared and most visible colors, but we also reported a systematic shift in the V-I color indexes.

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