Enceladus

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Enceladus General Information

- Diameter 314 miles (505 km)
  - Fit in Arizona (Pozio 1995)
  - 1/7th of Earth's moon diameter
- Herschel discovered in 1789
  - During the equinox of Saturn (reduced glare from rings)
- Thought to create E-Ring
- Known geological activity
- Possible potential life

http://photojournal.jpl.nasa.gov/catalog/PIA03550

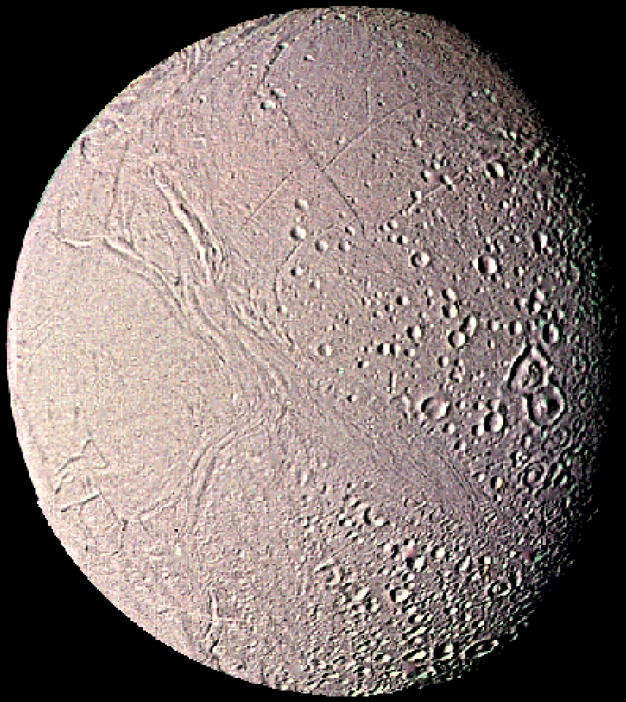
Satellites of Saturn

- Enceladus is the 6th largest satellite
  - Hard to detect because of the scattered light from the planet and rings
  - Albedo higher than for any other known solar system body (1.4 I)
- Orbits at 3.94 Saturn radii
- Orbital period: 1.37 Earth-days
- Orbital eccentricity: 0.0047

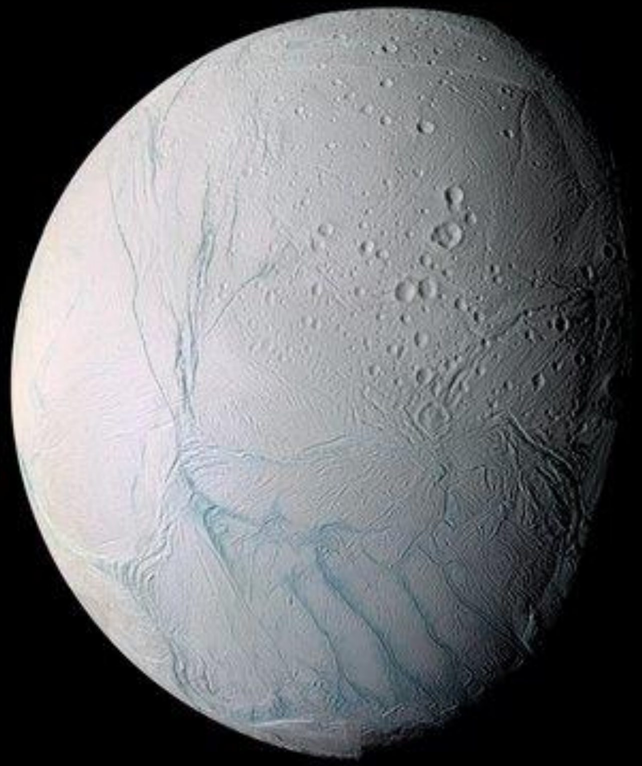
Image: NASA

Voyager vs Cassini images

Voyager 1 Image (NASA)

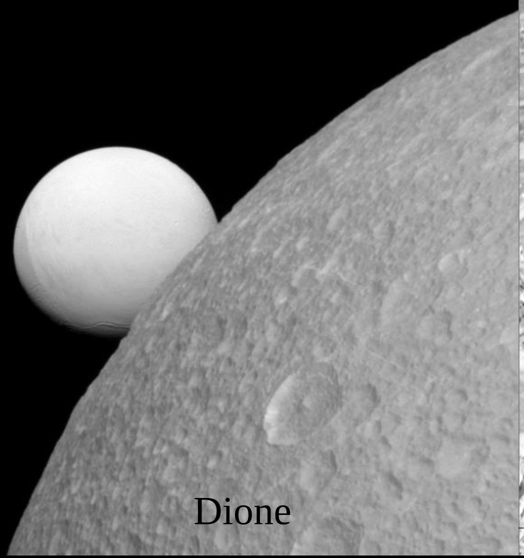


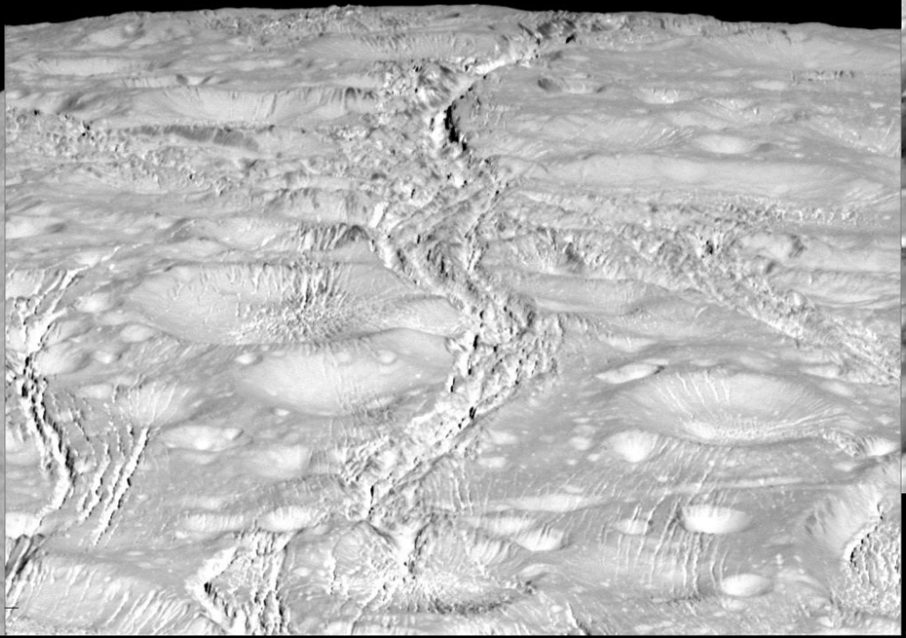
Voyager 2 Image (NASA)

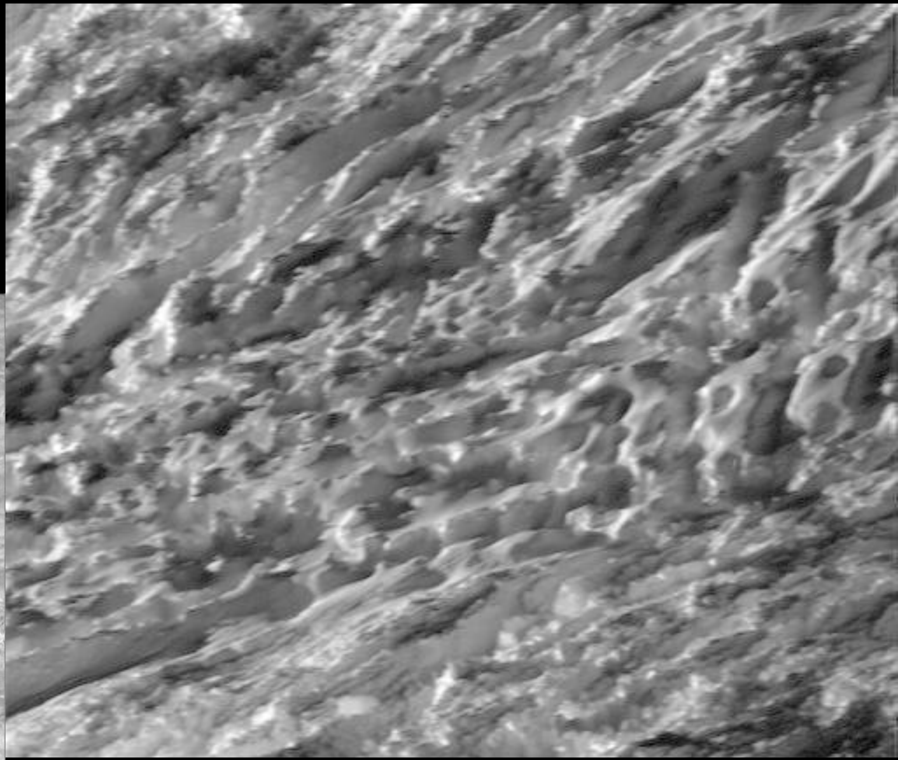


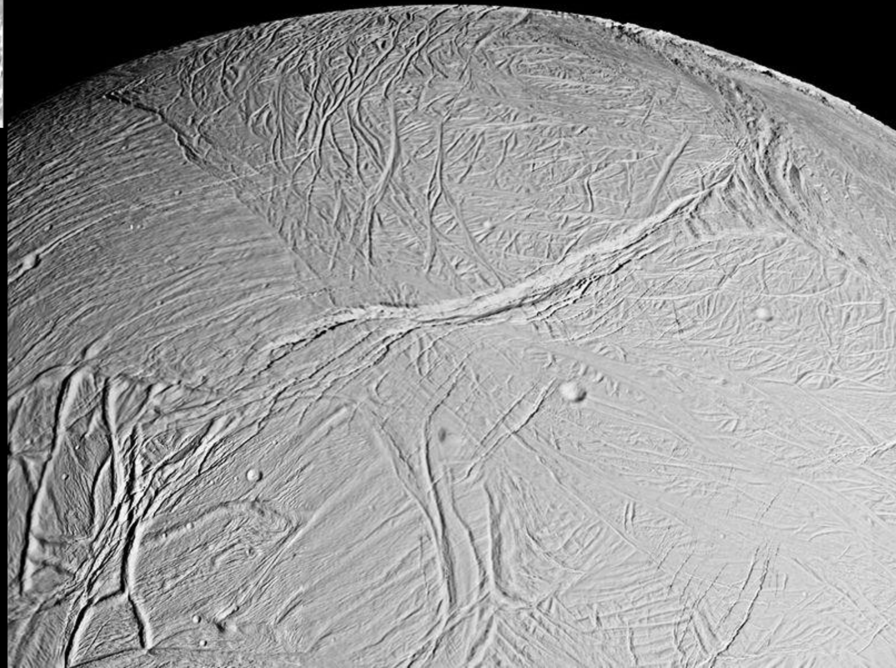
Cassini Image (NASA)

