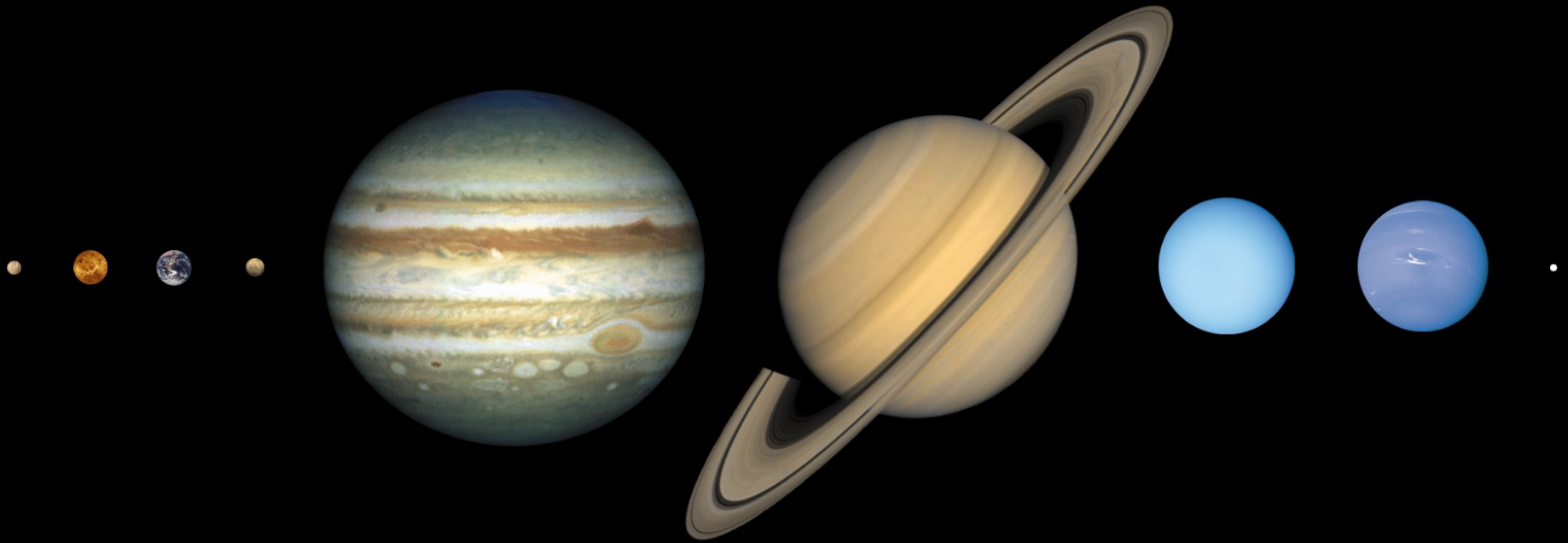
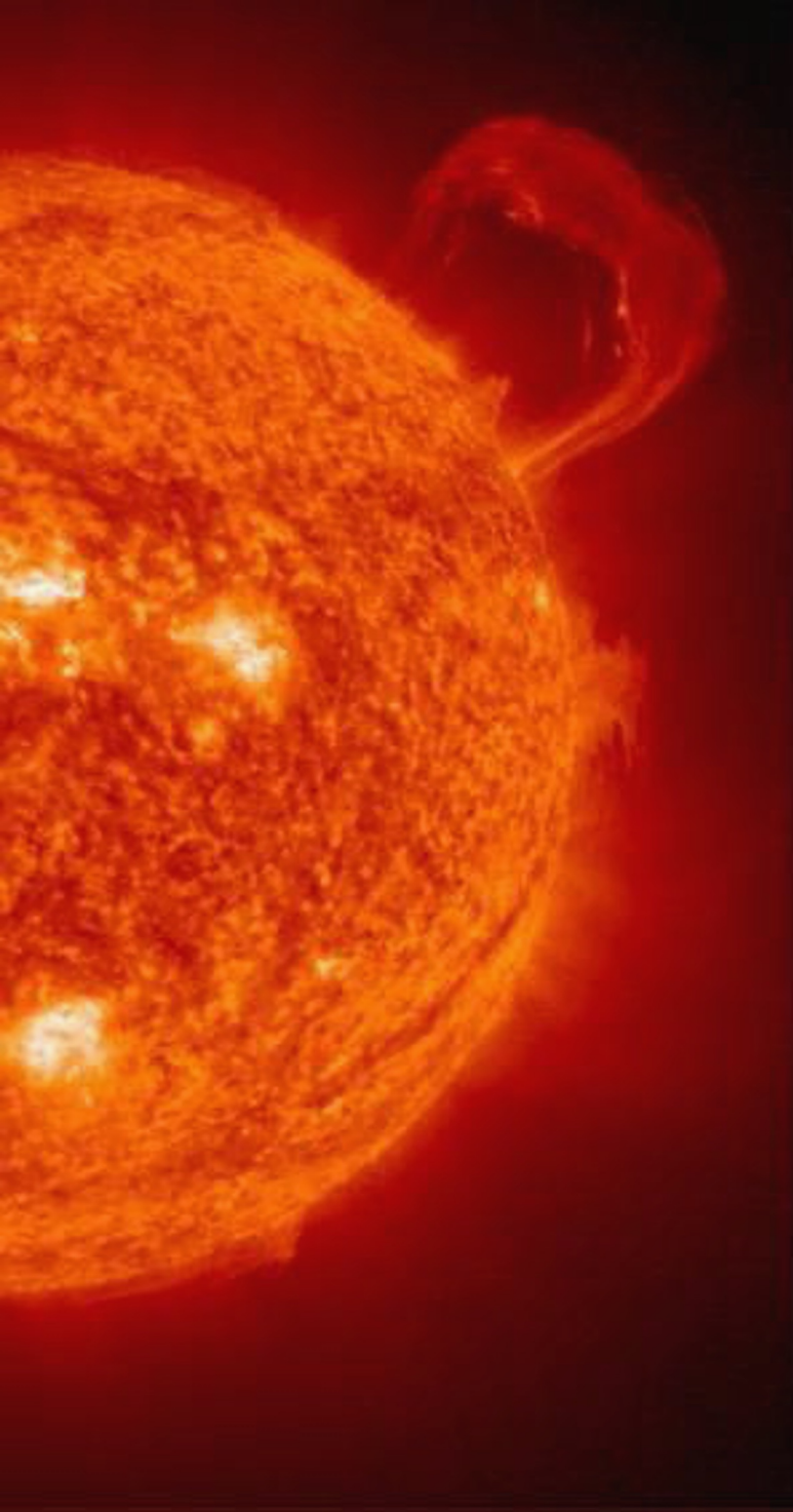


A Solar System Overview



Alan P. Witzgall, NJAA



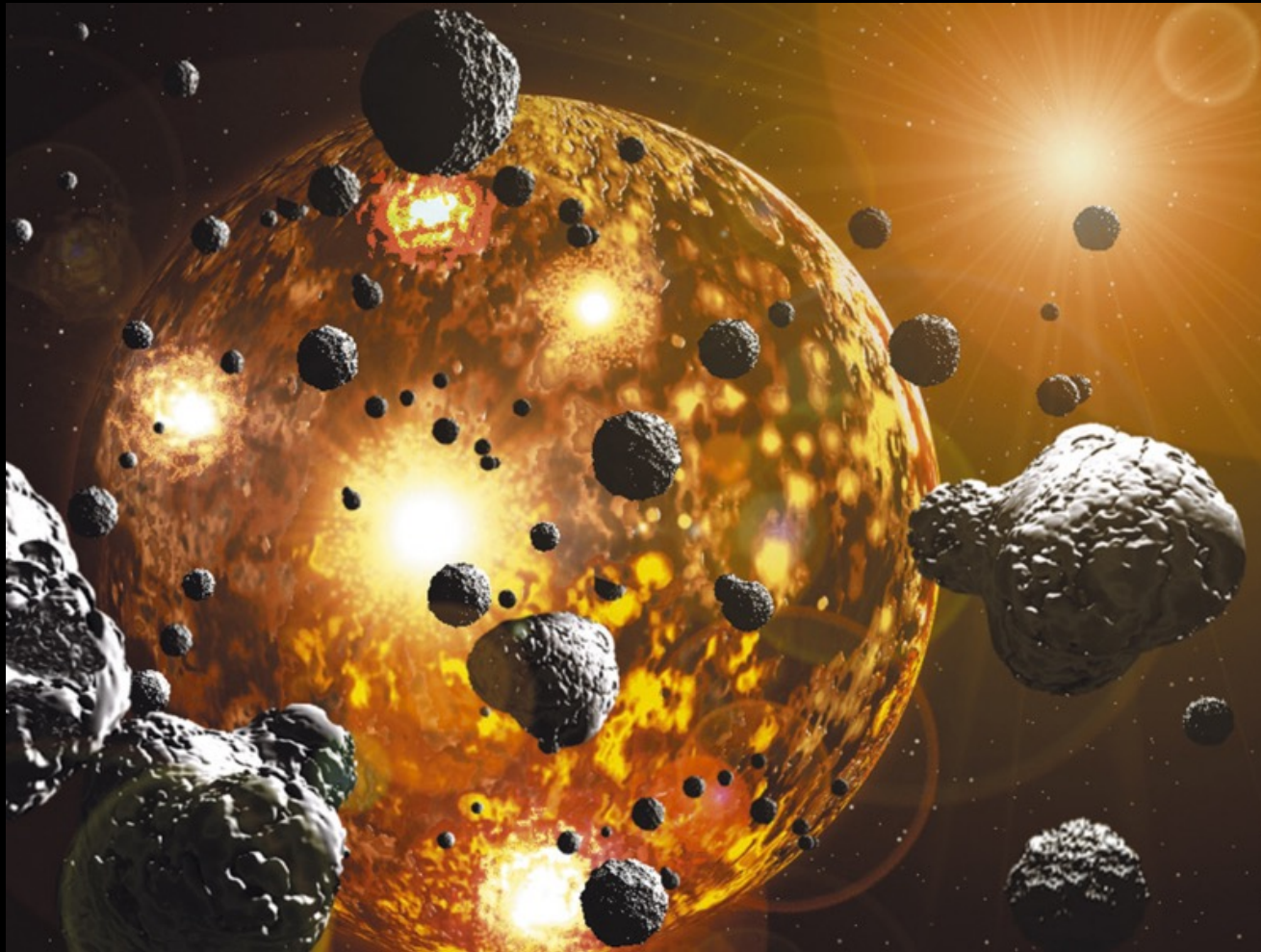
The Sun

- At the Center
- 99.85% mass of Solar System
- 92% H / 8% He
- Source of solar wind,
planetary and space weather

Origin of the Solar System

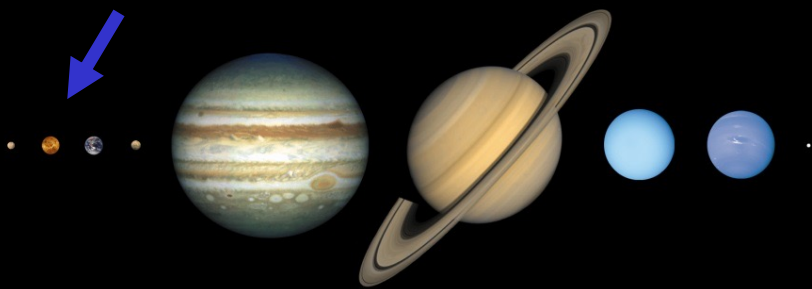


Forming a rocky planet



Inner Planets

- “Terrestrial Planets”
- Rocky
- Dense
- Metal cores (iron)



Asteroids

- “Minor planets” or “planetoids” less than 1000 km across
- Source of most meteorites
- Asteroid Belt between Mars and Jupiter
- Occasionally run into Earth and other planets

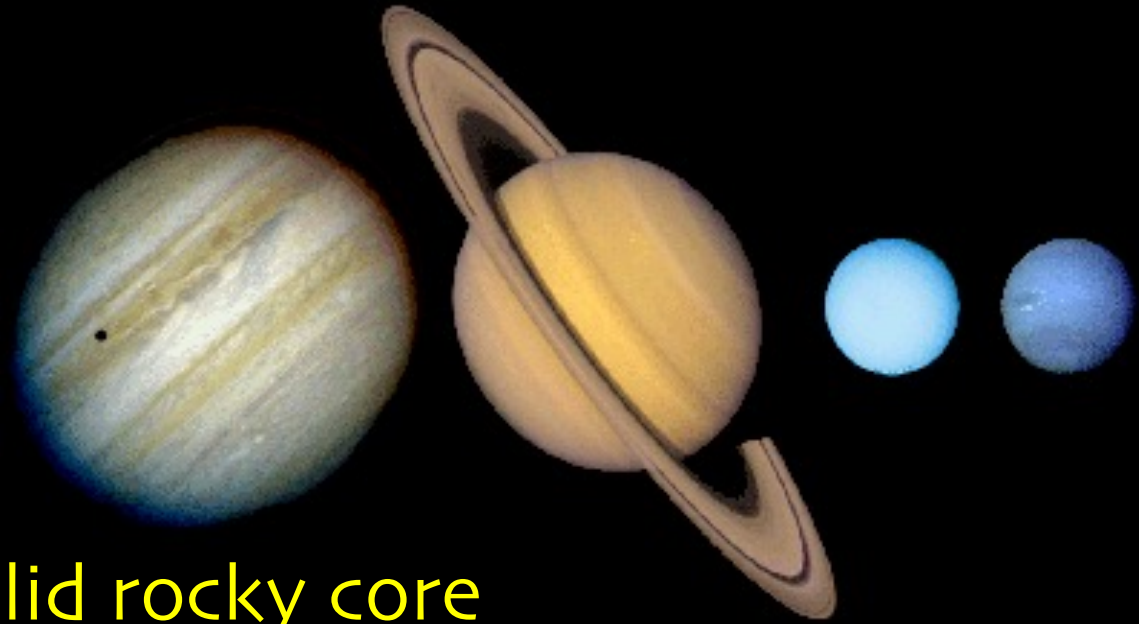


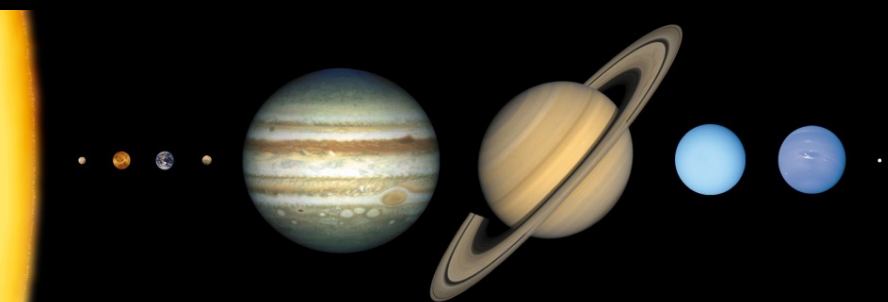
Ida



Outer Planets

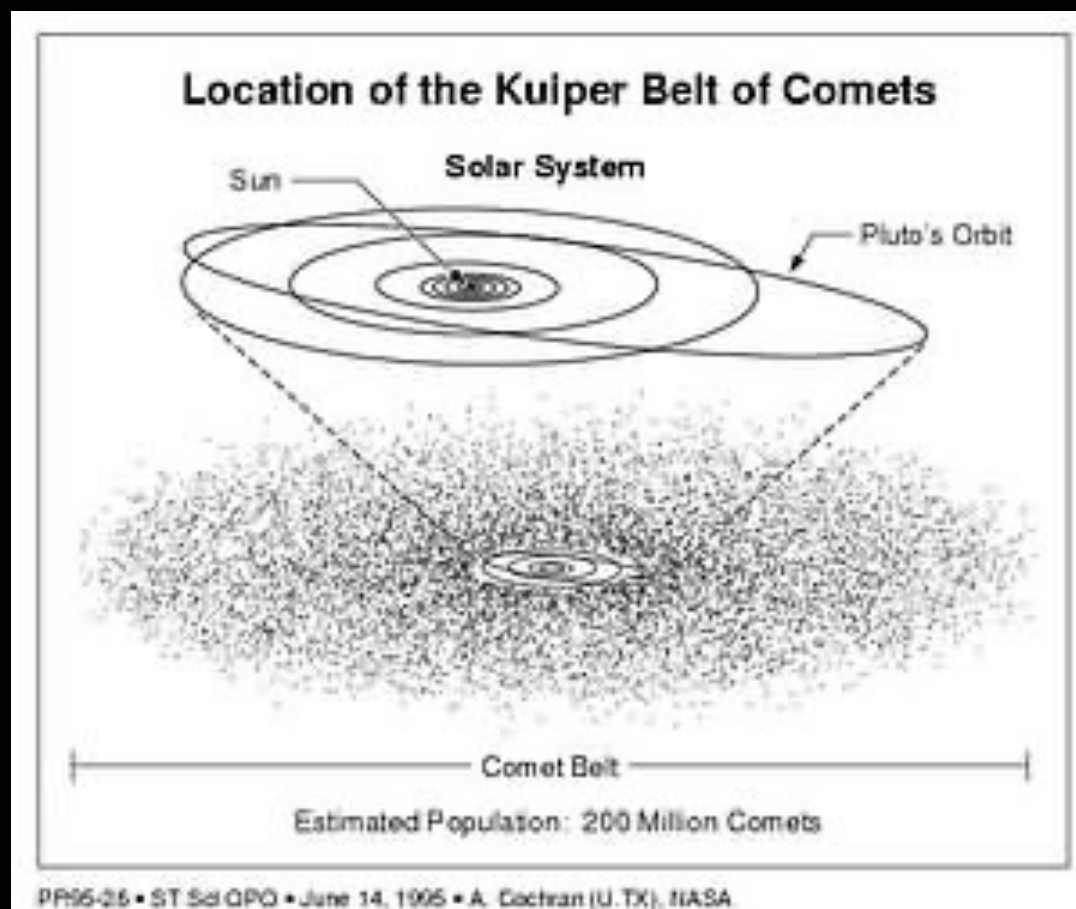
- Large!
- Gases and liquids
- No solid surface
- May have a small solid rocky core
- Tumultuous atmospheres - rapid winds, large storms
- Rotate relatively quickly





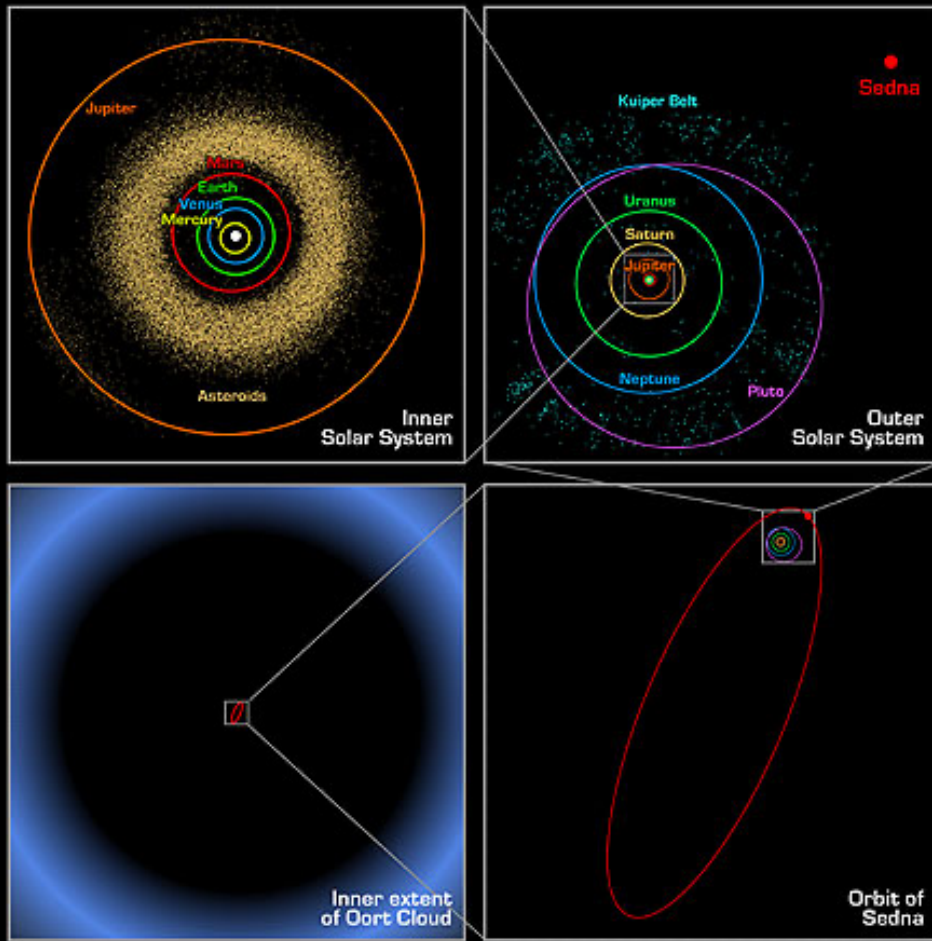
Kuiper Belt

- Disk of debris at the edge of our Solar System
- Source of short-period comets

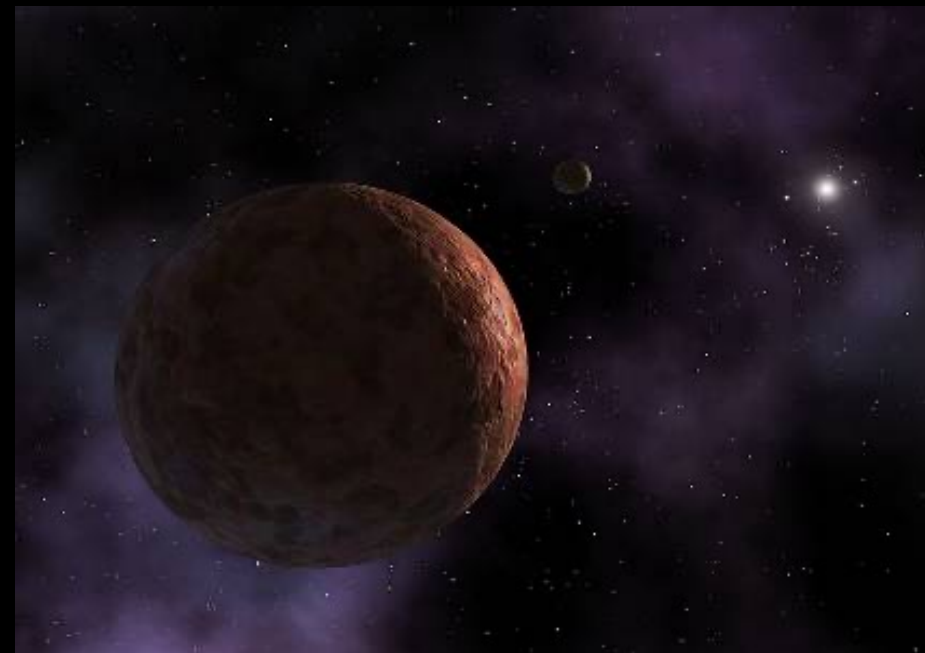


Oort Cloud

- Sphere of widely spaced comets, dust
- Up to 30 trillion km from Sun
- Long-period comets (random time and direction)



Relative position of Sedna to Kuiper Belt: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)
<http://www.spitzer.caltech.edu/Media/releases/ssc2004-05/ssc2004-05d.shtml>



Artist's conception of Sedna: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)
<http://www.spitzer.caltech.edu/Media/releases/ssc2004-05/ssc2004-05b.shtml>



The Inner Planets

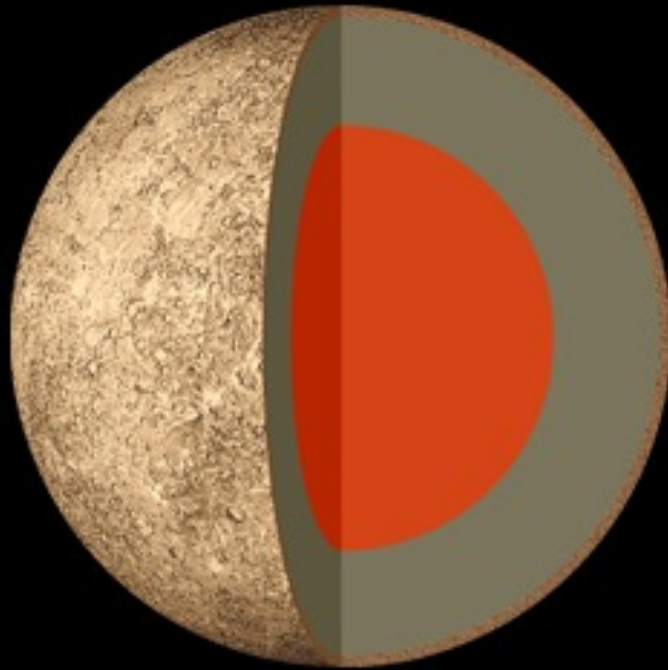
Image: Lunar and Planetary Laboratory:
http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=178

Mercury

- Smallest rocky planet (0.4 Earth)
- Closest to Sun, moves around fastest (88 days)
- Surface -173 to 427 °C (-280 to 800 °F)
- Water Ice Caps – no tilt of axis so poles stay cold
- No atmosphere
- Mariner 10 fly-bys in 1974 and 1975 – 40% of surface mapped



Mercury



Dense as earth 5.43 g/cc

Surface is made of light minerals (spectrum similar to Moon)

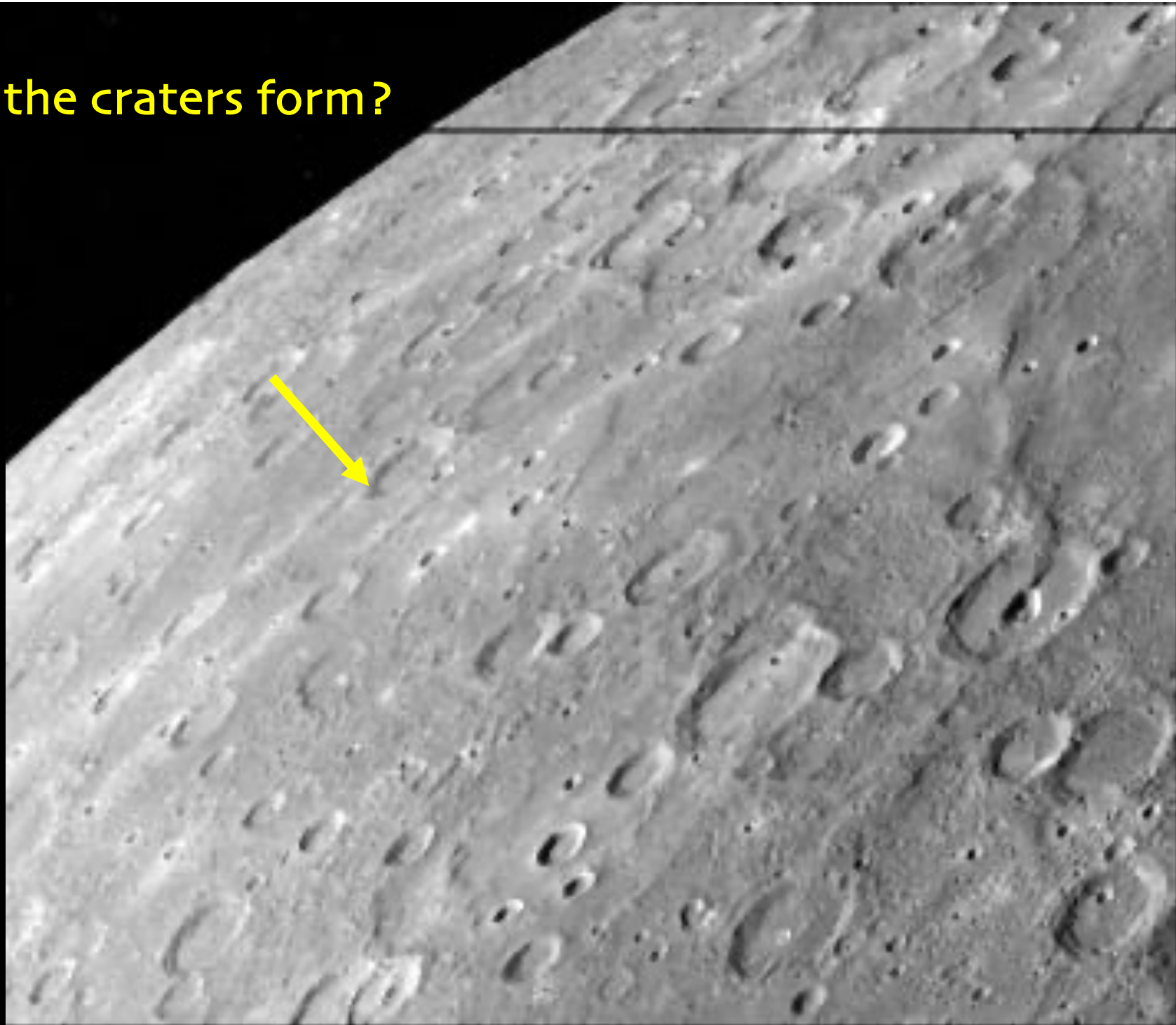
75% iron and nickel – large core – size of our moon

Why so large?

