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Apse-alignement in narrow-eccentric ringlets. The comparative case of the ε-ring of Uranus and the ring system of (10199) Chariklo.

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Abstract

The discovery of ring systems around objects of the outer Solar System provide a strong motivation to estimate better their physical and orbital properties, which shall help to refine models about their origin. In the case of the ring system of (10199) Chariklo, where there is evidence that the rings are eccentric, we apply a theory of apse-alignement, to derive information about the most plausible combinations of the values of its surface density, eccentricity and eccentricity-gradient, as well as the masses and location of their -presently undetected- shepherd-satellites.

1. Introduction

Ring systems have been recently discovered around the centaur (10199) Chariklo [1], trans-Neptunean object (136108) Haumea [2] and there is compelling evidence that (2060) Chiron [3] is also surrounded by rings. It has been shown that the rings of (10199) Chariklo are stable under close encounters with the major planets [4], but their migration timescale by Poynting-Robertson effect is approximately 10^7 yr [1] and the one by viscous collisional dissipation is only about 10^6 yr [1], which suggests that the rings are being confined in their present location by shepherd satellites, estimated to be of about 1km in size [1]. Moreover, occultations of (10199) Chariklo reveal that the rings are probably eccentric [5 and references therein]. We review the theoretical models of narrow-eccentric ringlets based on the equations of motion of the Lagrangian-displacement quantities, as it was applied to the ε-ring of Uranus and the Titan-ringlet of Saturn [6,7], and we apply it to the case of the ring system of (10199) Chariklo.

2. Methods

The angular momentum available to sustain the eccentric figure of the ring, which corresponds to the m=1 wave-mode, is supplied by the shepherd satellites and, for an outer Linblad resonance, is given by [6]:

$$(dJ_{m+1}/dt)/m+1=-(dE_{dis}/dt)/\Omega \qquad (1)$$

where Ω is the orbital frequency, dJ_{m+1}/dt is the angular momentum time rate corresponding to the m+1 satellite gravitational perturbing potential and dE_{dis}/dt is the energy dissipation rate in the ring, which can be caused either by viscous self-interactions along the whole ring or by the extreme compaction that may occur at the pericenter. For the case of the ϵ-ring of Uranus, this condition gives an excellent agreement in the later case [6]. For Charilo's system we compute the favourable combinations of mass of the satellite and resonance wave number, m, such that condition (1) is satisfied, for the 2 mentioned models of dissipation.

On the other hand, the rigid precession condition can be put as,

$$(\Omega_0-\omega_{prec}(r_0)).e(r_0).r_0=g_{int}(r_0)/\Omega, \qquad (2)$$

where Ω_0 is the pattern-frequency, $\omega_{prec}(a_0)$ is the local precession-frequency , r_0 is the distance to the central object, $e(r_0)$ the local eccentricity and $g_{int}(r_0)$ is the acceleration produced both by the self-gravity of the ring, gs_{SF}, and by selfinterations, g_{SI}. In the left-hand side we find the impulse necessary to kill the differential precession induced by the oblateness of the central object and on the right-hand side we find the forces that can counteract it. Using this condition, we can put a constraint on the value of the surface density and the collisional impulse [6]. This condition is obtained averaging in an angle that co-rotates with the pattern frequency, therefore we obtain a description radially across the ring.

3. Results

In Figure 1 we illustrate the radial distribution of impulses to produce a rigid precession. In Figure 2 we show the estimated mass of the shepherd satellite in the ring system of Chariklo, necessary to balance the eccentricity decay, calculated for 2 models of dissipation. In Figure 3 we plot the radially integrated self-interactions-impulse of each model.

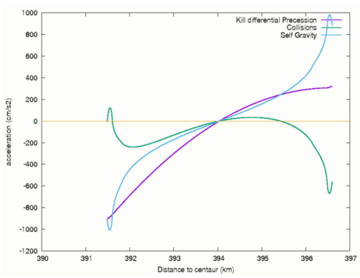

Figure 1: Radial distribution of impulses, $-g_{int}$, gs_{SF}, and g_{SI}. in Chariklo's system, for a model with eccentricity of 0.04, the eccentricity gradient 0.1 and surface density 20 g/cm^2.

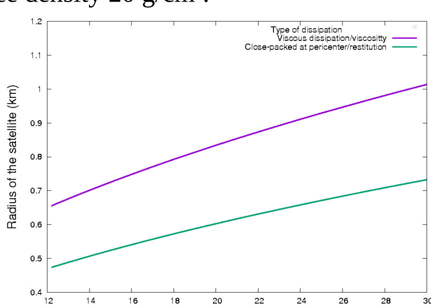

Figure 2: Estimated physical radii of the shepherd satellite (density 1g/cm^2), in Chariklo's system, as a function of the distance to the ring, for 2 models of dissipation. The eccentricity in this model is 0.012.

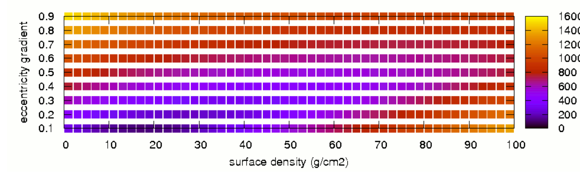

Figure 3: The integrated self-interactions impulse for different values of eccentricity gradient and surface density. The inner eccentricity in this case is 0.04.

4. Conclusions

We discuss how to produce a more precise determination of the mass of the ring system as well as the mass of the shepherds, for cases in which the rings are eccentric. When applied to the case of the centaur (10199) Chariklo we find that, if the ring is closed-packed at pericenter, the size of the shepherd satellites are in the range of ~1km. if not, their size can be considerably larger. Our preferred solution gives a plausible value for the surface density somewhat smaller than 20 g/cm^2 and a value eccentricity gradient of about 0.1. These results should offer additional constraints to primordial theories of these type of rings.

Acknowledgements

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