All Images: Cassini (NASA)









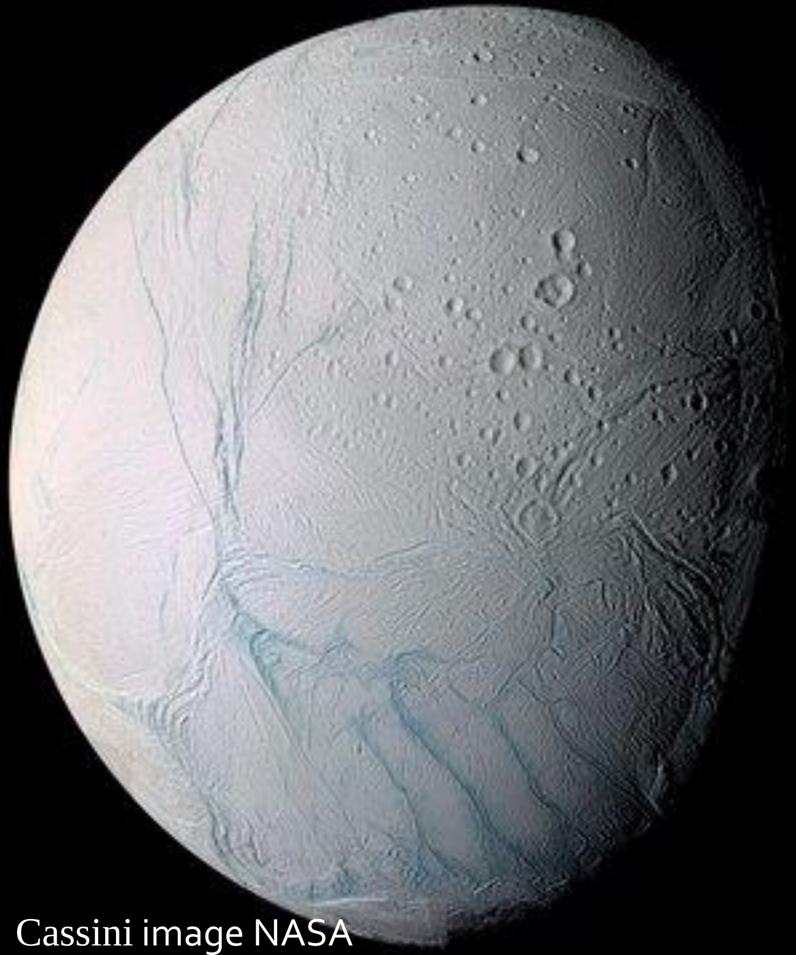
Things to notice:

- 2015 closest dive ever
- Brightness of Enceladus
- Plume and how far it reaches
- Complicated geologic history

Cratering

- Has largest range in crater density
  - Heavily craters areas (south polar terrain)
  - Near Tiger stripes lowest density
  - Time span is more than 4 billion years ago
  - Where younger (geothermal) region is 500,000 years old

