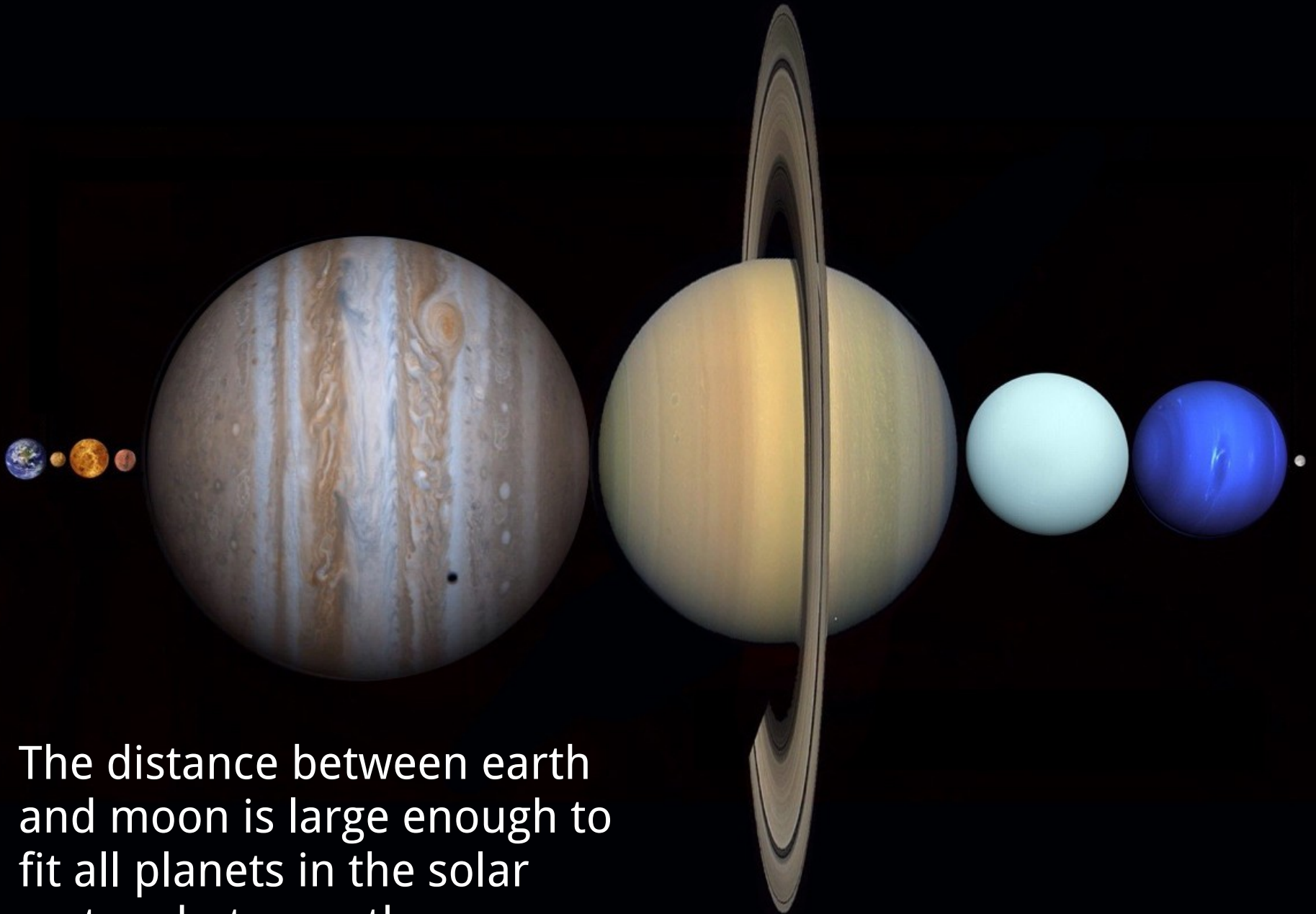


# Announcements

- Midterm 2 results
  - Median score 34 (76% / 68% without bonus)
  - Mean 32.55 (72 / 65%)
  - Maximum 46, minimum 11
- All extra credits entered to D2L → check
- Today: Highlights of the solar system
- Monday: Extrasolar planets, midterm discussion
- Wednesday: Start with galaxies



The distance between earth and moon is large enough to fit all planets in the solar system between them.

# Mars

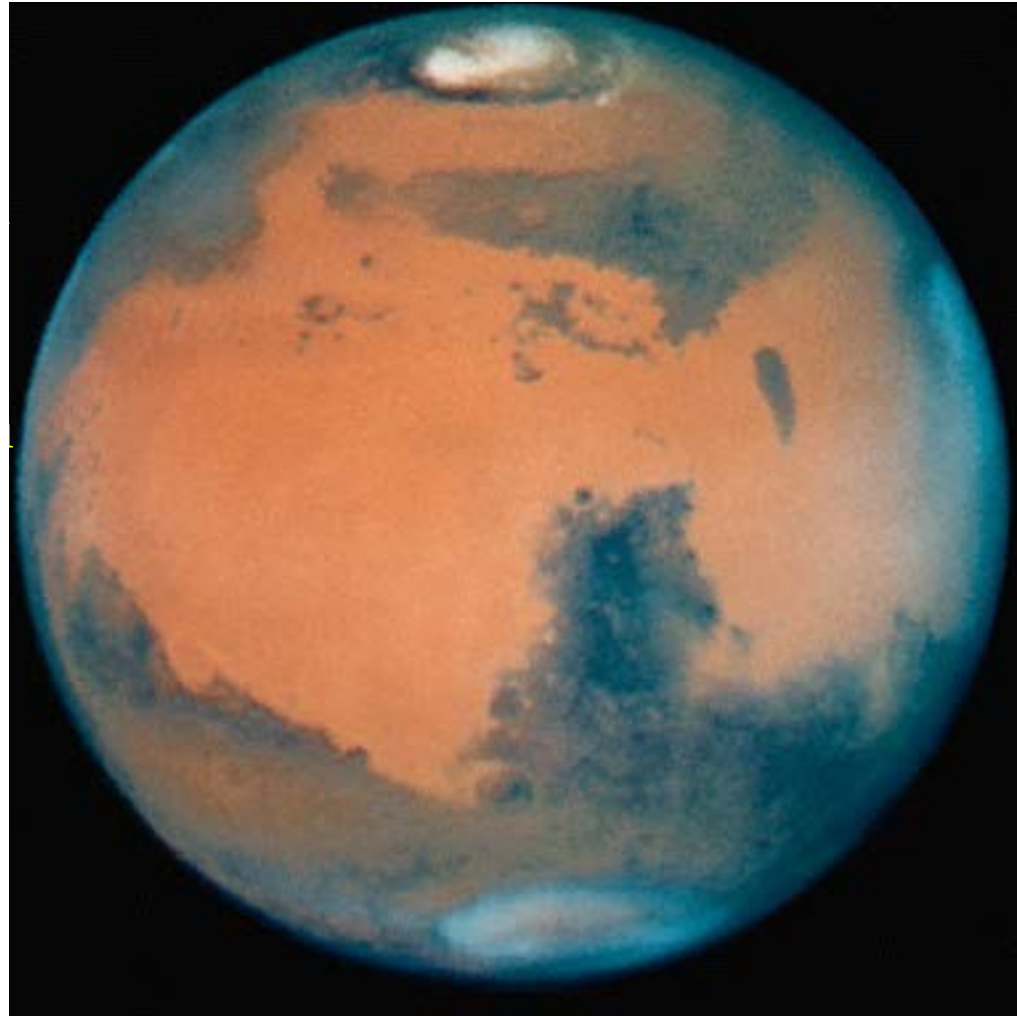
Radius  $\sim$  3400 km  
-  $\frac{1}{2}$  radius of earth

Mass  $\sim$  10% of  
Earth

Density  $\sim$  3900  
kg/m<sup>3</sup> - smaller  
than Earth -  
density of rock.

Thin atmosphere

Extinct volcanoes

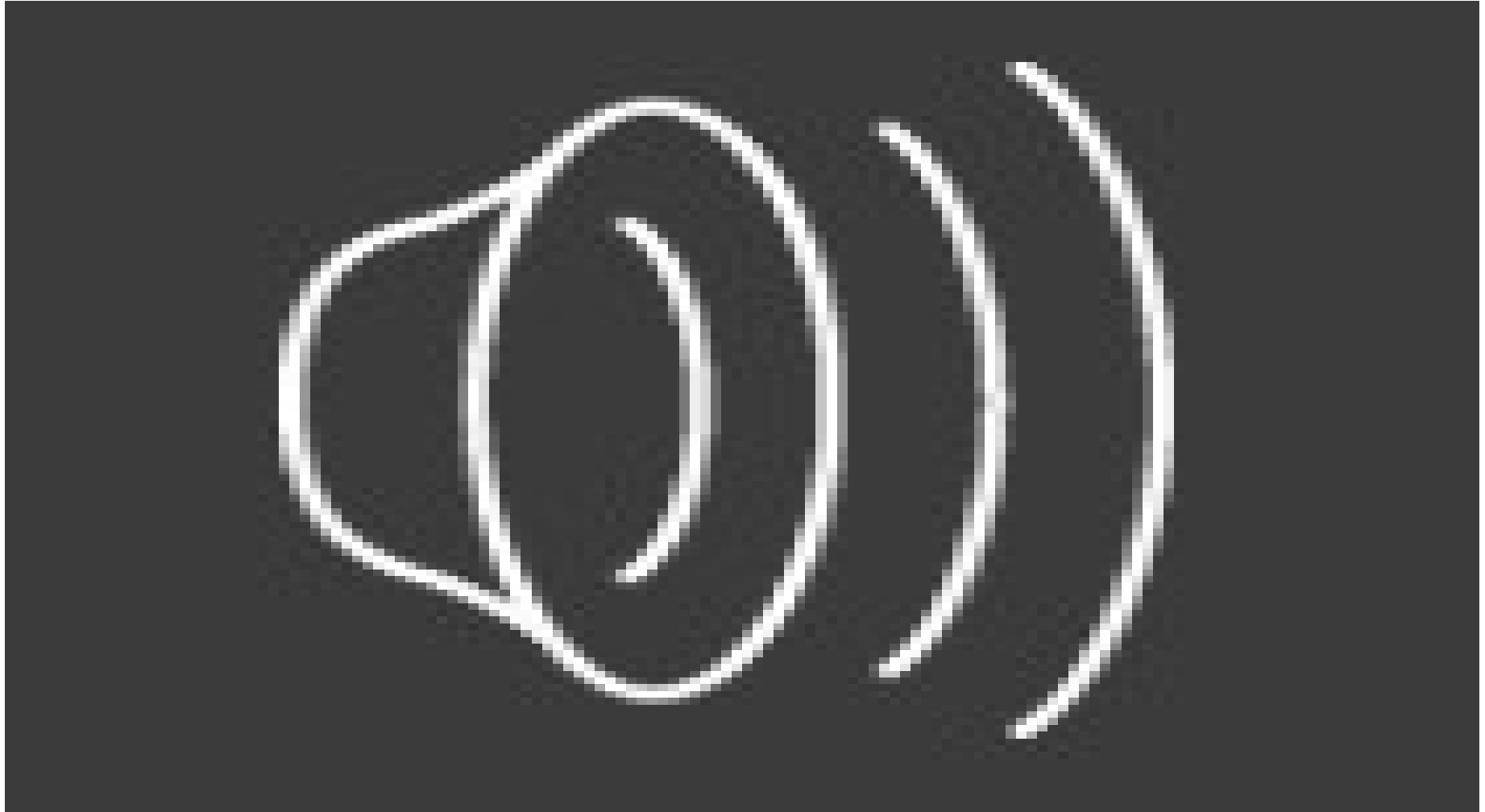


# Mars

- Called the red planet because of its red color – due to rust, iron oxide
- Has nearly a 24 hour day – very similar to earth
- Atmosphere is made mainly of carbon dioxide, but it is very thin – 1/150 that of earth. Remember Venus is 90x that of earth
- Has seasons – tilt of Mars is close to that of earth.



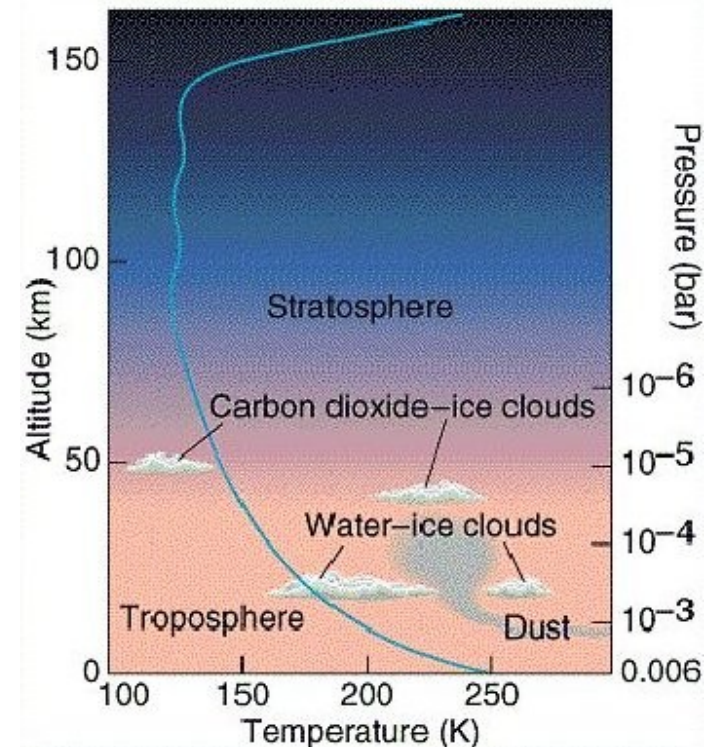
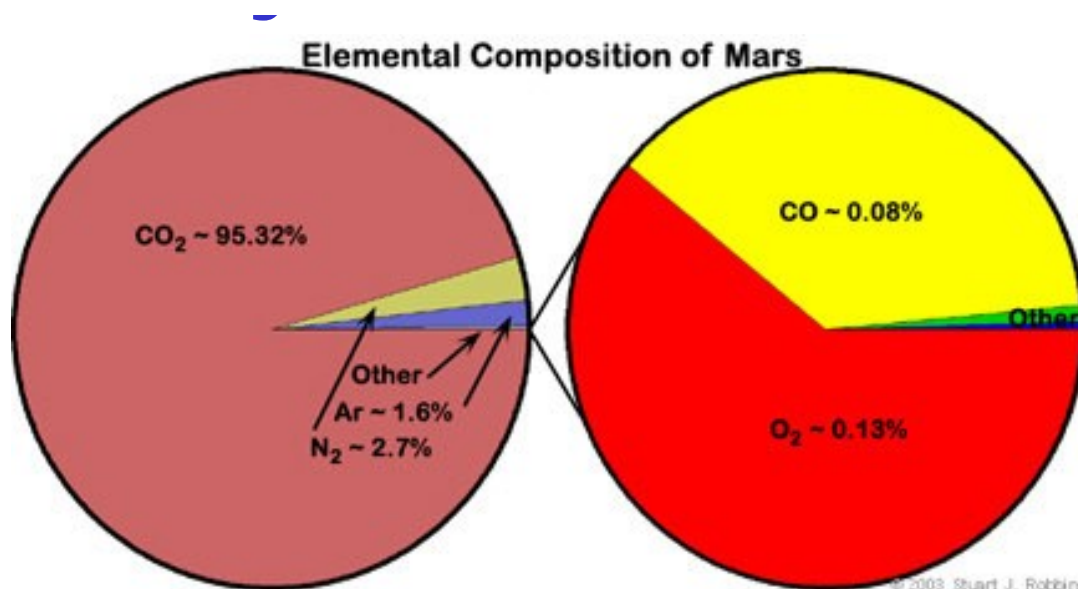
# Mars: Panorama view of Mars Science Lab/Curiosity Rover Landing site



# Mars: Atmosphere

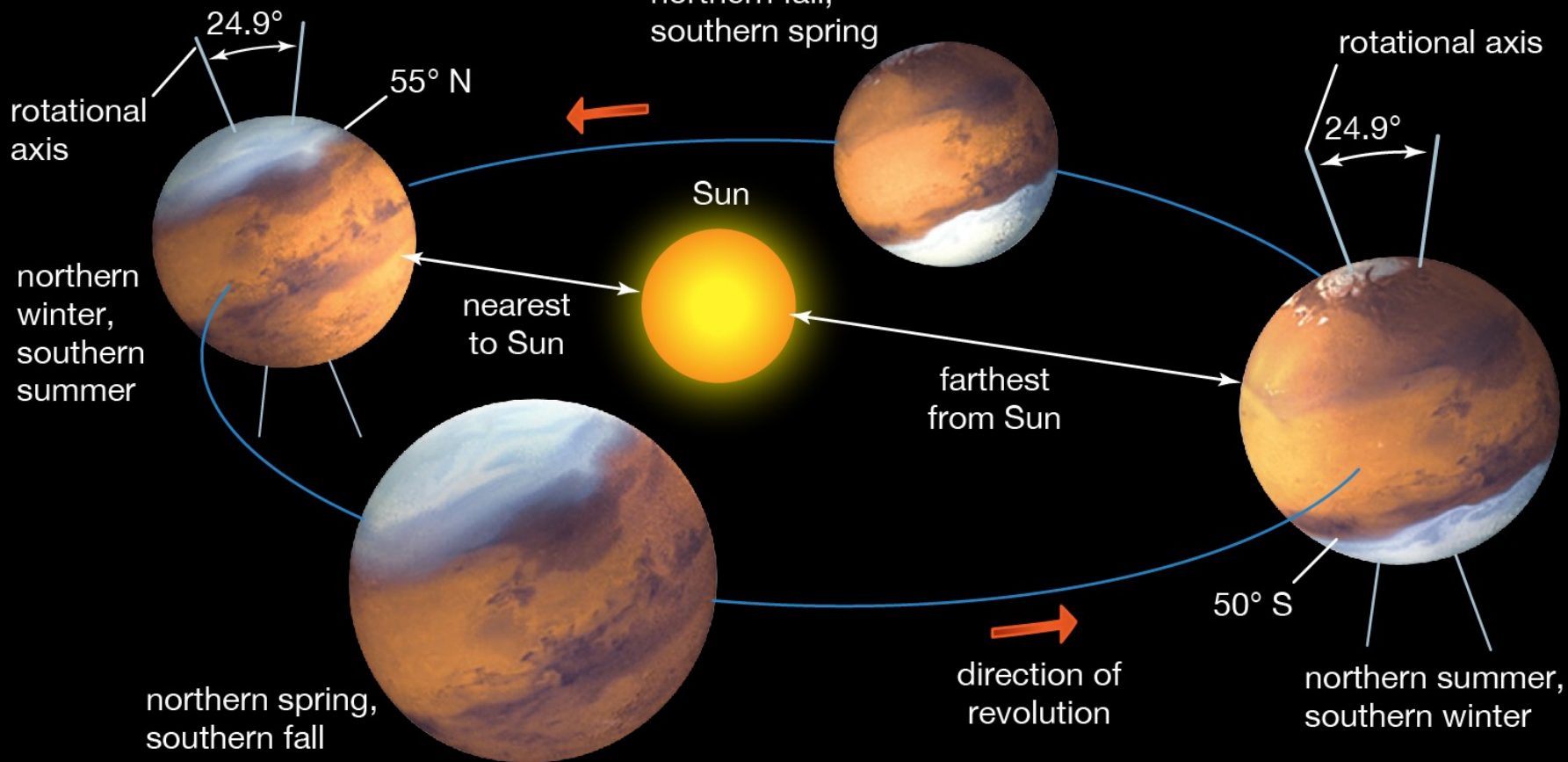
Atmosphere is mainly  $\text{CO}_2$  (carbon dioxide) with some nitrogen and argon.

