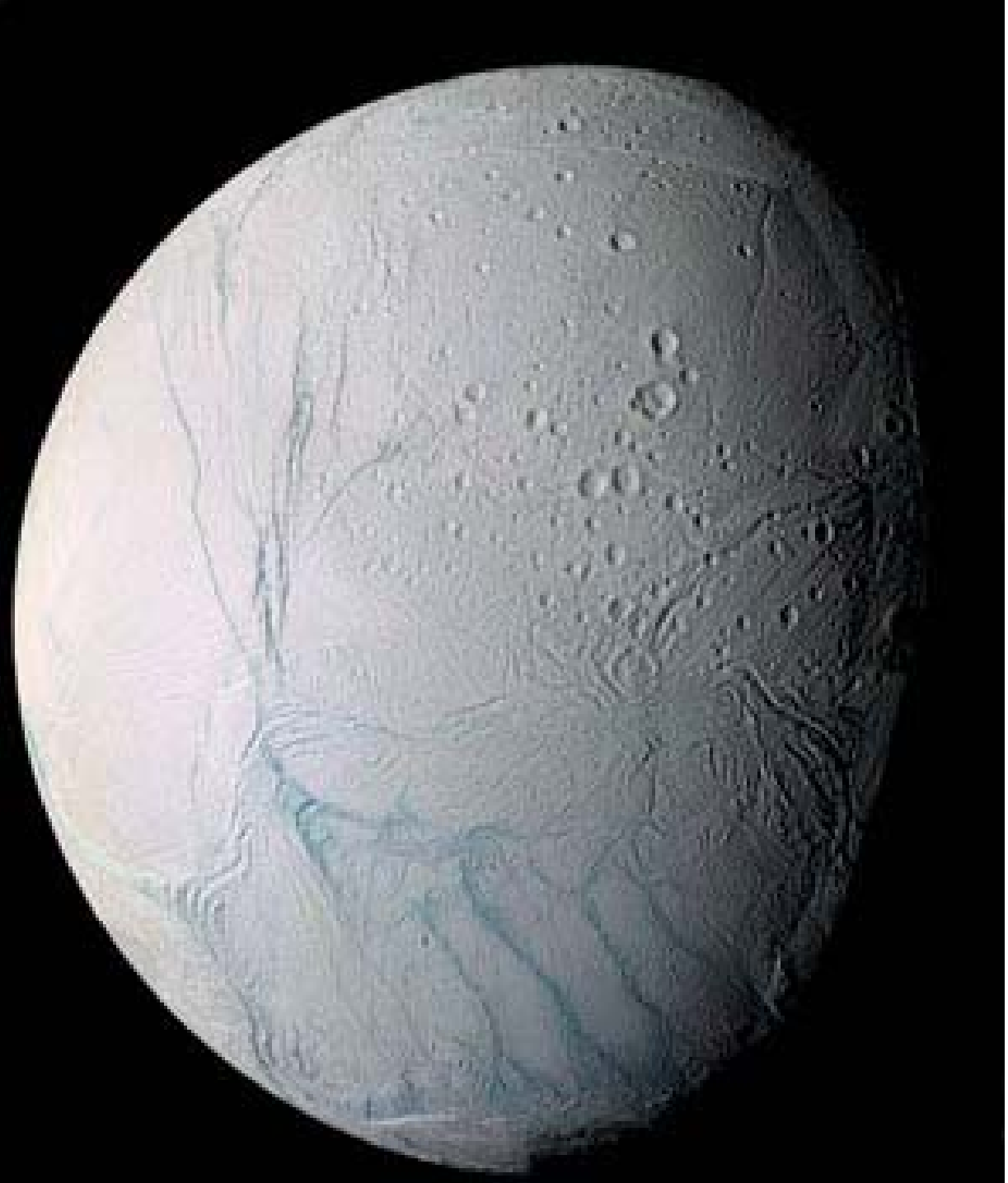


Jupiter and Saturn's Satellites of Fire and Ice

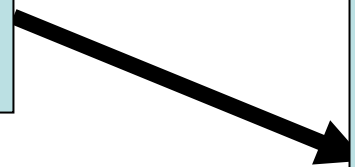
Chapter Thirteen

Introduction To Modern Astronomy I: Solar System

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-15)

Sun and Life: Highlights
(Chap. 16 & 28)



Ch7: Comparative Planetology I
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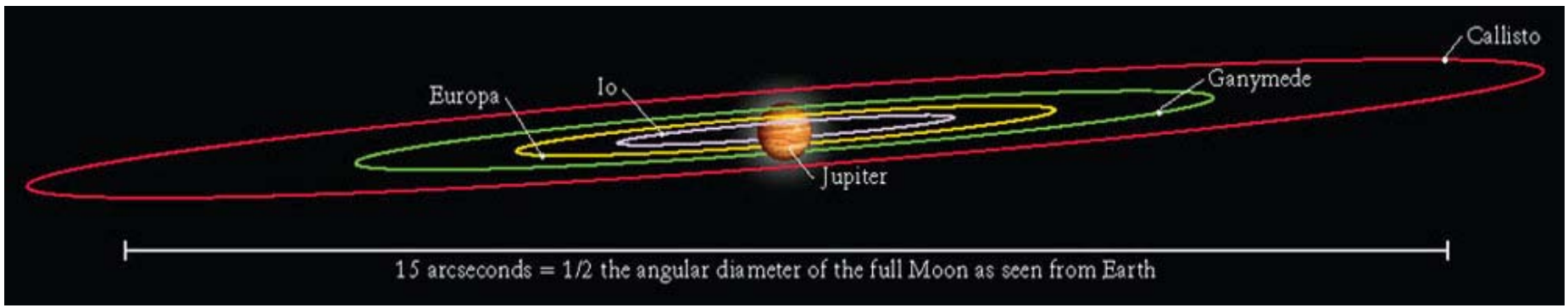
Ch9: The Living Earth
Ch10: Our Barren Moon
Ch11: Mercury, Venus and Mars

