Compositional Mapping of the Galilean Moons by Mass Spectrometry of Dust Ejecta

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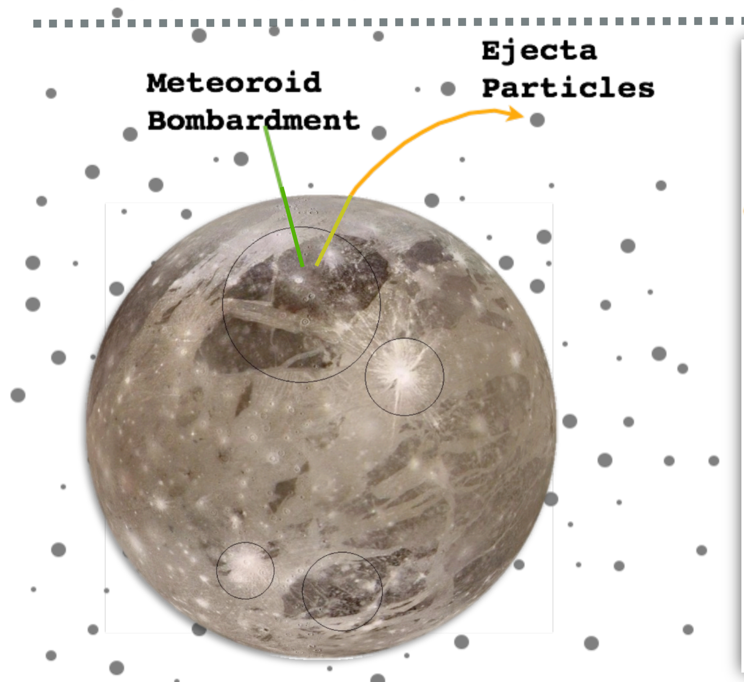
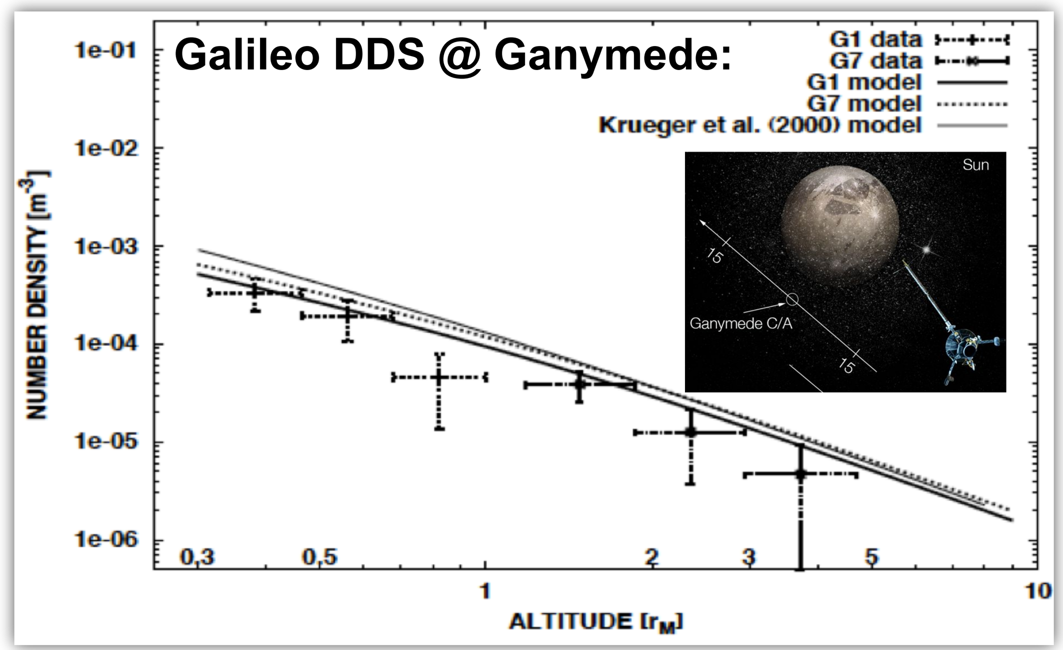
SUMMARY: The Galilean icy moons are enshrouded by dust clouds lifted from their surfaces by micro-meteroid bombardment. It is relatively easy to analyze these particles as almost unaltered samples of planetary surfaces at flybys or from an orbiter. In this novel approach dust is no longer the target but instead the means of the research. The method is based on the well established technique of dust detection by impact ionisation. It allows the qualitative and quantitative analysis of a huge number of samples and thus combines the advantages of remote sensing and a lander. The detected particles can be traced back to the point of ejection at the surface and information on the molecular composition can be acquired. The main scientific output is a compositional map from thousands of samples taken from a greater part of the surface. The approach has a ppm-level sensitivity to non-icy materials as salts and other anorganic compounds as well as organic compounds embedded in the ice matrix. Regions which were subject to endogenic or exogenic alteration (resurfacing, radiation, old/young regions) can be distinguished and investigated. In particular exchange processes with Europa's & Ganymede's subsurface ocean is determined with high quantitative precision. SUDA is an improved, low-mass (~7kg), high TRL, instrument based on the heritage of instruments onboard Ghiotto, Ulysses, Galileo, and Cassini. Lab-models have been built and tested.