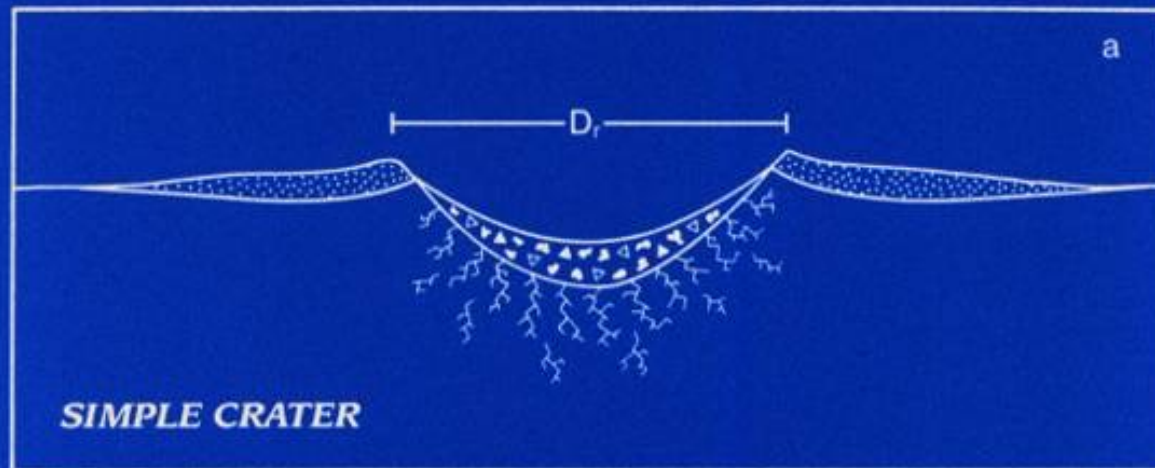
Magnetic field remnant

Geologically inactive?

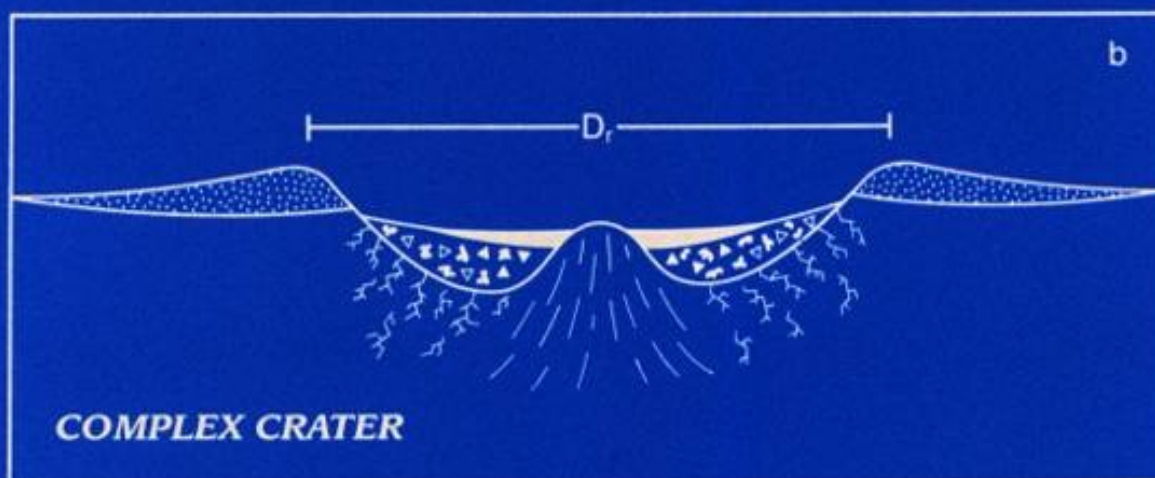
How did the craters form?

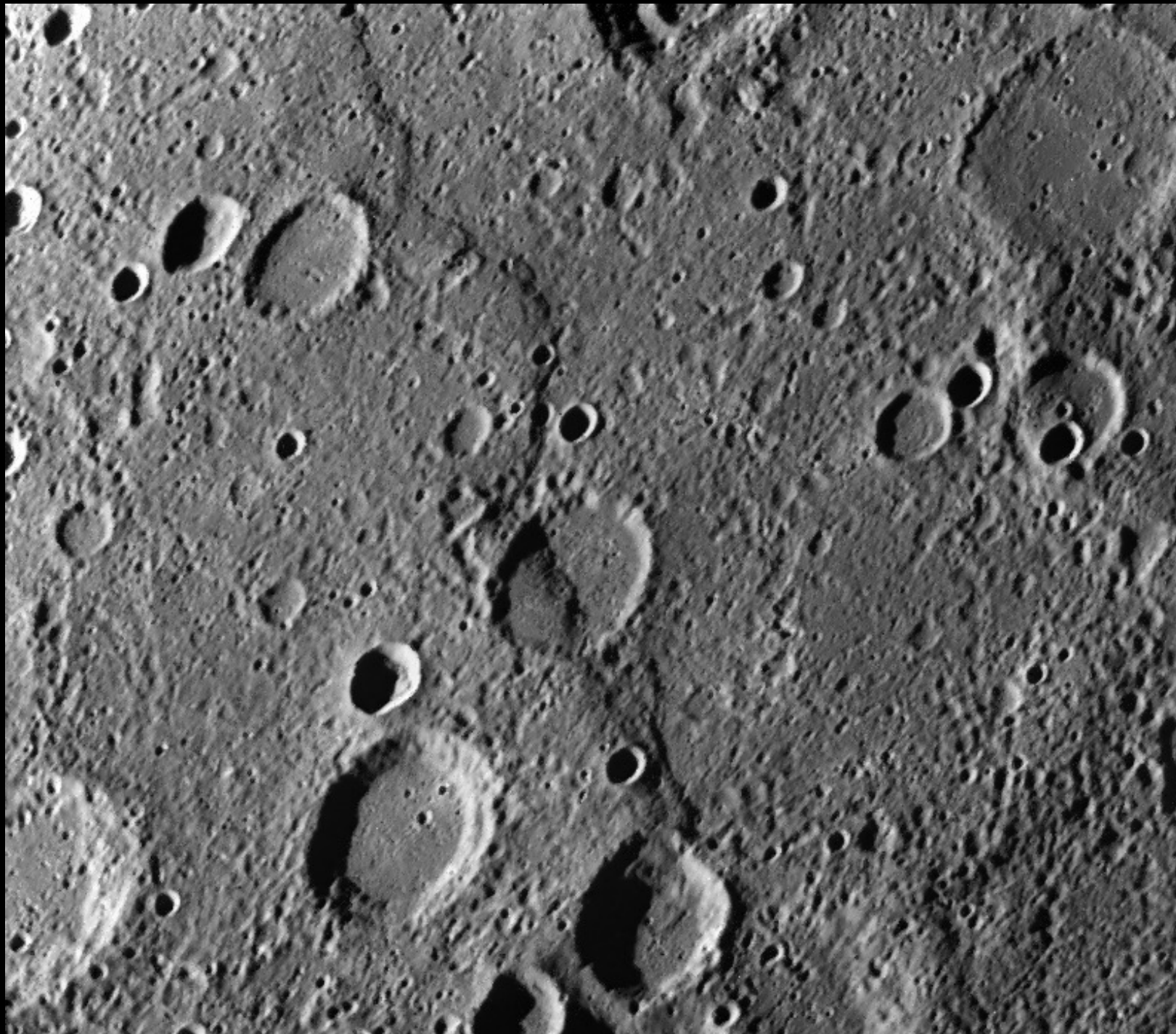


Mariner image from: <http://photojournal.jpl.nasa.gov/catalog/PIA02430>



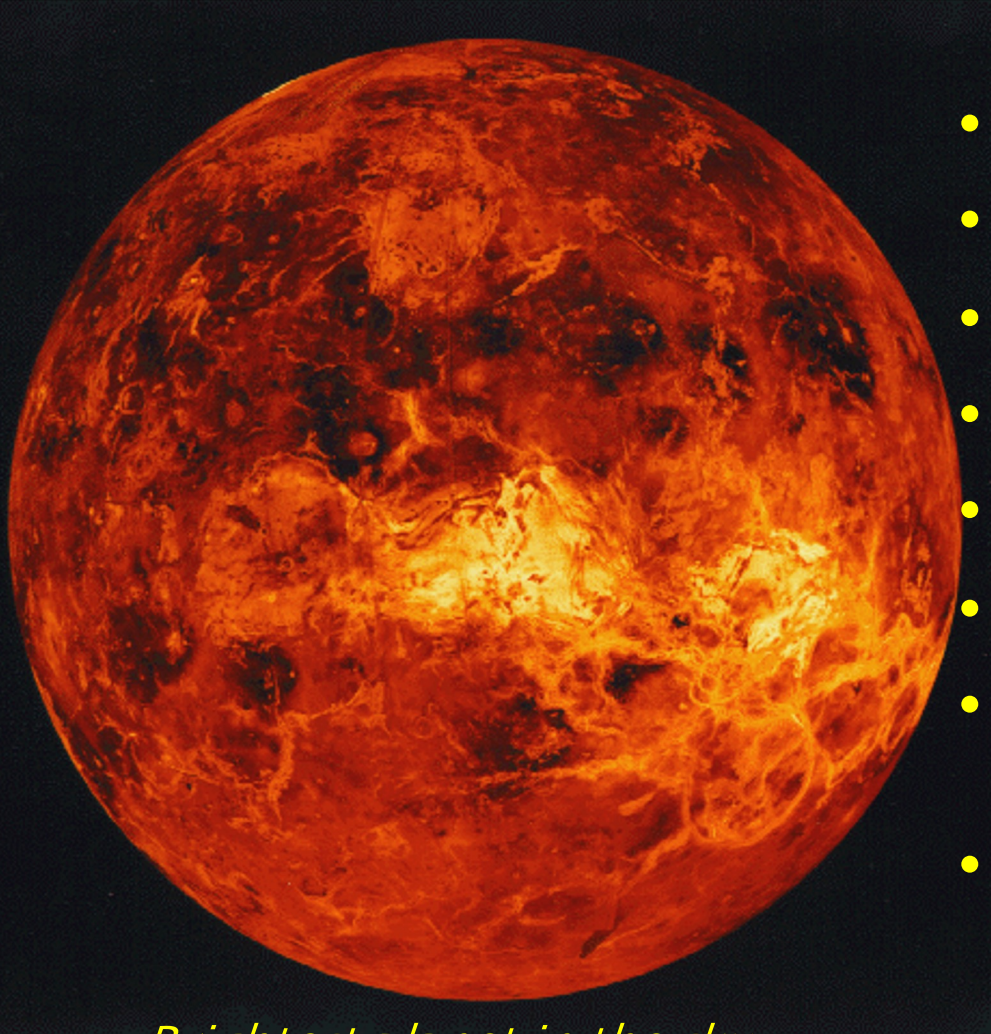
- ▲ Shocked breccia
- △ Unshocked breccia
- ⚡ Impact melt
- ⊞ Impact ejecta
- ⚡ Fractured bedrock





Mariner image at <http://photojournal.jpl.nasa.gov/catalog/PIA02444>

Venus



*Brightest planet in the sky.
Can cast shadows on Earth!*

- Nearly the same size as Earth (.95)
- Slowest rotation of any planet (243 days)
- Spins 'backwards'
- Surface temp 377 to 487 C
- 710 to 908 F ... hotter than Mercury
- Cloud covered – radar observations
- Dry!
- Very thick atmosphere mostly CO₂
- Surface pressure is 100 times higher than Earth's
- Runaway greenhouse



Where Do Atmospheres Come From?



Image from LPI: http://www.lpi.usra.edu/education/timeline/gallery/slide_33.html

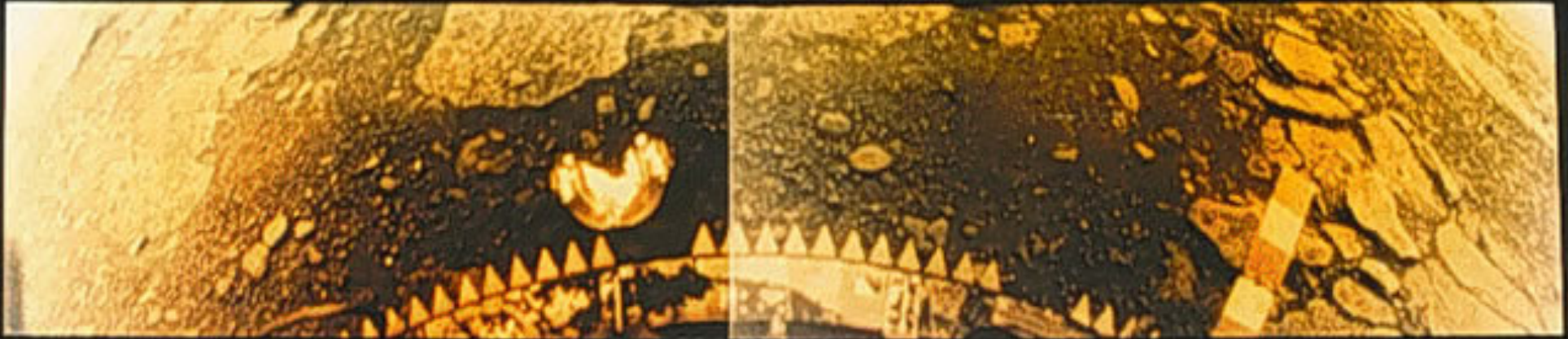


All Planets with Volcanism –
Including Earth!

Only Earth has life
(As far as we know ...)



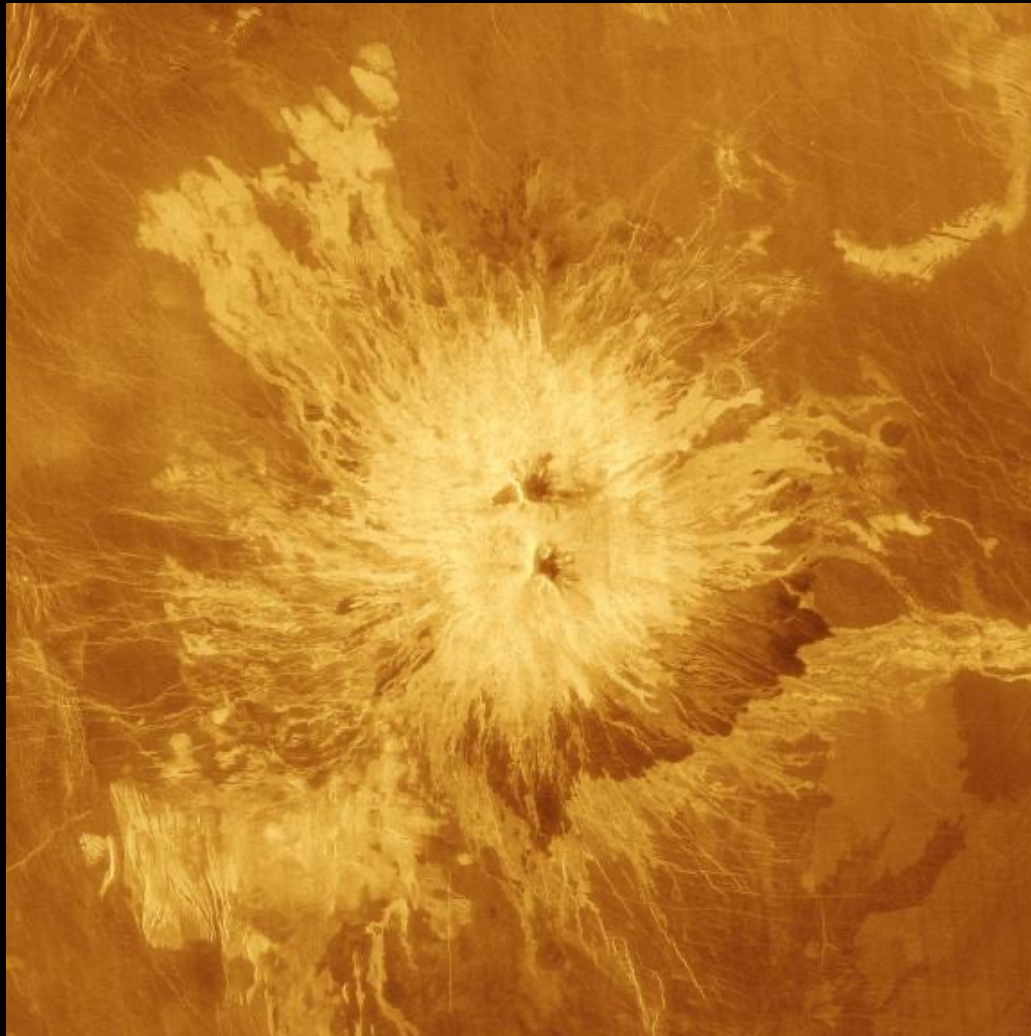
Venera Images - 1982



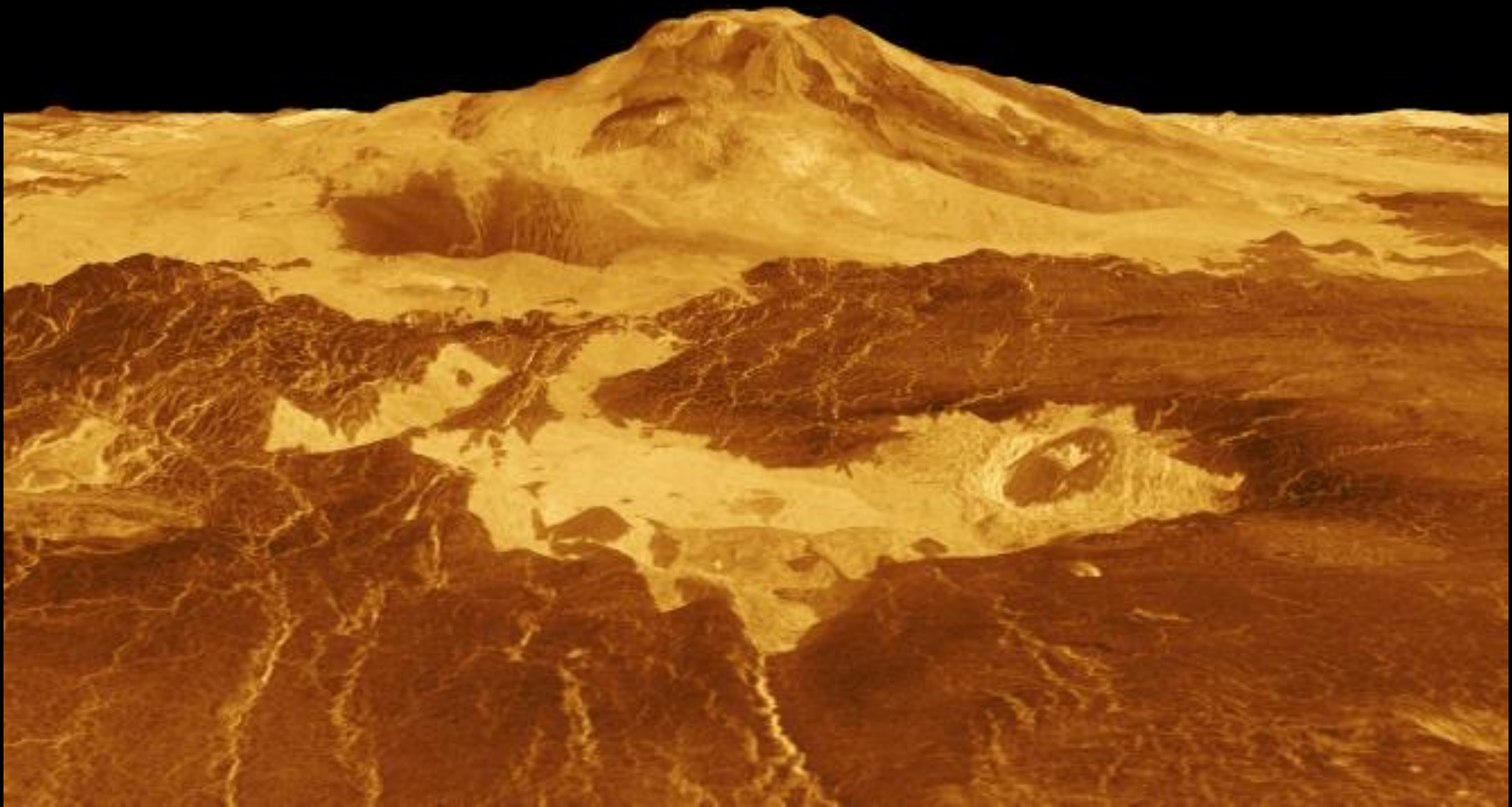
Mariner 2 Fly-by in 1962; 23 “visits” since,
including Venera landers, Magellan and Venus Express Orbiters

Sapas Mons – 1.5 km (0.9 mi) high, 400 km (248 mi) across
Atla Regio

Volcanic flood plains cover 85% of surface
1100 volcanic centers identified



Maat Mons – 8 km (5 mi) high, Aphrodite Terra Region



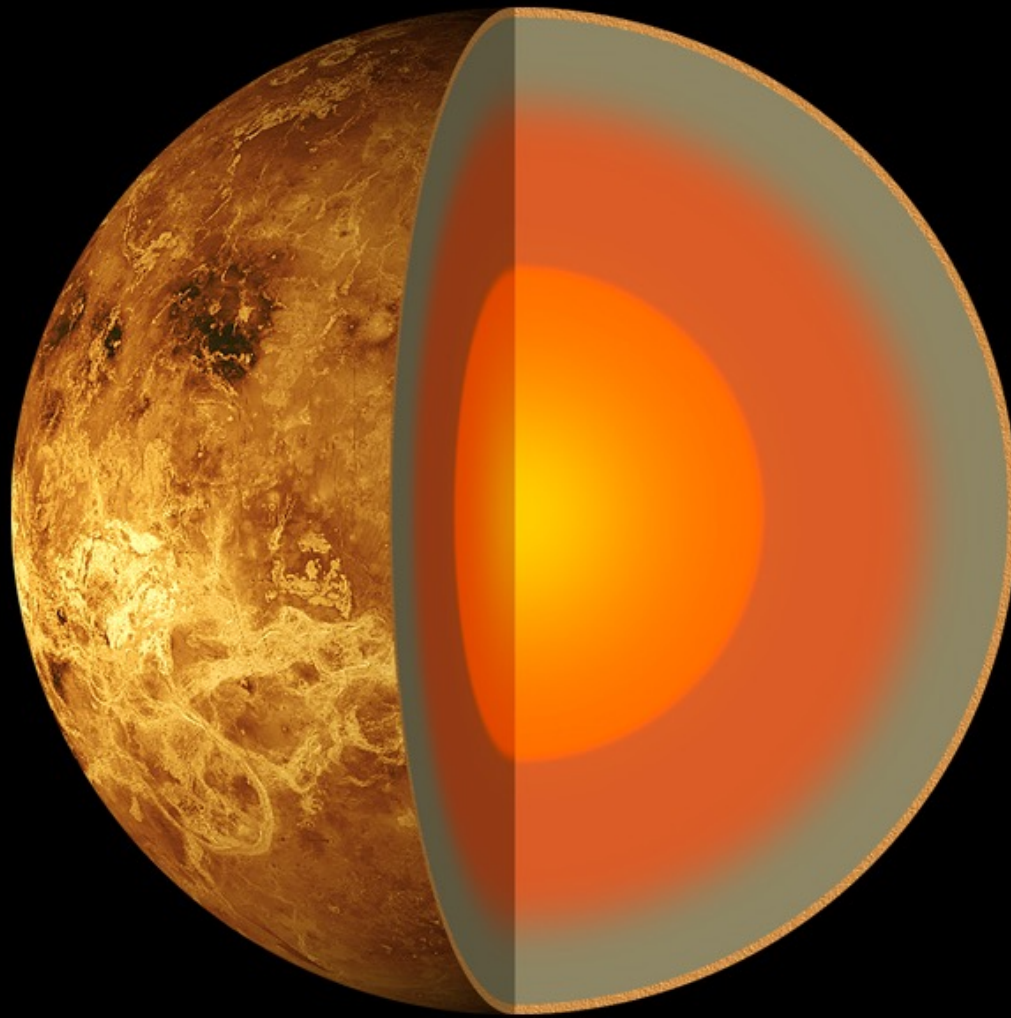
What's missing on Venus?



Few impact craters – what does this tell us?

No craters less than 3 km (meteoroid ~ 30 m across)

Atmospheric filters out small meteors



No interior data,
density similar to earth;
so probably a core

Surface 300-500 million
years old

Few, random craters,
sharp edges

Basalts

No magnetic field; solid
core

Probably still
geologically active –
active volcanism

Earth

7900 mile (12756 km)
diameter

23 degree axis tilt (seasons!)

