How to Sniff Europa's Hidden Ocean

Sascha Kempf & the SUDA Team

NASA's New Paradigm:

Exploration of Habitable Worlds

Habitability?

Potential Habitability Requires Concurrent Availability of Three Ingredients:

1. Liquid water

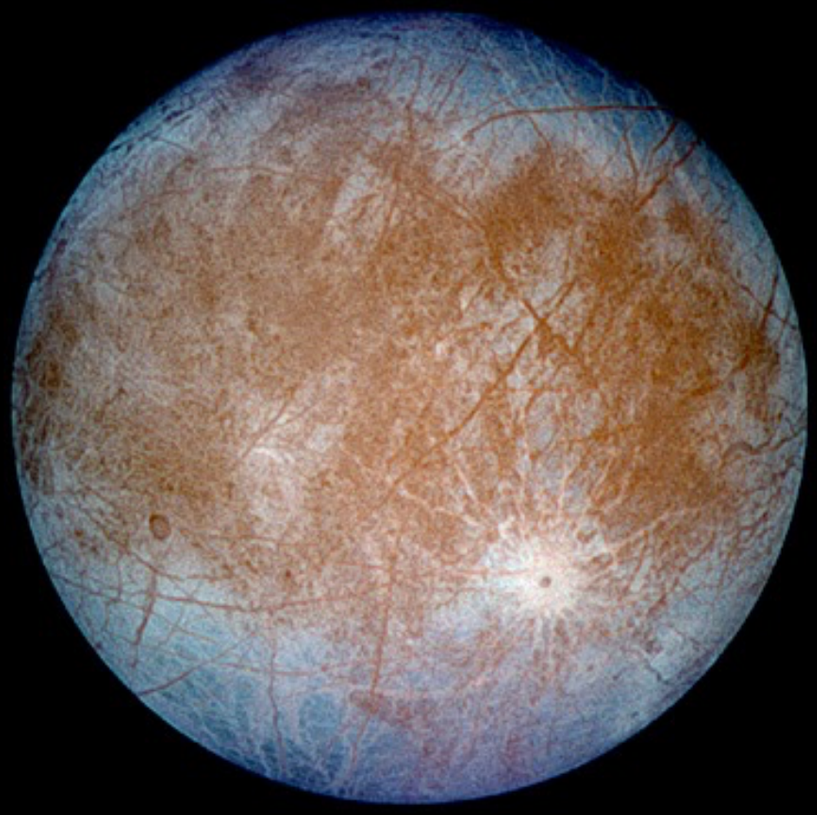
2. Source of energy with which to create and maintain complex molecules and structures

