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Formation of Janus and Epimetheus from Saturn's rings as co-orbitals, thanks to Mimas' 2:3 inner Mean Motion Resonances

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Abstract

We show that the past confinement of Saturn's rings by Mimas' 2:3 mean motion resonances leads to the formation of two equivalent mass seeds to Janus and Epimetheus on the same orbit. This could explain the origin of their fascinating mutual horseshoe orbits configuration, in the frame of satellite formation from the spreading of the rings beyond the Roche radius [1, 3].

Figure 1: Janus and Epimetheus seen by Cassini.

1. Introduction

Janus and Epimetheus orbit Saturn at $151\,461$ km on average, on mutual horseshoe orbits with orbital separation 50 km, exchanging position every 4 years (see figure 1). This configuration is unique and intriguing : their orbital separation should converge to zero in about 20 Myrs only [4], and no satisfactory model for the origin of this co-orbital resonance exists yet. Recently, it has been demonstrated with a 1D model [1] that Janus and Epimetheus probably formed from the spreading of the rings beyond the Roche radius. However, this previous work did not address the origin of the horseshoe configuration. Here, we study this phenomenon in the frame of the elliptical restricted 3-body problem, where ring particles are perturbed by mean motion resonances with the outer satellite Mimas.

2. Our model

Two types of resonances play different roles. The Lindblad resonance (LR) confines the rings radially, and prevents their spreading. This is illustrated for instance by the confinement of the outer edge of the B-ring by Mimas' 1:2 LR (which helps preserving the Cassini division), and by the confinement of the outer edge of the A-ring by Janus' 6:7 LR [5]. In contrast, the $n:n+1$ Corotation resonance (CR) confines the rings azimuthally in n capture sites (akin Neptune's arcs).

Because of Saturn's J_2, Mimas' 2:3 CR is 130 km closer to Saturn than the 2:3 LR. Today, they are both slightly outside the Roche radius and do not interact with the rings. But Mimas is migrating outwards under the influence of the ring torque et Saturn's tides. A few hundred million years ago, both the 2:3 LR and CR with Mimas were just inside the Roche radius. At this time, the rings were confined by the 2:3 LR, and the two capture sites of the CR were full of ring material (top left panel of figure 2).

When Mimas migrated outwards so that its 2:3 mean motion resonances receded past the Roche radius, the captured material agglomerated into two bodies of $\sim 10^{15}$ kg on the exact same orbit, as sketched on top right and bottom left panels of figure 2.

These bodies then migrate outwards together due to their interaction with the rings, in mutual horseshoe orbits. The rings spawn new small satellites, eventually accreted by the proto-Janus and the proto-Epimetheus, following the pyramidal regime of the ring spreading model [3] (see the bottom right panel of figure 2). The two bodies thus grow in mass. These merging events also excite their orbital separation, leading to a configuration close to the present one.

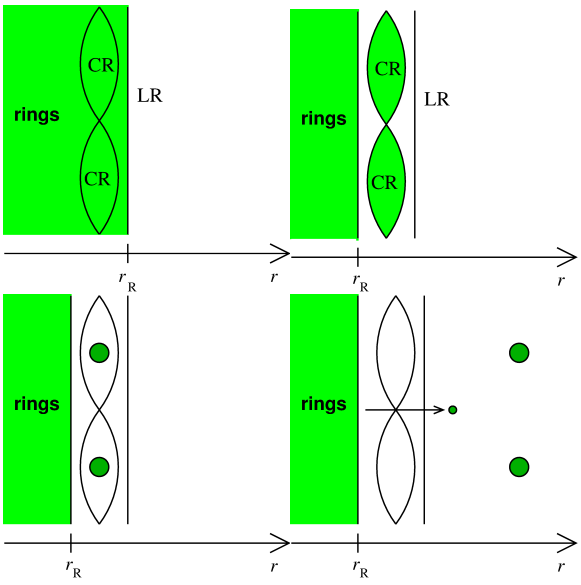

Figure 2: Sketch of our scenario for the formation of Janus and Epimetheus from the spreading of the rings
Top left : initial condition, Mimas confines the rings with it's 2:3 LR.
Top right : Mimas migrates outwards and its 2:3 mean motion resonances are now outside the Roche radius.
Bottom left : the ring material captured into the corotation sites agglomerates into 2 bodies on the same orbit.
Bottom right : the two bodies migrate outwards, while accreting satellitesimals spawn by the spreading of the rings.

3. Summary and perspective

We propose a novel solution to one of the most exciting mysteries of modern celestial mechanics : the origin of Janus and Epimetheus' mutual horseshoe configuration. In the frame of the recently developed model of formation of Saturn's regular satellites from the spreading of the rings beyond the Roche radius [1, 2, 3], Mimas' 2:3 Lindblad and Corotation resonances provide perfect conditions for the formation of 2 equal sized bodies on the same orbit.

References

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