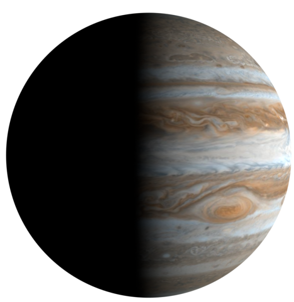
Outer Solar System

1. Jupiter

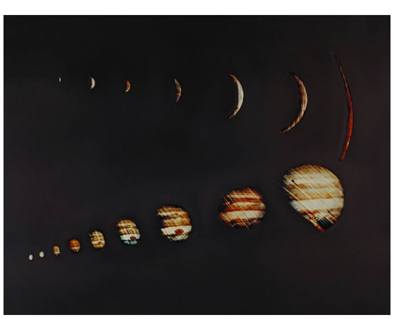
Jupiter has been observed since the 7th or 8th century BC.



Jupiter, half illuminated

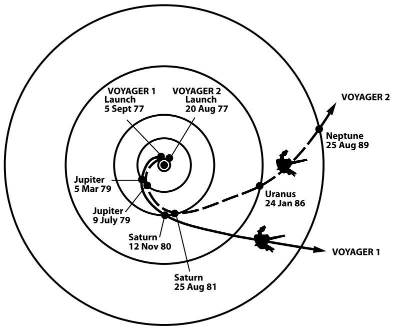
Based on textures from NASA/JPL/Space Science Institute

The first flyby was in 1972.



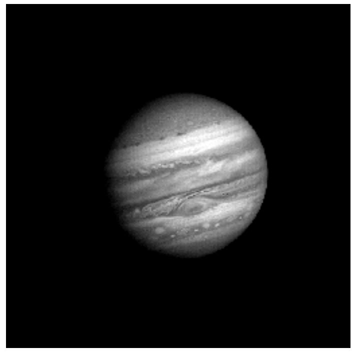
Pioneer 10 passing Jupiter in 1972

NASA



Voyager's Grand Tour

By Voyager_Path.jpg: created by NASAderivative work: Hazmat2 (talk) - Original from http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=2143This file was derived fromVoyager Path.jpg:, Public Domain, https://commons.wikimedia.org/w/index.php?curid=18049439



Voyager 1 approaching Jupiter in 1979

1.1 Pressure & Density & size

Let's start with Hydrostatic equilibrium

$$\frac{dP}{dr} = -\frac{GM_r\rho}{r^2} \tag{1}$$

where M_r is the mass contained within a radius r.

We can find the total mass within a radius r by integrating the density times the volume of a single shell:

$$M_r = 4\pi \int_0^r \rho(r) r^2 dr \tag{2}$$

To a first approximation, let us take the average density which makes is a constant: $\rho(r) = \bar{\rho}$ Thus we can do the integral above and get

$$M_r = \frac{4\pi}{3}\bar{\rho} r^3 \tag{3}$$

allowing us to rewrite hydrostatic equilibrium as:

$$dP = -\frac{4\pi}{3}\bar{\rho}^2 G r dr \tag{4}$$

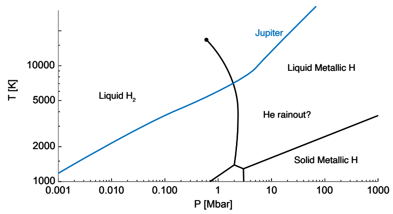
We can integrate both sides of this, going from the center out to R:

$$\int_{P_c}^0 dP = -\frac{4\pi}{3}\bar{\rho}^2 G \int_0^R r dr \tag{5}$$

and then obtain an expression for the pressure at the center

$$P_c = \frac{2\pi}{3}\bar{\rho}^2 G R^2 \tag{6}$$

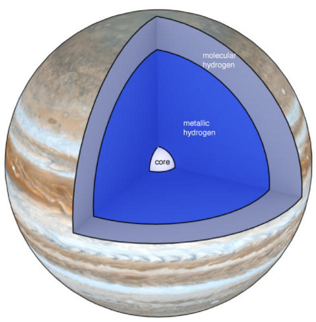
The center of Jupiter based on this comes out to be 11.2 times that of the earth's core, or 10^7 atm



