Physics, Chemistry, and Dynamics of Interplanetary Dust
ASP Conference Series, Vol. 104, 1996
Bo A. S. Gustafson and Martha S. Hanner (eds.)

Measurement of Dust Electric Charges by the Ulysses and Galileo Dust Detectors

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1. Introduction

The Galileo and Ulysses dust detectors can detect electric charges of dust particles. Dust particles entering the sensor (see, e.g., Grün et al. 1992) may be detected by the charge Q_p that they induce to the charge grid. All suitably massive dust particles - charged or uncharged - are then detected by the cloud of ions and electrons they produce during the impact on the hemispherical target after the time of flight between the charge grid and the target. After separation in the electric field, ions and electrons are collected by separate electrodes and produce two pulses of opposite polarity. From the two pulse heights and the rise times, the mass and impact speed of the dust particle are derived.

The induced charge measurement is, however, the most difficult kind of measurement made by Galileo and Ulysses Dust Detectors for two reasons:

a) Dust particles in space are expected to be mostly only weakly charged by photoelectrons and low-energy plasma electrons. At a typical surface potential of $U = +5V$, the smallest spherical particle exceeding detection threshold has a radius of about 20 μm or a corresponding mass of 3×10^{-8} g at an assumed density of 1 g·cm^{-3}. Most of the particles detected so far are much smaller than this.

b) The charge grid is the measuring channel most exposed to ambient noise from both internal and exterior causes. Noise signals a factor ten above the threshold are quite common.

2. Data

We selected from all events detected by both detectors the events which were reliably identified as particle impacts. Assuming spherical particles with density 1 g·cm^{-3}, we derived the surface potentials U_p assuming that Q_p are the particle charges and not noise. As a criterion for identification of a possible real measurement of a particle charge, we required compatibility of particle speeds derived independently from the time of flight and rise times. The dust particles in interplanetary space should be positively charged, so we confine further discussion only to detections of signals $Q_p > 0$. The Ulysses dust detector recorded

https://doi.org/10.1017/S0252921100502085 Published online by Cambridge University Press