It is so cold that the atmosphere freezes onto the poles as frozen  $\text{CO}_2$  depending on the season

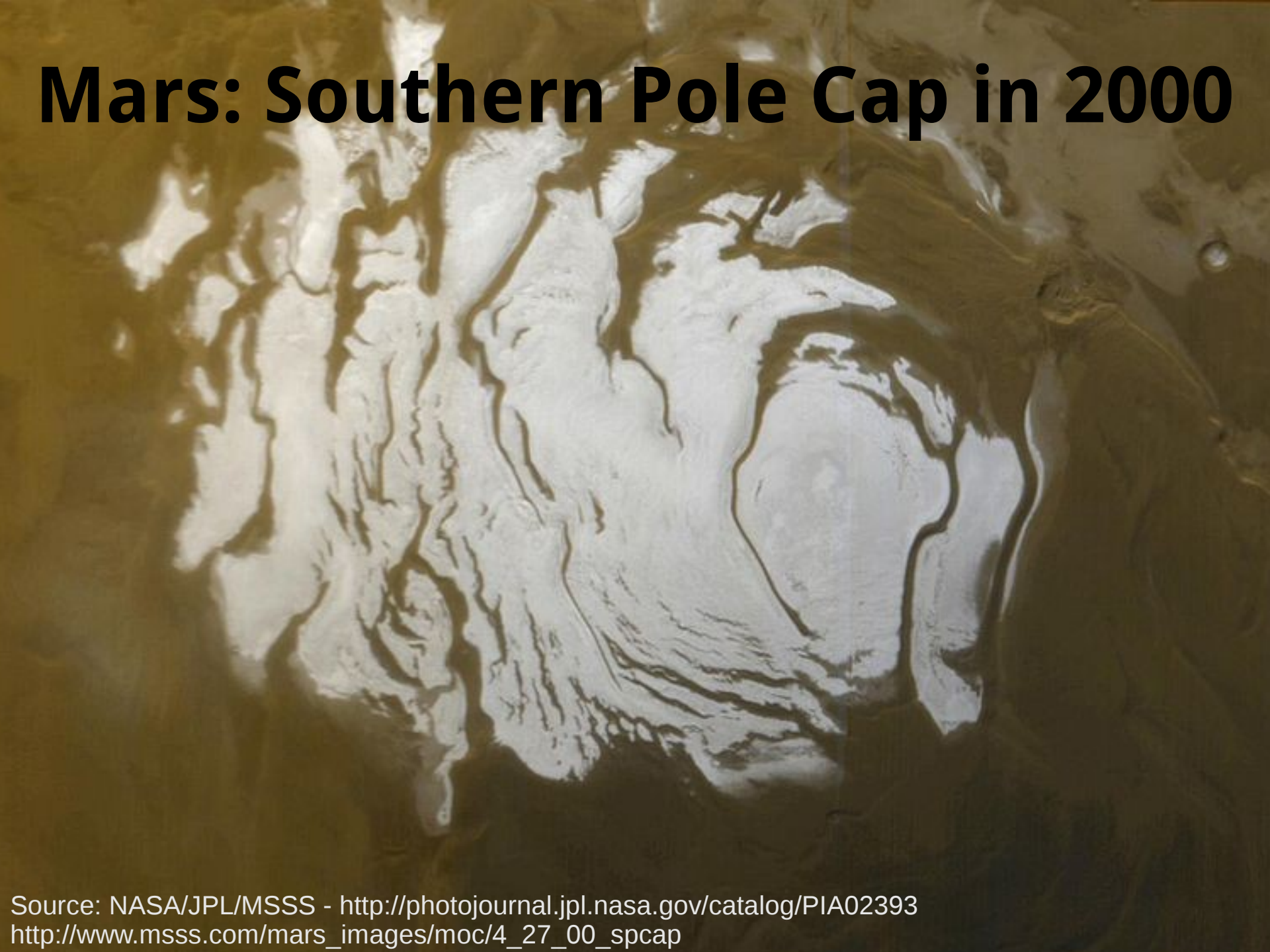


# Seasons on Mars

## Martian seasons



# Mars: Southern Pole Cap in 2000



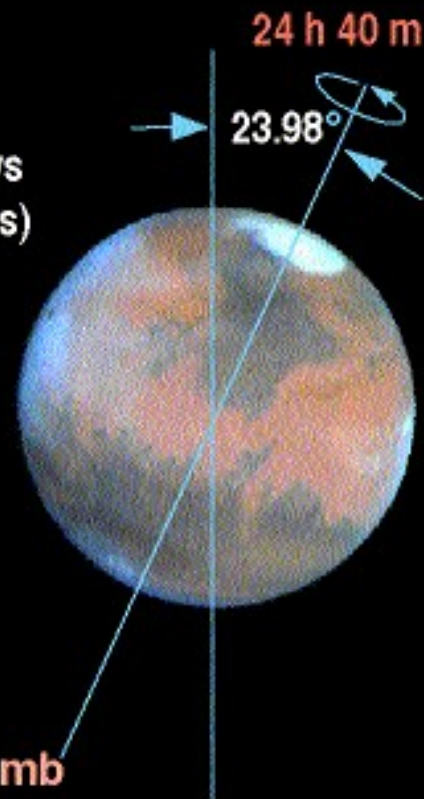
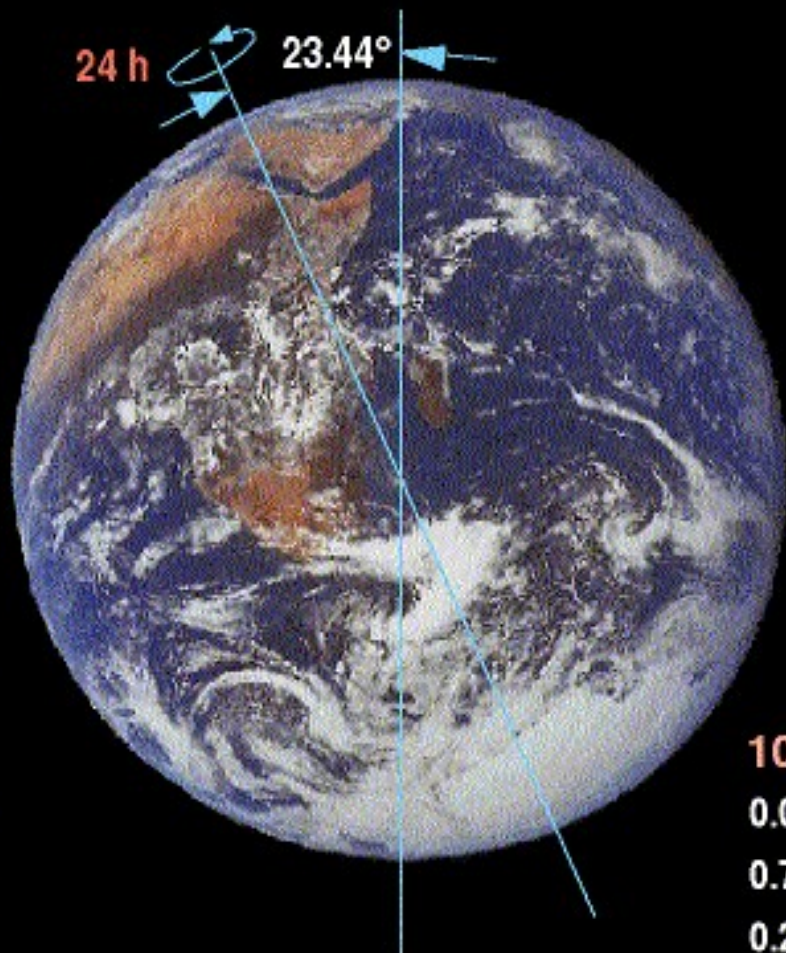
Source: NASA/JPL/MSSS - <http://photojournal.jpl.nasa.gov/catalog/PIA02393>  
[http://www.msss.com/mars\\_images/moc/4\\_27\\_00\\_spcap](http://www.msss.com/mars_images/moc/4_27_00_spcap)



# EARTH

# COMPARISON

# MARS



## YEAR

365 Days      686 Days  
(667 Sols)

## GRAVITY

38% of earth

## SUNLIGHT

44% of earth

## ATMOSPHERE

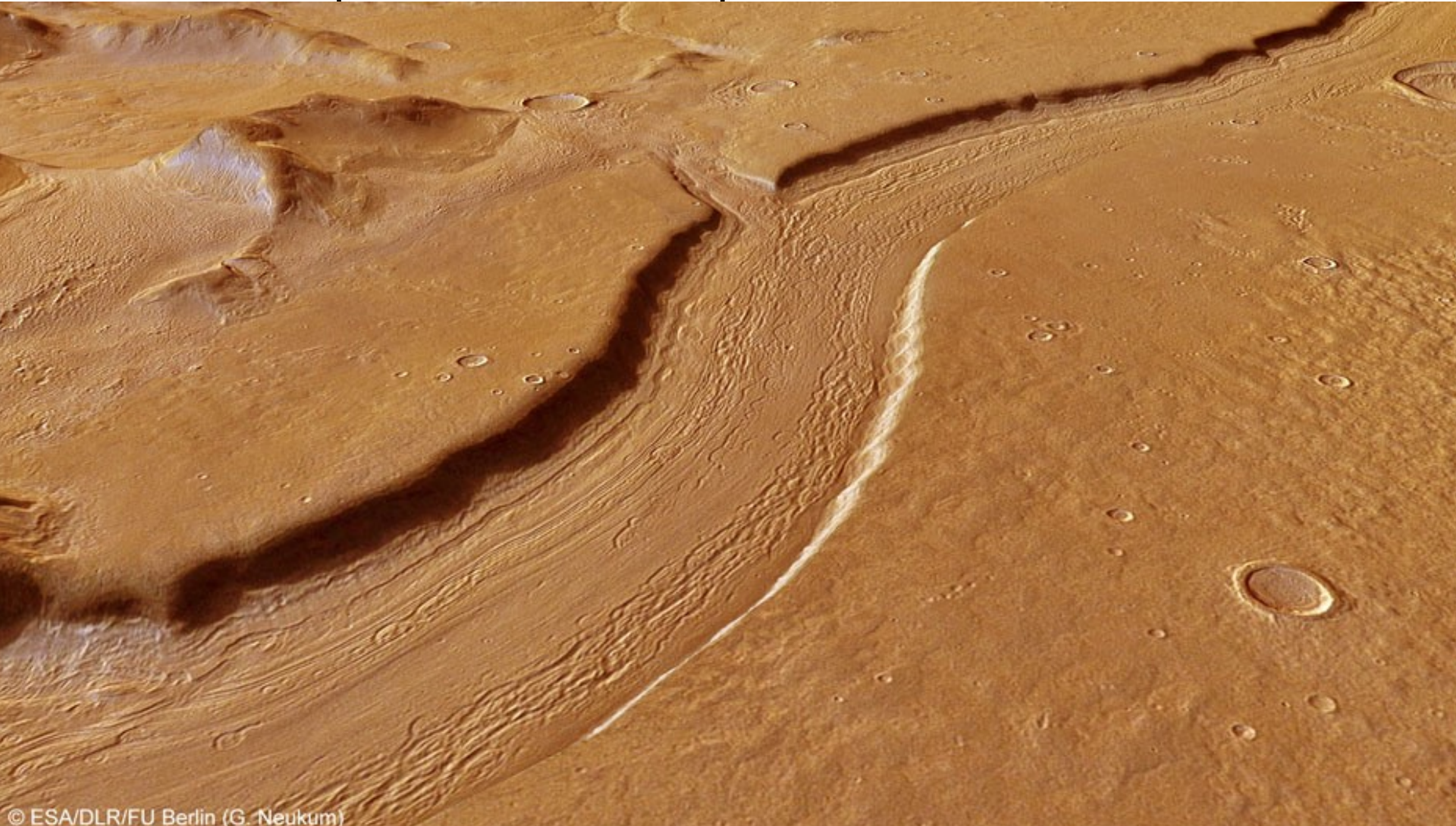
1013mb	Total	7.6 mb
0.00035	CO <sub>2</sub>	0.95
0.781	N <sub>2</sub>	0.027
0.210	O <sub>2</sub>	0.0013
0 to 0.04	H <sub>2</sub> O	0 to 0.00021
0.0093	Ar	0.016

Mars, courtesy  
P. James and NASA

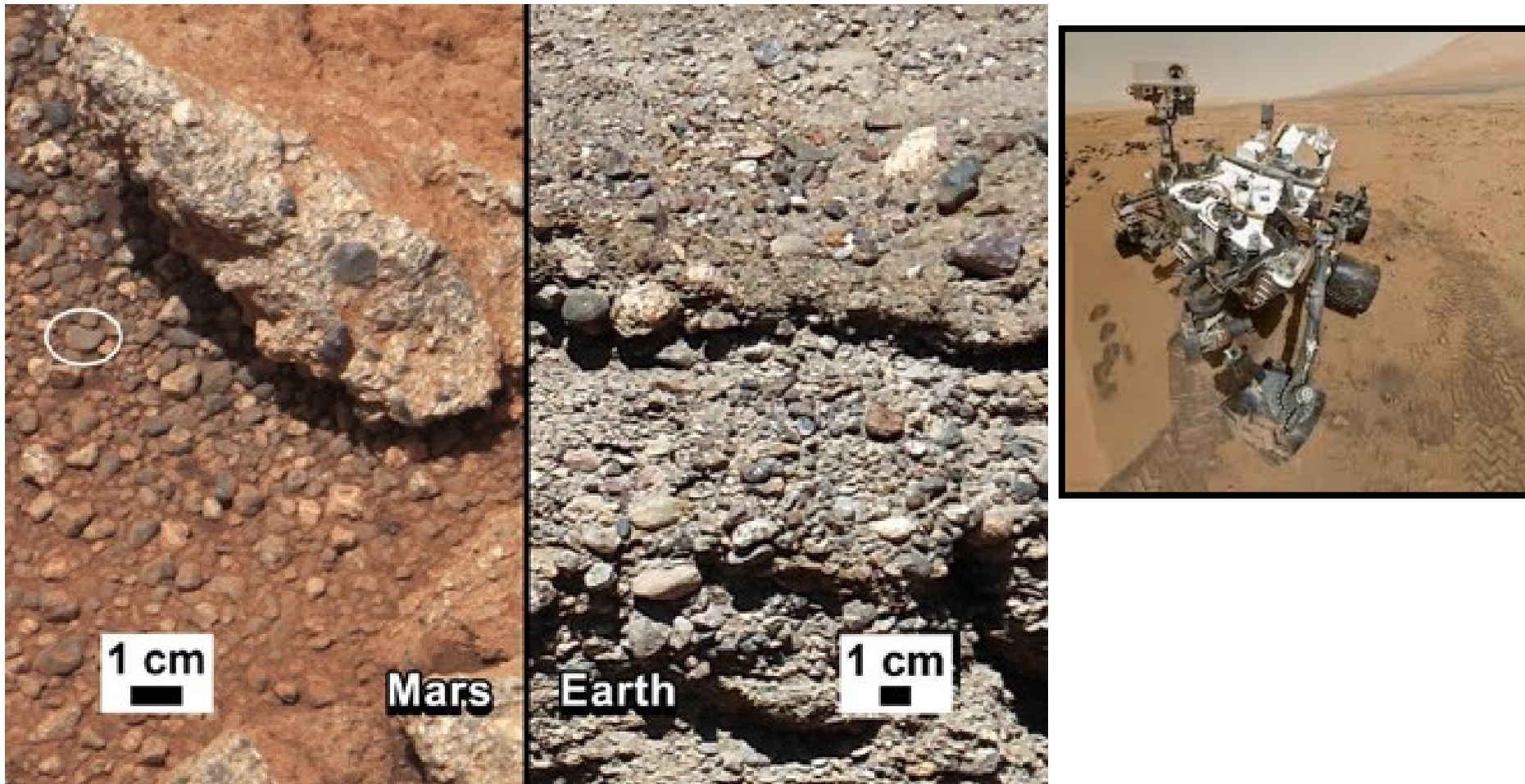


# Water on Mars – maybe in the past

The atmosphere of Mars might have been thicker in the past, so thick as to support liquid water on the surface. There is evidence of liquid water on the past Martian surface.



