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Orbital Evolution of the Lunar Ejecta

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Abstract. We have estimated the flux of lunar ejecta near the Earth, e.g., the cumulative flux of ejecta larger than 10^{-13}g is 10^{-10}particles $cm^{-2}s^{-1}$. In addition, our numerical simulations for the orbital evolution of lunar ejecta lead to the orbital characterization of these ejecta. Since our calculations suggest that the incident direction of lunar ejecta onto the Earth is nearly isotropic, it is expected that the dynamical properties of lunar ejecta make it possible to distinguish them from other IDPs.

1. Introduction

Interplanetary dust particles(IDPs) have been collected in the stratosphere. Most IDPs are thought to be supplied from comets and asteroids, and a minor part may come from the moon.

In this study, we will examine orbital evolution of the lunar ejecta thrown out from the surface of the moon by hypervelocity impact of interplanetary dust particles and meteoroids. Alexander et al. (1984a,b) examined the flux of lunar ejecta and the dynamics of the transport from the lunar surface to the Earth's magnetosphere. We shall reexamine this subject based on another flux model derived from impact laboratory experiments (Nakamura & Fujiwara, 1991). Moreover we investigate the orbital evolution of lunar ejecta by numerical simulations, taking into account the gravity of the Sun, Earth and the moon as well as solar radiation pressure forces. Consequently we will estimate an average velocity of the lunar ejecta at the upper atmosphere of the Earth and the azimuthal distribution of impact directions relative to the Earth.

2. Flux of the Lunar Ejecta

We assume that the speed of impacting particles on the moon is 20 km s^{-1} and that the flux on the moon is isotropic (Grün et al. 1985). Since we neglect the sporadic nature of impacts onto the moon, we assume that an upper mass limit of impacting grains is 10^2g. The number density of lunar ejecta produced by an impact of meteoroids is estimated using laboratory measurements of collisional events by Davis et al. (1981) and Nakamura & Fujiwara (1991). The flux of the impacting particles by Grün et al. (1985) is used. The flux of lunar ejecta which escape from lunar gravitational field is shown in Fig. 1. We found that large ejecta ($> 10^{-10}$g) do not escape from the lunar gravitational field at these low velocities. On the other hand, we found that, a large number of small lunar

