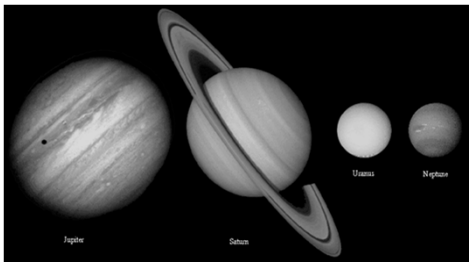
Chapter 14

Jupiter and Saturn

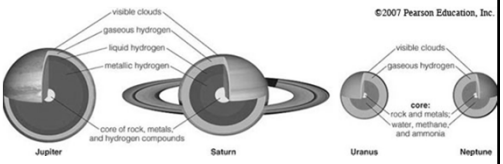
The Outer Planets



The Jovian planets – Jupiter, Saturn, Uranus and Neptune.

http://abyss.uoregon.edu/~js/images/jovian_worlds.gif

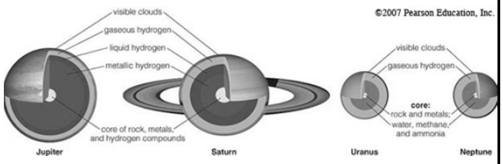
The Outer Planets (2)



Jupiter and Saturn have liquid metallic hydrogen in their interiors, have rings, emit more energy than they absorb from the sun and have belt and zone circulation.

http://lasp.colorado.edu/education/outerplanets/giantplanets_interiors.php

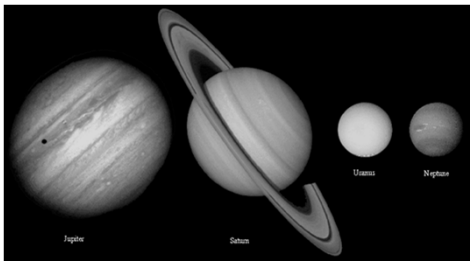
The Outer Planets (3)



Uranus and Neptune have interiors with gaseous hydrogen and a rock and metal core, but no metallic hydrogen.

http://lasp.colorado.edu/education/outerplanets/giantplanets_interiors.php

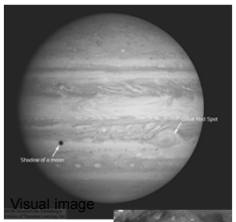
The Outer Planets (4)



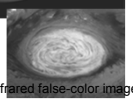
All of the outer planets have extensive satellite systems, with many moons of many different sizes.

http://abyss.uoregon.edu/~js/images/jovian_worlds.gif

Jupiter



Visual image



Infrared false-color image

Largest and most massive planet in the solar system:

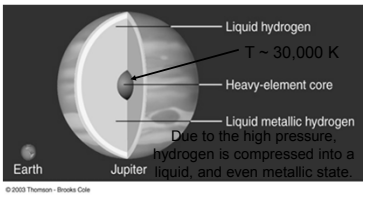
Contains almost ¾ of all planetary matter in the solar system.

Most striking features visible from Earth: Multi-colored cloud belts

Explored in detail by several space probes: Pioneer 10, Pioneer 11, Voyager 1, Voyager 2, Galileo

Jupiter's Interior

From radius and mass → Average density of Jupiter ≈ 1.34 g/cm^3
=> Jupiter can not be made mostly of rock, like Earthlike planets.
→ Jupiter consists mostly of hydrogen and helium.



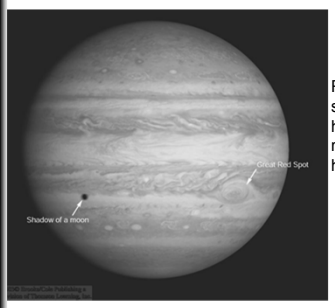
Due to the high pressure, hydrogen is compressed into a liquid, and even metallic state.

The Chemical Composition of Jupiter and Saturn

Composition of Jupiter and Saturn (by mass)

Molecule	Jupiter (%)	Saturn (%)
H_2	78	88
He	19	11
H_2O	0.0001	—
CH_4	0.2?	0.6
NH_3	0.5?	0.2

Jupiter's Rotation



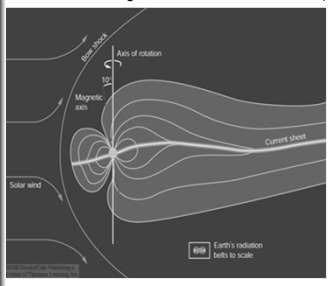
Jupiter is the most rapidly rotating planet in the solar system:

Rotation period slightly less than 10 hr., and the center rotates faster than the higher latitudes.