Motivation





Galileo dust detector (DDS) heritage

- **detection of dust envelopes** around Europa, Ganymede, and Callisto [1]
- **surface samples** delivered to orbit by micro-meteroid bombardment
- **but: DDS not equipped with TOF - spectrometer for compositional analysis**

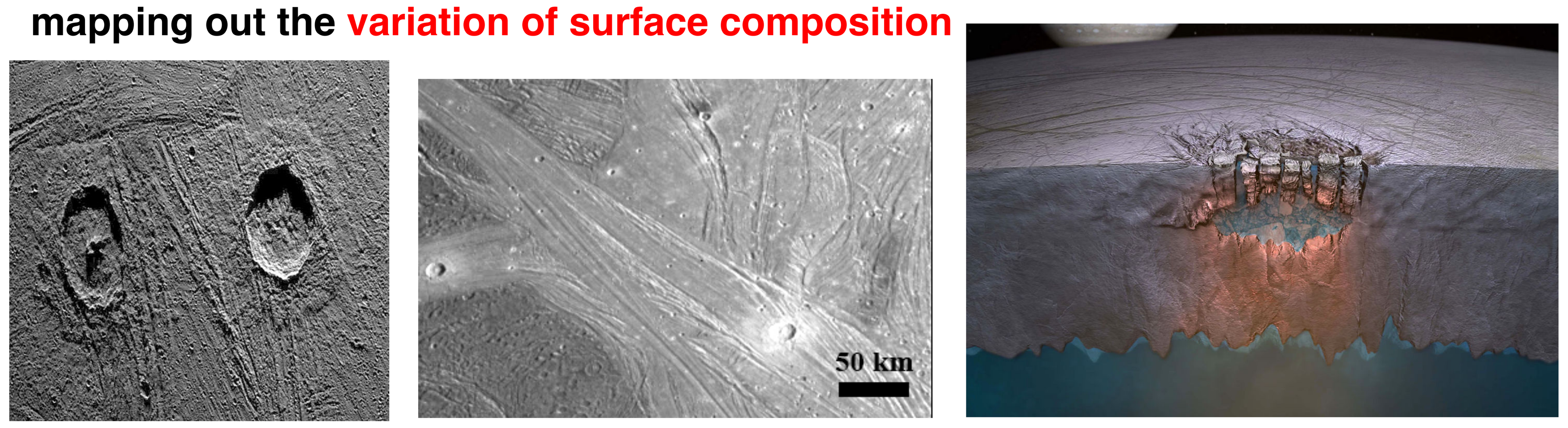
Modern dust telescope: Compositional surface mapping [2]

- **TOF-MS infers precise in situ particle composition → surface composition**
- **direct information on the origin on the surface**
- **unique tool to achieve scientific goals of JUICE & Europa Clipper missions**

Science Objectives

Science capabilities

- **quantitative in situ analysis of unaltered micron-sized surface samples**
- **ppm - sensitivity to salts, hydrated & unhydrated minerals, organic compounds**
- **tracing back individual grains to the surface with accuracy of < 100 km: mapping out the variation of surface composition**