Surface temps -73 to 48 C
(-100 to 120 F)

Thick atmosphere, mild
greenhouse effect

Liquid water – lots! - at
surface

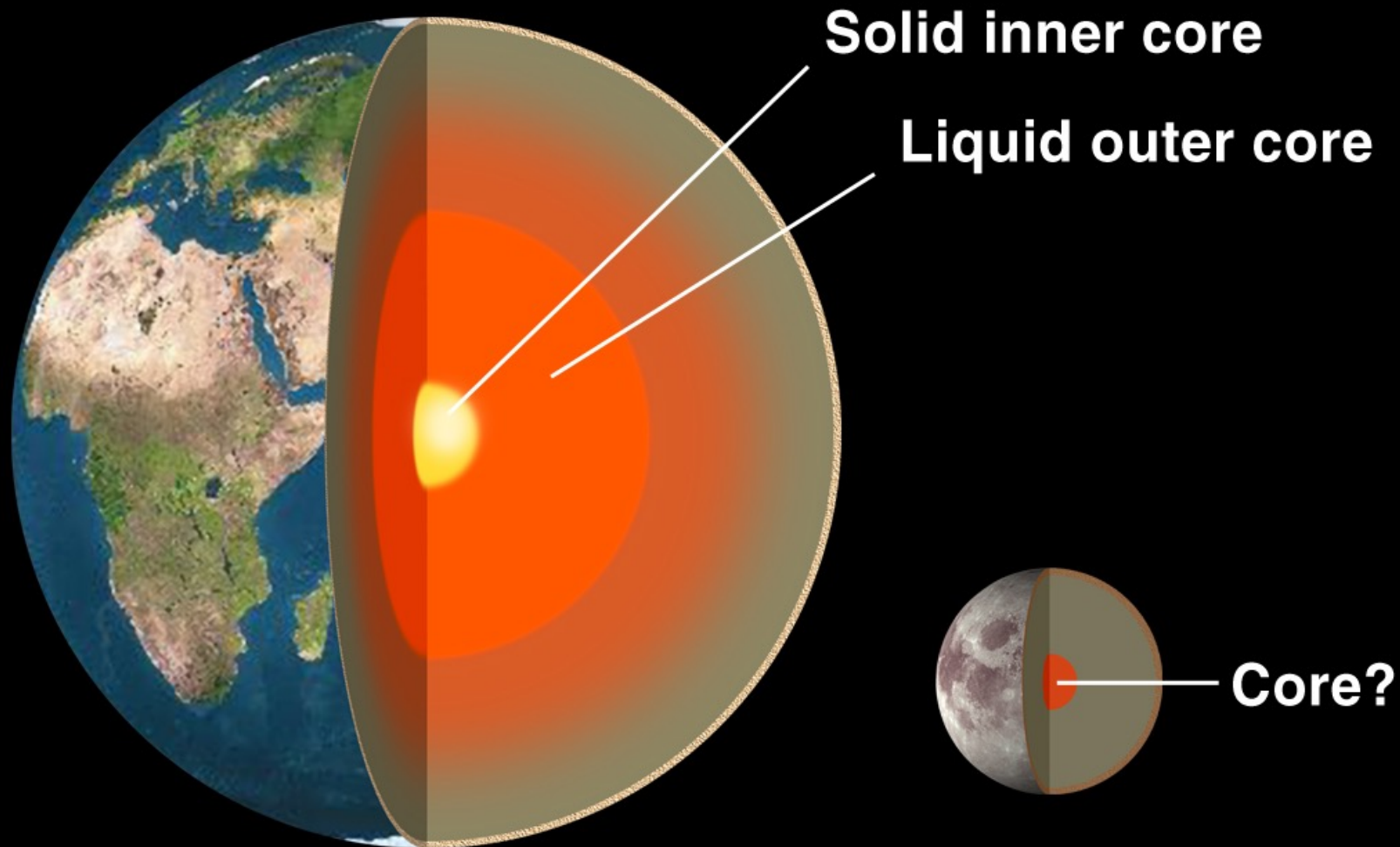


Can see it without a telescope!

The Homeworld from Apollo 8

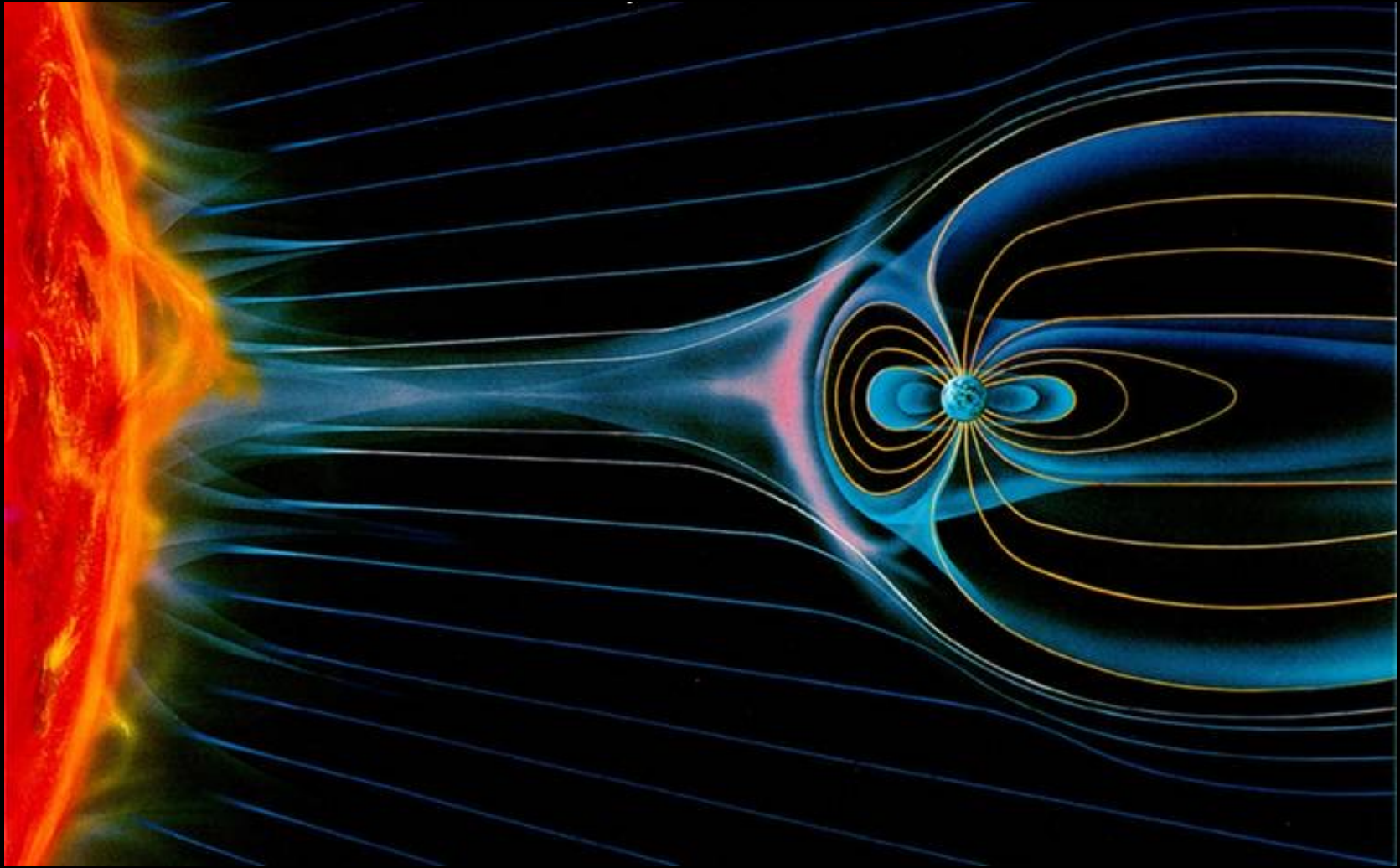


Geologically active
Core, mantle, crust
Magnetic field



Who Cares About a Magnetic Field?

We do!



National Geophysical Data Center, Artist: E. Endo
<http://www.ngdc.noaa.gov/seg/geomag/icons/solarexp.jpg>

Mars

6794 km diameter (4,220 miles) –
about $\frac{1}{2}$ of Earth's

25 degree axis tilt (seasons!)

Rotates once every ~24.5 hours and
orbits the Sun once every 687 days

Very cold -83 to -33 C (-117 to -27 F)

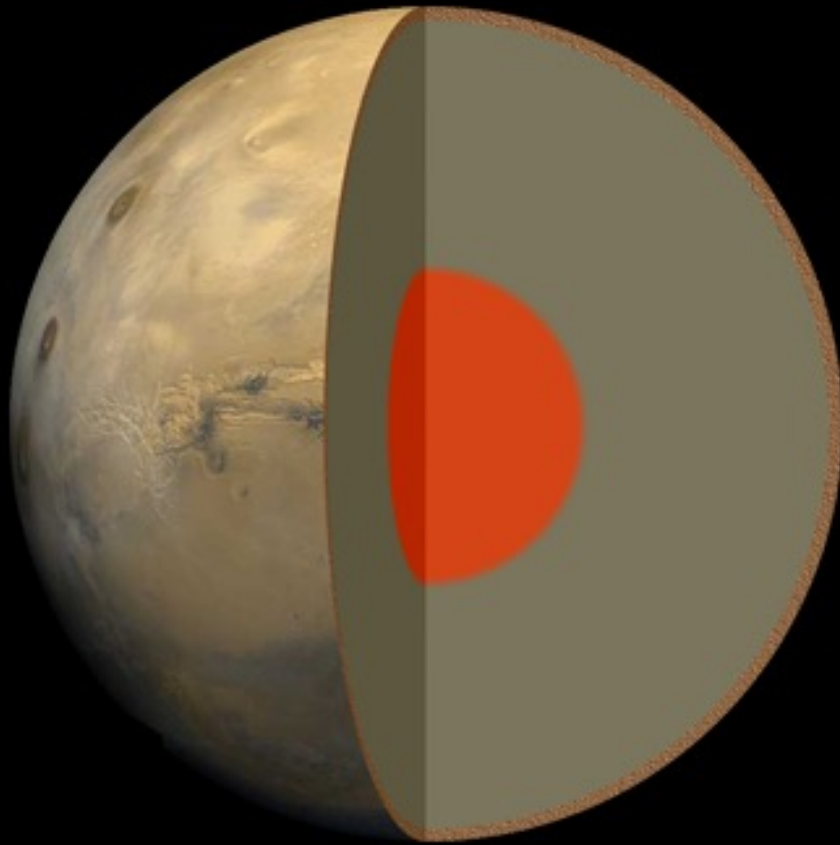
Thin atmosphere, 95% CO₂, & 3% N

Occasional liquid water at surface;
ice in poles and regolith

Two small moons - Phobos (Fear)
and Deimos (Terror)



Mars



Surface gravity: 38%
About like Mercury's,
because of Mars' low
density

Crust – thick – supports
huge volcanoes

No magnetic field – had one
once because Mars
meteorites show some
magnetism; solid core?

Meteorites – as young as
180 million year old basalts

Color-coded Elevations on Mars, MOLA Altimeter, MGS Mission

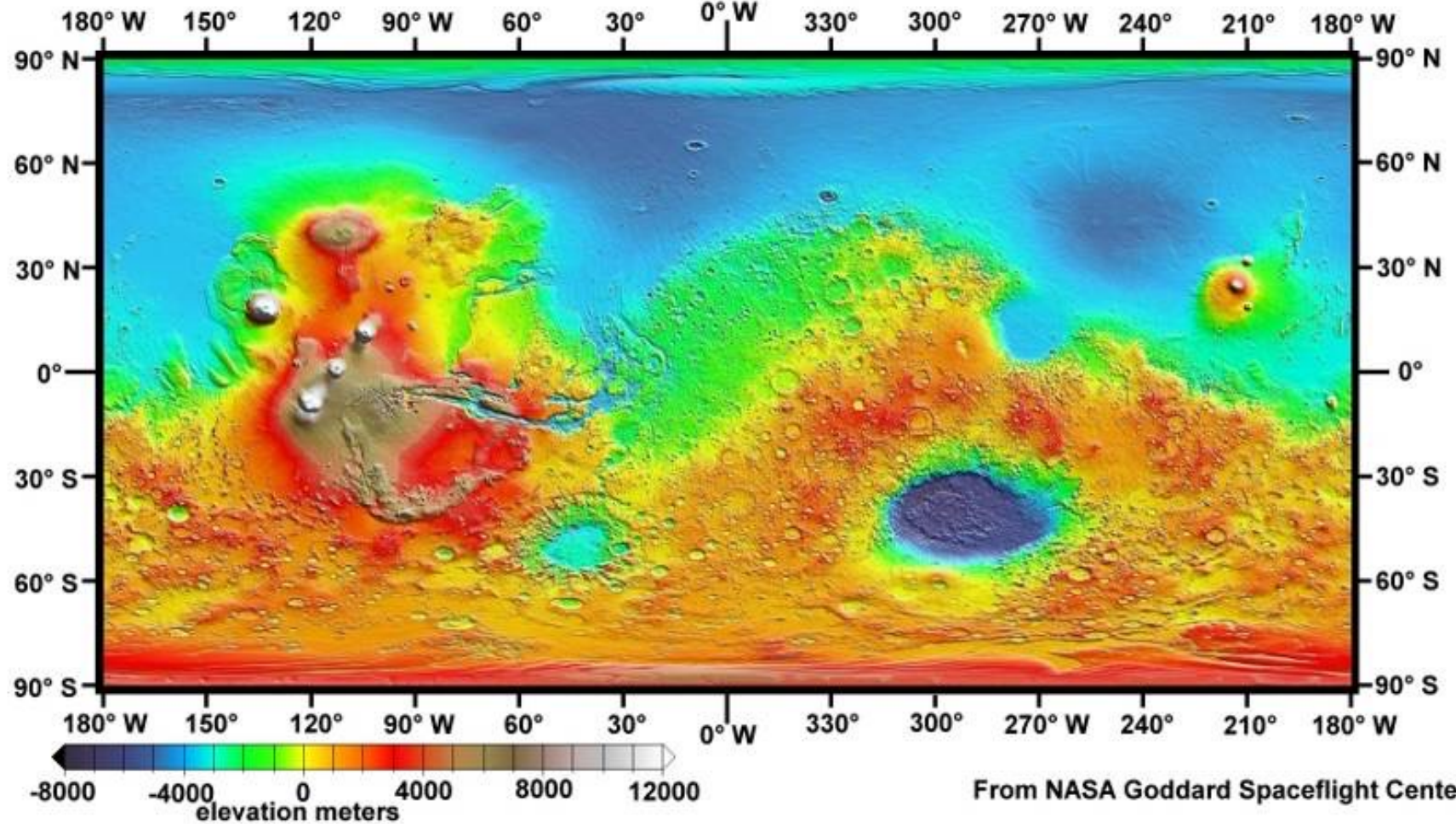
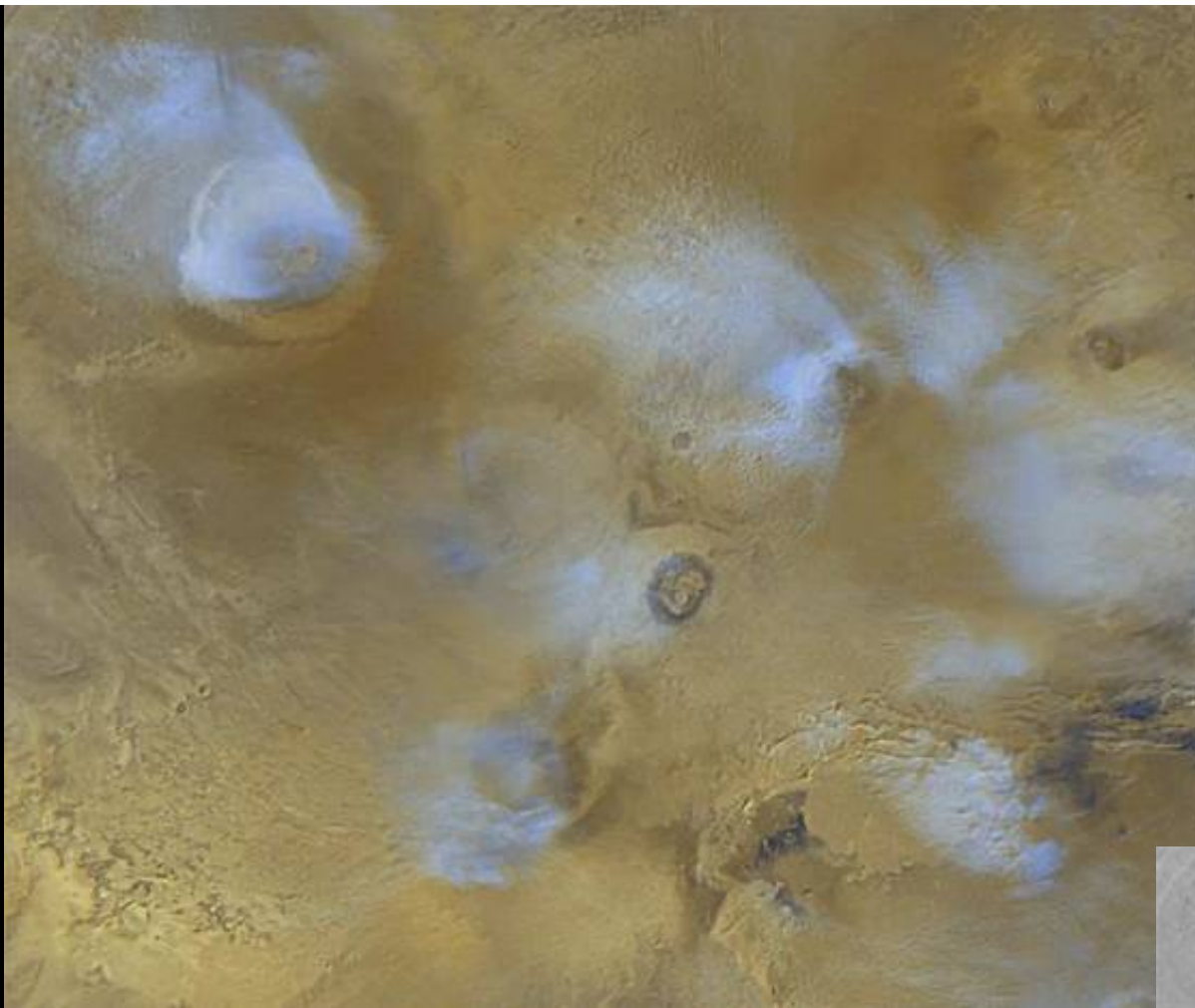
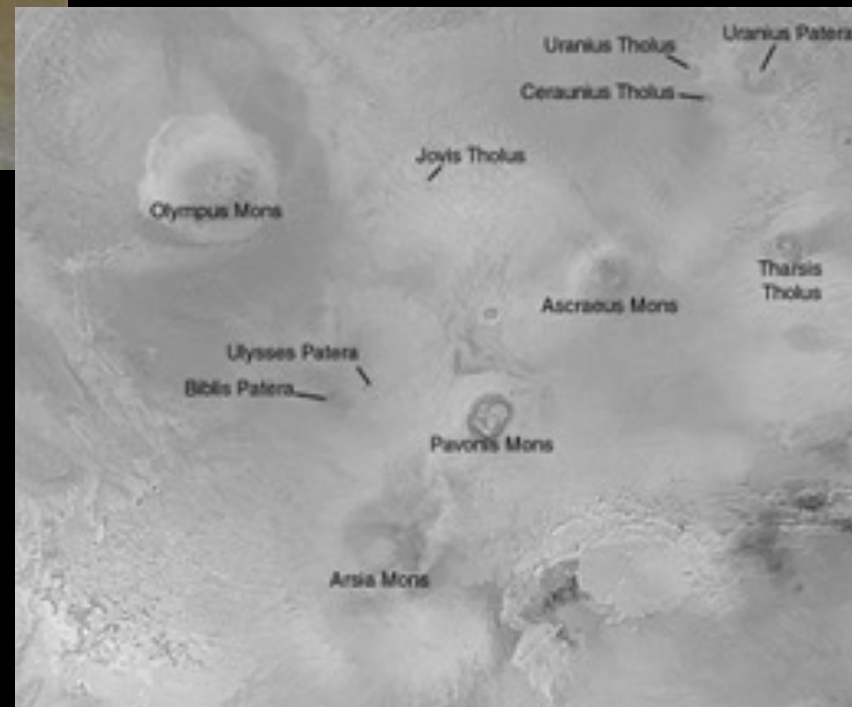


Image available at <http://www.lpi.usra.edu/science/treiman/greatdesert/workshop/marsmaps1/>

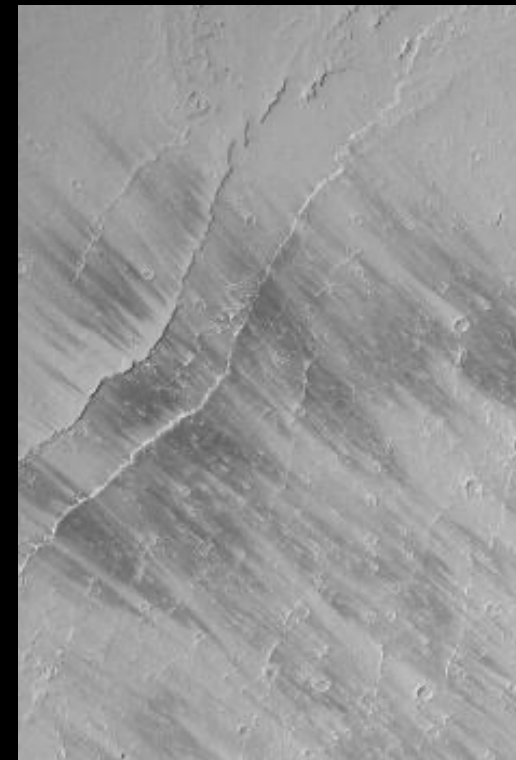
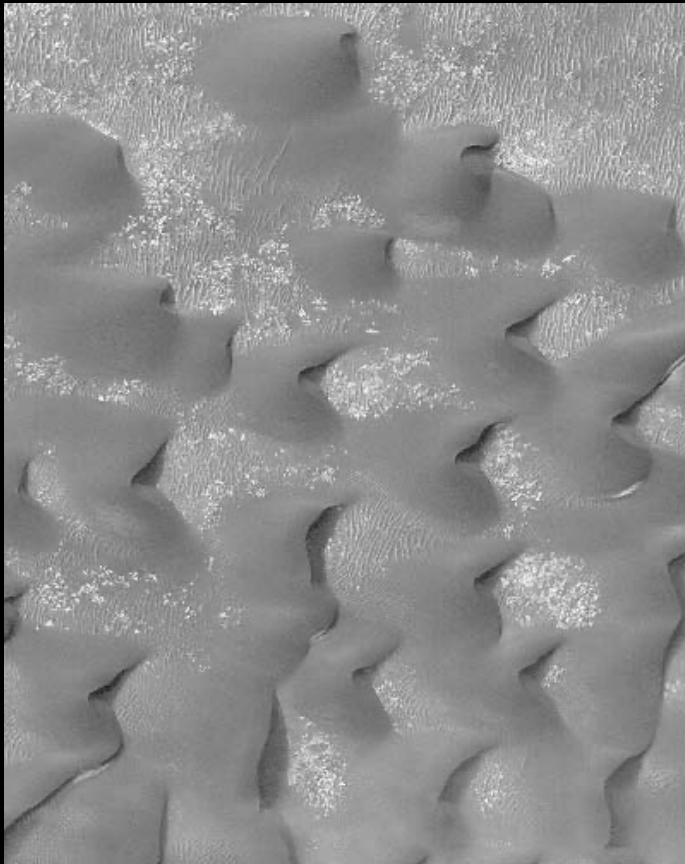


Western edge of
Tharsis Region

Tharsis Bulge:
2,500 miles across
6 miles high



Dune Fields, Wind Streaks, Dust Storms



MGS image at
<http://mars.jpl.nasa.gov/gallery/sanddunes/20020418b.html>

MGS image at
http://www.msss.com/mars_images/moc/2003/11/03/

Hubble image of Mars at <http://mars.jpl.nasa.gov/newsroom/pressreleases/20070108a.html>

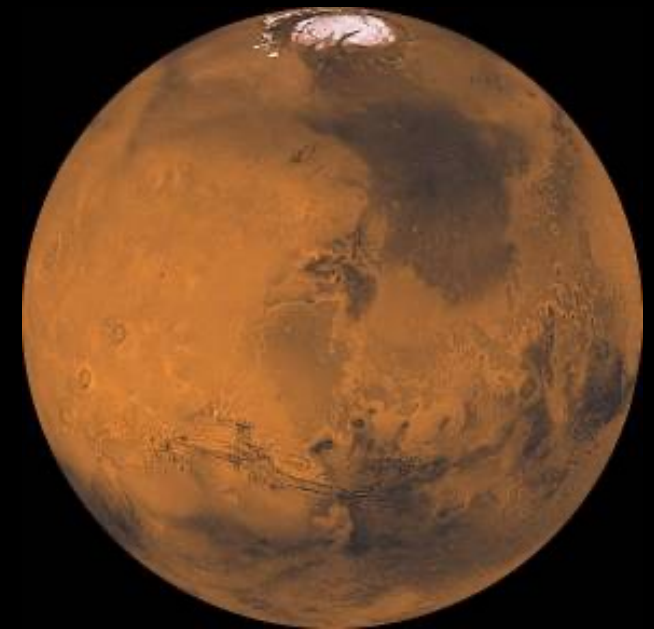


Viking image at http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/vl2_p21873.html



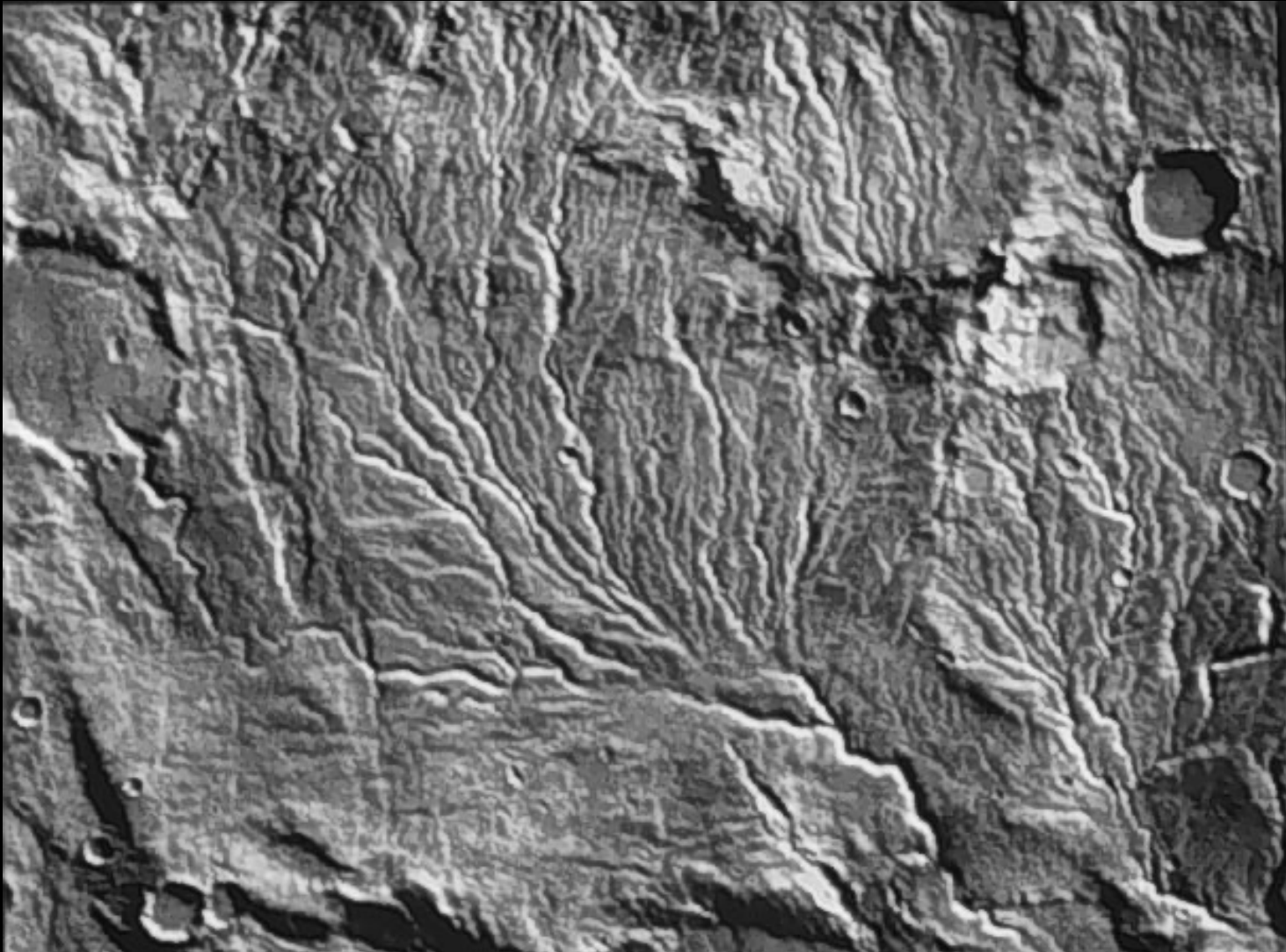
MGS image of ice cap: <http://mars.jpl.nasa.gov/gallery/polaricecaps/PIA02393.html>

- Water ice and dust
- CO₂ layer – winter
- Caps expand and contract during seasonal changes



Viking Image at <http://photojournal.jpl.nasa.gov/catalog/PIA00407>

Liquid Water in the Past?



