The Interior of Giant Planets

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Outline

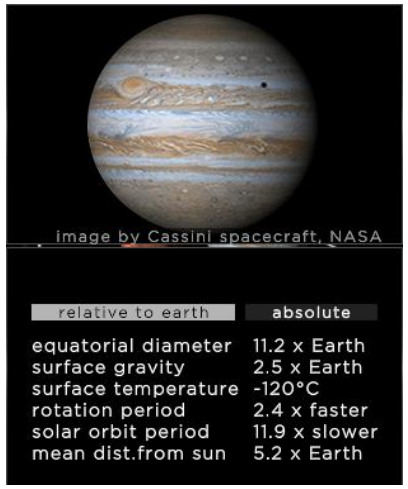
1. What is a planet?
2. Nuclear fusion
3. Properties of Jupiter
4. Summary
5. Sources

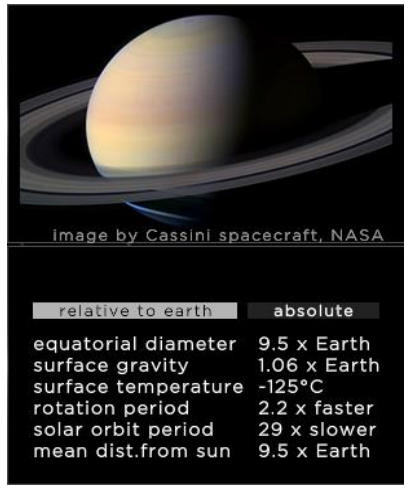
1. What is a Planet?

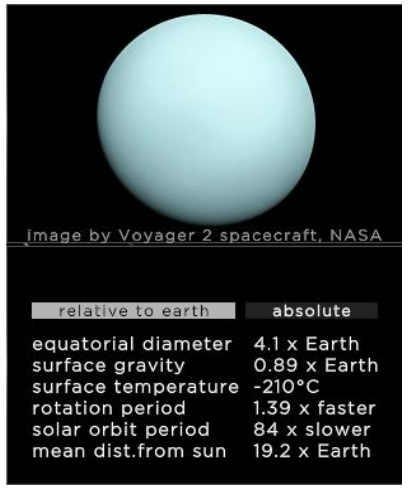
- Definition by International Astronomical Union IAU
  1. orbits the sun
  2. has sufficient mass to be round, or nearly round
  3. not a satellite (moon) of another object
  4. has removed debris and small objects from the area around its orbit

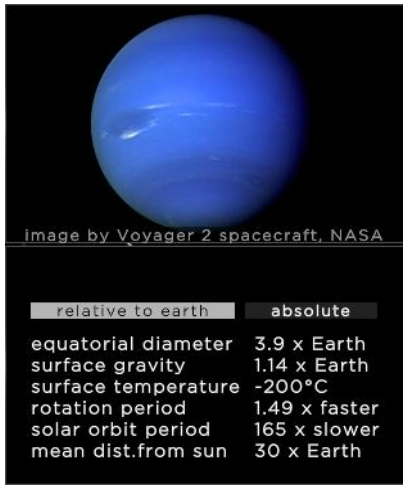
- Others:
  - Dwarf planets
  - Extrasolar planets
  - Stars
  - Brown Dwarfes
  - Planetary Mass Object (PMO)

Jovian Planets





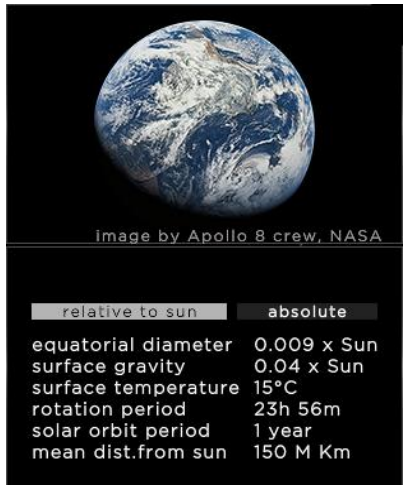


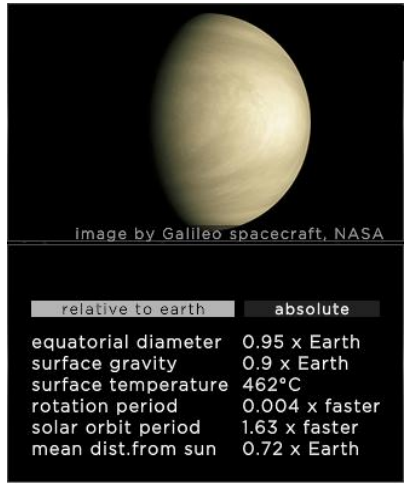


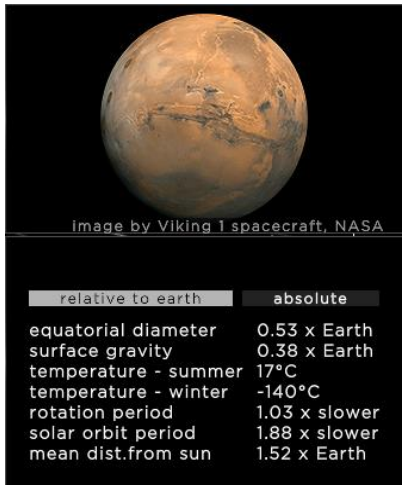
- Giant planets/ Gas planets
- are not composed entirely of gas
- Helium, hydrogen are main components
- higher amounts of methane and ammonia (Neptune, Uranus)
- high temperatures in the middle -> rocky core believed to be liquid heavy compounds (nickel)

