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Asymmetries in the dust flux at Mercury

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Abstract

Meteoroid impacts are an important source of neutral atoms in the exosphere of Mercury. Impacting particles of size smaller than 1 cm have been proposed to be the major contribution to exospheric gases ([2]). We have computed by means of N-body numerical integrations the orbital evolution of a large number of dust particles, in the size range between $5 - 100\ \mu m$, originating from both asteroidal and cometary sources. They migrate inward under the effect of drag forces until they encounter a terrestrial planet or eventually fall into the Sun. We have computed the flux of particles hitting Mercury's surface, the corresponding distribution of impact velocities and the asymmetries in the particles distribution on the Mercury orbit.

1. Introduction

The major sources of the dust population in the inner Solar System are asteroid collisions and debris released by short-period comets. The dust grains produced in the asteroid belt slowly evolve under solar radiation forces and the gravitational force of the Sun and planets. In particular, particles smaller than 1 cm are significantly perturbed by Poynting-Robertson and solar wind drag and spiral towards the Sun on timescales that depend on their size and composition. During their journey, they may be not only gravitationally scattered by terrestrial planets but also trapped into one or more mean motion resonances ([3], [5], [6]). Because of the interplay between the gravitational perturbations of the planets and the Poynting-Robertson drag, the orbital evolution can be quite complex. As a consequence, models based on a uniform and steady flux of dust grains from the Main Belt into the inner regions of the Solar System may be inappropriate. A full numerical approach is required to estimate how the grain population evolves while approaching the Sun. We study the long-term evolution of dust grains (i.e., r < 1 cm) coming from both asteroidal and cometary sources. By means of numerical simulations, we estimate the flux of dust particles on the surface of Mercury and their impact velocity distribution ([1]). The overall flux is tuned on the basis of direct measurements of the mass accretion rate of cosmic dust at Earth orbit from Long Duration Exposure Facility (LDEF) satellite ([4]).

2. Equations

To estimate the meteoritic flux at the heliocentric distance of Mercury we utilize the dynamical evolution model of dust particles of Marzari and Vanzani ([5]). It numerically integrates a $(N+1)+M$ body problem (Sun + N planets + M body with negligible mass) with the high-precision integrator RA15. Radiation and solar wind pressure and Poynting-Robertson drag are included as perturbative forces together with the gravitational attractions of all the planets in the Solar System.

Adopting the same formalism as Marzari and Vanzani ([5]) the gravitational term is given by:

$$\mathbf{F}_{gra} = \mathbf{F}^k + \mathbf{F}^d + \mathbf{F}^{ind}\,, \qquad (1)$$

where $\mathbf{F}^k$ is the keplerian force, $\mathbf{F}^d$ is the direct force and $\mathbf{F}^{ind}$ is the indirect force. Equation (1) can be written as

$$\begin{aligned} \mathbf{F}_{gra} &= \frac{Gm(M_{Sun}+m)\mathbf{r}_{Sun}}{r_{Sun}^3} \\ &+ \frac{Gm\sum_{j=1}^{N} m_j \mathbf{r}_j}{r_j^3} + \frac{Gm\sum_{j=1}^{N} m_j \mathbf{r}_{Sun,j}}{r_{Sun,j}^3}\,, \end{aligned} \qquad (2)$$

where r_{Sun} is the distance between the Sun and dust particles, r_j is the distance between planets and dust particles, m is the mass of dust particles and N is the number of planets.

The non-gravitational term is made up of two terms: the radiation force, $\mathbf{F}_{rad}$ and the force given by the solar wind, $\mathbf{F}_{wnd}$,

$$\mathbf{F}_{ngra} = \mathbf{F}_{rad} + \mathbf{F}_{wnd}\,, \qquad (3)$$

where

$$\mathbf{F}_{rad} = \frac{S}{c}\left(1 - \frac{\dot{r}}{c}\right) A Q_{pr} \hat{\mathbf{p}} = f_r \hat{\mathbf{p}}\,, \qquad (4)$$

and

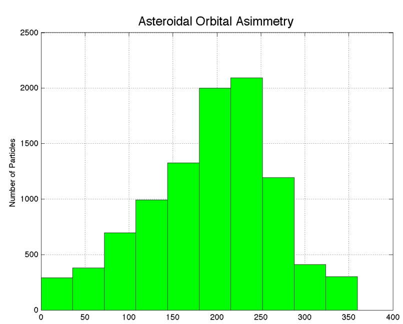
$$\mathbf{F}_{wnd} = \sum_j \frac{\eta_j u^2}{2} A C_{D,j} \hat{\mathbf{u}} = f_w \hat{\mathbf{u}}\,. \qquad (5)$$

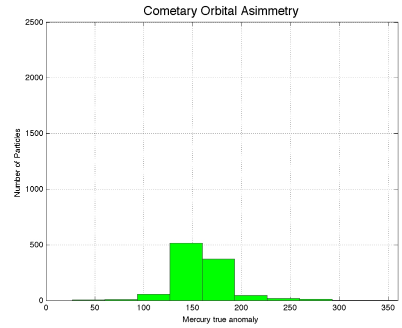
3. Calibration of the flux

To calibrate our flux, i.e. to compute the real number of grains which are represented by our test particles, we need to know the density of particles within our initial ring. The way that we consider to calibrate the density of our initial dust ring takes into account the observed flux of grains on the Earth. With this intent we record during each simulation the close encounters of test particles with the Earth. We then extrapolate, as for Mercury, the flux $g_E(r)$ of particles of a given size r on the Earth surface. We then derive a set of calibration coefficients $C(r)$ for all the sizes we considered in our simulations given by $C(r) = g_M(r)/g_E(r)$. These coefficients are used to “transport”the curve of the Earth meteoroid flux given by Love and Brownlee (1993), obtained from experimental data taken by satellite LDEF, to Mercury ([1]).

4. Figures

The dynamical model developed allows us to give an estimate of the dust particles asymmetries in the Mercury’s orbit. The figures 1 and 2 show the orbital asymmetry of asteroidal and cometary dust grains as a function of the Mercury true anomaly angle. The flux shown in the figures below has not been calibrated, but it is a direct output of the dynamical model.





5. Summary and Conclusions

We have analysed the dynamical evolution of micrometeoroids, originating from both asteroidal and cometary sources, to Mercury with the aim of computing the flux of meteoroids on the surface of the planet. In our numerical model we include the gravitational perturbations of all the planets and the Poynting-Robertson drag. We obtain interesting results in the flux determination but also in the asymmetries of dust particles in the orbit of Mercury. We are working on the relation between dust asymmetries and the planet latitude.

References

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