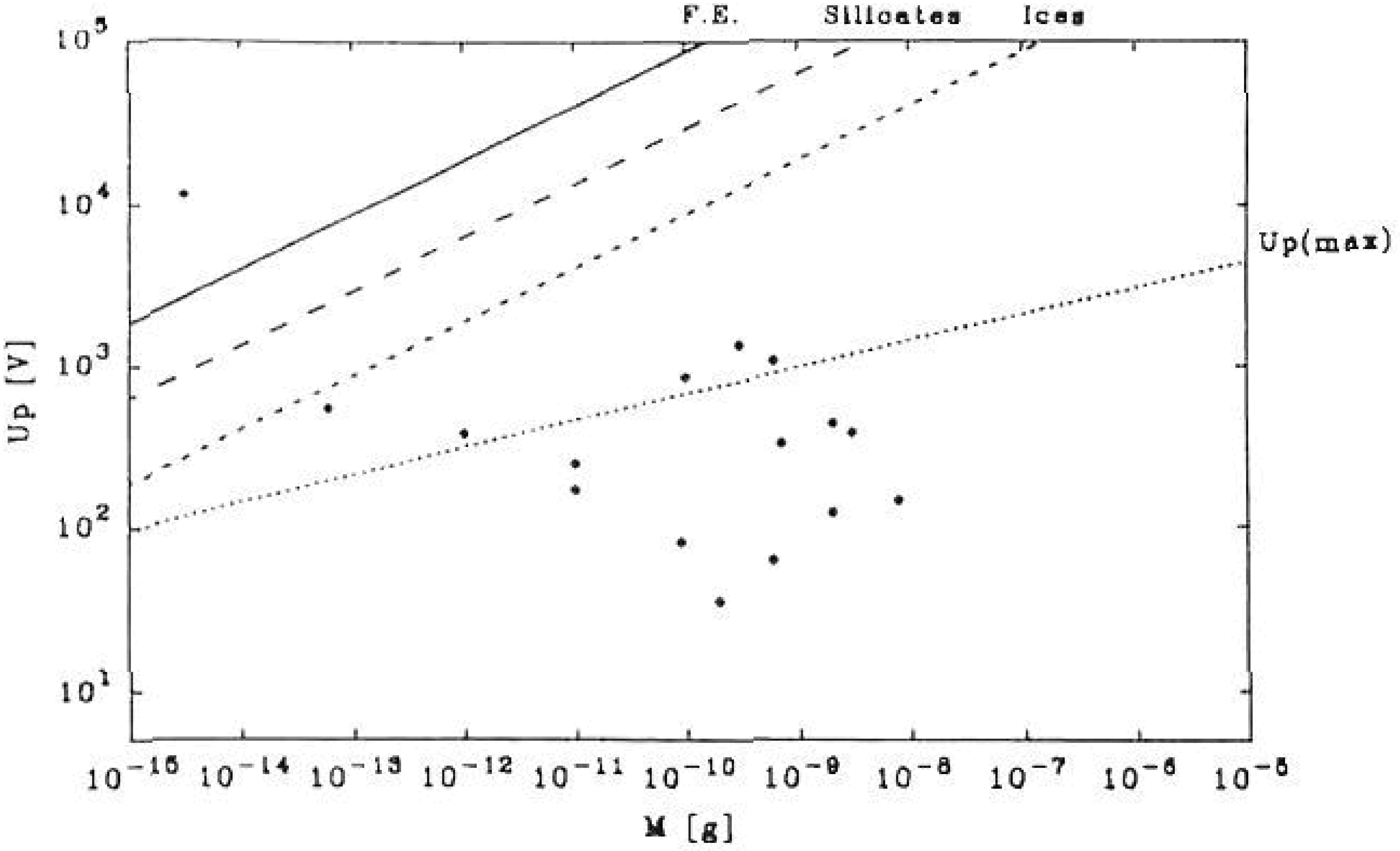

Figure 1. Dependence of U_p on the mass M for dust particles detected by Ulysses dust detector.

16 particles, during the first three years, with $Q_p > 0$ that meet the criterion of compatible speeds.

See Figure 1 for the dependence of U_p on the particle mass M. The Galileo dust detector detected bigger particles and, therefore, the probability to detect particle charges is higher. It recorded 34 impacts of particles with $Q_p > 0$ during the first four years of operation which meet the speed criterion.

The dependence of U_p on M for these particles is shown in Figure 2. It is seen in both figures that values of U_p are generally high compared to the expected +5 V. With the Helios micrometeoroid experiment it was tried for the first time to detect charges carried by individual dust particles. Assuming particle sphericity, the measurements also indicated, for four out the seven biggest particles ($m > 10^{-9}$ g), high electrostatic potentials of at least +100 V (Leinert and Grün 1990).

Q_p is also sensed by the target, not only by the entrance grid. As a charged particle approaches the target, the target signal is driven positive before the impact occurs and negative only some time thereafter. Thus it can appear as if the ion signal would have appeared first and the target signal second. This was frequently observed during tests of the Ulysses sensor with positively charged dust particles from the dust accelerator. This was also observed by both dust detectors for the majority of the particles with $Q_p > 0$ that meet the speed criterion.

