# Summary of Cassini Ring Science

- The low mass estimate of Saturn's rings (~1.54 x $10^{19}$ kg) suggests that the rings are very young, ~10 to 100 million years old

- The rings could of formed during the age of the dinosaurs

- The rings most likely formed late in Saturn's history

- The rings are continually being pulled into Saturn by its gravity, as a dusty rain of ice particles under the influence of Saturn's magnetic field

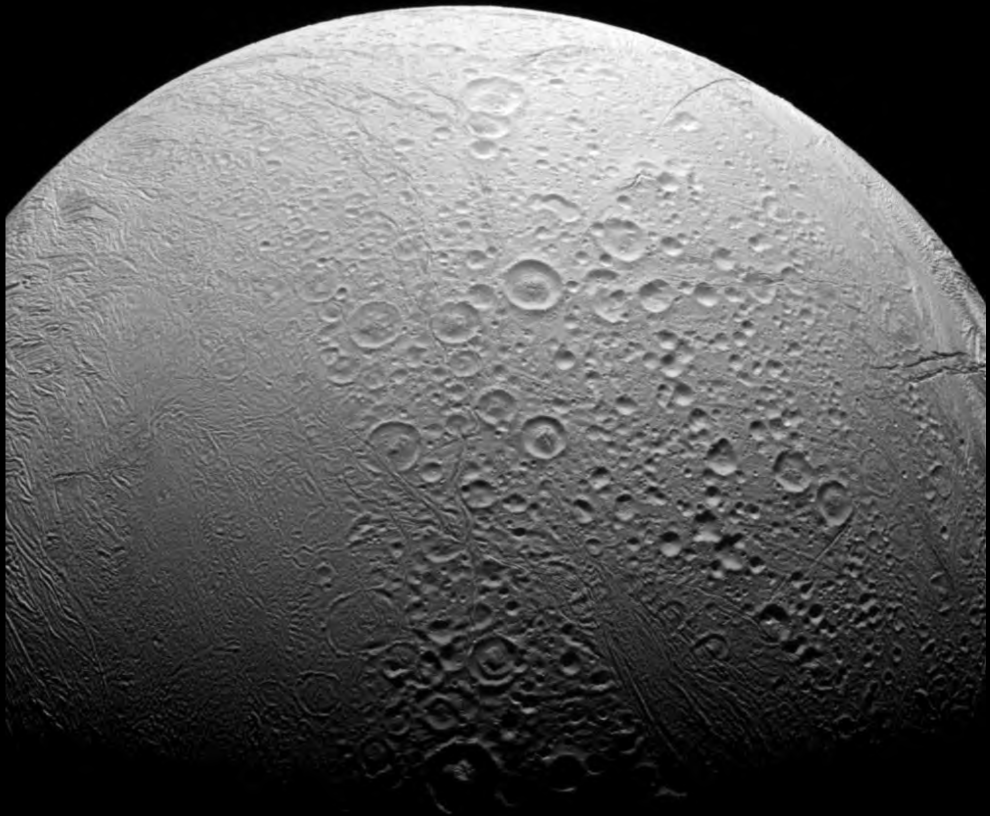
- If this sink process continues then the rings could be depleted in ~300 million years

*Image Credit: NASA/JPL/Space Science Institute*

# Enceladus’ Surface

**Early in the mission, Cassini’s cameras revealed Enceladus’ south polar to be almost entirely free of impact craters, with extensive cracks in the surface.**

**The south polar region contains unique tectonic patterns, and is the youngest surface on Enceladus.**



**The lack of impact craters suggests the south polar surface is geologically-fresh, and constantly being renewed.**

*Image Credit: NASA/JPL/Space Science Institute*

# Activity on Enceladus

- Early in the mission, Cassini's magnetometer recorded something around Enceladus deflecting Saturn's magnetic field

- Specifically, magnetometer data revealed a "dip" in the magnetic field around Enceladus

