

## **Fine-scale spiral structure of Saturn's main rings: theory and simulations**

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We review our recent studies of morphology and dynamics of low and moderately high optical depth regions of the Saturnian ring system of discrete mutually gravitating particles with special emphasis on its fine-scale spiral structure (cylindric structures of the order of 100 m or so). The very existence and the value of the critical wavelength  $\lambda_{\text{crit}} \sim 100$  m of the fine structure in a local version of both kinetic and hydrodynamic stability theories is explained. It is shown that there is a dominant Fourier mode of maximum instability of gravitational Jeans-type collective oscillations in Saturn's rings (and the associated number of spiral arms and the pitch angle). We again argue that sufficient velocity dispersion prevents the Jeans instability from occurring but inelastic interparticle collisions reduce the relative particle velocities so that the Jeans instability may be an effective generating mechanism for the recurrent fine structure of the ring system.

The viscosity (the angular momentum flux) in Saturn's ring disk is also investigated. It is suggested that in such a system the self-sustained hydrodynamic turbulence may arise as a result of the Jeans instability. The turbulence is related to stochastic motions of 'fluid' elements. We show that in the Jeans-unstable Saturnian ring disk the turbulent viscosity may exceed the ordinary microscopic viscosity substantially. The main result of local  $N$ -body simulations of planetary rings by Daisaka et al. (2001, *Icarus* **154**, 296-312) is explained: in the presence of the gravitationally unstable density waves, the effective turbulent viscosity  $\nu_{\text{eff}}$  is given as  $\nu_{\text{eff}} = CG^2\Sigma^2/\Omega^3$ , where  $G$ ,  $\Sigma$ , and  $\Omega$  are the gravitational constant, the surface mass density of a ring, and the angular velocity, respectively, and the non-dimensional correction factor  $C \approx 10$ . We argue that both Saturn's rings and their irregular of the order of 100 m or even

less fine structure are not likely much younger than the solar system. The validities of the theory are verified by  $N$ -body simulations. The stability analysis and simulations presented here would have to be regarded as an explanation of the long-term recurrent ring structure in the range of few tens to few hundreds meters in regions of Saturn's A, B, and C rings with optical depth  $\tau \lesssim 2 - 3$  that has been revealed in 2005-2006 CASSINI spacecraft high-resolution measurements.