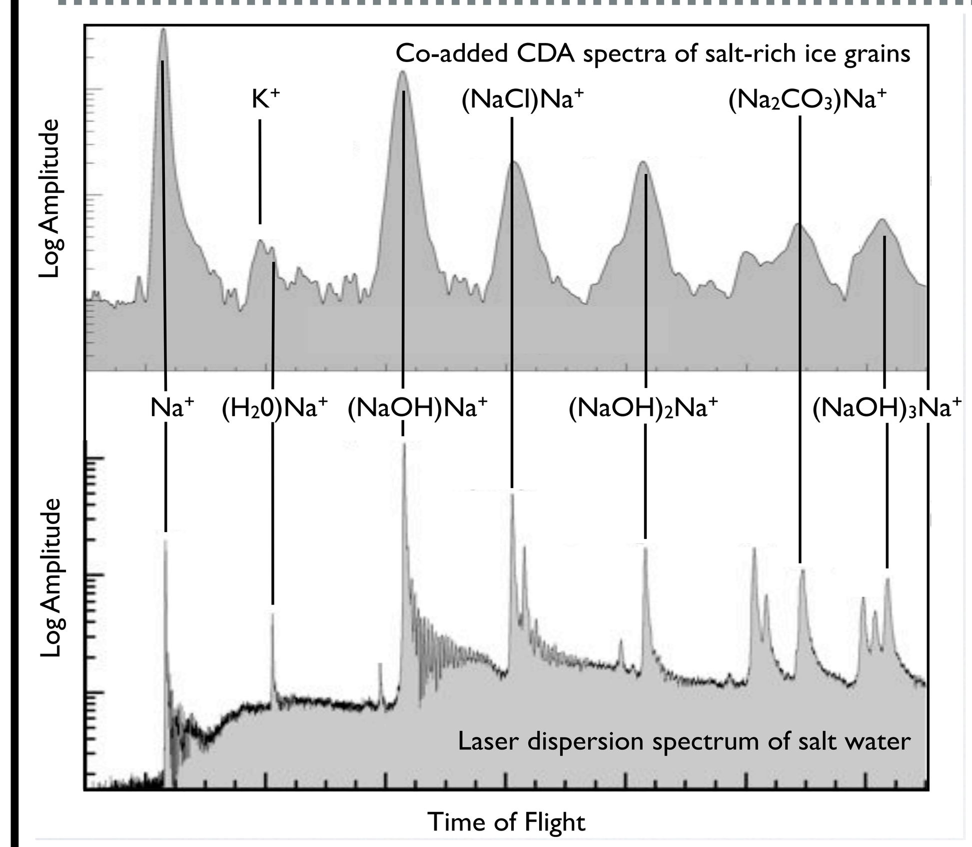


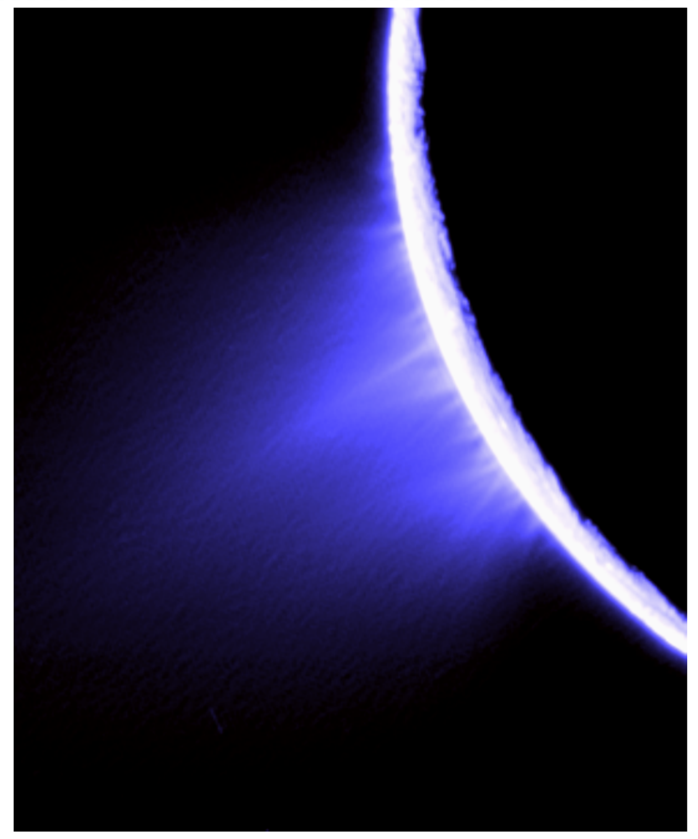
Ganymede & Europa science objectives addressed