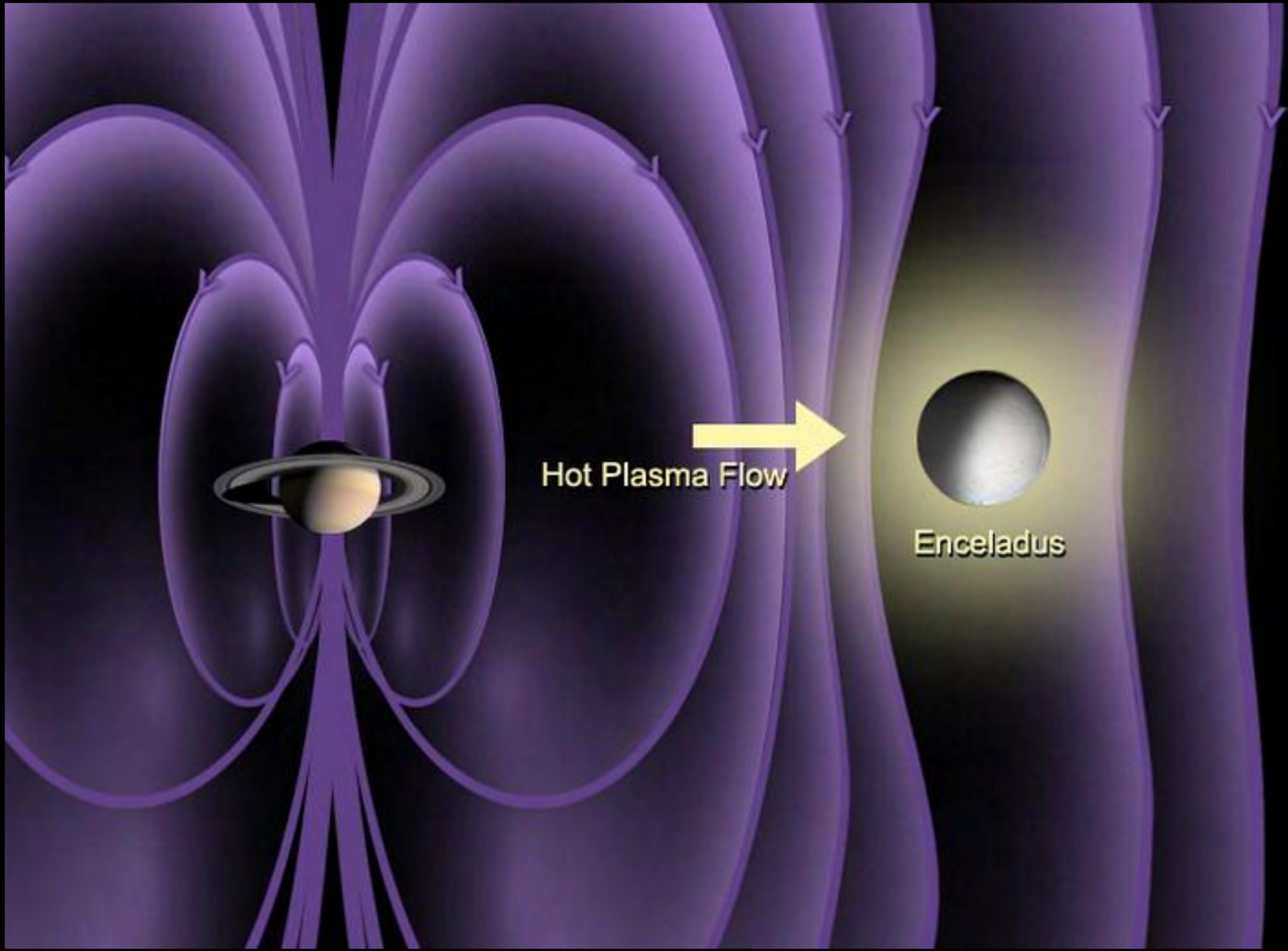



*Image Credit: NASA/JPL/Space Science Institute*

# Enceladus Temperature Map

- Enceladus has a very high albedo, reflecting ~80% of sunlight impinging on it, so only ~20% is available to heat the surface
- Based on predicted temperatures, the poles are expected to be even colder than the equator
- When CIRS first observed thermal maps of Enceladus' south polar surface, they expected to the temperatures similar to the north polar surface
- Surprisingly, CIRS observed a dramatic "hot spot" on Enceladus' south polar surface, which was indicative of internal heat leaking out of the moon

