EPSC Abstracts
Vol. 11, EPSC2017-845, 2017
European Planetary Science Congress 2017

Formation of moon induced gaps in dense planetary rings

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Abstract

Discs are a common structure in the universe that appears on a vast range of different size scales: Galaxies, active galactic nuclei, protoplanetary discs, solar systems and planetary rings. Recent works have shown that bodies embedded in protoplanetary discs or planetary rings create S-shaped density modulations called propellers if their mass deceeds a certain threshold or cause a gap around the entire circumference of the disc if the embedded bodies mass exceeds it. Two counteracting physical processes govern the dynamics and determine what structure is created: The gravitational disturber excerts a torque on nearby disc particles, sweeping them away from itself on both sides thus depleting the discs density and forming a gap. Diffusive spreading of the disc material due to collisions counteracts the gravitational scattering and has the tendency to fill the gap. Propeller structures where predicted and discussed in detail by Spahn and Sremčević [1, 2] and were later discovered by the Cassini spacecraft [3, 4, 6, 5]. Cassini found the tiny moon Daphnis in the Keeler division [7] and just recently the ALMA radio telescope for the first time discovered gaps in a protoplanetary disc [8] thus might have indirectly whitnessed the birth of protoplanets.

We develop a nonlinear diffusion model that accounts for those two counteracting processes and describes the azimutally averaged surface density profile an embedded moon creates in planetary rings. The gaps width depends on the moons mass, its radial position and the rings viscosity allowing us to estimate the rings viscosity in the vicinity of the Encke and Keeler gap in Saturns A-Ring and compare it to previous measurements [9, 10]. We show that for the Keeler gap the time derivative of the semi-major axis as derived by [11] ($\frac{\mathrm{d}a}{\mathrm{d}t} \sim \frac{1}{x^4}$) is underestimated yielding an underestimated viscosity for the ring. We therefore derive a corrected expression for said time derivative by fitting the solutions of Hill's equations for an ensemble of test particles. Furthermore we estimate the masses for potentially unseen moonlets in the C-Ring and Cassini division.

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