Ch12: Jupiter and Saturn
Ch13: Satellites of Jupiter & Saturn

Ch14: Uranus, Neptune and Beyond
Ch15: Vagabonds of Solar System

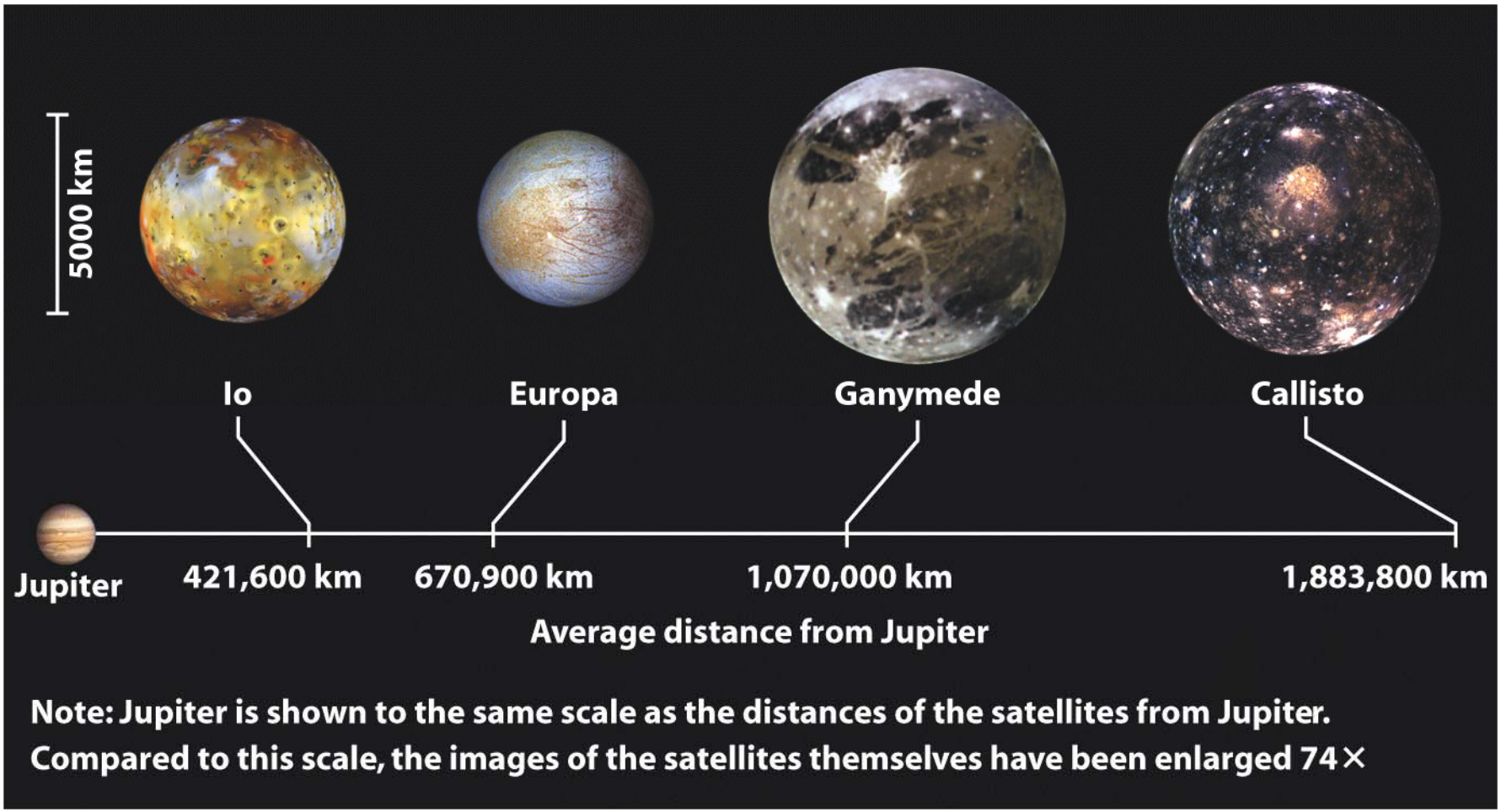
Jupiter's Galilean satellites

- Four Galilean satellites: Io, Europa, Ganymede, Callisto
- They orbit in nearly the same plane as Jupiter's equator
- All are in **synchronous rotation**
  - Rotation period and orbital period are in a 1-to-1 ratio
- They are in **rhythmic relationship, or resonance**
  - Io: 1.77 days; Europa: 3.55 days; Ganymede: 7.15 days
  - The orbit periods are in the ration of 1:2:4
  - Caused by gravitational forces among the satellites themselves



1303001.swf **Movie: Orbits of Galilean Satellites**

Jupiter's Galilean satellites



They all have solid surface.
They do not have atmosphere

Jupiter's Galilean satellites

table 15-1 The Galilean Satellites Compared with the Moon, Mercury, and Mars

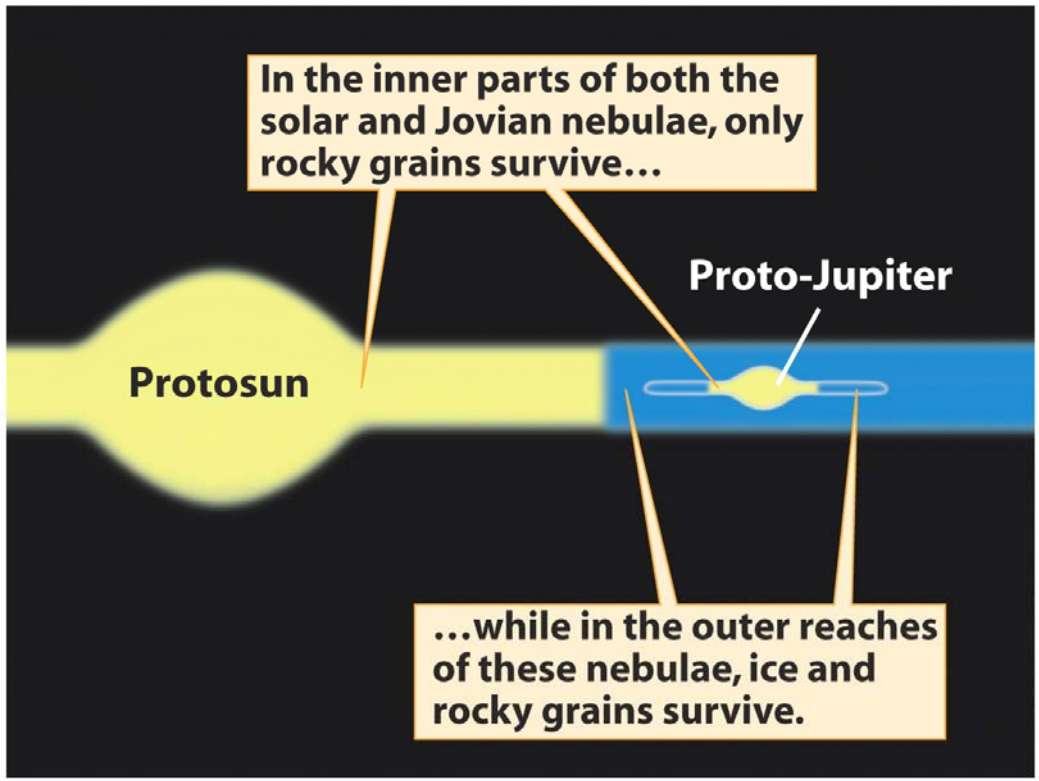
	Average distance from Jupiter (km)	Orbital period (days)	Diameter (km)	Mass (kg)	Mass (Moon = 1)	Average density (kg/m^3)	Albedo
Io	421,600	1.769	3642	8.932×10^{22}	1.22	3529	0.63
Europa	670,900	3.551	3120	4.791×10^{22}	0.65	3018	0.64
Ganymede	1,070,000	7.155	5268	1.482×10^{23}	2.02	1936	0.43
Callisto	1,883,000	16.689	4800	1.077×10^{23}	1.47	1851	0.17
Moon	—	—	3476	7.349×10^{22}	1.00	3344	0.11
Mercury	—	—	4880	3.302×10^{23}	4.49	5430	0.12
Mars	—	—	6794	6.419×10^{23}	8.73	3934	0.15

- The two innermost Galilean satellites, Io and Europa, have roughly the same size and density as our Moon
- They are composed principally of rocky material
- The two outermost Galilean satellites, Ganymede and Callisto, are roughly the size of Mercury
- Lower in density than either the Moon or Mercury, they are made of roughly equal parts of ice and rock

Origin of Galilean satellites

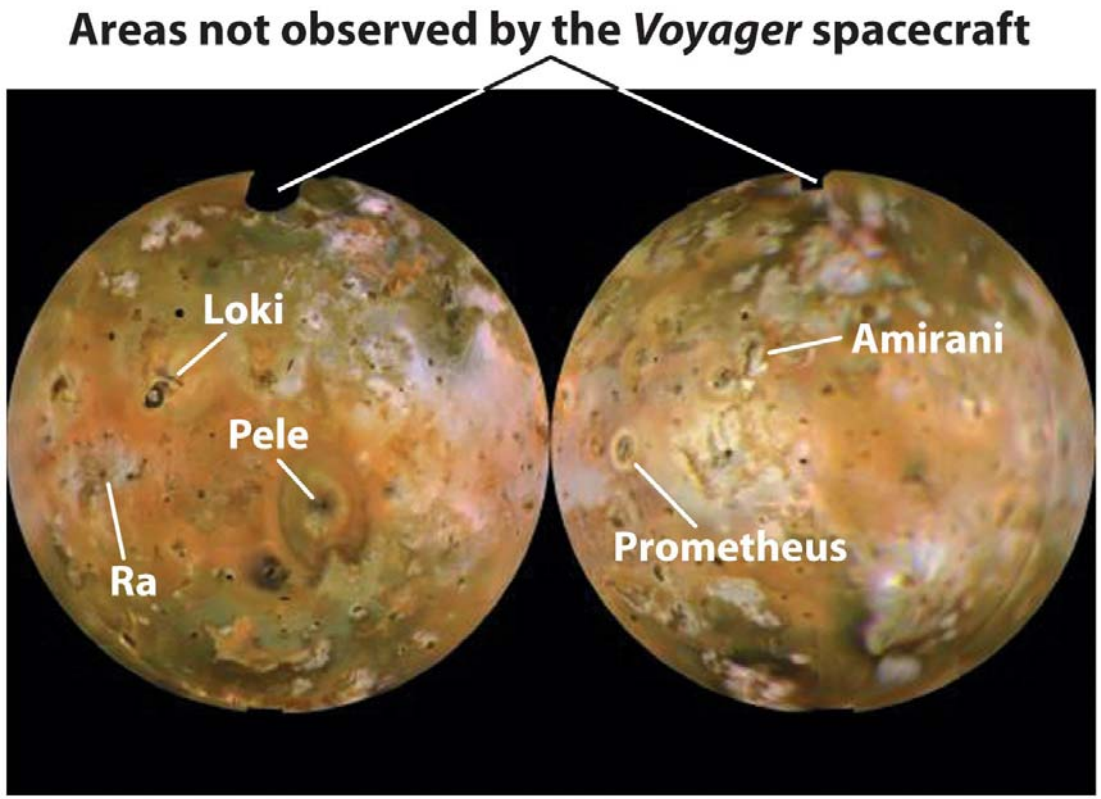
- They formed out from a **“Jovian nebula”,** like the solar nebula in miniature
  - Similarity in density pattern: decrease as moving outward

- Jupiter is called a “failed star”
- Its internal temperature and pressure is not high enough to ignite nuclear reaction



Io's Internal Heat

- Because of its small size, Io was expected geologically dead
- However, Io is geologically extremely active
- It has no impact craters
- Io has numerous volcanoes; some are active