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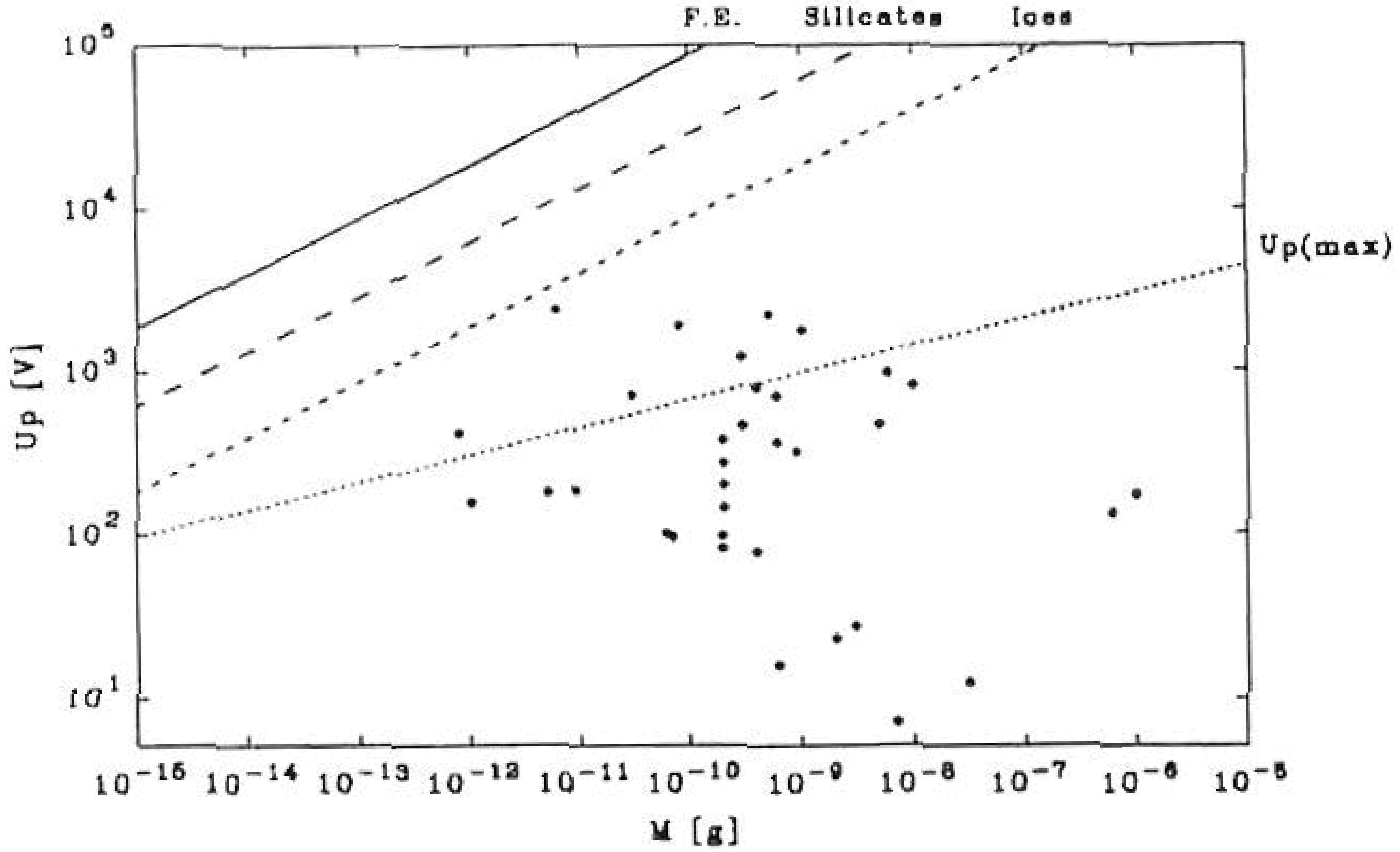

Figure 2. Dependence of U_p on the mass M for dust particles detected by Galileo dust detector.

3. Discussion

For a sphere with a radius r and a surface electrostatic potential U, the density of surface charges is expressed by $\sigma_r = Q/(4\pi r^2) = \epsilon_0 E_r = \epsilon_0 U/r$, where Q means the total charge on the surface of the grain and ϵ_0 is the dielectric constant of vacuum. The detected particles can be, however, highly non-spherical. It is well known that the charge distribution on the surface of a non-spherical particle is not uniform; such a particle can carry more electric charges and its charge-to-mass ratio can be higher compared to a spherical one. For instance, in the case of prolate and oblate spheroids the electric charge for a given electrostatic potential and the mass is increasing with the ratio of the major to minor axis (Mendis 1981).

We assume a simple model of a non-spherical particle in which protrusions on the surface of a spherical particle with a radius r are represented by hemispheres with a small radius of curvature a. The charge density σ_a on a hemisphere is given in the first approximation by $\sigma_a = \epsilon_0 U/a = \sigma_r r/a$ (Mukai 1991). Therefore, such particles at the potential U can carry more charges than spherical particles.

If we consider, as a model example, a particle of radius r, the surface of which is fully covered by the same number of convex and concave hemispheres of radii a=r/x (for meridian cut of such a particle see Figure 3), the total charge for a given potential will be x times higher compared to the spherical particle or the potential will be x times lower for a given charge. (The total surface area of all convex hemispheres is the same as the surface area of a spherical particle with radius r). The surface electric field strength will, however also be x times higher corresponding to x times higher potential of the spherical particle, which is giving