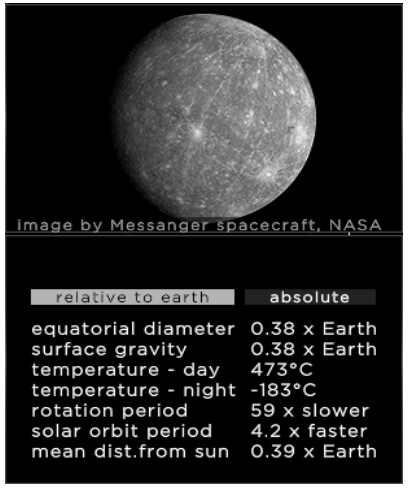
http://nineplanets.org/tour/

Terrestrial Planets









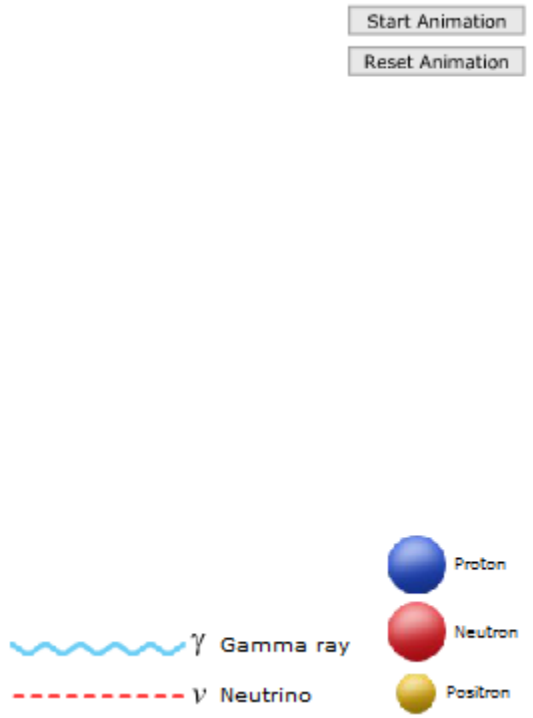
- Earth like planets
- Solid planetary surface
- central core made mostly of iron
- density trends towards lower values as the distance from the Sun increases

2. Nuclear fusion

- Stars: Nuclear fusion process
  - Proton-proton reaction (≈27 MeV)
  - Carbon-Nitrogen-Oxygen Cycle (CNO-Cycle)
  - Mass of our Sun
    $1{,}9884 \cdot 10^{30}$ kg $\pm$ $2 \cdot 10^{26}$ kg

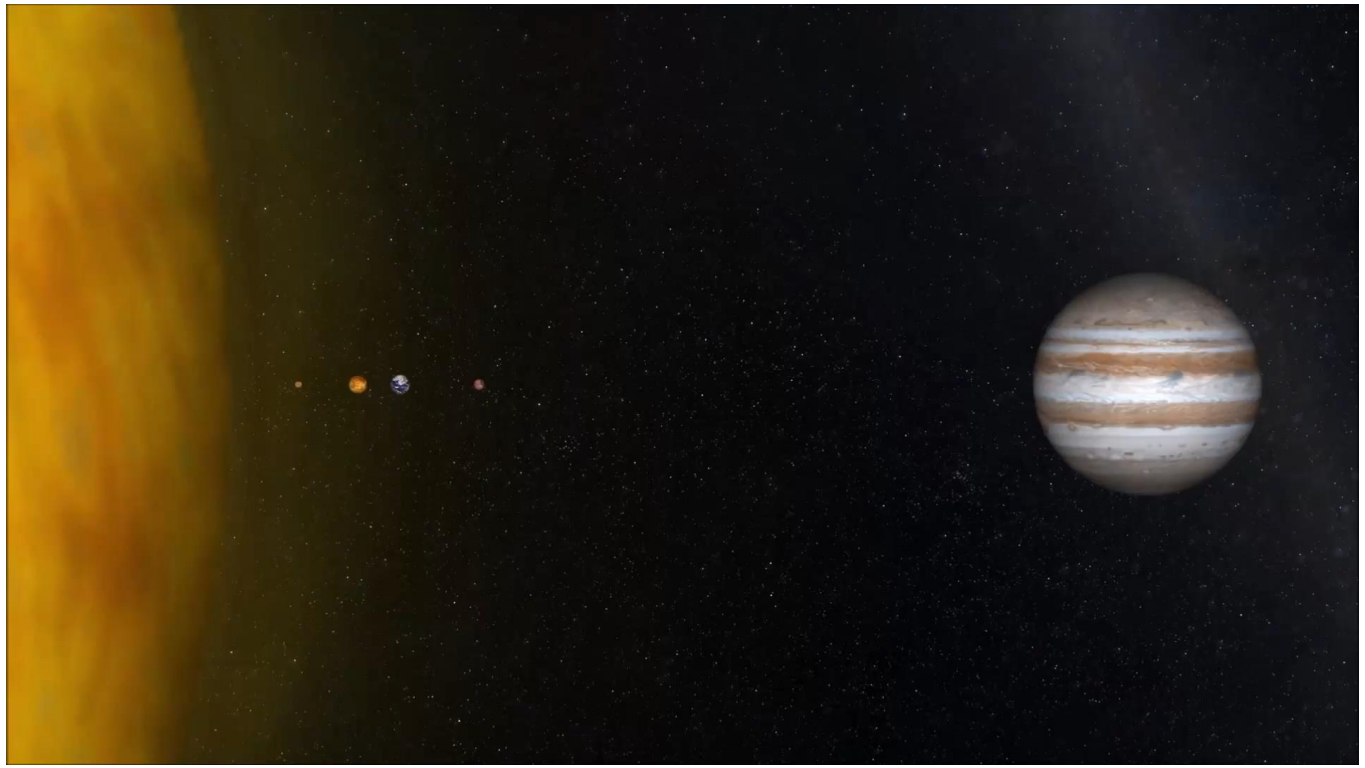
- not possible in Jupiter's interior -> Mass not large enough -> Temperature not getting high enough