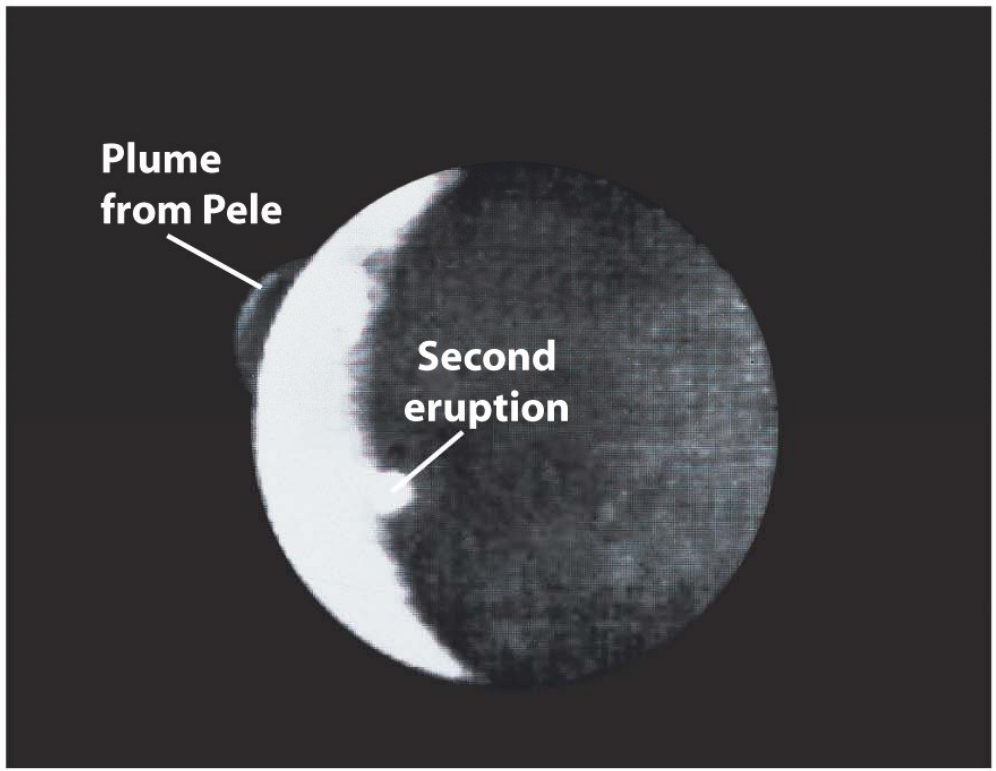


Io's Numerous Volcanoes

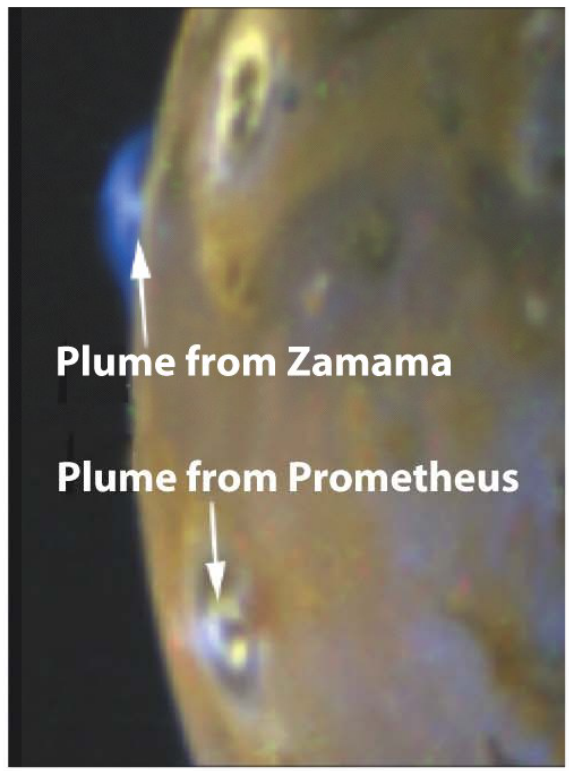
The extraordinary colors are due to the volcanic deposit of sulfur compounds

Io's Internal Heat

- Plumes are more like geysers: heated steam erupts explosively.
- The plumes are probably sulfur dioxide (SO_2)

