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Overstability in fully self-gravitating system

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Abstract

Saturn's rings exhibit a wealth of radial structure covering a vast range of lengthscales [1]. On the shortest scales, quasi-periodic density variations of wavelengths ranging from one to a few hundred meters are observed intermittently populating several locations of the inner A-ring as well as the less opaque areas of the B-ring[2].

While external phenomena such as perturbations due to Saturn's inner satellites would explain other structures in the rings [3, 4, 5], it seems that these oscillatory density variations have an intrinsic origin related to some kind of instability in very dense collisional systems. A promising explanation for this sub-kilometer axisymmetric structures is the *viscous overstability* [6]. This mechanism, contrary to the viscous instability originally proposed, takes place when the dynamic shear viscosity grows sufficiently rapidly with the surface density. In this way, the collisional flow is directed from sub-dense regions to over-dense regions, such as in a viscously stable ring [7]. However, the system overshoots during the smoothing process and therefore generates sinusoidal perturbations with respect to time but with exponentially growing amplitudes (in the linear approximation). The superposition of these waves, with amplitudes saturated due to non-linear phenomena, could well yield structures such as those seen in the B-ring [16].

Viscosity overstability has been studied in the context of hydrodynamic and kinetic models [8, 9], as in N-body simulations [6, 10]. Self-gravitational N-body simulations were the ones that directly demonstrated for the first time the formation of spontaneous growth of axisymmetric oscillations. However, these structures can also be observed in non-gravitational simulations but shifted to much greater optical depth ($\sim$ 3-4) [6]. Therefore, the development depends sensitively on the collisional dynamics of the ring particles [7] and is not linked to the gravitational interaction between them. So far, the theoretical knowledge of overstable ring systems rely mainly on results based on approximative treatments of the self-gravity in terms of a enhanced ratio of the vertical to planar oscillation frequency [17]. This approximation leads to the generation of structures at optical depths ≥ 1. The trick has been widely used in hydrodynamic models that study both linear and non-linear weak evolution [11, 12]. In spite of this, including self-gravity may instigate non-axisymmetric wake structures that could compete with the overstables ones and alter their properties [10], not only the conditions for the onset but also their saturation. In this way, self-gravitational simulations would seem to limit the growth of excited wavelengths compared to collisional only simulations [13, 14]. This is illustrated in Figures 1 to 4.

We present a systematic study of fully self-gravitational large scale N-body simulations, expanding upon the study of [6]. For this purpose a new method is used, combining the tree-based routines of the open source REBOUND [15] with soft-particle impacts. We examine the factors which determinate the threshold density required for the triggering of overstability, both in non-gravitational and self-gravitational cases, and compare the saturation wavelengths.

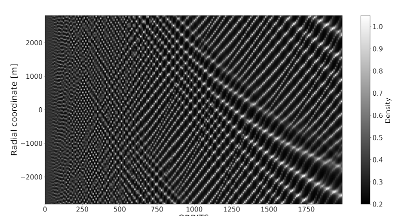

Figure 1: Stroboscopic space-time diagram of a non-gravitating simulations with optical depth τ = 1.2 and coefficient of restitution ϵ = 0.5.

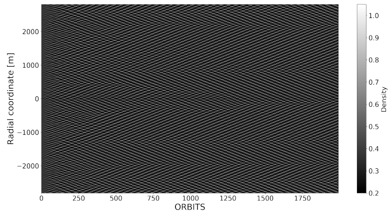

Figure 2: Stroboscopic space-time diagram of a self-gravitating system (same setup as Fig.1 and $r_h = 0.57$).

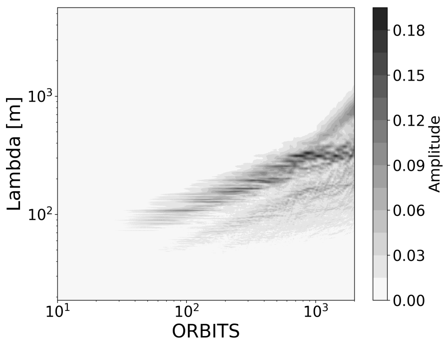

Figure 3: Evolution of the amplitude spectrum corresponding to Fig.1.

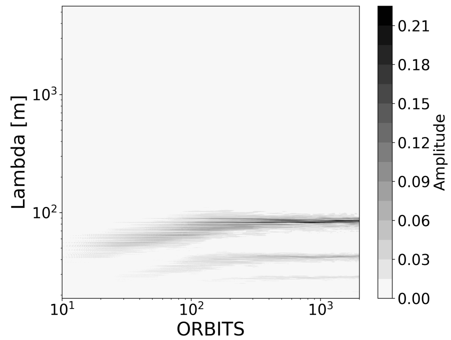

Figure 4: Evolution of the amplitude spectrum corresponding to Fig.2.

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