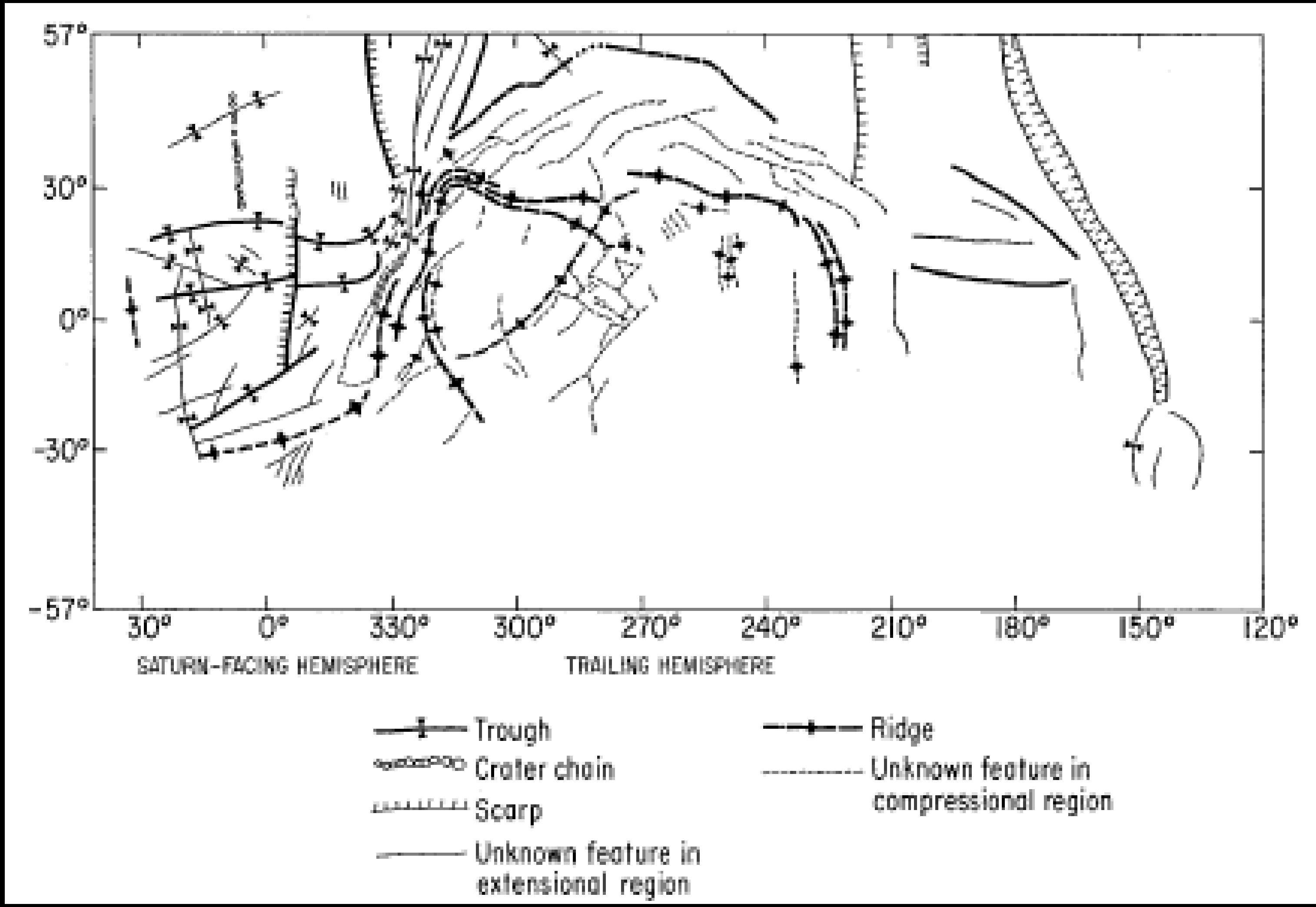
Cassini image NASA



Cassini image NASA

Enceladus complex geological history

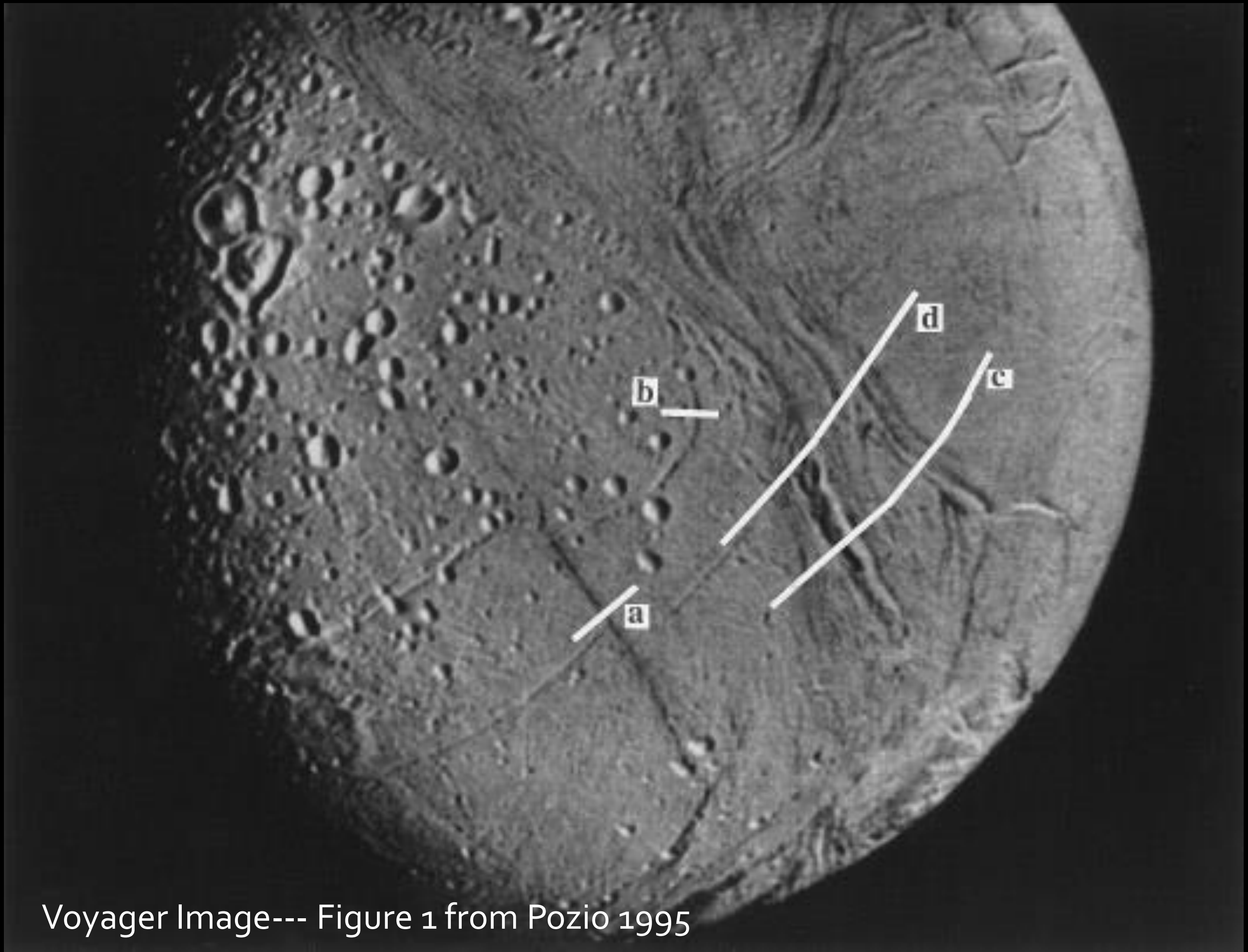
- 4 Terrains
  - Cratered Planes → Older and more heavily cratered
  - Ridged Planes → Younger terrain, compressional setting
  - Rifted Terrain → Extensional setting
  - Banded Terrain → Variability in cratering (areas of young and old)



Pozio 1995

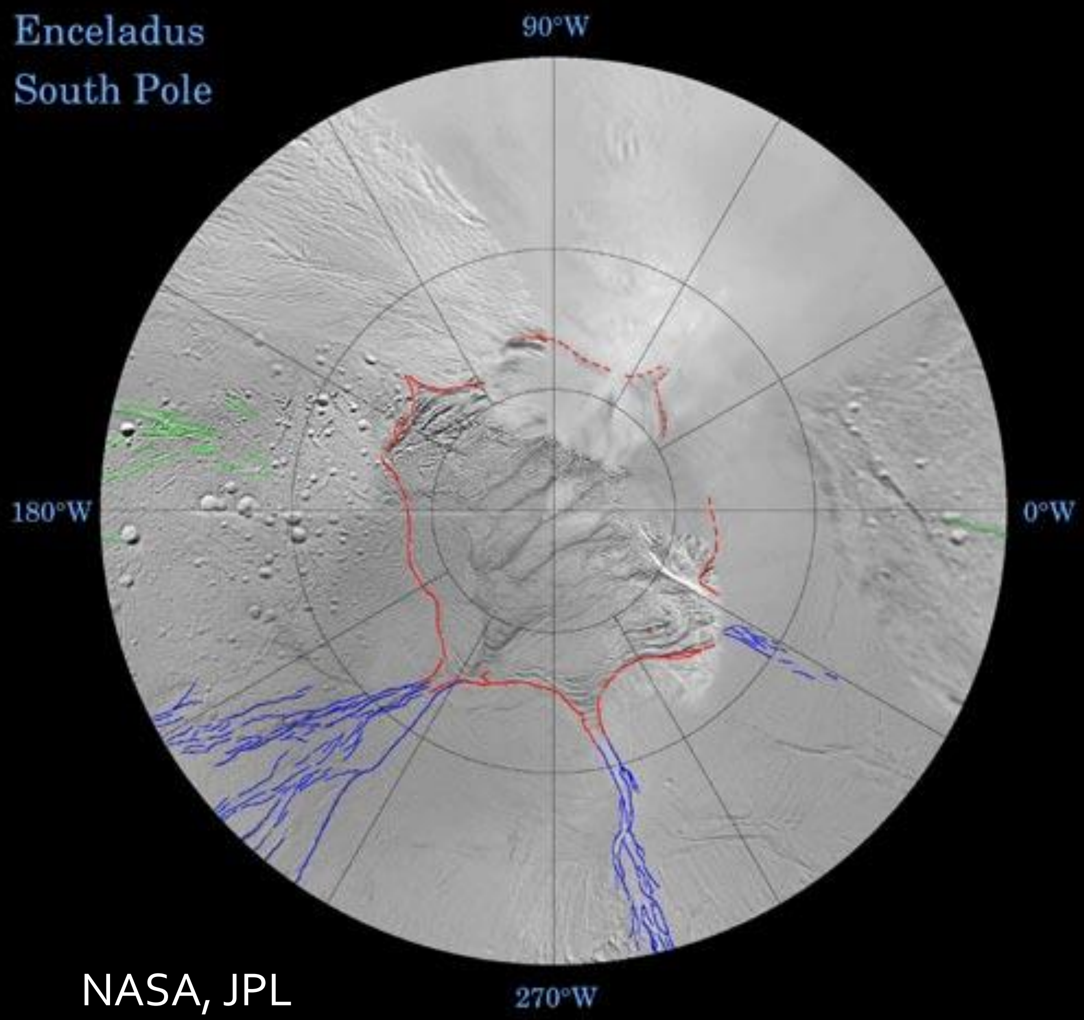
Examples of geologic terrains

- Pozio 1995
  - A) Right lateral strike slip fault
  - B) Trough
  - C and D) Compressional fold belts



Voyager Image--- Figure 1 from Pozio 1995

Active South Pole

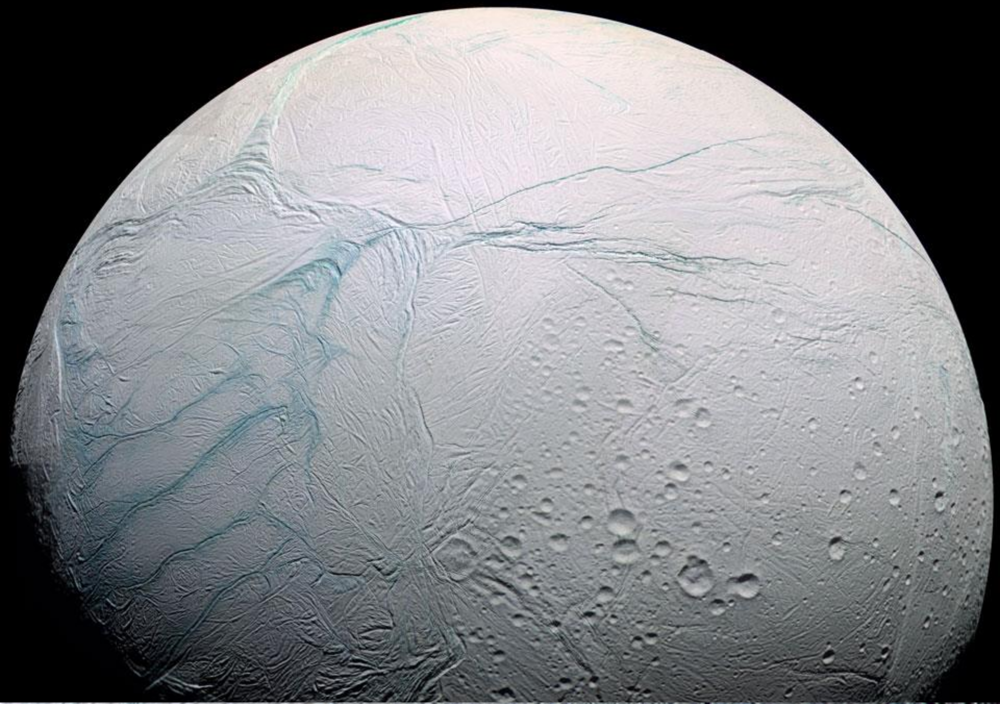


NASA, JPL

- Subsolar temp 75 K
- South Pole 85 K
  - Not due to seasonal affects
- Separated from rest of Enceladus by a series of :
  - Scarps
  - Parallel ridges
  - Troughs
- Covers an area of 70,000 km
  - Y shaped discontinuities interrupt this

Tiger Stripes

- 4 stripes: Linear depressions
  - Alexandria, Cairo, Baghdad, and Damascus
    - Baghdad and Damascus strongest sources
  - High Temperature: 175 K
  - 500 m deep 2 km wide and 130 km long
  - Spaced 35 km apart
  - Similar shapes and orientations
  - ~45 degrees from Saturn direction
  - Large absorption
  - Sharp relief



Temporal Variation in the Tiger Stripes

- Tidal forces cause opening and closing of stripes
- Govern the time of eruptions
- Each orbit the tiger stripes spend half of the time in tension (rifts)
  - Explosive volatiles
    - Shear heating contributes
- February plume activity less than January
  - February most of the stripes would switch to compression
  - pericentre, most of the system is in compression