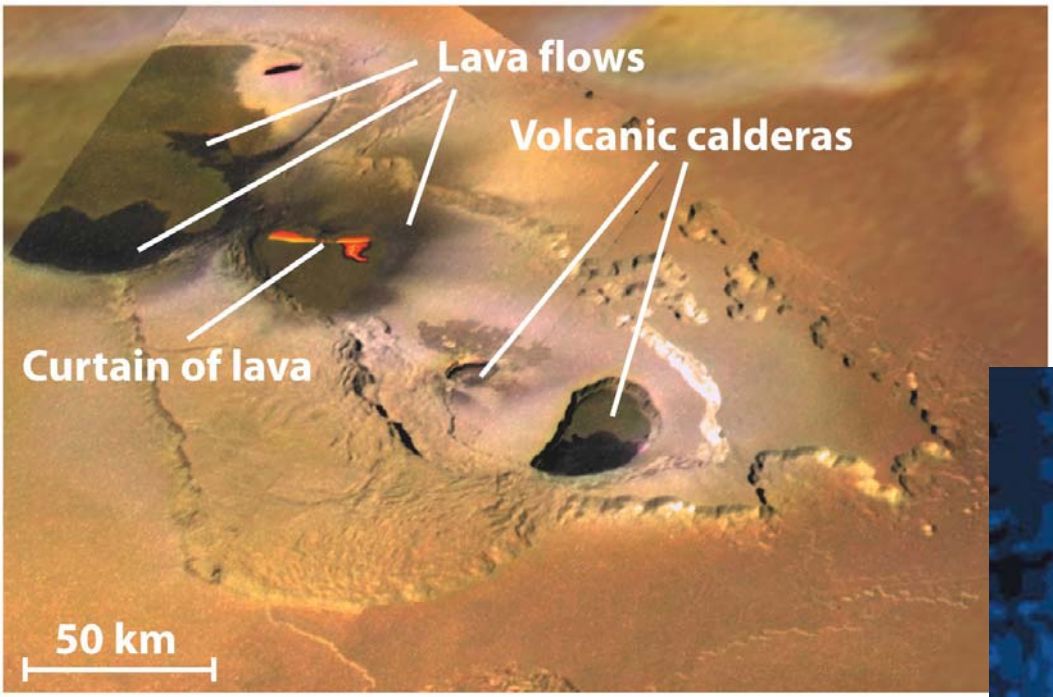


(a) *Voyager 1*, March 1979



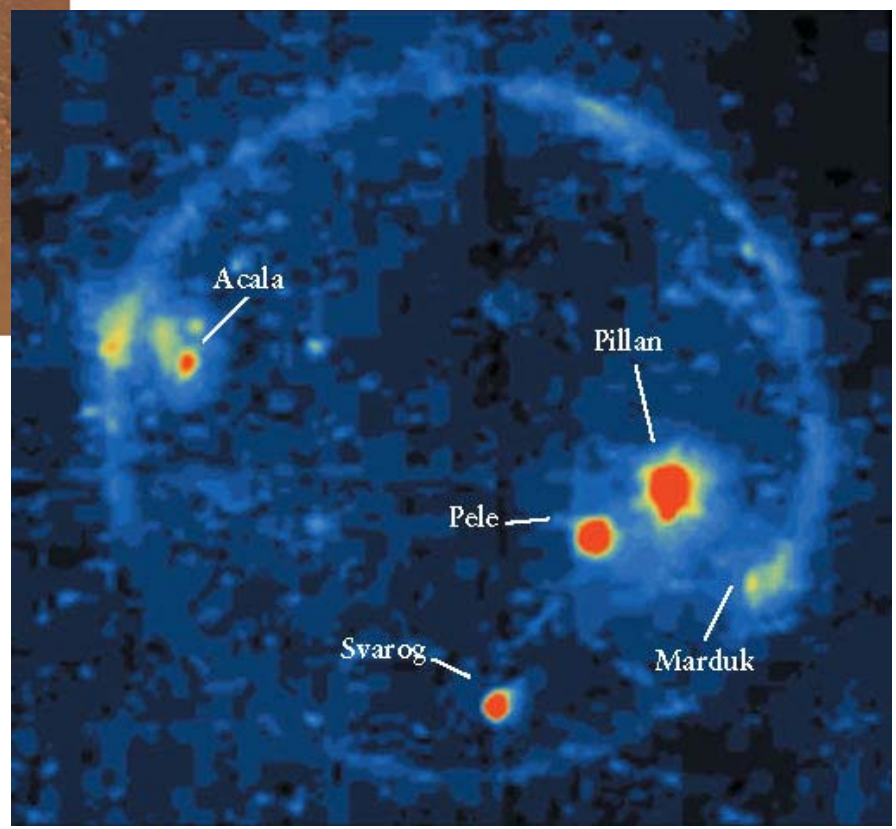
(b) *Galileo*, November 1997

Io’s Internal Heat



Io’s Volcano: erupting lava

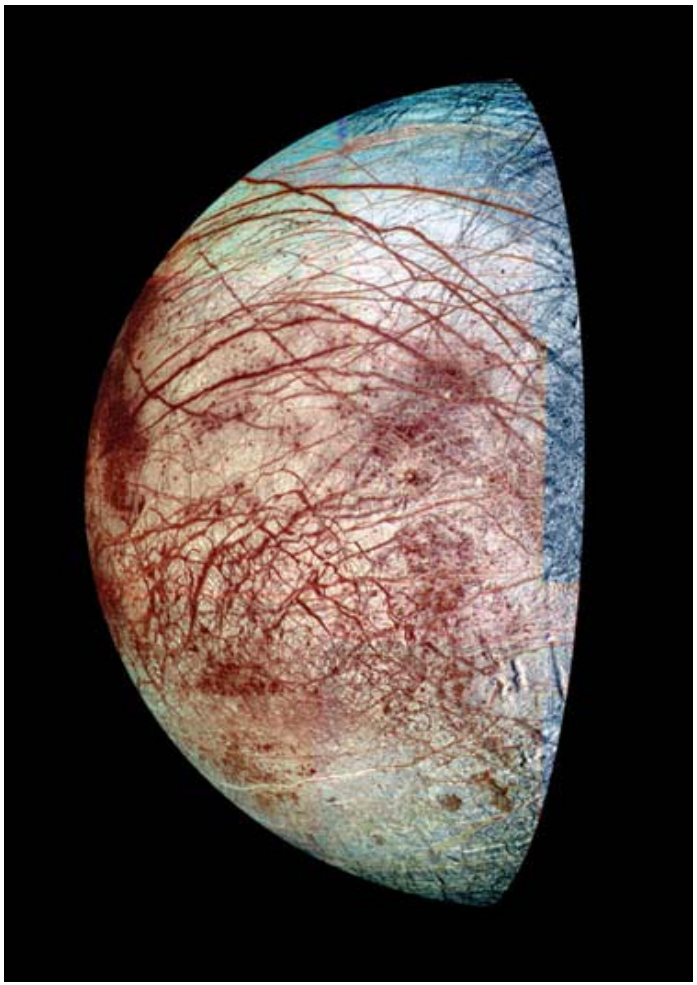
Glowing Volcanoes (Infrared image



Io's Internal Heat

- The energy to heat Io's interior and produce the satellite's volcanic activity comes from **tidal forces that flex the satellite**
- Europe and Ganymede exert rhythmic gravitational force on Io, and distort Io's orbit into ellipse
- Io's long axis "nods" back and forth half degree
- The tidal stress that Jupiter exerts on Io varies periodically
- The varying tidal stresses alternatively squeeze and flex Io
- This tidal flexing is aided by the 1:2:4 ratio of orbital periods among the inner three Galilean satellites
- Tidal heating provides 2.5 Watts of power per square meter of Io's surface
- As comparison, the average heat flow through Earth is 0.06 Watts per square meter.

Europa

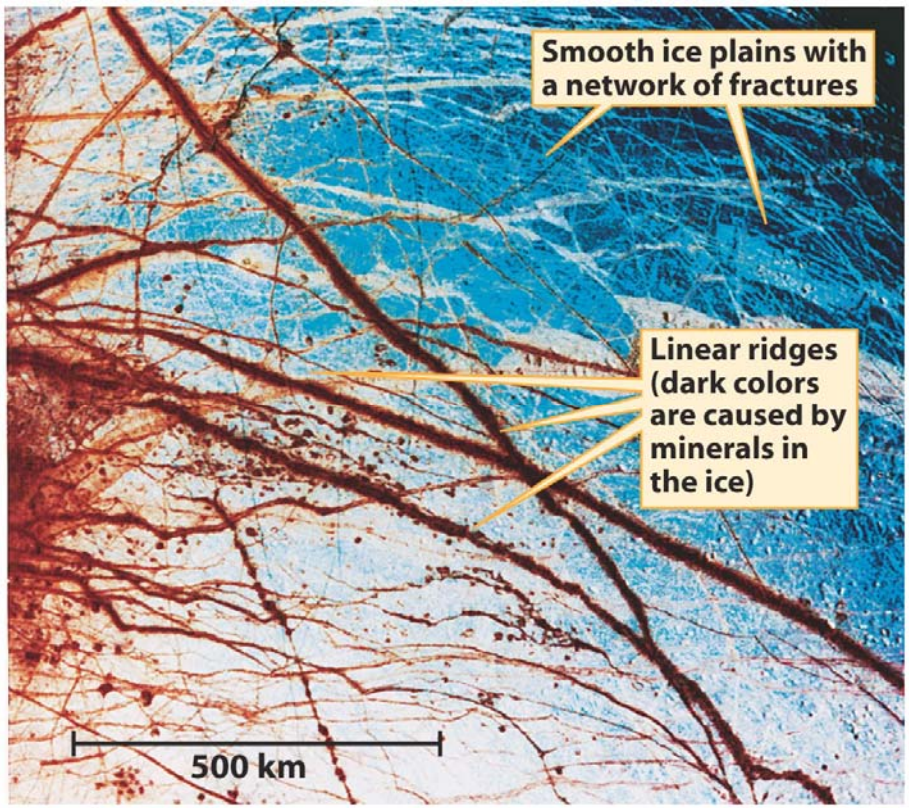


Smoothest Body in the Solar System

- Europa is covered with a smooth layer of water ice
- It is geologically active, since there are almost no craters on surface.
- Water is brought from interior to the surface, making a fresh, smooth layer of ice.
- Europa is too small to retain the internal heat it had when it first formed.
- As for Io, tidal heating is responsible for Europa's internal heat

Europa

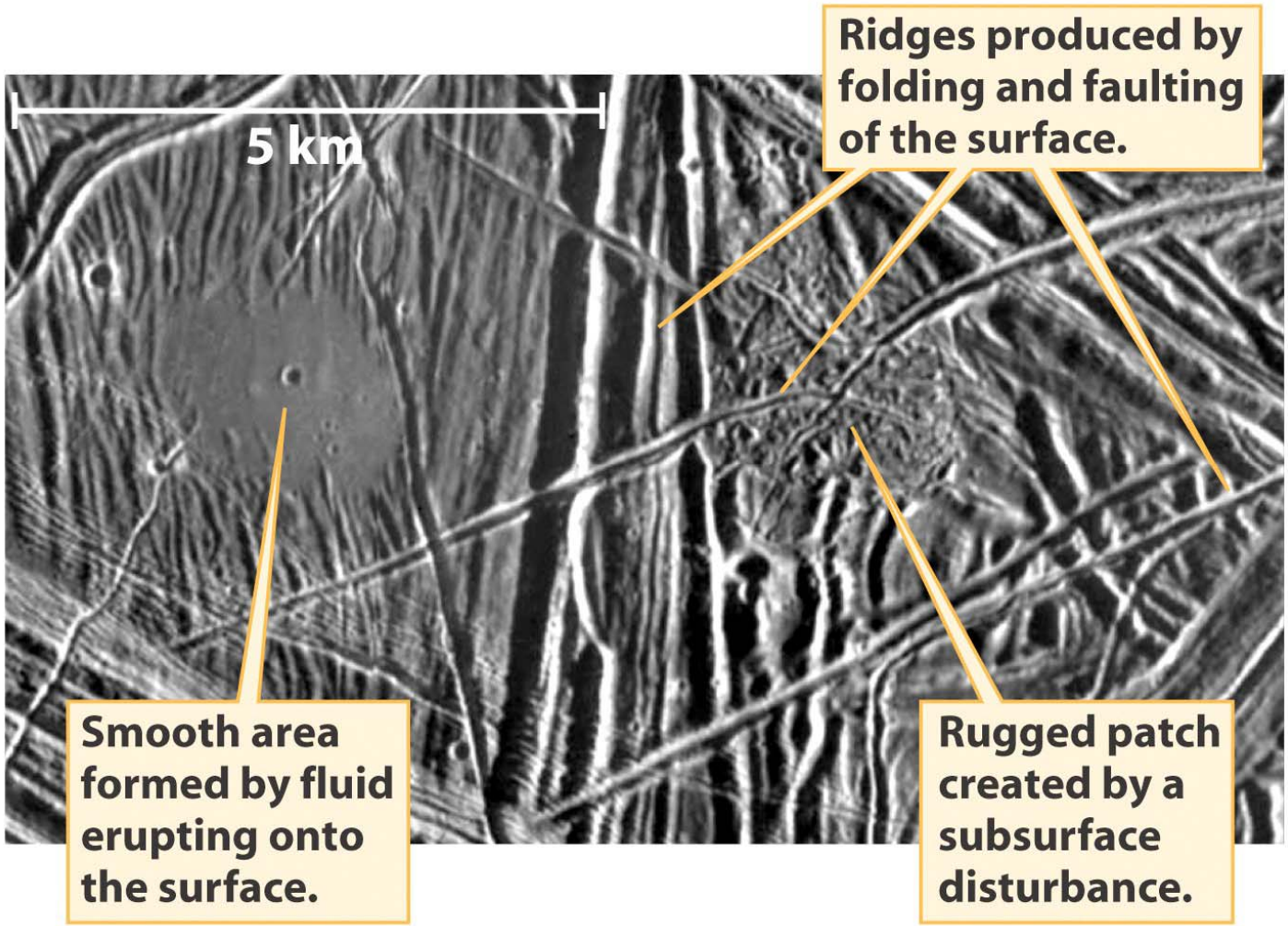
- Spectrum analysis indicates that the surface is pure water
- Its density indicates it is a rocky ball, therefore, water is a small fraction of mass (10%)



