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Compositional Mapping of a Satellite Surface with a Dust Mass Spectrometer

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Abstract

Measuring the composition of cosmic dust in the vicinity of icy satellites provides unique insight into the physical and chemical conditions at its origin as demonstrated by Cassini's dust detector [Postberg et al., 2006, Postberg et al., 2009]. Information about the geological activities on and below a moon's surface is contained in the types and amounts of organic and inorganic components embedded in the dominant surface material. The basic idea of the proposed compositional mapping [Postberg et al., 2011] is that moons without an atmosphere are wrapped in clouds of dust particles (roughly micron sized) ejected by micro-meteroid impacts from the moon's surfaces [Krüger et al., 1999]. The composition of these dust particles can be analysed by an orbiter instrument. The ejecta particles move on ballistic trajectories and most of them re-collide with the moon. As a consequence, an almost isotropic dust cloud forms around the moon. From the statistics of the particles in the cloud, one can constrain their location of origin on the surface. Thus, from their composition one can conclude, with given probability, on the composition of a certain part of the surface. In this way, recording a large sample of dust grains with an orbiter, it will be possible to resolve compositional variations on the surface and relate them to topological features.

1. Dust Clouds around Satellites

In 1999, the Galileo dust instrument measured the density profiles of the tenuous dust exospheres around each of the Galilean satellites [Krüger et al., 1999]. The cloud density declines asymptotically with the distance as $r^{-5/2}$. This implies that a spacecraft in close orbits around such a satellite will be hit by a substantial number of ejecta arriving from apex direction with approximately spacecraft speed. The dynamic properties of the cloud particles are clearly distinct from any other kind of cosmic dust likely to be detected in the vicinity of the satellite. A detailed model of such a cloud was developed and applied to the Galileo measurements [Krivov et al., 2003].

2. The SUDA instrument

Built at the University of Colarado, the SUrface Dust Analyser (SUDA) is a time-of-flight, reflectron-type impact mass spectrometer, optimised for a high mass resolution which only weakly depends on the impact location. The small size ($268\times250\times171$ mm^3), low mass ($<$ 5 kg) and large sensitive area (220 cm^2) makes the instrument well suited for the challenging demands of a mission to the Galilean moons Europa, Ganymede, and Callisto. A full-size prototype SUDA instrument was built in order to demonstrate its performance through calibration experiments at the Heidelberg dust accelerator with a variety of cosmochemically relevant dust analogues. The effective mass resolution of m/Δm of 150-200 is achieved for mass range of interest m = 1-150.

3. Compositional Mapping

For every dust particle detected in the vicinity of the moon, the instrument is capable of constraining the location of origin on the surface. To this end we employ the statistics of particle trajectories in the ejecta cloud, constrained by measurement of grains' velocity along the instrument axis. We perform Monte Carlo simulations to demonstrate that compositionally distinct features in excess of 30 km on the surface can in this way be resolved by SUDA. As an example we show the compositional mapping of the dark lobated feature Thrace Macula (140km diameter) on Europa during at flyby at 25km distance (figure 1, upper panel). On the trajectory (white stripe, closest approach marked in blue) particles are detected at certain instances (black crosses) from a simulated cloud of ejecta particles. The cloud properties are consistent with those measured by the Galileo space-

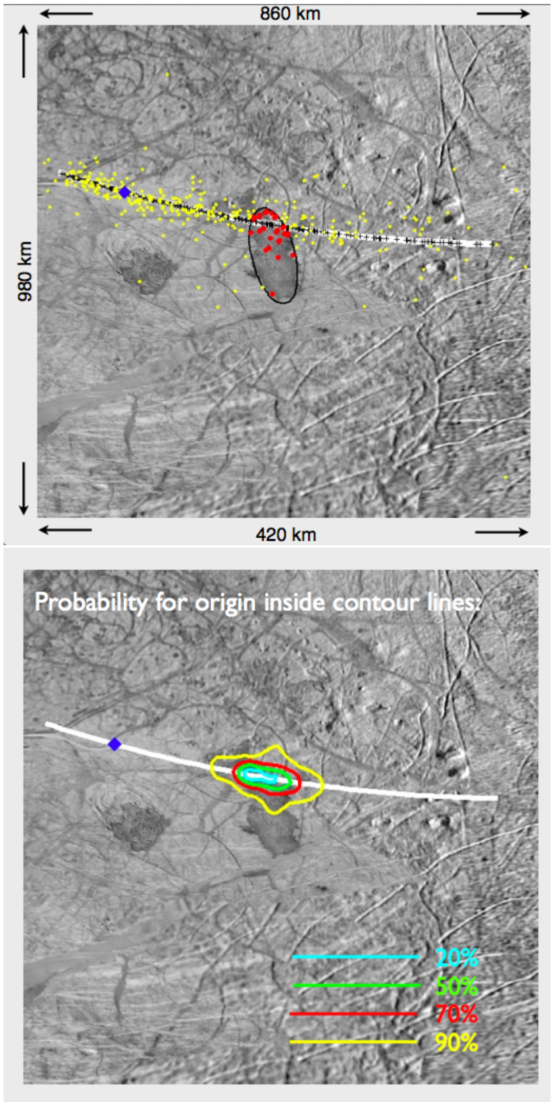

Figure 1: Monte Carlo simulation of dust sampling and compositional mapping (see text for explanation). *Upper panel*: Simulated 25 km flyby over Thrace Macula on Europa. *Lower Panel*: If particles from Thrace Macula are distinct in composition, one can relate this type with high significance to this feature.

craft [Krüger et al., 1999] and a random representation of the cloud is constructed from the model of [Krivov et al., 2003]. In figure (1) particle origins are marked with yellow dots on the surface. If they stem from Thrace Macula (black oval) a surface feature with distinct, darker color, then particle origins are marked in red.

In the simulation we can now select the particles from Thrace Macula and test in how far it is possible to reconstruct their location of origin. In the real measurement one would apply this procedure to a group of particles that stand out with a distinct compositional feature in their mass spectrum. The result of the simulation is shown in the lower panel of figure (1). The contours show the probability that the selected group of particles originated from inside the contour. One obtains a probability map that is symmetric around the trajectory. This is because the instrument does not measure the lateral velocity component of the grain at impact. Only the velocity component along the detector axis is measured with a given accuracy. This information is used to constrain the unmeasured velocity components from the statistics of the model ejecta cloud. In this way it is possible to correlate the measurement with the Thrace Macula feature.

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