The Phase Diagram of Hydrogen

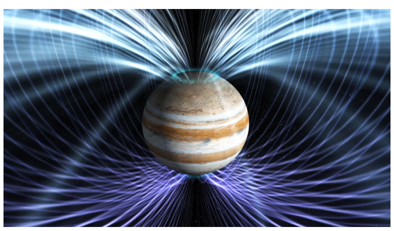
Based on Figure 10.11 - Ryden & Peterson

Hydrogen will become a metal at very high pressures.



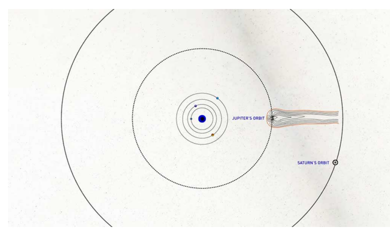
The internal structure of Jupiter

1.2 Jupiter's Magnetosphere



Artistic Impression of Jupiter's Magnetic Field lines

NASA's Goddard Space Flight Center, Images courtesy of NASA/JPL/SwRI



Jupiter's magnetic field extends up to nearly 2 million miles from the planet. Its influence likely reaches beyond the orbit of Saturn.

NASA's Goddard Space Flight Center Images courtesy of NASA/JPL/SwRI

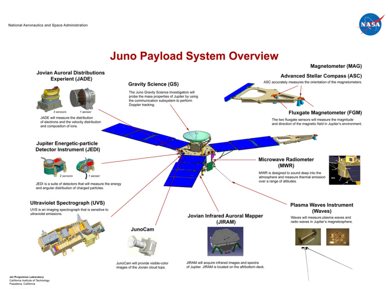
Jupiter's Auroras from the Juno spacecraft.

NASA/JPL-Caltech/SwRI/Bertrand Bonfond

Our understanding of the Auroras is still being developed.

1.3 Juno Mission

By National Aeronautics and Space Administration (NASA) - Juno Mission to Jupiter (2010 Artist's Concept) at the official NASA website., Public Domain, https://commons.wikimedia.org/w/index.php?curid=41408653



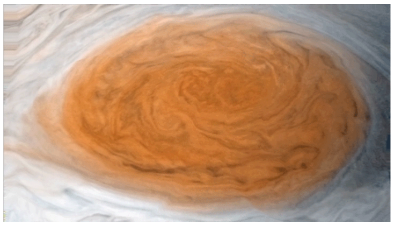
The instruments onboard Juno.

Credit: NASA/JPL

The cube in between the dish and the main hexagonal region is the Juno Radiation Vault.

Juno Gallery →

1 cm thick titanium prevents some radiation from reaching the sensitive electronics inside the vault.



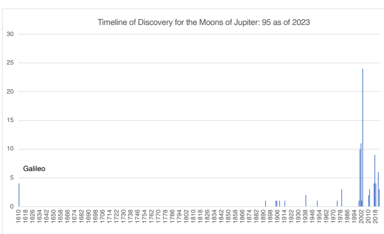
Winds around Jupiter's Great Red Spot are simulated in this JunoCam view that has been animated using a model of the winds there. The wind model, called a velocity field, was derived from data collected by NASA's Voyager spacecraft and Earth-based telescopes.

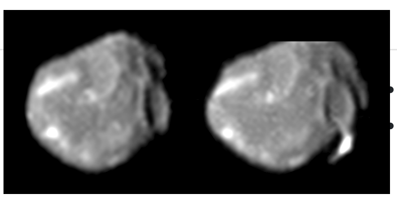
NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstadt/Justin Cowart

1.4 Jovian Satellites

First four discovered by Galileo in 1610

For a long time, there were only 4... Now we have found ~~69~~ ~~79~~ ~~80~~ 95.





Amalthea, as photographed by the Galileo spacecraft. The left photograph is from August 12, 1999 at a range of 446,000 kilometers. The right photo is from November 26, 1999 at a range of 374,000.