- A worldwide network of long cracks on the surface
- The cracks are produced by the tidal force which stretches and compresses the icy crust

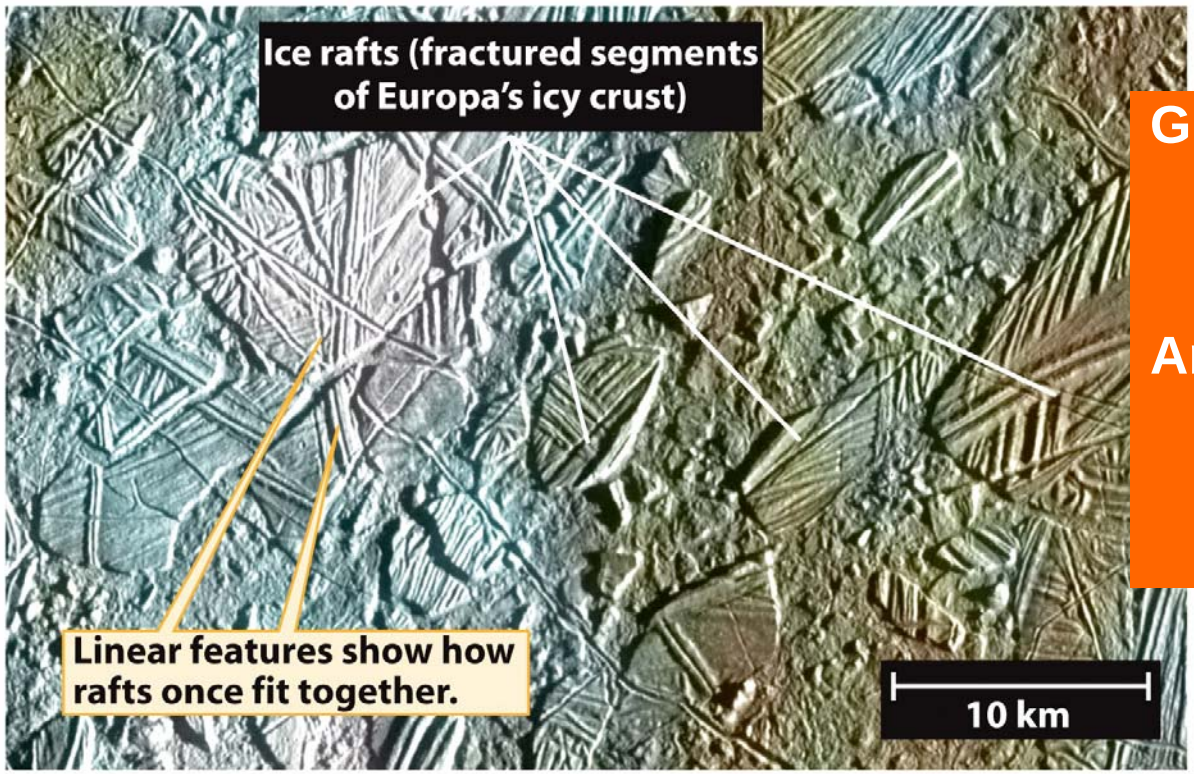
Europa

The smooth area indicates that liquid water was erupted onto the surface



Europa

- Icy rafts indicate that there is a subsurface layer of liquid water or soft ice
- Liquid water, equivalent to the lava in the Earth, breaks down the crust and moves the pieces.



Ice rafts on Europa

Global liquid water underneath the icy surface?

Any life developed in the water in the past 4.5 billion years?

ASTR 111 – 003 **Fall 2007**
Lecture 12 Nov. 19, 2007

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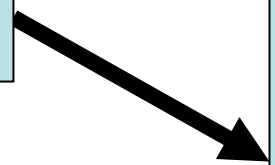

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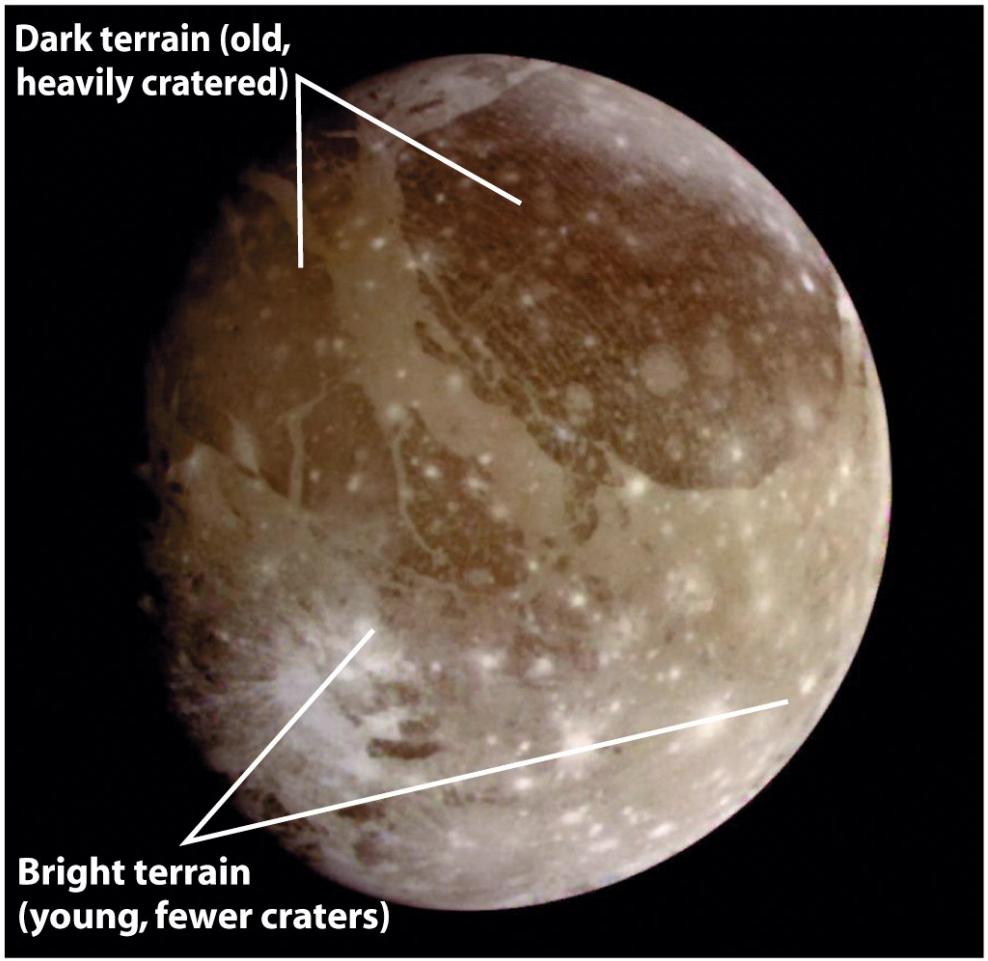
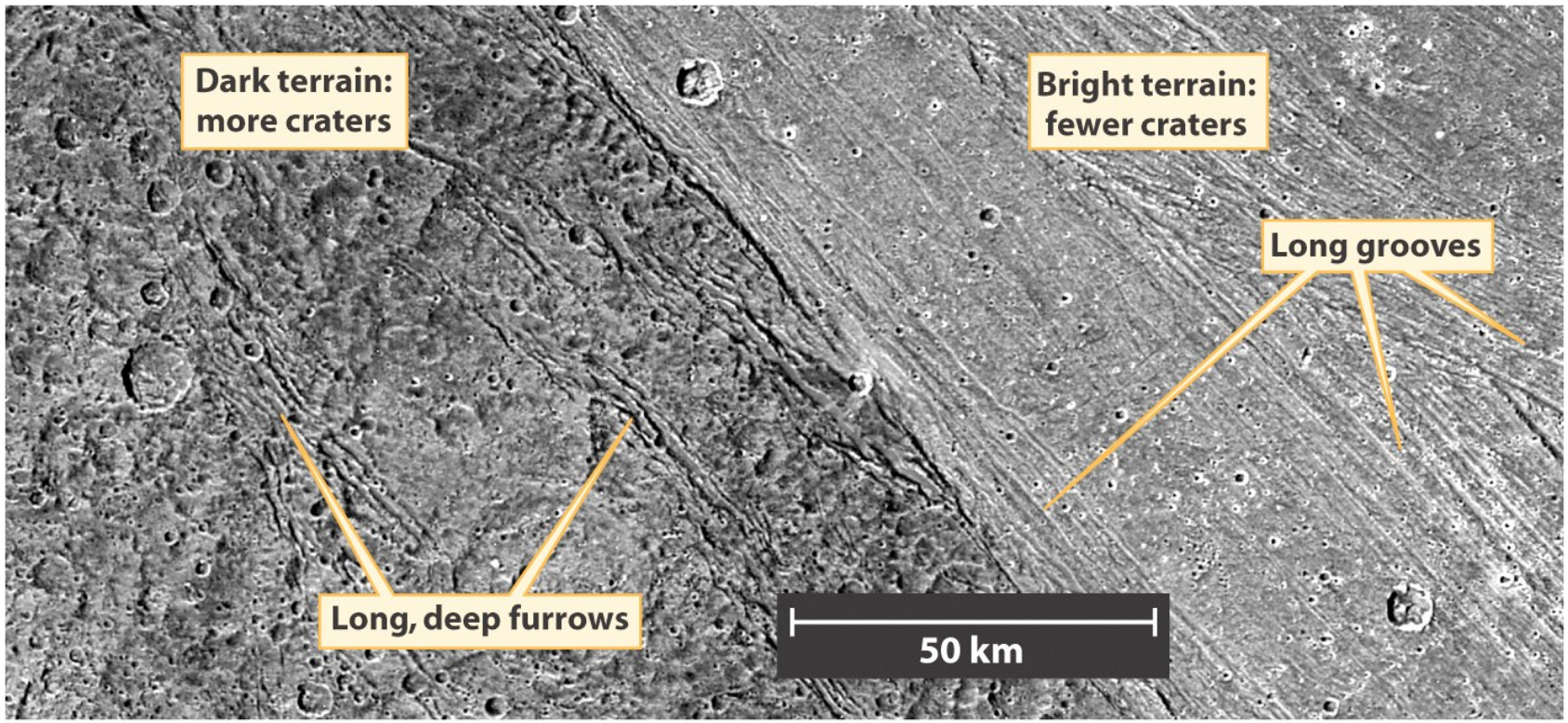
Ganymede