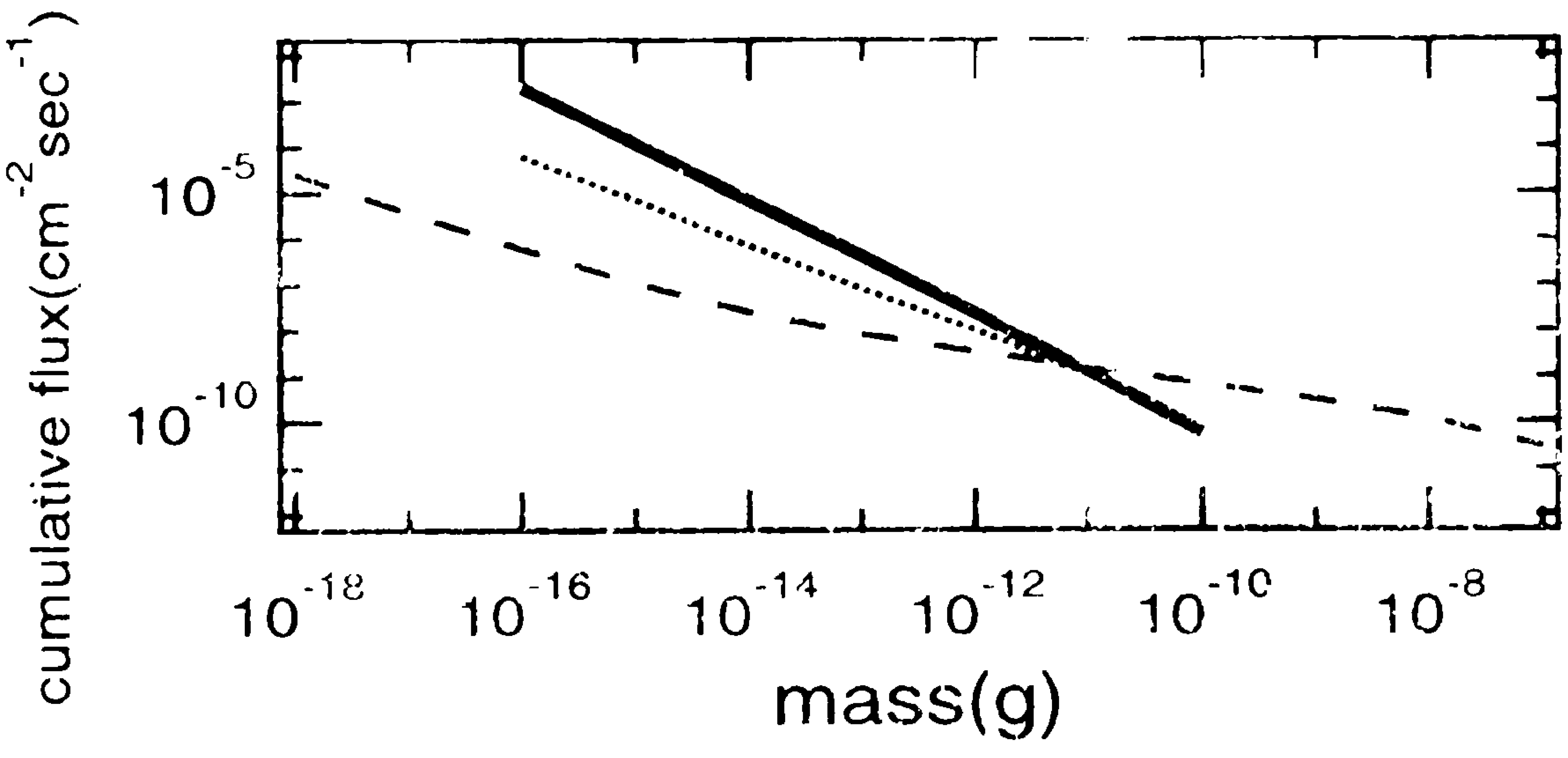

Figure 1. Cumulative flux of lunar ejecta near the lunar surface estimated here (solid curve) and by Alexander et al. (1984b) (dotted curve). The expected flux of interplanetary dust estimated by Grün et al. (1985) is also shown (dashed curve).

ejecta can escape from the moon. Especially, the flux of ejecta $< 10^{-12}$g exceeds that of the impacting particles. A comparison to the estimate by Alexander et al. (1984b) suggests that our flux is higher by a few orders of magnitude than their flux. The difference is due to our use of laboratory measurements recently obtained by Nakamura & Fujiwara (1991).

3. Orbital Evolution

After leaving the surface of the moon, lunar ejecta are influenced by the gravity forces of the Sun, Earth and the moon as well as by solar radiation forces. Here we have tried to examine the equations of motion under these forces and have performed calculations of the trajectories of lunar ejecta by numerical simulations for some initial conditions. We assumed that the angle between the ejection vector and the lunar surface is 45°. By using β, a ratio of the solar radiation pressure force to the gravitational force of the Sun (Burns et al. 1979) as a parameter, we have examined the orbital evolution of lunar ejecta as a function of β.

We found that the transit time of most ejecta from the moon to the upper atmosphere of the Earth is approximately one week, which agrees with the results of Alexander et al. (1984b). This means that the major fraction of lunar ejecta that reach the Earth arrive along a direct trajectory.

The average velocity of lunar ejecta has been found to be about 10 km s^{-1} when they reach the near-earth region. This value corresponds to the velocity of free fall toward the Earth from lunar orbit. It is reached because the major portion of lunar ejecta arriving in the near-Earth region falls directly after leaving the gravitational field of the moon, as noted above. This velocity is lower than the velocity expected for other IDPs, i.e., McDonnell (1978) reported impact speeds of grains near the Earth up to 100 km s^{-1} and an average near 43 km s^{-1} for grains of about 10^{-12}g. In addition, we have found that the velocity of lunar ejecta near the Earth is independent of the size.