- 12 MJ – deuterium fusion possible
- 75 MJ – hydrogen 1 fusion possible



http://astro.unl.edu/classaction/animations/sunsolarenergy/fusion01.html

3. Properties of Jupiter



https://www.youtube.com/watch?v=NkqXMztPWIU

- largest and heaviest of all planets (143.000 km radius, $M_J = 1{,}898 \cdot 10^{27}$ kg = 318 * $M_\oplus$)
- has at least 67 moons (including Ganymed, Callisto, Io and Europa)
- components (per volume):
  - hydrogen 89.8±2.0%
  - helium 10.2±2.0%
  - ethane (C_2H_6) 0.0006%
  - water (H_2O) 0.0004%
  - methane (CH4) ≈ 0.3%
  - ammonia (NH_3) ≈ 0.026%
  - hydrogen deuteride ≈ 0.003%

time

1973/74 Pioneer 10/11

1979 Voyager 1/2

1992 Ulysses

1995 Galileo

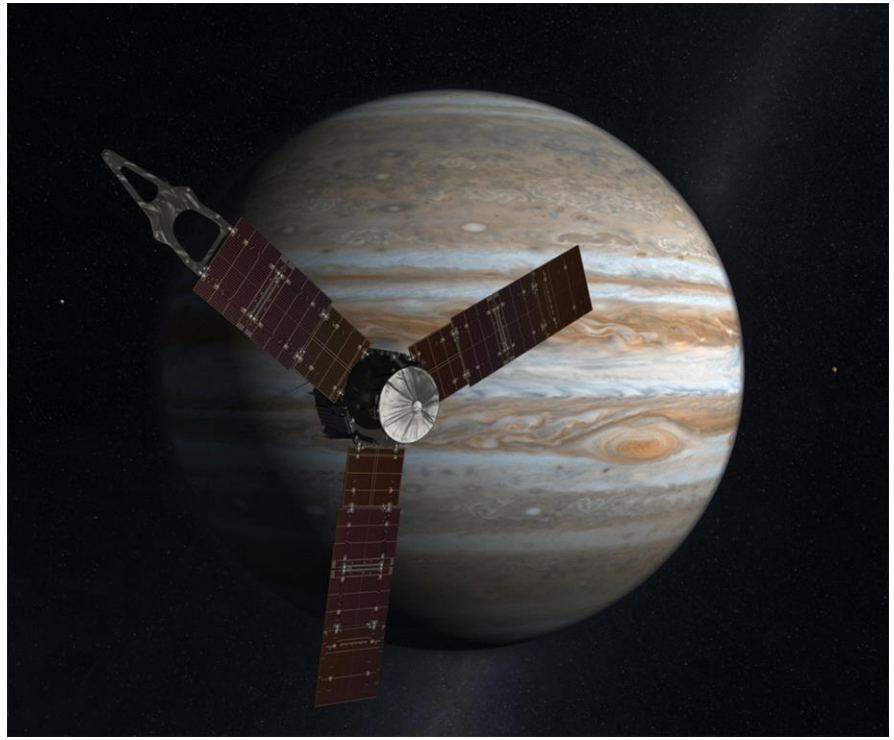
2000/2001 Cassini

Now: JUNO and JUICE

JUNO

- water in Jupiter's atmosphere
- measure composition, temperature, cloud motions and other properties
- map Jupiter's magnetic and gravity fields
- magnetosphere near the planet's poles (esp. at auroras)