Viking image from:

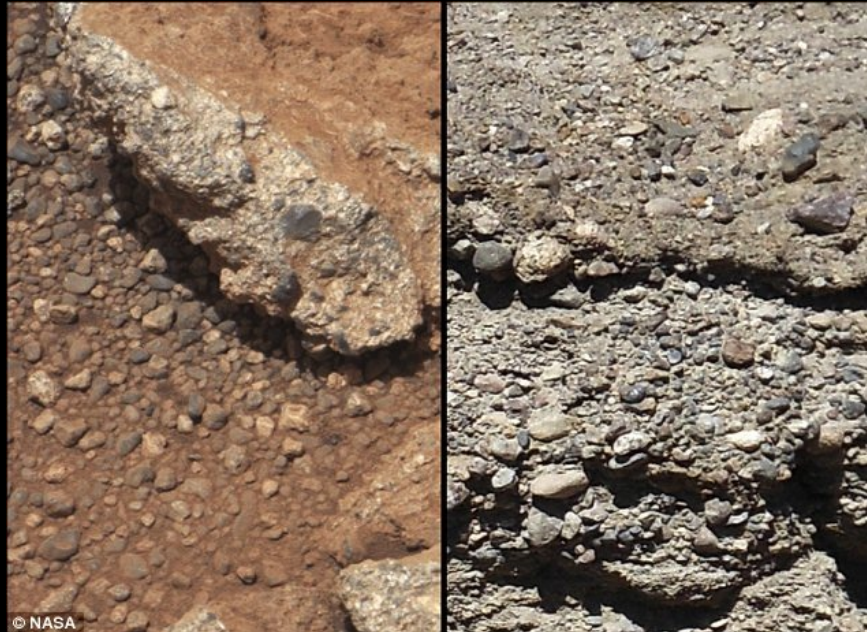
http://www.lpi.usra.edu/publications/slidesets/redplanet2/slide_26.html



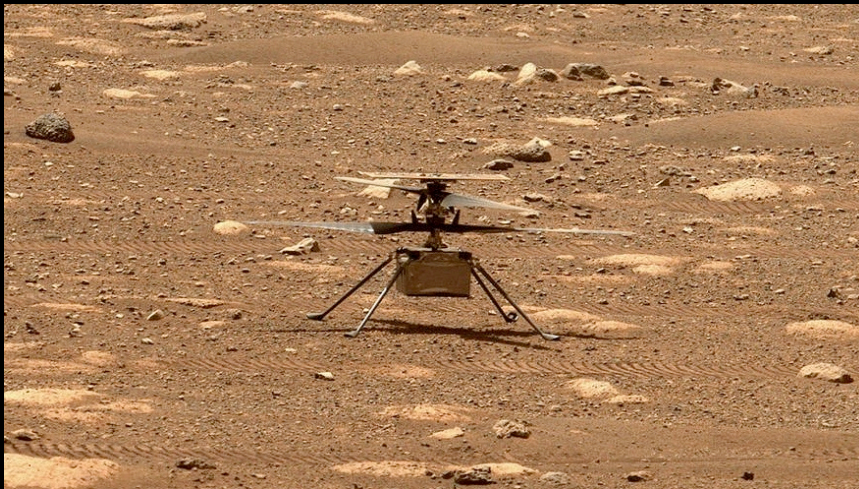
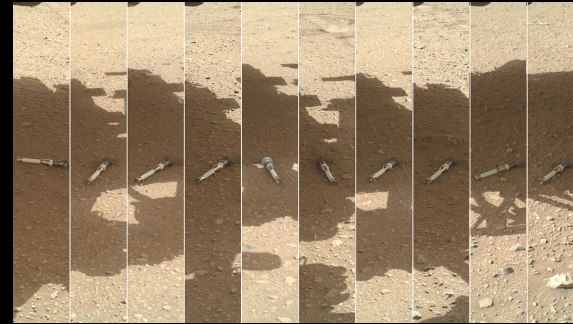
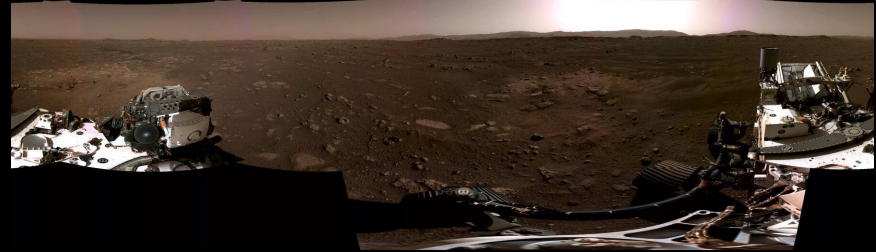
Past Oceans on
Mars? Yes

Possibly lots of
water ~3.5 – 4
billion years ago
... acidic, salty

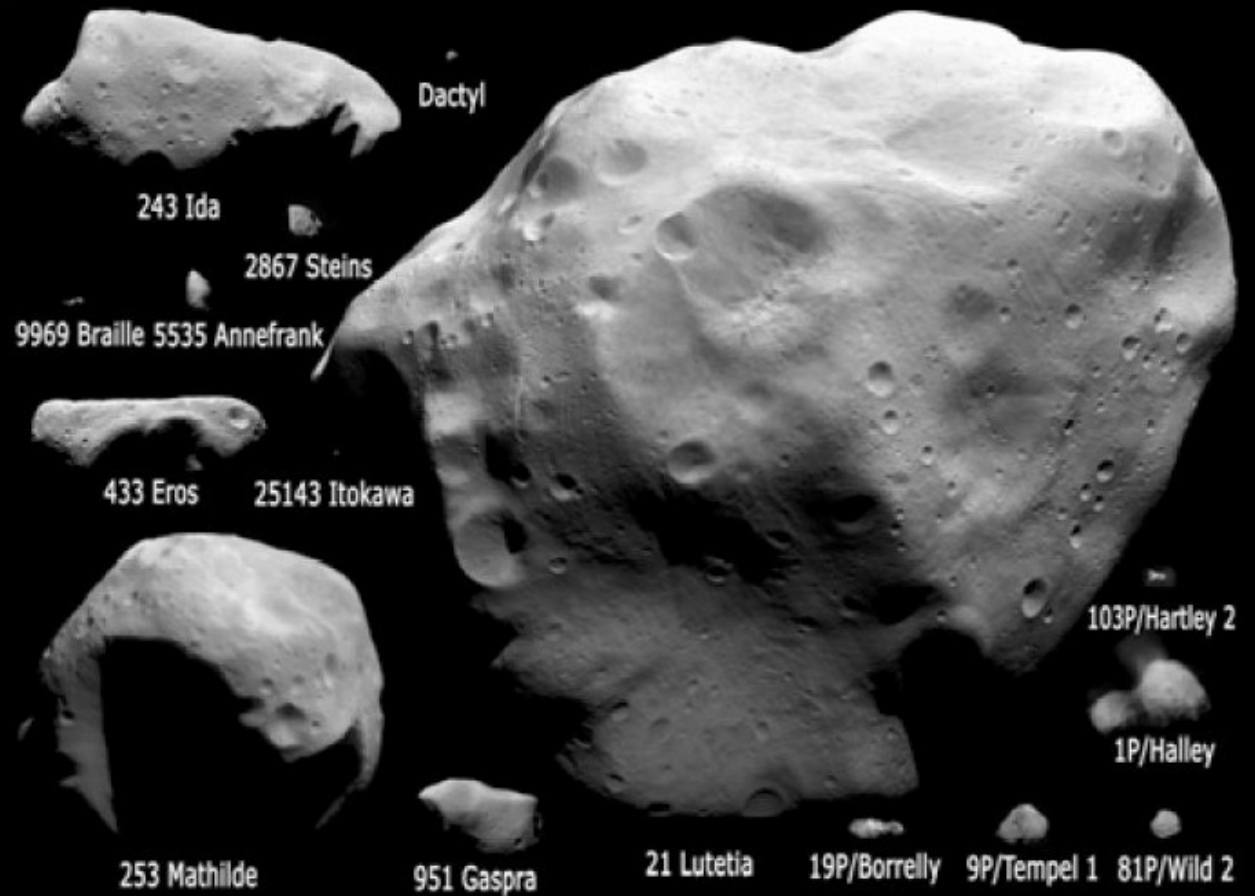
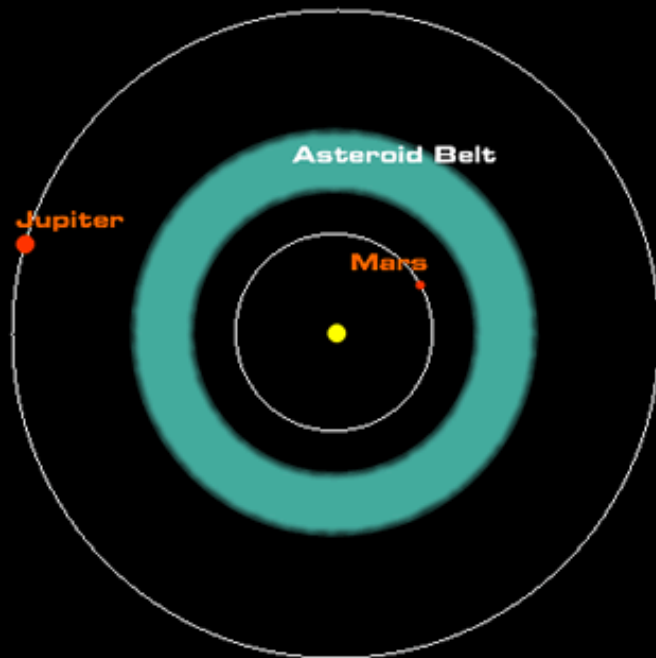
Curiosity on Mars



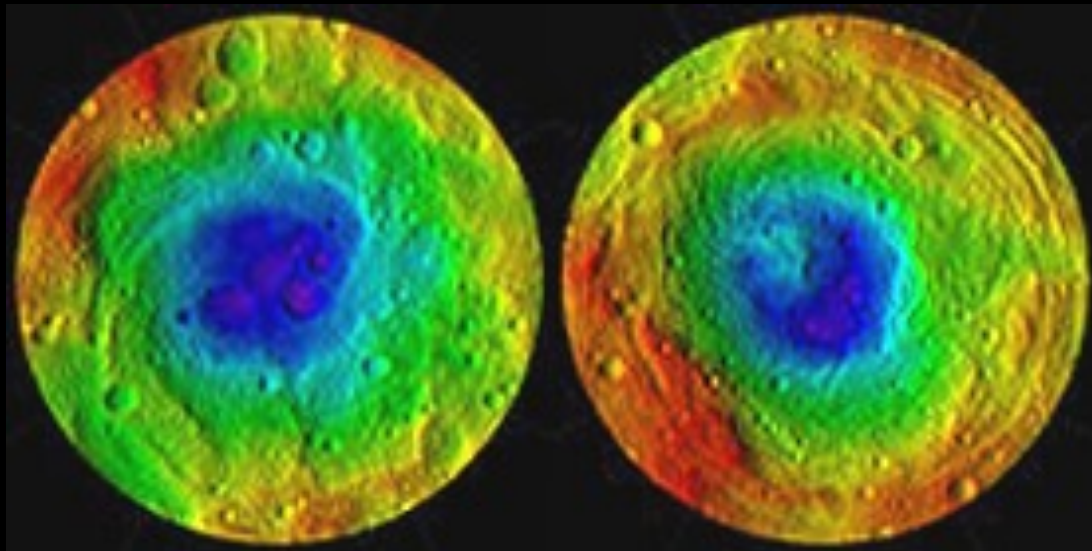
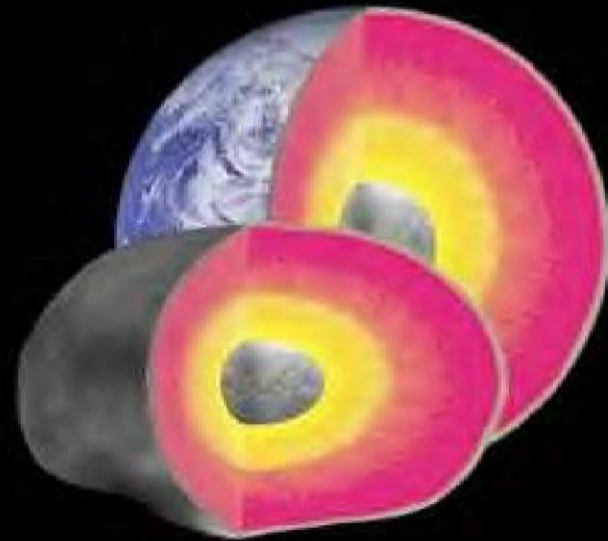
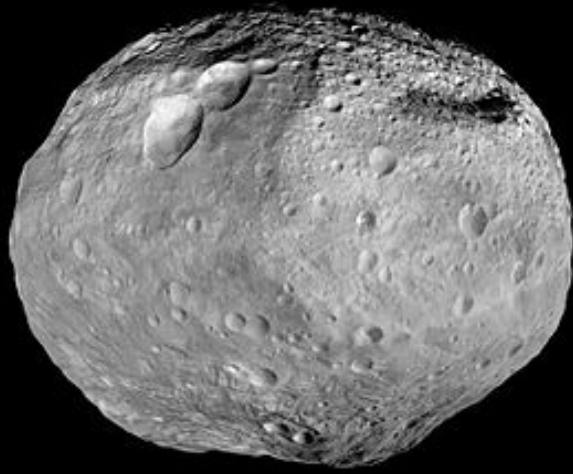
Perseverance and Ingenuity on Mars



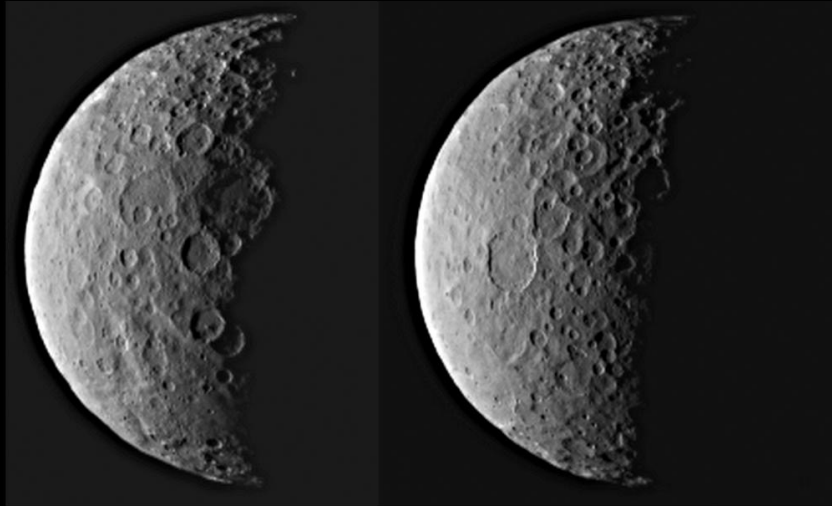
Asteroids



Amazing 4Vesta

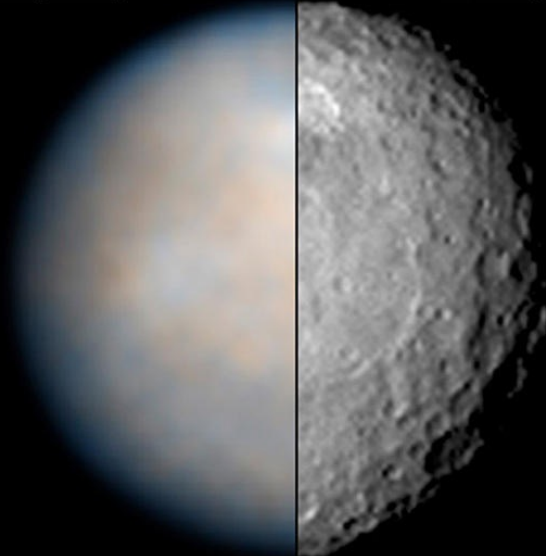


Exploring 1Ceres



Hubble (2004)

Dawn (2015)

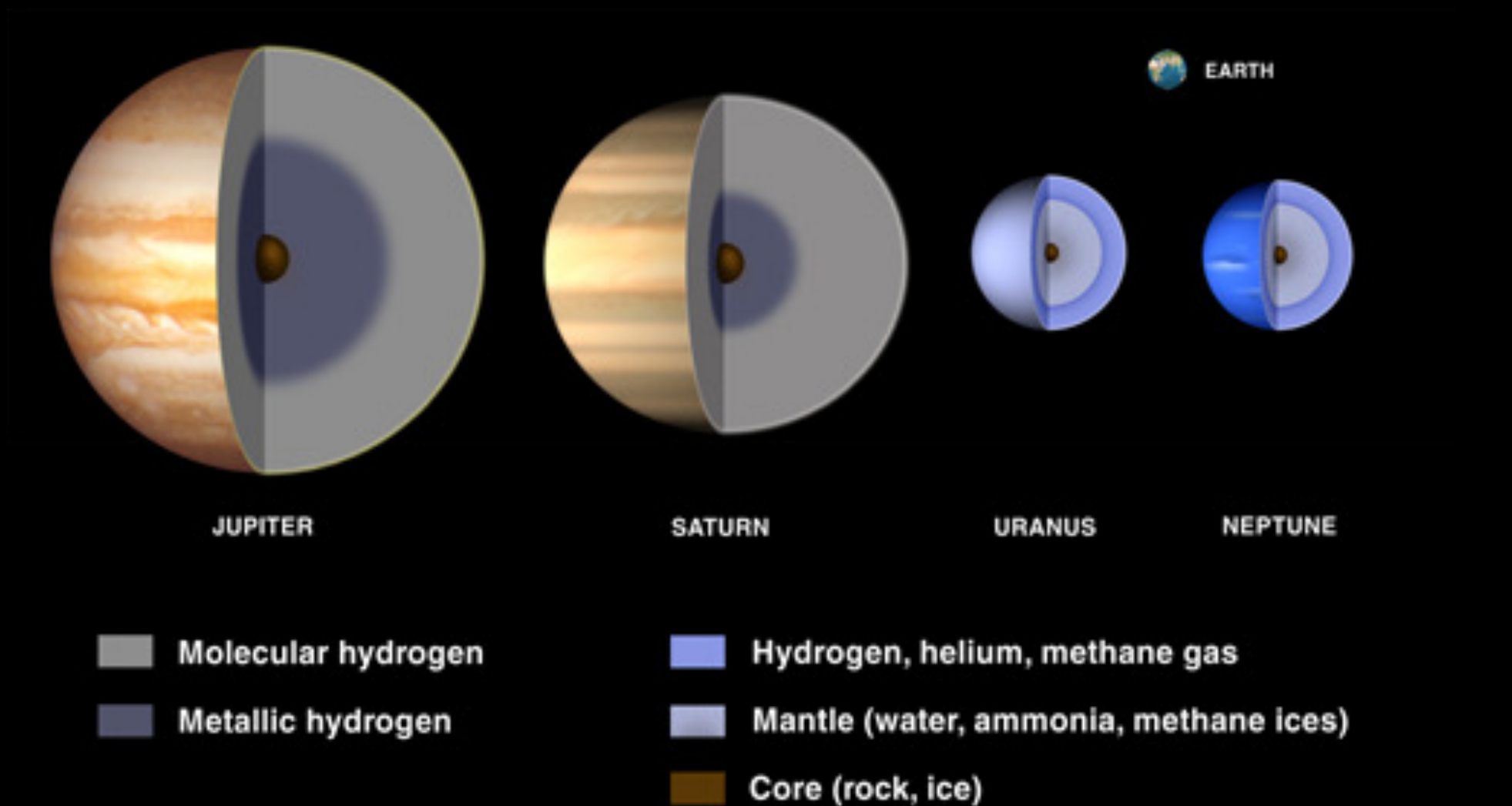


Ceres: NASA/JPL-Caltech

The Outer Solar System



Image: Lunar and Planetary Laboratory:
http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=178



- Small rocky cores – hot? cold?
- Mostly hydrogen and helium
- Where's the surface?

Jupiter

4



- 88,700 miles (143,000 km) diameter – 11x Earth
- 2x mass of all other planets combined (318 x Earth);
- 100 pounds on Earth = 254 on Jupiter
- 90% H and 10% He (75/25% by mass)
- Methane, water, ammonia, rock
- Rocky core – liquid metallic hydrogen – electrical conductor, generates magnetic field
- Composition similar to Solar Nebula

Jupiter



4

- Cloud-tops average = -153°C = -244°F .
- ~10 hour rotation / 12 year orbit
- Fly-bys: Pioneer 10, 11, Voyager 1, 2, Ulysses, Cassini
- Orbiter: Galileo – 8 years, Juno in 2016-present

Jupiter Moons

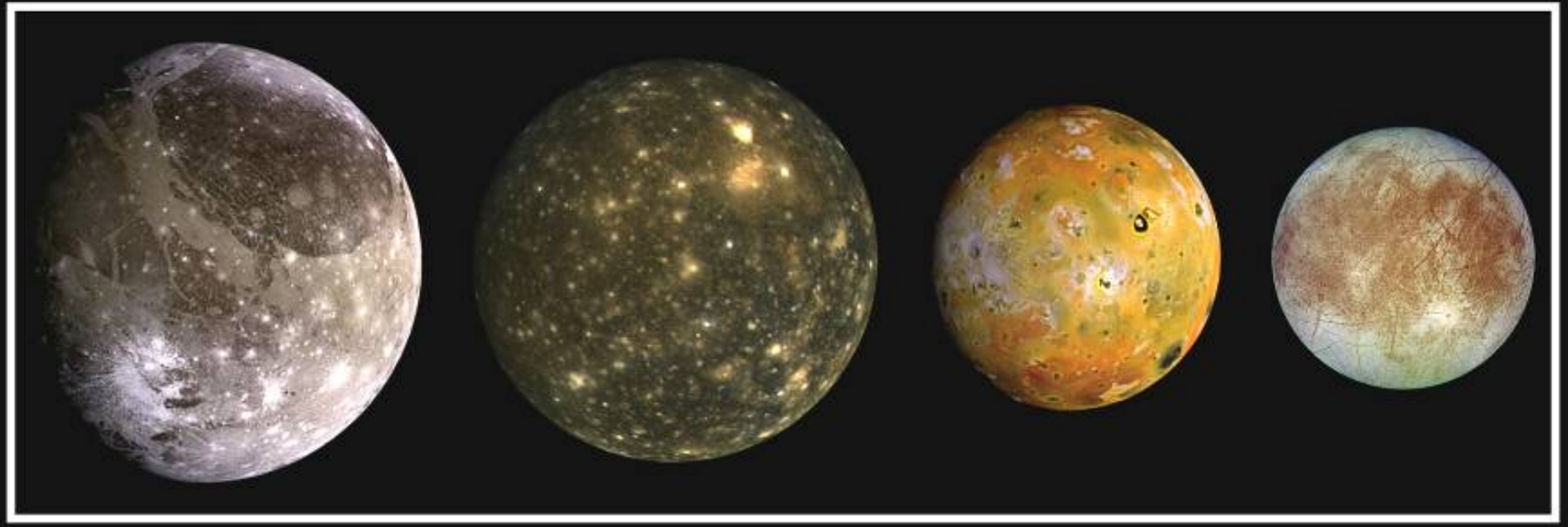


Image from http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=2099

Galileo – 1610 – Four “Galilean” Moons of Jupiter
95 moons ... and counting!
Rings! Rocky particles, no ice