- Ganymede has two kinds of terrain
- Dark terrain
  - Heavily cratered
  - Older
- Bright terrain
  - Less cratered
  - Younger
- In opposite, moon has young but dark mare, and old but bright highland.
- Water ice versus Rocky lava

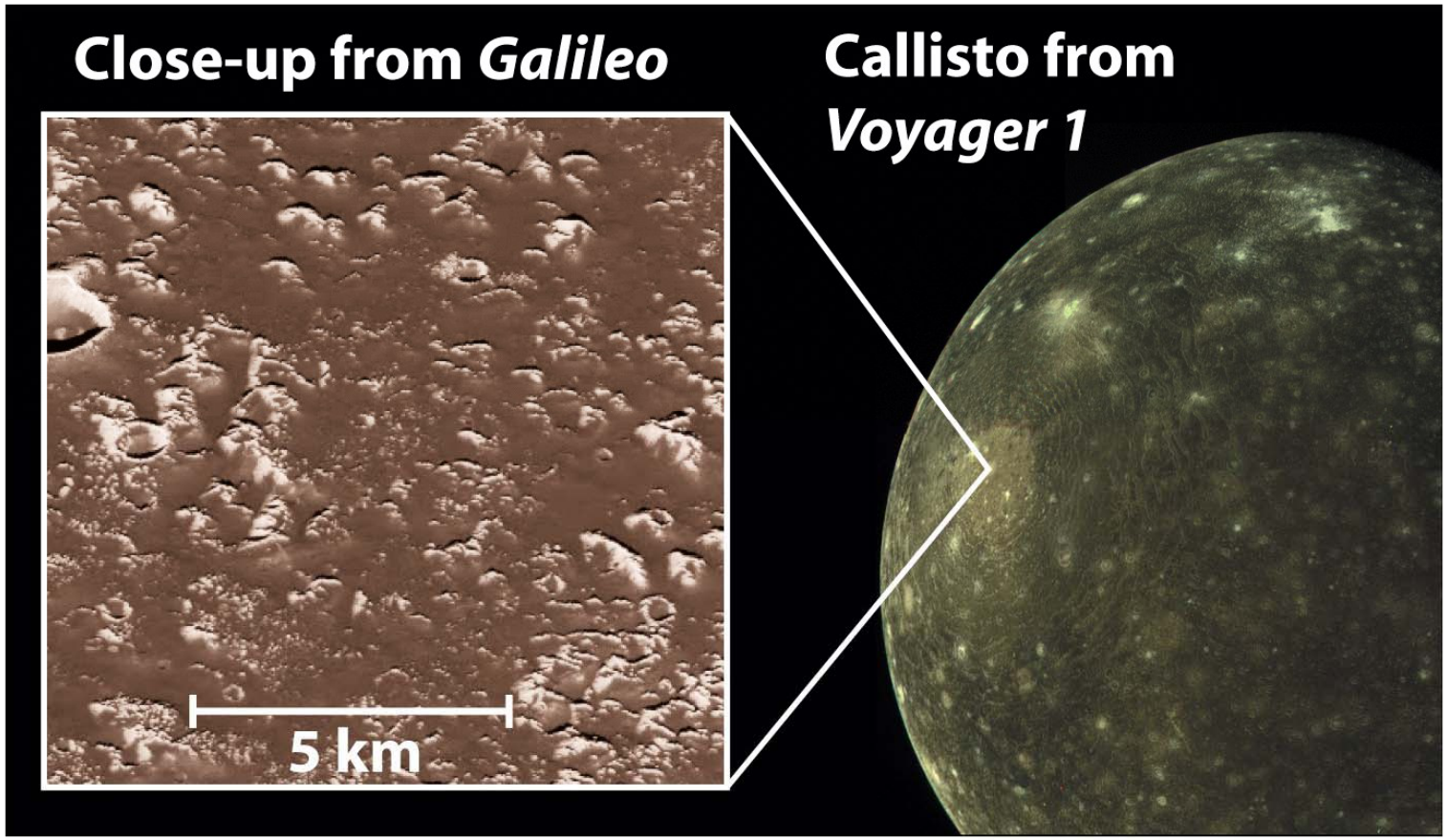
Ganymede

- Ganymede may have liquid water about a billion years ago
- Stresses produced the long grooves.
- Bright terrain represents relatively fresh ice, flooded by water through cracks in the crust.
- It was warmer in the past



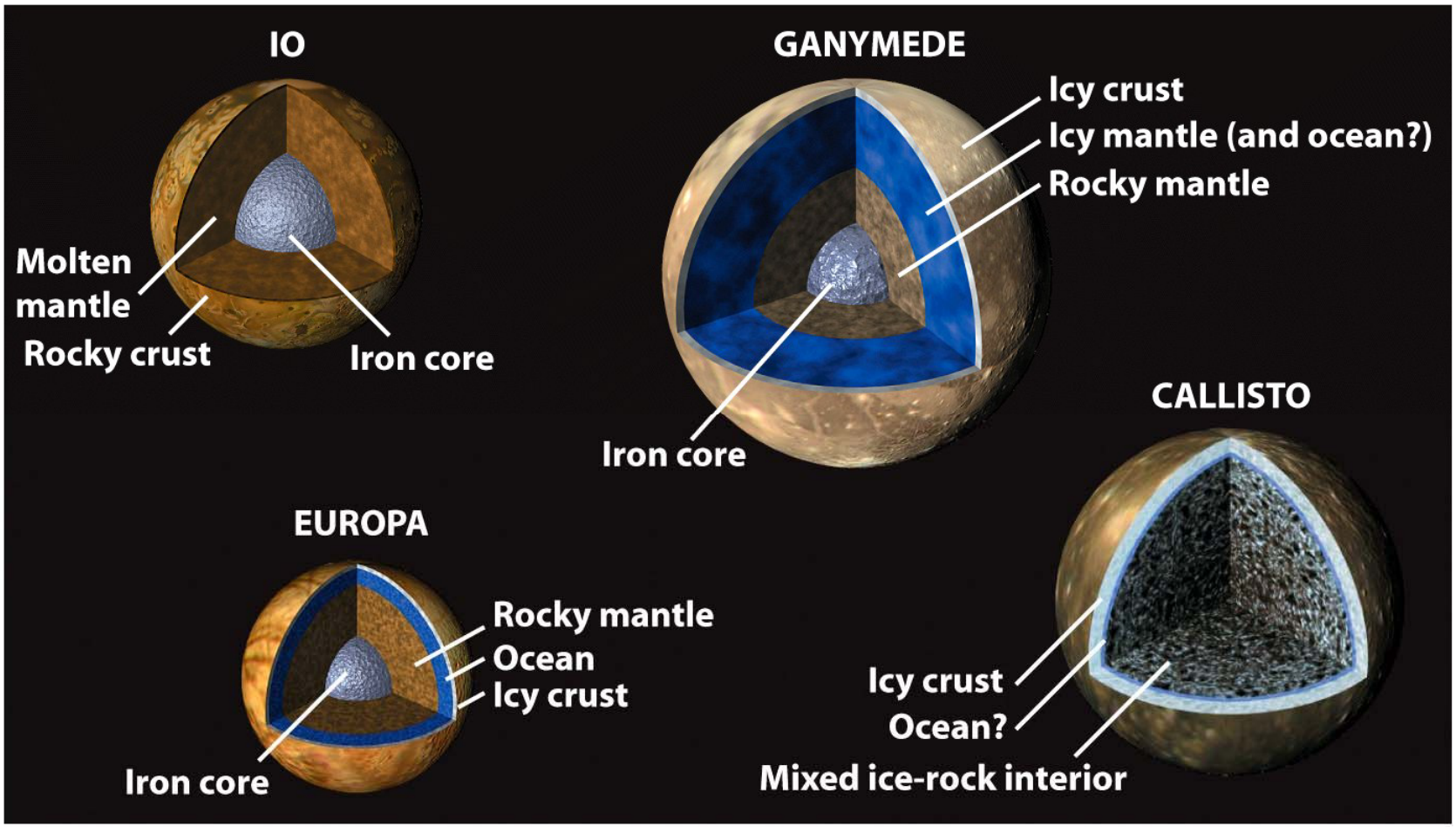
Callisto

- Callisto has numerous craters → very old
- The puzzle? No craters less than 1 km. Some unknown processes have selectively erased only the smallest craters



