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Non-Linear Dynamics of Saturn's Rings

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Non-linear processes can explain why Saturn's rings are so active and dynamic. Ring systems differ from simple linear systems in two significant ways:
1. They are systems of granular material: where particle-to-particle collisions dominate; thus a *kinetic,* not a *fluid* description needed. We find that stresses are strikingly inhomogeneous and fluctuations are large compared to equilibrium.
2. They are strongly forced by resonances: which drive a non-linear response, pushing the system across thresholds that lead to persistent states.

Some of this non-linearity is captured in a simple Predator-Prey Model: Periodic forcing from the moon causes streamline crowding; This damps the relative velocity, and allows aggregates to grow. About a quarter phase later, the aggregates stir the system to higher relative velocity and the limit cycle repeats each orbit, with relative velocity ranging from nearly zero to a multiple of the orbit average: 2-10x is possible.

Results of driven N-body systems by Stuart Robbins: Even unforced rings show large variations; Forcing triggers aggregation; Some limit cycles and phase lags seen, but not always as predicted by predator-prey model.

Summary of Halo Results: A predator-prey model for ring dynamics produces transient structures like 'straw' that can explain the halo structure and spectroscopy: Cyclic velocity changes cause perturbed regions to reach higher collision speeds at some orbital phases, which preferentially removes small regolith particles; Surrounding particles diffuse back too slowly to erase the effect: this gives the halo morphology; This requires energetic collisions (v ≈ 10m/sec, with throw distances about 200km, implying objects of scale R ≈ 20km); We propose 'straw'.

Transform to Duffing Eqn : With the coordinate transformation, $z = M^{2/3}$**,** the Predator-Prey equations can be combined to form a single second-order differential equation with harmonic resonance forcing.

Ring dynamics and history implications: Moon-triggered clumping at perturbed regions in Saturn's rings creates both high velocity dispersion and large aggregates at these distances, explaining both small and large particles observed there. This confirms the triple architecture of ring particles: a broad size distribution of particles; these aggregate into temporary rubble piles; coated by a regolith of dust. Aggregates can explain many dynamic aspects of the rings and can renew rings by shielding and recycling the material within them, depending on how long the mass is sequestered. We can ask: Are Saturn's rings a *chaotic* non-linear driven system?