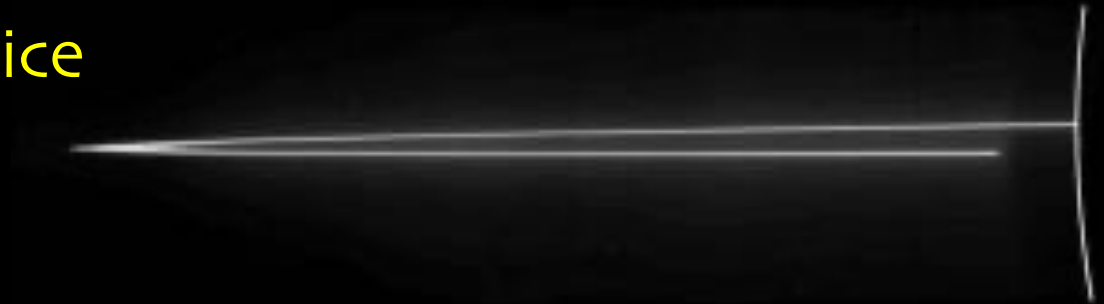
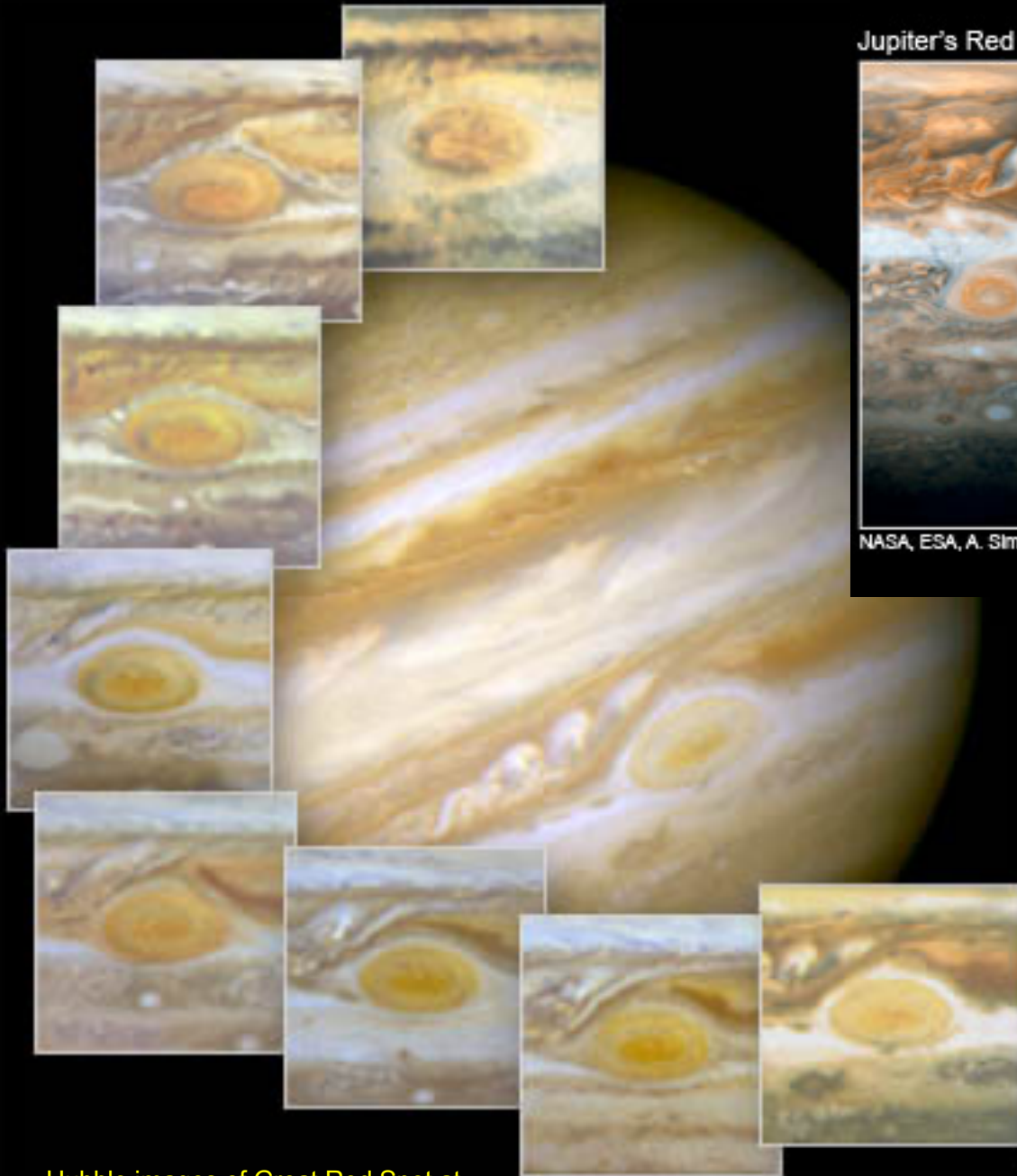
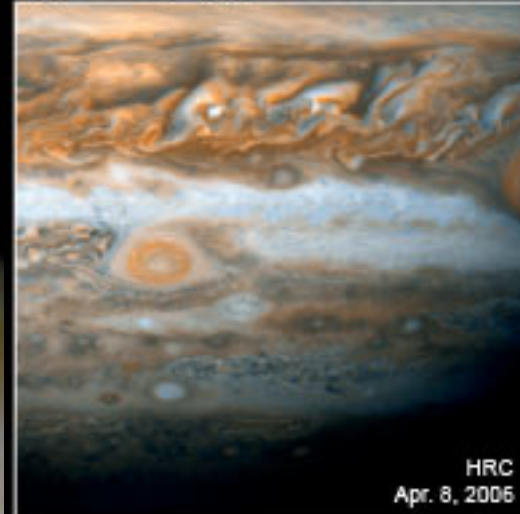


Image from <http://pds-rings.seti.org/jupiter/galileo/PIA00657.html>

Storms on Jupiter

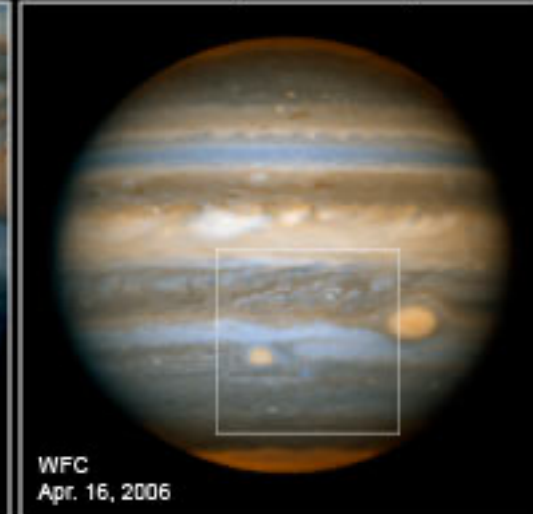


Jupiter's Red Spots



NASA, ESA, A. Simon-Miller (NASA/GSFC), I. de Pater, and M. Wong (UC Berkeley)

Hubble Space Telescope ■ ACS



STScI-PRC06-19

Giant Red Spot – at least
300 years old
3 x size of Earth
Winds up to 400 km / hr
“Red Spot Jr”

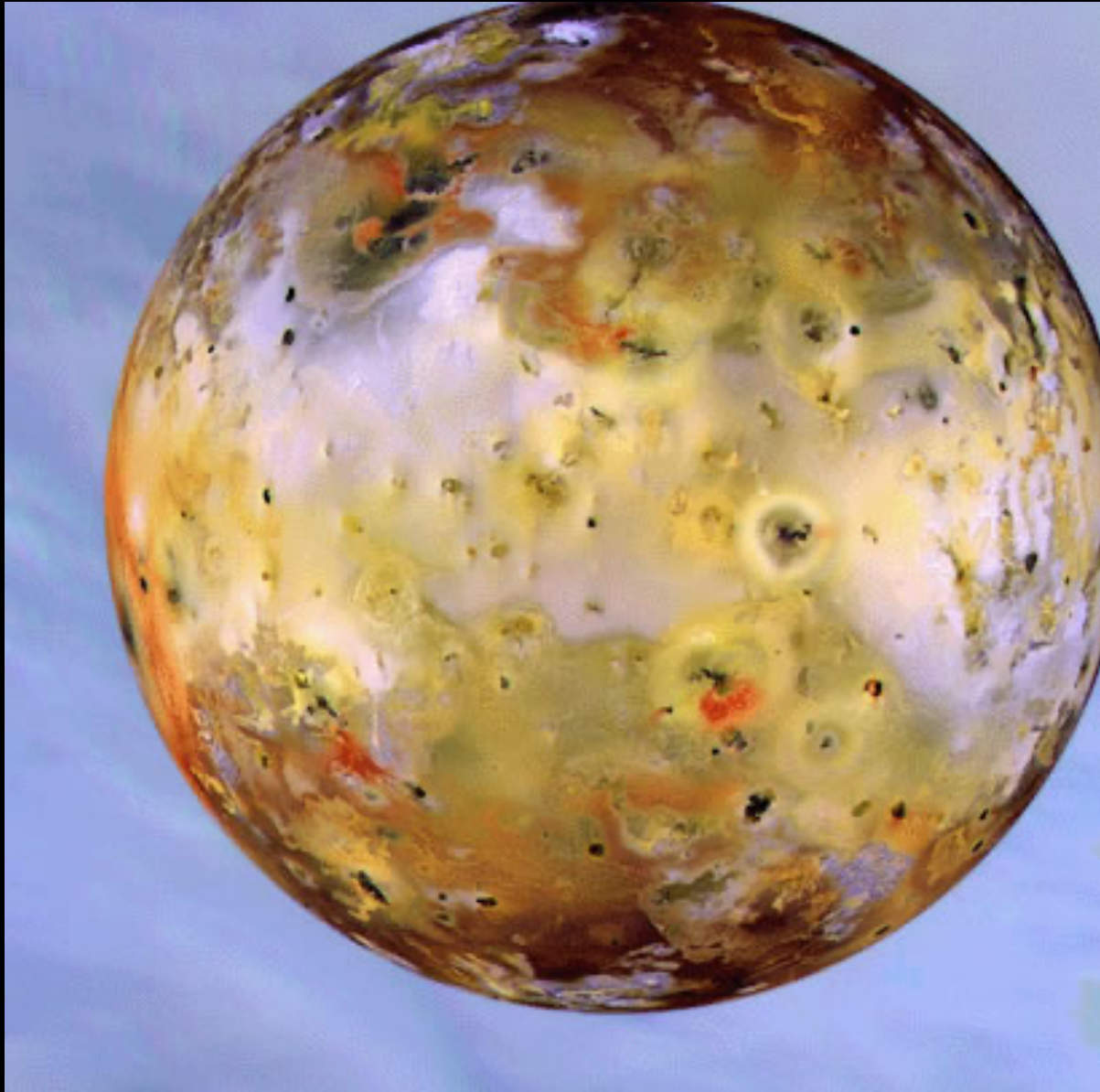
Hubble images of Great Red Spot at
<http://hubblesite.org/newscenter/archive/releases/solar%20system/jupiter/1999/29/image/a/results/20/>

Aurora



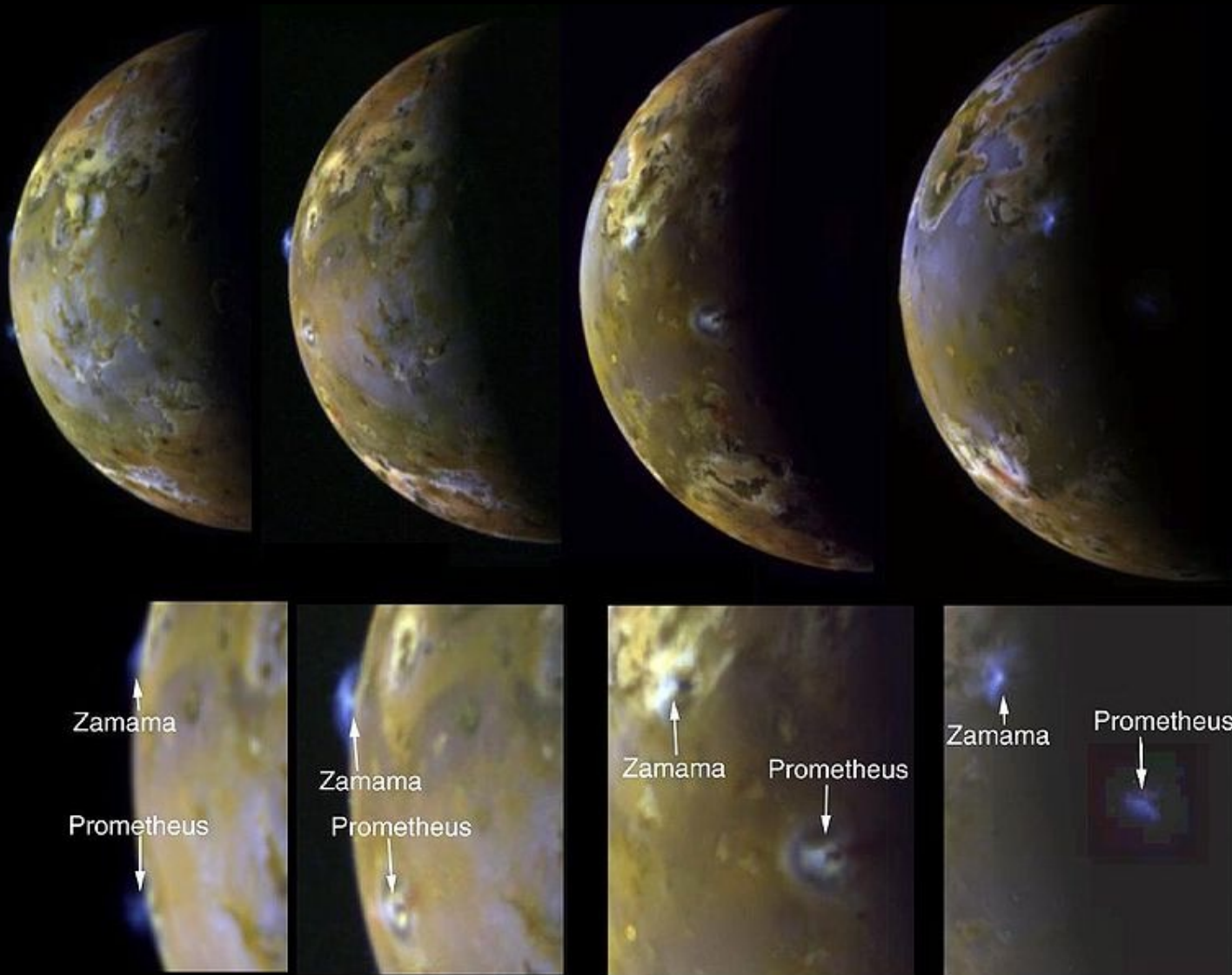
Hubble image from http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=1866

Io



NASA Galileo Image at: http://www.lpi.usra.edu/publications/slidesets/ss_tour/slide_23.html

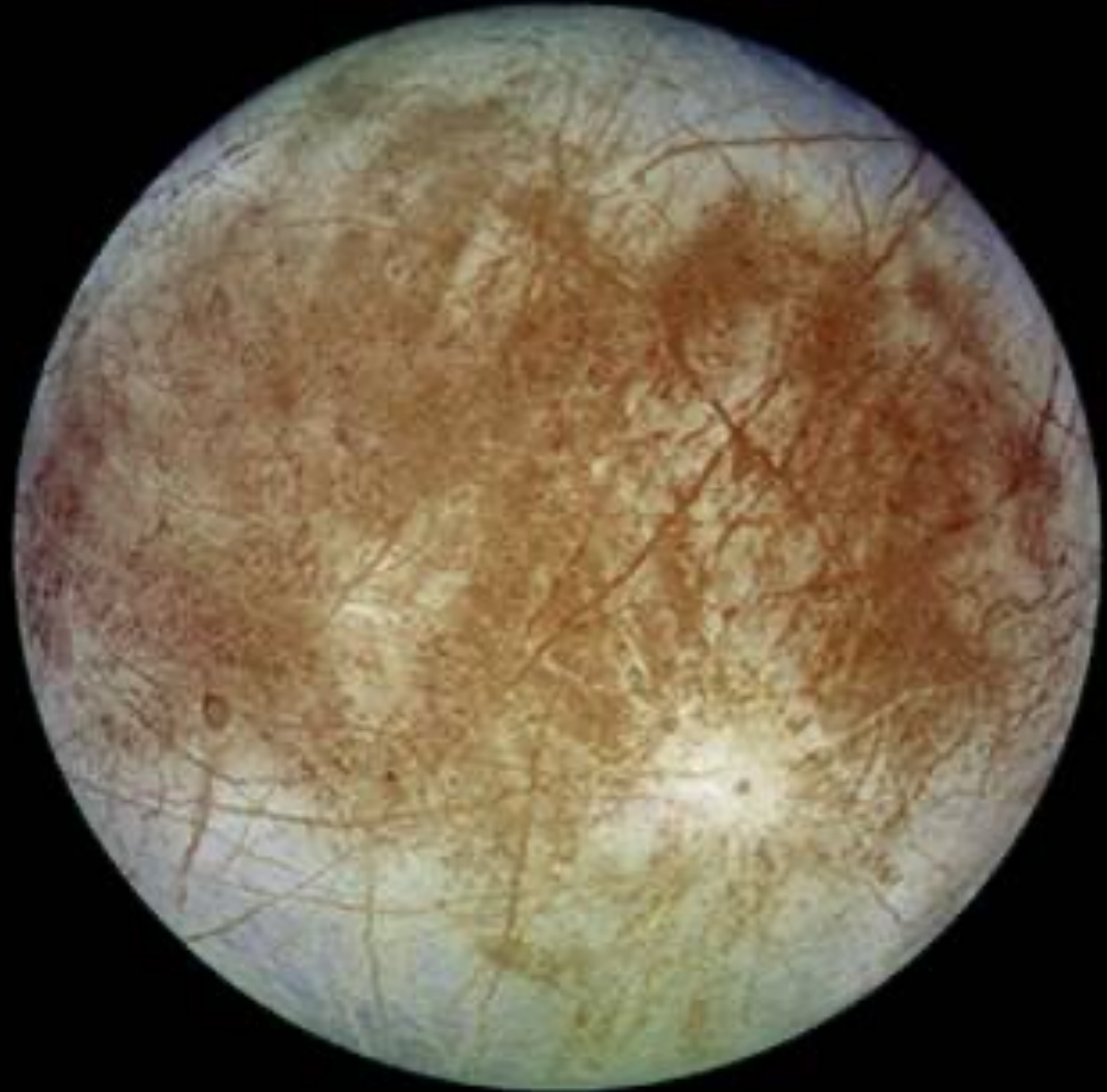
Volcanic Activity!



Io



Europa



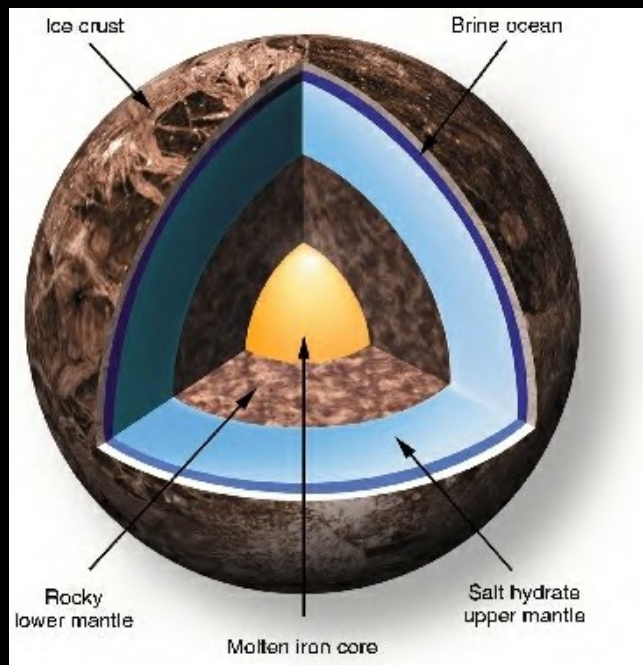
NASA Galileo image at: http://www.lpi.usra.edu/publications/slidesets/ss_tour/slide_24.html

Europa



Ganymede

- largest moon in Solar System; bigger than Mercury
- Has a magnetic field
- older regions may be 4 billion years old
- has tectonics with ice crust
- Has a salty ocean under ice



Callisto

- mostly made of ice and rock, without a real core
- craters are “mushy”; not eroded exactly...
- strong new evidence of salty ocean underneath an ice crust
- large like Ganymede but heavily cratered and dark



Image from <http://photojournal.jpl.nasa.gov/catalog/PIA03456>

Saturn

- 9x the size of Earth
- 75% hydrogen and 25% helium
- Water, methane, ammonia and "rock"
- Rocky core
- Winds up to 500 m / second
- -290 F
- Rings – 185,000 miles wide , ~2 miles thick
- Water ice rings
- **274 moons** and counting!
- 11 hour rotation / 29 year orbit
- Pioneer / Voyager Fly-by / Cassini/Huygens!



<http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?imageID=849>



Saturn from Cassini



Rather chilly in the rings

Red -261 F

Blue -333 F

Green -298 F

Image from:

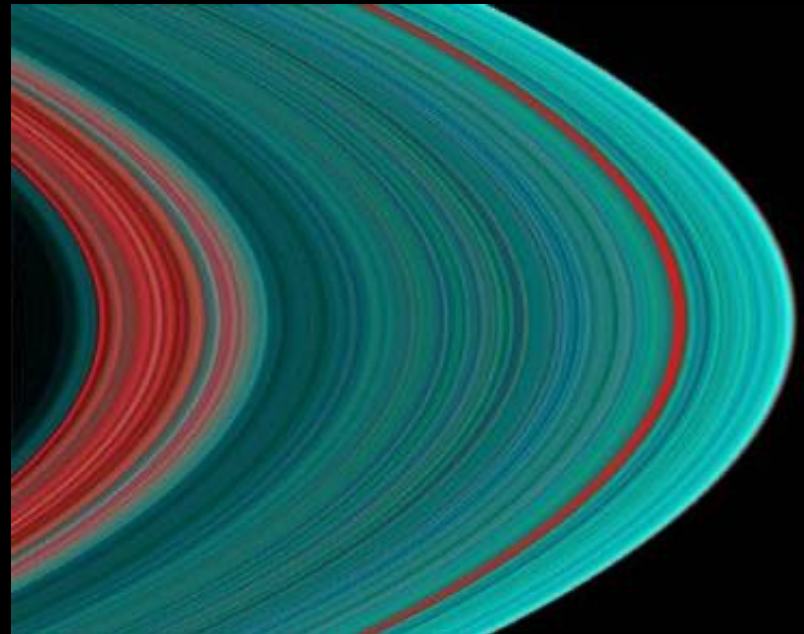
<http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?path=../multimedia/images/rings/images/PIAo6425.jpg&type=image>

'Dirty Snow'

Turquoise= water ice

Red = "dirty"

<http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?imageID=846>

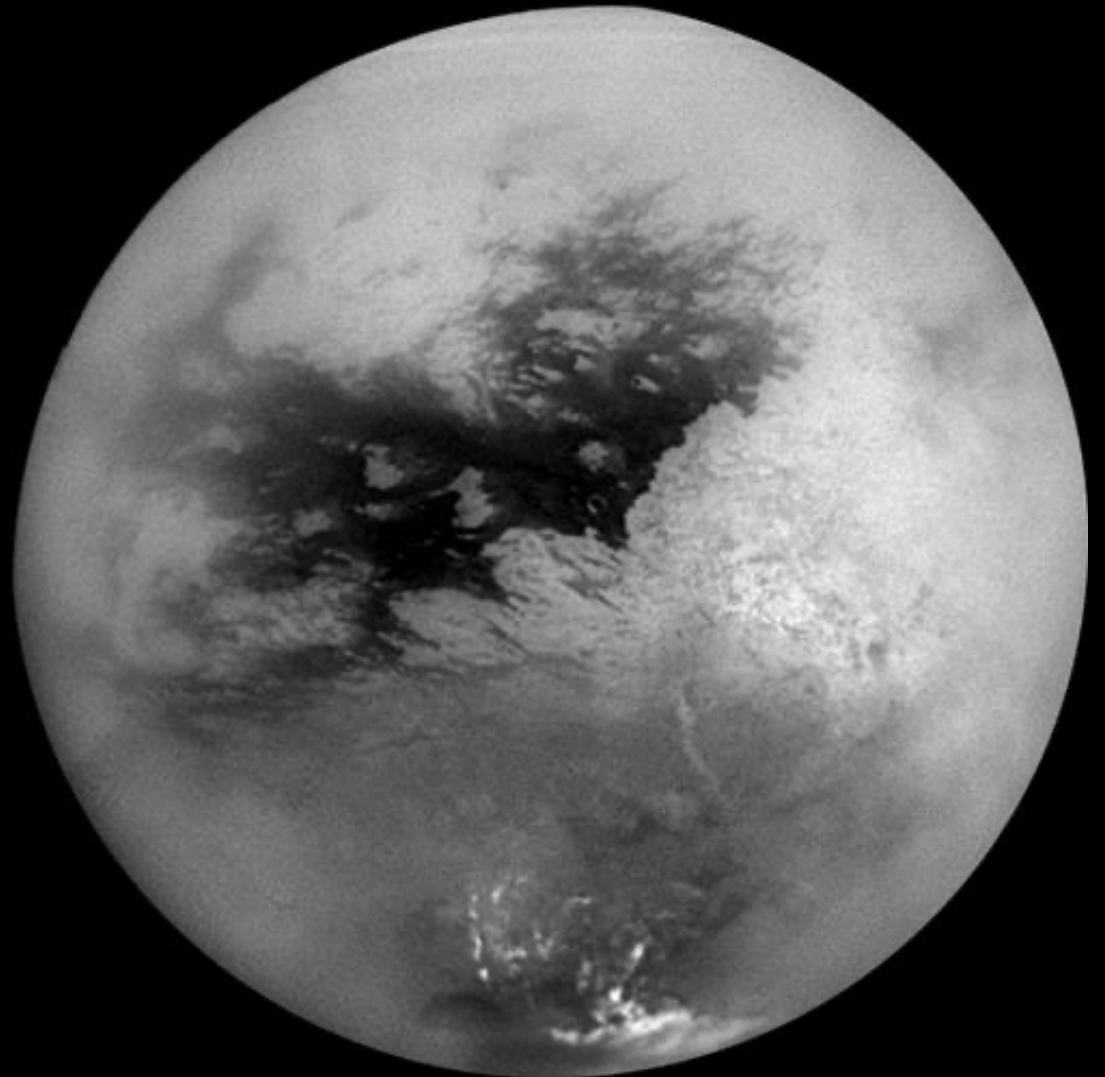


A Stormy Saturn



Titan!

Clues to Early Earth?