# Evidence for water on Mars



September 2012: Curiosity rover finds ancient streambed, pebbles moved and smoothed by water, present for thousands to millions of years

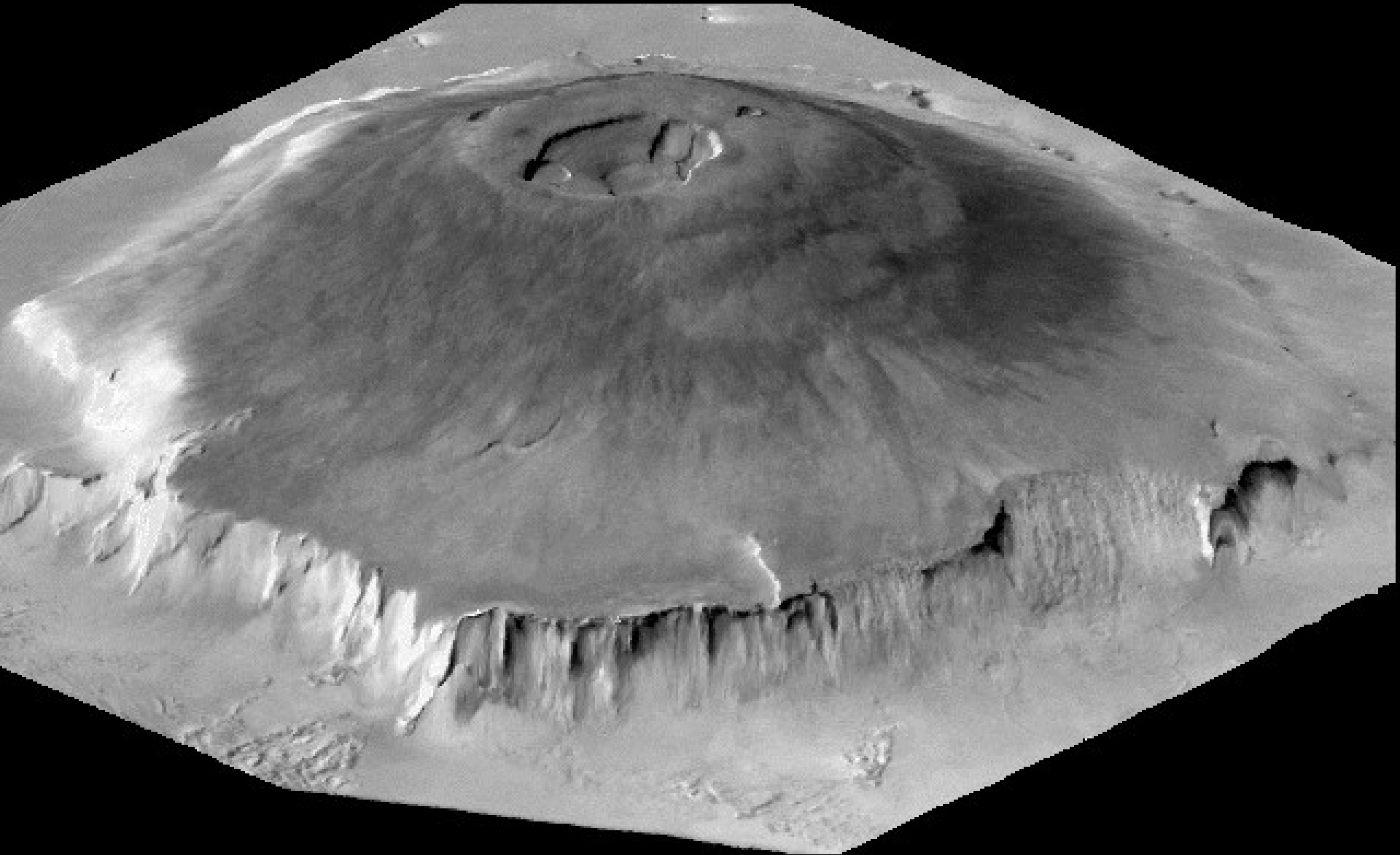




Opportunity found hematite rich "blueberries" that are very different from the rock underneath. The growing consensus is that these small, strange, gray orbs were slowly deposited from a bath of dirty water.



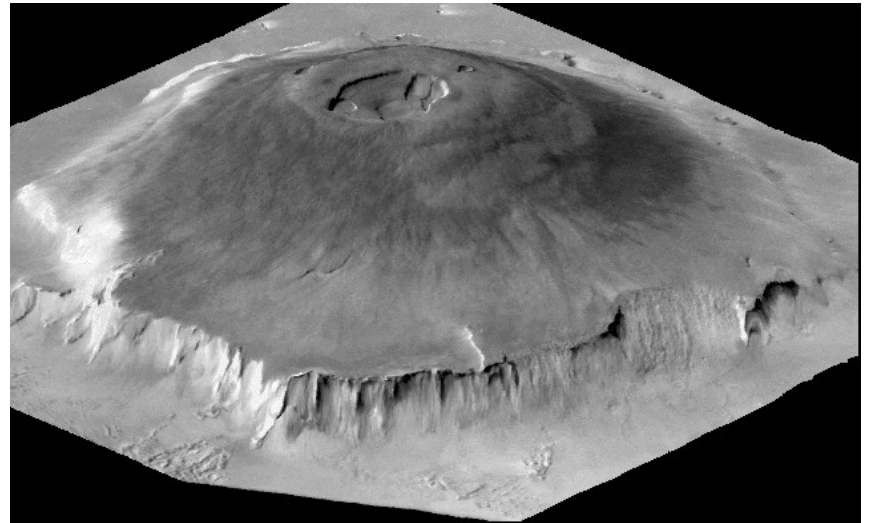
# Olympus Mons



# Volcanism on Mars – Olympus Mons

Has huge volcanoes – now extinct. Olympus Mons is the largest volcano in the solar system, 3 x the size of Mount Everest!

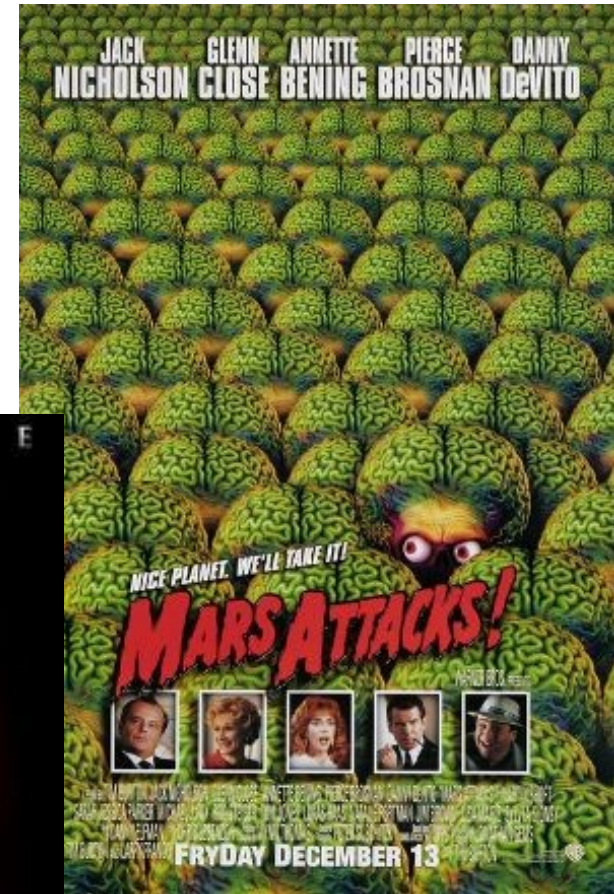
These are also shield volcanoes. They are much larger than ones on Earth and Venus because of lower gravity.



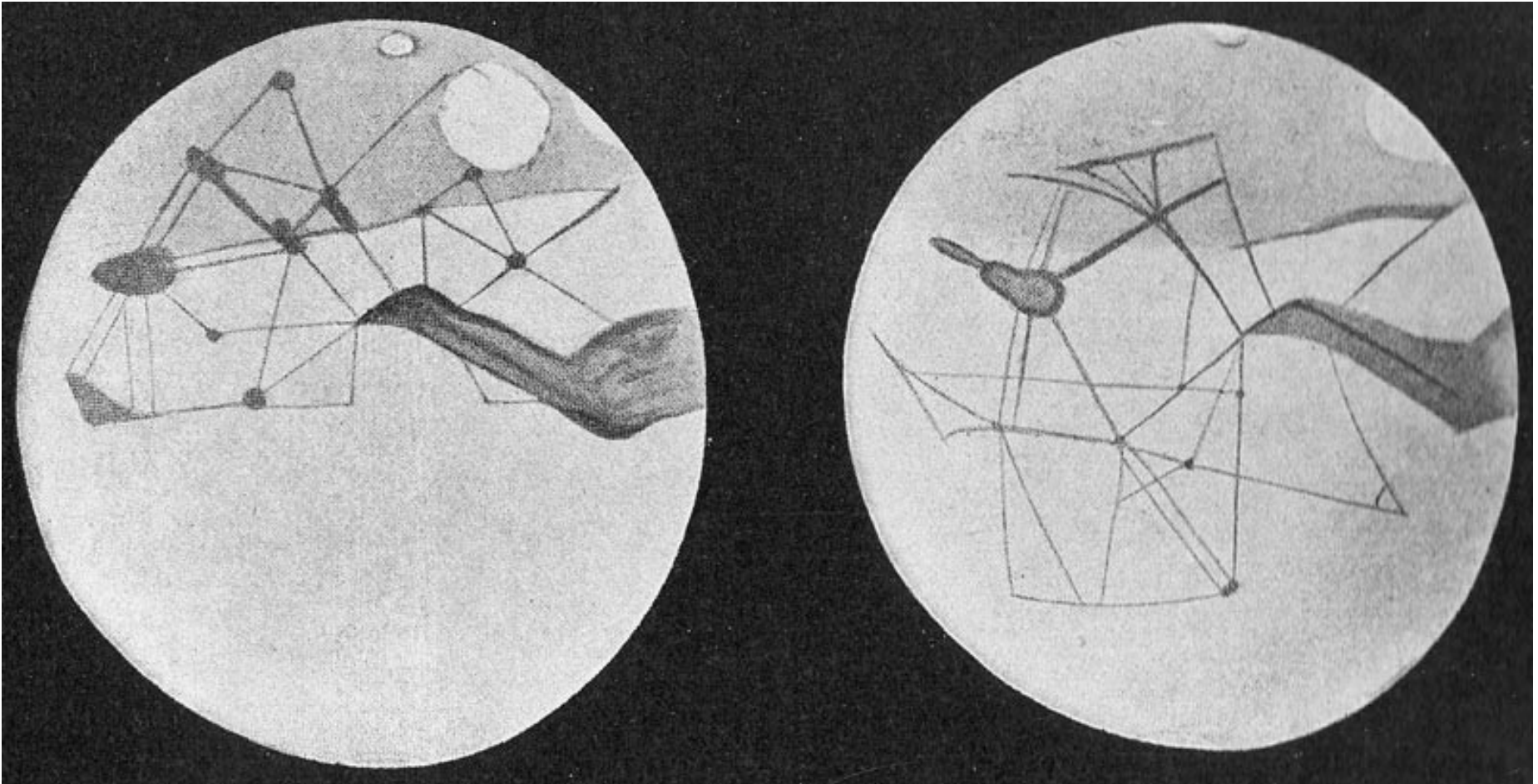
# Life on Mars

The idea of life on Mars is a very old one.

The fact that Mars was so similar to Earth drove a lot of the early speculation.



# Life on Mars



In the 19th century astronomers believed that they saw canals on Mars – evidence of intelligent life



# Life on Mars



Meteor ALH840001 is a Martian meteorite with possible indications of early Martian life.

Very controversial – shows both mineral deposits of magnetite and possible fossils of nanobacteria

# Jupiter

Radius ~ 10 x Earth's

Mass ~ 300 x Earth's

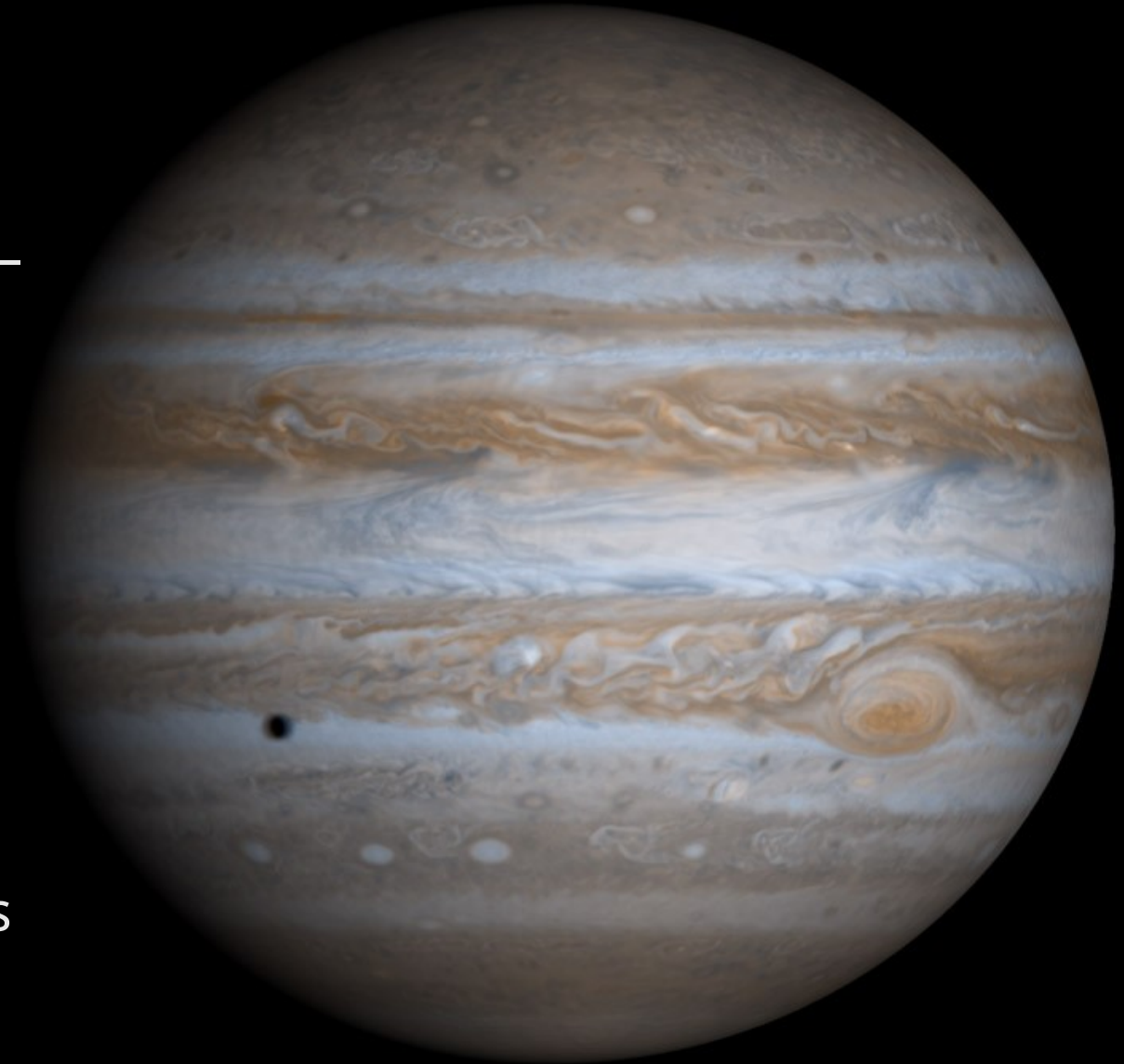
Density ~ 1300 kg/m<sup>3</sup> –  
about same as water

Compose of mainly  
hydrogen and helium

No surface

Strong magnetic field

Rapid rotation ~ 10 hrs



Jupiter as seen from Cassini

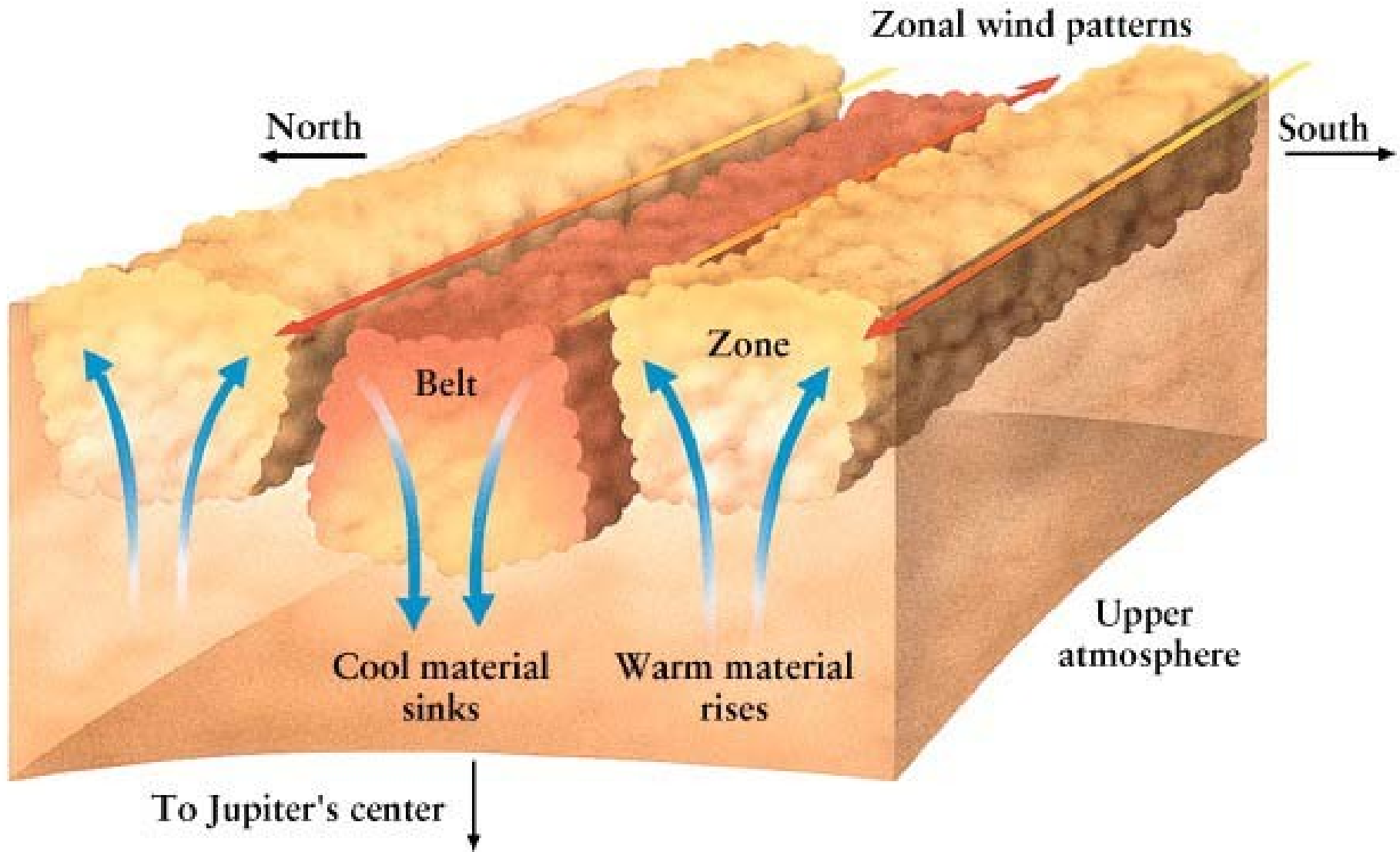
Source: <http://nssdc.gsfc.nasa.gov/planetary/factsheet/jupiterfact.html>