- **non-water-ice compounds in ice shell, relation to surface geology**
- **exchange processes with interior and subsurface ocean**
- **habitability, astrobiology**
- **tectonic activity, resurfacing events, volcanism**
- **is there ongoing geological activity?**
- **coupling of the surface to exogenous environment: space weathering, surface age**
- **monitor material infall (i.e. particles from Io)**

[1] Krüger *et al.*, (1999) *Detection of an impact generated dust cloud around Ganymede*, Nature, 299
[2] Postberg *et al.*, (2011) *Compositional Mapping of Planetary Moons by Mass Spectrometry of Dust Ejecta.* PSS,doi:1016/j.pss2011.05.001
[3] Postberg *et al.*, (2009) *Sodium Salts in E Ring Ice Grains from an Ocean below the surface of Enceladus*. Nature, 459
[4] Postberg *et al.*, (2011) *A saltwater reservoir as the source of a compositionally stratified plume on Enceladus*. Nature, 474
[5] Kempf *et al.*, (2011) *Linear high resolution dust mass spectrometer for a mission to the Galilean satellites*. PSS in press
[6] Srama, et al., (2008) *A small dust Telescope for the Measurment of interplanetary dust.* EPSC Conference Abstract, Vol. 3

Test case: Enceladus with Cassini CDA





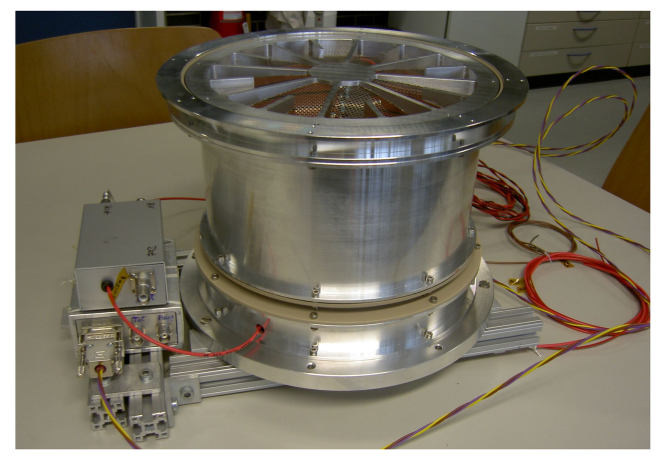
TOF-spectra from Cassini CDA [3]:
- **sampling of ice grains from Enceladus plumes**
- **extreme sensitivity to non-water compounds in ice matrix**