Cassini image from: <http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?imageID=1179>

Average surface temperature -179°C

Atmosphere of N ($>90\%$), CH_4 , Ar

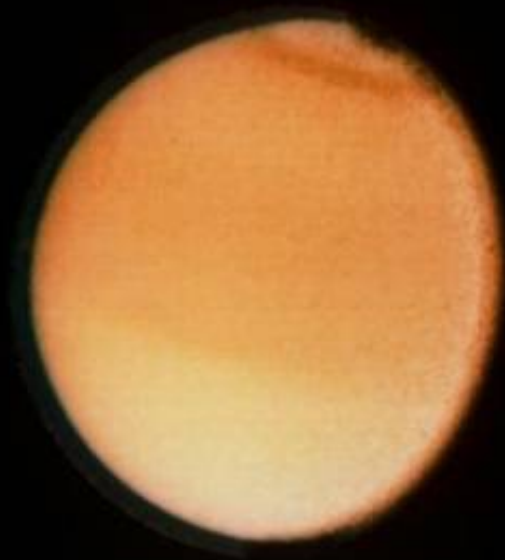
Hydrocarbon-rich rivers/seas
(ethane – C_2H_6)

Water ice

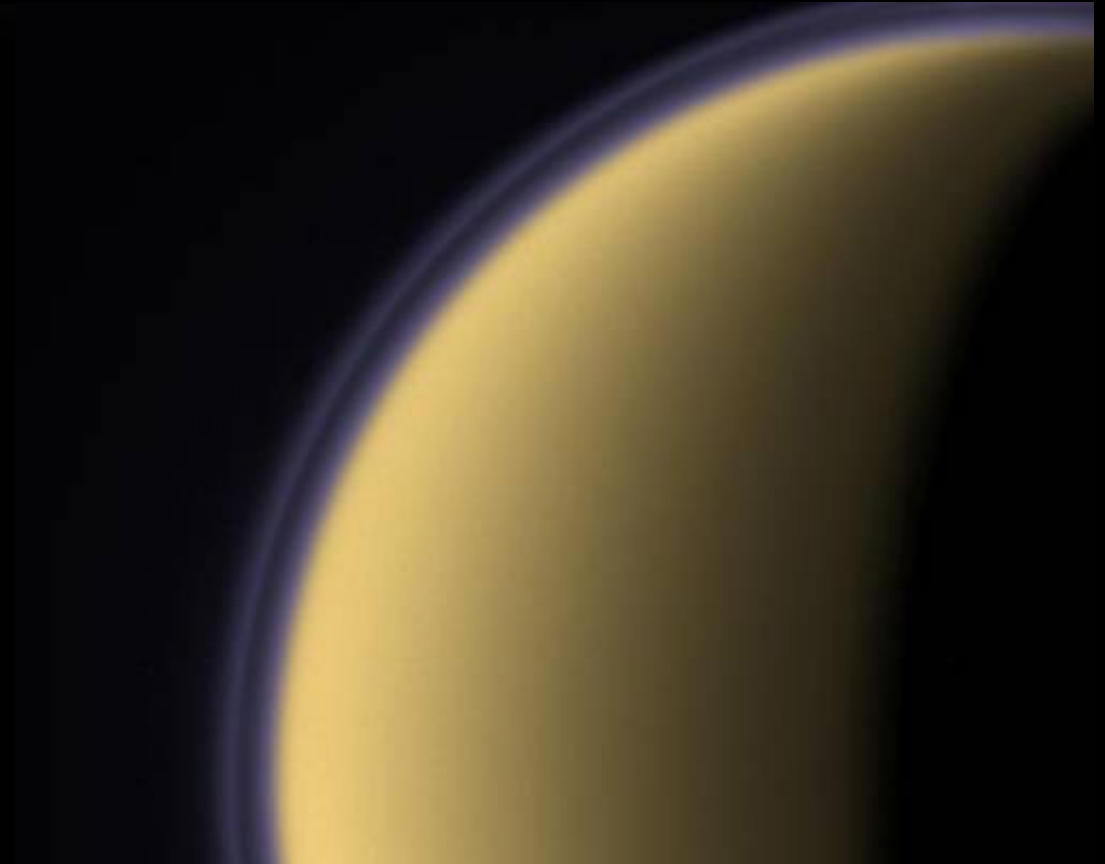
Atmosphere $1.5 \times$ Earth

Titan

Clues to Early Earth?



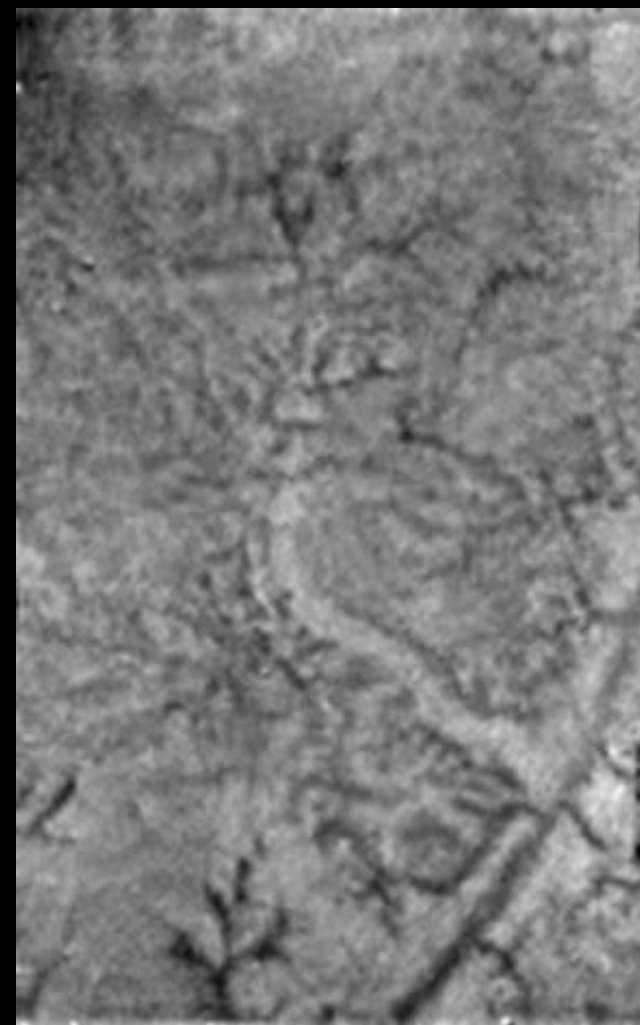
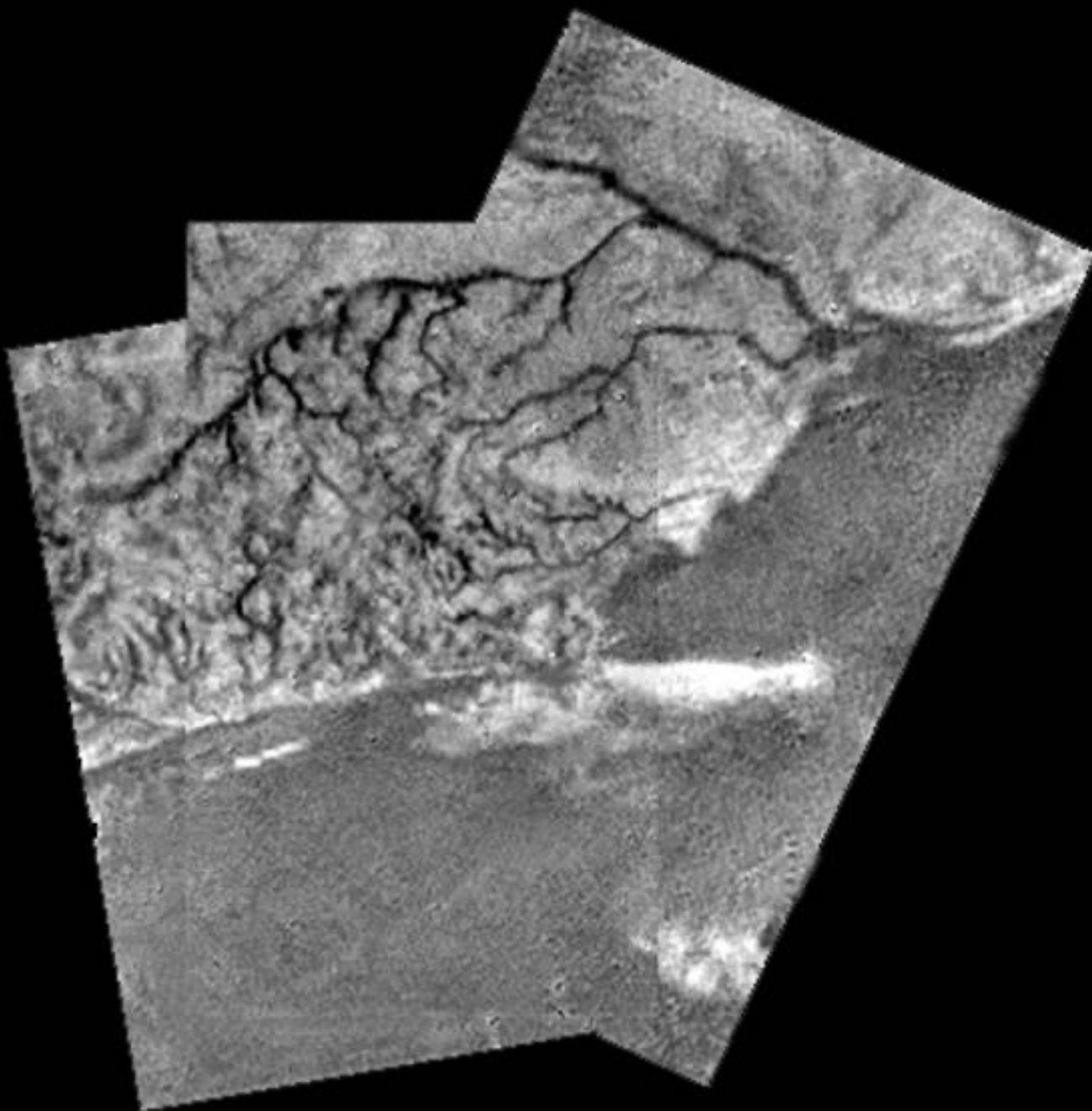
Voyager image at <http://photojournal.jpl.nasa.gov/catalog/PIA01532>



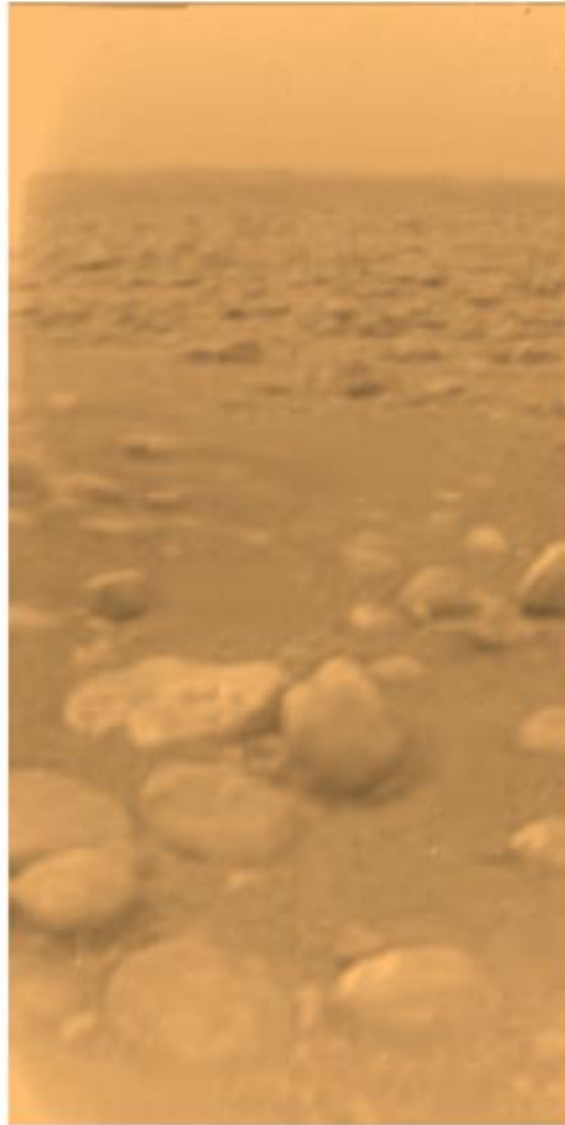
Cassini image at http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=2783



Huygens image from: <http://photojournal.jpl.nasa.gov/catalog/PIA07231>



Huygens images from: <http://photojournal.jpl.nasa.gov/catalog/PIA07236>
And <http://photojournal.jpl.nasa.gov/catalog/PIA07238>



Huygens image at : <http://photojournal.jpl.nasa.gov/catalog/PIA07232>

Cratered Moons



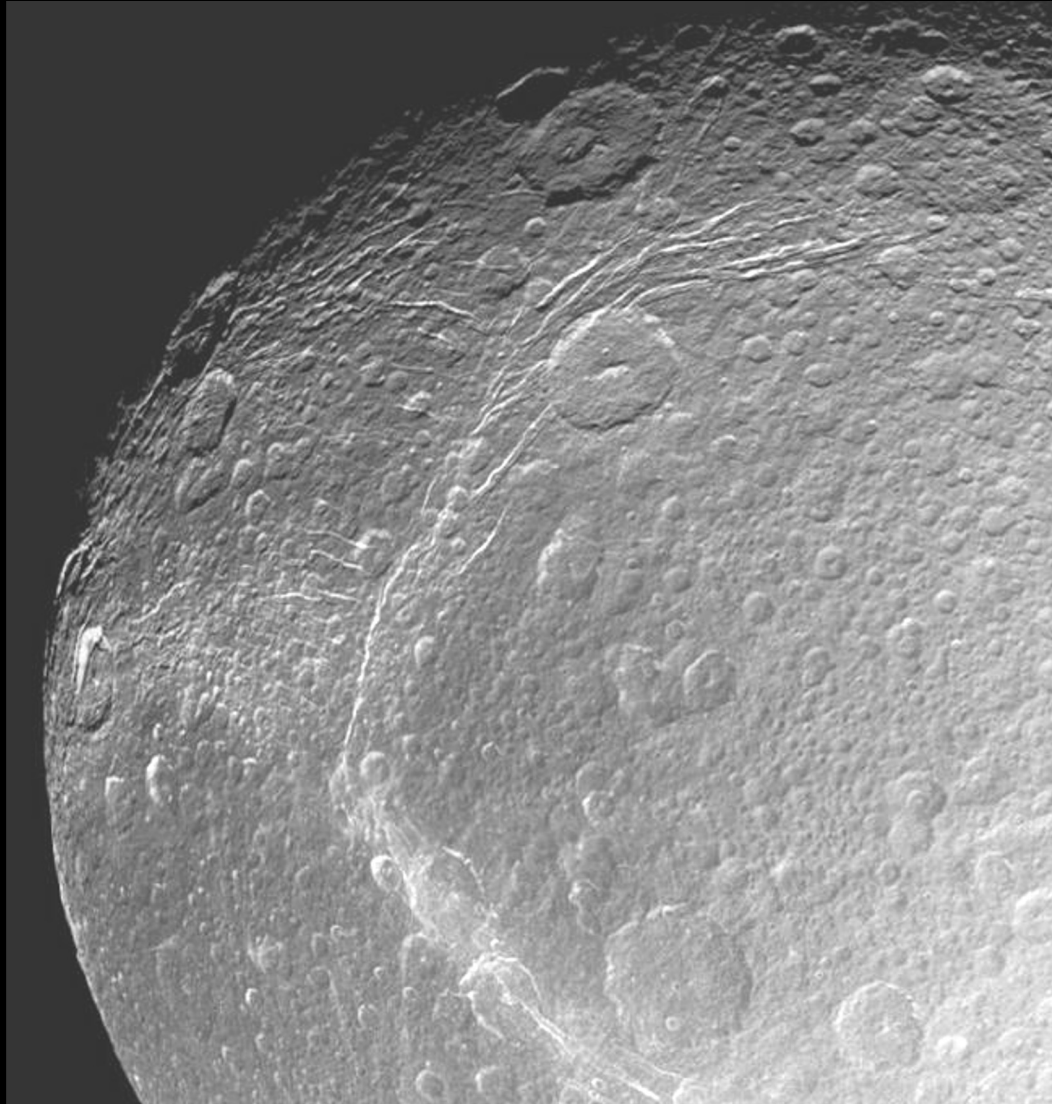
Mimas



Phoebe

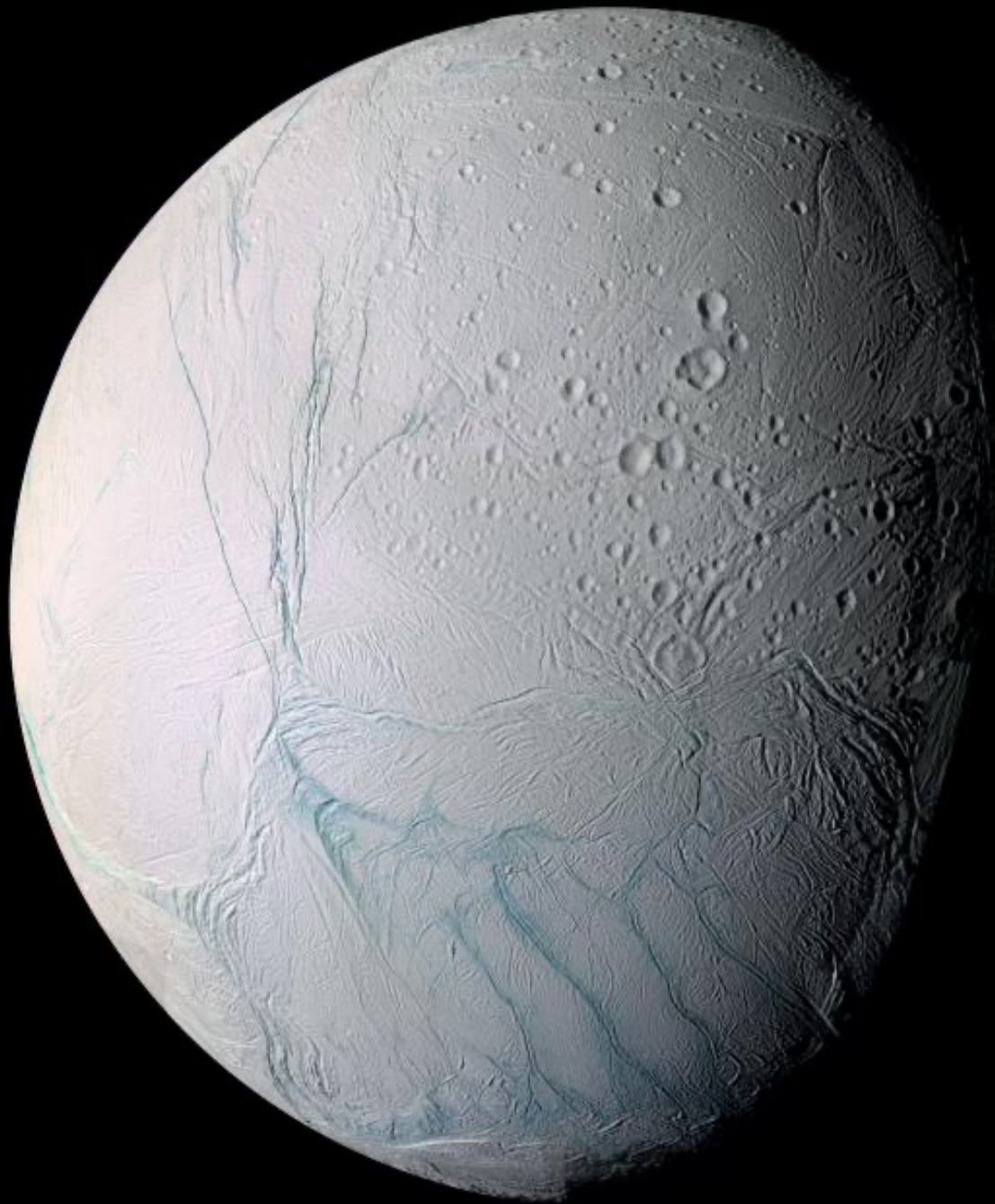
Cassini images from: <http://photojournal.jpl.nasa.gov/catalog/PIA06582>
And http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=3823

Dione from Cassini



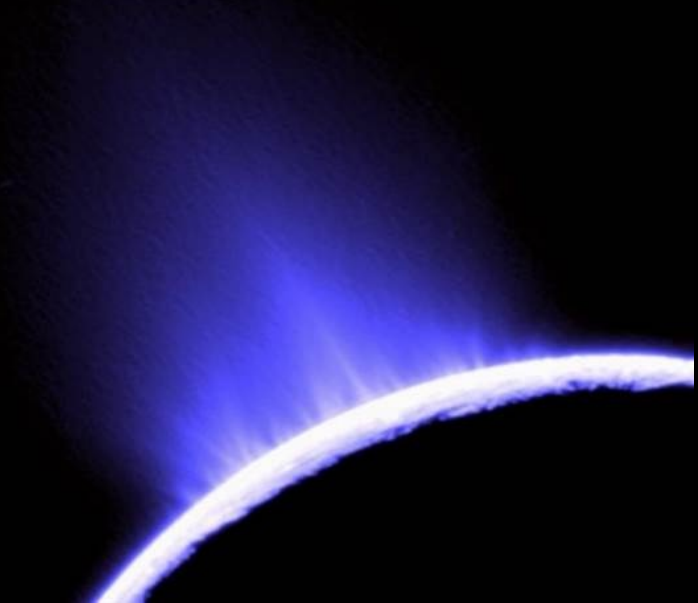
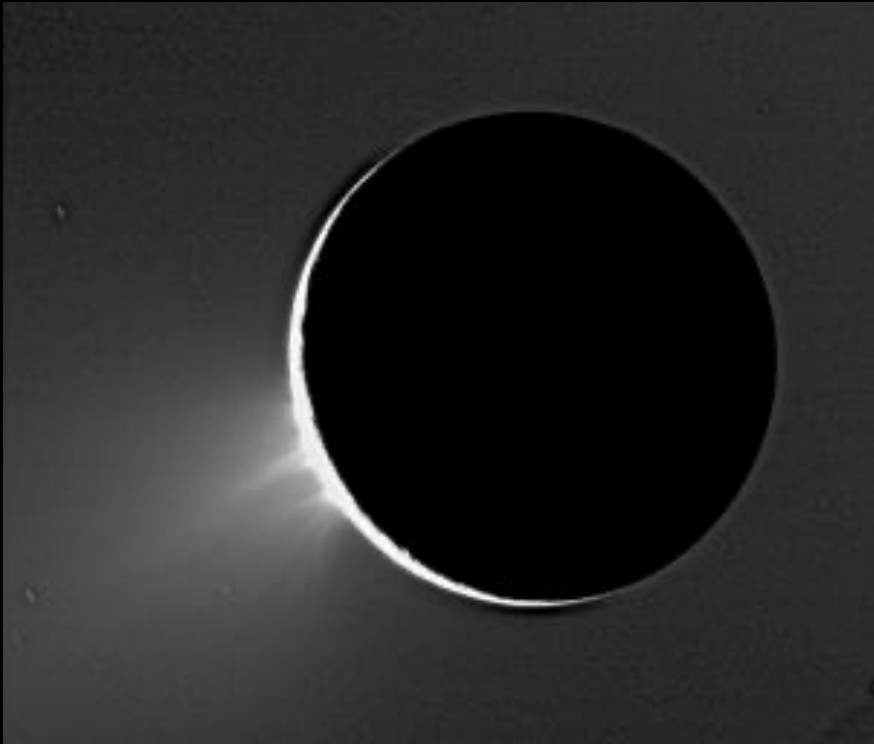
Cassini image from: <http://photojournal.jpl.nasa.gov/catalog/PIA06162>

Enceladus



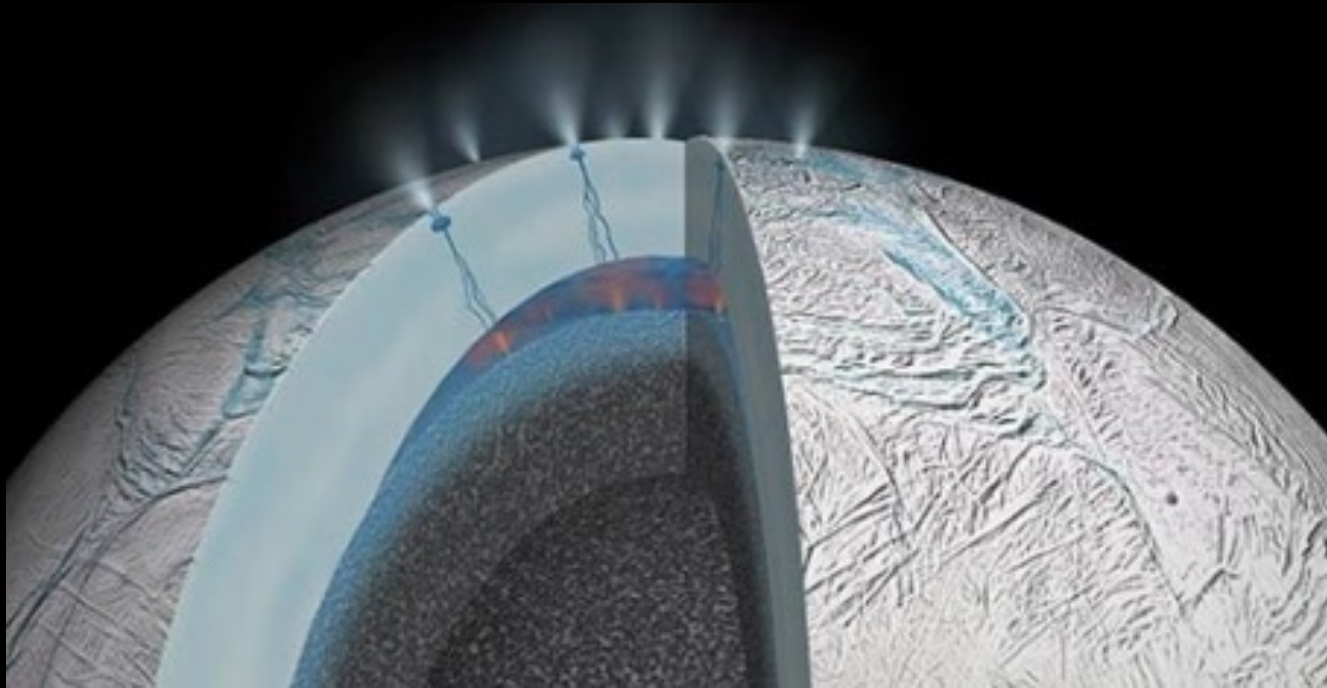
Cassini image from: <http://photojournal.jpl.nasa.gov/catalog/PIA06254>