By NASA / JPL - http://photojournal.jpl.nasa.gov/catalog/PIA02532, Public Domain, https://commons.wikimedia.org/w/index.php?curid=176487

Amalthea

- Dimensions: 250 × 146 × 128 km
- Mean radius: 83.5±2.0 km

Not very big...

The pressure a the center of the moon will be given by:

$$P_c = \frac{2\pi}{3}\bar{\rho}^2 G R^2 \tag{7}$$

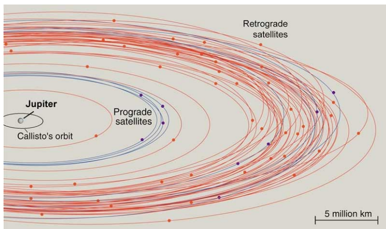
Whatever the moon is made out of will have a compression strength, S. If the pressure is comparable to this value, then the object will begin to become spherical:

$$\frac{2\pi}{3}\bar{\rho}^2 G R^2 \approx S \tag{8}$$

solving for R_{sph}

$$R_{\text{sph}} = \left(\frac{3S}{2\pi G}\right)^{1/2}\frac{1}{\bar{\rho}} \tag{9}$$

Material	Strength (S)	Density (kg/m^3)	R_{sph}
Iron	4×10^8	8000	210
Rock	2×10^8	3500	340
Iron	1×10^8	900	300

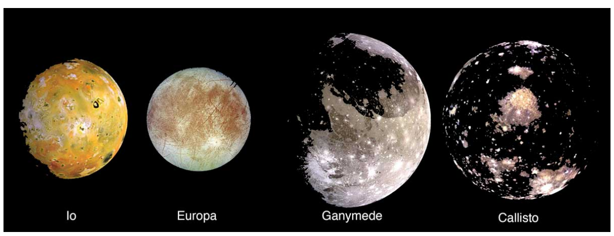


A lot of moons

ref

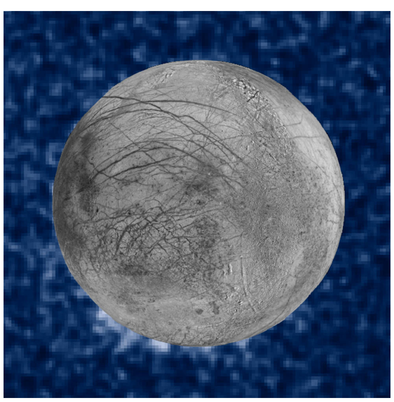
Nasa Eyes Link

The vast majority are rather small, 2-3 km in diameter, are farther out, have more eccentric orbits. Some are prograde, some retrograde.



The four Galilean Moons of Jupiter: left to right: Io, Europa, Ganymede, Callisto

NASA/JPL/DLR

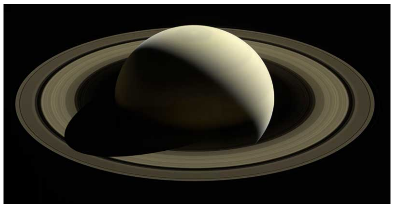


Possible water plume erupting from Europa's surface.

NASA/ESA/W. Sparks (STScI)/USGS Astrogeology Science Center

Europa

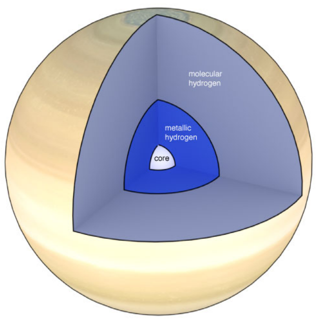
2. Saturn



Saturn and its rings.

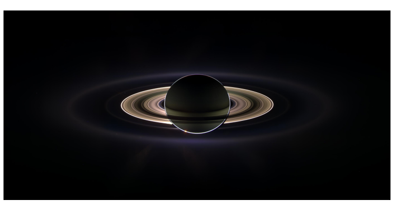
NASA/JPL-Caltech/Space Science Institute

Similar to Jupiter, but smaller.