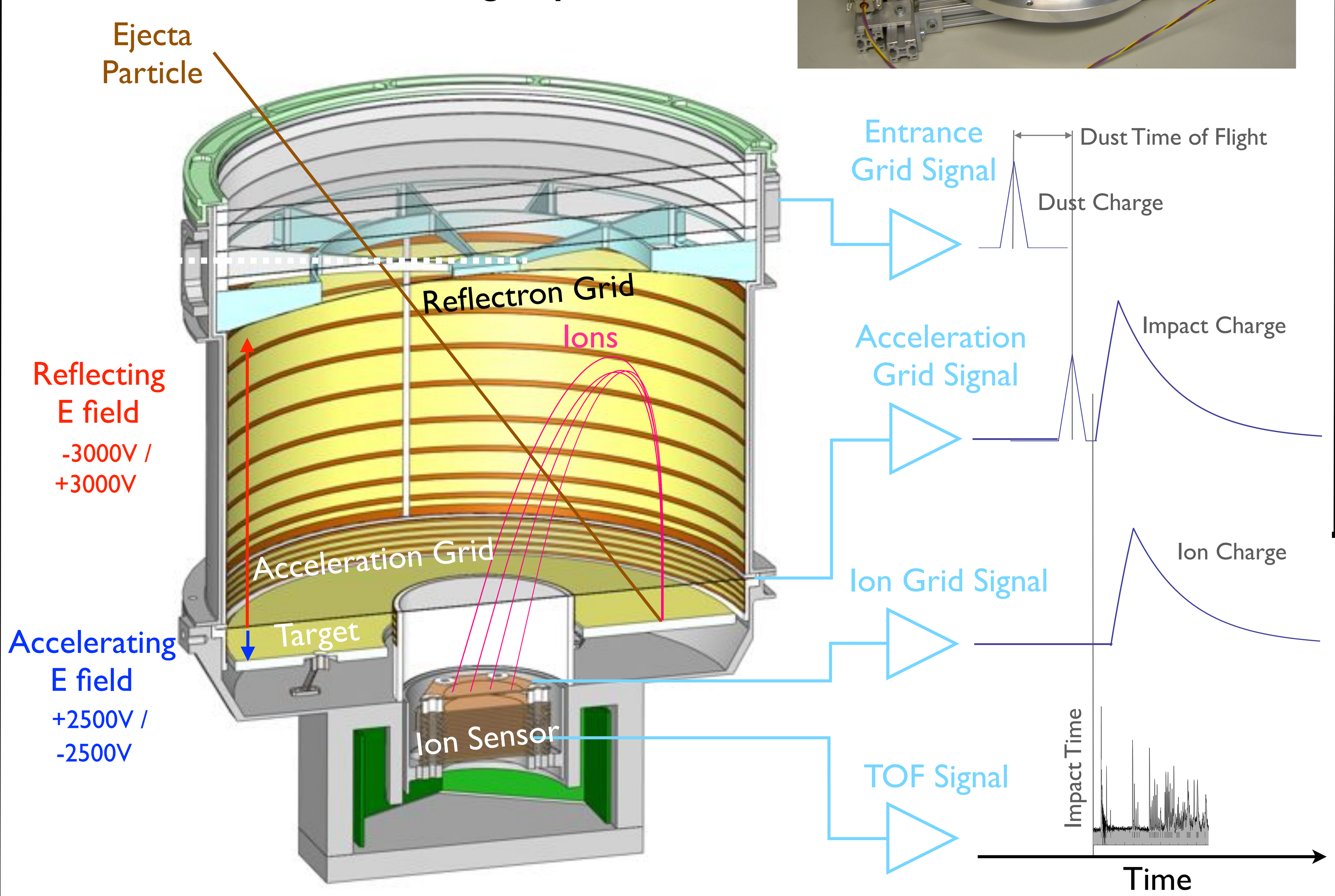
Enceladus dust measurements:
- **revealed subsurface salt water**
- **directly measured ocean composition**
- **spatially resolved profile of ice plume shows compositional diversity [4]**

SUDA - SUrface Dust Analyzer [2,5,6]

Improvements from CDA to SUDA

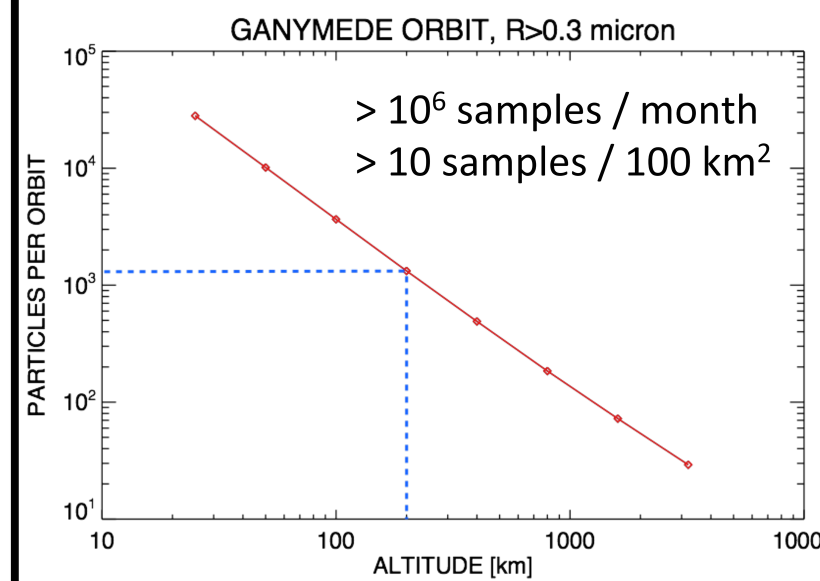
- **10 x higher mass resolution**
- **3 x wider mass range**
- **3 x lighter**
- **10 x higher sensitivity**
- **accurate backtracking of particles**

