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Self-gravity density waves in Saturn's main rings: the effect of finite disk thickness

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The fine-scale of the order of 100 m or even less density structure of the Saturnian brightest A and B rings with the appearance of record-grooves has been revealed by Voyager stellar occultation (e.g., Cuzzi et al. 2002, Fig. 2b therein) and Cassini scince images (Porco et al. 2005, Fig. 5A therein). Both spacecraft missions have shown that these relatively large "irregular variations" in optical depth are not associated with any resonances with known satellites. On a small scale the rings, surprisingly, have been observed to be undergo variation and oscillations with time and ring longitude (Smith et al. 1982). The latter indicates that probably the irregular variations are wave phenomena, and different instabilities of small-amplitude gravity perturbations may play important roles in ring's dynamics. In this work, the problem of the linear stability of the Saturnian ring system of mutually gravitating particles is examined with special emphasis on its fine-scale of the order of 100 m density wave structure (almost regularly spaced, aligned cylindric density enhancements and rarefications). Jeans' gravitational instabilities of gravity perturbations (e.g., those produced by a spontaneous disturbance) are analysed analytically through the use of hydrodynamic equations. An essential feature of this study is that the theory is not restricted by any assumptions regarding the thickness of the system. The simple model of the ring disk is considered: the disk is considered to be thin and its vertical structure is considered in a horizontally local approximation. In the equilibrium state, the density is regarded as nonuniform between two sharp surfaces, with a vacuum exterior. A self-consistent stratified vertical equilibrium with self-gravity is therefore computed. A plasma physics method is given for the solution of the self-consistent system of the gasdynamical equations

and the Poisson equation describing the stability of Saturn's rings when the system is perturbed in an arbitrary manner. That is, when a gravity perturbation does not distort the rings' plane (modes of even symmetry with respect to the equatorial plane, or even perturbations) and when does distort the rings' plane (odd perturbations). This approach is introduced here for the first time in an astrophysical context. The predictions of the theory are compared with observations and are found to be in good agreement. Particulary, it is shown that in good agreement with simulations and observations the physical scale of these longitudinal spiral density enhancements and rarefications (the width and the separation of the self-gravity density waves) is about 30-100 m. It is also shown that the spiral density enhancements are flattened structures, with height/width ratio of about 0.3. A separate investigation based on high-resolution of the order of 10 m observations of Saturn's A and B rings should be done to confirm (or deny!) this prediction.

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