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Detection of rapid orbital expansion of Saturn's moon Titan

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Abstract

The Saturn satellite system is a complex dynamical system with several gravitational interactions happening between the satellites, the rings and the central body, such as resonances, librations and tides. These intricate dynamics carry information on the formation and evolution of the Saturn and Solar systems.

The gravitational pull exerted on Saturn by each of its moons raises a tidal bulge on the gas giant. Because of poorly understood dissipative processes happening in the host planet, the tidal bulge is not directed along the direction of the moon, but there is an angular displacement, called tidal lag angle. In particular, the bulge is leading in front of the moon, because the planet rotation is faster than the orbital motion. In presence of a tidal lag, there is an exchange of energy and angular momentum between the planet rotation and the moon orbital motion. On one side, the moon exerts a tidal torque on the planet, causing a reduction of its rotation rate. On the other side, the bulge accelerates the moon, that migrates outward. The classical tidal theory predicts a small migration rate for Titan and the middle-sized moons of Saturn. However, previous analyses, [4][5], evidenced that the mid-sized moons of the Saturn system are migrating faster than expected, motivating new moon formation scenarios [1][2]. Moreover, while the classical tidal theory assumes a constant tidal lag for all the moons, [4] and [5] evidenced a frequency dependent nature of the Saturn's quality factor, highlighted by the different quality factor obtained at Rhea's frequency.

Using two completely independent approaches we constrained the outward migration of Titan, the biggest moon of the Saturn system. In the first approach, the orbit of Titan was determined by reconstructing the trajectory of the Cassini spacecraft during 10 gravity-dedicated flybys. The orbit determination of Cassini, performed using classical radiometric observables, allowed to reconstruct very accurately the orbit of Titan during the timespan of the Cassini mission. The second approach, instead, used classical astrometric measurements performed from ground since 1886, with the addition of Voyager, HST and Cassini data, to reconstruct the orbit of the eight main moons of Saturn, the four Lagrangian moons of Dione and Tethys, as well as Methone and Pallene.

In both analyses we obtained a large orbital expansion for Titan. This fact suggests that the moon was formed significantly closer to Saturn and it has migrated by a substantial amount, over the lifetime of the solar system. The estimated values are not compatible with a constant quality factor for Saturn. Although, the estimated outward migration is consistent with the resonance locking tidal theory [3]. This mechanism predicts that the tidal dissipation, due to inertial waves in Saturn's convective envelope or gravity modes in Saturn's deep interior is reinforced at certain frequencies. The moons can get caught in these resonances as Saturn's structure evolves provoking an outward migration of the moons on a timescale determined by Saturn's internal evolution.

This fact motivates a revision of the evolutionary history of the Saturn's moon system.

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