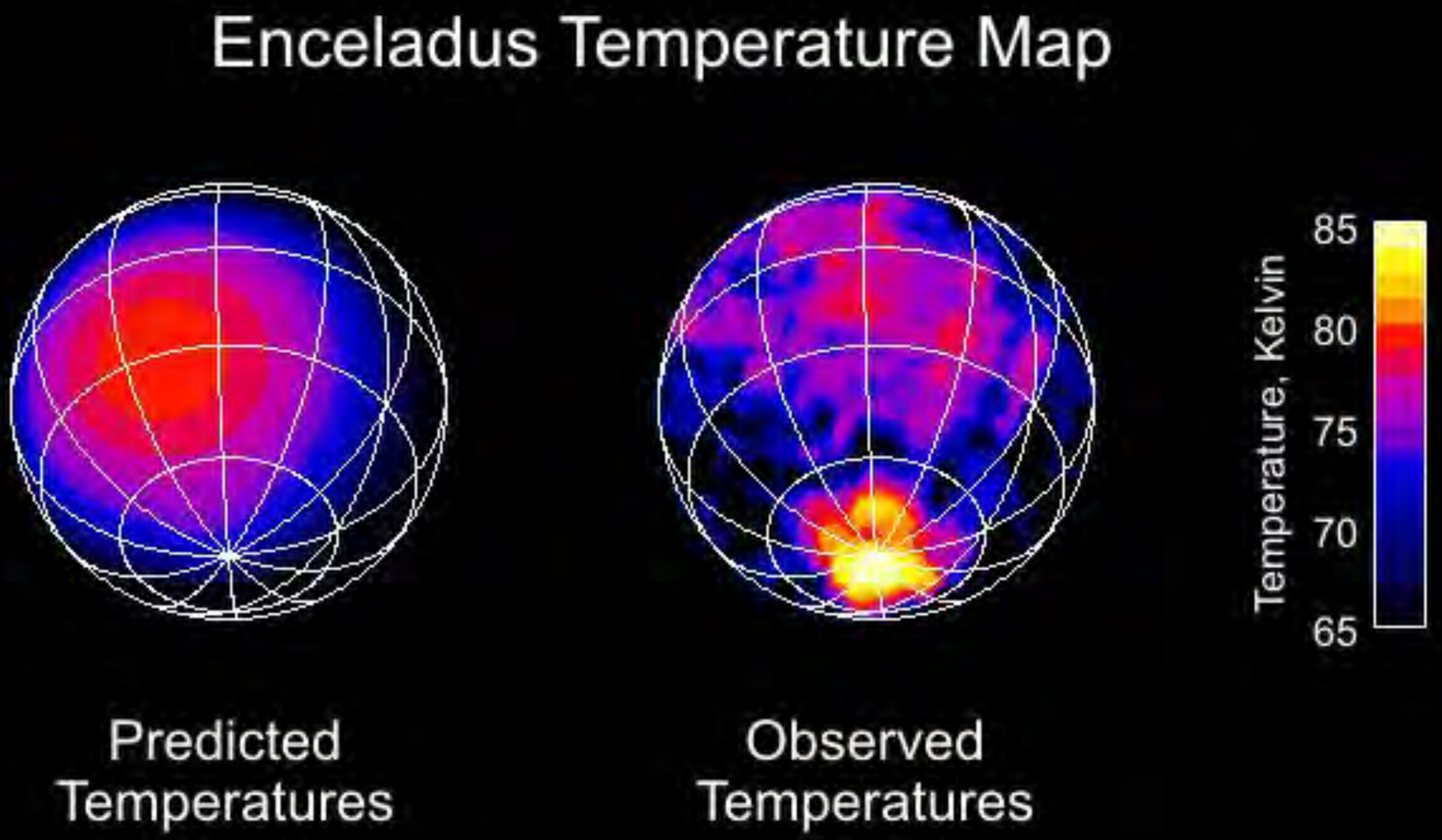



*Image Credit: NASA/JPL/Space Science Institute*

# Enceladus' Tiger Stripe Temperatures

- Subsequent CIRS observations revealed elevated temperatures over Enceladus' four fissures – the tiger stripes

- The temperature increase is consistent with endogenic heating


*Image Credit: NASA/JPL/Space Science Institute*

# Enceladus Imaging Observations

- Cassini’s Imaging Science Subsystem (ISS) followed up with images of Enceladus
- Inconclusive results were initially returned
- At this time, the ISS science team thought that there was some sort of diffraction effect observed in the Enceladus images
- But then, the iconic high-phase angle (161˚) ISS image of Enceladus was recorded, with the moon backlit by the sun
- This image definitely proved Enceladus had plumes