Centrifugal forces stretch Jupiter into a markedly oblate shape.

Jupiter's Magnetic Field

Discovered through observations of decimeter (radio) radiation



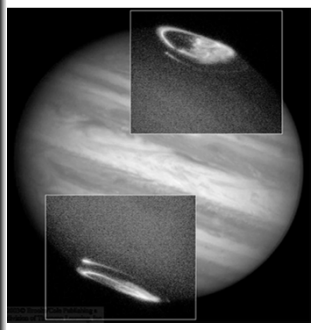
Magnetic field at least 10 times stronger than Earth's magnetic field.

Magnetosphere over 100 times larger than Earth's.

Extremely intense radiation belts:

Very high energy particles can be trapped; radiation doses corresponding to ~ 100 times lethal doses for humans!

Aurorae on Jupiter



Just like on Earth, Jupiter's magnetosphere produces aurorae concentrated in rings around the magnetic poles.

~ 1000 times more powerful than aurorae on Earth.

Jupiter's Atmosphere

Jupiter's liquid hydrogen ocean has no surface:

Gradual transition from gaseous to liquid phases as temperature and pressure combine to exceed the critical point.

Jupiter shows limb darkening → hydrogen atmosphere above cloud layers.

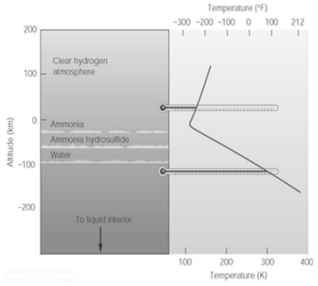
Only very thin atmosphere above cloud layers;

transition to liquid hydrogen zone ~ 1000 km below clouds.

Jupiter's Atmosphere (2): Clouds

Three layers of clouds:

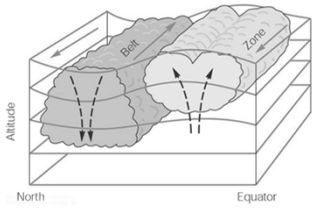
1. Ammonia (NH_3) crystals
2. Ammonia hydrosulfide
3. Water crystals



The Cloud Belts on Jupiter

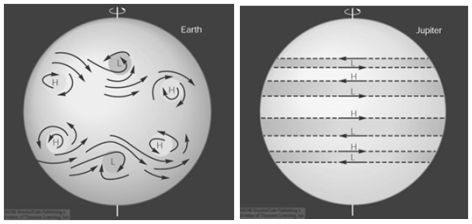
Dark belts and bright zones.

Zones higher and cooler than belts; high-pressure regions of rising gas.



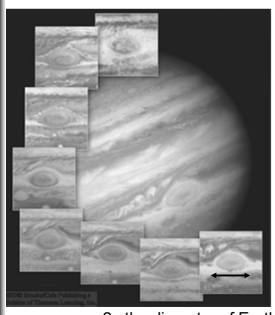
The Cloud Belts on Jupiter (2)

Just like on Earth, high-and low-pressure zones are bounded by high-pressure winds.



Jupiter's cloud belt structure has remained unchanged since humans began mapping them.

The Great Red Spot



~ 2x the diameter of Earth

Several bright and dark spots mixed in with cloud structure.

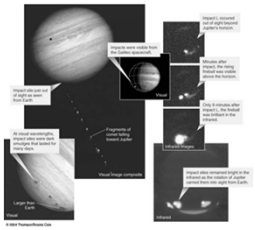
Largest and most prominent: The Great Red Spot.

Has been visible for over 330 years.

Formed by rising gas carrying heat from below the clouds, creating a vast, rotating storm.

Comet Impacts on Jupiter

Impact of 21 fragments of comet SL-9 in 1994



Visual: Impacts seen for many days as dark spots

Impacts occurred just behind the horizon as seen from Earth, but came into view about 15 min. later.

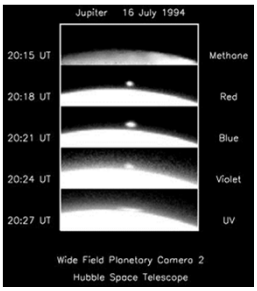
Impact sites appeared very bright in the infrared.

