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Angular Momentum Loss from Planet-Satellite Systems: Implications for Early Venus

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Abstract

We explore if the very slow rotation of Venus could be a consequence of a past orbital evolution of a satellite. We use numerical integrator previously used for Earth-Moon system [1]. We concentrate on hypothetical satellites less massive then the Moon, and we identify three mechanisms that remove angular momentum from the system: Laplace plane transition [2], Moon-Sun cross tides [3], and chaotic spin-orbit resonances [4] (the last affecting mostly prograde systems). We show that in some cases a moonless, slow-spinning planet is a natural outcome of these processes.

1. Introduction

Venus currently has no satellites and the slowest rotation of any major Solar System body. Despinning by solar tides over the age of the Solar System would require Venus to have a relatively slow early rotation, measured in days rather than hours. This is in contrast with early Earth, which had proposed spin periods in the 2.3-5 hr range [5, 6]. Given recent proposals that early Earth could have lost much of its angular momentum through various dynamical mechanisms [6, 1], we decided to explore how these and other dynamical effects could have affected a Venus that had a substantial satellite. We concentrated on satellites 3-10 times less massive than the Moon which would not an contribute excessive amount of spin to Venus if they were to de-orbit. We used the numerical integrator SISTEM, previously developed for the Earth-Moon system [1], which fully models lunar and solar tides and solar perturbation on the lunar orbit.

2. Angular momentum loss

2.1 Laplace Plane Transition

The first mechanism of angular momentum loss involves the instability of circular satellite orbits at the transition between different Laplace Planes for satellites of high-obliquity planets. The Laplace Plane is the plane around which an orbit precesses, and is typically a plane of symmetry for the perturber. For close-in satellites, the Laplace plane is the equatorial plane of the planet, while for distant satellites chiefly perturbed by the Sun it is the plane of the ecliptic. For low obliquity planets, these two Laplace planes smoothly connect at intermediate distance. But for planets with an obliquity above about 69 degrees [2], there is a chaotic region between the zones where the two Laplace planes are valid. Cuk et al. (2016) [1] showed that a planet-satellite system with a high obliquity can lose a large fraction of its angular momentum to heliocentric orbit during the moon's passage through this chaotic transition.

We find that, if Venus had a satellite and an initial obliquity of 80 degrees or more, the system could have lost large majority of its angular momentum during the Laplace Plane transition.

2.2 Moon-Sun Cross Tides

Our integrator fully accounts for the interaction between the moon and the tidal bulge raised by the Sun, and vice-versa. These torques remove the non-ecliptic component of the angular momentum from the planet's rotation, which is transferred into the heliocentric orbit [3].

We find that this term can be significantly more important for past Venus than the solar tides alone. It is particularly relevant for an initially fast-rotating planet, and can lead to prolonged angular momentum drain if the obliquity of Venus was perturbed by planetary resonances.

2.3 Spin-Orbit Coupling

It has long been established that Venus could have had chaotic obliquity in the past, especially if its initial rotation was prograde [4]. The addition of a small satellite does not change this basic mechanism, as the additional precession it causes may not be enough to shift Venus out of the zone of chaotic obliquity. Additionally, the satellite would generally contribute to the slowing-down of Venus's rotation, which would make chaotic obliquity more likely, even for an initially fast-rotating Venus. Chaotic obliquity is a very likely outcome for an initially prograde Venus, as its precession would be in the same sense as the precession of the nodes of planetary orbits. This effect is much less pronounced for initially retrograde orbits.

3. Summary and Conclusions

We will present the results of our numerical simulations at the meeting. The preliminary results point to a wide variety of outcomes, many of which include an almost complete angular momentum loss from an initially fast-rotating Venus.

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