3. Raw materials for biosynthesis. Life on Earth requires C, H, N, O, P, and S.

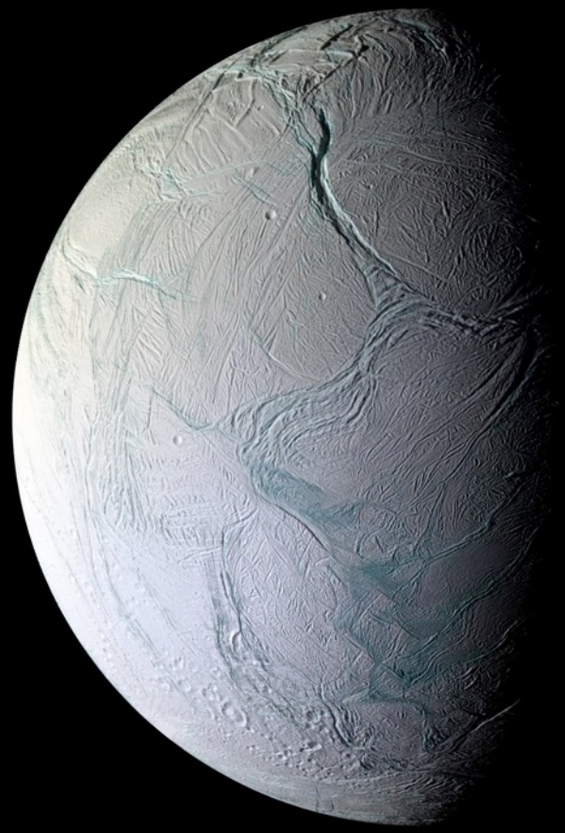
Liquid Water is Rare

Earth

Europa



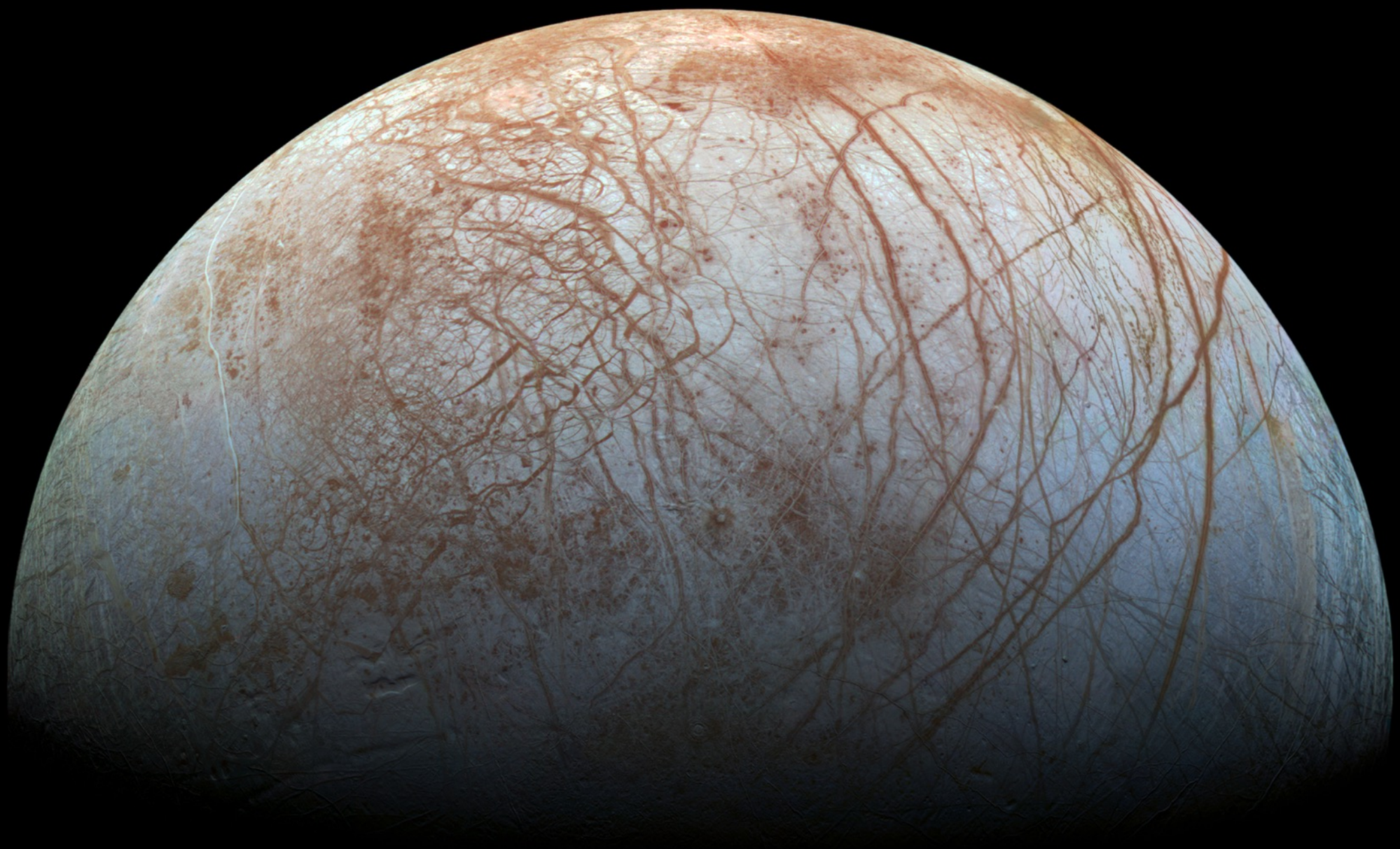
Enceladus



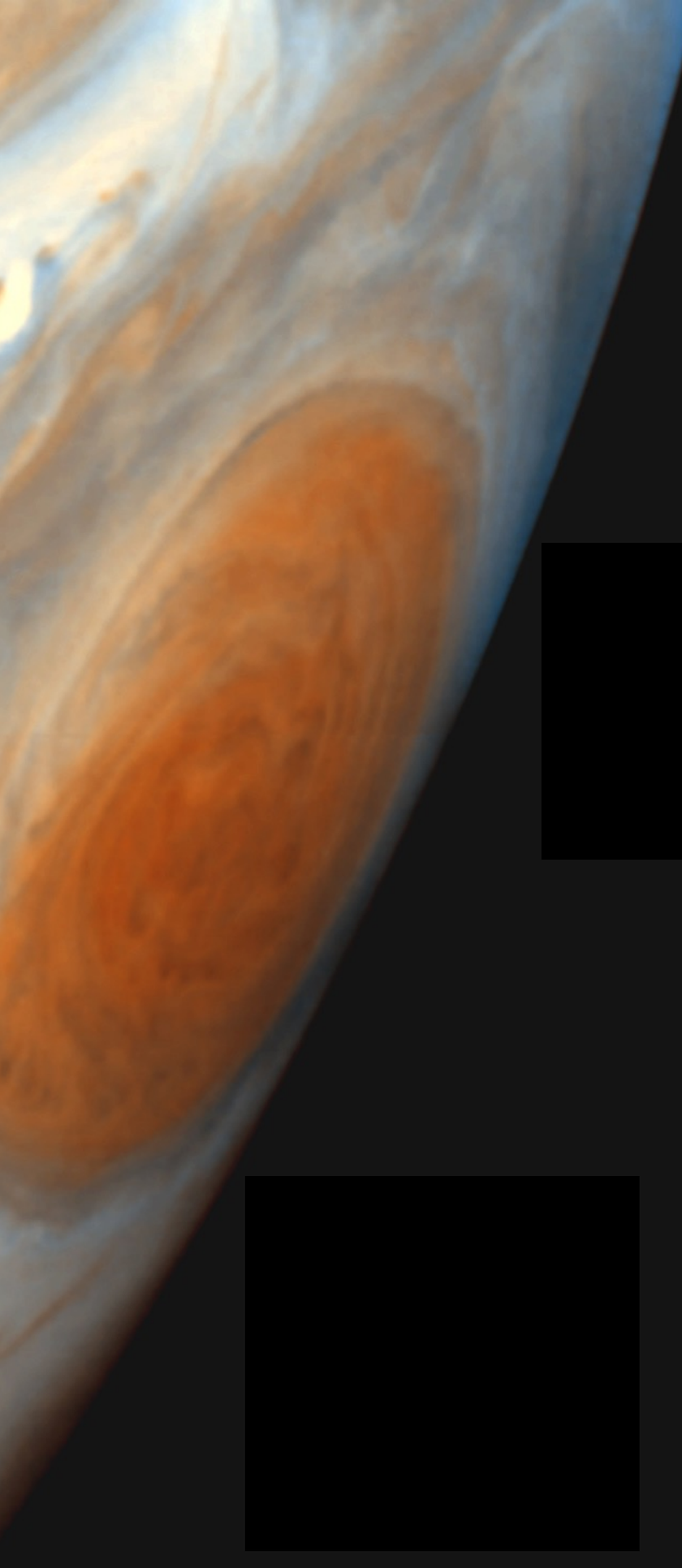
Jovian System

Saturnian System

Europa



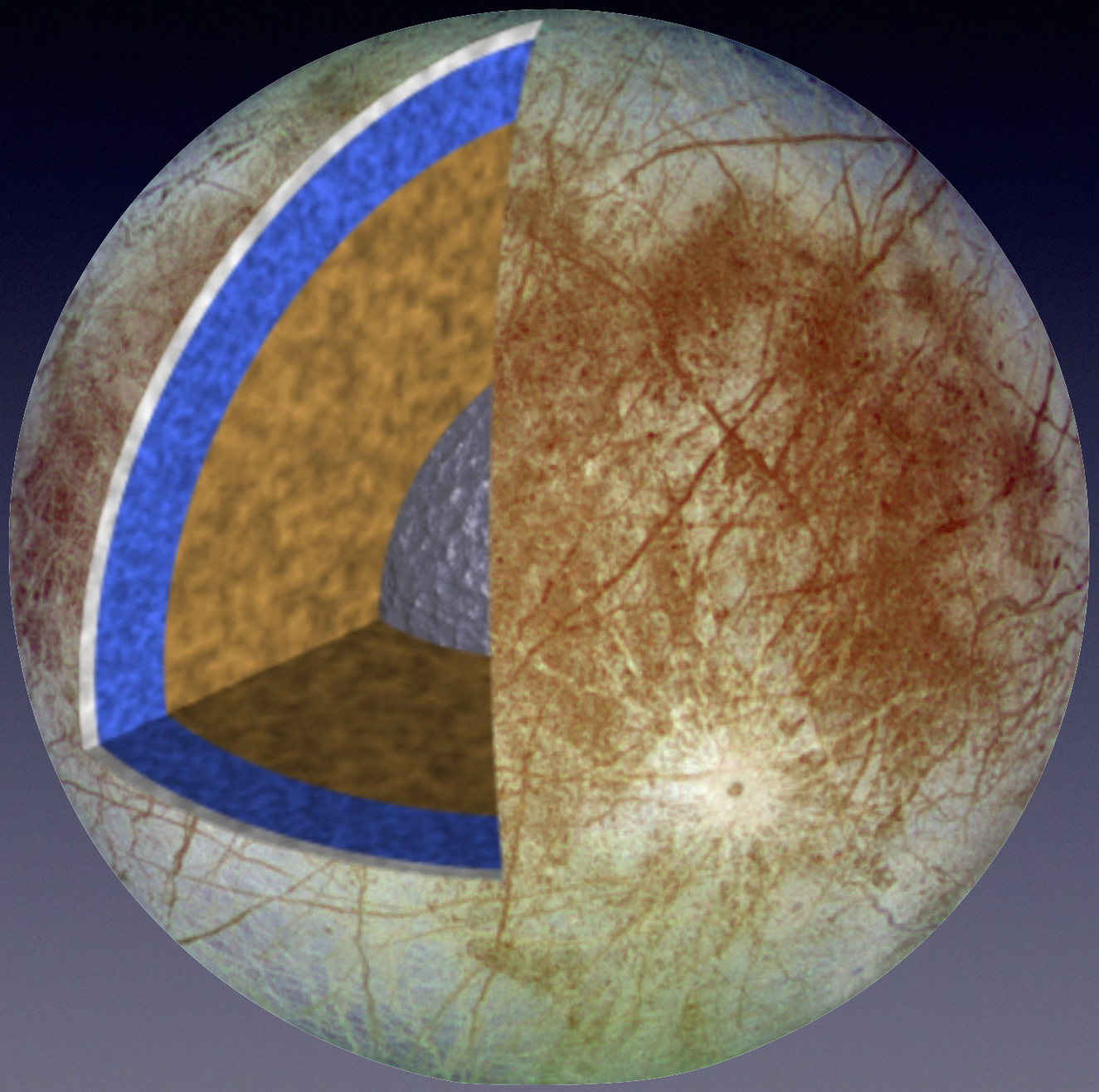
Habors a Subsurface Ocean



Galilean Moons

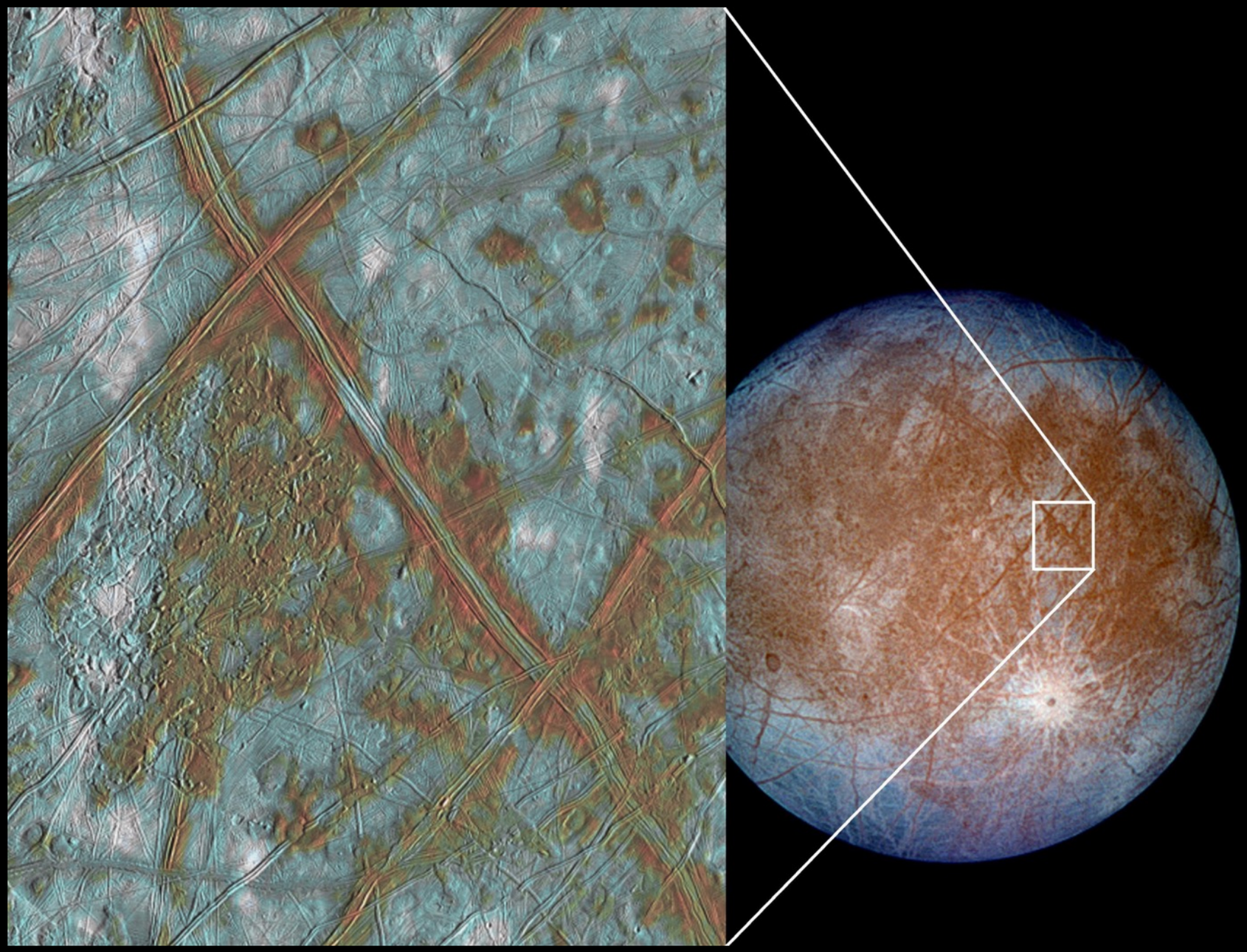
- Io (Size 3643 km)
- Europa (Size 3121 km)
- Ganymede (Size 5262 km)
- Callisto (Size 4820 km)

Europa: Key Parameters



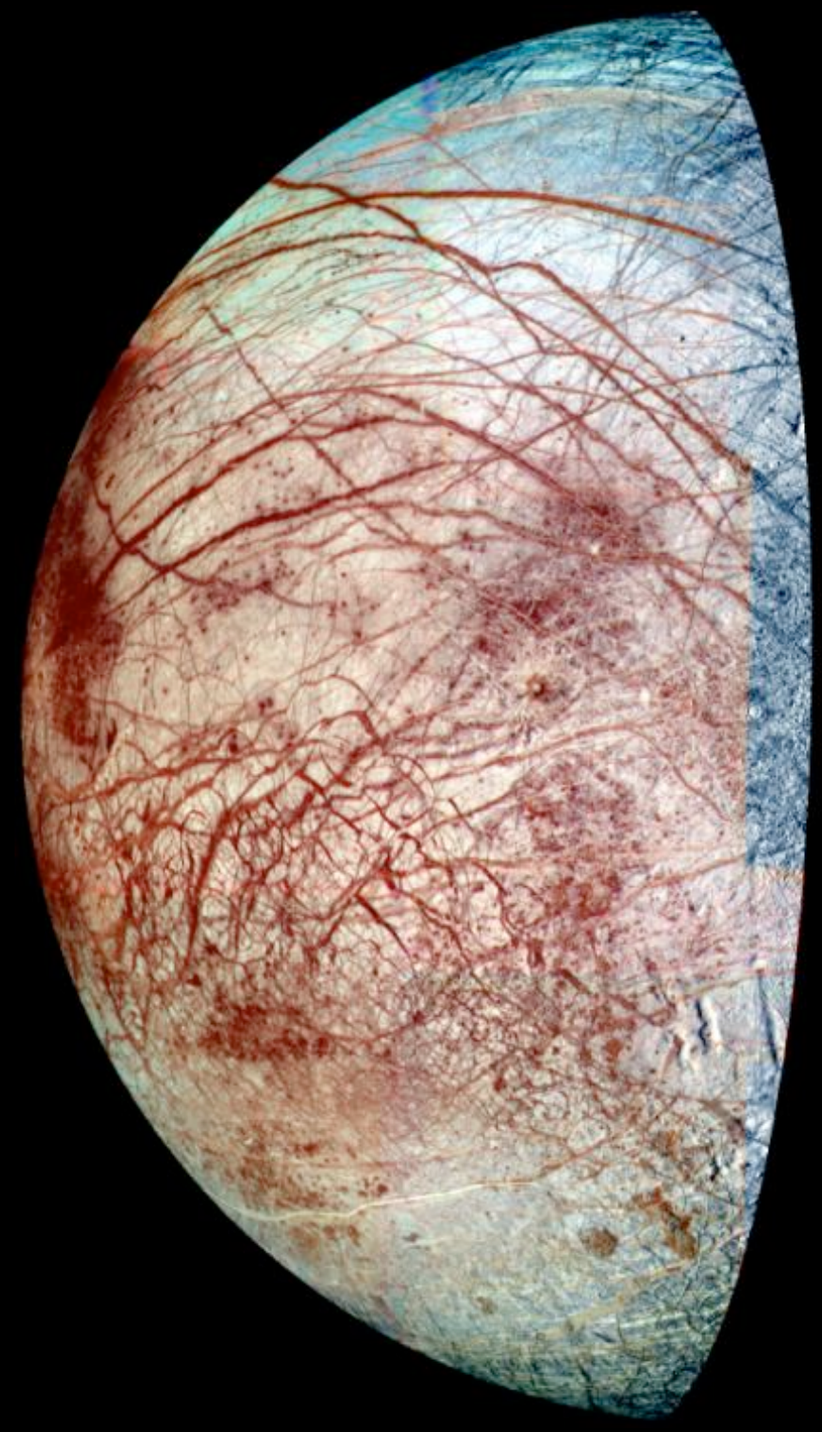
- Radius: 1,561 km
- Escape Speed: 2,040 m/s
- Hill Radius: 13,661 km
- Thickness of Ice Crust:
  - 80 - 150 km
    Anderson et al., *Science*, **281**, 1998
  - Water Pockets at 3 km
    Schmidt et al., *Nature*, **479**, 2011