The internal structure of Saturn

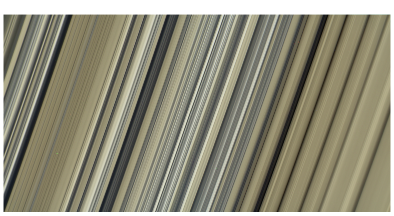
2.5 The Rings!



The rings of Saturn illuminated by the sun.

NASA/JPL/Space Science Institute

They are individual orbiting bodies, ranging in size from micrometers to about 10 meters. Mostly water-ice. They are very thin, < 10 meters.



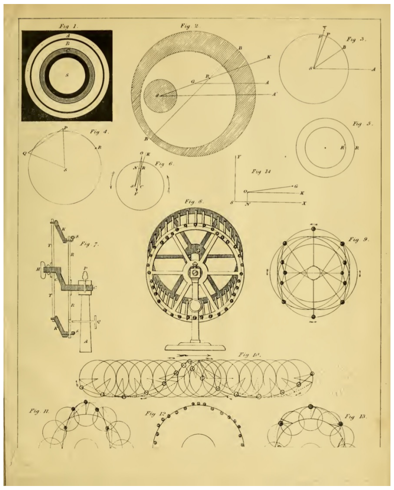
NASA/JPL-Caltech/Space Science Institute

About the rings

Origin is still being debated.

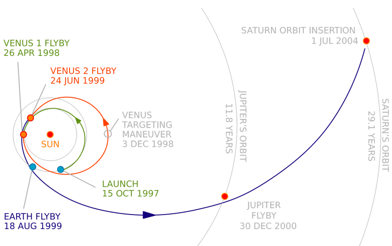
Theory A: Existing moon get smashed (either through tidal forces, or collision).

Theory B: Rings formed when Saturn did.



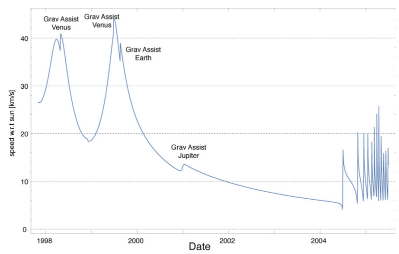
J.C. Maxwell - On the stability of the motion of Saturn's rings .

Cassini-Huygens



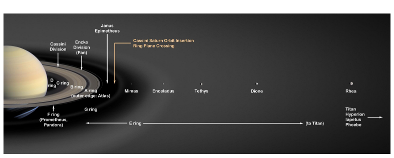
This graphic depicts Cassini's interplanetary flight path beginning with launch from Earth on 15 October 1997, followed by gravity assist flybys of Venus (26 April 1998 and 21 June 1999), Earth (18 August 1999), and Jupiter (30 December 2000). Saturn arrival was on 1 July 2004.

NASA / Jet Propulsion Laboratory - Caltech



Speed (heliocentric) of Cassini as a function of time.

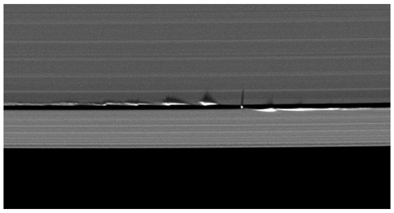
2.6 Saturn's Moons



This is an artist's concept of Saturn's rings and major icy moons.

NASA/JPL

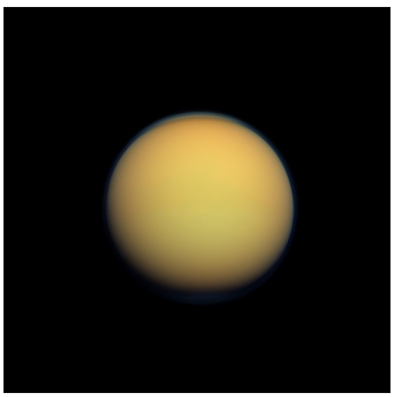
Daphnis and Pan are shepherd moons. They clear out a section of the rings.