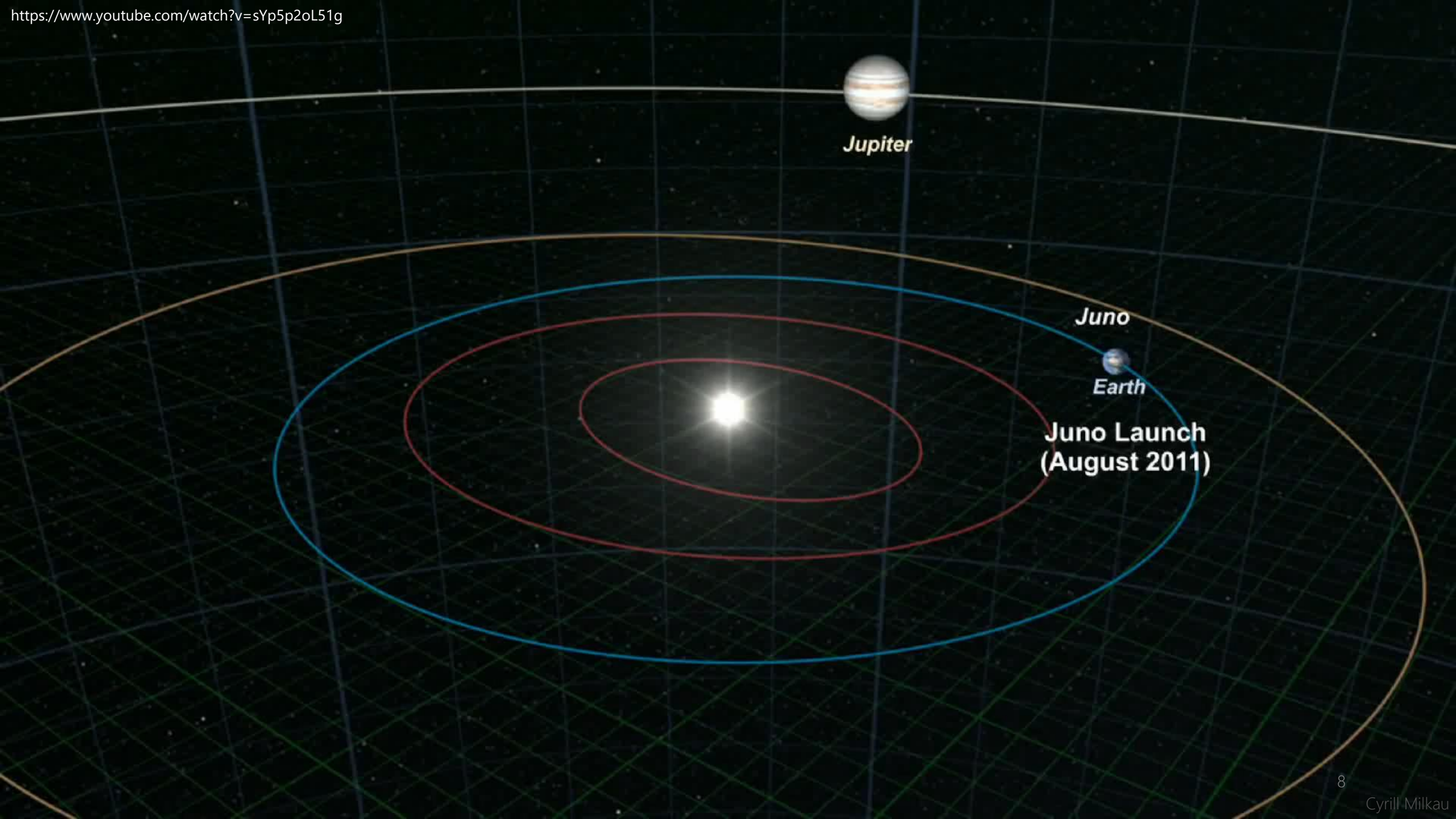
Launch:	August 5, 2011
Deep Space Maneuvers:	August/September 2012
Earth flyby gravity assist:	October 2013
Jupiter arrival:	July 2016
Orbiting Jupiter:	20 months (37 orbits)
End of mission:	February 2018



http://www.nasa.gov/sites/default/files/images/492704main_junoartist200904-full_full.jpg

NASA Logo: http://www.nasa.gov/sites/default/files/images/nasaLogo-570x450.png

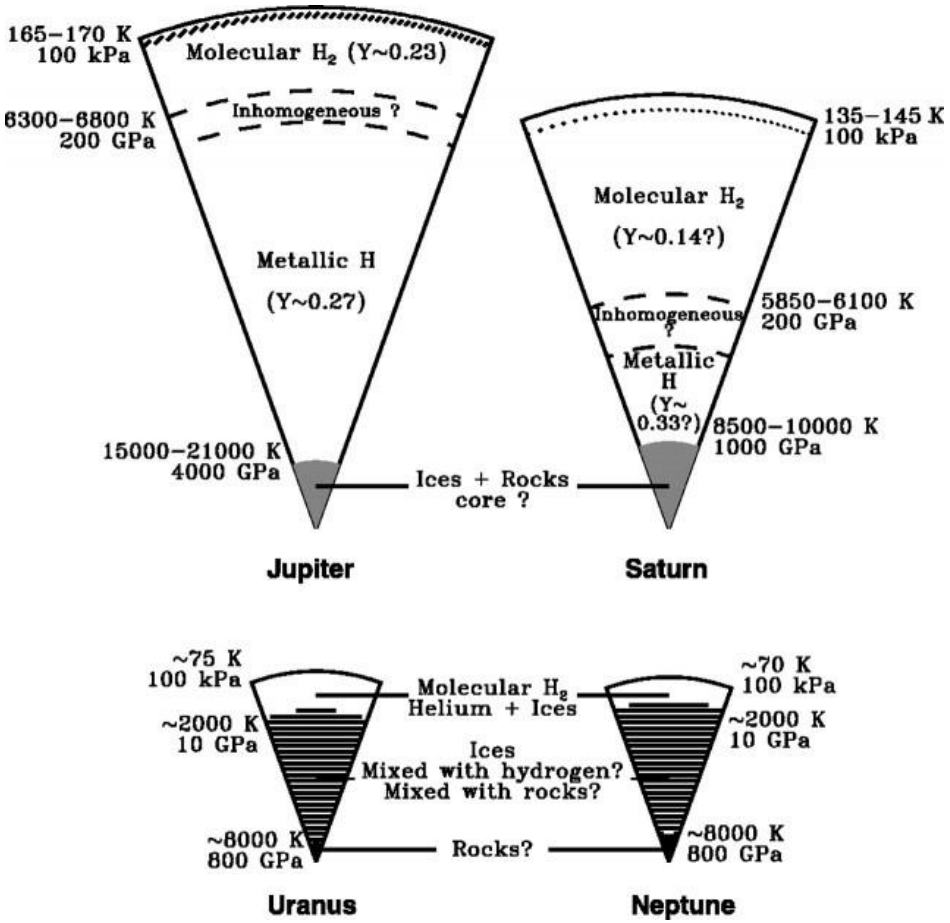
https://www.youtube.com/watch?v=sYp5p2oL51g