Europa's Surface Provides Evidence For Liquid Water

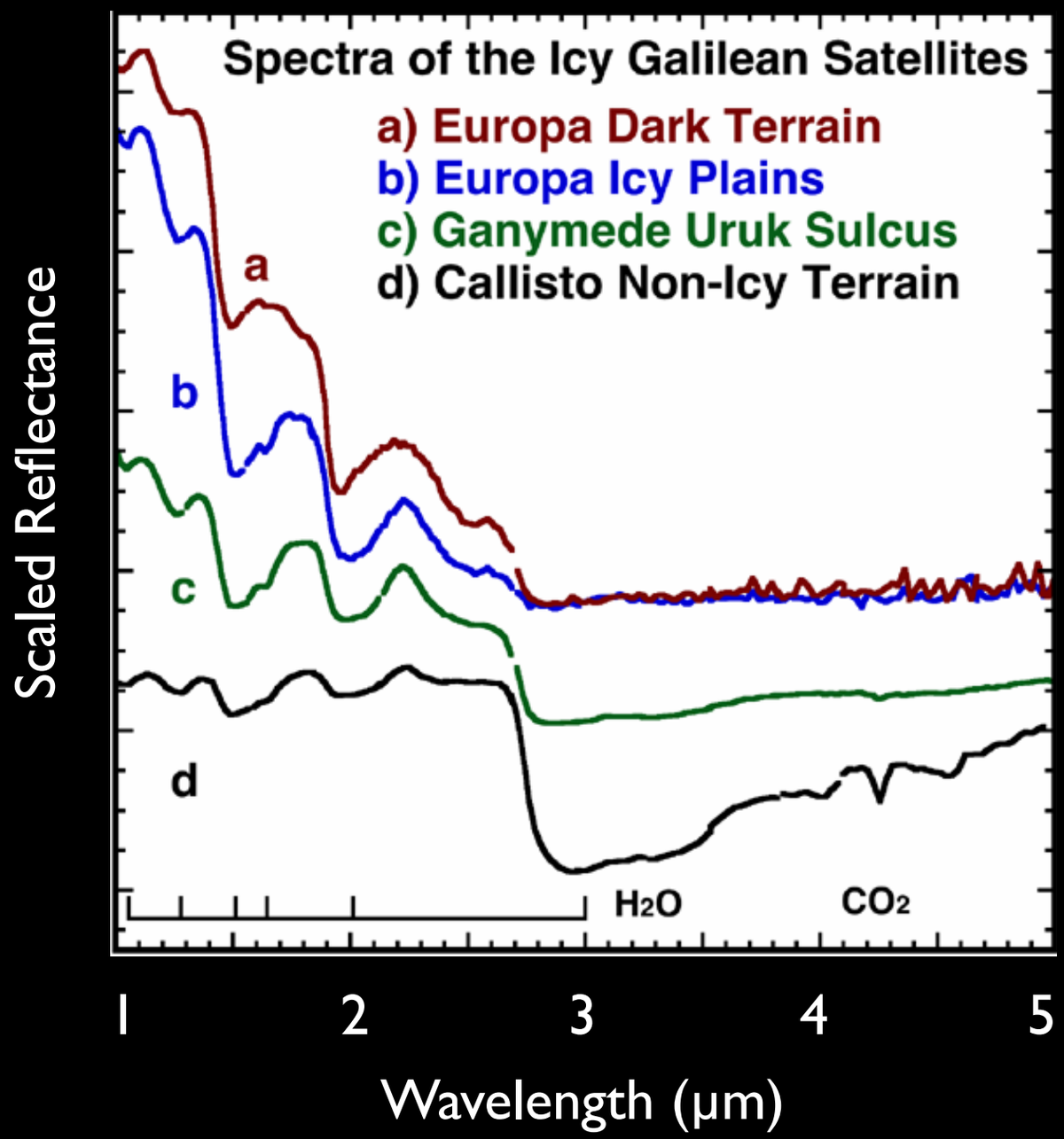


Surface Geology

- Rigdes
- Chaotic Terrains
- Pull-apart Bands



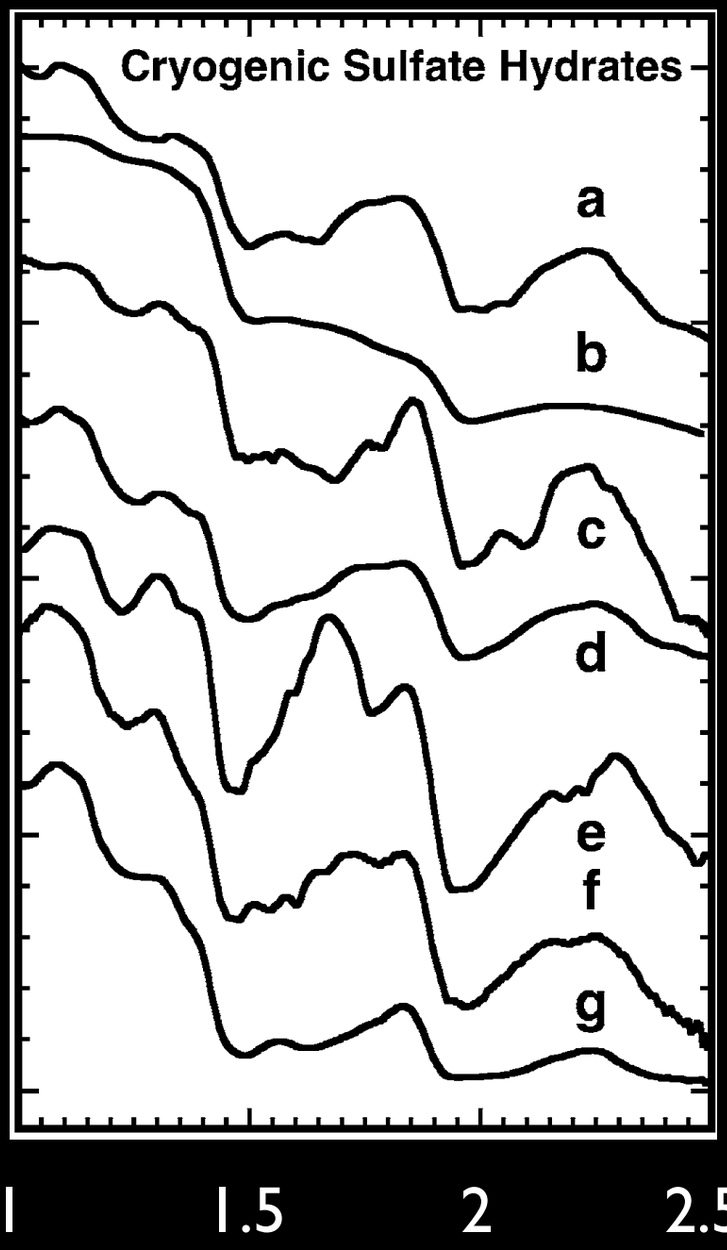
Surface Composition



Dalton et al., 2010

- Water ice
- Dark Terrains:
  - Hydrated Sulfate Minerals
  - Unknown Compounds
- SO_2
- CO_2
- Organics?

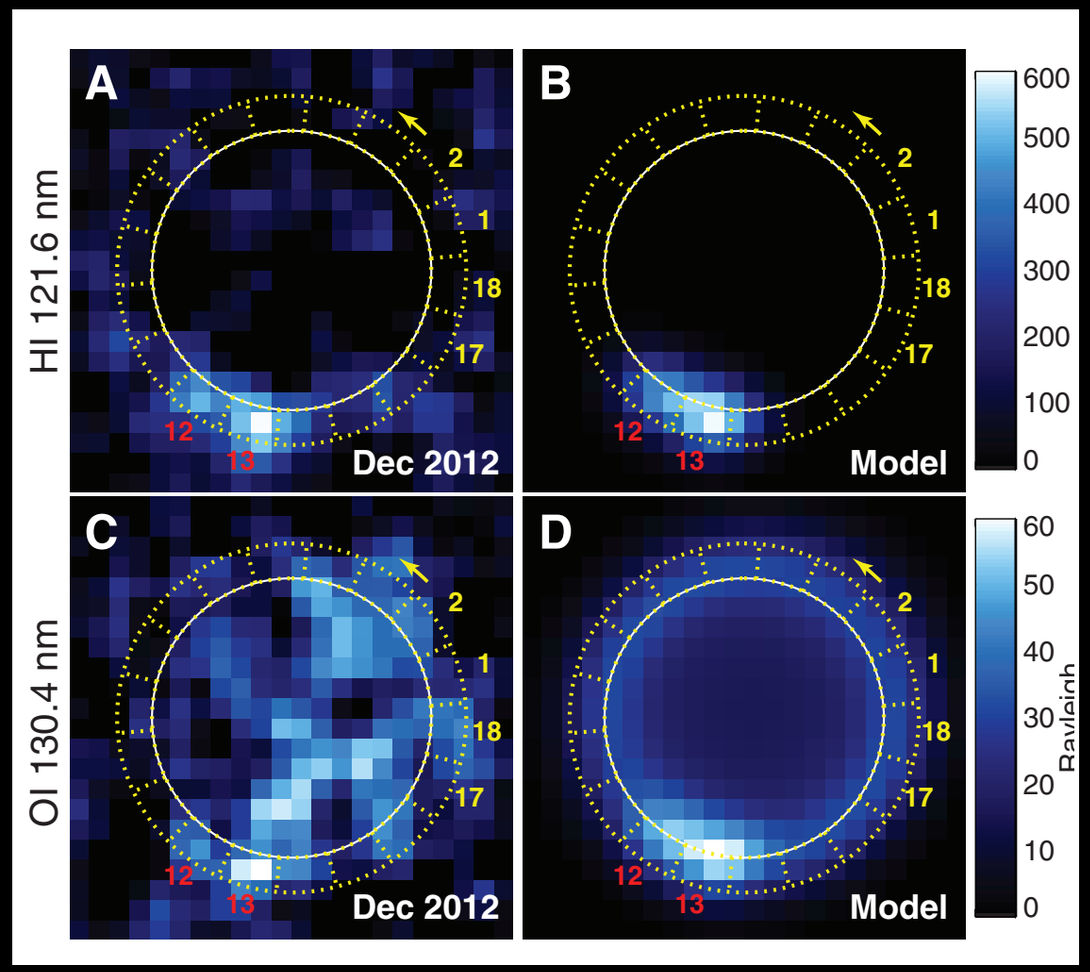
Hydrated Minerals



- Mixtures of
  - $MgSO_4$ n(H_2O)
  - Na_2SO_4 n(H_2O)
    - H_2SO_4 n(H_2O)
- Match the Galileo Spectra (Dalton et al., 2005)
- There is an Element of Ambiguity

