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Dust Clouds of the Galilean satellites

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Abstract

All Galilean satellites are enshrouded in clouds of dust particles that have been lifted by meteoroid impacts from the moon's surfaces. The particles move on ballistic trajectories, most of which re-collide with the satellite. In situ mass spectroscopic analysis of these particles provides spatially resolved mapping of the surface composition of Europa and Ganymede. Even trace amounts of endogenic and exogenic minerals (e.g., salts), cyanogen-, sulfur-, and organic compounds which are embedded in ejected ice grains can be quantified with high accuracy. The achieved knowledge about surface-interior exchange processes could provide information about the internal composition of the satellites. Next generation dust detectors are very sensitive to cryo-volcanic phenomena. Mass spectra of particles emitted by such an activity carry unaltered signatures of the subsurface, probably oceanic, composition of the satellite.

1. Introduction

Dust particles detected by sensors on spacecraft carry precious information about their parent bodies. For example, the composition of dust grains ejected from a moon's surface by meteoroid impacts can be analyzed by a dust mass spectrometer on a spacecraft orbiting the moon. Thus, the compositional in-situ analysis of a satellite's surface can be performed even without a lander. High resolution compositional data of dust measured in the vicinity of a dust-producing moon such as Ganymede provides key chemical constraints for understanding the satellite's history and geological evolution.

The analysis of emitted solids (released either by meteoroid impact or active venting) by a dust camera is complementary to studies by remote sensing methods (e.g. by infrared spectroscopy) and analysis of the gas phase (by an ion and neutral mass spectrometer such as Cassini's INMS[12]). Unfortunately, interpretation of optical spectroscopy data is often not unique. This is of particular relevance for the hydrated salts exposed on Europa's and Ganymede's surfaces which probably come from the internal ocean[6].

Table 1: Parameters of dust exospheres of the Galilean satellites: the moon radius R_m, the ejecta mass production rate M^+, and value of n_0 defined in Eq. (1) computed for ejecta cloud populated by grains $>$ 200 nm. The flux and speed of the interplanetary meteoroids was assumed to be $F_{imp}^{\infty} = 7.6 \cdot 10^{-16}$ kg m^{-2}s^{-1} and $v^{\infty} = 9\,\mathrm{km\,s^{-1}}$[4].

Moon	Radius (km)	Yield	n_0 (m^{-3})
Callisto	2 410	89	$3.5 \cdot 10^{-5}$
Ganymede	2 631	251	$1.4 \cdot 10^{-4}$
Europa	1 561	201	$6.7 \cdot 10^{-4}$

Next generation dust mass spectrometers such as the Surface Dust Analyser (SUDA) are very sensitive to different types of salts and carbonaceous material. Only direct sampling will provide unambiguous evidence for the origin of the surface materials and it is important that both, solid and gas phases be measured. For example, Cassini's dust detector CDA[10] found sodium salts in the dust particles from Saturn's satellite Enceladus [8], while groundbased, telescopic, high-resolution spectroscopy and the Cassini INMS did not detect any sodium in the emerging plume gas [9].

2. Dust exospheres of atmosphere-free moons

Atmosphere-free satellites are enshrouded in clouds of dust particles ejected by meteoroid impacts from the moon's surfaces. This process is very efficient: a typical interplanetary 10^{-8}kg micrometeoroid impacting a Jovian moon produces a large number of dust particles, which total mass is of the order of a few thousand times of the impactor's mass[3] (see Tab. 1). The so-called ejecta particles move on ballistic trajectories, most of which have lower initial speeds than the moon's escape speed and re-collide with the satellite. As a consequence, an almost isotropic dust exosphere forms around the moon[4, 11]. In 1999, the Galileo dust instrument measured the density profiles of the tenuous dust exospheres around the Galilean satellites Callisto, Ganymede, and Europa[5]. On the other hand, particles ejected fast enough to escape from the moon's gravity may from tenuous dust rings such as Jupiter's gossamer rings[7, 1].

The number density n of a dust exosphere around a moon with the radius R_M approximately scales with the distance $\hat{r} = r/R_M$ as

$$n(\hat{r}) = n_0 \left(1 + \frac{2}{3}\hat{r}^{-1}\right)^{\frac{1}{2}\beta_v} \hat{r}^{-\frac{5}{2}}, \tag{1}$$

where β_v is the slope of the ejecta speed distribution, which is $\beta_v = 1.7$ for the dirty ice surfaces of the Galilean satellites and $\beta_v = 3$ for the regolith surface of the Earth moon[4]. The cloud density declines asymptotically as $\sim r^{-5/2}$, i.e. the cloud extent is only of a few moon radii. However, spacecrafts in close orbits around a satellite is likely to detect a substantial number of ejecta. This fact is the basis of the innovative "surface dust spectroscopy" technique that allows to perform an in-situ composition analysis of a satellite's surface by an orbiter instrument[2].

The maximum speed of the cloud particles must be smaller than the moon's escape speed, which in turn is smaller than the speed of a spacecraft in orbit around the moon. This implies that the cloud particles hit the dust detector with approximately spacecraft speed v_{sc} and arrive from apex direction. 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. The small difference between v_{sc} and the dust impact speed is the ejecta speed in the frame of rest and can be measured with a high resolution trajectory sensor.

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