Never-before-seen looming vertical structures created by the tiny moon Daphnis cast long shadows across the rings in this startling image taken as Saturn approaches its mid-August 2009 equinox.

NASA/JPL/Space Science Institute

2.7 Titan



Natural color view of Titan from the Cassini spacecraft.

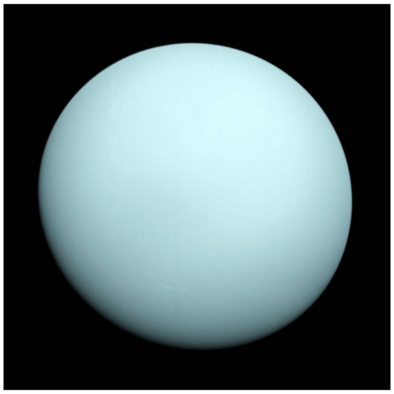
NASA/JPL-Caltech/Space Science Institute

In 2005, the Huygens probe landed on the surface of Titan. It is still the farthest landing away from earth.

The color x2 super-resolution image of the Titan's surface as seen by the Huygens probe.

ESA/NASA/JPL/University of Arizona; processed by Andrey Pivovarov

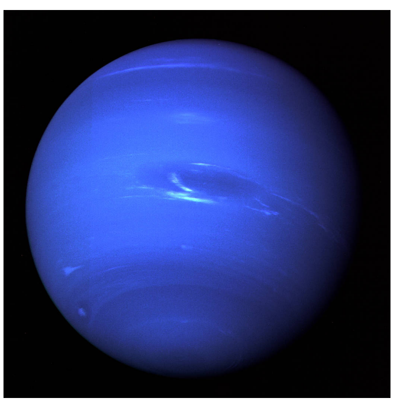
3. Uranus

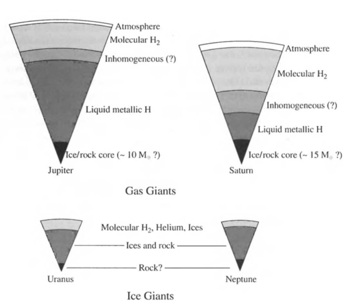


Arriving at Uranus in 1986, Voyager 2 observed a bluish orb with extremely subtle features. A haze layer hid most of the planet's cloud features from view.

Credits: NASA/JPL-Caltech

4. Neptune





Carroll and Ostlie, figure 21.6

5. Dwarf Planets

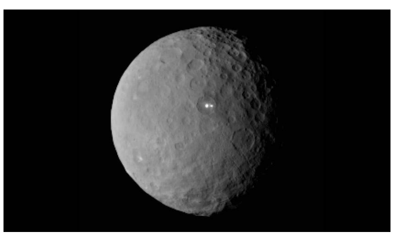
Pluto and its largest moon Charon.

Credits: NASA

5.8 Pluto

Pluto's Moons: Charon, Styx, Nix, Kerberos, Hydra

Ceres



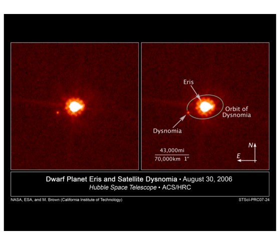
The dwarf Planet ceres.

NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Ceres lies between Mars and Jupiter in the asteroid belt.

Dawn spacecraft is in orbit. (ion drive)

Eris



The dwarf Eris and its Moon Dysnomia ceres.

https://hubblesite.org/contents/media/images/2007/24/2145-Image.html

6. Classification

Science starts out as a method of classifying things. Conifers vs. Deciduous. Alive vs. not Alive. Solid vs. Liquid. Planet vs Dwarf planet. (Planets used to just be considered 'wandering' stars.) As our tools and observations become more refined, usually with the help of Mathematics, our classifications and definitions can change. This is ok. If we stubbornly insist on making sure everything fits into nice neat and static categories, we can miss the bigger picture and structure of the world.

Let's consider the case of planets. For many centuries, it was easy. There were only five: Mercury, Venus, Mars, Jupiter and Saturn, and they all behaved similarly, so lumping them together was easy.