# Jupiter

- Multicolored bands in atmosphere
- Bands are caused by convective cells that are stretched by rotation
- Most prominent feature is the Great Red Spot – a hurricane that has persisted for at least 300 years



# A convective cell in Jupiter's outer atmosphere



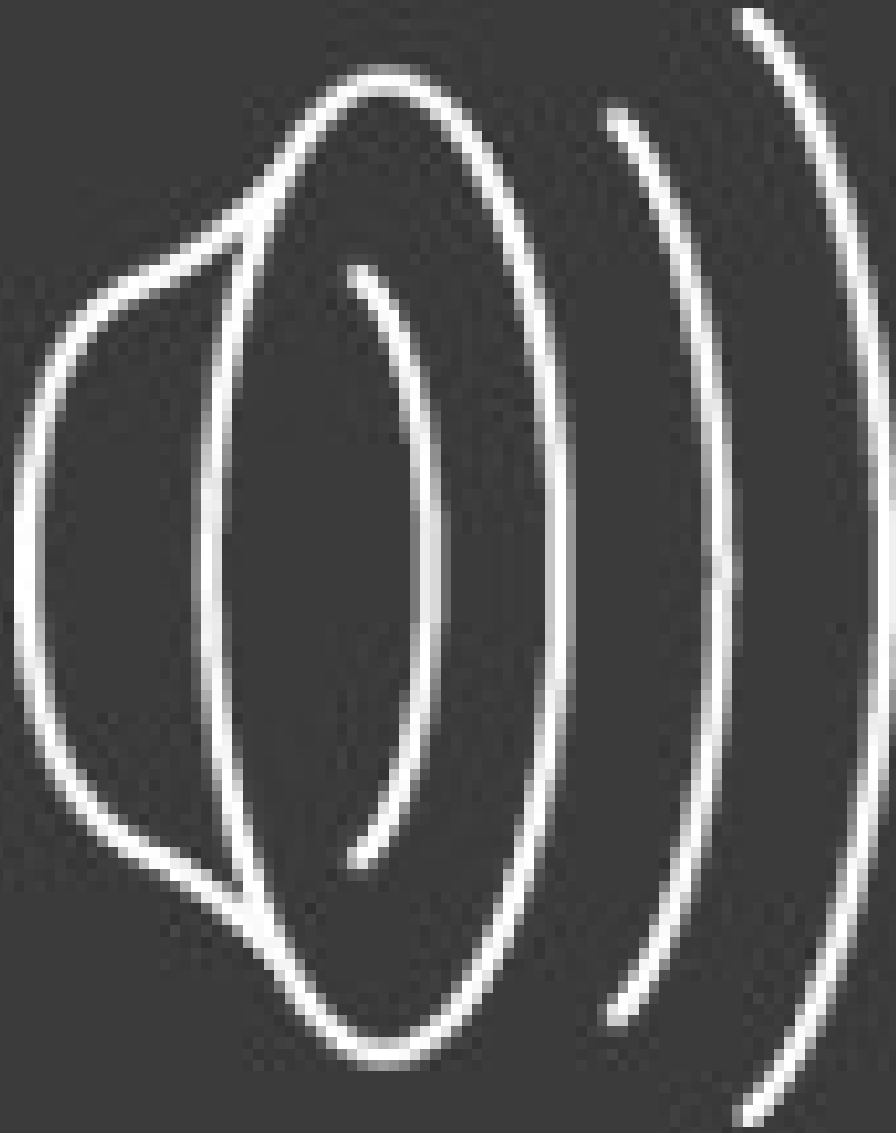


# Jupiter's outer atmosphere

These belts are high and low pressure regions, as we also have on Earth

However, because of the Jupiter's rapid rotation and thick atmosphere, these belts stretch around the planet rather than being localized







# Jupiter's Great Red Spot





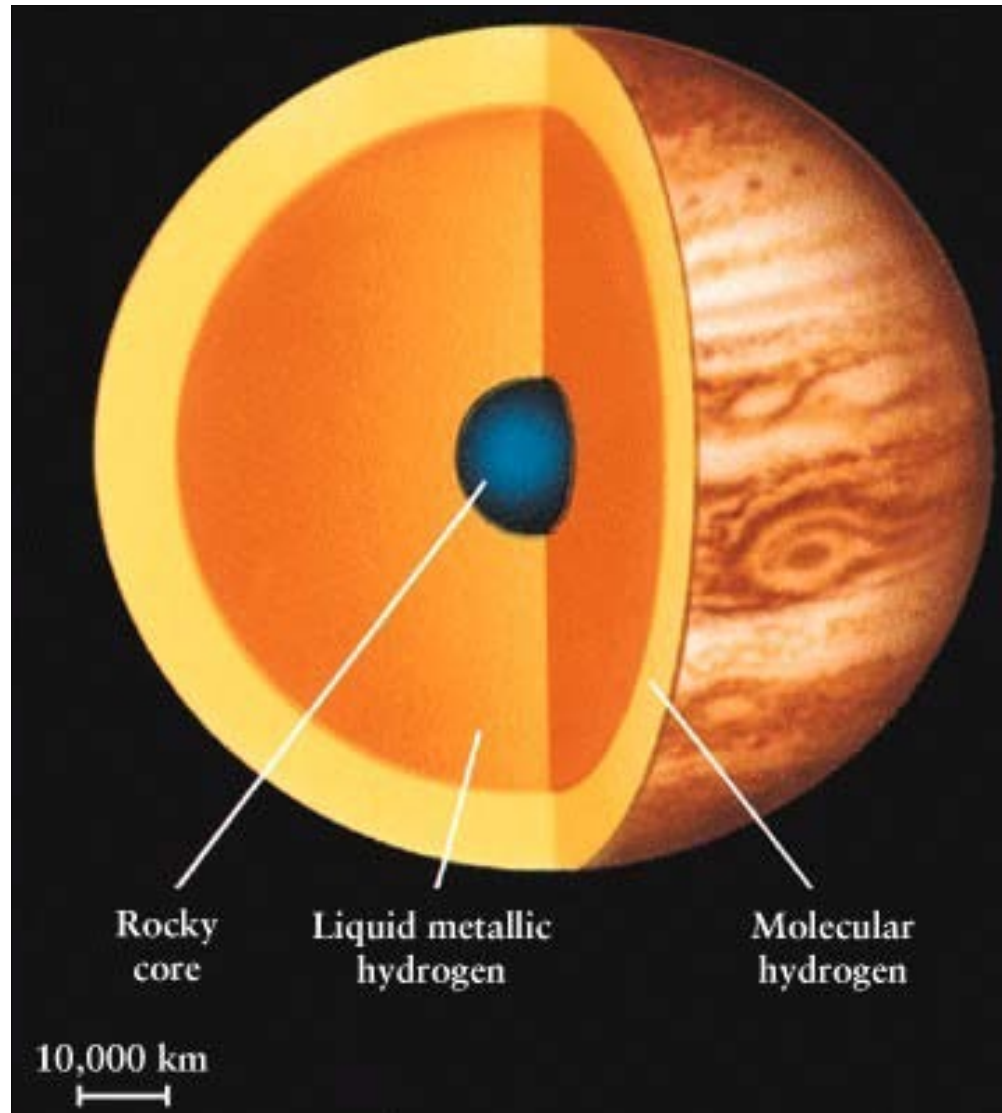
# Structure of Jupiter

Inner core rocky, like Earth

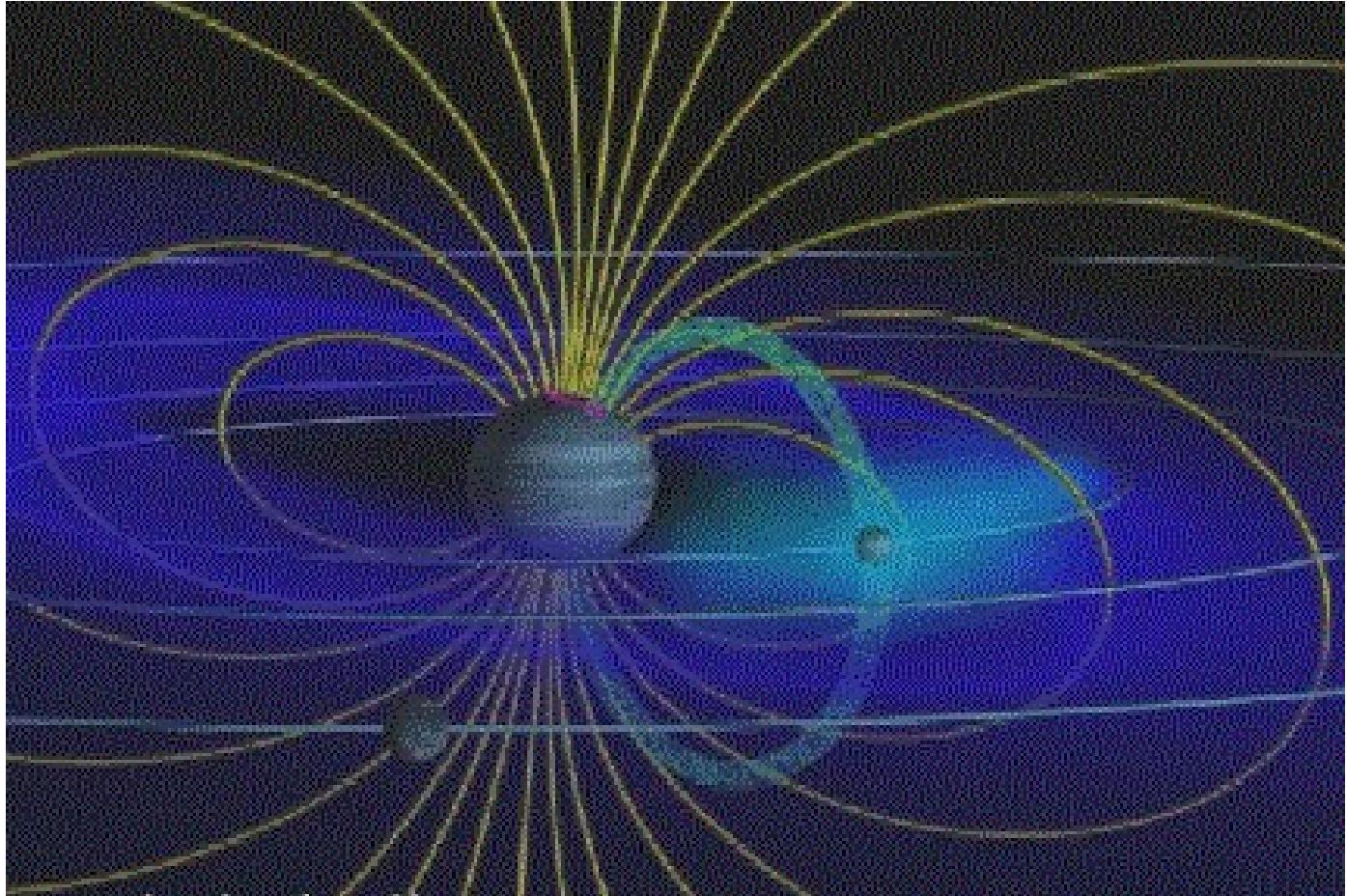
Mantle is **liquid metallic hydrogen**: under very high pressures, hydrogen becomes liquid and acts like a metal – able to conduct electricity

Outer mantle is molecular hydrogen

Atmosphere very convective with large, persistent weather features



# Magnetic field of Jupiter



The rapid rotation, strong convection and conducting metallic hydrogen in Jupiter give it a very strong magnetic field, 20,000 times stronger than that of Earth

# Magnetic field of Jupiter



**Jupiter Aurora**

HST • STIS

NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

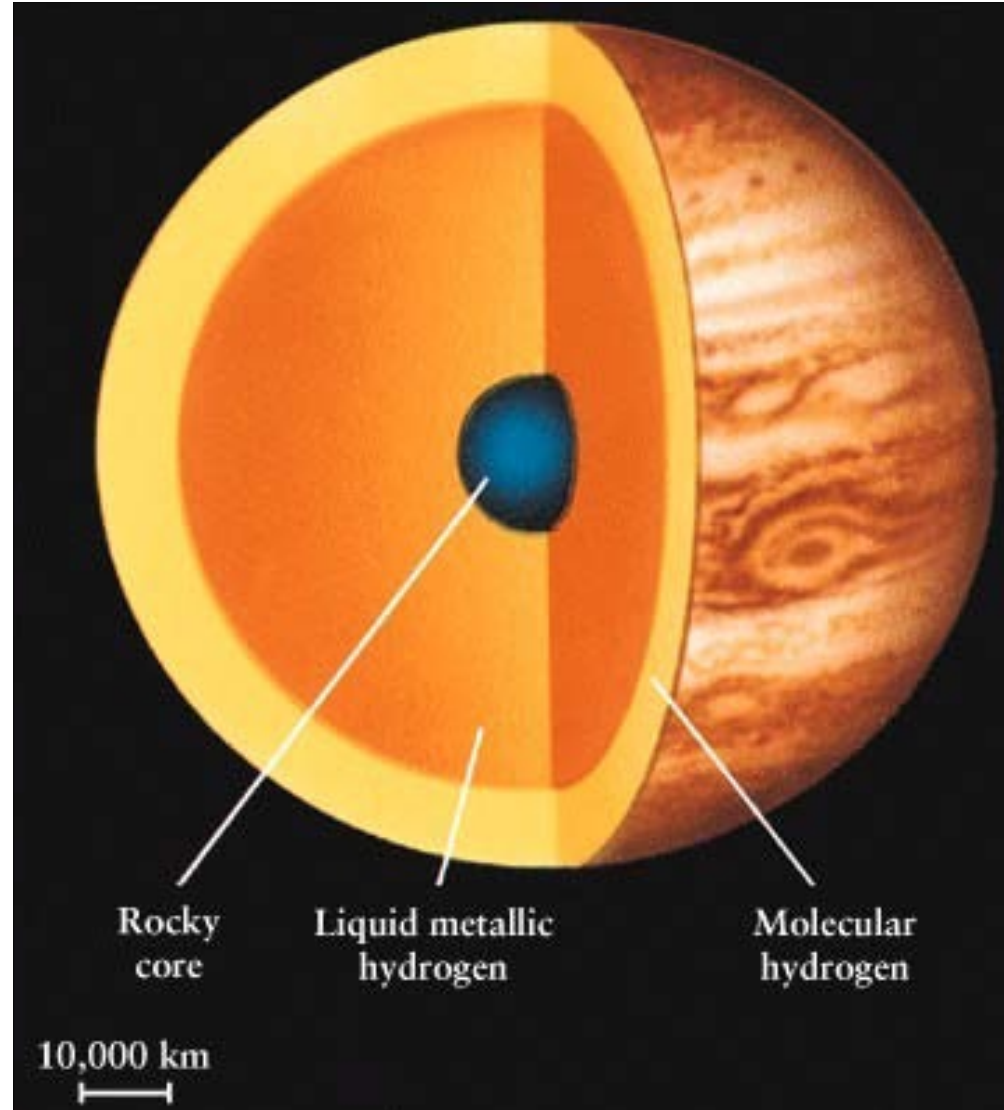
The interaction with the solar wind produces aurora on Jupiter like the aurora on Earth

# Internal Heating

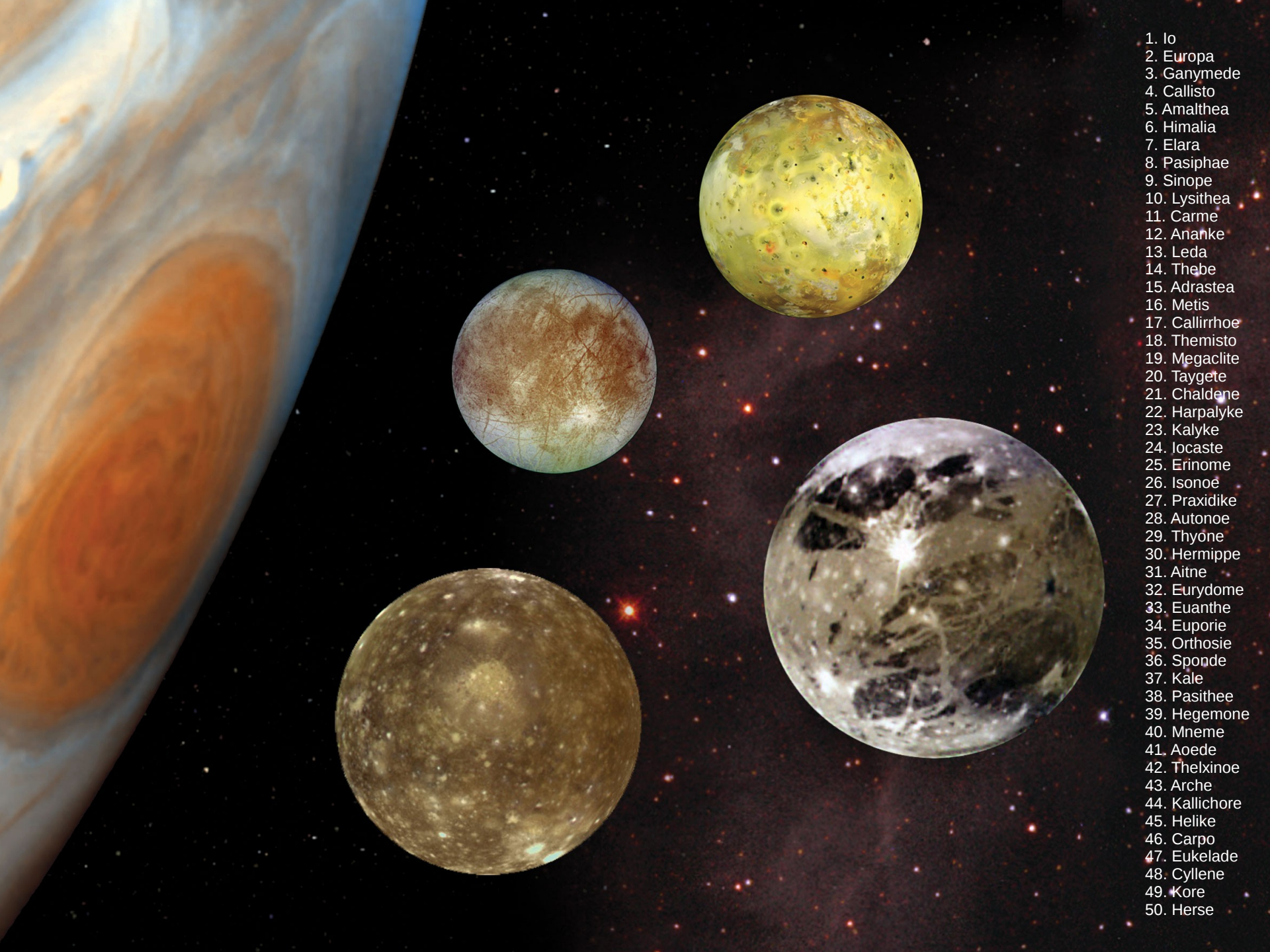
Jupiter gives off twice as much heat as it receives from the Sun

This heat is from its formation 4.5 billion years ago – it is still cooling!