Impacts released energies equivalent to a few megatons of TNT (Hiroshima bomb: ~ 0.15 megaton)!

Comet Impacts on Jupiter (2)

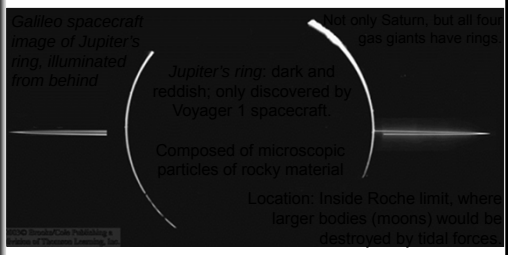
Impact of fragment A created a fireball above the planet as imaged by the HST.

Spectroscopic studies revealed absorption lines in the Jovian spectrum due to diatomic sulfur (S_2), carbon disulfide (CS_2), ammonia (NH_3) and hydrogen sulfide (H_2S), along with Fe, Mg, and Si.

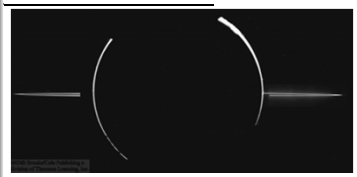


http://hubblesite.org/newscenter/archive/releases/1994/30/image/a/format/web/

Jupiter's Ring

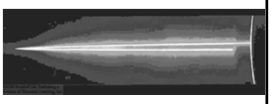


Jupiter's Ring



Rings must be constantly re-supplied with new dust.

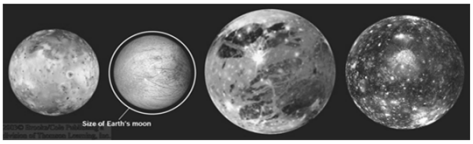
Ring material can't be old because radiation pressure and Jupiter's magnetic field force dust particles to spiral down into the planet.



Jupiter's Family of Moons

Over two dozen moons known now; new ones are still being discovered.

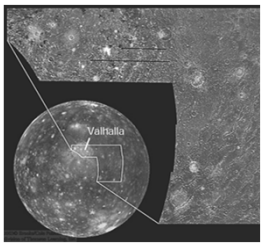
Four largest moons already discovered by Galileo: The Galilean moons



Io Europa Ganymede Callisto

Callisto: The Ancient Face

Tidally locked to Jupiter, like all of Jupiter's moons.



Av. density: 1.79 g/cm^3

→ composition: mixture of ice and rocks

Dark surface, heavily pocked with craters.

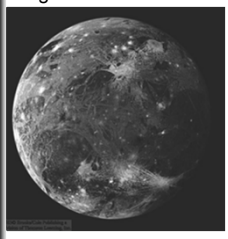
No metallic core: Callisto never differentiated to form core and mantle.

→ No magnetic field.

Layer of liquid water, ~ 10 km thick, ~ 100 km below surface, probably heated by radioactive decay.

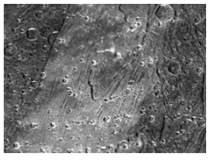
Ganymede: A Hidden Past

Largest of the 4 Galilean moons.



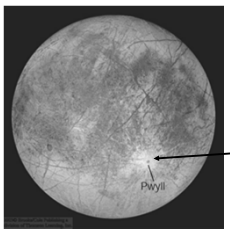
- Av. density = 1.9 g/cm^3
- Rocky core
- Ice-rich mantle
- Crust of ice

1/3 of surface old, dark, cratered; rest: bright, young, grooved terrain



Bright terrain probably formed through flooding when surface broke

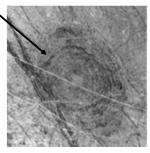
Europa: A Hidden Ocean



Av. density: 3 g/cm^3

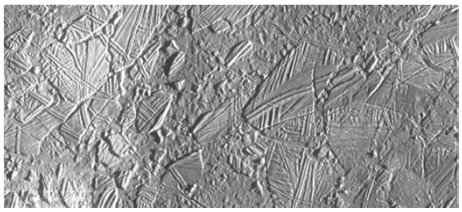
→ composition: mostly rock and metal; icy surface.

Close to Jupiter → should be hit by many meteoroid impacts; but few craters visible.



→ Active surface; impact craters rapidly erased.