Geyzers of water jet from surface of Enceladus

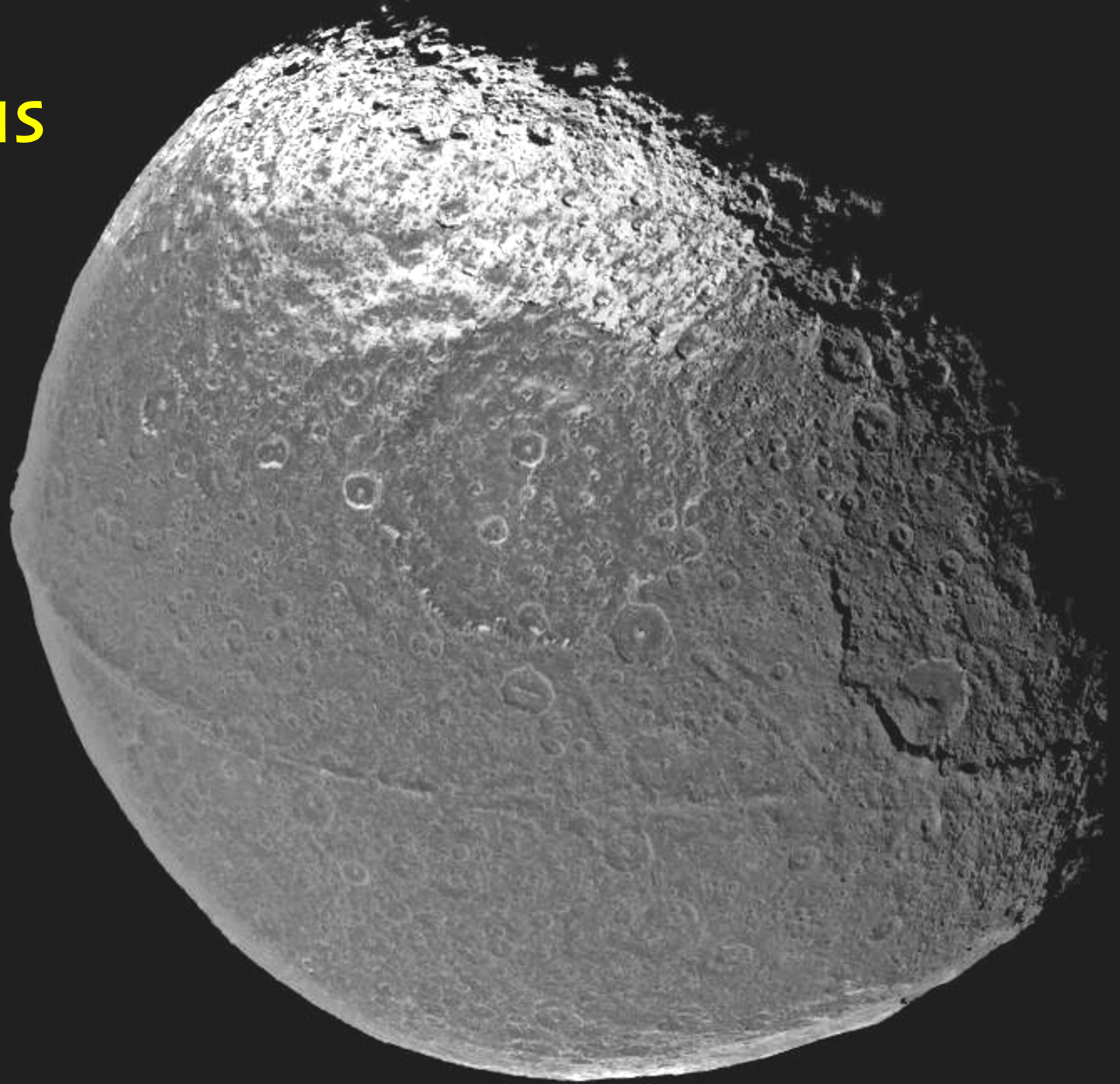


Cassini images from: <http://photojournal.jpl.nasa.gov/catalog/PIA07758> and <http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?imageID=2071>

Enceladus' vents

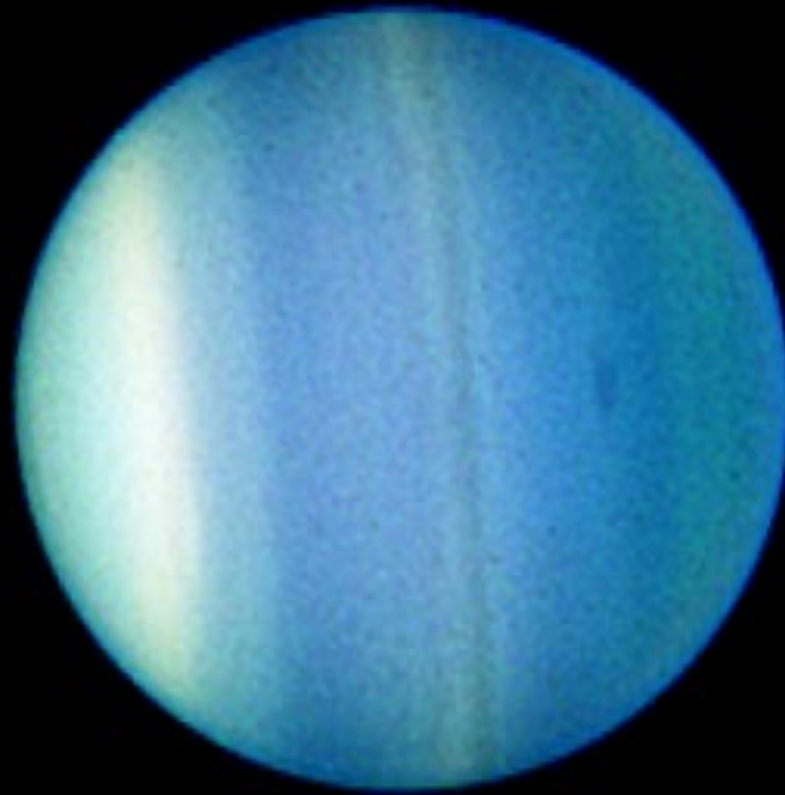


Iapetus



Cassini image from: <http://photojournal.jpl.nasa.gov/catalog/PIA06166>

Uranus



*First planet discovered with a telescope!
William Herschel, March 13th, 1781*

Uranus

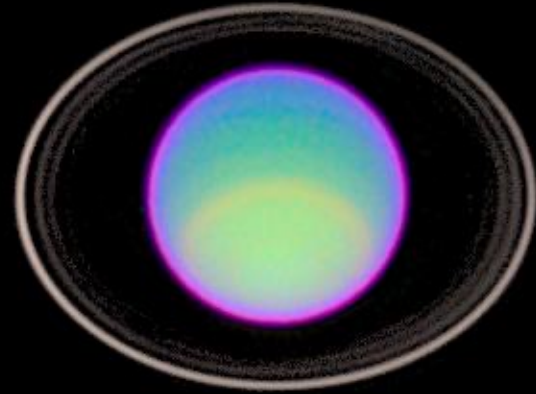
- 4x the size of Earth
- 15% H, little helium – mostly water ices
- Offset rotation axis
- Blue from methane absorption of red light (atmosphere)
atmosphere has mostly hydrogen and helium
- 13 rings, 27 satellites
- -350 F at 'surface'
- 18 hour rotation, 84 year orbit
- Spins on an axis inclined 92 degrees
- Voyager fly-by



Uranus



Voyager 2 Image from: <http://photojournal.jpl.nasa.gov/catalog/PIA01977>



Hubble Image from: <http://photojournal.jpl.nasa.gov/catalog/PIA01280>



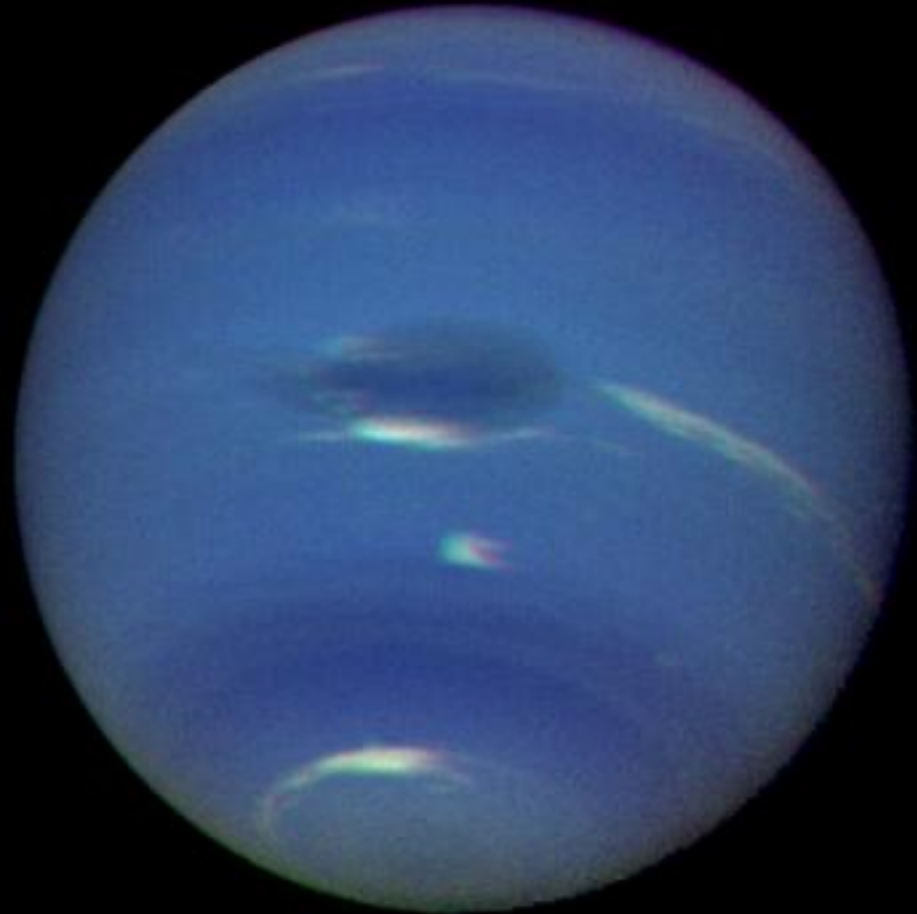
Hubble Image from:
<http://hubblesite.org/newscenter/archive/releases/solar%20system/uranus/1998/35/image/a/results/20/>

Uranus from JWST



Neptune

**First planet discovered
with mathematics!**



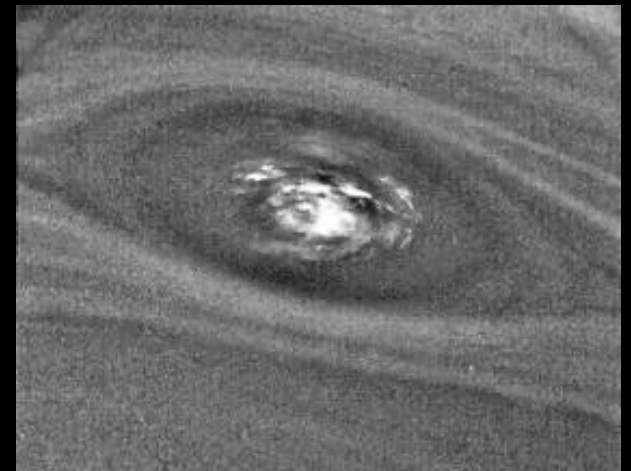
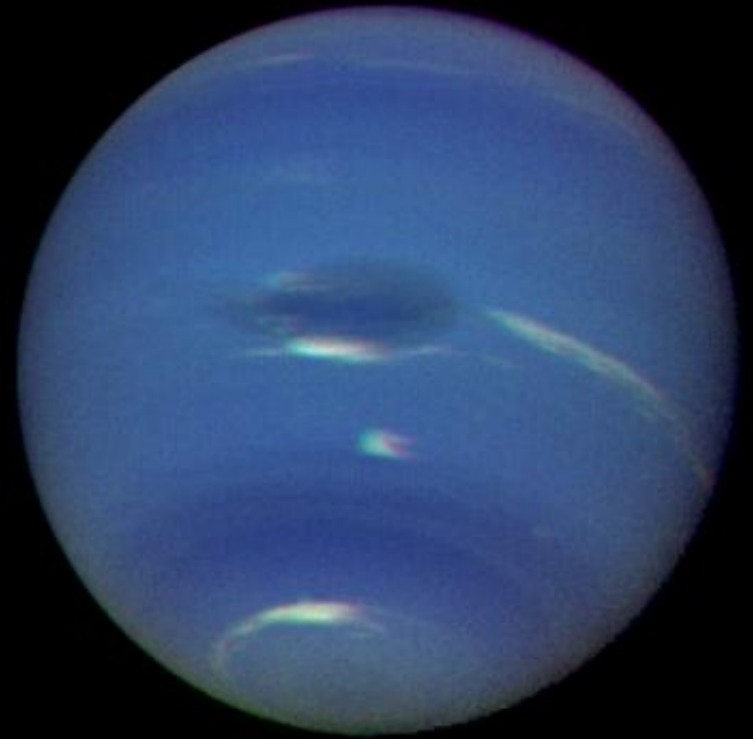
**Calculated by Leverrier & Adams 1846
Confirmed by Galle and D'arrest 1846**



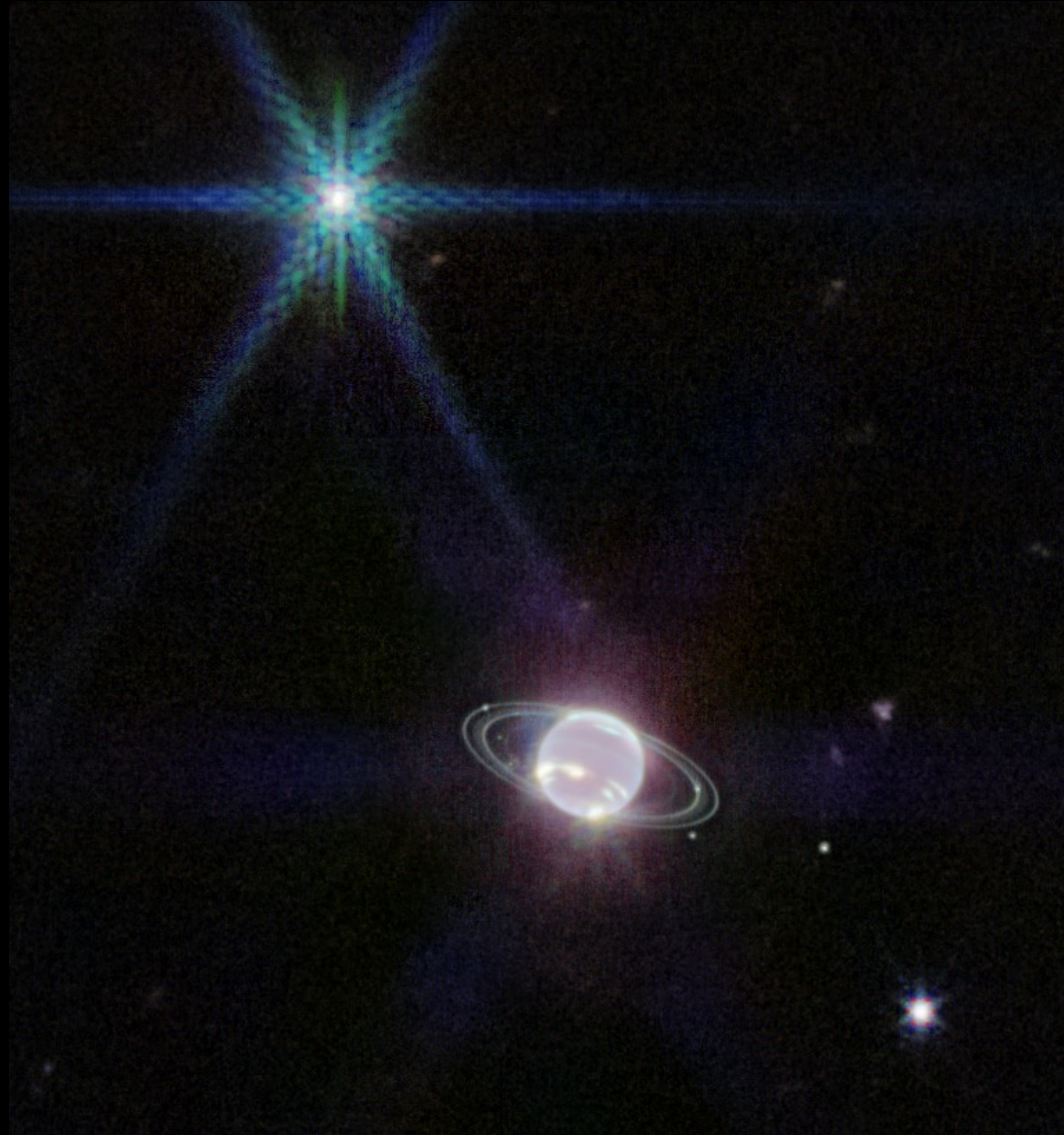
Image from: <http://photojournal.jpl.nasa.gov/catalog/PIA02245>

Neptune

- Ices and rock - 15% H and little He
- H, He, methane atmosphere (blue!)
- Small rocky core?
- Has storm "Great Dark Spot"
- White Spot (Scooter) zips around every 16 hours....
- 5 Rings of unknown composition
- 14 moons
- 18 hour rotation / 165 year orbit
- Voyager (1989)



Rings of Neptune JWST



Triton

- Cryovolcanos-- geysers
- Thin atmosphere (nitrogen, methane)
- Ridges and valleys, melting

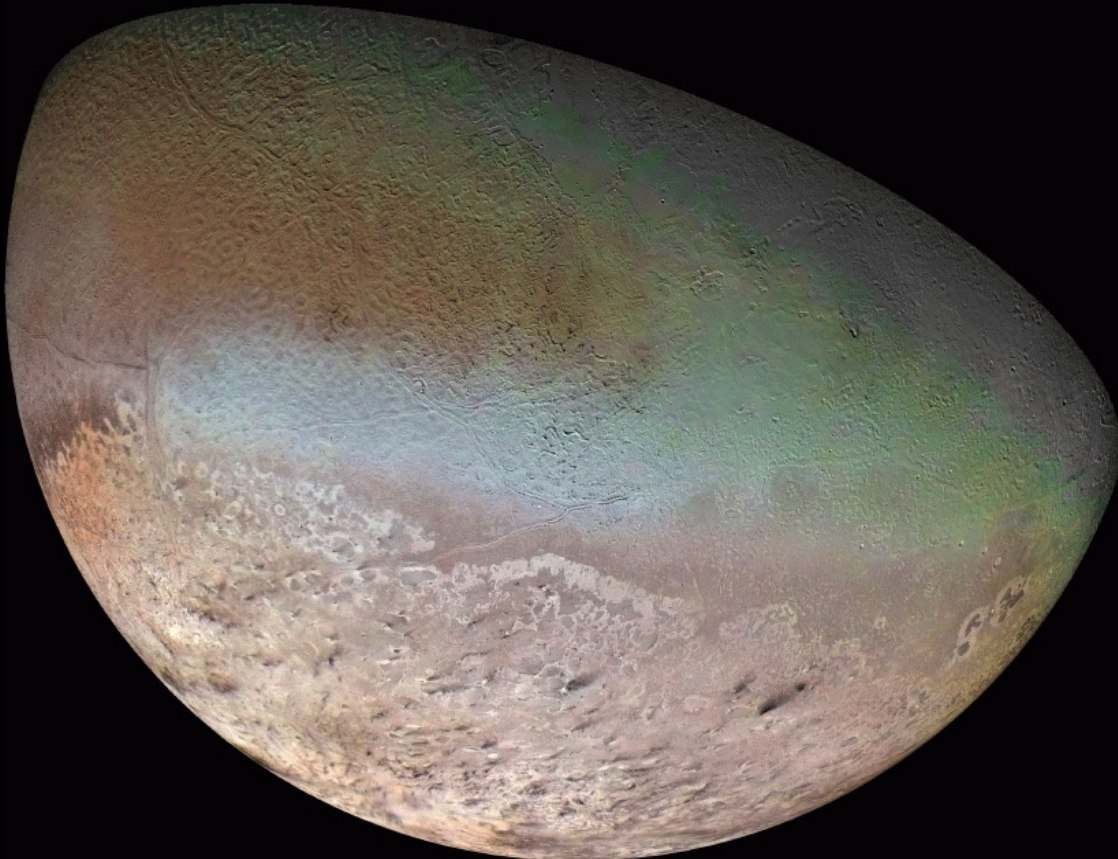


Image: <http://photojournal.jpl.nasa.gov/catalog/PIA01538>

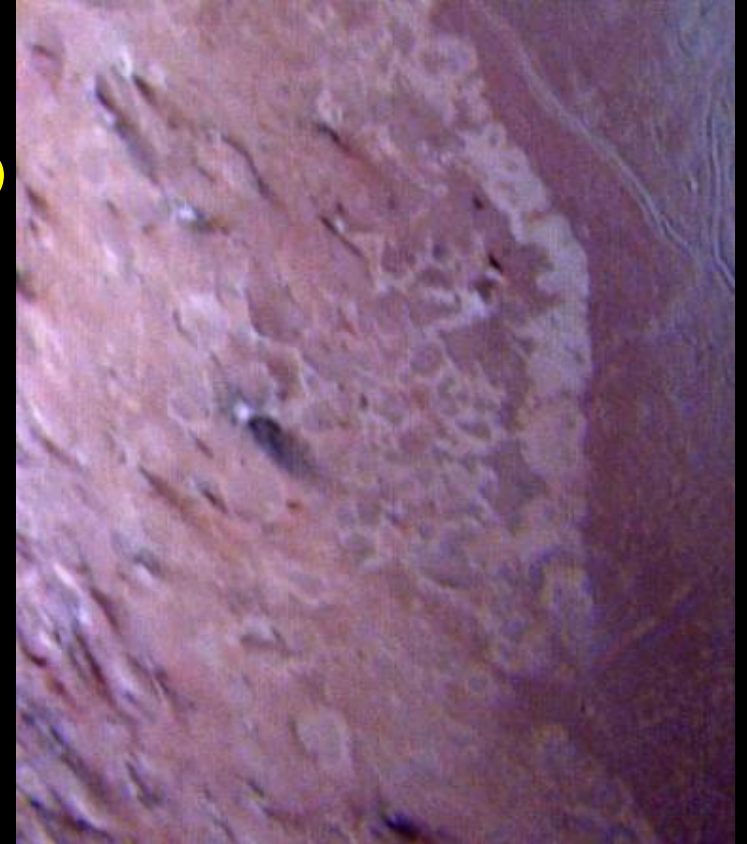


Image: <http://photojournal.jpl.nasa.gov/catalog/PIA02214>

Pluto

P

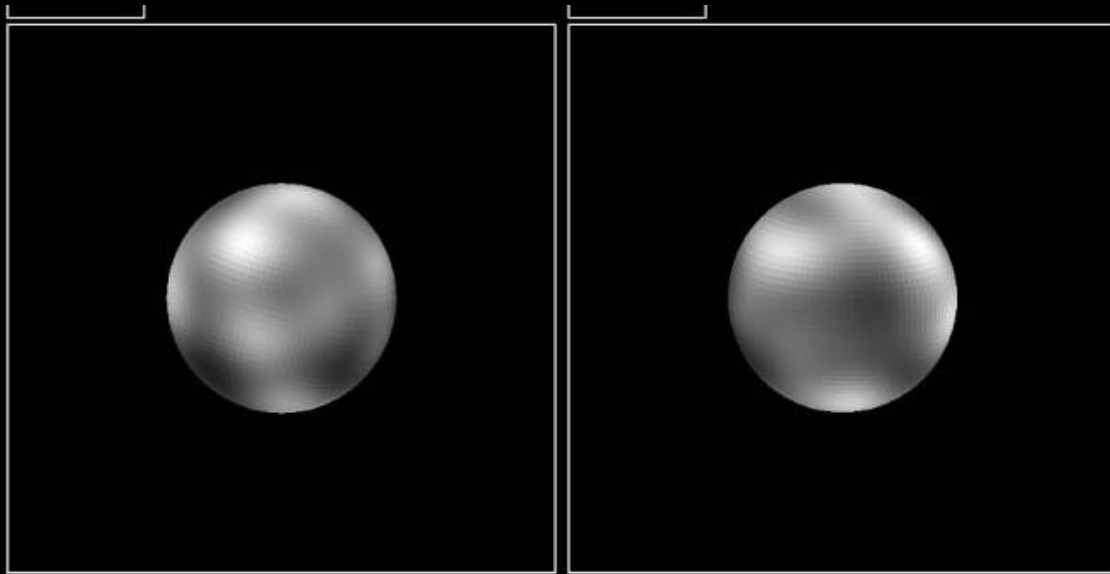


Image from <http://hubblesite.org/newscenter/archive/releases/solar%20system/2006/29/image/a/format/web/>

Pluto

- Diameter - 1,413 miles (2274 km) - $\frac{2}{3}$ size of Earth's Moon
- Rotation: $6 \frac{1}{3}$ days
- Orbit: 248 years highly elliptical
- Sometimes is inside Neptune's orbit (for ~20 yrs)
- Light from Sun takes 4.5 hours to reach it
- Surface of water and methane ice, frozen nitrogen
- When closest to the Sun, heat produces an thin atmosphere

**Calculated in 1927-29 by many
Discovered by Clyde Tombaugh 19**



Pluto

HST • FOC

PRC96-09a • ST ScI OPO • March 7, 1996 • A. Stern (SwRI), M. Buie (Lowell Obs.), NASA, ESA

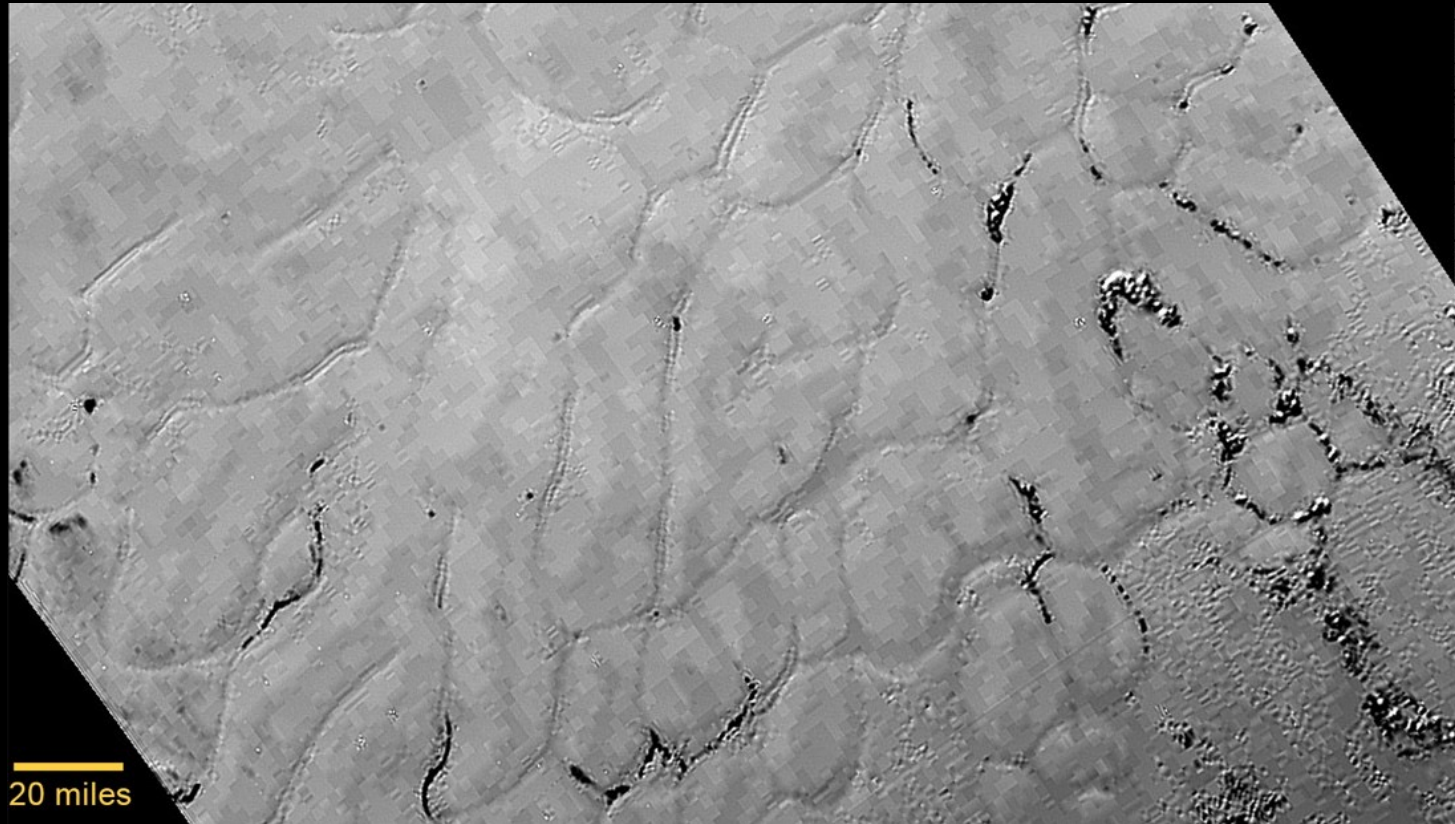
At Last!