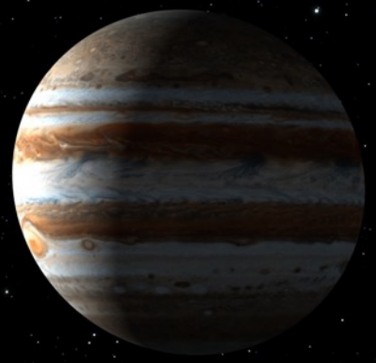
There is Even Evidence For A Plume

December 2012 Hubble Observation Versus Atmosphere Plume Model

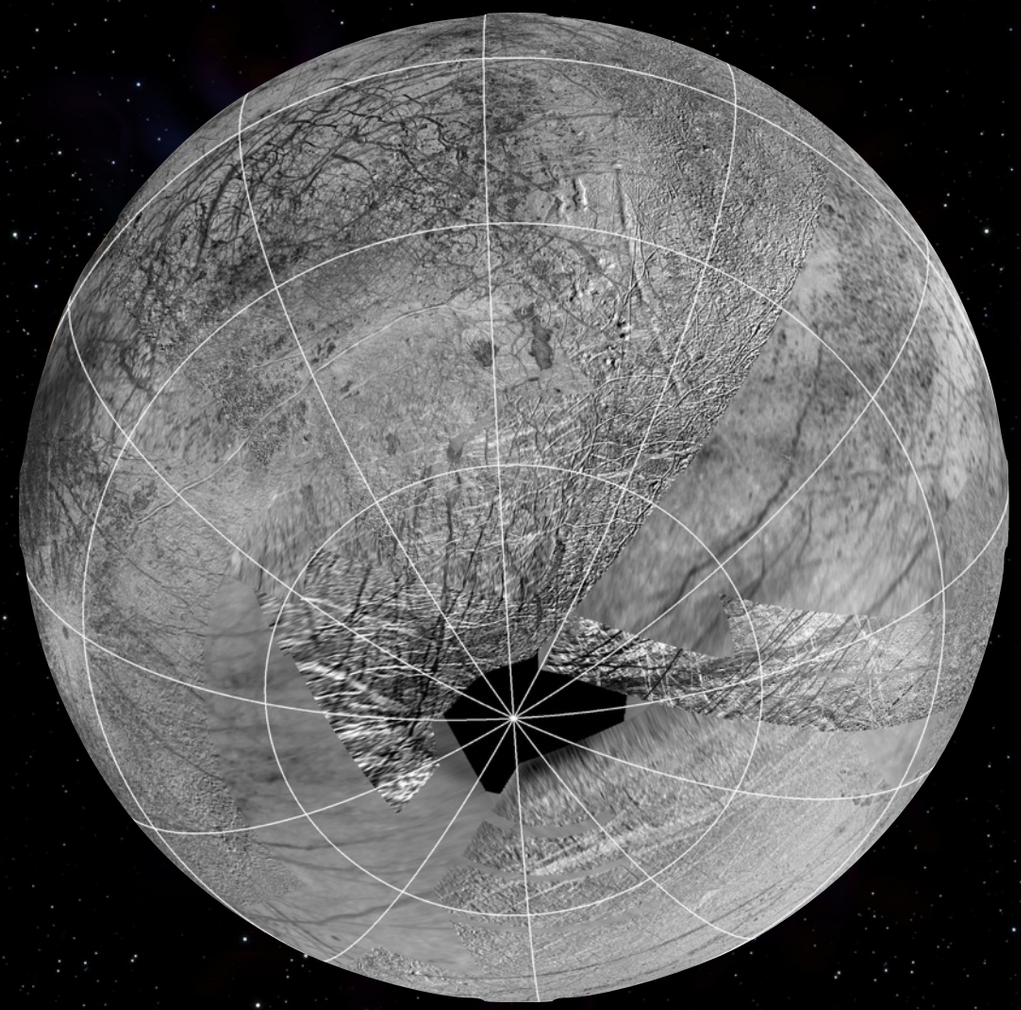


Roth et al., *Science*, **343**, 2014

Europa Plume

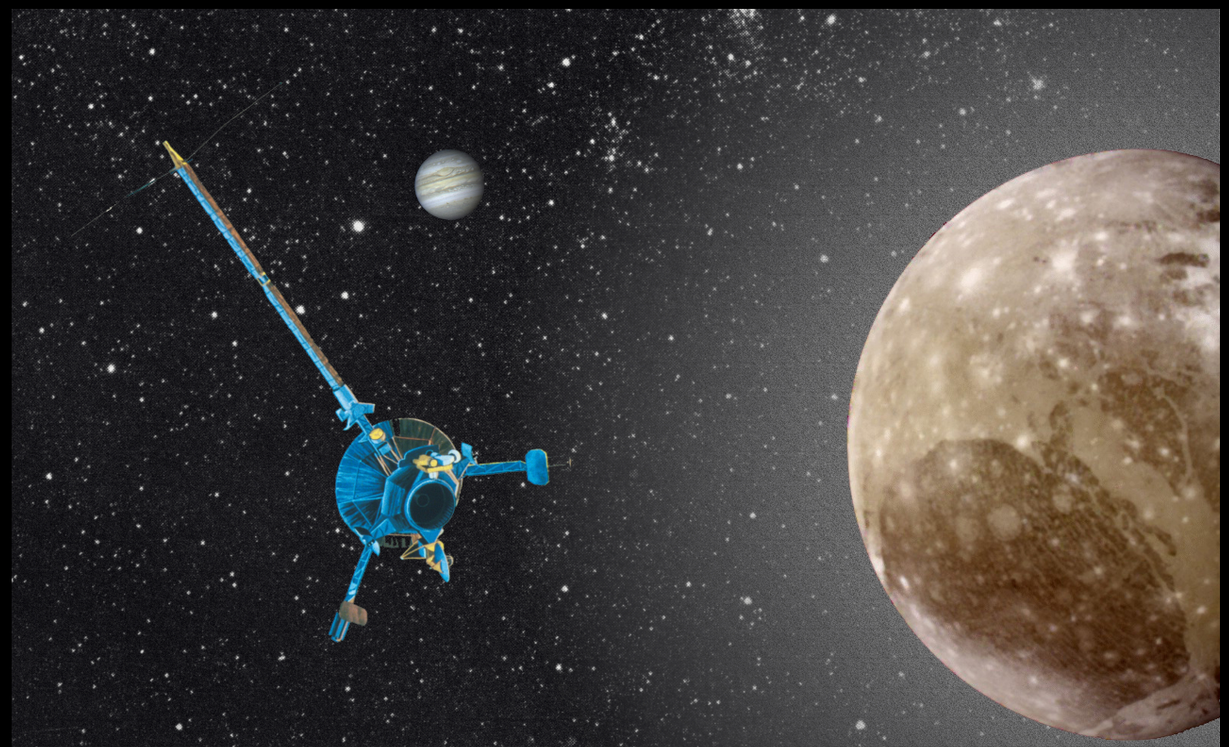


- Plume height: ~ 200 km
  - Requires initial gas speeds of ~700 m/s
  - Europa escape speed is 2040 m/s
- O_2 column density: $10^{19} m^{-2}$
  - Implies H_2O column of $1.5 \cdot 10^{20} m^{-2}$
  - Enceladus: $0.90 \pm 0.23 \cdot 10^{20} m^{-2}$
    Hansen et al., *GRL*, **38**, 2011



How To Sniff An Subsurface Ocean?

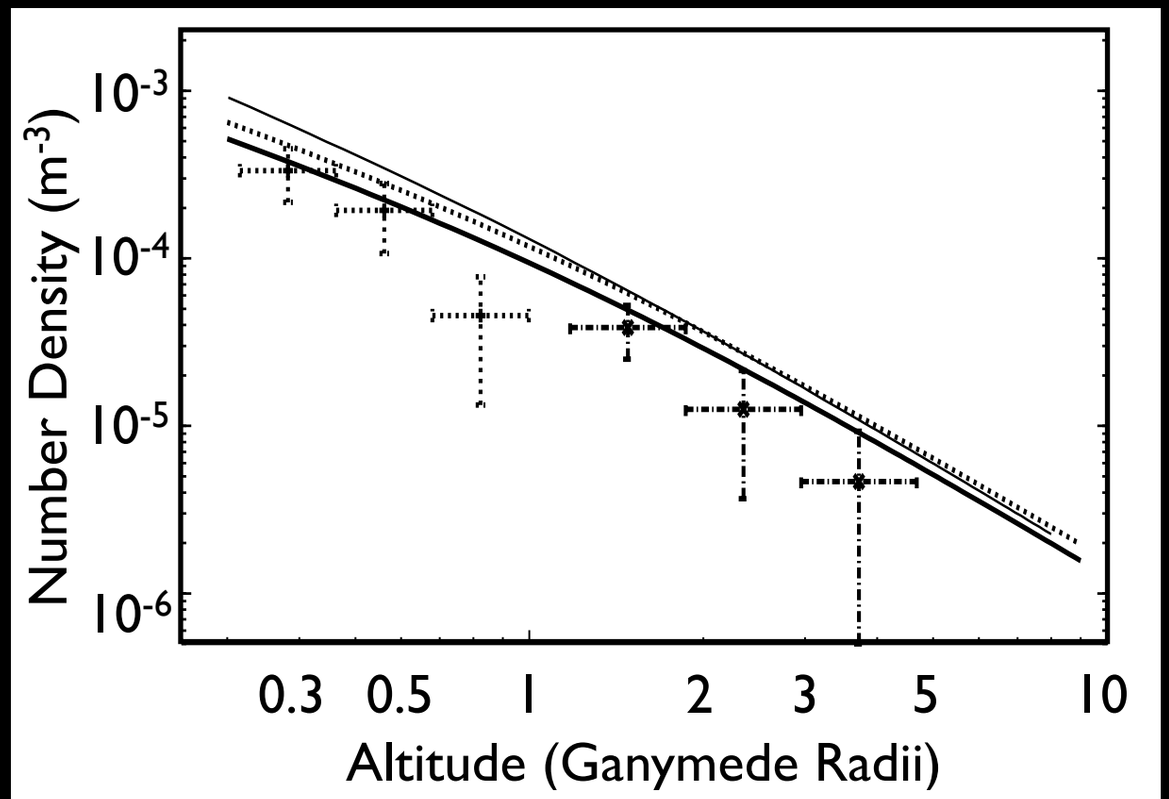
Ejecta Clouds



Galileo Dust Detector:

Galilean Satellites Wrapped in Dust Clouds

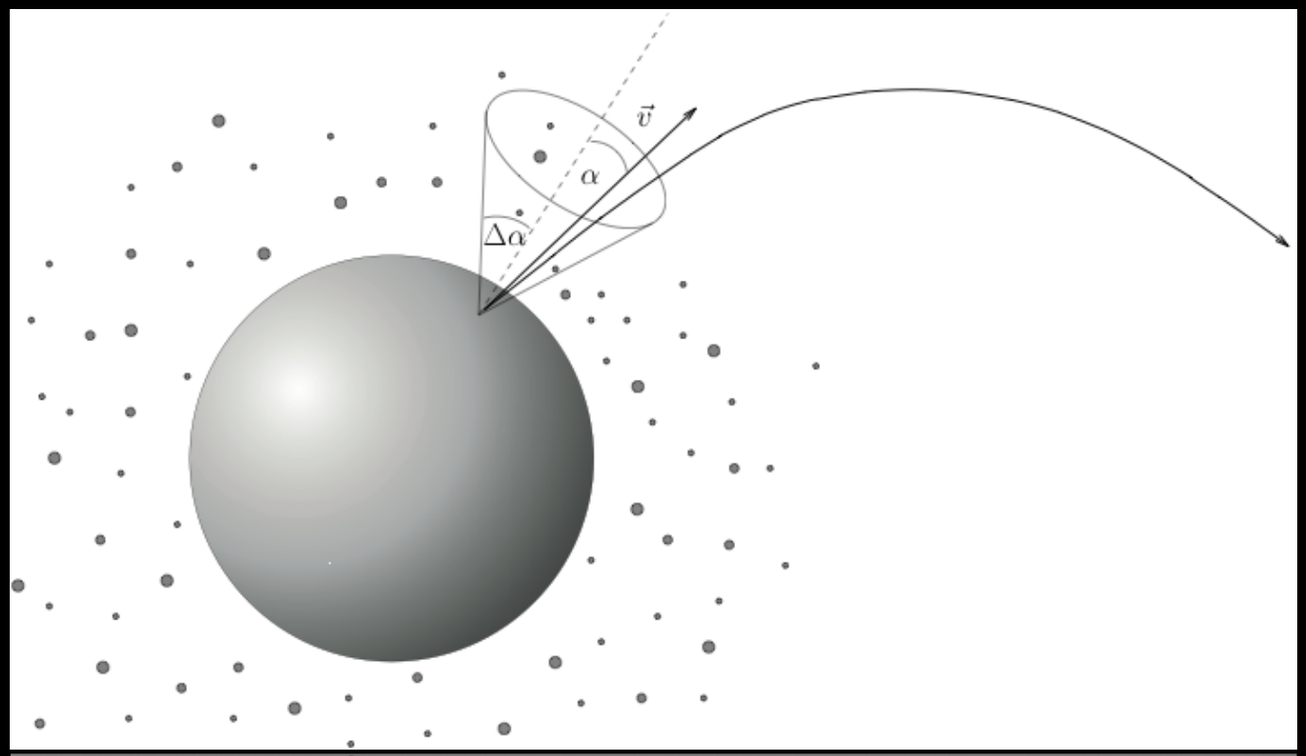
(Krüger et al., Nature, 1999)



Almost Isotropic Clouds Composed of Surface Ejecta

Ejecta Production

Meteoroid Impacts Produce Ejecta



Sremcevic et al., Icarus, 2005

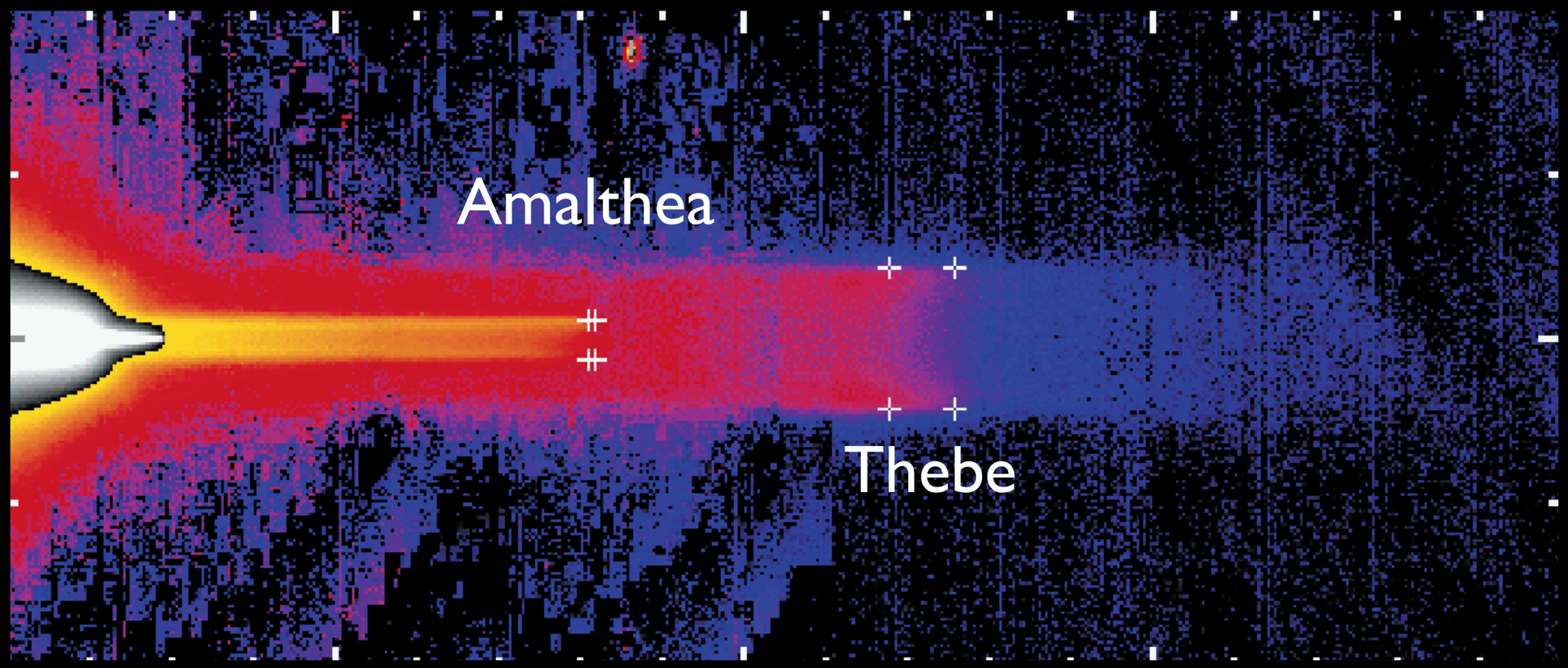
Ganymede Mass Yield ~ 4000

Koschny & Grün, Icarus, 2001; Krivov et al., Icarus, 2003

- Gravitationally Bound Ejecta Populate Cloud
- Some Ejecta Escape:
  - Feed Rings
  - Moon Mass Loss Mechanism