The Surface of Europa

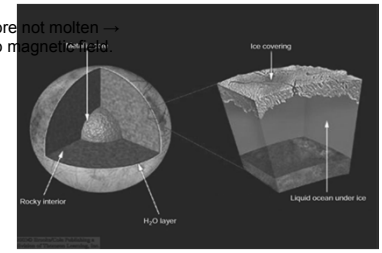


Cracked surface and high albedo (reflectivity) provide further evidence for geological activity.

The Interior of Europa

Europa is too small to retain its internal heat → Heating mostly from tidal interaction with Jupiter.

Core not molten → No magnetic field.



Europa has a liquid water ocean ~ 15 km below the icy surface.

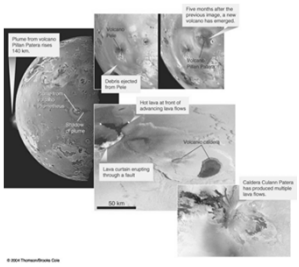
Io: Bursting Energy

Most active of all Galilean moons; no impact craters visible at all.

Over 100 active volcanoes!

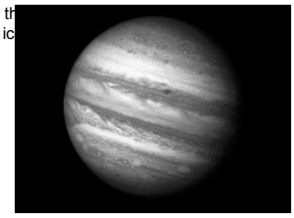
Activity powered by tidal interactions with Jupiter.

Av. density = 3.55 g/cm^3 → Interior is mostly rock.



The History of Jupiter

• Formed from cold gas in th outer solar nebula, where ic were able to condense.

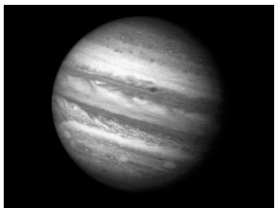


• Rapid growth

• Soon able to trap gas directly through gravity

• Heavy materials sink to the center

The History of Jupiter



• In the interior, hydrogen becomes metallic (very good electrical conductor)

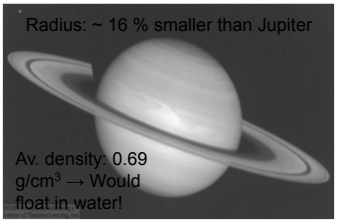
• Rapid rotation → strong magnetic field

• Rapid rotation and large size → belt-zone cloud pattern

• Dust from meteorite impacts onto inner moons trapped to form ring

Saturn

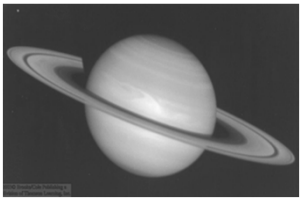
Mass: ~ 1/3 of mass of Jupiter



Rotates about as fast as Jupiter, but is twice as oblate → No large core of heavy elements.

Saturn

Mostly hydrogen and helium; liquid hydrogen core.



Saturn radiates ~ 1.8 times the energy received from the sun.

Probably heated by liquid helium droplets falling towards center.

Saturn-Cassini

Backlit image of Saturn and its rings.

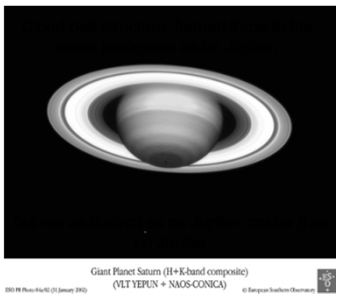
http://saturn.jpl.nasa.gov/photos/halloffame/

Saturn – Cassini (2)

An amazing view showing the shadow of Saturn's complex ring system.

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

Saturn's Atmosphere



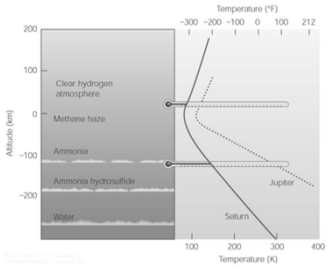
Giant Planet Saturn (H+K-band composite)
(VLT YEPUN + NAOS-CONICA)

Saturn's Atmosphere (2)

Three-layered cloud structure, just like on Jupiter

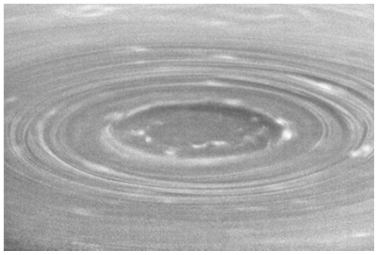
Main difference to Jupiter:

Fewer wind zones, but much stronger winds than on Jupiter:



Winds up to ~ 500 m/s near the equator!