Transport of this heat drives convection in the metallic hydrogen mantle – produces strong magnetic field

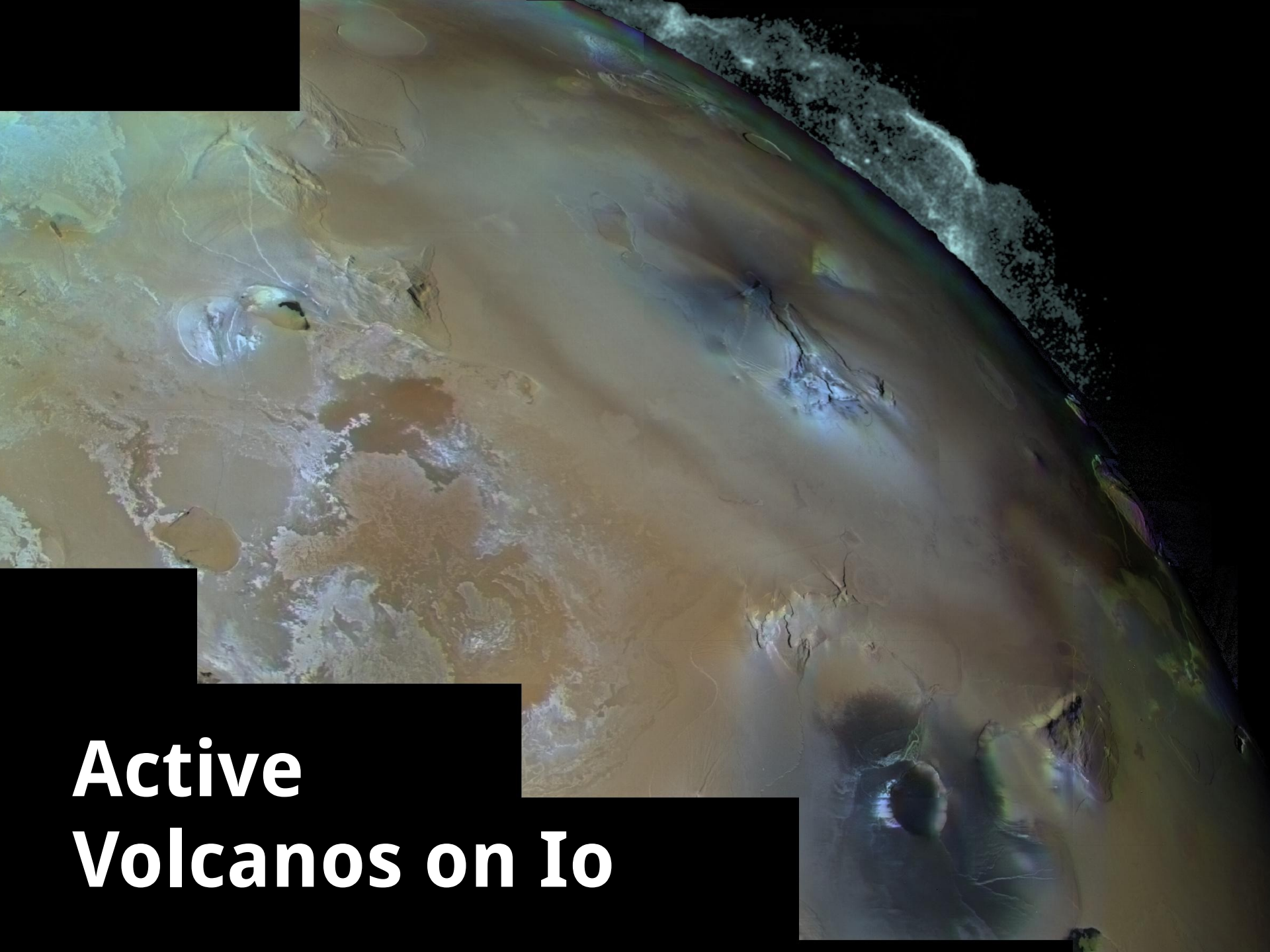






1. Io
2. Europa
3. Ganymede
4. Callisto
5. Amalthea
6. Himalia
7. Elara
8. Pasiphae
9. Sinope
10. Lysithea
11. Carme
12. Ananke
13. Leda
14. Thebe
- 15.Adrastea
16. Metis
17. Callirrhoe
18. Themisto
19. Megaclite
20. Taygete
21. Chaldene
22. Harpalyke
23. Kalyke
24. Iocaste
25. Erinome
26. Isonoe
27. Praxidike
28. Autonoe
29. Thyone
30. Hermippe
31. Aitne
32. Eurydome
33. Euanthe
34. Euporie
35. Orthosie
36. Sponde
37. Kale
38. Pasithee
39. Hegemone
40. Mneme
41. Aoede
42. Thelxinoe
43. Arche
44. Kallichore
45. Helike
46. Carpo
47. Eukelade
48. Cyllene
49. Kore
50. Herse

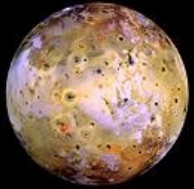




# Active Volcanos on Io

# Video of eruptions on Io

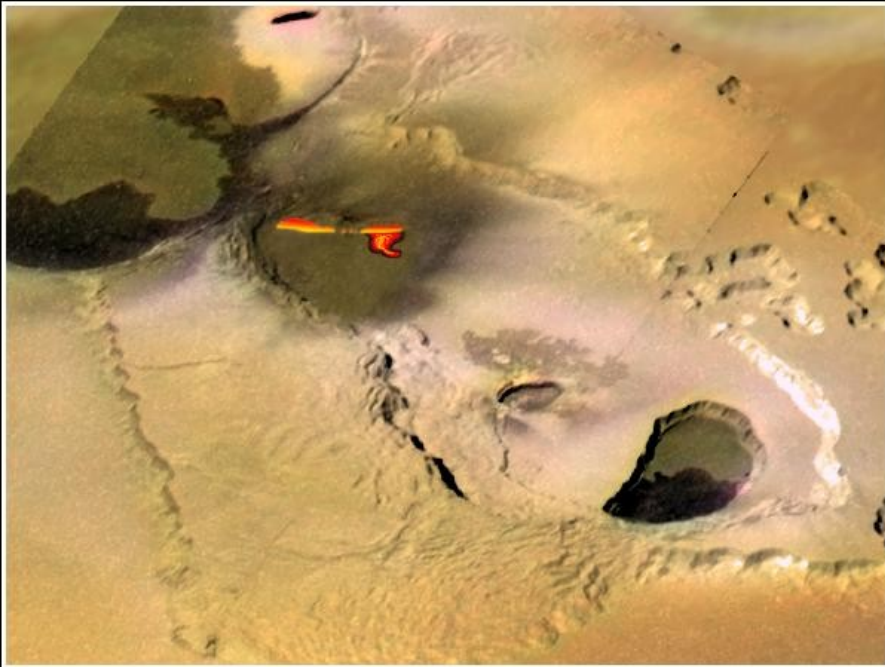




## Io — Tvashtar Catena

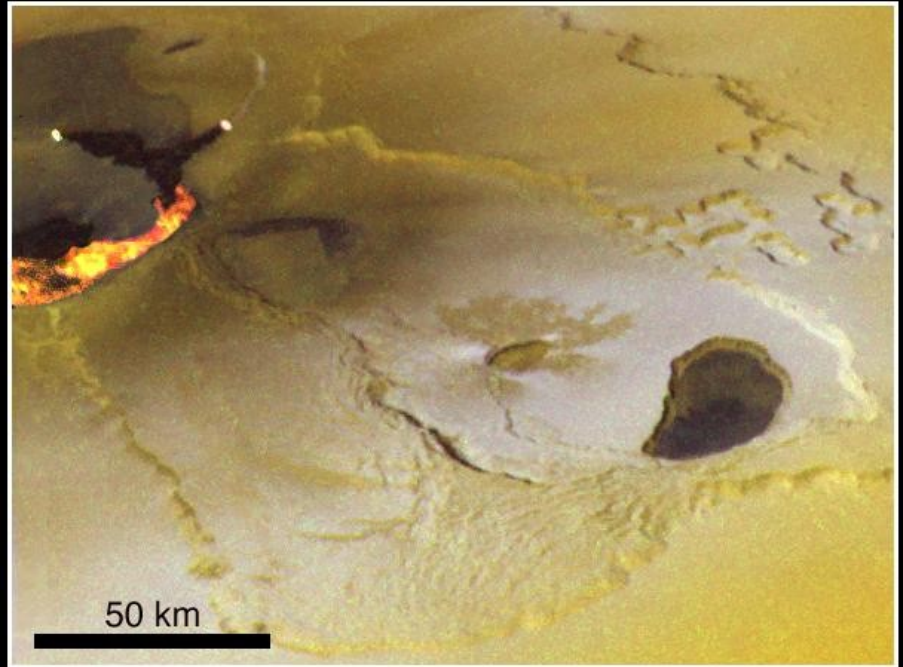
**I25 (26 Nov 1999)**

+ C21 low-resolution color  
+ fire fountain sketch



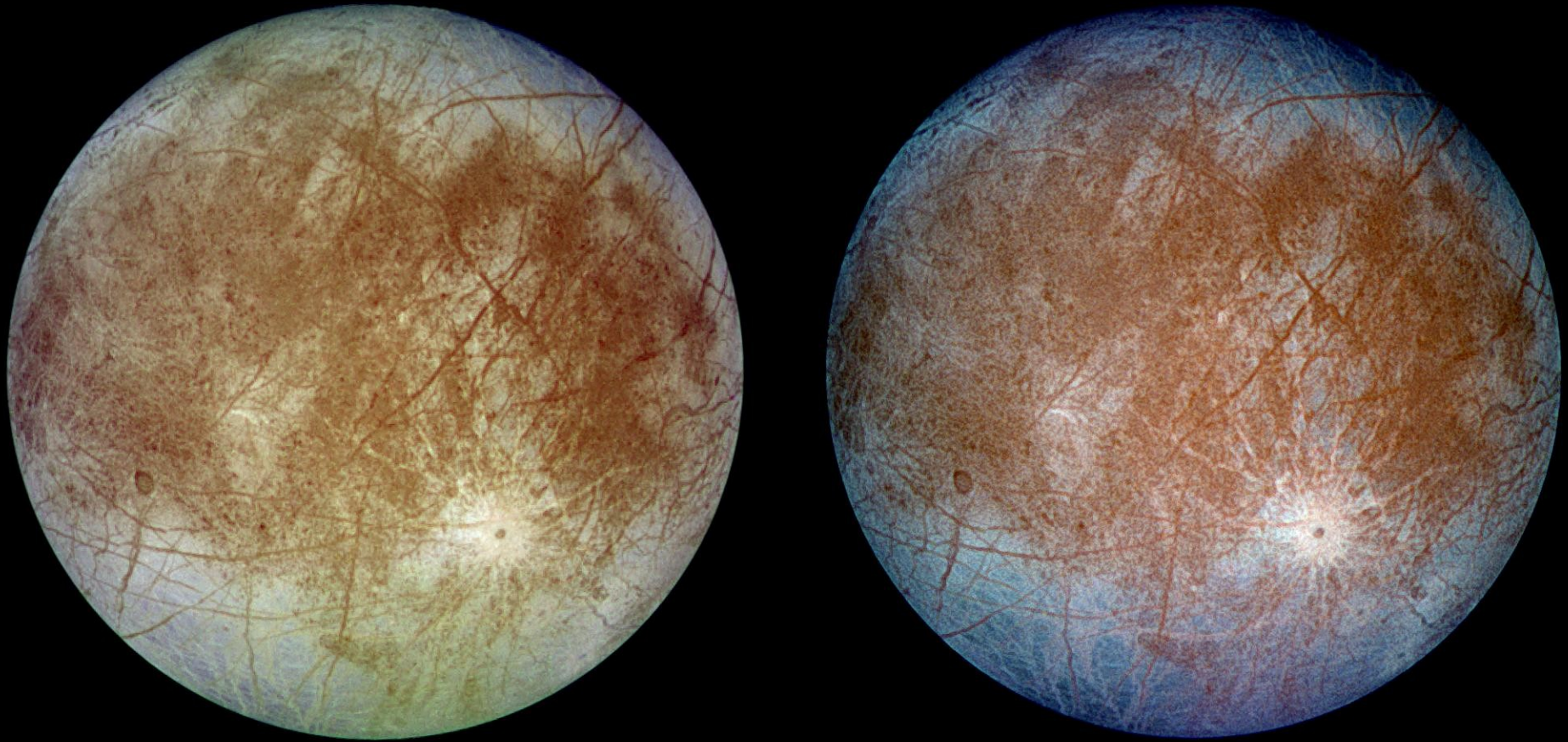
**I27 (22 Feb 2000)**

visible wavelength data  
+ IR data of active lava flow





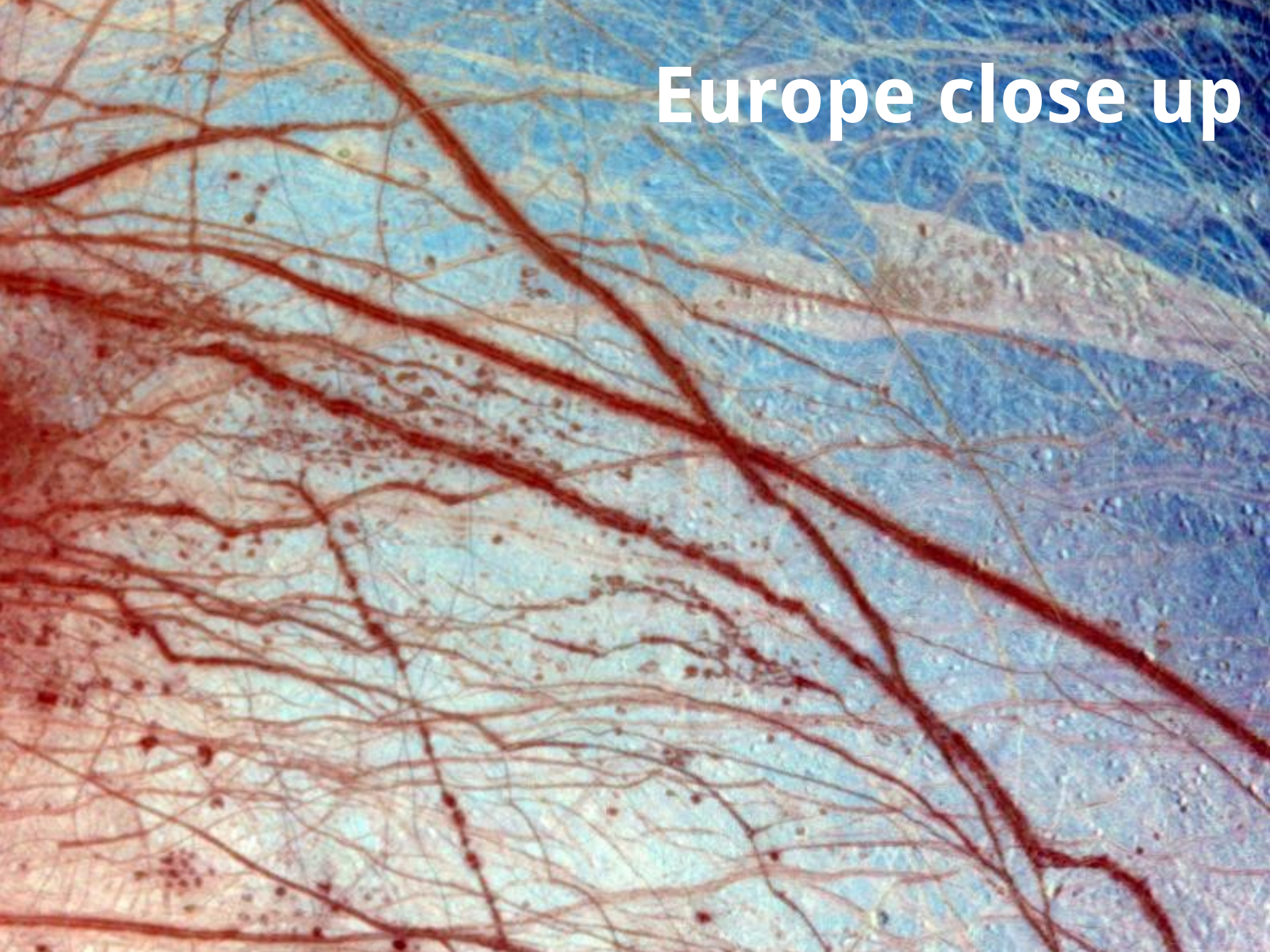
# Europa - True and False color



Europa is the next closest moon. It has an icy surface with large cracks and no craters! This means that craters are filled in somehow. This suggests liquid (probably water) under the icy surface.