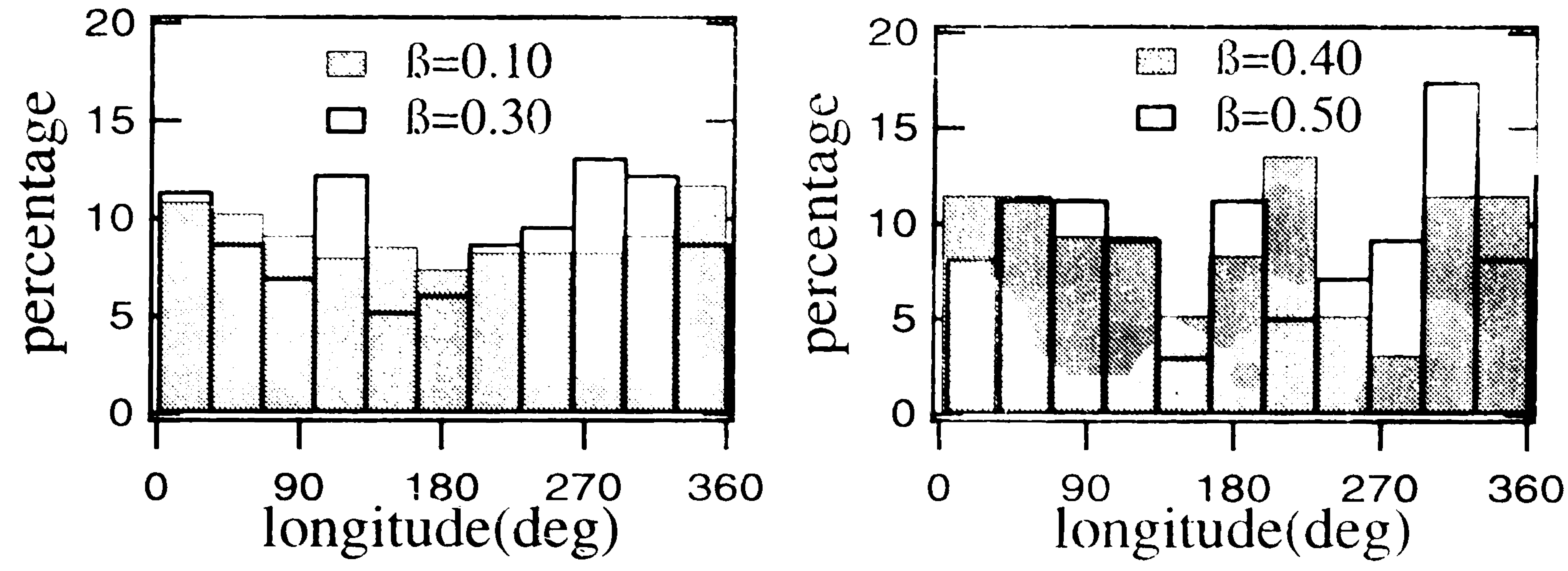

Figure 2. Distribution of impact directions of lunar ejecta onto the Earth. The apex of the Earth's motion and the direction to the Sun correspond to the longitude of 0°respectively 90°.

Figure 2 shows the distribution of impact directions of lunar ejecta onto the Earth. The values of $\beta = 0.1$, 0.3, 0.4 and 0.5, respectively, corresponding to masses of about $10^{-11}, 10^{-12}, 10^{-13}$ and 10^{-14}g. We found that the distribution becomes nearly isotropic. This differs from the orbital properties of other IDPs, that show at smaller masses an enhancement of the azimuthal distribution toward the Sun, called β-meteoroids by Żook & Berg (1975). Our simulations show that the distribution of impact directions of lunar ejecta is not affected by solar radiation pressure. This is because the distance between the Earth and the moon is too short to change the trajectories of lunar ejecta significantly by solar radiation pressure.

4. Conclusions

We have found that a large number of lunar ejecta are thrown out from the lunar surface. Particularly, the flux of particles with masses less than 10^{-12}g exceeds that of the background IDPs. The major portion of lunar ejecta that arrive to the near-Earth region take the shortest route from the moon. On the other hand, lunar ejecta which entered into orbit around the Earth cannot stay for a long time in that region. This comes from the computed result that the eccentricity of the orbit of these ejecta increases due to solar radiation pressure (Burns et al., 1979). Consequently, these orbits are distorted and these ejecta are scattered into heliocentric orbits due to the gravity of the moon. The average velocity of lunar ejecta is about 10 km s^{-1}, when they reach the near-Earth region. The velocity is lower than the average velocity of cometary particles. The distribution of incident directions of lunar ejecta to the Earth becomes nearly isotropic and independent of mass. It is known that the distribution of incident directions of other IDPs near the Earth tends toward the Sun for smaller grains (β-meteoroids) and concentrates in the apex direction of the Earth for larger grains (α-meteoroids). The dynamical properties of lunar ejecta may make it possible to distinguish them from other IDPs.