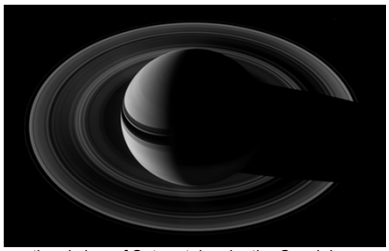
The Yet Yawning Gulf



The "Yet Yawning Gulf", a giant hurricane-like storm on the south pole of Saturn.

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

Saturn – Cassini, Rings



An exceptional view of Saturn taken by the Cassini spacecraft. The Cassini-Huygens mission has been one of the most successful (2004-present).

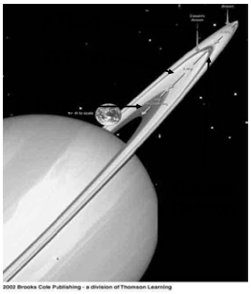
http://saturn.jpl.nasa.gov/photos/halloffame/

Saturn's Rings

Ring consists of 3 main segments: A, B, and C Ring

separated by empty regions: divisions

Rings can't have been formed together with Saturn because material would have been blown away by particle stream from hot Saturn at time of formation.



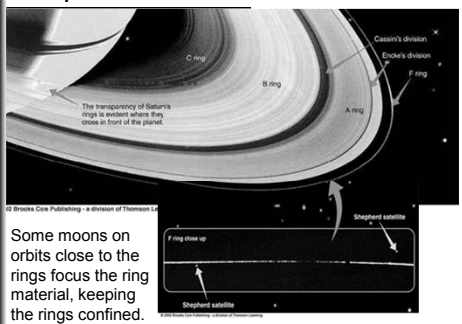
Rings must be replenished by fragments of passing comets & meteoroids.

Composition of Saturn's Rings

Rings are composed of ice particles

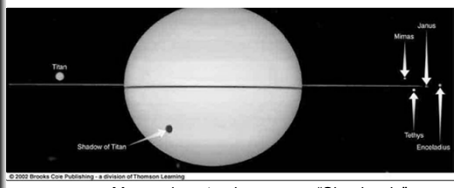
moving at large velocities around Saturn, but small relative velocities (all moving in the same direction).

Shepherd Moons



Some moons on orbits close to the rings focus the ring material, keeping the rings confined.

Divisions and Resonances

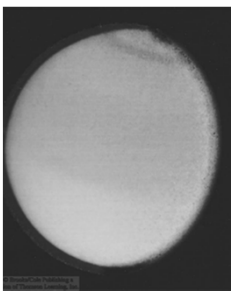


Moons do not only serve as "Shepherds".

Where the orbital period of a moon is a small-number fractional multiple (e.g., 2:3) of the orbital period of material in the disk ("resonance"), the material is cleared out

→ Divisions

Titan

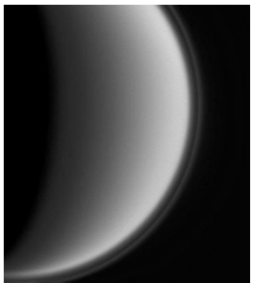


- About the size of Jupiter's moon Ganymede.
- Rocky core, but also large amount of ice.
- Thick atmosphere, hiding the surface from direct view.

Table 23-3 Organic Compounds Detected on Titan by a Voyager Infrared Spectrometer

C_2H_6	Ethane
C_2H_2	Acetylene
C_2H_4	Ethylene
C_3H_4	Methylacetylene
C_3H_8	Propane
C_4H_2	Diacetylene
HCN	Hydrogen cyanide
HC_3N	Cyanoacetylene
C_2N_2	Cyanogen

Titan

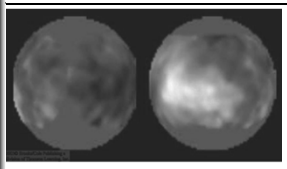


In 2004, the Cassini spacecraft arrived at Saturn with the probe Huygens.

This is a view of the methane-rich atmosphere of Titan from an early flyby of Cassini.

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

Titan's Atmosphere

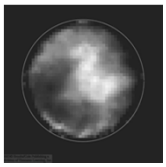


Because of the thick, hazy atmosphere, surface features were only visible in infrared images.

