EPSC Abstracts,
Vol. 2, EPSC2007-A-00191, 2007
European Planetary Science Congress 2007

How did the rings of Uranus form?

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Uranus is encircled by at least ten narrow, dense, and widely separated rings with a typical optical depth ~ 0.3, the first nine of which (6, 5, 4, α, β, η, γ, δ, and ϵ rings as seen going outward from Uranus) were discovered from the ground during observations of the planet's atmosphere in 1977. In this work, a fairly uniform, rapidly and differentially rotating disk of rarely colliding particles (when the frequency of interparticle collisions is much smaller than the local orbital frequency) in a planet–moon system is considered. A moon causes a number of orbital resonant effects in this continuous viscous (through ordinary collisions) disk. In the frame of hydrodynamical theory, the gravitational torques exerted by an exterior moon on particles at an inner Lindblad horizontal resonance and corresponding vertical resonance are estimated. It is shown that the torques are negative at these resonances, so gaps in the disk near each resonance may be created. The latter result can be used to provide a viable clue to solving of the puzzle of narrow, dense, and widely separated rings of Uranus. The model is advocated which suggests that the Uranian ring orbits have a close connection with small moons of the planet interior to the orbit of Miranda, from Cordelia to Mab discovered by VOYAGER 2 imaging observations in 1986. As angular momentum is transferred outward to the moon, material in the close vicinity of the resonances falls to the inner part of the system under study. On the other hand, in a collision disk the angular momentum is steadily concentrated onto a fraction of the mass which is spiraling away. In Uranus' system, this viscous radial spreading of the disk (and associated outward flow of angular momentum) may be terminated by the torque exerted by the moon via the low-order orbital resonance. This work was jointly supported by the Israel Science Foundation, the Binational U.S.–Israel Science Foundation, and the Israeli Ministry of Immigrant Absorption in the framework of the program "KAMEA."