Hurford et al., 2007

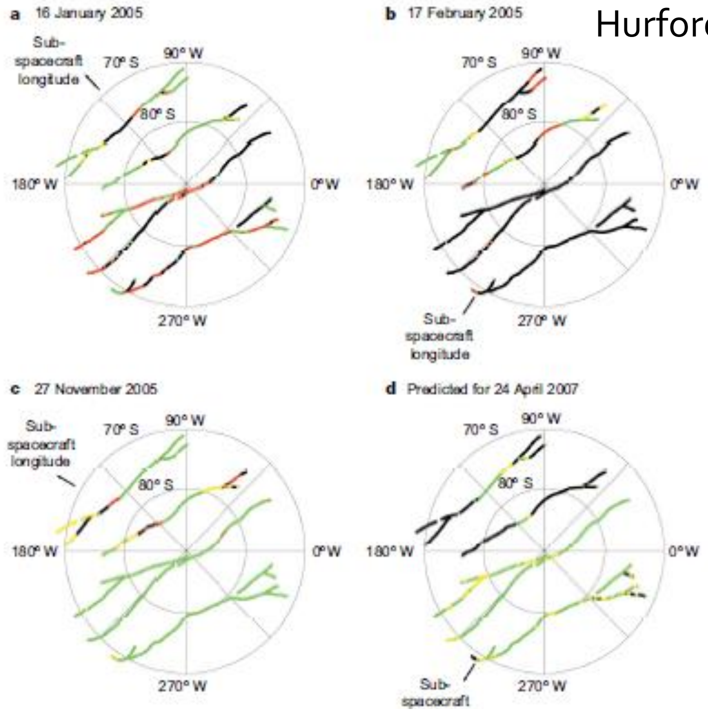
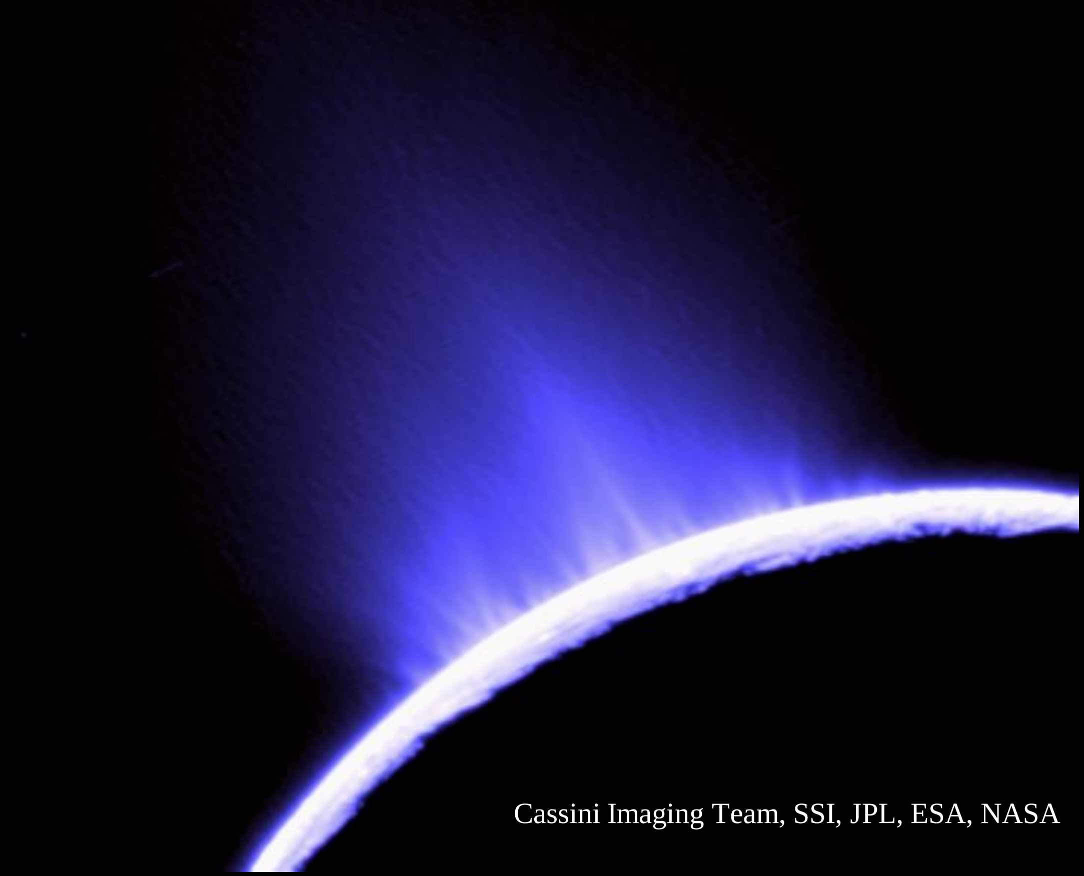


Figure S1. Plume observations from Cassini.

Plumes of Enceladus

NASA's Cassini orbiter in October 2007



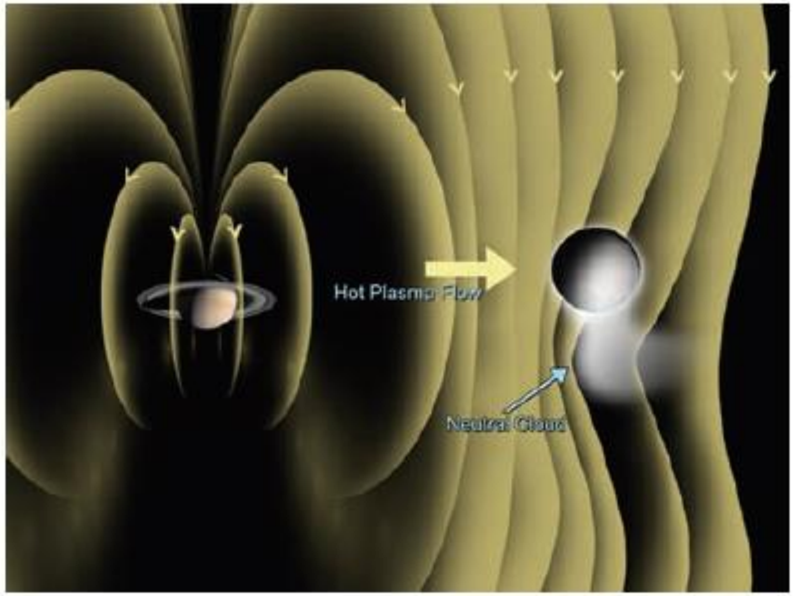
Cassini Imaging Team, SSI, JPL, ESA, NASA

- Discovered 2005
- High Phase angles (Porco et al., 2006)
  - Indicates fine forward scattered particles
  - Escape velocity 235 m/s
  - Most particles are falling back to the surface
    - Only 1% of particles escape to supply E- Ring
    - Making this region more reflective
- Vent Velocities
  - 300-500 m/s
- Over 70 Geysers
- Vent Temperatures as high as 225 K (Fortes 2007)

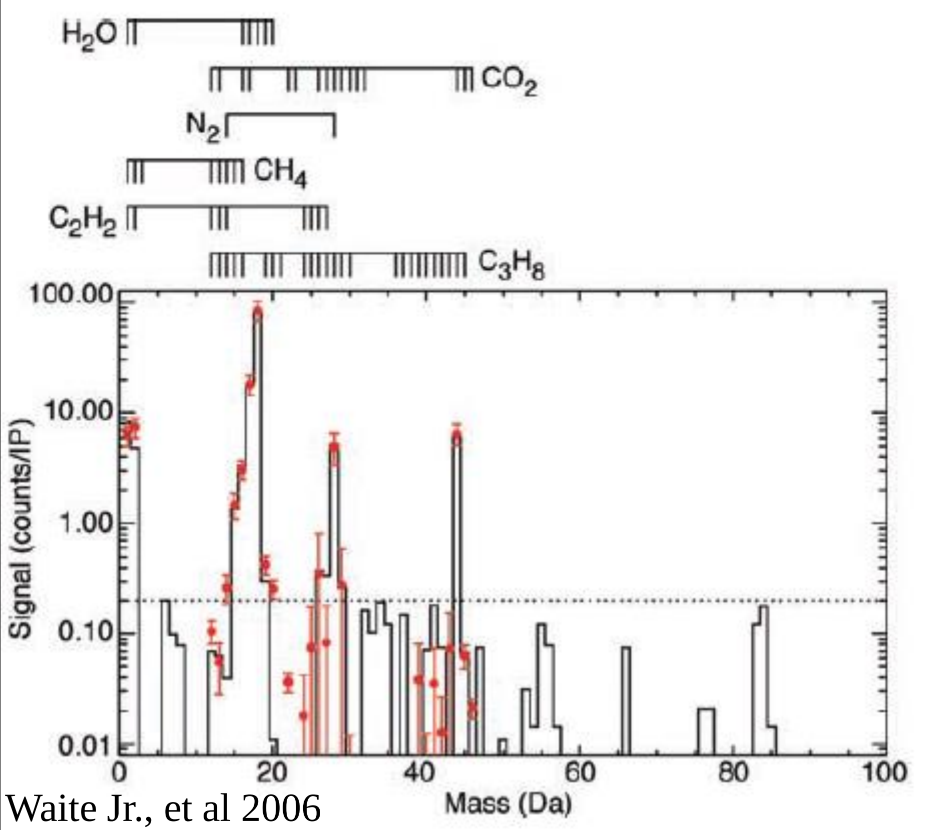
Magnetometer: Atmosphere

- Draped lines consistent with presence of atmosphere
  - Sputtered or sublimated atmosphere would be lost
  - Tenuous atmosphere has to come from geological activity
- Third flyby they descended close in altitude

Fig. 4. A schematic (where Saturn and Enceladus are not to scale) showing the corotating Saturn magnetic field and plasma being perturbed by the neutral cloud that is produced by a polar plume generated close to the south pole of Enceladus. This scenario fits the second two flyby observations.