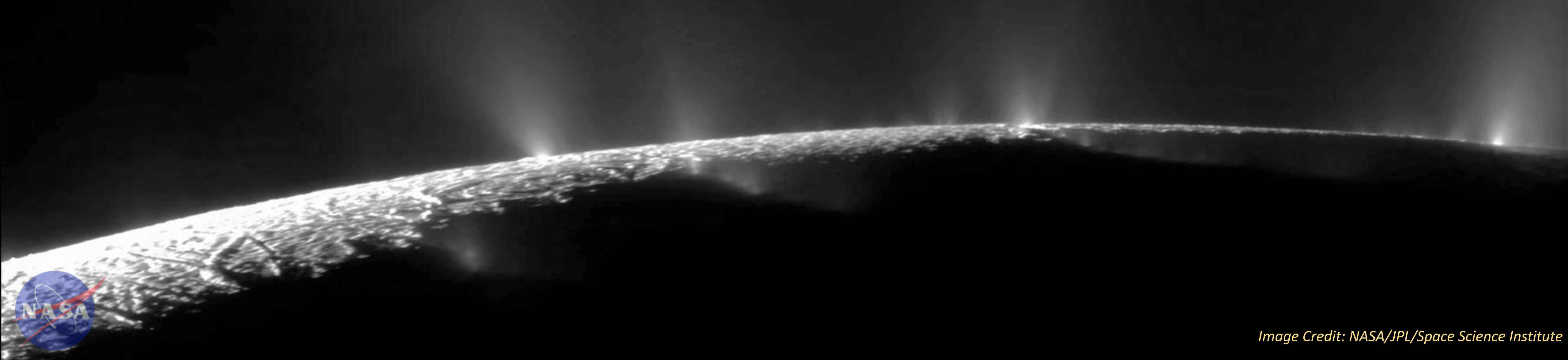


*Image Credit: NASA/JPL/Space Science Institute*

**Changing view of Enceladus’ plume over 6.5 hours**

*Movie Credit: NASA/JPL/Space Science Institute*

# Enceladus’ Icy Grains

- Most of Enceladus’ plume ejecta re-impacts its surface, with the smallest grains injecting into the E-ring
- The E-ring interacts with Mimas, Tethys, Dione, and Rhea, coating them with E-ring icy grains
- The E-ring particulates also affect the outer moons, like Titan
- Sodium salts were detected in Saturn’s E-ring icy particulates
- These salty ices suggest that Enceladus may harbor a large reservoir of subsurface liquid water

*Image Credit: NASA/JPL/Space Science Institute*

# Gravity Measurements

- Enceladus' S. polar surface is depressed
  → it is warmer, less dense
- Gravity measurements show a negative anomaly that is smaller than expected
- This suggests denser material at depth that compensates the missing mass near the surface
  → this is potentially liquid water, which is denser than ice
- These results confirm a sub-surface ocean
- The sub-surface liquid water ocean is the source of Enceladus' plumes
  → The ocean depth is ~10 km beneath an ice shell that is ~30 km thick (~5 km thick in south polar region)