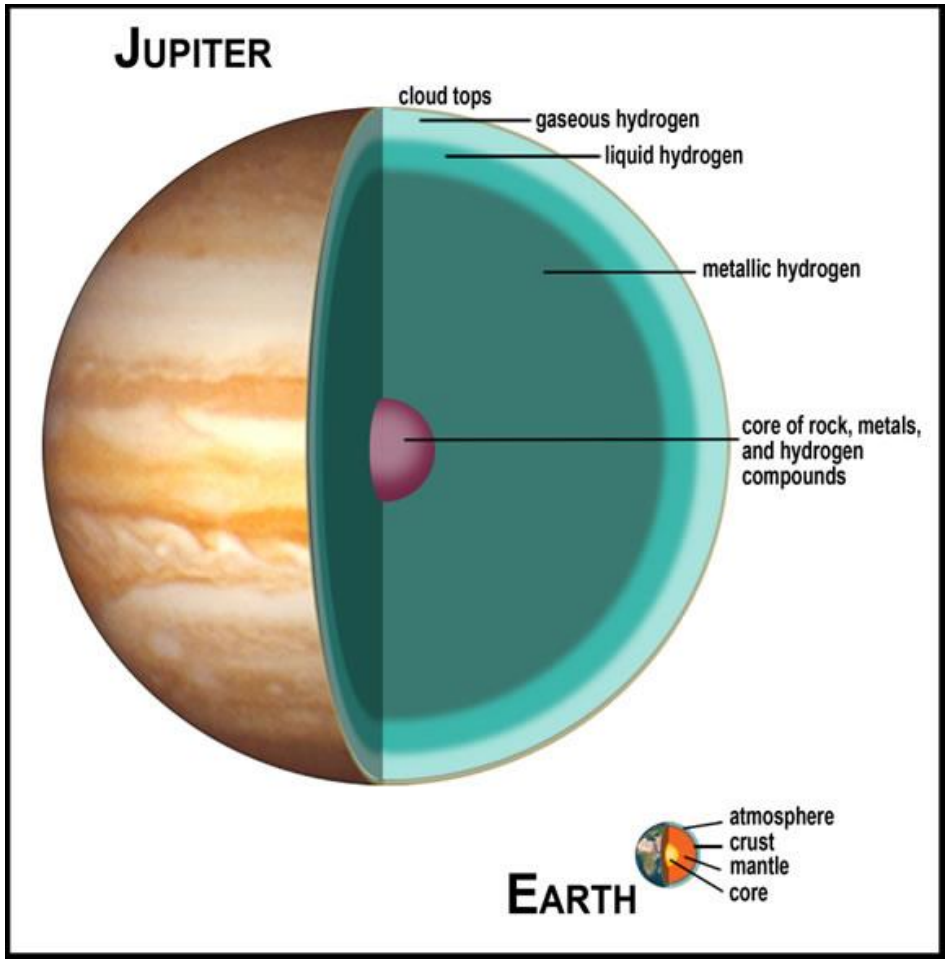


- Giant planets formation in protosolar nebula:
  - accretion of solid core
  - capture of surrounding gaseous hydrogen and helium
- 3 distinct regions:
  - rocky, icy core
  - fluid metallic hydrogen region
  - fluid molecular hydrogen region

https://www.youtube.com/watch?v=p1YjtEfUJ70

- Helium [Hydrogen] mass mixing ratio Y [X] -> Y/(X+Y) = 0.238 ± 0.007 lower than in protosolar nebula (0.280. ± 0.005)
- explained by first order liquid-liquid insulator-to-metal transition (LL-IMT) of hydrogen
- molecular and metallic hydrogen region quasi-homogeneous