Plume composition



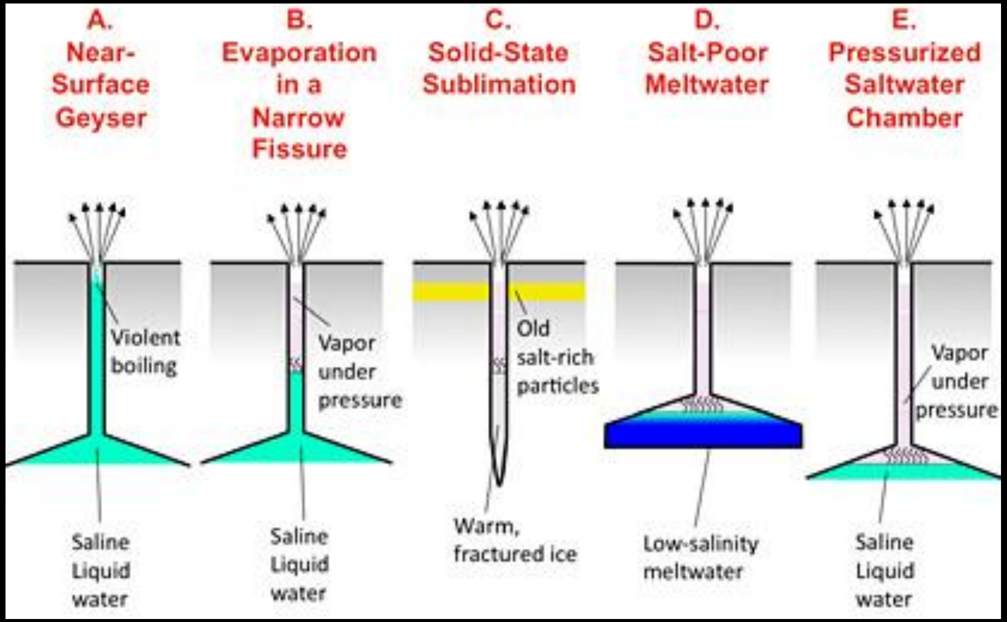
Waite Jr., et al 2006

- Cassini Ion Neutral Mass Spectrometer
  - H_2O: 91% $\pm$ 3%
  - N_2 or CO: 4% $\pm$ 1%
  - CO_2: 3.2% $\pm$ 0.6%
  - CH_4: 1.6% $\pm$ 0.4%

http://saturn.jpl.nasa.gov/video/videodetails/?videoID=104

Source of Plumes

- Sublimation
- Clathrate reservoir --- Frigid Faithful method
  - (Kieffer et al., 2006)
- Underground reservoir ---Ocean
  - (Collins and Goodman 2007)
- Boiling liquid erupting tiger strips --- Cold faithful
  - (Porco et al., 2007)
- Melt trapping Clathrates --- Frothy faithful
  - (Fortes 2007)
- Volatile generation by shear heating
  - (Nimmo et al., 2007)

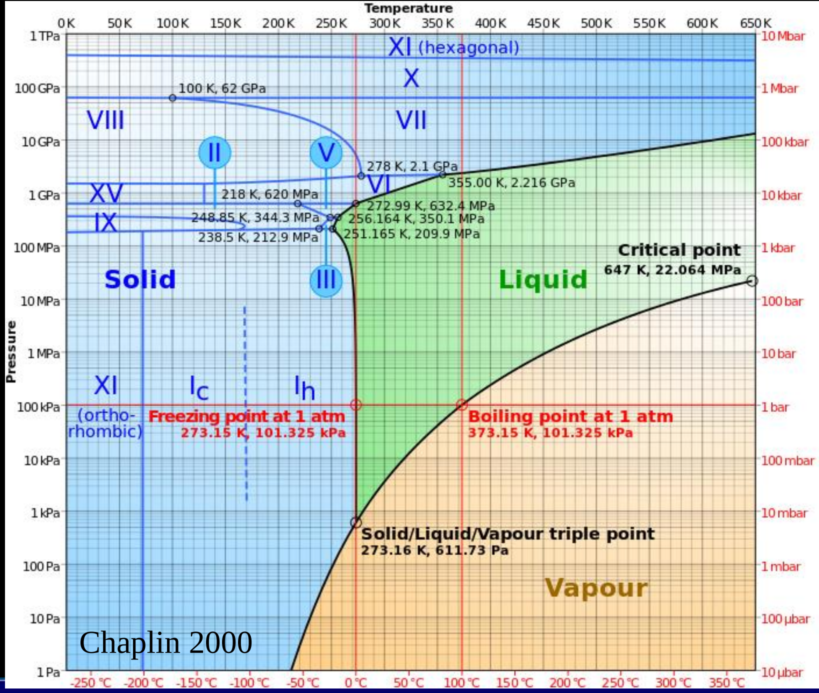


NASA/JPL/SWRI/University of Colorado

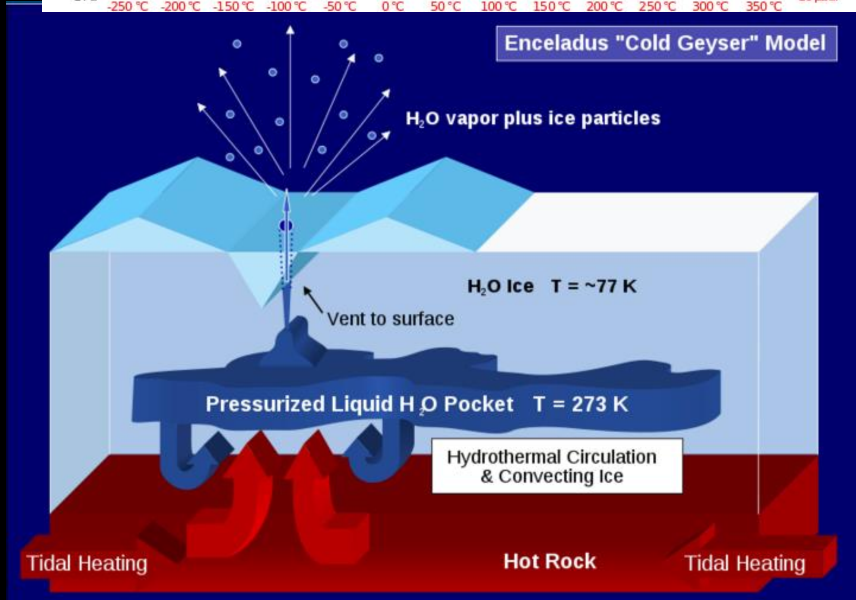
Source of Plumes

- Sublimation
  - Large ice/gas ratios observed goes against ice condensation out of vapor (Schuber et al., 2007)

- Boiling liquid erupting tiger strips (cold faithful) (Porco et al., 2007)
  – Composition (with the exception of CO_2) is an order of magnitude larger than the plausible solubility in cold water



