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Dynamics of particles in central Encke ringlet

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Abstract

The Encke gap is a 320 km wide division in the Saturn A ring centered at 133,581 km. There are at least 3 ringlets in Encke gap, and the central one shares the orbit with Pan [1]. Observations suggest that these ringlets are mainly composed of micron-sized particles [2]. The lifetime of these particles are restricted, mechanisms must be at work to replenish these ringlets. The kinetic balance of dust production, dynamical evolution, and loss of dust has been investigated in [3]. In this work, we focus on the particle dynamics in the Encke gap. Our results show that in the central Encke ringlet: (1) The solar radiation pressure provides a minimum particle radius of 7μm; (2) The plasma drag force pushes particle outward in a rate of $\sim 1\,\mathrm{km/yr}$; (3) Particles are in a 'modified' horseshoe orbit which is the result of horseshoe orbit plus plasma drag, this orbit prevent particles to reach large co-rotational longitudes of Pan.

1. Introduction

The time evolution of the total number of particle N in a dusty ringlet can be described by the gain rate $\dot{N^+}$ and loss rate $\dot{N^-}$

$$\frac{dN}{dt} = \dot{N^+} - \dot{N^-} \quad (1)$$

In central Encke ringlet, the kinky and clumpy structures are considered as results of embedded moonlets [1, 4]. These putative moonlets could serve as source and sink of ringlet particles [3]. Our main goal is to see the dynamical evolution of these particles after they are released from these putative moonlets.

2. Dynamics

The equation of motion for a particle orbiting Saturn is given by

$$m\ddot{\vec{r}} = \mathbf{F}_G + \mathbf{F}_{J2} + \mathbf{F}_{\odot} + \mathbf{F}_L + \mathbf{F}_C + \mathbf{F}_D \quad (2)$$

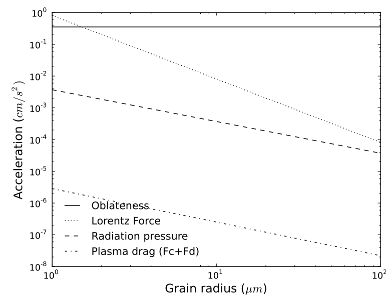

Figure 1: Comparison of perturbation forces for particle size range from 1 to 100μm in Encke gap. The plasma properties is described in the Section 2.2 and particles are charged to -4V. Although plasma drag force is relatively weaker, it is the only perturbation that changes the semi-major axis of particles, which accumulates over time.

The right hand side contains: gravitational force of Saturn, oblateness of Saturn, solar radiation pressure, Lorentz force, Coulomb drag force (between charged particles and plasma), and plasma direct collision. The terms $\mathbf{F}_G + \mathbf{F}_{J2}$ and $\mathbf{F}_L$ are given in [5], and the rest are discussed in the following. The comparison of the strength of these perturbations is shown in Fig. 1.

2.1. Solar radiation pressure

The orbit average parameter considering the solar radiation pressure with shadow of planet is introduced in [6], where the eccentricity is (for particles in central Encke ringlet)

$$e_f \approx 4.3 \times 10^{-3} \frac{Q_{pr}}{s/1\mu\mathrm{m}} \quad (3)$$

while s is particle radius and $Q_{pr} \approx 1$ is the solar radiation pressure efficiency of the particle. This indicates that for particles with radius smaller than 7μm, $e_f > 6 \times 10^{-4}$ and $ae_f > 80$ km (a is semi-major axis). The particle orbits are then intersect with outer Encke ringlet and are discarded due to collision.

2.2. Plasma Drag

The O^+ and O_2^+ ions over the Saturn main rings have been detected by Cassini spacecraft. Base on the model developed by [7] and our simple assumptions, we extrapolate the O^+/O_2^+ densities (1/2 cm^{-3}) and temperatures (2.5/4.2 eV) in Encke gap.

Plasma interacts with particles via direct collision and Coulomb forces. The former is given by [8], and the latter is taken from [9] (assuming Maxwellian plasma). Since plasma co-rotates with Saturn's spin, it is faster than ringlet particles which is in Kepler speed. So that ringlet particles are accelerated by plasma and their semi-major axes increase in a rate $\dot{a} \approx 1(10\mu\mathrm{m}/s)\ \mathrm{km/yr}$ for particle radius s between 1-100 μm.

2.3. Simulation results

The motion of particles are simulated by the RADAU integrator [10]. Examples are shown in Fig. 2. Plasma drag is pushing particles to larger radial distance. But particles are also in horseshoe orbit, once they encounter Pan at semi-major axes $a_{Pan} + da$, they will jump back to smaller radii $a_{Pan} - da$ and therefore the accumulated da by plasma drag is cancelled out (as shown in the solid line in Fig. 2).

The dashed line in Fig. 2 demonstrates a case when the plasma drag is decreasing with increasing semi-major axis. Such radial variation may be caused by different plasma properties. In such case, imagine a particle starts from $a_{Pan} - da$, because the plasma drag force decreases radially, when it encounter with Pan again, the semi-major axis would be $a_{Pan} + da'$, and da' is less than da. Therefore the particle trajectory is contracting.

Particles start from larger co-rotational longitudes need more time to encounter Pan. They may leave the horseshoe orbit (ringlet) before the encounter. Therefore ringlet particles in horseshoe orbit are confined to smaller co-rotational longitudes due to plasma drag.

3. Conclusion

We found that in the central Encke ringlet: (1) Solar radiation pressure provides a minimum particle size of 7 μm; (2) The plasma drag force pushes particle outward in a rate of $\sim 1\,\mathrm{km/yr}$; (3) Plasma drag drives particles to a 'modified' horseshoe orbit, where particles are restricted to smaller co-rotational longitudes. This may correspond to the observed arc-like structure in central Encke ringlet ([4]; M. Sremčević 2011, private communication).

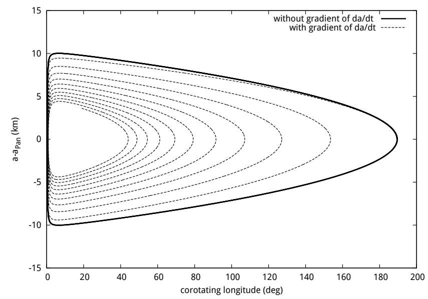

Figure 2: The trajectories of two 10μm particles in co-orbital frame of Pan in the presence of plasma drag, both trajectories are counter-clockwise.

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