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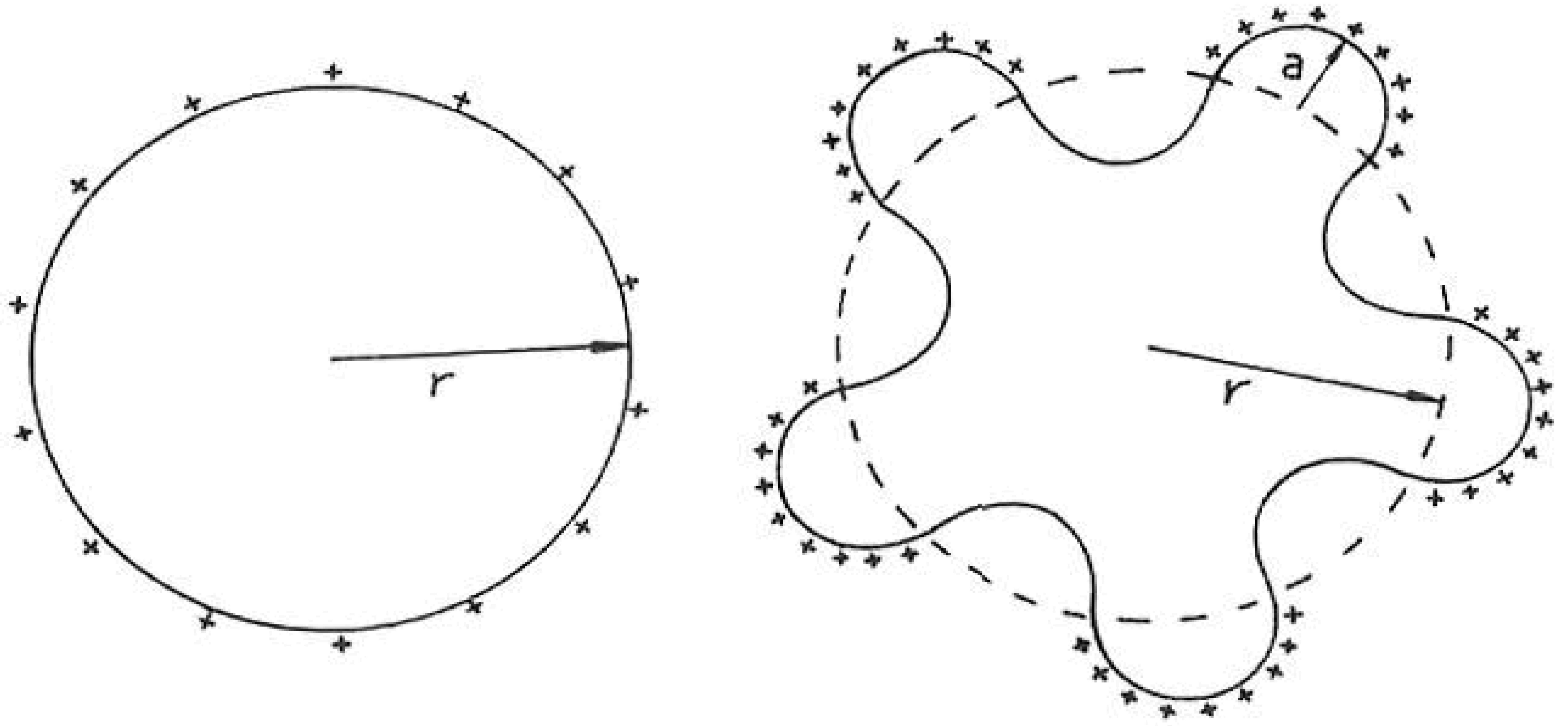

Figure 3. Comparison of charge distributions on the surface of a spherical particle and a non-spherical particle from our simple model.

a lower limit on a radius a. The surface electric field strength E has to be lower than the field strength at which electrostatic fragmentation ('electrostatic strcss' proportional to E^2 exceeding the tensile strength of a particle material) can occur or field emission of ions ($E = 3.10^{10} V/m$) is rapidly initiated. Figures 1 and 2 depict the lines of constant E which correspond to the field strength at which field emission of ions is rapidly initiated (denoted F.E.) and lines of constant E at which electrostatic fragmentation of 'big' samples of silicates and ices can occur. Tensile strengths of small particles are, however, uncertain and there exist indications that they can be significantly higher compared to 'big' samples, so that we consider field emission of ions a limiting physical process. Therefore, only electric charges on particles with U_p for which condition (U_p/5 Volt)$<$ ($U_{p_{F.E.}}/U_p$) is valid can be explained by our simple model ($U_{p_{F.E.}}$ is the value of U_p corresponding to the field emission limit of the respective particle). This condition is valid for the majority of particles in Figures 1 and 2, namely for all particles with U_p below the lines denoted U_p(max).

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