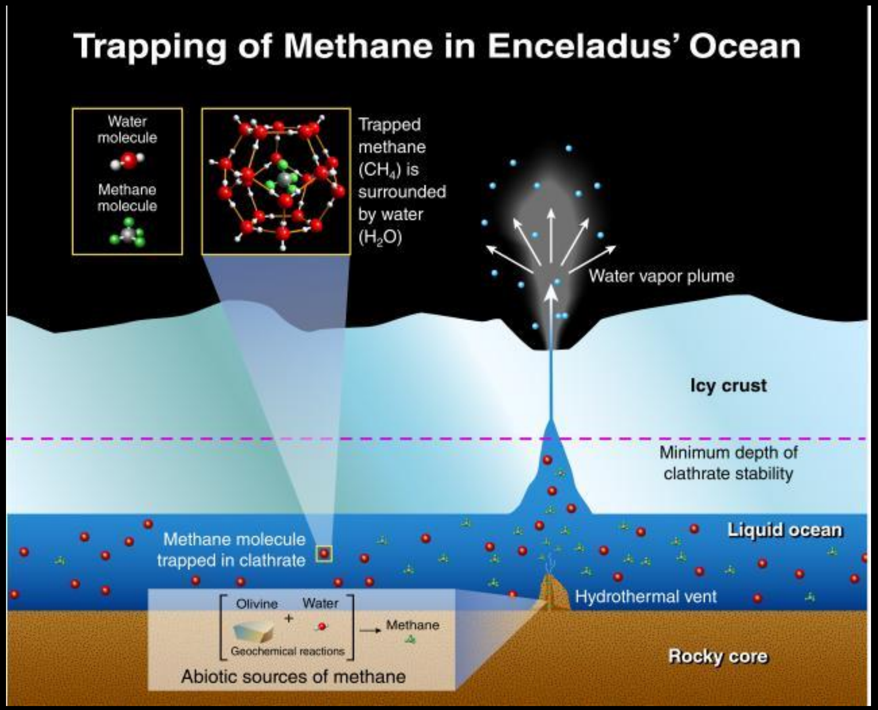
Chaplin 2000



http://saturn.jpl.nasa.gov/photos/

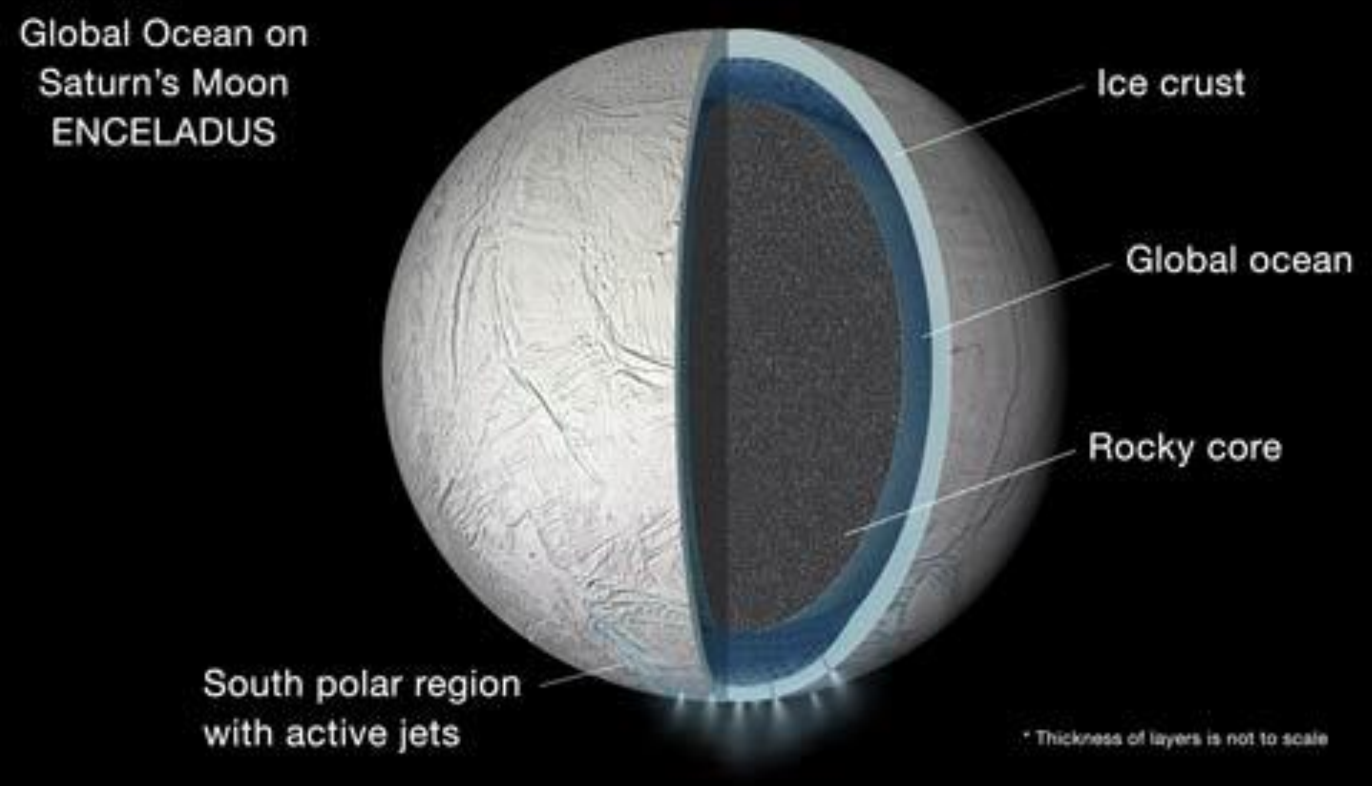
Source of Plumes: Frigid Faithful

- Clathrate reservoir (Frigid Faithful method) (Kieffer et al., 2006)
  - For:
    - No magmatism required
    - Explains the thermal anomaly in SPT in terms of latent heat
  - Against:
    - Model predicts outgassing will occur whenever tensional fractures penetrate the reservoir
      - But numerous fresh large scale tensional fractures at mid latitudes not venting (Fortes 2007 and Porco et al., 2006)
    - How can there a several km fracture that then is not filled with debris



http://saturn.jpl.nasa.gov/photos/

Ocean Reservoir (Collins and Goodman 2007)



http://saturn.jpl.nasa.gov/photos/

- Outgassing would be expected in extensional zones and not compressional zones
  - Agreement with the temporal variation suggested by Hurford et al., 2007

Sources of Plumes: Frothy Faithful (Fortes 2007)

- Cryovolcanic melt
  - moves toward surface traps clathrates which decompose at low P adding a explosiveness to eruption (Frothy faithful) (Fortes 2007)
- 2 layer model (consistent radius and density)
- Rocky core (16 MPa)
- Ice rich mantle (8.2 km deep)
- CM boundary Pressure 10 MPa
- In underground ice would see a formation of poly crystalline veins containing clathrates and salt hydrates
  - Evidence of crystalline water ice from Tiger Stripes
- Argue against ocean because not consistent with vent temperature

Composition of Enceladus

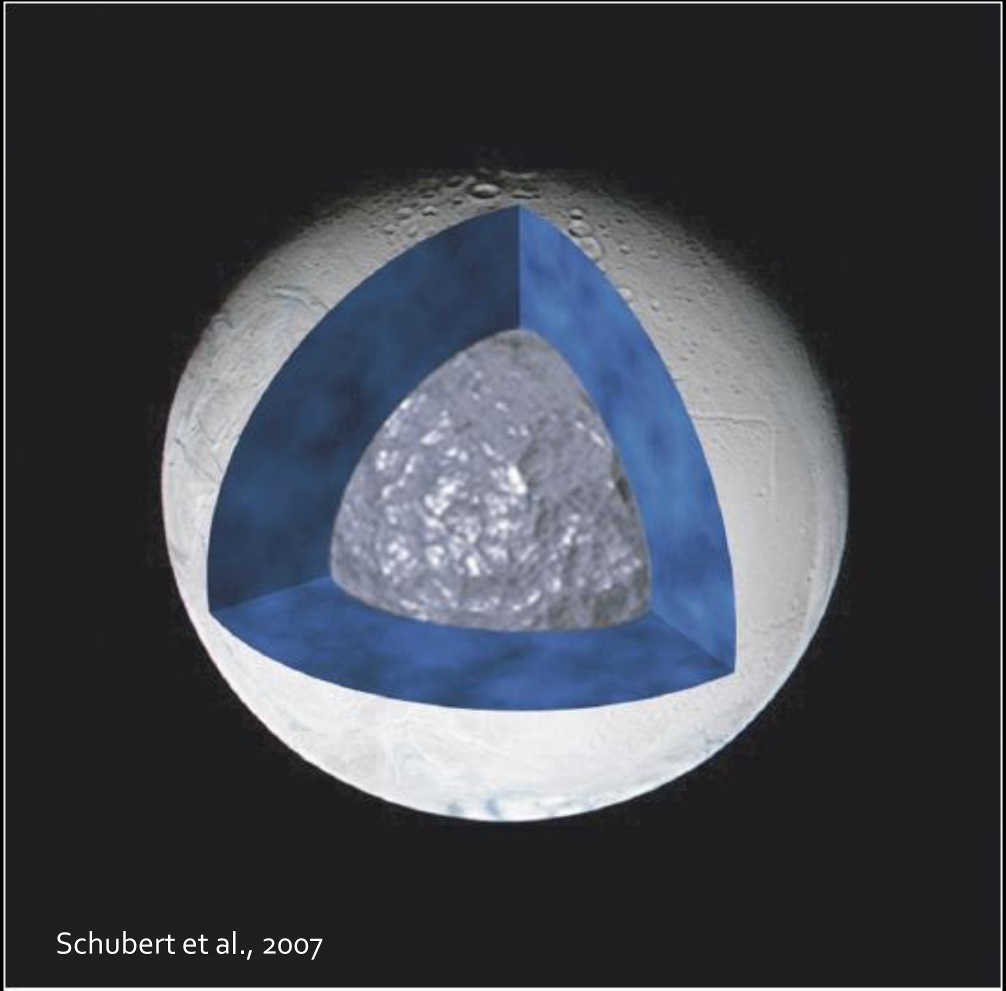
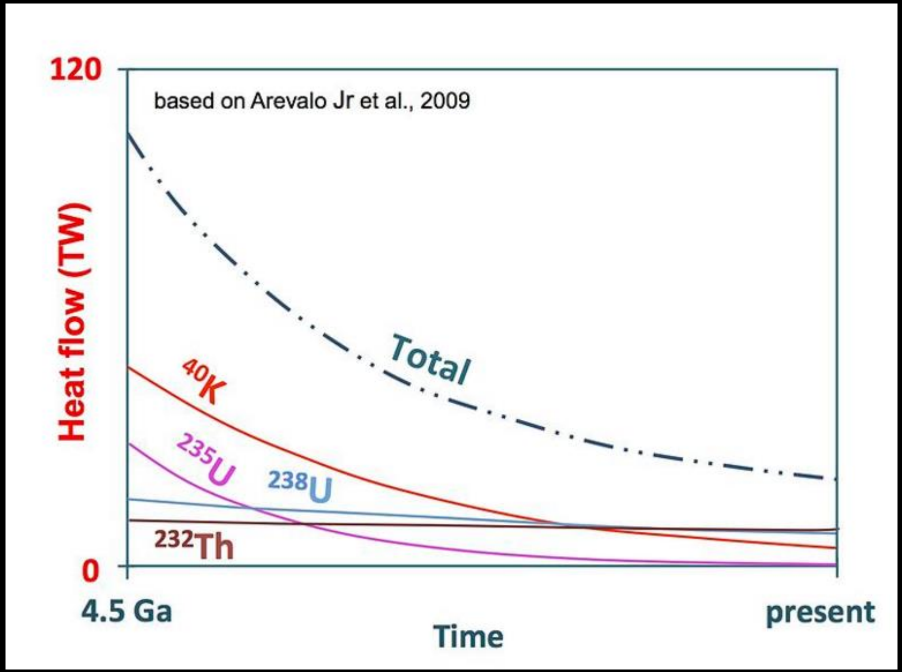


Fig. 2. Illustration drawn to scale of a differentiated Enceladus with a rock-metal core and thick ice shell.

- Differentiation early in its evolution
- Melting of ice through radiogenic heating (^{26}Al)
- Hot rocky core 105 km radius
- Liquid ocean 70 km deep
- 15 km ice shelf
- Interior above freezing
  - Combo radiogenic and tidal heating

Radiogenic Heating

- Less than for other satellites of similar size (Pozio 1995)
  - Less dense so lower content K, U, and Th.
- Schubert et al., 2007
  - melt ice by 500 Myr assuming accretion T of 200K
    - Basing on decay of ^{26}Al this would be even less just a few Myr.
  - Suggests long lived radioactivity facilitates tidal heating and is a source of energy for differentiation.
    - Warmer ice the more affective the tidal deformation.
    - Would explain the discrepancy between Enceladus and Mimas



Mimas discrepancy: Why is Mimas so cold?