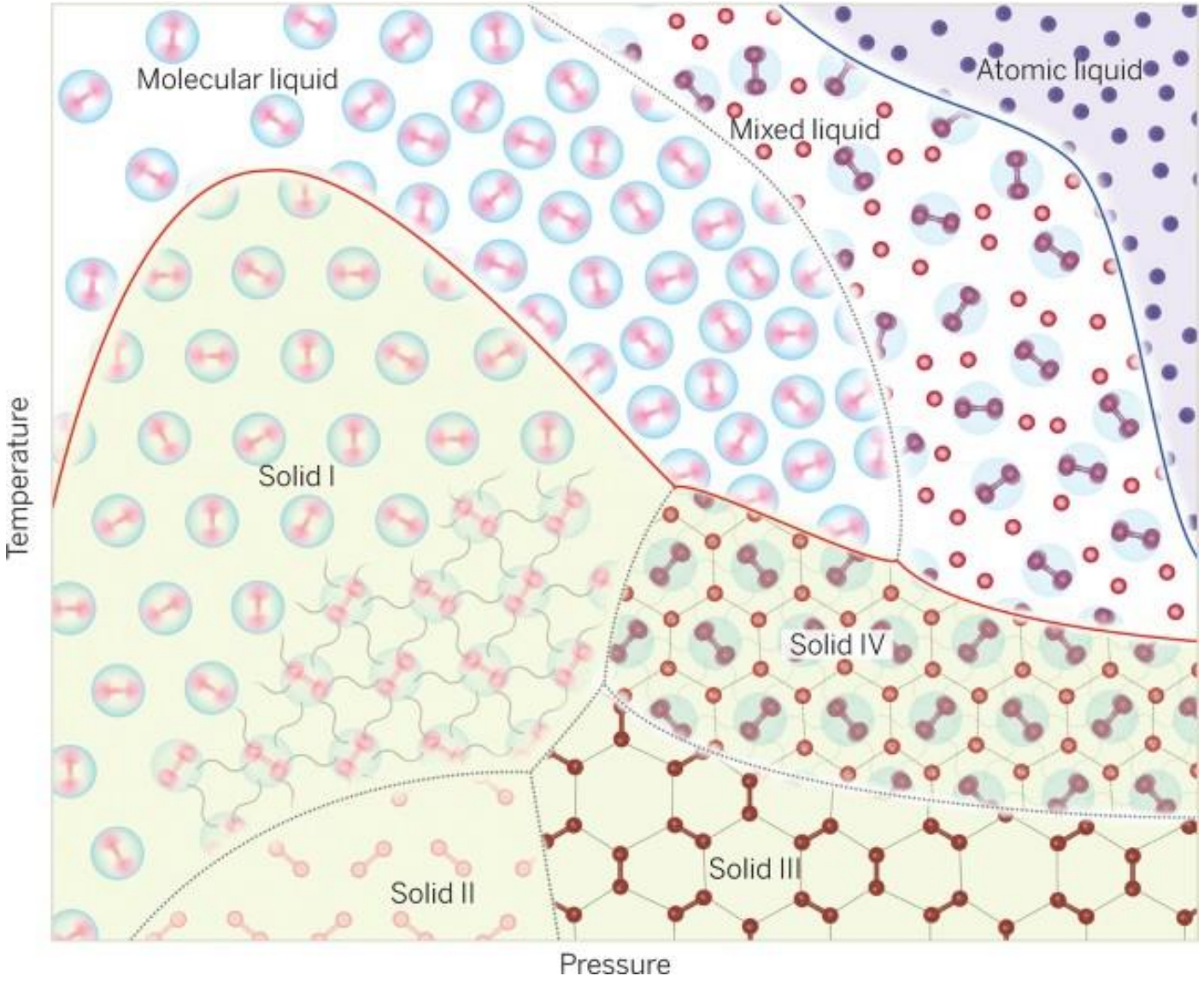




Tristan Guillot, "Interiors of Giant Planets Inside and Outside the Solar System," Science 286: 72-77, 1999, doi: 10.1126/science.286.5437.72.

http://www.lpi.usra.edu/education/explore/solar_system/images/interior.jpg

Schematic phase diagram of hydrogen

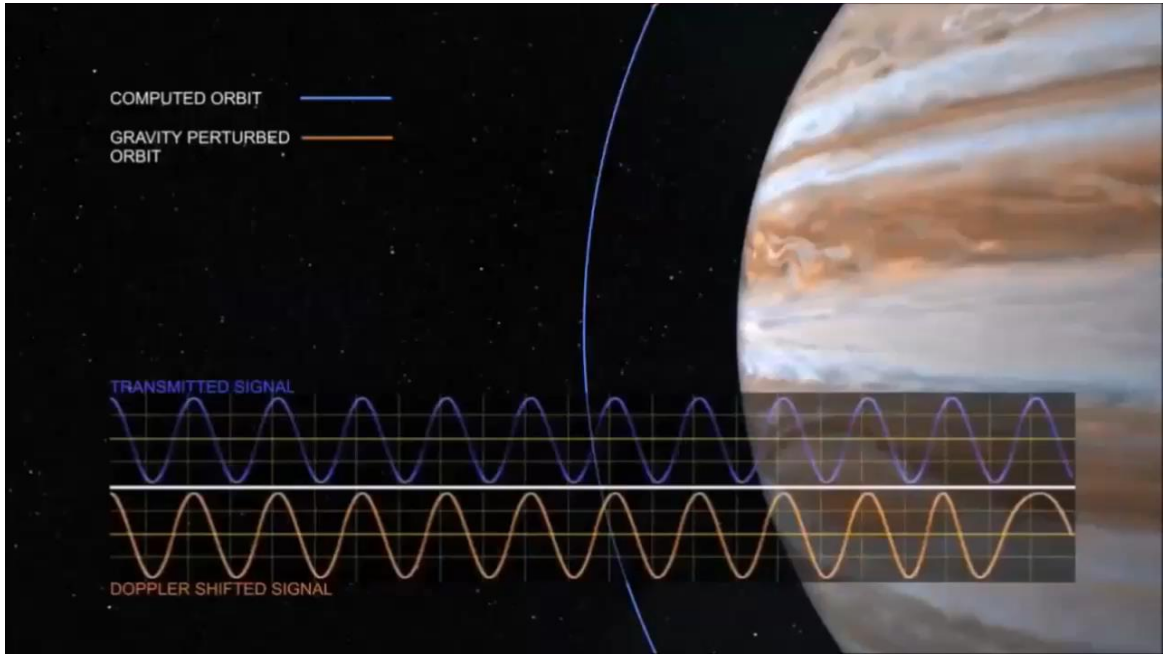


http://mappingignorance.org/fx/media/2015/07/Figure2-kundson-z-machine-giant-planets-640x522.jpg