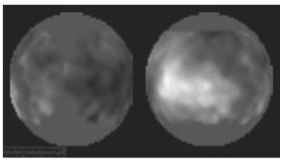
Many of the organic compounds in Titan's atmosphere may have been precursors of life on Earth.

Surface pressure: 50% greater than air pressure on Earth

Surface temperature: 94 K (-290 °F)



Titan's Atmosphere

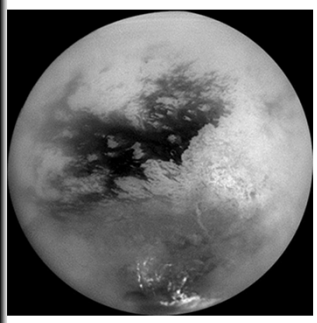


→ methane and ethane are liquid!

Methane is gradually converted to ethane in the atmosphere

→ Methane must be constantly replenished, probably through breakdown of ammonia (NH_3).

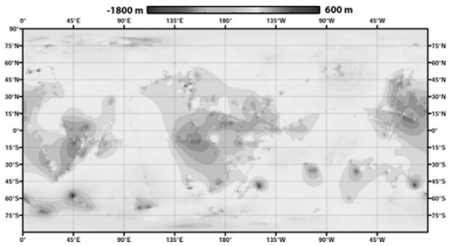
Titan



A high-resolution image of Titan, showing the clouds and some surface features.

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

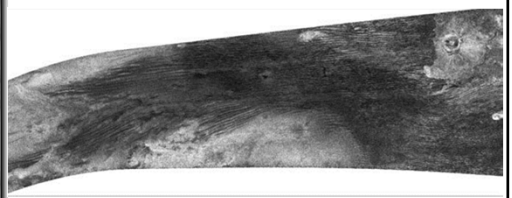
Titan



Radar map of Titan, done by Cassini between 2004 and 2011. Xanadu is the large elevated region in the center.

http://photojournal.jpl.nasa.gov/catalog/PIA16844/

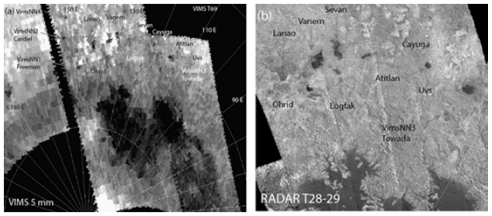
Titan



The dark lines in this image are linear dunes, similar to sand dunes on Earth in Egypt and Namibia. The dune fields on Titan encircle the moon between the latitudes of ~30 degrees north to ~30 degrees south, with the notable exception of the continent-sized Xanadu (bright hazy area to left). At upper right is the crater Ksa. Dunes, craters and large uplifted regions are major features of Titan.

http://photojournal.jpl.nasa.gov/catalog/PIA14500/

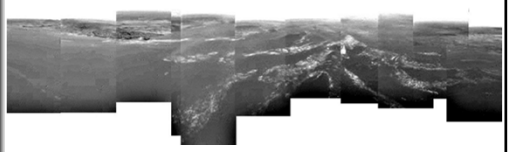
Titan



"Lake Country" on Titan. Methane lakes and rivers cross the surface of Titan. Ligeia Mare, about 50,000 square miles (125,000 square kilometers) in area, is the large lake near the bottom of both images.

http://photojournal.jpl.nasa.gov/catalog/PIA16844/

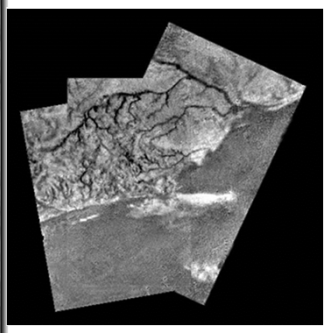
Titan



Composite image of the terrain surrounding Huygens during its descent onto the surface of Titan.

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

Titan

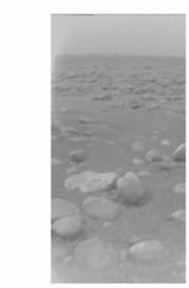


River channels on Titan's surface captured during Huygen's descent in January, 2005.

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

Titan

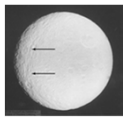
Stunning full-color image of Titan taken after Huygen's historic landing on Titan on January 14, 2005. "Rocks" are probably frozen water and hydrocarbon compounds.



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

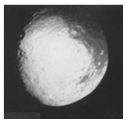
Saturn's Smaller Moons

Saturn's smaller moons formed of rock and ice; heavily cratered and appear geologically dead.



