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The dust environment near Methone, Anthe and Pallene

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Abstract

The ISS (Imaging Science Subsystem) of the Cassini spacecraft has detected three arcs/ring along the orbit of the three tiny moons: Methone, Anthe and Pallene [1]. Latest result by the CDA (Cosmic Dust Analyzer) instrument onboard Cassini confirmed the Pallene dust torus. The goal of this study is to understand the dynamics of particles after they have been ejected from surface of these tiny moons. The considered forces are gravity from the oblate Saturn, gravity from Mimas and Enceladus (nearby massive moons), Lorentz force, solar radiation pressure, and plasma drag. Among these forces, plasma drag pushes particles into larger semi-major axes in the rate of $\sim$ 100 km/yr for 10 μm particles. On the other hand, particles may temporarily trapped into resonances of Mimas or Enceladus. Such 'resonant lock' has been described by Dermott et al. 1994 for dust from asteroid belt temporarily locked by Earth resonances. This implies the higher number density of particles near resonances, such as the already known Methone and Anthe arcs. We will present the numerical simulation for the Methone and Anthe arcs as well as the Pallene torus and compare our results to observation.

1. Introduction

Three arcs/ring at orbit of the tiny moons (diameter $<$ 10km) Methone, Anthe, and Pallene have been observed [1]. These moons are located in the Saturn E ring between Mimas ($\sim 3R_s$, R_s is Saturn radii) and Enceladus ($\sim 4R_s$). The arcs near Methone and Anthe can be explained by the azimuthal confinement of nearby corotation resonances with Mimas, while the Pallene ring does not seem to have such a confinement [1].

The dust source of these arcs/ring are likely the ejecta from interplanetary micrometeoroid impact on these moons [1]. Once the ejecta escape the moons, their motion are controlled by several perturbing forces, as shown later in Eq. (1). Our main goal is to understand the dynamics of these ejecta and to compare with observation.

2. Dynamics

The equation of motion is [3, 4] :

$$m\ddot{\mathbf{r}} = \mathbf{F}_S + \mathbf{F}_m + \mathbf{F}_L + \mathbf{F}_\odot + \mathbf{F}_D + \mathbf{F}_C \qquad (1)$$

with the particle mass m and its acceleration $\ddot{\mathbf{r}}$. At the right hand side, we have the gravitational force from oblate Saturn $\mathbf{F}_S$ and from Mimas/Enceladus $\mathbf{F}_m$. Lorentz force $\mathbf{F}_L$ and solar radiation pressure $\mathbf{F}_\odot$ can be found in, e.g., Horanyi et al. 1992. The particles interact with plasma via direct collision ($\mathbf{F}_D$) and coulomb interaction ($\mathbf{F}_C$) [5, 6].

To calculate $\mathbf{F}_D$ and $\mathbf{F}_C$ we adapt the model where plasma interactions are dominated by water group ions with densities $\sim$40-50 cm^{-3} in this region [7].

2.1. Method

We simulate particle motion by the RADAU integrator [8, 9]. Particles are ejected from the surface of Methone, Anthe, and Pallene with initial velocity larger than the small escape velocity of these moons.

2.2. The perturbed orbit of particles

The perturbed orbit of particle orbiting planet under these forces has been discussed in [1, 3, 4, 10] and are consistent with our simulation results:

- Due to plasma drag, the semi-major axes of particles increase in a rate (da/dt) of about 100 km/yr for 10 μm particles. Note that da/dt is inverse proportional to particle size.

- The eccentricities e and inclinations i of particles are either determined by the initial e, i, or interplay of $\mathbf{F}_\odot$, $\mathbf{F}_L$, and planetary oblateness. The maximum e and i induced by the solar radiation pressure [11] are $e_{max} = 0.03Q_{pr}(1\,\mu\mathrm{m}/s)$ and $i_{max} = 0$, where s is particle radius and $Q_{pr} \approx 1$

is radiation pressure efficiency. $i_{max} = 0$ is because the extra force by solar radiation pressure is canceled out in one particle orbit, and in such case the i is determined by the initial i.

- Oblateness of Saturn and Lorentz force both cause the precession of particle orbits. The latter is ignorable for particles with radius larger than a few microns.
- Coulomb drag force $\mathbf{F}_C$ is ignorable (compare to $\mathbf{F}_D$) in this application.

3. Life of particle

At this point we may describe the life (birth, evolution, and death) of particles near Methone, Anthe, and Pallene as follow:

- Particles are produced and ejected from one of the tiny moons during impactor-eject process.
- Particles ejected from Methone and Anthe are likely trapped in corotation eccentric resonances (CER) in the beginning. Some may escape the trapping and migrate outward due to plasma drag forces. During outward migration, particles may again temporarily trapped in other resonances, as shown in Fig.1. Furthermore, result also show a trend that larger particles are more likely trapped in the resonances than smaller particles, probably due to smaller drag force which makes the larger ones inefficient to escape resonant lock.
- Particles may eventually collide with the next moon they encounter, or eroded due to plasma sputtering [12].

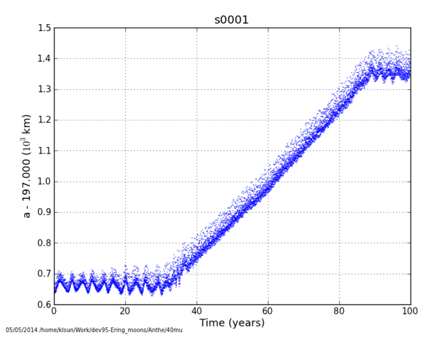

Figure 1: The time evolution of semi-major axis of a 40 μm test particle ejected from Anthe.

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