Gravitational field

- measuring changes in spacecraft velocities (velocity as a function of time – often measured)
- Doppler shift of the radio signal
- density variations – gives information about storms

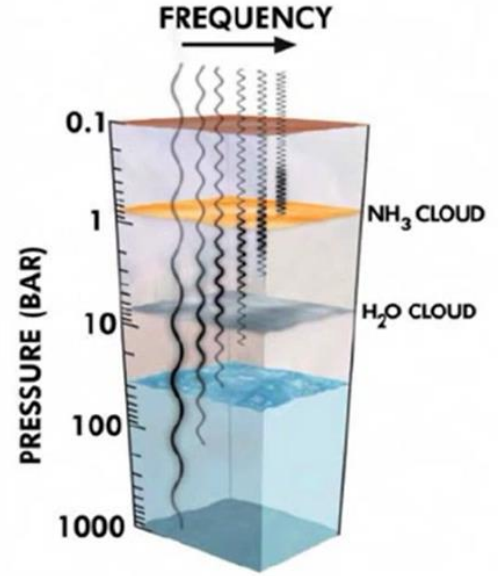
http://www.nasa.gov/images/content/236607main_goldstonedish.jpg



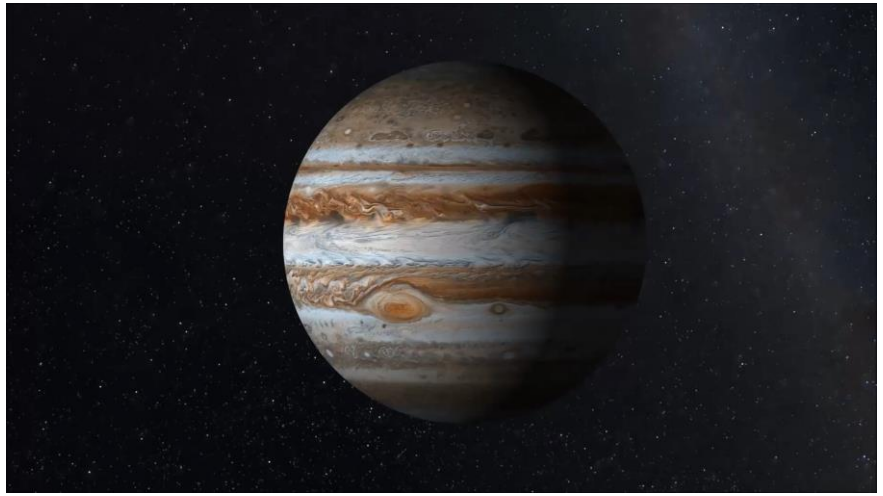
https://www.youtube.com/watch?v=ulzq_mlU-fA

Atmosphere

- storms are observed -> GRS
- heat generated inside (emits 2.5 times of the energy it receives from the sun – Kelvin-Helmholtz-mechanism)
- coming out as infrared or microwave energy (absorbed by water)



https://www.youtube.com/watch?v=layVZv6UE7A&index=1&list=PL7QxvGn3bZ0mHbHn3_OYYCQTrxfk-zuFH