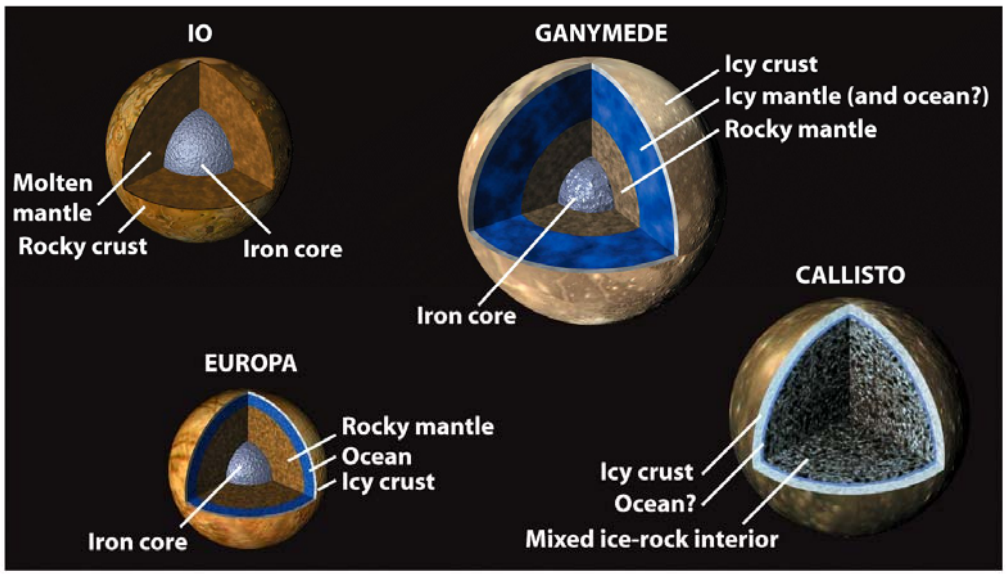
Interiors of Galilean Satellites

- Iron core, rocky and icy mantle, and icy crust
  - except Io, which has a rocky crust



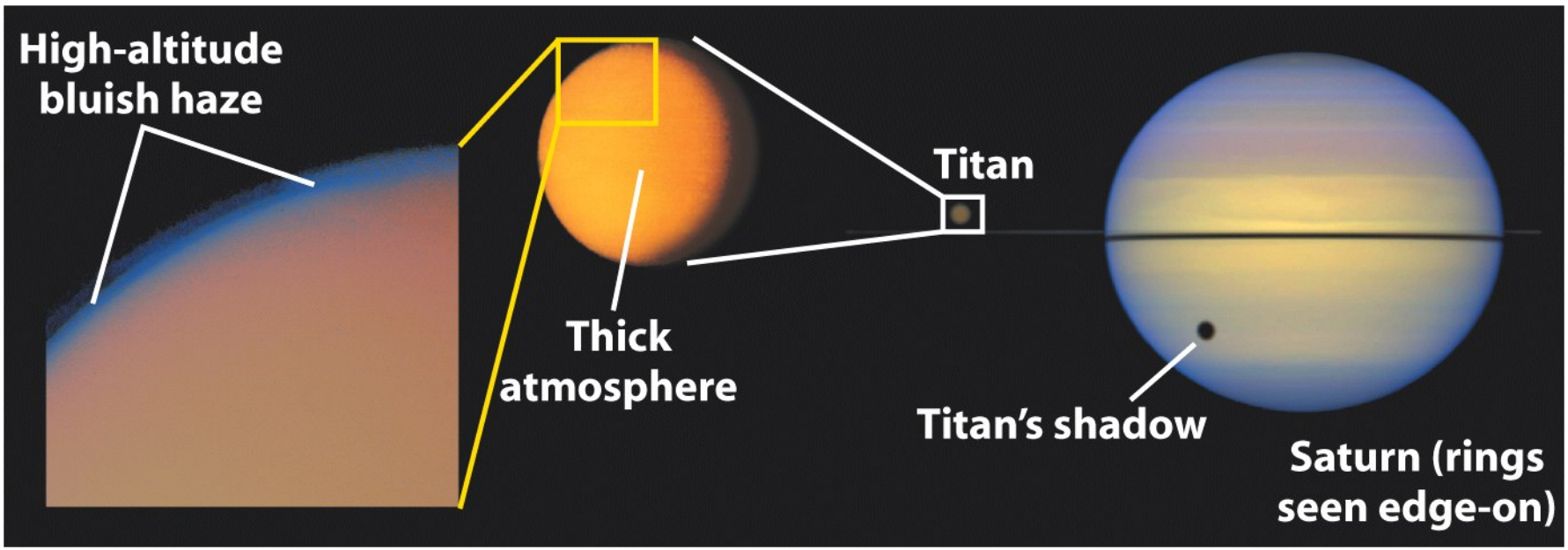
Interiors of Galilean Satellites

- Europe and Ganymede may have global liquid water ocean beneath the icy crust
  - Explain the fresh icy surface
  - Explain the presence of magnetic field
    - "Salty" water acts as conducting fluid for the dynamo
    - Ammonia is probably the "salt", also acting as antifreeze



Titan

- Titan is the largest satellite of Saturn; D = 5150 km
- **Titan has a thick atmosphere !!**
  - Explain the featureless appearance
  - The only satellite in the solar system with an appreciable atmosphere
  - Because it is cool enough and massive enough to retain atmosphere



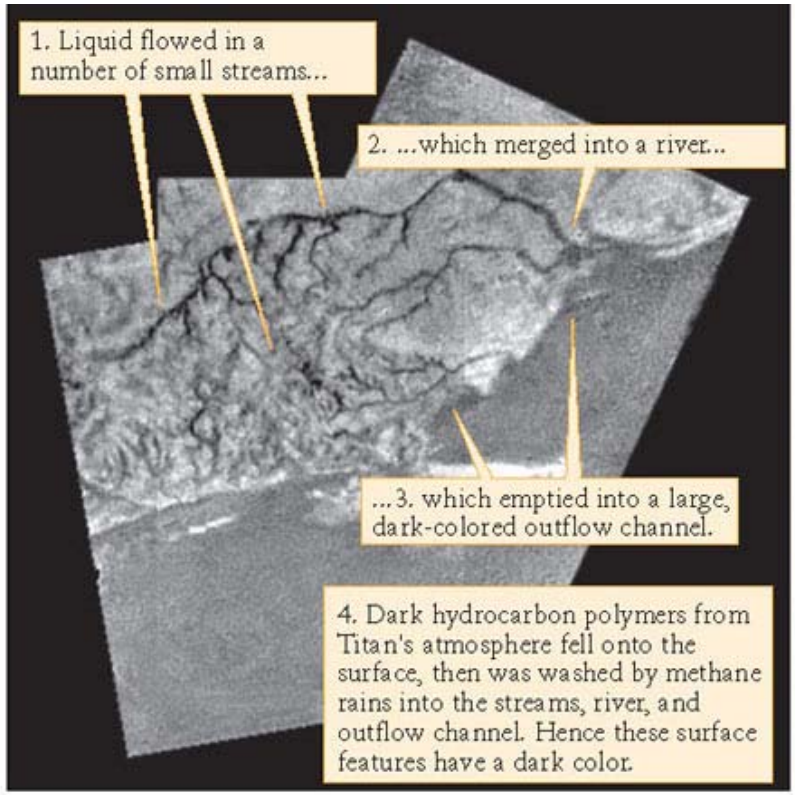
Titan

- Titan's atmosphere is 95% nitrogen, which came from ammonia (NH_3)
  - The Sun's ultraviolet radiation breaks ammonia easily
  - Hydrogen atoms escape into space
- The second most abundant gas is methane (CH_4)
- The **haze** in the atmosphere is from h**ydrocarbons**, the carbon-hydrogen compounds produced by the interaction between methane and ultraviolet light from the Sun, e.g., ethane (C_2H_6)