Cassini Imaging Team, NASA

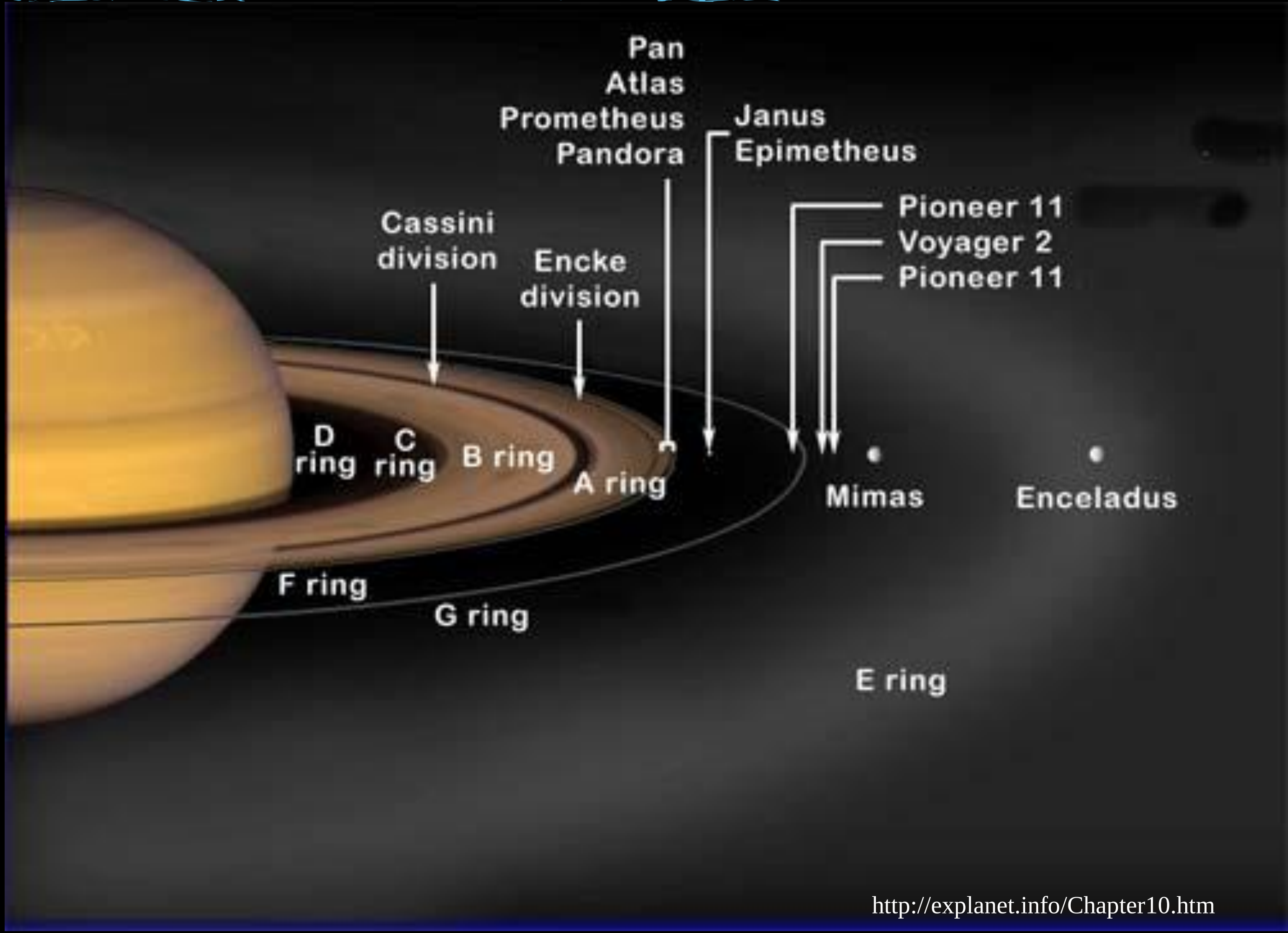
- Contains less rock than Enceladus
  - Little radiogenic heating so less susceptible to tidal heating
- Despite proximity to Saturn and larger eccentricity (0.0196) than Enceladus

Tidal Heating

- Tidal heat flow could be as great as 5 mW/m2
- 2:1 resonance with Dione
- Possible past 1:4 spin/orbital
- Shear heating by tidally driven lateral fault motion (Nimmas et al.,2007)
  - Cause a release of vapor
  - Gas could escape through cracks

E Ring (Outermost and Largest ring)

- Peak density of E ring with orbit of Enceladus (Hanson et al., 2006)
- Narrow particle size (0.3 to 3 micrometers) suggests liquid or vapor origin.
- Extends from 3 to 8 Saturn Radii
- Life of 1 micrometer grain < 50 years
  - Sputtering is too long of a process to replace these grains
- Plumes
  - Source of these particles which would imply activity for last 15 years



http://explanet.info/Chapter10.htm

Future Missions!!

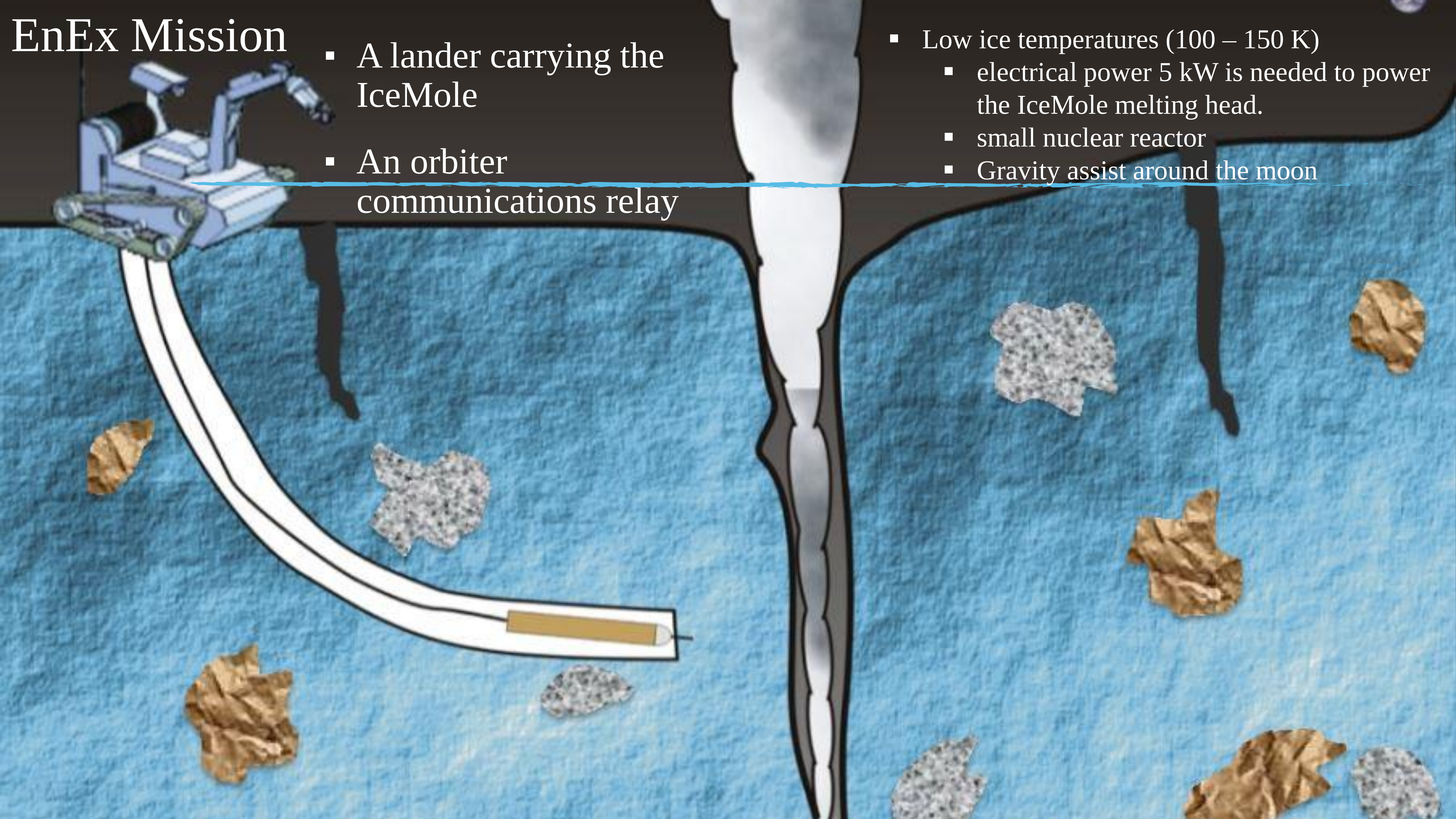
Proposed Mission Ideas

- Enceladus Explorer (EnEx)
  - German Aerospace Center
    - Deutsches Zentrum fuer Luft und Raumfahrt, (DLR)
- Goal: Design a mission to Enceladus and create operable drilling technique using icemole.
- Ice Mole:
    - ice melting probe for clean sampling and in-situ analysis of ice and subglacial liquids
    - Combo of melting and drilling
-