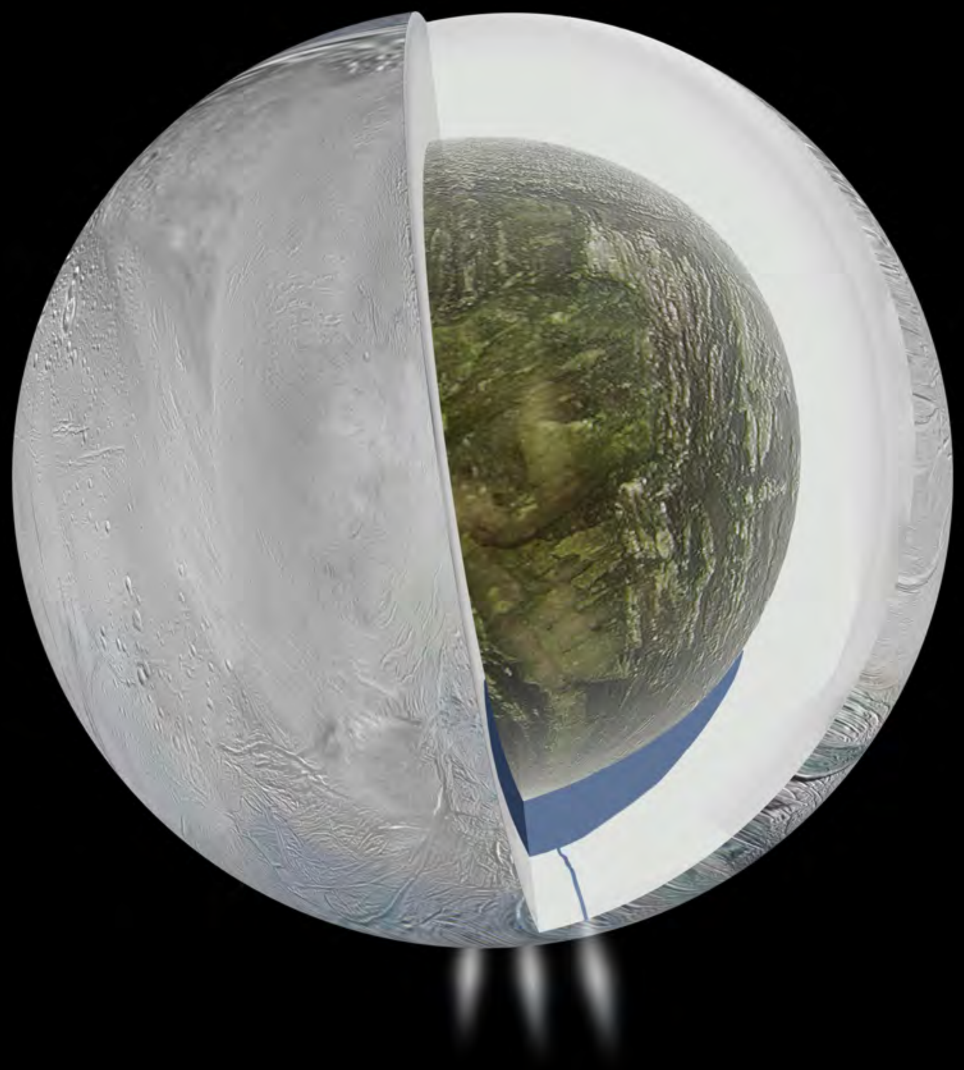


*Image Credit: NASA/JPL/Space Science Institute*

# Plume Chemical Composition

**Enceladus' plumes were *in situ* sampled by Cassini's INMS instrument during very close flybys, detecting $H_2O$, $CO_2$, CO, other volatile gases, and organic compounds**

**Table 1 | INMS determination of plume composition on 9 October 2008**

| Species | Volume mixing ratio |
|---|---|
| $H_2O$ | $0.90 \pm 0.01$ |
| $CO_2$ | $0.053 \pm 0.001$ |
| CO | [0.044] |
| $H_2$ | [0.39] |
| $H_2CO$ | $(3.1 \pm 1) \times 10^{-3}$ |
| $CH_3OH$ | $(1.5 \pm 0.6) \times 10^{-4}$ |
| $C_2H_4O$ | $<7.0 \times 10^{-4}$ |
| $C_2H_6O$ | $<3.0 \times 10^{-4}$ |
| $H_2S$ | $(2.1 \pm 1) \times 10^{-5}$ |
| $^{40}Ar$ | $(3.1 \pm 0.3) \times 10^{-4}$ |
| $NH_3$ | $(8.2 \pm 0.2) \times 10^{-3}$ |
| $N_2$ | $<0.011$ |
| HCN† | $<7.4 \times 10^{-3}$ |
| $CH_4$ | $(9.1 \pm 0.5) \times 10^{-3}$ |
| $C_2H_2$ | $(3.3 \pm 2) \times 10^{-3}$ |
| $C_2H_4$ | $<0.012$ |
| $C_2H_6$ | $<1.7 \times 10^{-3}$ |
| $C_3H_4$ | $<1.1 \times 10^{-4}$ |
| $C_3H_6$ | $(1.4 \pm 0.3) \times 10^{-3}$ |
| $C_3H_8$ | $<1.4 \times 10^{-3}$ |
| $C_4H_2$ | $(3.7 \pm 0.8) \times 10^{-5}$ |
| $C_4H_4$ | $(1.5 \pm 0.6) \times 10^{-5}$ |
| $C_4H_6$ | $(5.7 \pm 3) \times 10^{-5}$ |
| $C_4H_8$ | $(2.3 \pm 0.3) \times 10^{-4}$ |
| $C_4H_{10}$ | $<7.2 \times 10^{-4}$ |
| $C_5H_6$ | $<2.7 \times 10^{-6}$ |
| $C_5H_{12}$ | $<6.2 \times 10^{-5}$ |
| $C_6H_6$ | $(8.1 \pm 1) \times 10^{-5}$ |

Waite et al. (2009)