The Mountains of Pluto



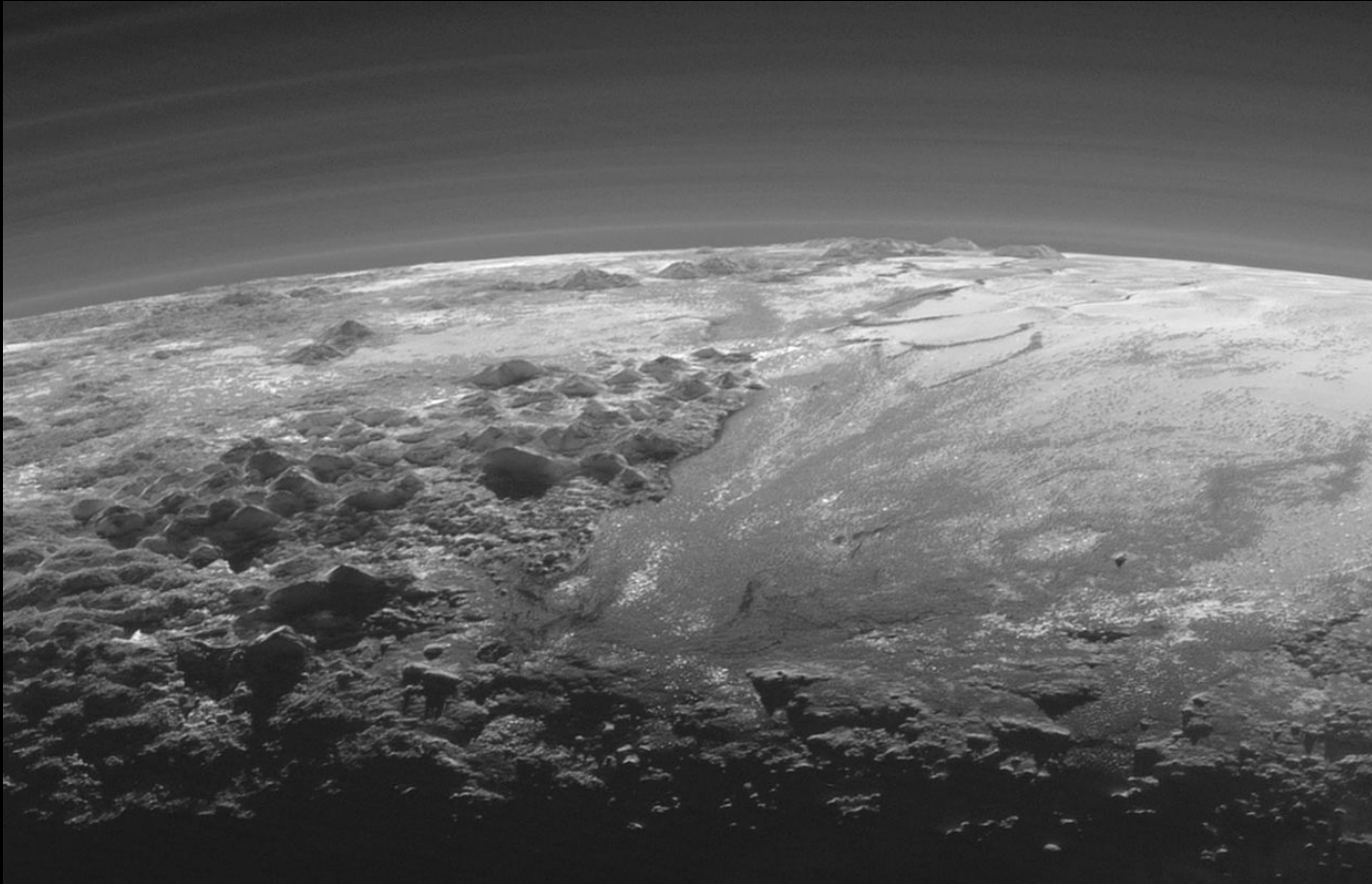
Ice fields on Pluto



A view of an active atmosphere



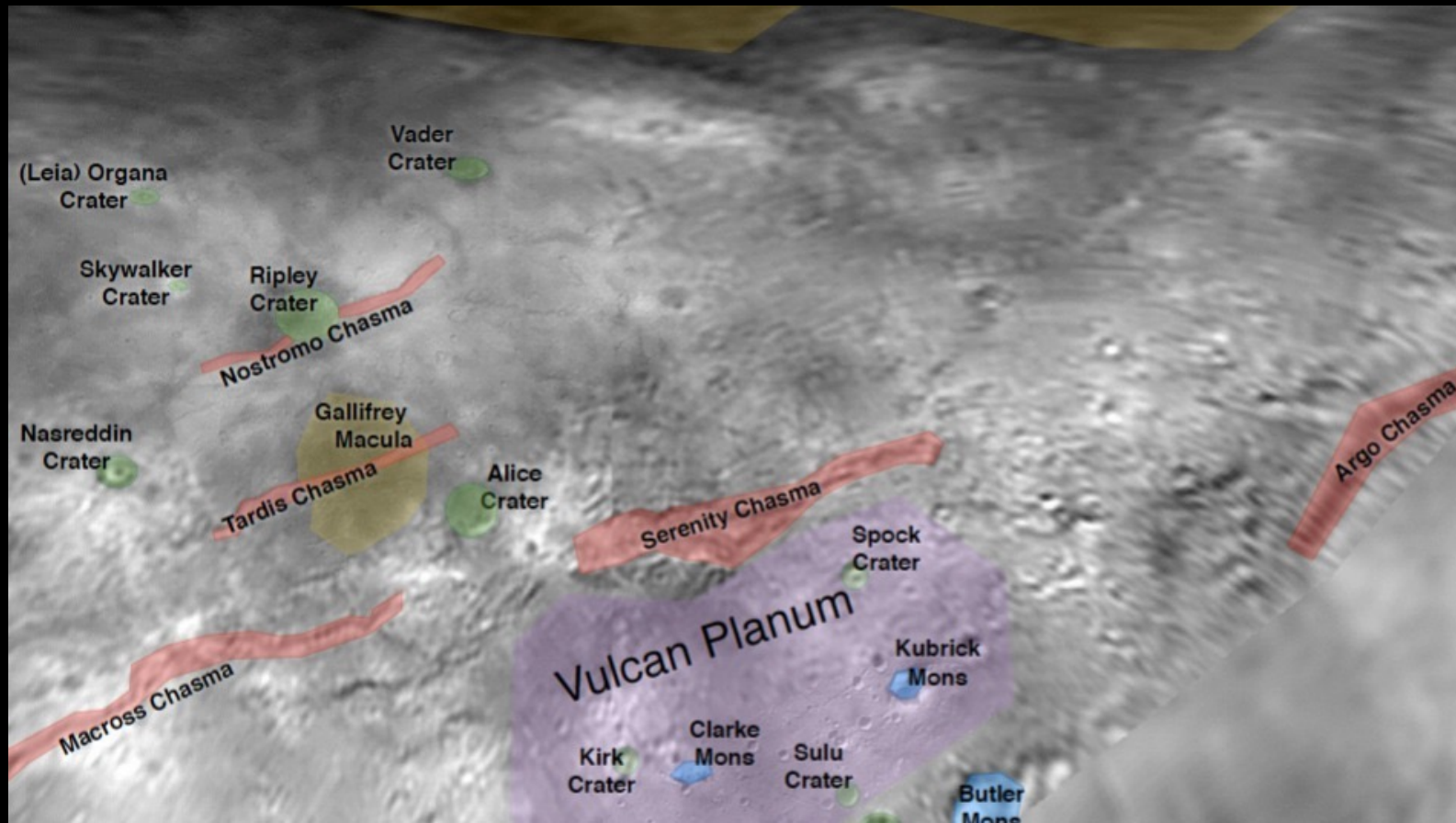
What a view!



Charon

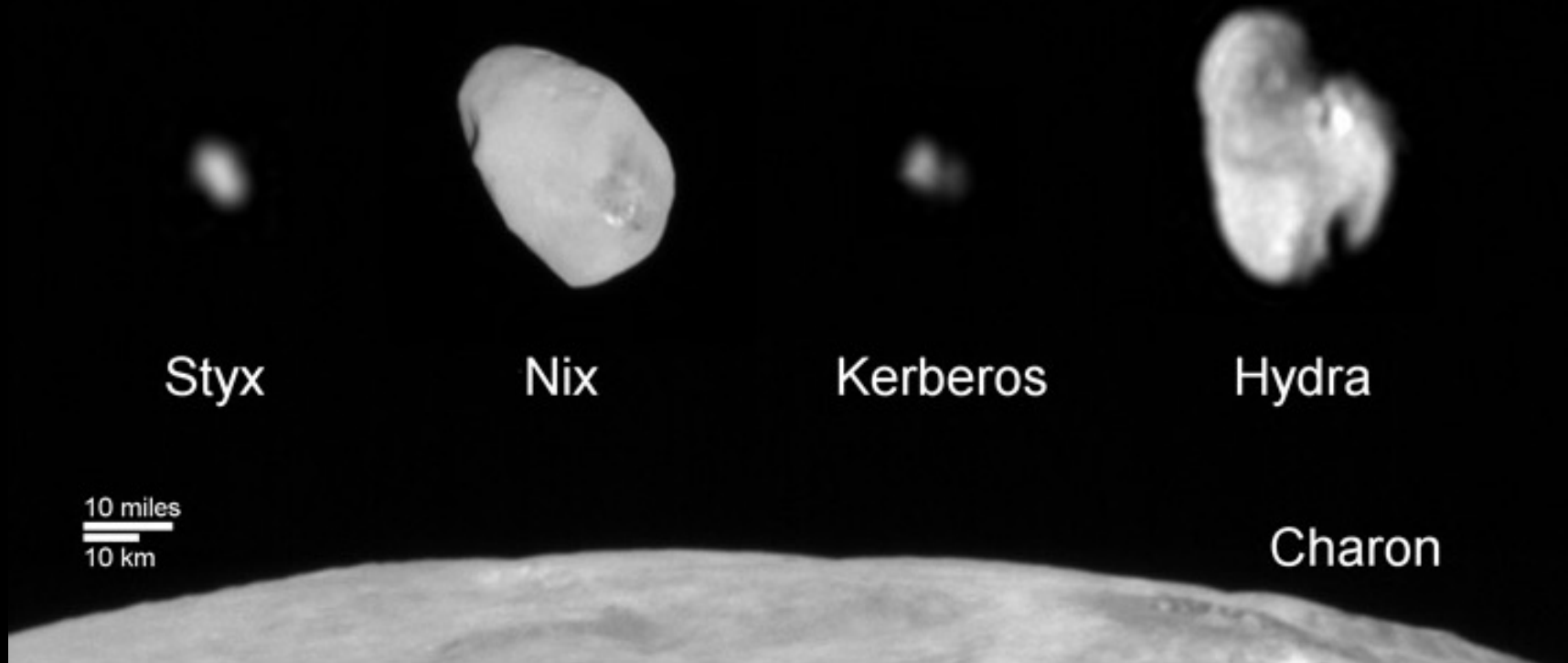


A map of Charon



All names are tentative

A least 5 moons



Is Pluto a Planet?

What Makes a Planet a Planet?

According to the IAU:

- Orbits the Sun
- Round
- Has “cleared out” its orbit (??)

Is Pluto a Planet?

Yes

It has always been considered a planet

No

Very small
Very elliptical orbit
Out of plane of ecliptic
Same material as Kuiper belt objects?

Largest known trans-Neptunian objects (TNOs)



Size Comparison



Small Planet Survey

Kuiper Belt

Weywot



Quaoar



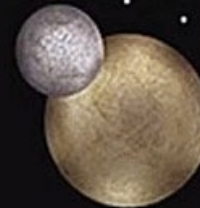
Sedna



Haumea



Makemake



Pluto



Eris

Dysnomia



(90482)
Orcus



(28978)
Ixion



(20000)
Varuna



2002
AW197

Asteroid Belt



(1) Ceres



(2) Pallas



(4) Vesta

Scale
1000 km

Comets

- 'Dirty snowballs' - small objects of ice, gas, dust, traces of organic material



Comet Parts

Nucleus, Coma and
Dust tail – white, reflects sun.
600,000 to 6 million miles long

Ion tail – Solar UV breaks down CO
gas, making them glow blue. As long
as 100 million miles long!

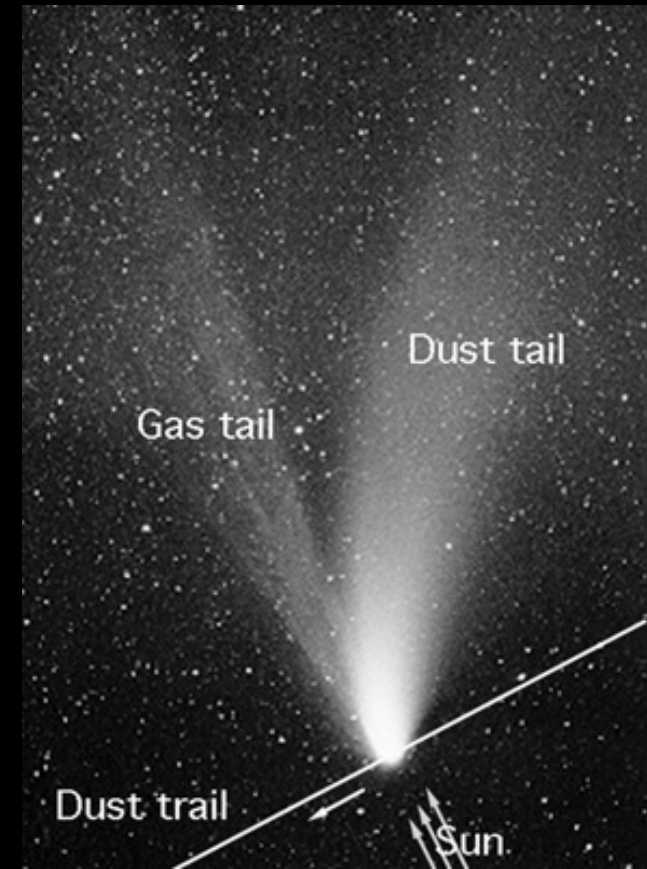
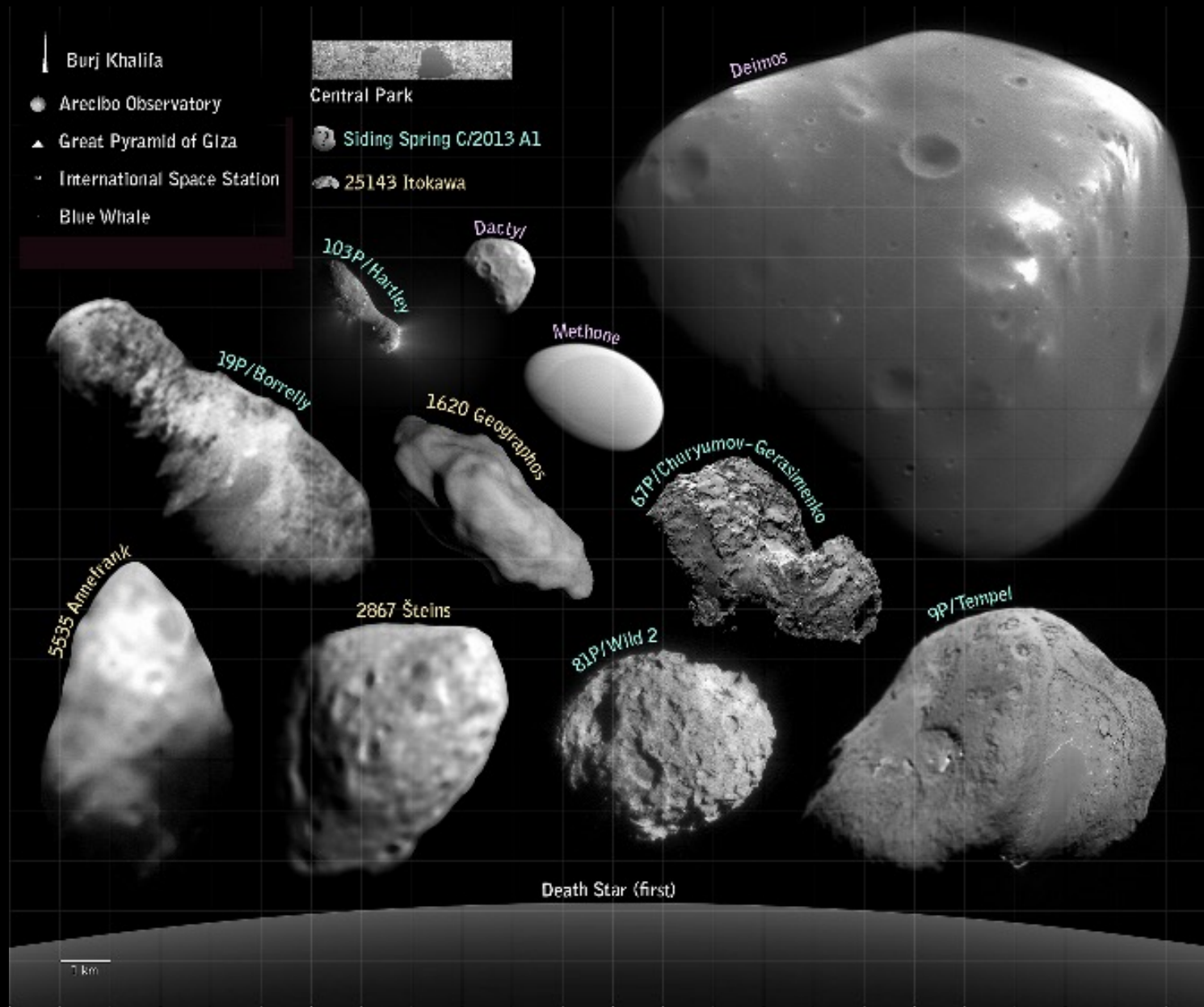
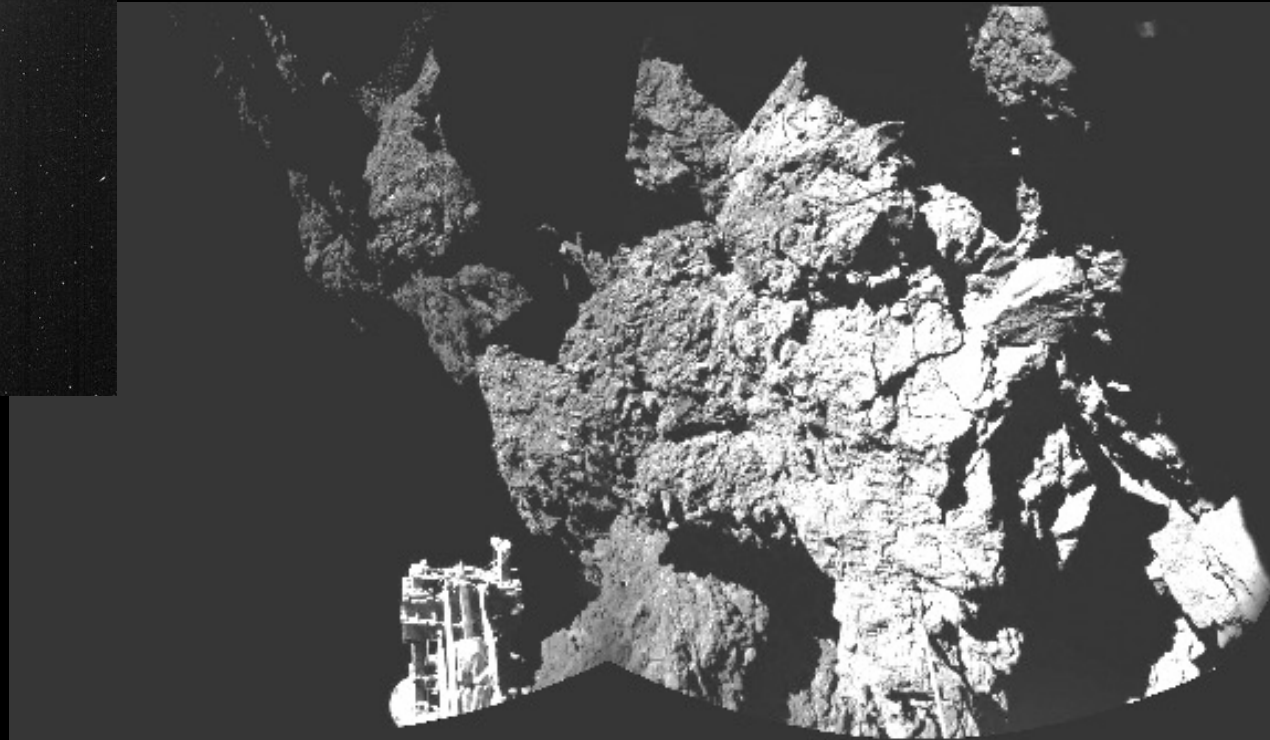
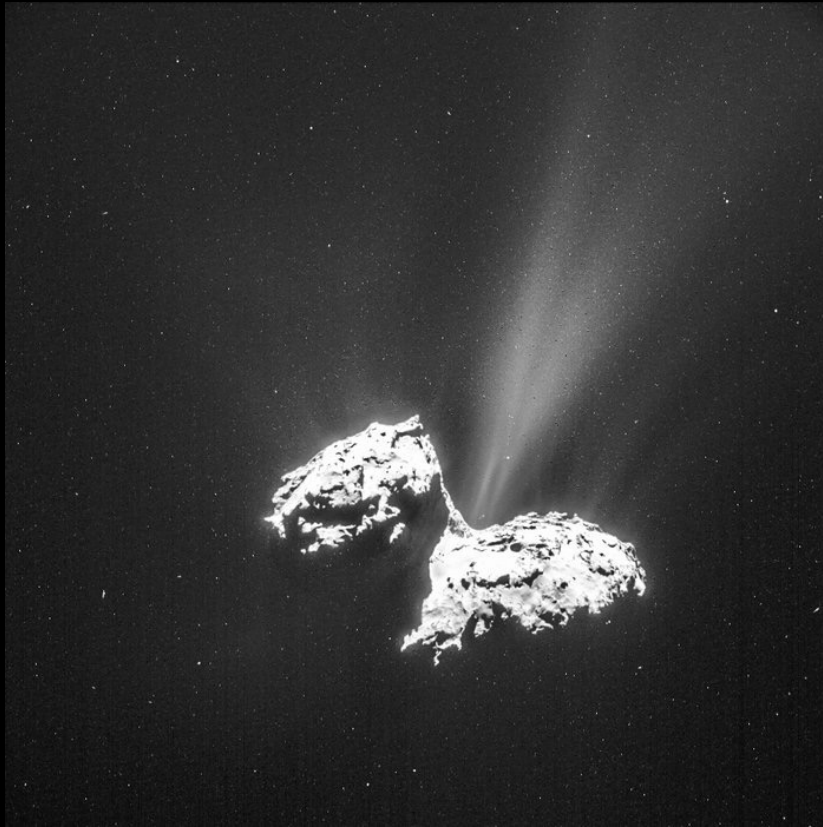


Image credit: K. Jobse, P. Jenniskens and NASA Ames Research Center
http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=903

Comets from Spacecraft



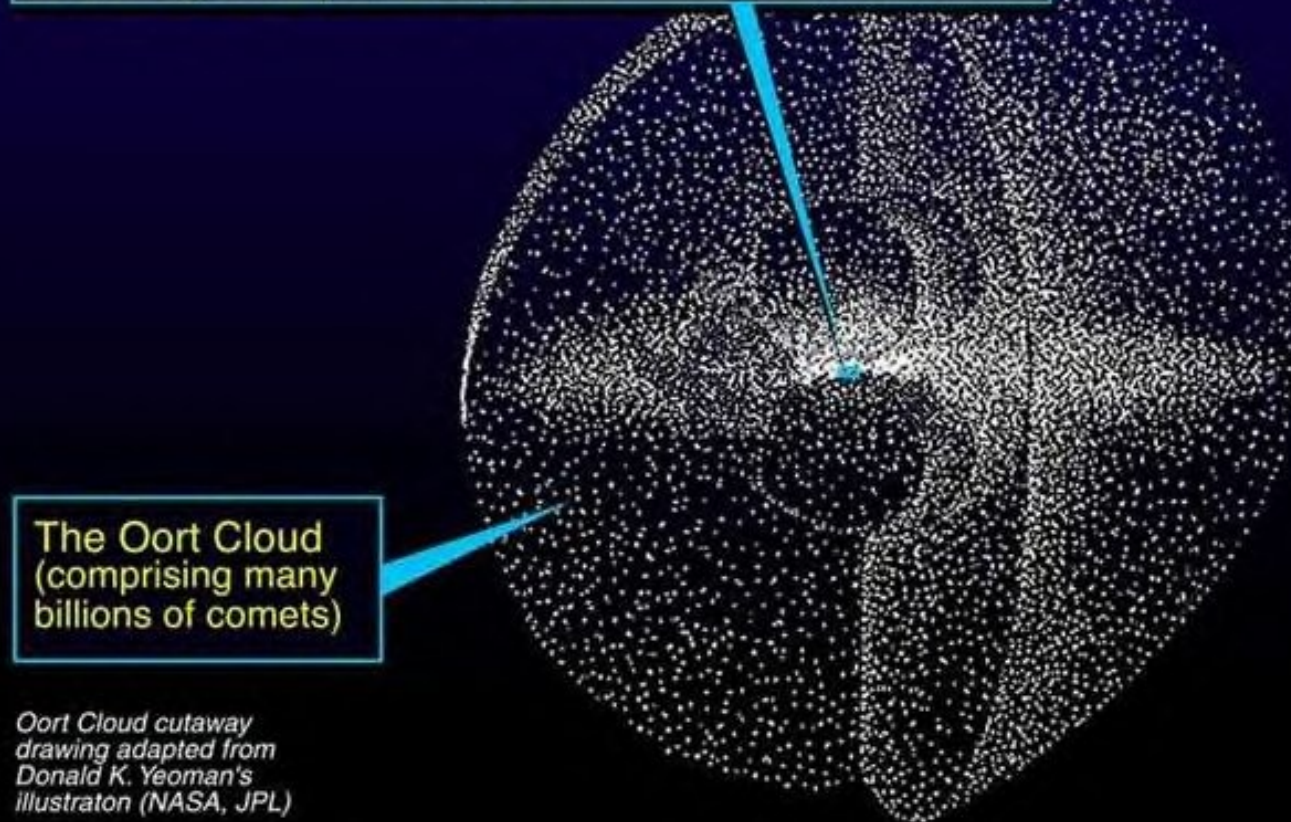
Comet p/67 from Rosetta and Philae



From Voorhees State Park



The Source of Comets



The Explorer's View