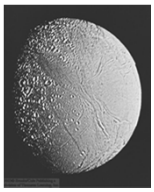
Tethys:

Heavily cratered; marked by 3 km deep, 1500 km long crack.



Iapetus:

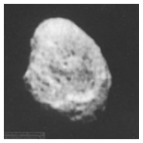
Leading (upper right) side darker than rest of surface because of dark deposits.



Enceladus:

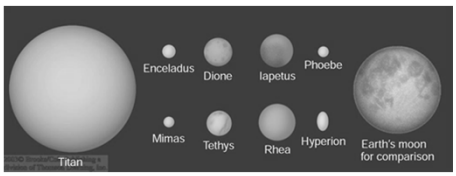
Possibly active; regions with fewer craters, containing parallel grooves, possibly filled with frozen water.

Saturn's Smaller Moons (2)



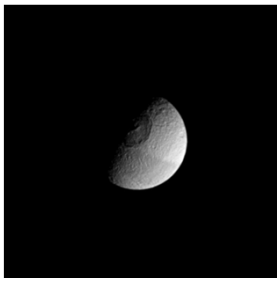
Hyperion: Too small to pull itself into spherical shape.

All other known moons are large enough to attain a spherical shape.



Tethys

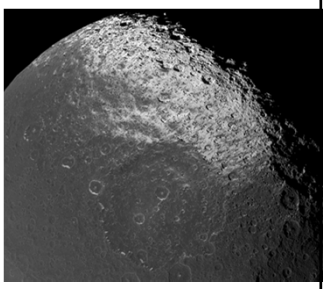
Huge crater on Tethys captured by Cassini in 2012. Lit terrain is on the leading hemisphere of Tethys (660 miles, or 1,062 kilometers across). A similar feature on Mimas gave it the name “Death Star”.



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

Iapetus

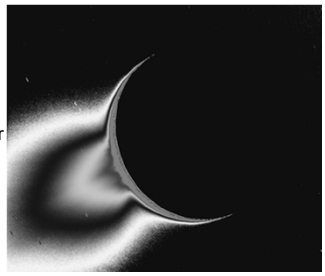
Iapetus showing its dark leading edge. Dark deposits are probably dust.



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

Enceladus

A false-color image of Enceladus showing an eruption of heated water near its south pole. Heat from tidal forces creates the unique geysers.



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

Enceladus

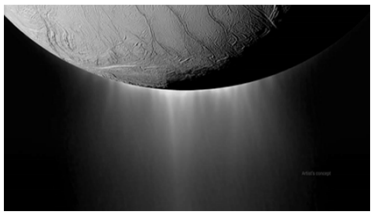
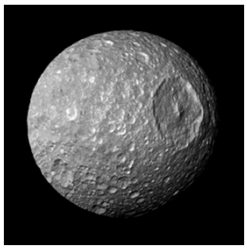


Image of Enceladus’ south pole geysers taken during close flyby on October 28, 2015.

https://www.nasa.gov/feature/jpl/deepest-ever-dive-through-enceladus-plume-completed/

Mimas

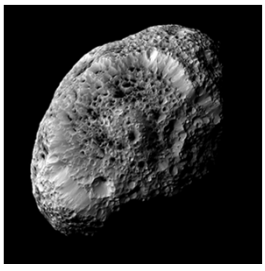
Mimas was nicknamed “The Death Star” because of this large crater. Mimas is 396 kilometers (246 miles) across, and the crater is 130 km (86 miles) across.



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

Hyperion

Sponge-like Hyperion (168 miles, or 270 kilometers across) has an irregular shape, and it tumbles through its orbit.



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

Phoebe

Phoebe was photograped by Cassini in 2004. The mean radius of Phoebe is only 106.8 kilometers (66 miles).

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

Rhea

Rhea is 949 miles, or 1,528 kilometers across. The surface of Saturn's moon Rhea bears witness to its violent history. On some of Rhea's terrains, craters are so densely packed that they lie on top of each other, newer impacts often erasing the older craters.

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

The Origin of Saturn's Satellites

- No evidence of common origin, as for Jupiter's moons.
- Probably captured icy planetesimals.
- Moons interact gravitationally, mutually affecting each other's orbits.
- Co-orbital moons (orbits separated by only 100 km) periodically exchange orbits!
- Small moons are also trapped in Lagrange points of larger moons Dione and Tethys.