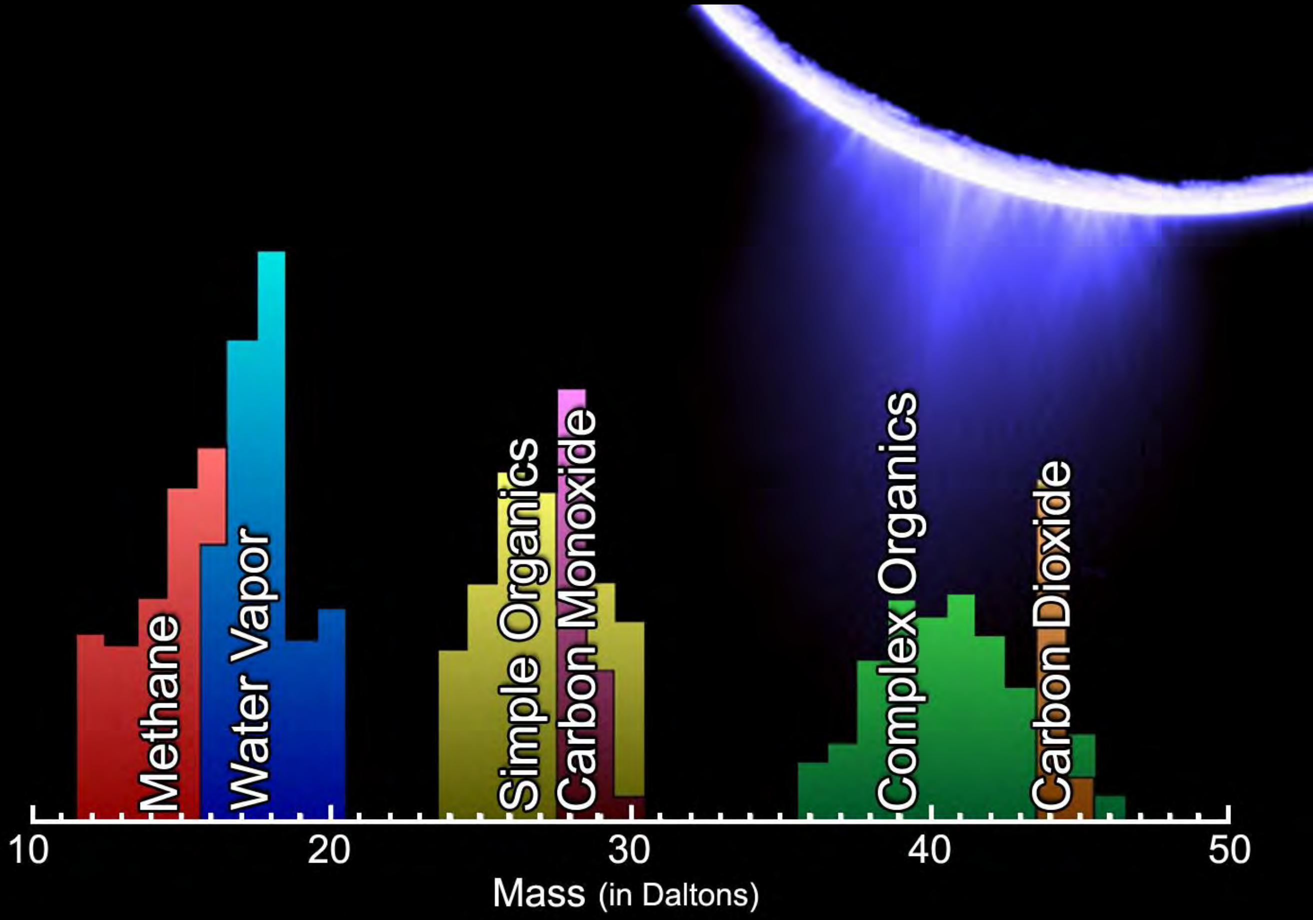