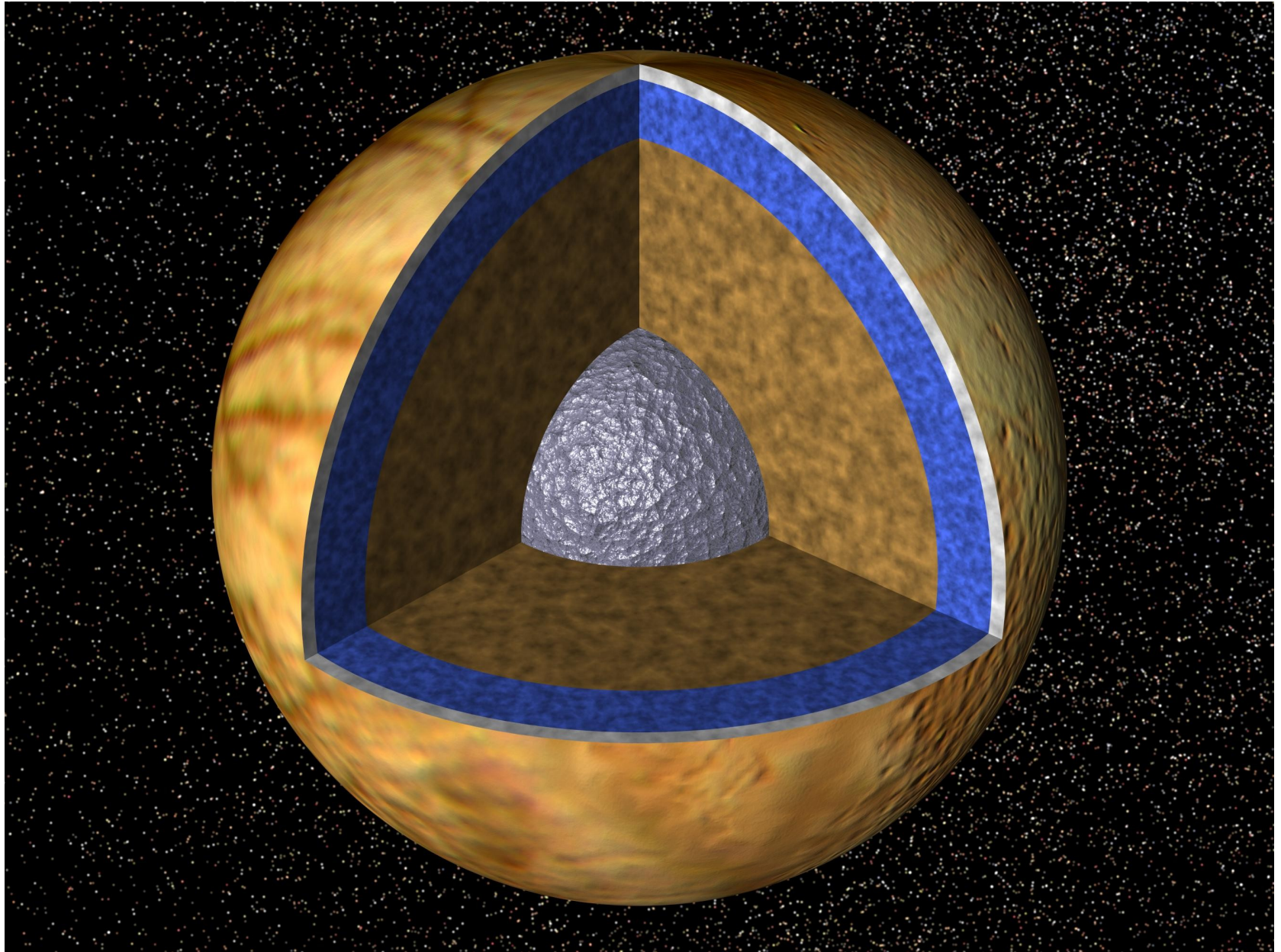


**Europe close up**



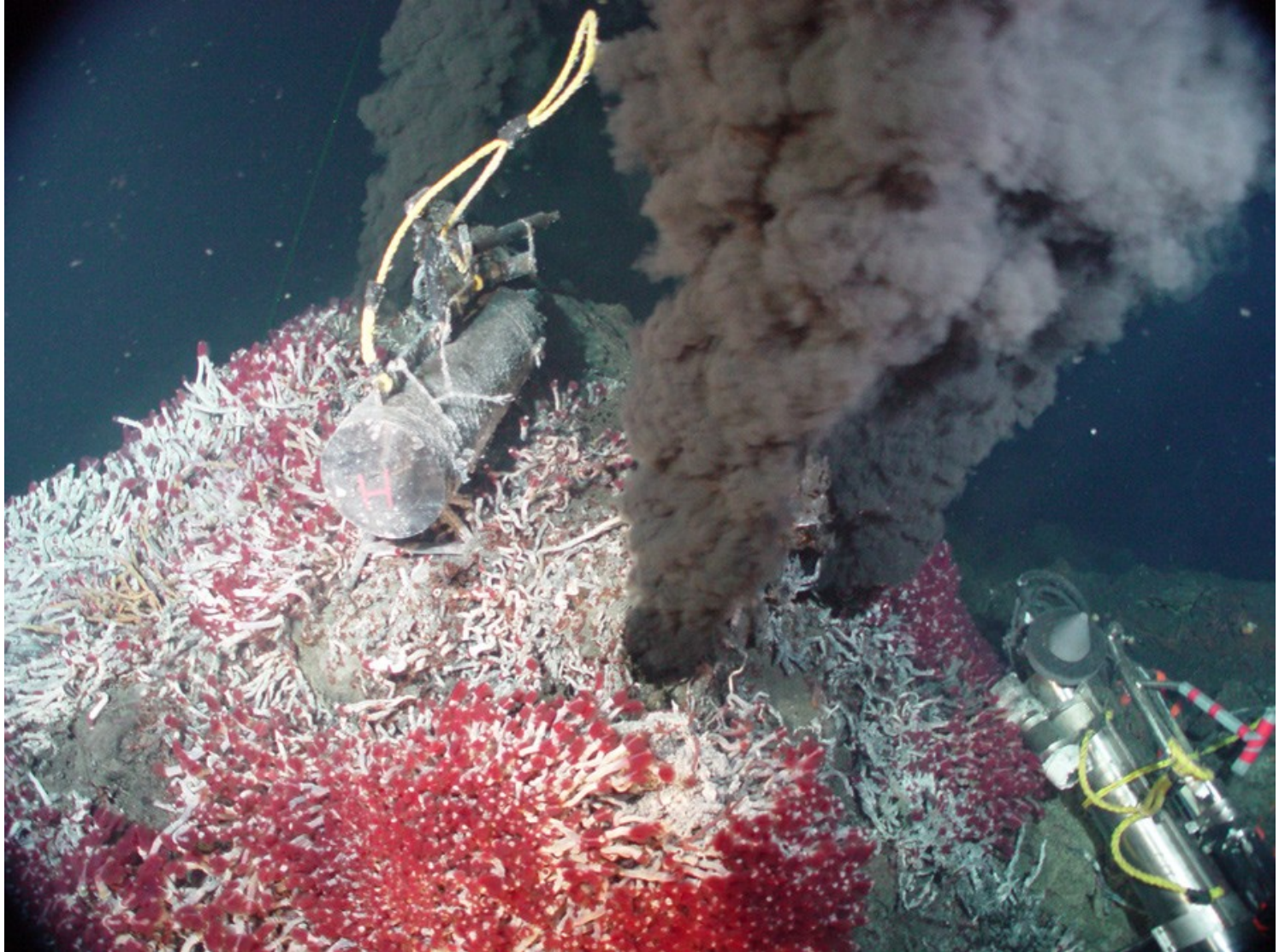


# Europa – Liquid water ocean under ice





# Potential for underwater volcanos to sustain life underneath the Io ice crust







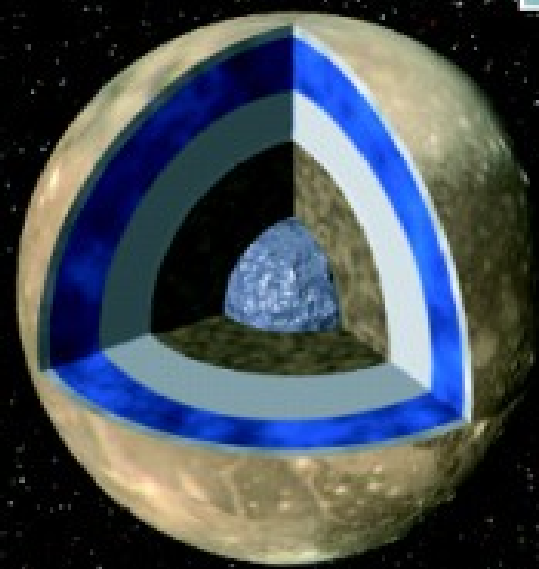
Io



Europa



-  iron-rich core
-  silicate mantle
-  ocean
-  ice



Ganymede



Callisto



# Rings of Saturn Fly-through



# Saturn

Radius ~ 10 times Earth, mass ~ 100 times Earth

Density ~ 700 kg/m<sup>3</sup> - less than water, Saturn would float!

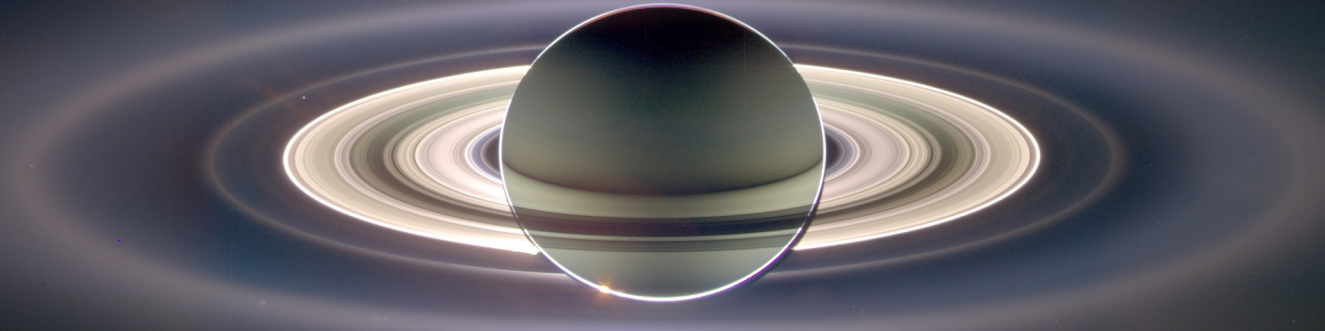
Composed of mainly hydrogen and helium

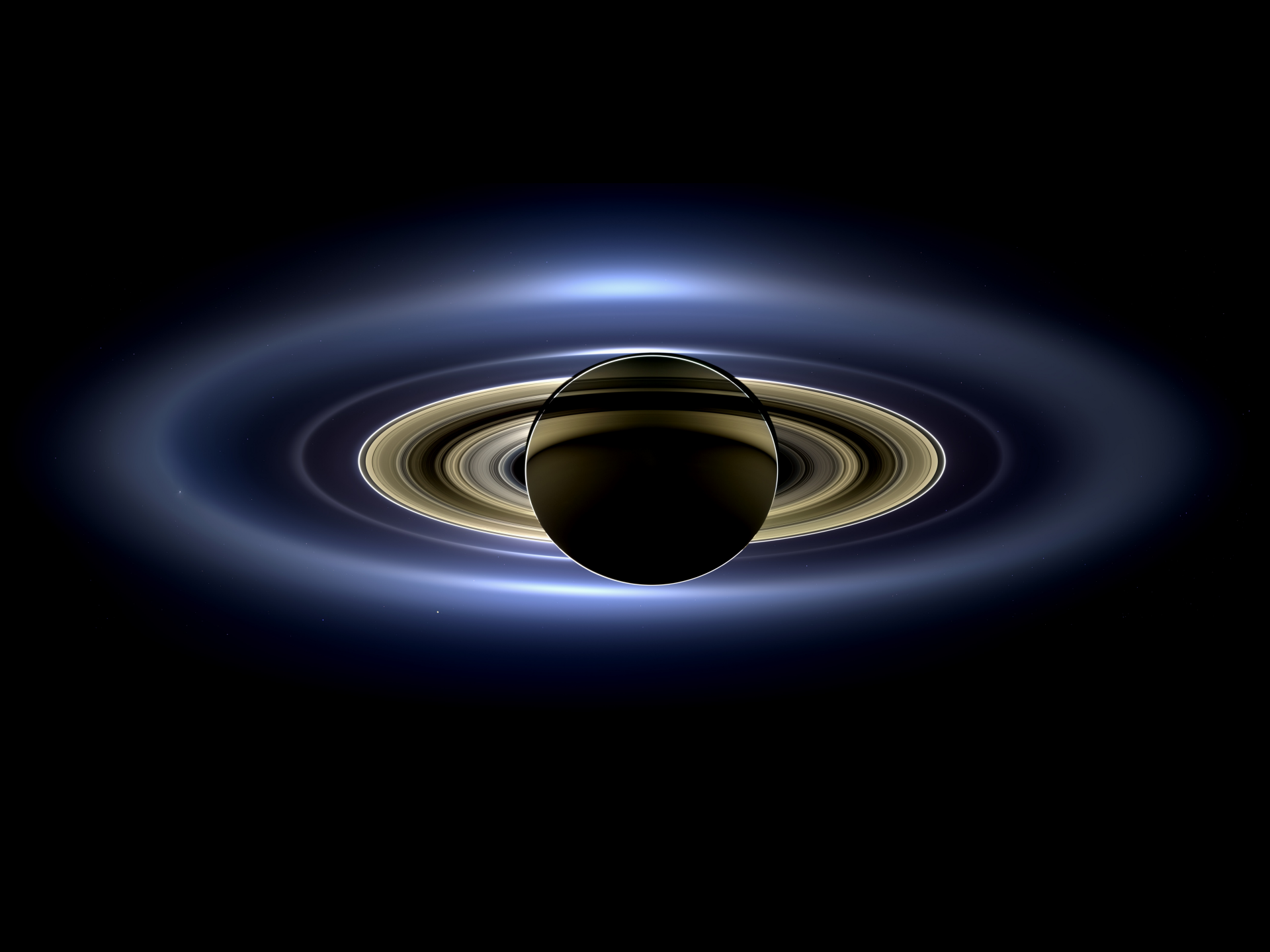
No surface

Strong magnetic field



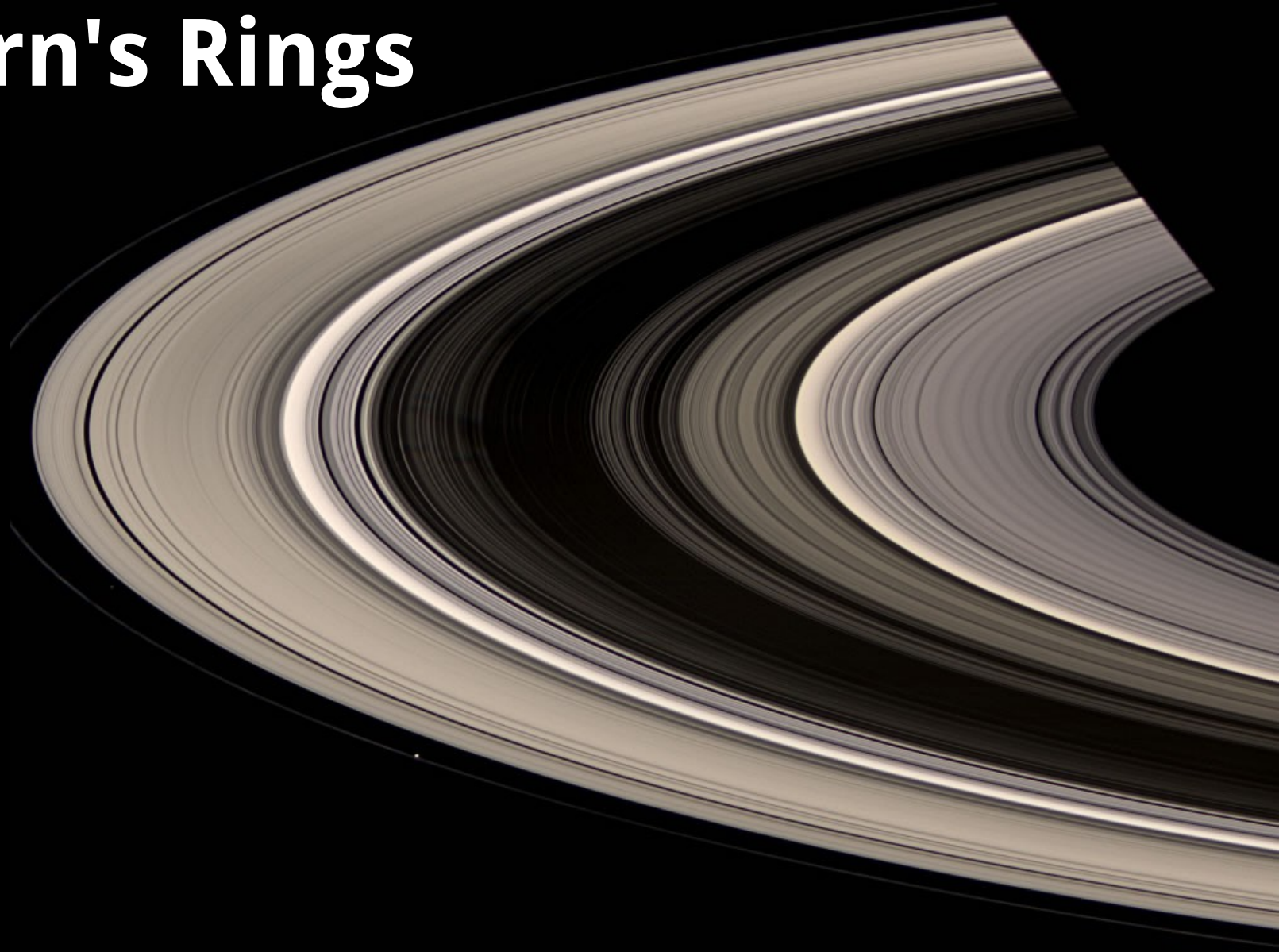
Saturn eclipses the Sun, from the Cassini spacecraft