Ejecta Production @ Work

Ejecta Escaping from Moon‘s Gravity feed Rings

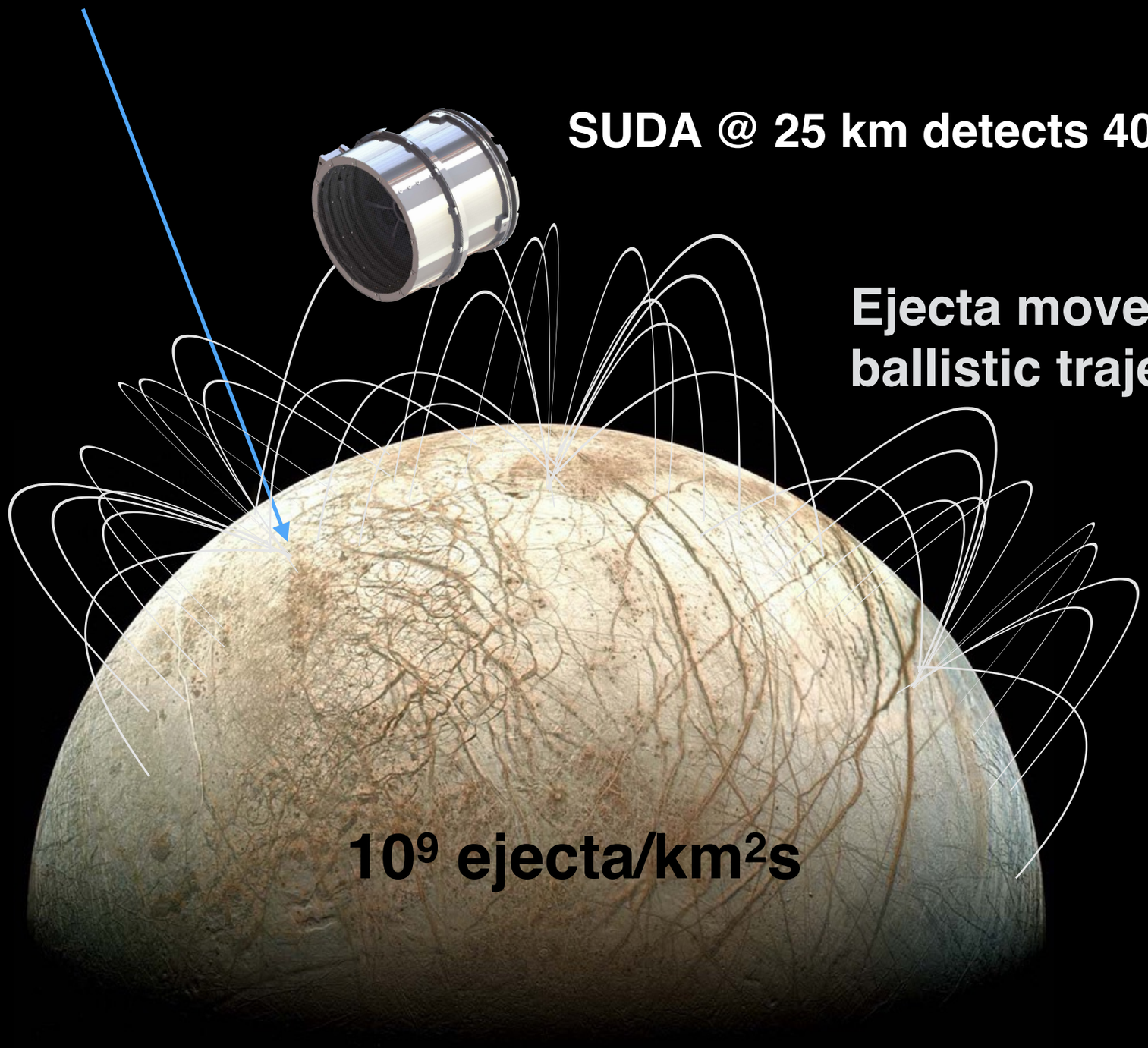


Burns et al., Science, 1999

Gossamer Rings‘ extent coincides with moons‘ orbital extremes

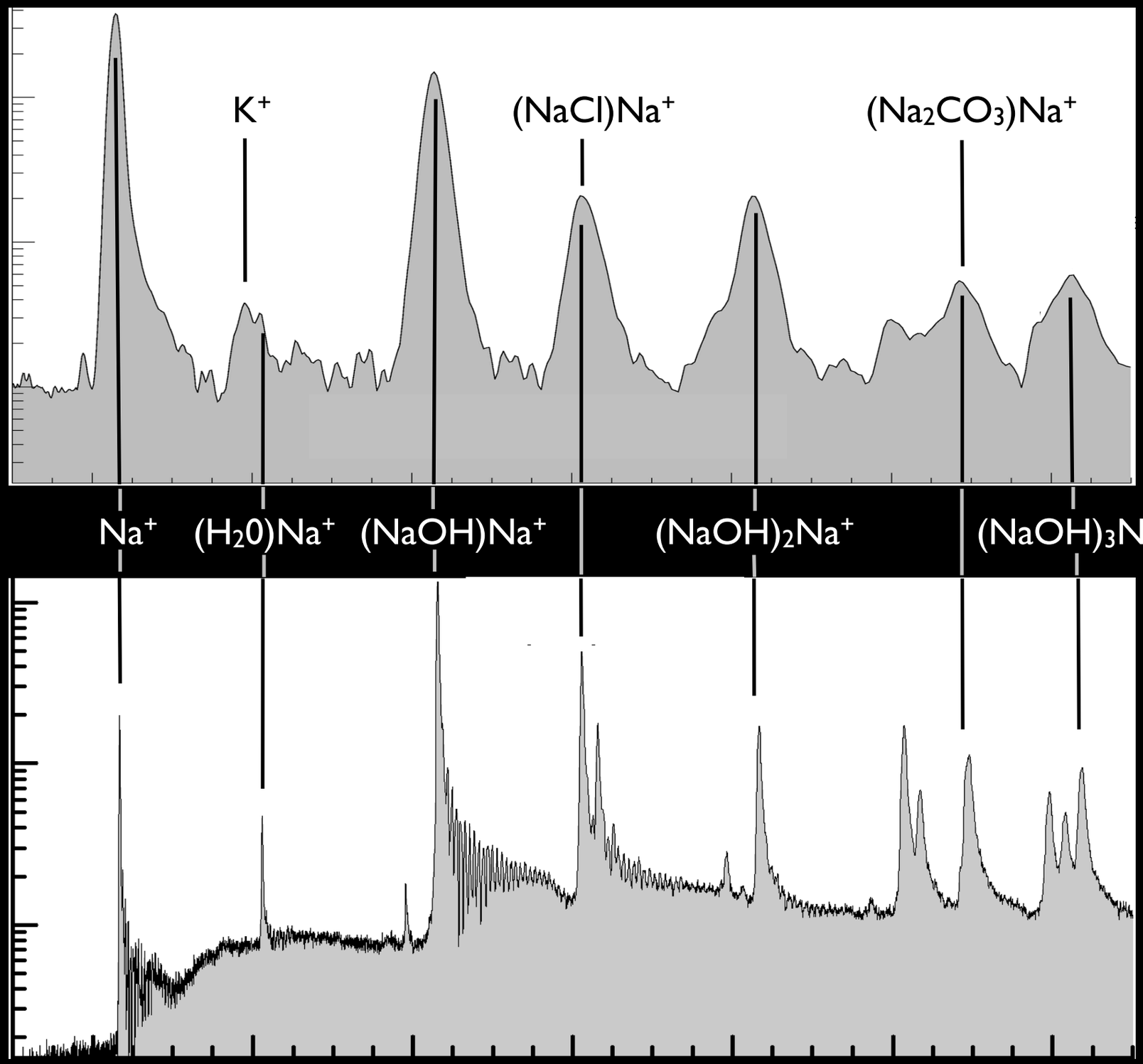
Ejecta Are SUDA's "Photons"

100 μm micrometeoroid impacts generate ~500 kg ejecta/second



Ejecta - “Photons” - Really?

Ejecta Are Pieces From the Surface

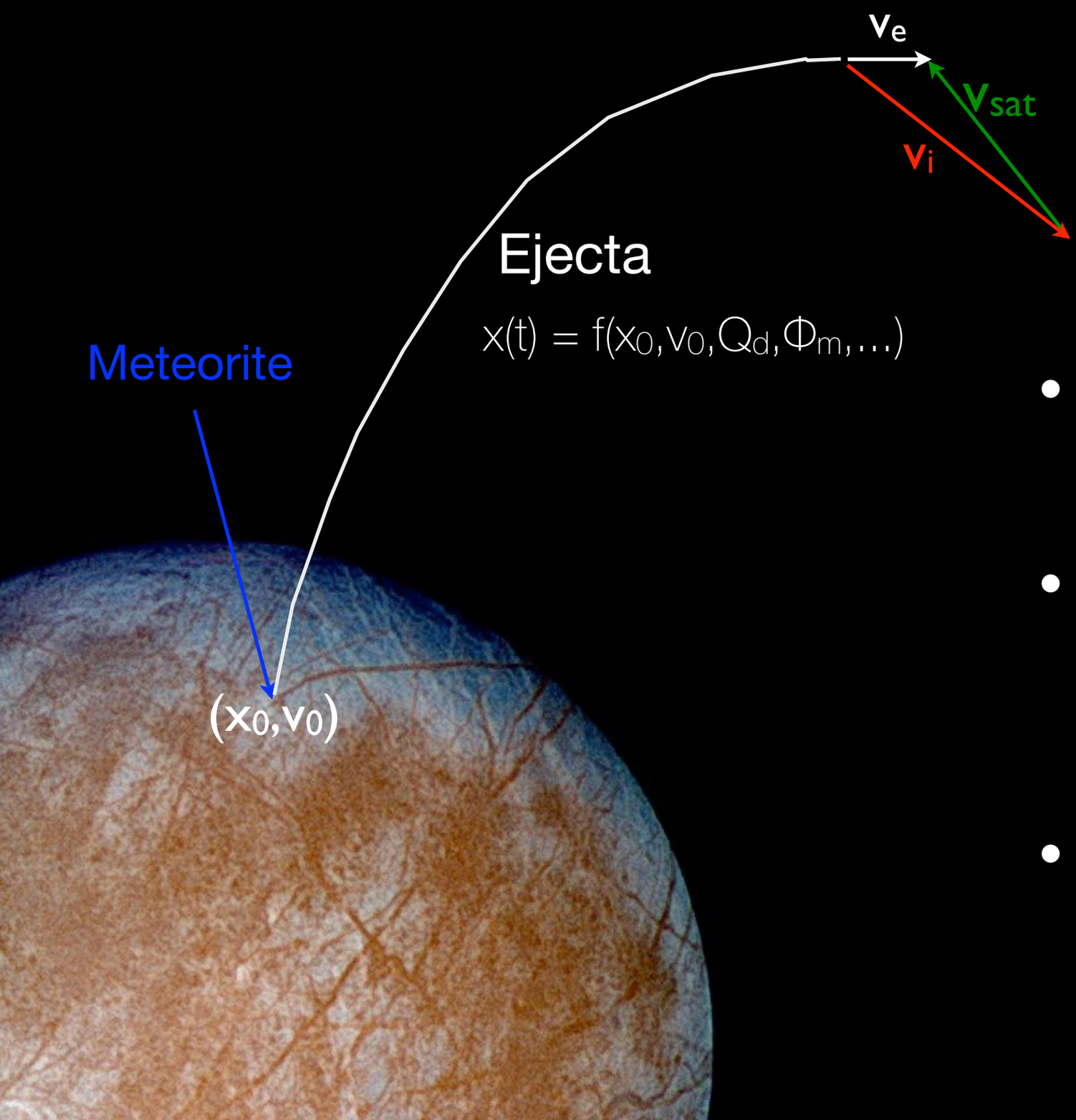


Salt-rich Enceladus Ice Grains (6%)