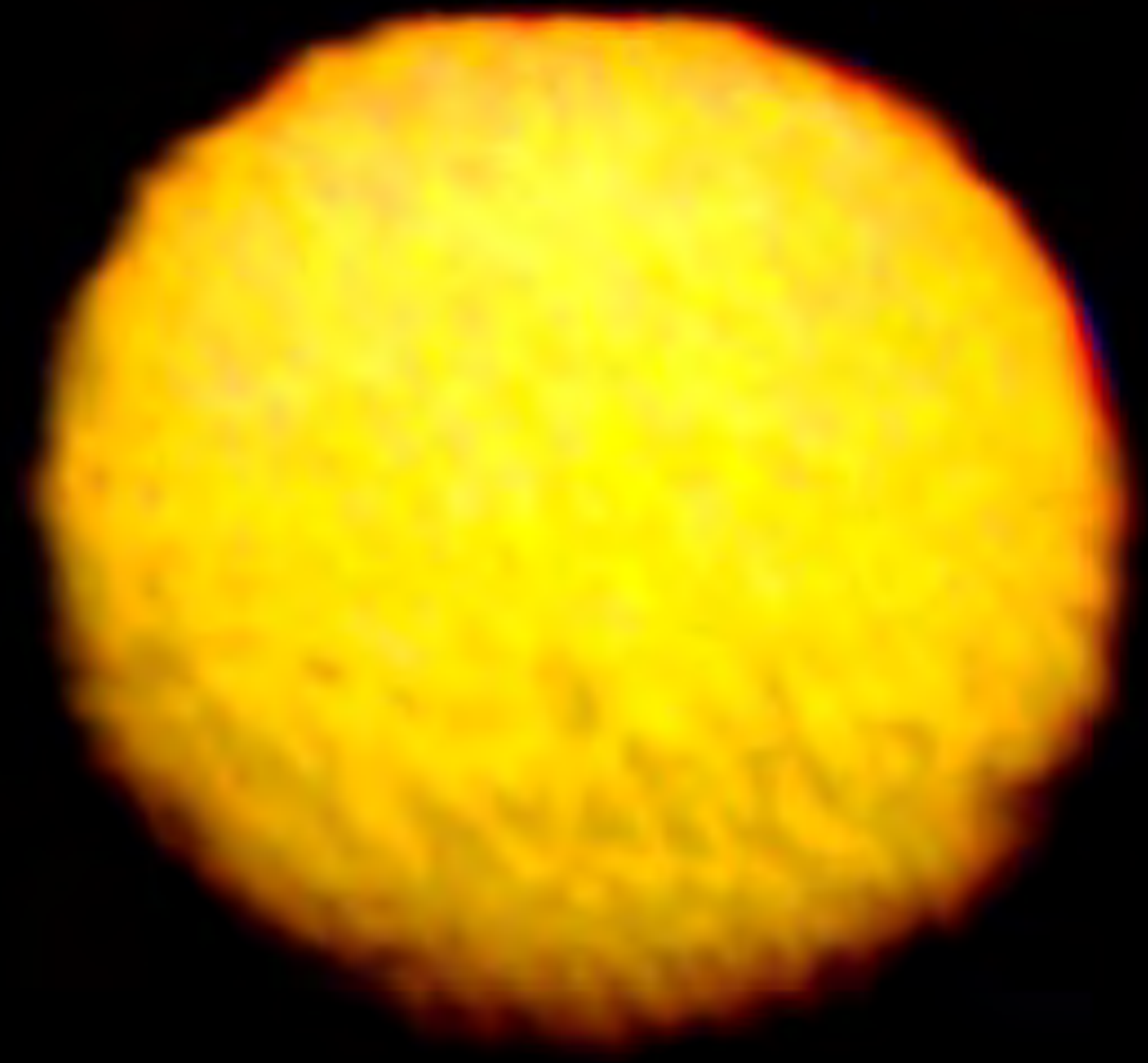