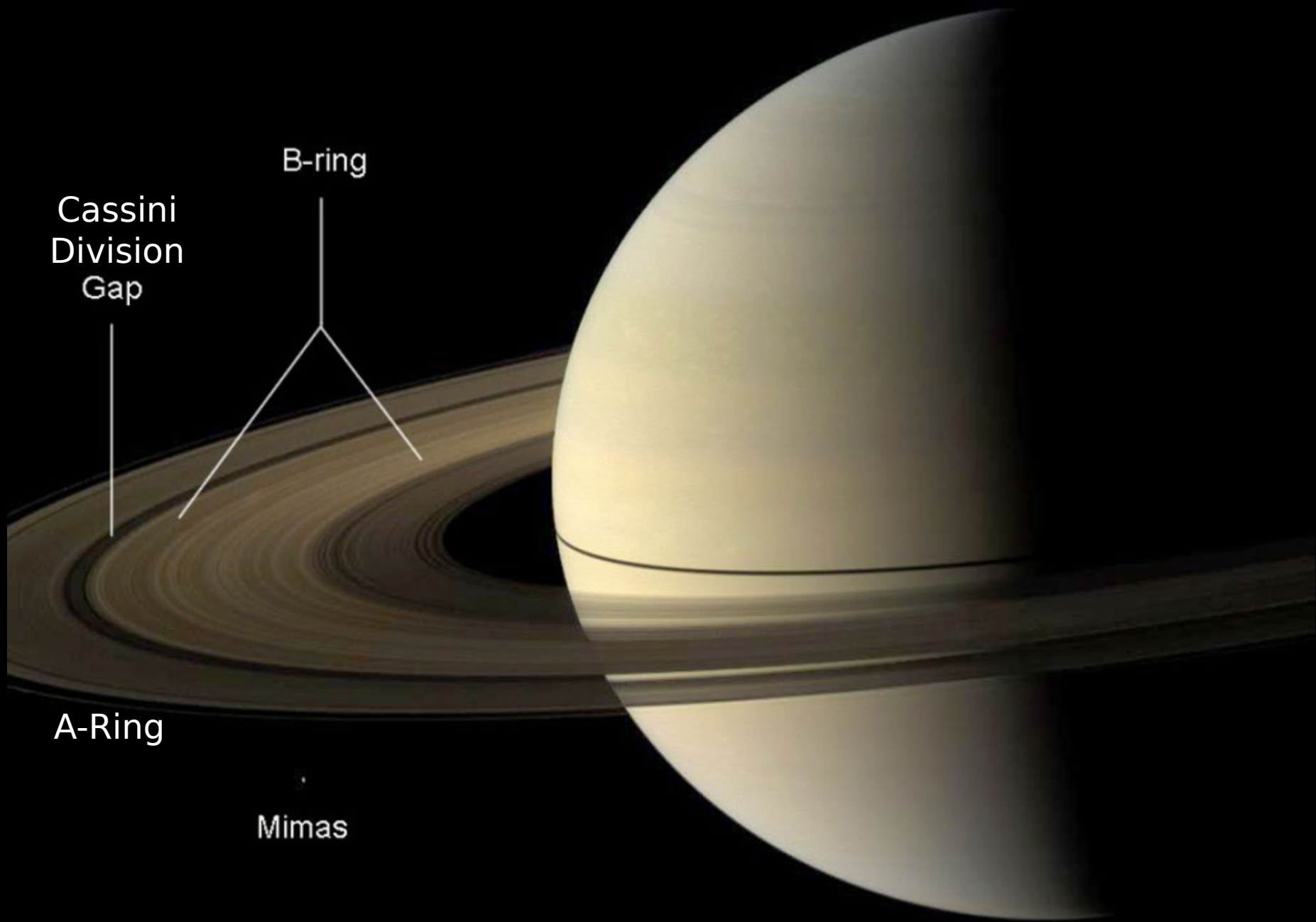






# Saturn's Rings





Cassini  
Division  
Gap

B-ring

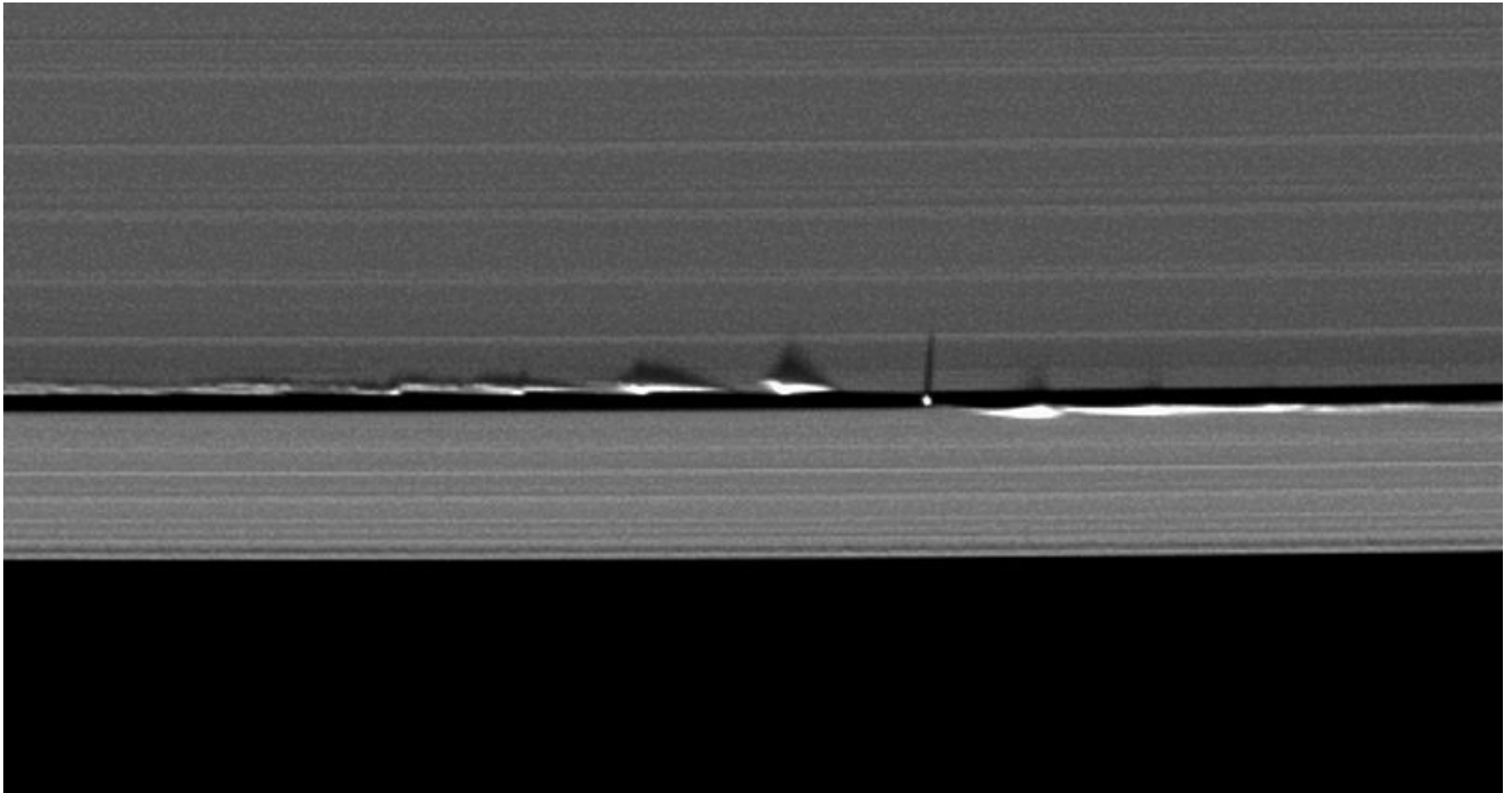
A-Ring

Mimas



# Saturn's Rings

- Made of icy particles from 1 cm to a few meters in size
- The many divisions in the rings are due to tiny moons between the divisions known as **shepherd moons**

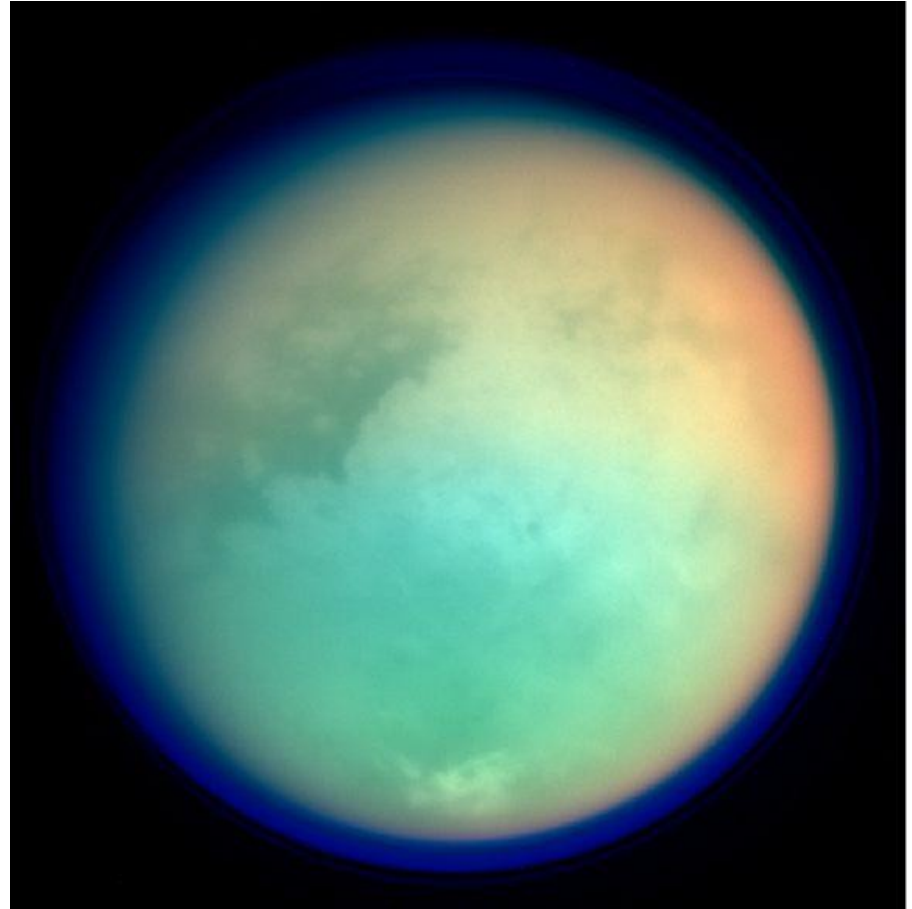


# Real footage of Saturn & Jupiter



# Moons of Saturn: Titan

- Saturn's largest moon – 2nd largest in solar system (Jupiter's Ganymede is largest)
- Only other body in solar system with stable surface liquid: seas and lakes of methane
- Nitrogen-rich (98%) atmosphere, thicker and denser than Earth's
- Evidence for methane rain



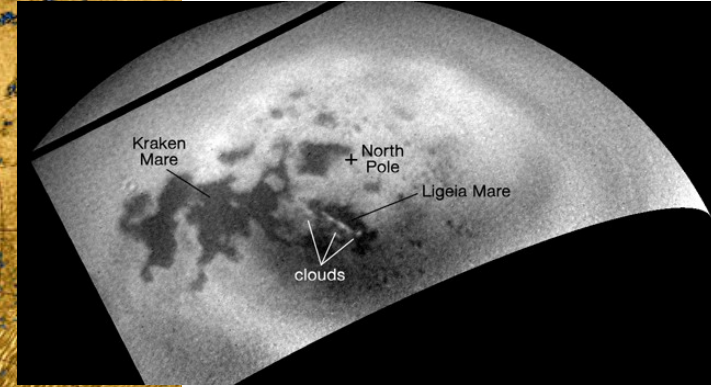
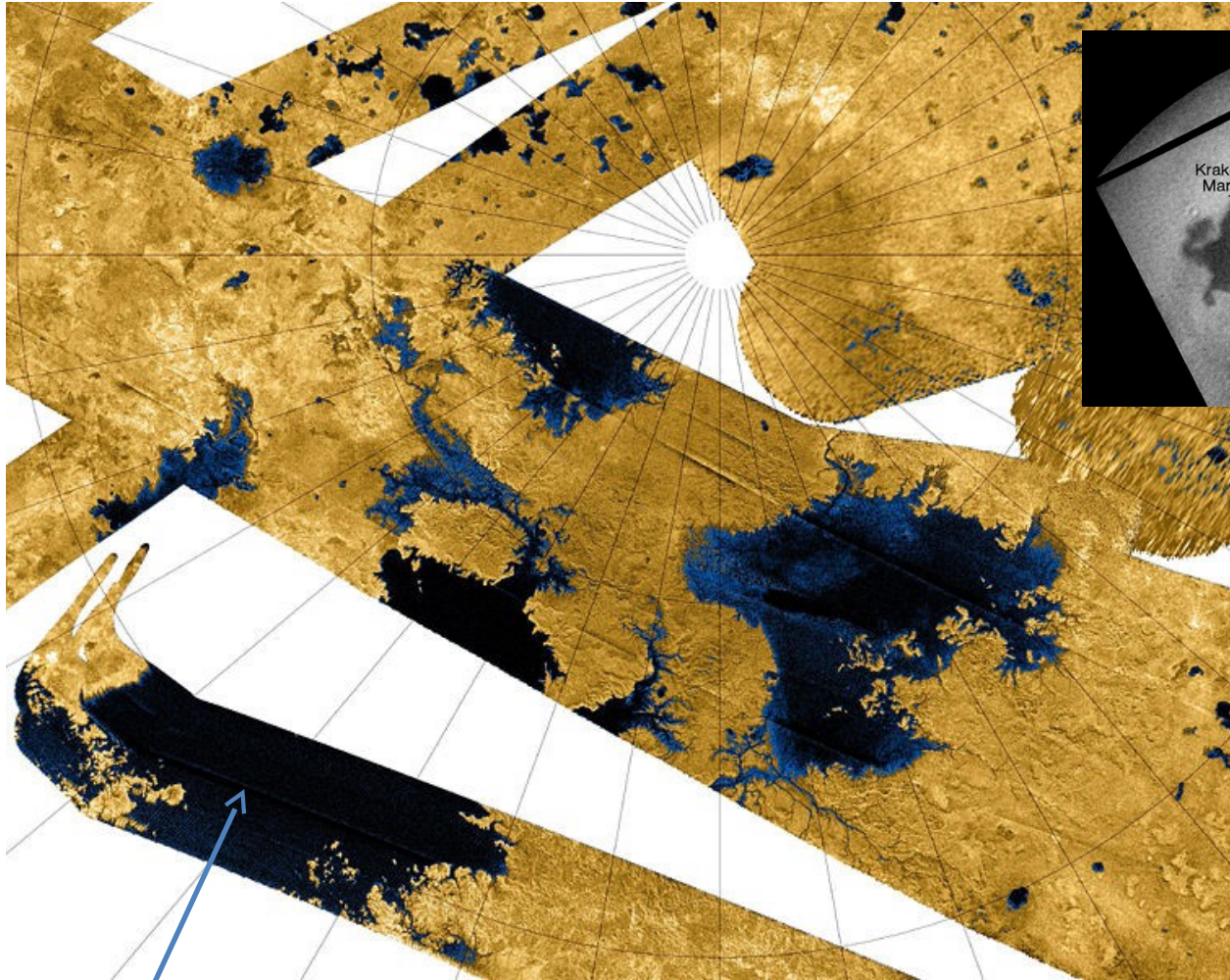
False color image of Titan



# Video of Descent through Titan's atmosphere



# The Lakes of Titan

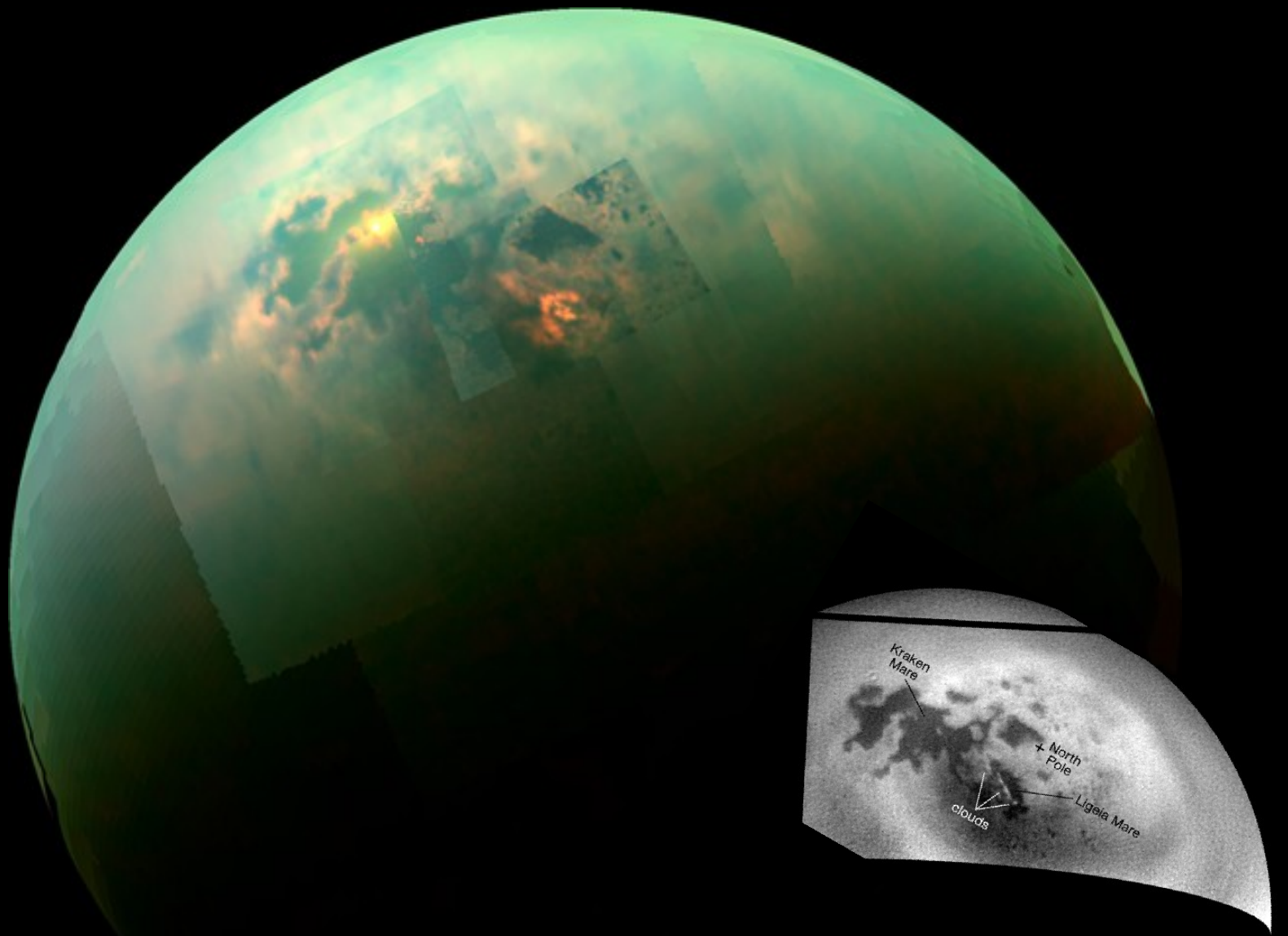


Weather on Titan: Cloudy with a chance of methane rain  
<http://phys.org/news/2014-08-cassini-tracks-clouds-titan-sea.html#nRlv>