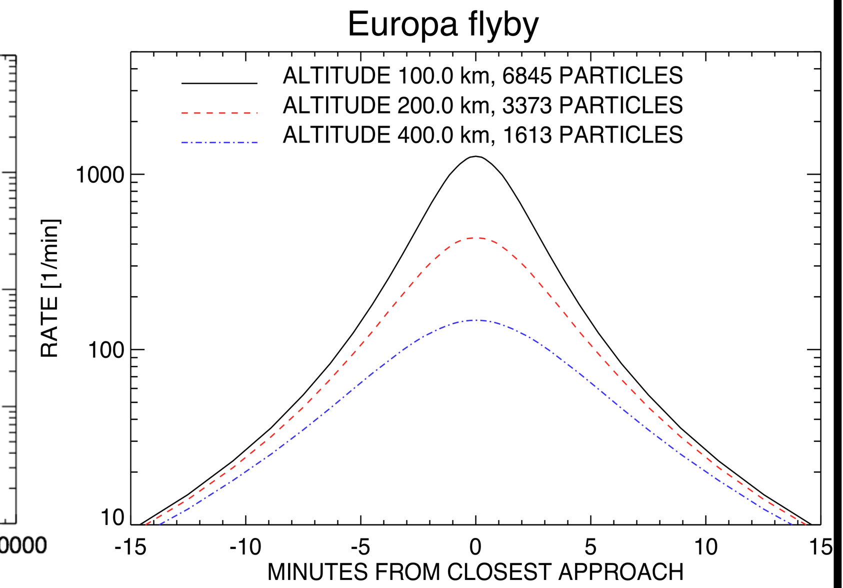




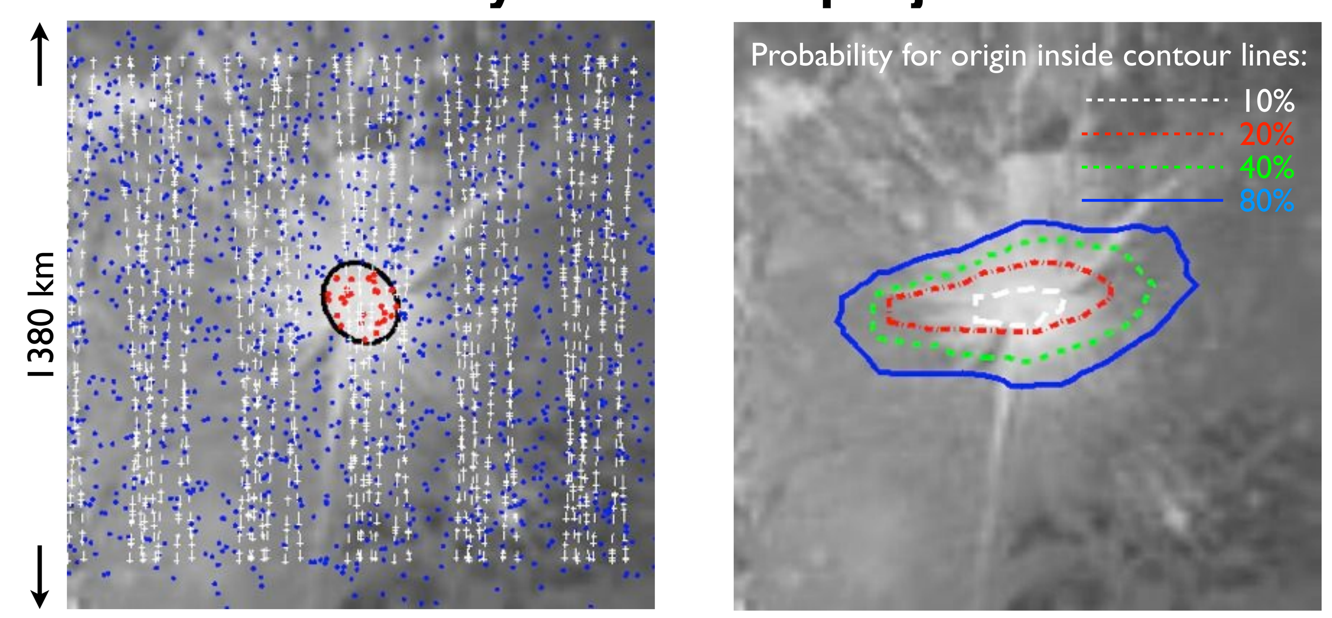
Performance at Ganymede and Europa [2,5]