Laser Dispersion of Salt Water

Postberg et al., Nature, 2009

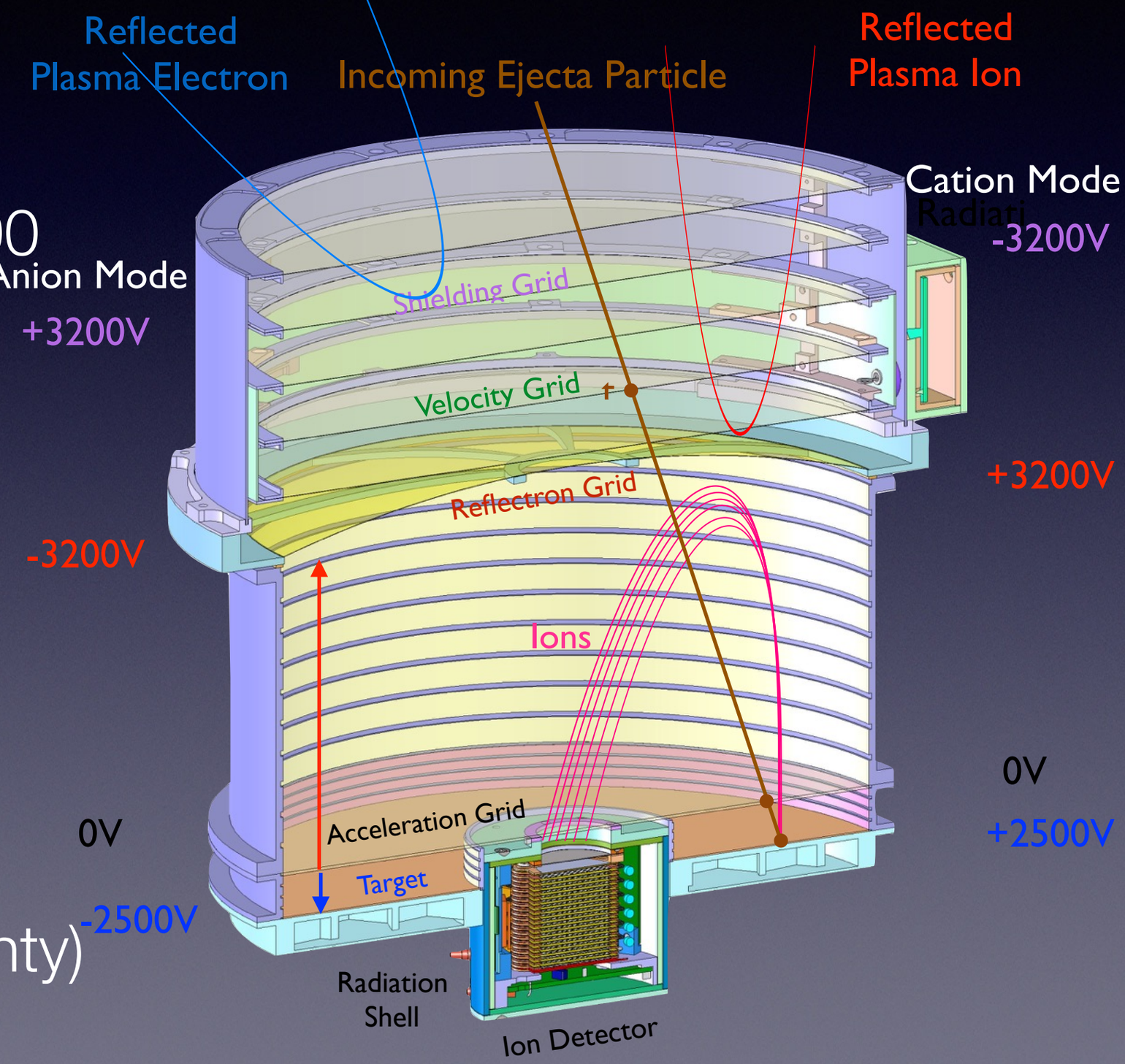
Ejecta Move on Ballistic Trajectories



- Meteorite impact splashes up multiple ejecta
- Satellite moves relative to ejecta:
  $v_i = v_e - v_{sat}$ (≈Apex)
- Know Starting Position:
  $x_0 = f(x_i, v_i, Q_d(t_i), t_i, \ldots)$

SUrface Dust Analyzer (SUDA)

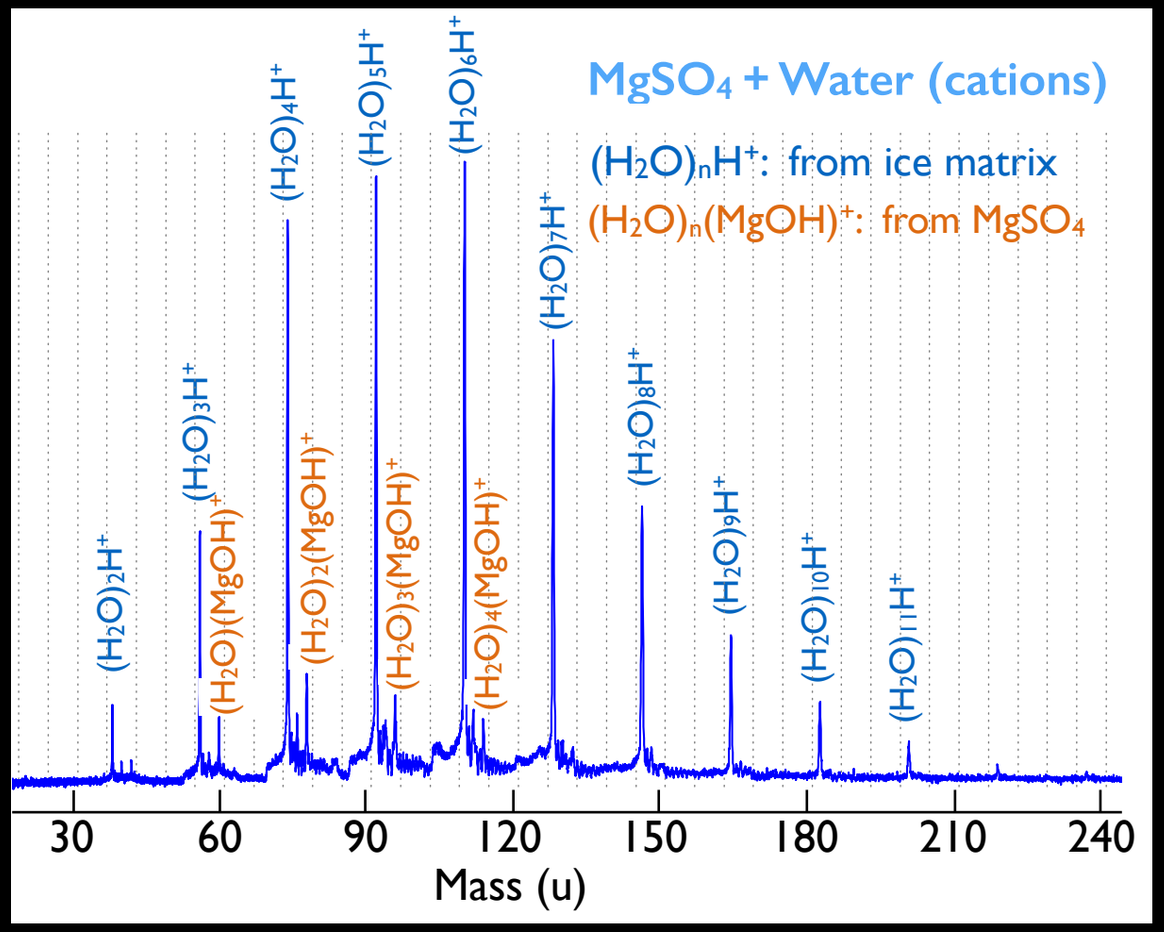
- Mass Spectrometer:
  - Mass Resolution ~ 200
  - Electrostatic Mirror:
    - Parabolic Grid
    - Ring Electrodes
  - ± Polarity
- Trajectory Sensor:
  - Velocity (1% Uncertainty)



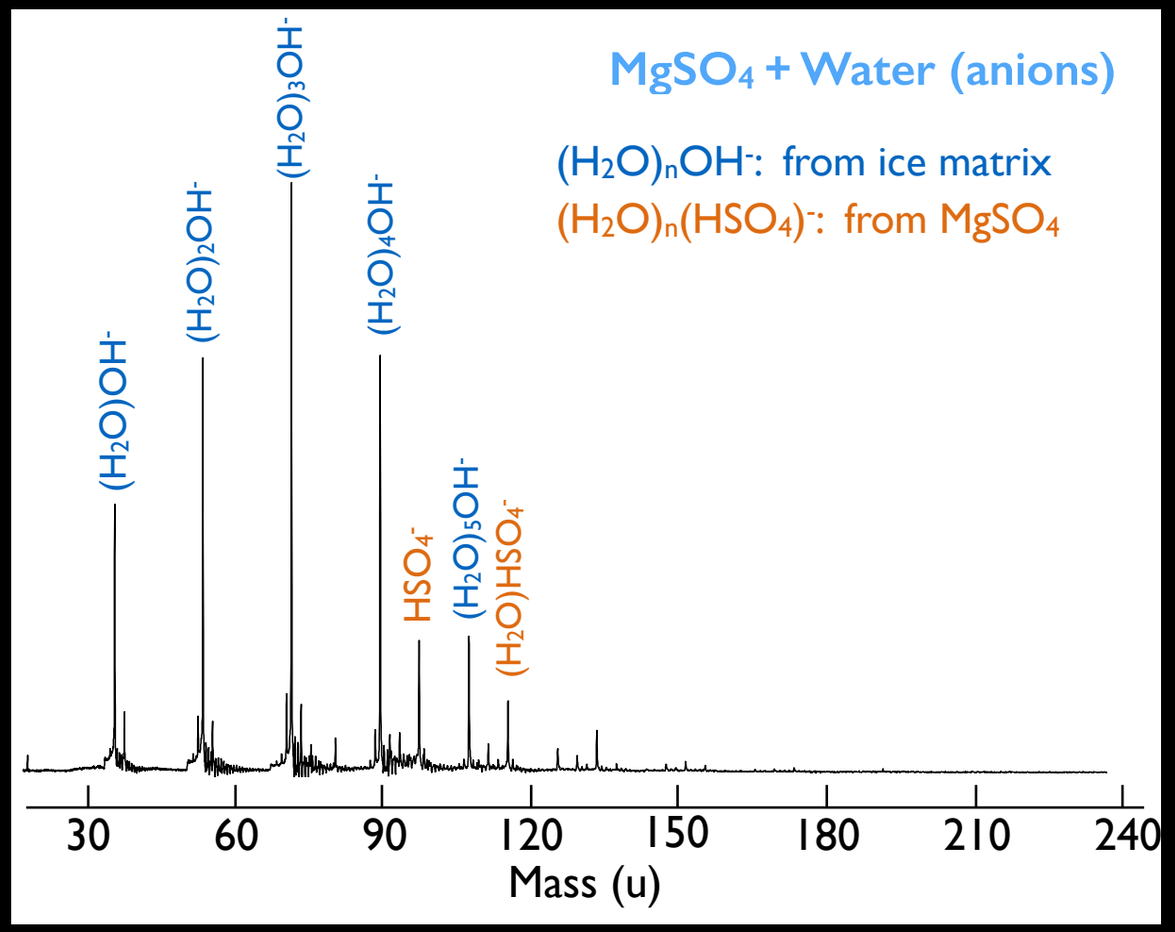
SUDA @ Europa

Water + $MgSO_4$

Cations:



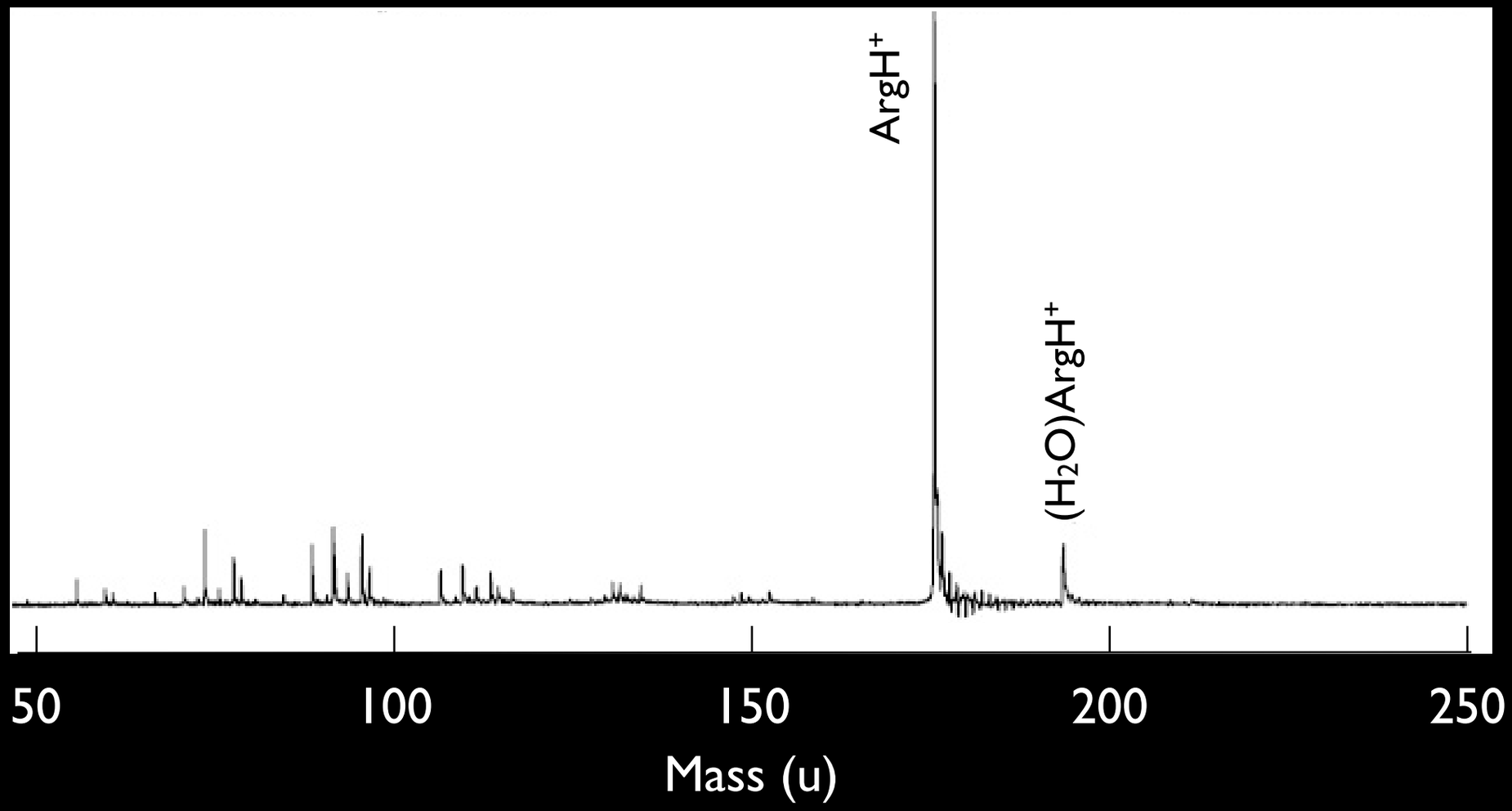
Anions:



Laser–assisted dispersion spectra of $MgSO_4$ at a concentration of 0.1 ppm in water

SUDA @ Europa

Argenine + Water (Cations)



Laser–assisted dispersion cation spectrum of the amino acid arginine ($C_6H_{14}N_4O_2$) dissolved in water at a concentration of 10^{-4} mol/l.

SUDA Will Collect

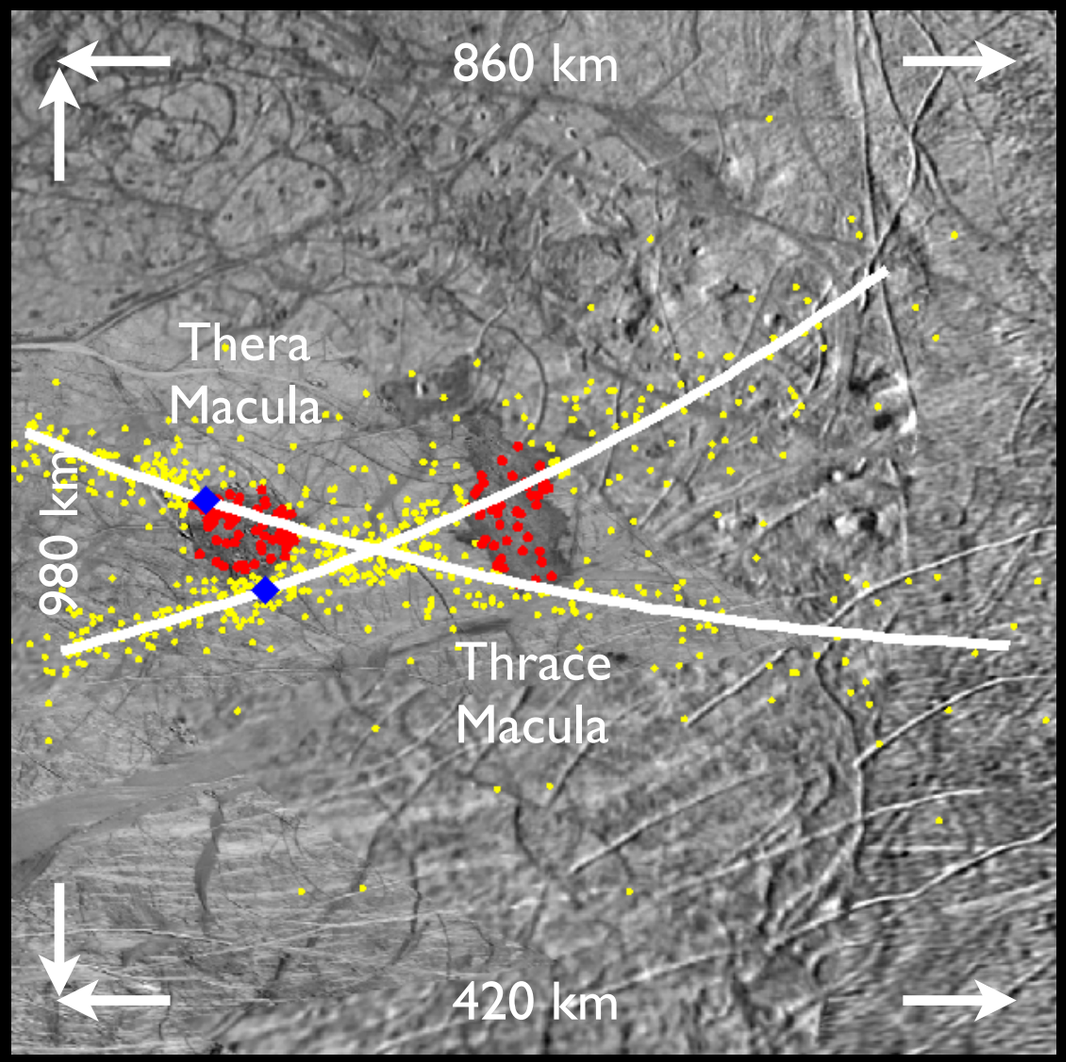
Europa Clipper Flybys:

Flyby	Impact Rate	Total Sample #
Europa 25 km	40 per second	5300
Europa 50 km	14 per second	2700
Europa 100 km	5 per second	1350

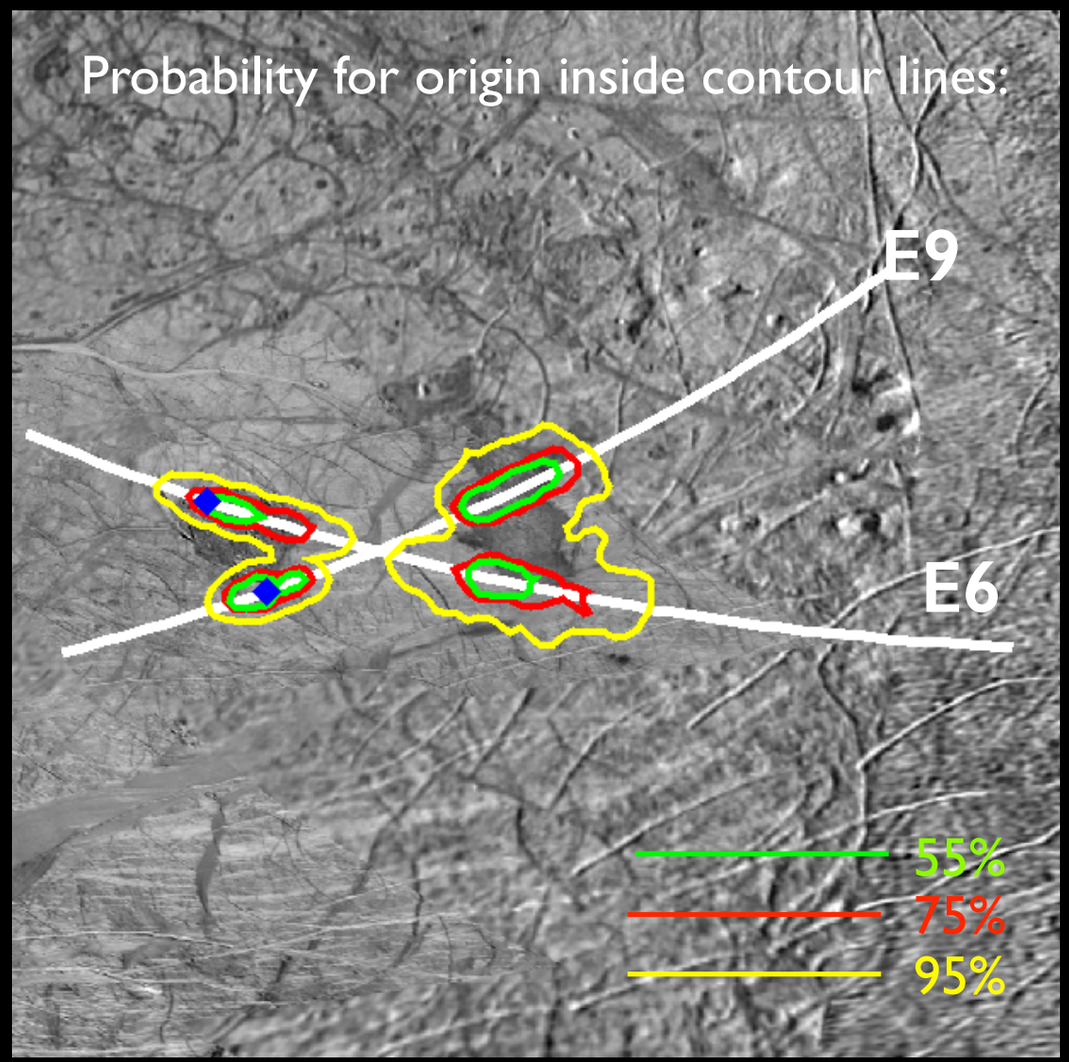
In total, SUDA will collect about 120 000 samples from Europa's surface

SUDA Composition Map

Dark Lobated Features Thrace & Thera Macula on Europa



MC Simulation for SUDA Compositional Mapping



16
S
32.065
^{23}Na
^{24}Mg
^{26}Mg
^{25}Mg
^{27}Al
^{28}Si
^{29}Si
HO—S—OH ·nH$_2$O
SUDA