Titan is cold  
- methane becomes liquid

Kraken Mare

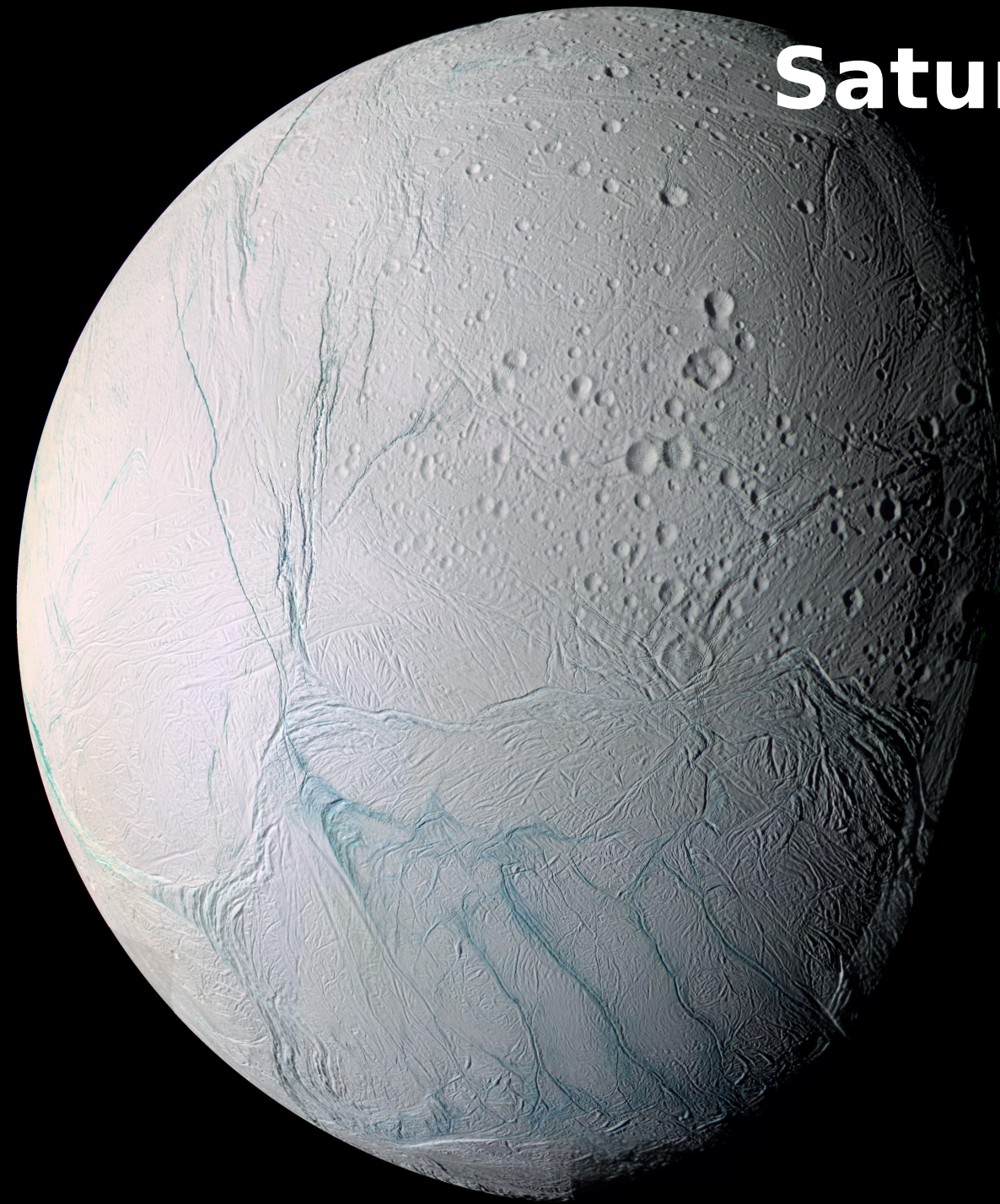
Radar mosaic of Titan's north polar region. Blue coloring shows areas of low reflectivity caused by lakes of liquid ethane and methane.



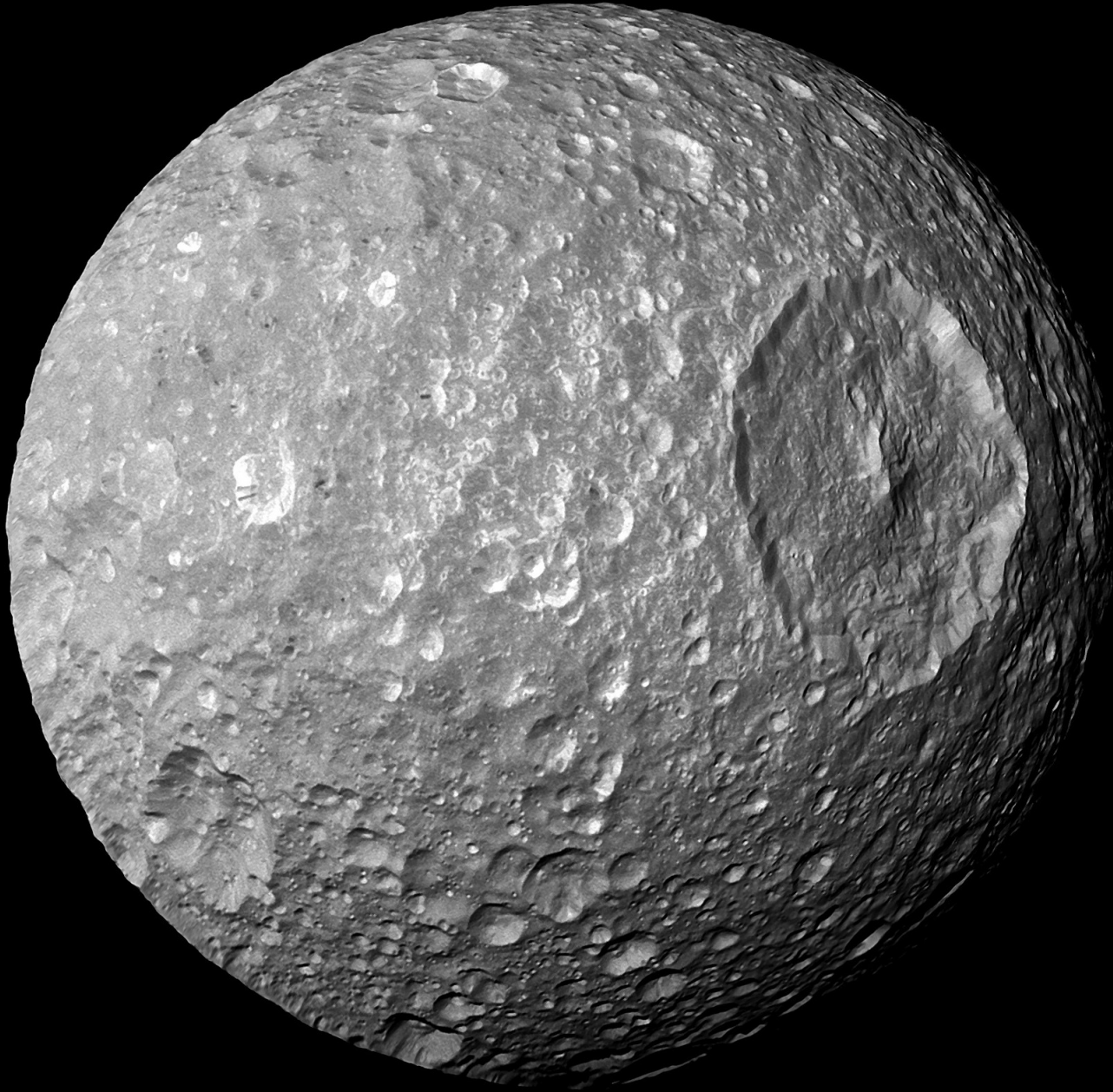
# Sun glinting of the Kraken Mare on Titan



# Saturn's Moons: Enceladus

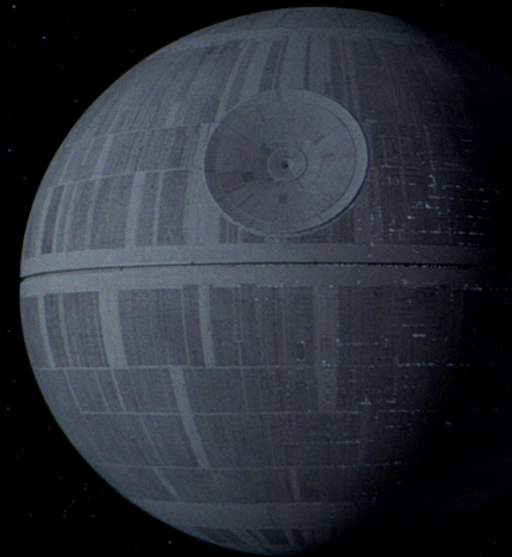
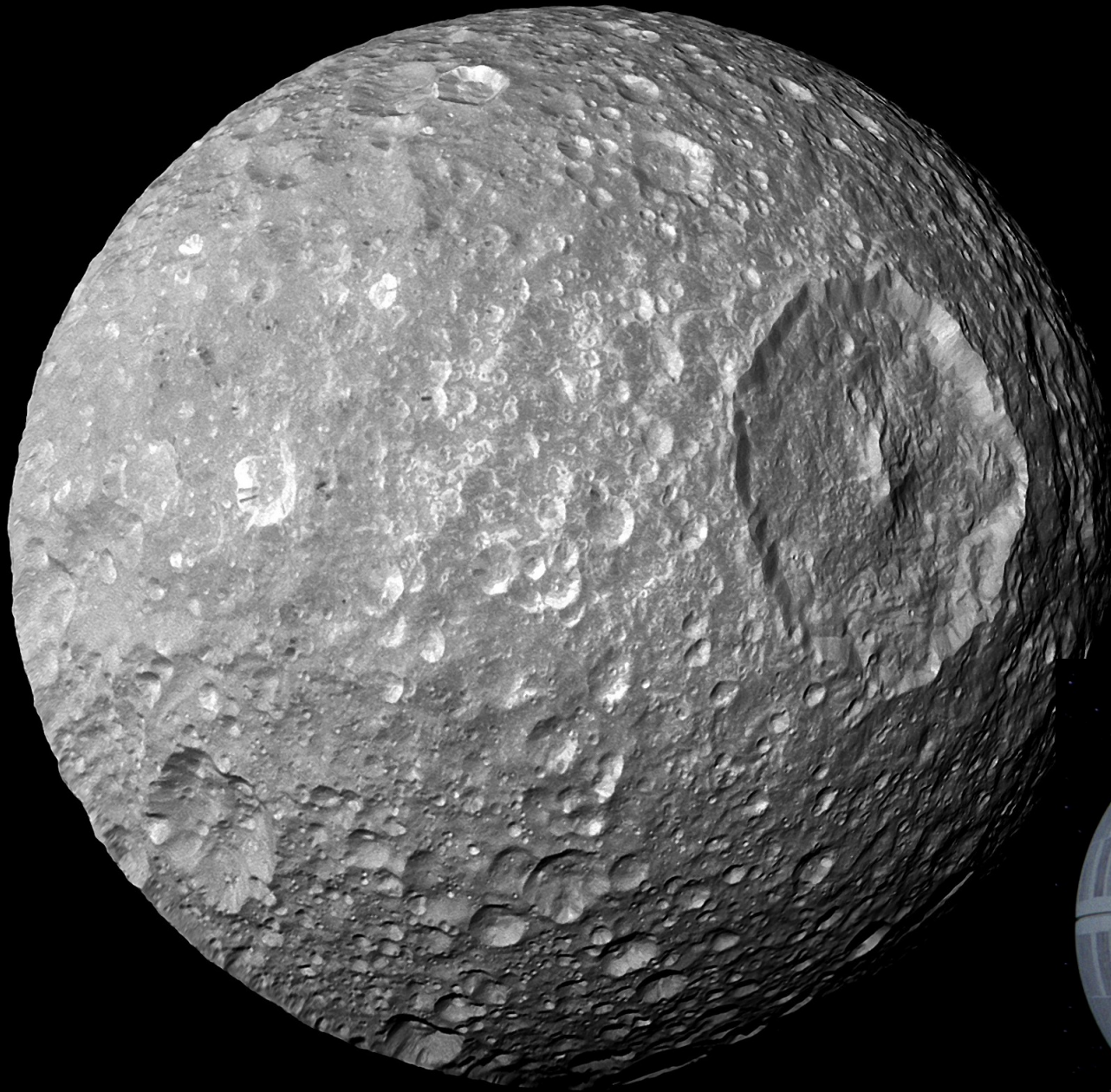


# Mimas





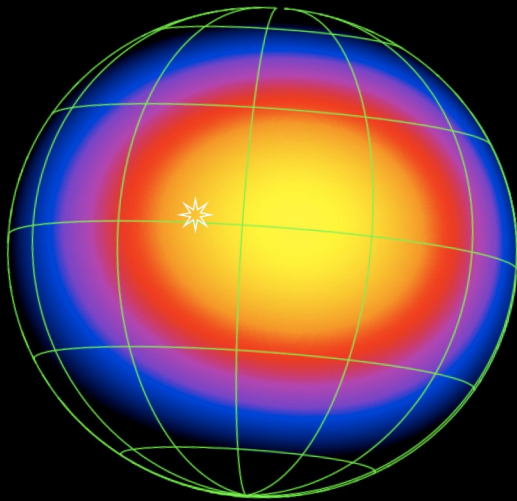
# Mimas



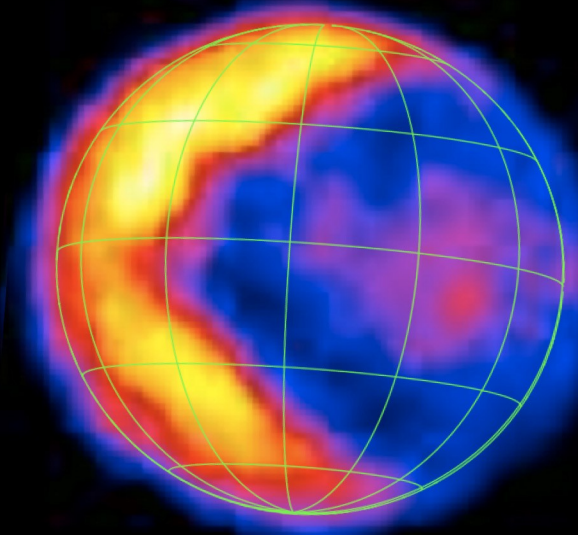


# Mysterious Temperatures on Mimas

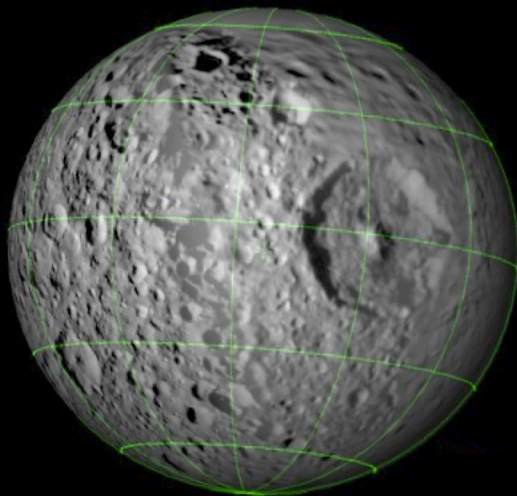
Expected  
Temperatures



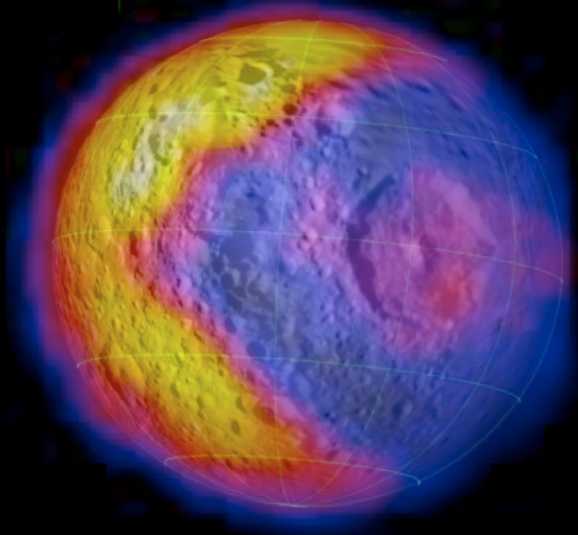
Actual  
Temperatures



Visible-Light Map



Combined Map



Surface  
Temperature

96  
94

-290

92  
90

-295  
-300

88  
86

-305

°K °F

84  
82

-310  
-315

80  
78

-320

76  
74

-325