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Dust Spectroscopy of Jovian Satellite Surface Composition

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Abstract

All Galilean satellites are enshrouded in clouds of dust particles that have been lifted by meteoroid impacts from the moons 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 cryovolcanic phenomena. Mass spectra of particles emitted by such an activity carry unaltered signatures of the subsurface, probably oceanic, composition of the satellite. The instrument will address the following JGO/GEO science objectives:

- Determine global surface compositions and chemistry, especially related to habitability
- Characterize the ice shells and any subsurface water, including the heterogeneity of ice, and the nature of surface-ice-ocean exchange
- Understand the formation of surface features, including sites of recent or current activity and characterize candidate sites for future in-situ operation
- Understand the Jovian satellite system, especially as context for Europa and Ganymede
- Determine the interactions occurring in the Jovian system: Compositional and dynamic monitoring of dust expelled by Ios volcanoes, determine mass infall on Europa and Ganymede

Satellite Geology and Geochemistry by Dust Spectroscopy

Dust particles are small samples from the solid surface of, for example, a satellite such as Europa or Ganymede. In the absence of a lander for in situ analysis, composition analysis of a satellites surface can be carried out by analyzing the ejected dust particles in the vicinity of the satellite and its exosphere. Collecting and analyzing dust particles from low altitude orbit establishes a direct link to the grains origin at the surface and provides a very good opportunity to get information on the surface and subsurface composition in the regions where surface material has only recently been exposed. Data obtained by measuring the dust in the vicinity of a satellite can provide key chemical constraints for revealing the satellites composition, history, and geological evolution.

The analysis of emitted solids (released either by meteoroid impact or active venting) by a dust telescope 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, INMS). Interpretation of optical spectroscopy data is often not unique. This is of particular relevance for the hydrated salts exposed on Europas and Ganymedes surfaces which probably come from the internal ocean [1]. The detector proposed here is 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, the Cassini CDA instrument found sodium salts in the dust particles from Saturns satellite Enceladus [2], while groundbased, telescopic, high-resolution spectroscopy and the Cassini INMS did not detect any Na in the emerging plume gas [3].

Instrument Description

The Dust Telescope (DT) is composed of two parts, the Trajectory Sensor (TS) and a Mass Spectrometer (MS) subsystem. This sensor is an in-situ instrument detecting and analyzing individual impacts of sub-micron and micron sized dust grains. First, the dust particles pass the Trajectory Sensor with its four planes of wires measuring the induced electrical charge of the grains to derive their trajectory information. The

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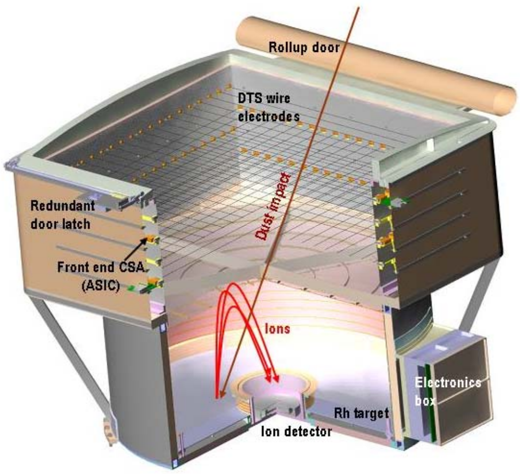

Figure 1: Dust Telescope (DUNE-SMEX version) with the four planes of wires of the Trajectory Sensor (top) and the time-of-flight mass-spectrometer (bottom). A particle impacting on the target generates electrons, ions, and charged cluster-molecules which are focused to the ion detector in the centre. Data acquisition is triggered by the electron signal collected at the target and by the ion signal.

grains impact on the plane target of the MS at the bottom of the instrument (Fig. 2) generating electrons and ions which are analyzed in a time-of-flight spectrometer. The two subsystems the Trajectory Sensor and the Mass Spectrometer are spatially separated but combined in a compact design and their size is scalable to adjust for the modeled dust flux ($0.01\mathrm{m}^{-2}$ to $1\mathrm{m}^{-2}$).

The Trajectory Sensor

This subsystem determines in-situ the speed, mass, primary charge and trajectory of micrometeoroids with particle sizes of between 0.3 and $60\,\mu$m. The measurement is based on charge induction of the particle primary charge onto individual metal wires [4]. Each wire is connected to a separate charge sensitive amplifier of high sensitivity. Particles in space are charged to positive potentials of approximately $+5$ V. Therefore, particles a micron-sized grain already carries a surface charge of 0.6 fC. This charge corresponds to 3500 electrons and can easily be measured with advanced techniques. However, environmental conditions with higher plasma or gas densities lead to variations of the grain surface charges and the potential might be lower than 5 V. This is not considered as a problem since the sensitivity is given by the noise of the electronics which is $1.5 \cdot 10^{-17}$ C. A signal-to-noise ratio of 10 leads to a detection threshold of $0.3\,\mu$m for grains with 1 V and to a detection threshold of $1.4\,\mu$m for grains with 1 V surface potential.

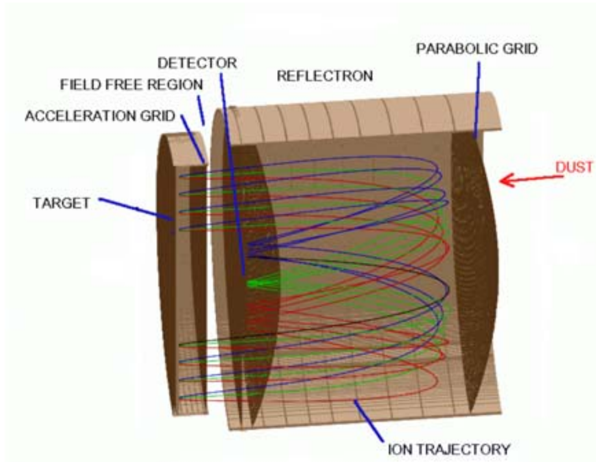

Figure 2: Ion optics of the mass spectrometer

The Mass Spectrometer

The TOF spectrometer design provides both a large sensitive area ($0.02\,\mathrm{m}^2$ to $0.1\,\mathrm{m}^2$) and a high mass resolution ($M/\Delta M \sim 200$). An even higher mass resolution (up to 60,000) will be reached in case the Orbitrap system is integrated into the dust telescope. Dust particles enter the aperture and fly through a set of shielding and reflectron grids before they impact on the plane, ring shaped target. A dust impact of ~ 1.6 km s^{-1} generates charged and uncharged fragments, electrons, ions, and neutral and charged molecule clusters. A high voltage of 5 kV separates the charges and the electron pulse is detected by a charge sensitive amplifier connected at the target which triggers the measurement. Although the impacts might occur with rather low velocities (~ 2 km s^{-1}), the impact of icy dust grains still produces a significant amount of impact charges. The ions enter the reflectron and are focused towards an ion detector. The retarding field of the reflectron was optimized to achieve the best spatial and time focusing at the ion detector area.

References

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