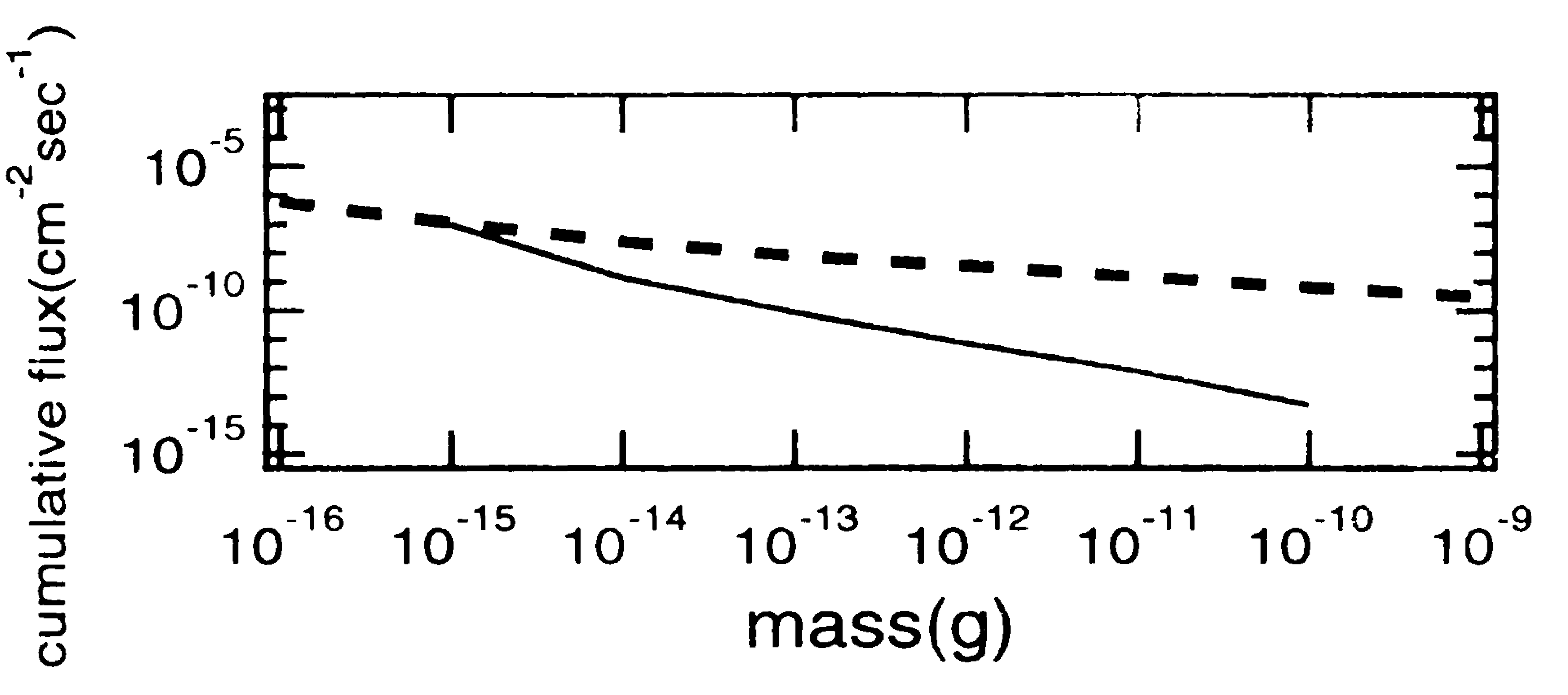

Figure 3. Flux of lunar ejecta impacting the Earth (solid curve). The expected flux of interplanetary dust estimated by Grün et al. (1985) is also shown (dashed curve).

From our numerical simulations of the orbital evolution of lunar ejecta, we have estimated the lunar ejecta flux impacting the Earth (Fig. 3). The flux is lower than that of the background IDPs at masses $> 10^{-15}$g. However the low velocity of lunar ejecta, compared with that of other IDPs, may result in higher survival probability of lunar ejecta during its entrance to the upper atmosphere of the Earth. The existence of lunar ejecta among particles collected in the upper atmosphere of the Earth has not been confirmed although larger meteorites originating from the moon have been found in the antarctic (Warren 1994). We hope that future measurements of dynamical properties of interplanetary dust near the Earth and the moon will confirm the existence of lunar ejecta.

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