*Image Credit: NASA/JPL/Space Science Institute*

# Titan Before Cassini

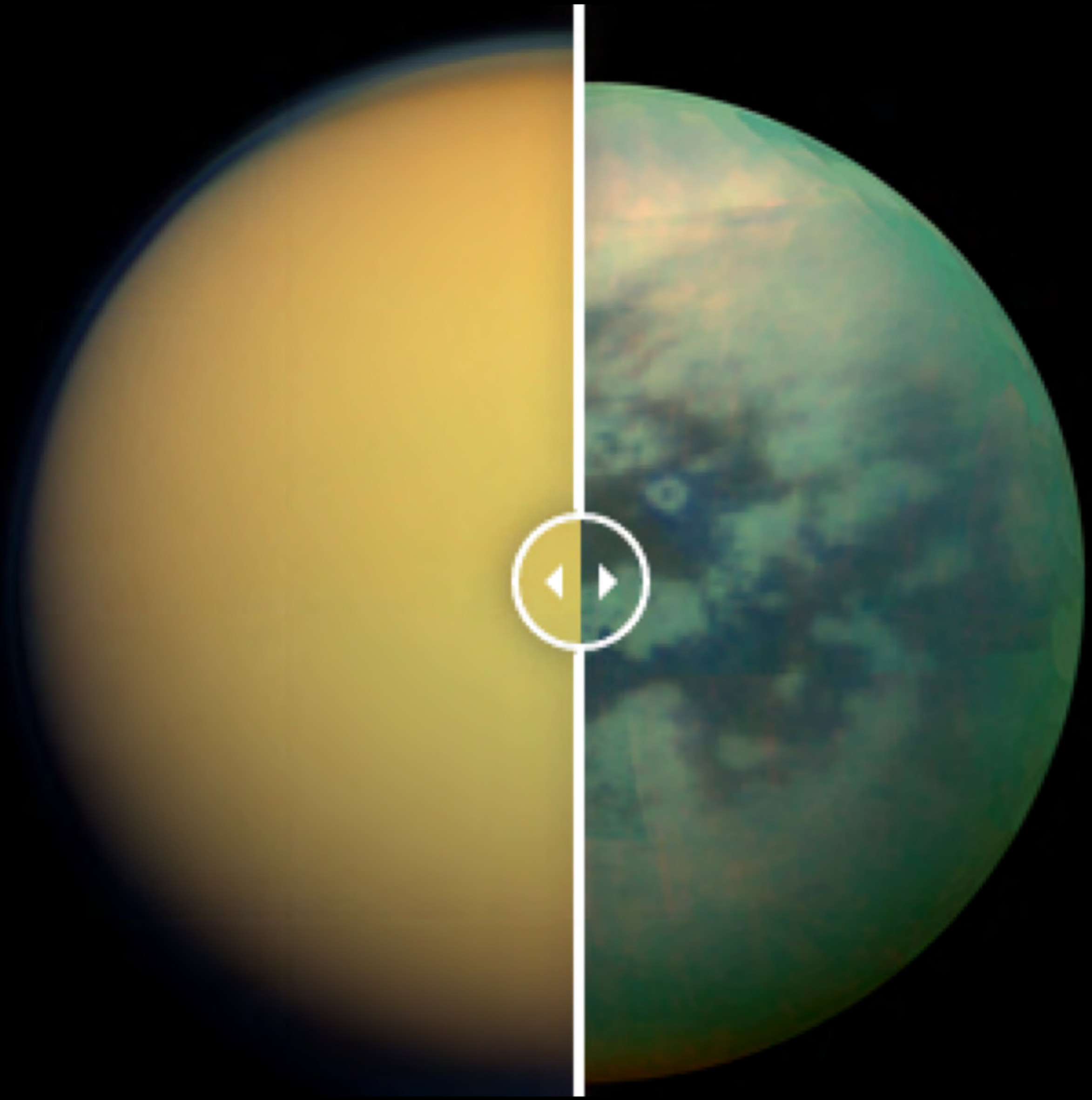
- In 1979, Pioneer 11 flew by Titan and returned the first high spatial resolution data of its atmosphere
- Pioneer 11 carried a scanning photopolarimeter with red and blue broad band filters
- Strong polarization near 90° phase angle, which is always unavailable from Earth, suggested that small particulates were suspended in Titan's atmosphere



# Titan Before Cassini

- This is an image of Titan from the Voyager 1 flyby in 1980
- Titan has a thick nitrogen-rich atmosphere that extends into space – more than 10 times that of the Earth's atmosphere
- It is a smog-covered moon with an impenetrable atmosphere in the visible

# Cassini Reveals Titan's Surface



- Titan's surface is marked by regions of bright and dark terrain
- The equatorial region shows sand dunes that are most likely composed of water ice coated in atmospheric organic ices/smog
- Titan possesses many parallels to Earth: lakes, rivers, channels, dunes, rain, clouds, and mountains

*Image Credit: NASA/JPL/Space Science Institute*

# Titan's surface from Huygens DISR

- After a 2 hour and 27 minute descent through Titan's atmosphere, the Huygens probe landed on Titan's surface
- Images of this aerial view were taken at ~8 km above Titan's surface
- Bright highlands are water ice
- Dark lowlands resemble a dry lakebed
- The dark, branching drainage channels indicate that rushing liquid $CH_4$ had once flowed on Titan's surface
- Cassini RADAR later revealed that liquid $CH_4$ lakes and seas are confined to Titan's polar regions

Image credit: ESA/NASA/JPL/University of Arizona