EnEx Mission

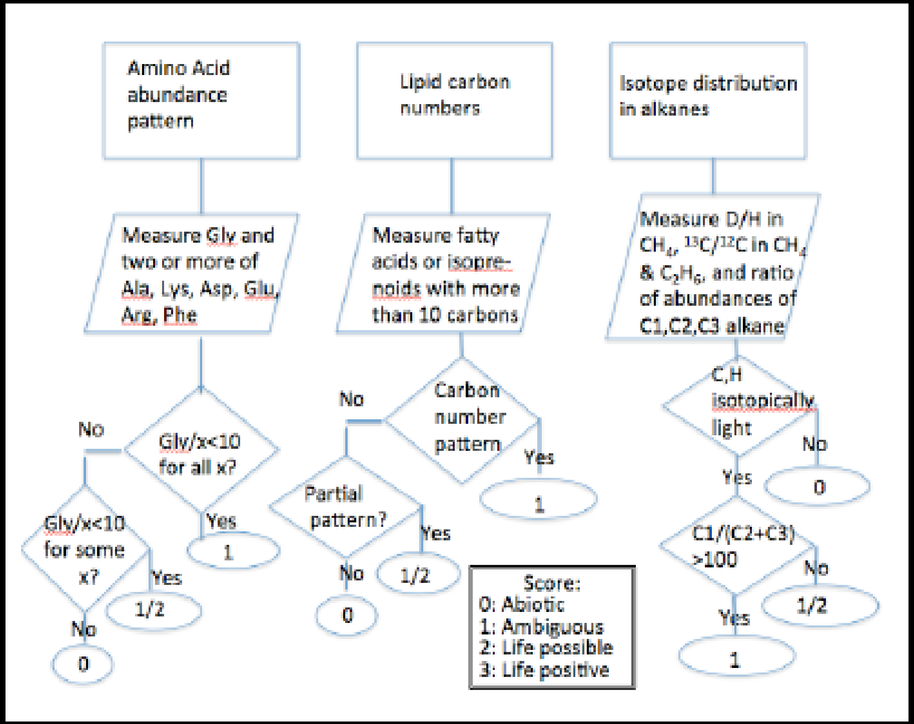
- A lander carrying the IceMole
- An orbiter communications relay

- Low ice temperatures (100 – 150 K)
  - electrical power 5 kW is needed to power the IceMole melting head.
  - small nuclear reactor
  - Gravity assist around the moon



Enceladus Life Finder (ELF)

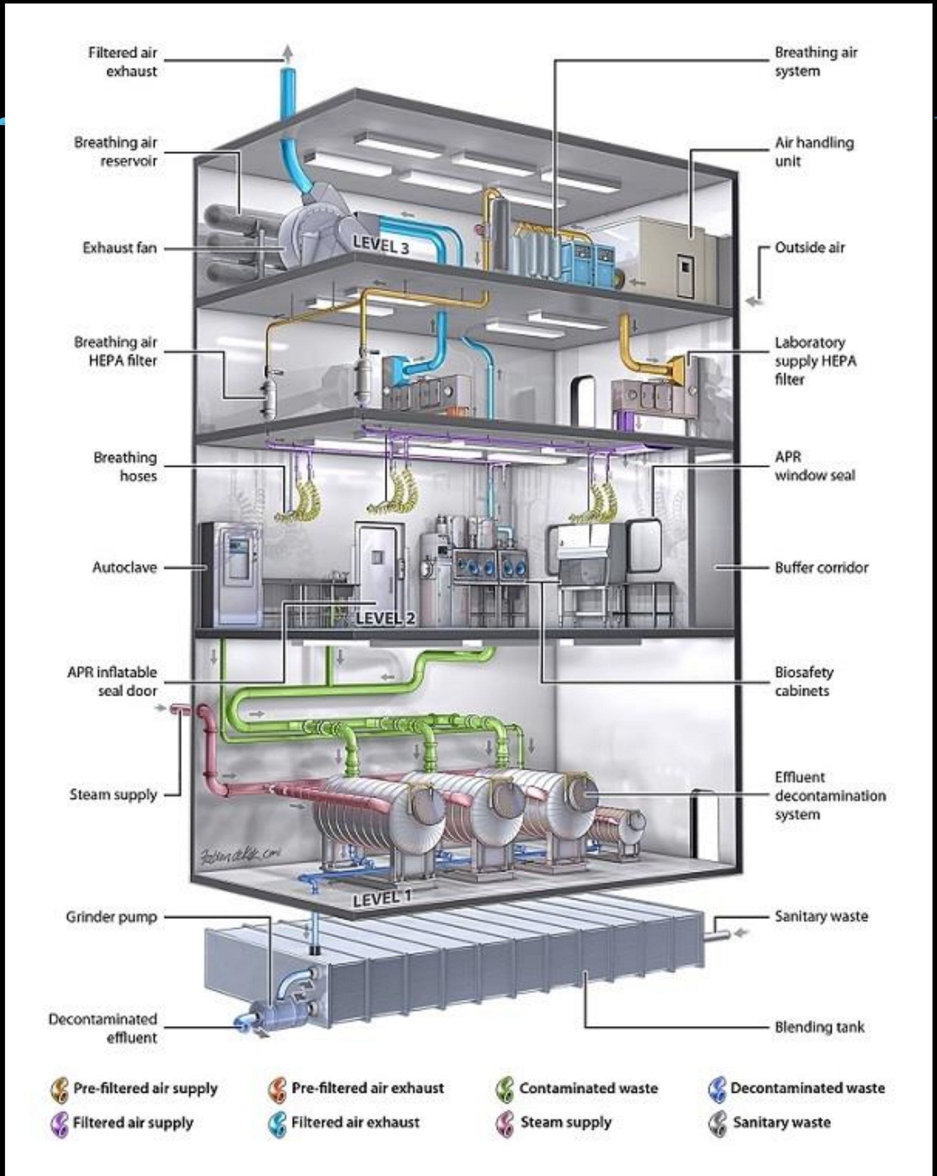
- Enceladus Life Finder (ELF)
  - United Launch Alliance Atlas V rocket
    - endure a 9.5-year-long journey to Saturn
  - Probe fly through the plumes Solar energy
    - 2 mass specs.
      - One focused on plume gas
      - Other focused on actual grains



- Goals
  - pH, oxidation state, organics that are a result of biological processes
  - Test hardness of amino acids (instrument development)

LIFE

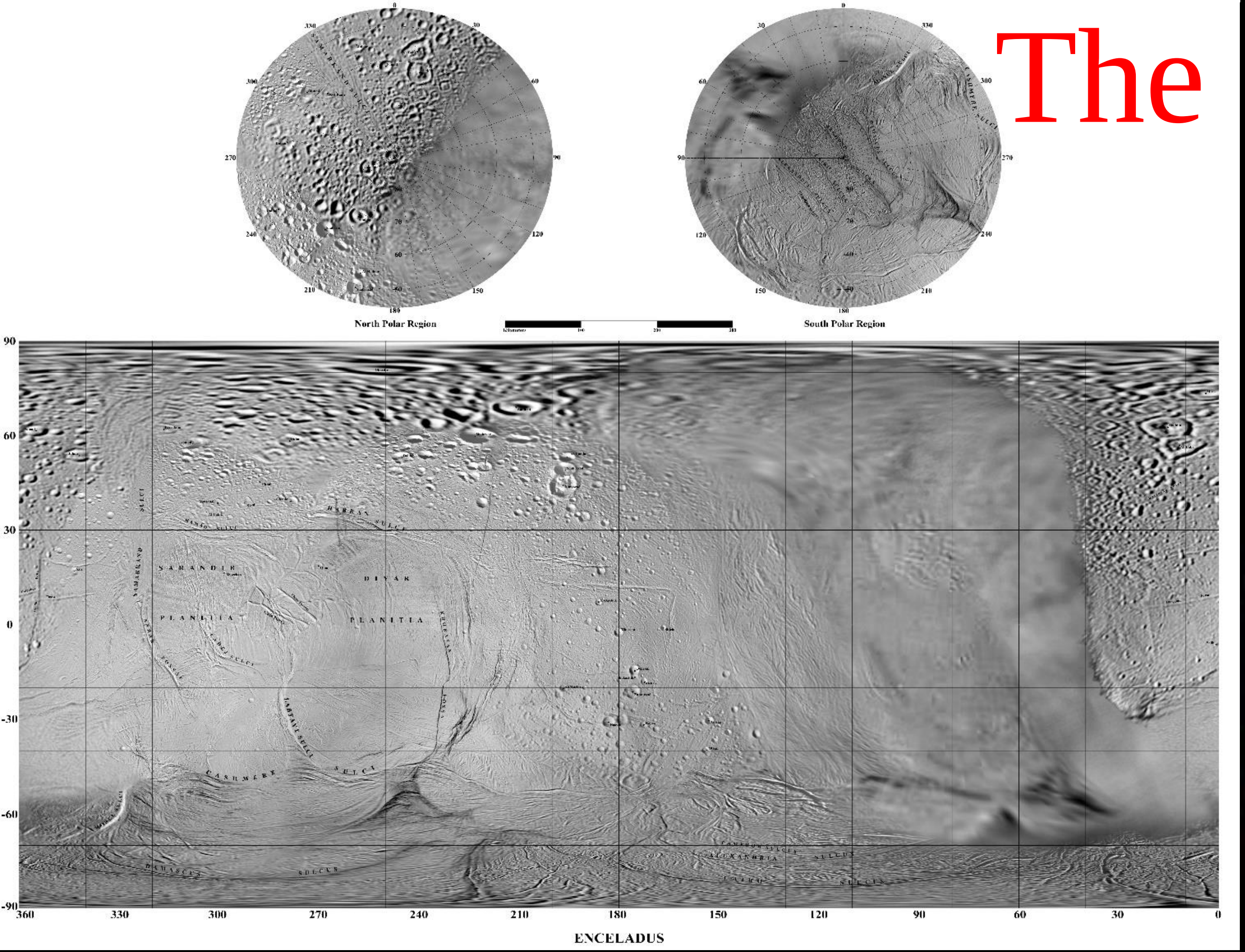
- Mission would be to fly through plumes
- Plan for a sample return capsule
- Also have mass spec for insitu analysis and a camera
- Requires BSL 4 containment center
  - Japan has offered to pick up this part of the bill
    - Building a BSL 4 on its ocean going research vessel



Future Missions

- My thoughts:
  - Lander
  - Seismometers on the ground
  - Collect data from the ground on the switch extension to compression
  - Great to return a sample
    - But we would have to really be careful with contamination
    - I think we would want a back up sample carrier
    - Laser induces plasma mass spec?
    - In situ X-ray Diffraction – What kind of ice do we have

The End


North Polar Region
South Polar Region
SARANDIB
PLANITIA
DIYAR
PLANITIA
ENCELADUS