Titan

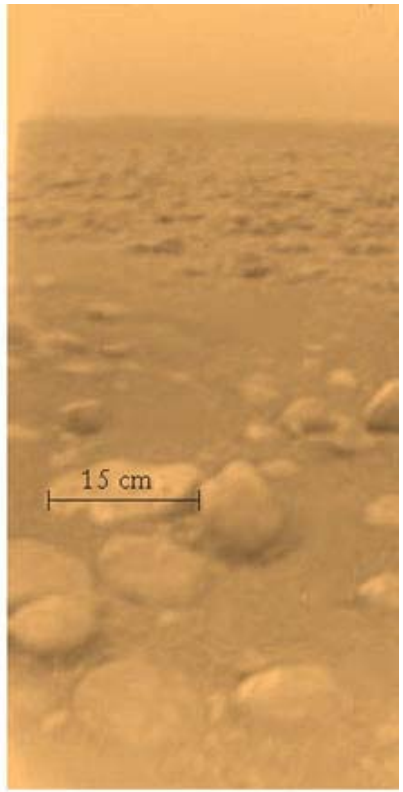
(a)

Surface



(b)

Streams and Rivers



"rocks": chuck of water ice

- Cassini-Huygens mission:
  - launched in Oct. 1997, entered orbit in June 2004
- Huygens lander: entered the Titan's atmosphere on Jan. 14, 2005, took 2.5 hour to descend, and continued to return data for about 70 minutes after touch down.

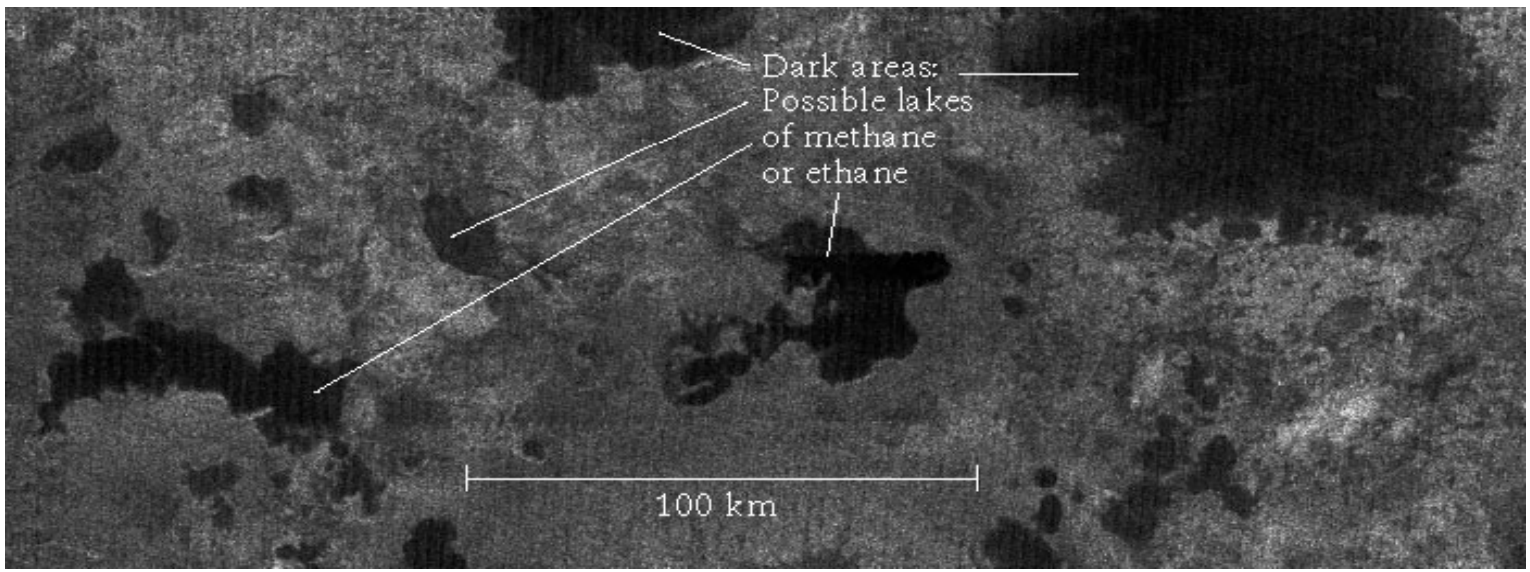
Titan

Movie:
Huygens's Animated Descent

Movie

Titan

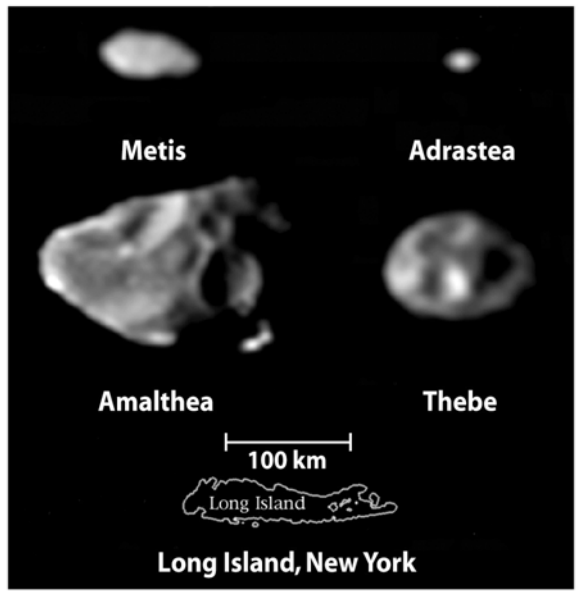
- Like water on Earth, methane on Titan can be gas, liquid and solid (at the temperature of ~ 95 K, -178°C, -288°F,)
- Channels of streams and rivers are found on the surface
- Lakes are found
- These are formed out from liquid methane.



Possible Methane Lakes on the Surface of Titan

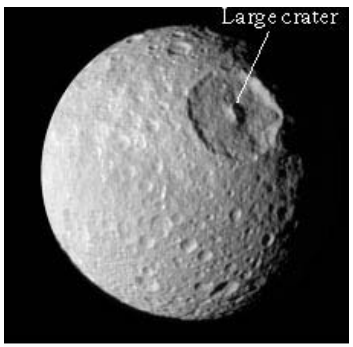
Jupiter's small satellites

- As of 2006, Jupiter has 63 known satellites
- Except the four planet-size Galilean satellites, the other satellites are small.
- Many of them move in orbits that are noticeably **inclined** to the plane of Jupiter's equator
- Many of these orbits are **retrograde orbits:** in the direction opposite to Jupiter's rotation
- These small satellites are probably asteroids captured by Jupiter's gravity
- However, the Galilean satellites are formed out from "Jovian Nebula"

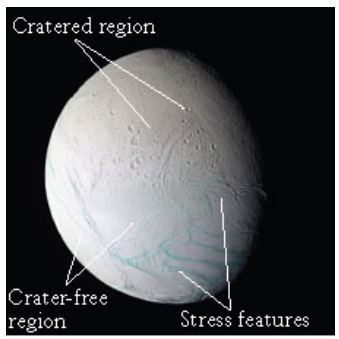


Saturn's Small Satellites

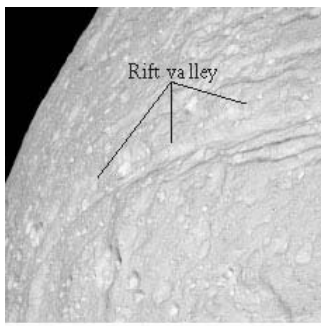
- As of 2006, Saturn has 56 known satellites (31 in 2004)
- In addition to Titan, six moderate-sized moons (~ 1000 km) circle Saturn in regular orbits with synchronous rotation: Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus
- Many smaller moons are captured asteroids in large retrograde orbits



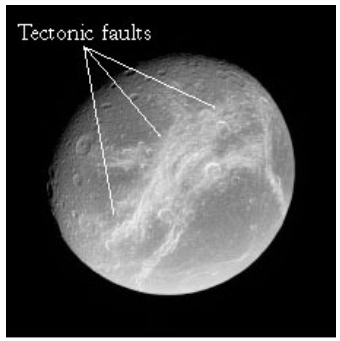
(a) Mimas
(diameter 392 km)



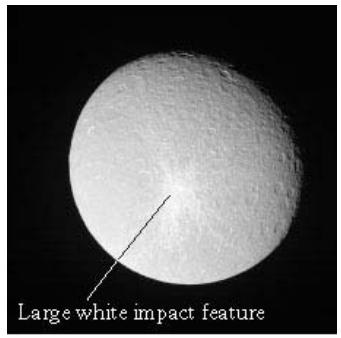
(b) Enceladus
(diameter 500 km)



(c) Tethys
(diameter 1060 km)



(d) Dione
(diameter 1120 km)



(e) Rhea
(diameter 1530 km)

(f) Iapetus
(diameter 1460 km)

Saturn's Six Mid-Sized Satellites

Final Notes on Chap. 13

- There are 10 sections in total.

- The following sections are not covered
  - 13-5 (Io plasma torus)