High detection rates from an orbiter and at flyby's



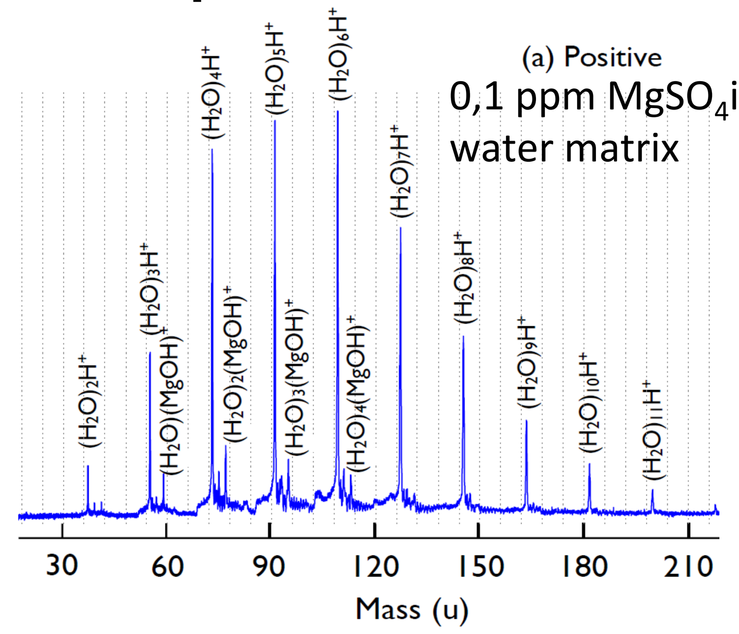


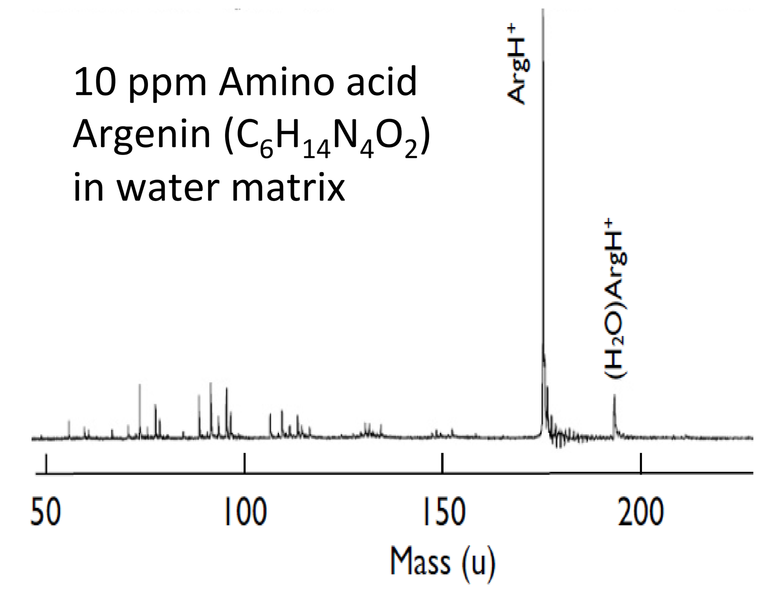
Accuracy of surface projection



Monte Carlo simulation: compositional mapping of crater Tros (93 km) from a Ganymede orbit. Surface features down to 30 km can be resolved from 200 km altitude.

Lab spectra of minerals & organics with ppm-sensitivity





Salts & Minerals
- **Distinct spectra @ 2 km/s impact speed**
- **Analysis of cations & anions**
- **High quantitative precision**
- **Detection independent of hydration state**

Complex Organics
- **No molecular breakup at impacts < 7 km/s**
- **Detection of unaltered surface compounds**
- **Analysis of cations & anions**

SUDA performance

polarity:	cation & anion
mass resolution:	m/Δm > 200
simultaneous mass range:	1 – 500 amu
grain size (composition):	0.2 – 10 μm
grain size (velocity):	0.3 – 100 μm
speed range:	1 – 10 km/s
max. detection rate:	10 s^{-1}
event time resolution:	0.01 s

SUDA resources

total mass:	7 kg + shielding
sensitive area:	225 cm^2
power consumption:	7 W (nominal)
radiation w.o. shielding:	250 kRad
max. data rate:	13 kbps (peak)
TRL:	5 – 9
heritage:	Galileo, Ulysses, Stardust, Cassini