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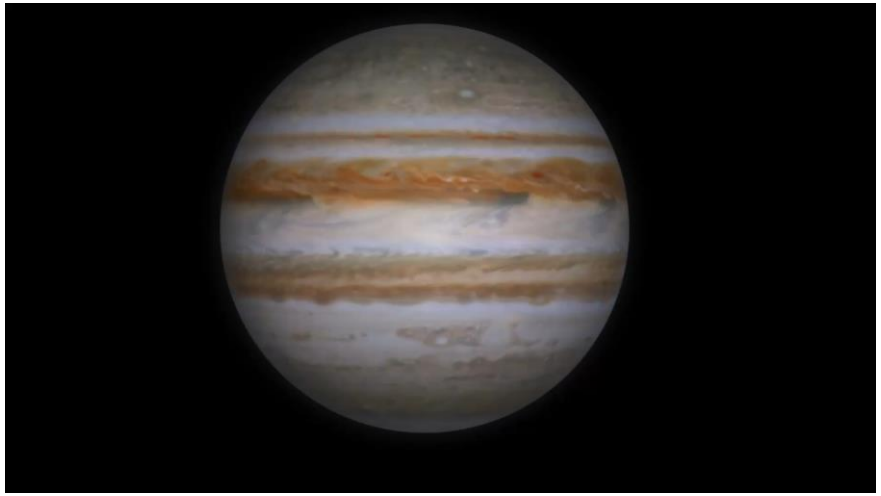
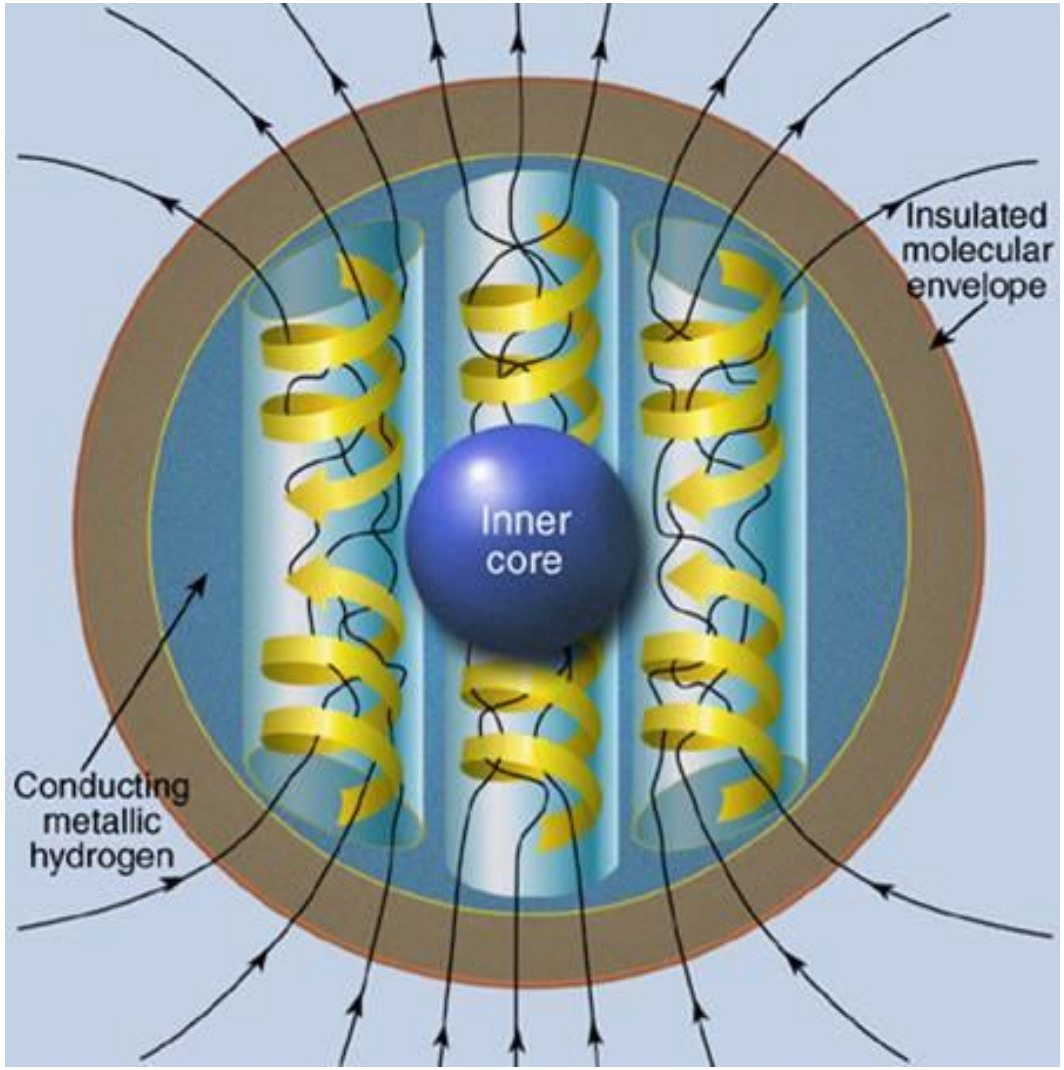


https://www.youtube.com/watch?v=MNt79d7deoA

Magnetic field

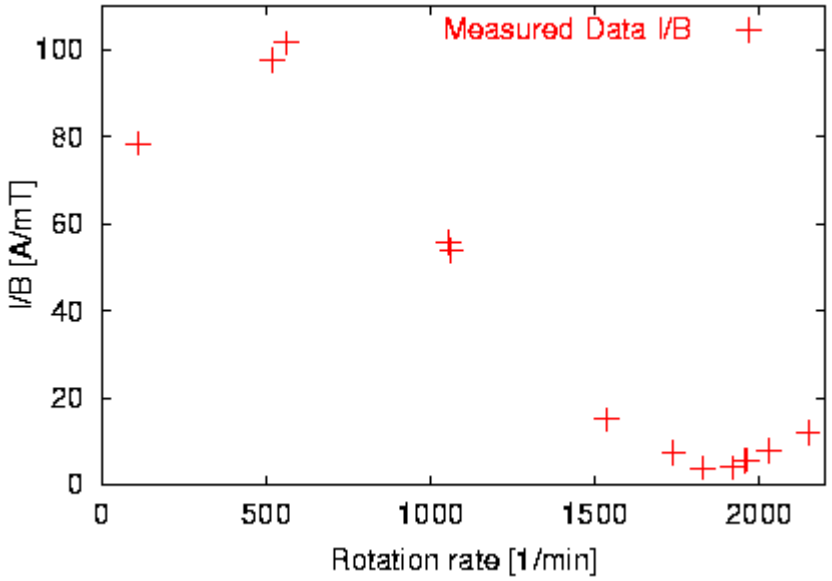
- moving ionized Hydrogen and fast self rotation (10h per rotation) causing the dynamo effect
- dynamo effect leads to magnetic dipole field
- equatorial field strength ≈ 428 µT (4.28 G) [ten times stronger than the earths]
- Jupiter's Magnetosphere second largest structure in solar system



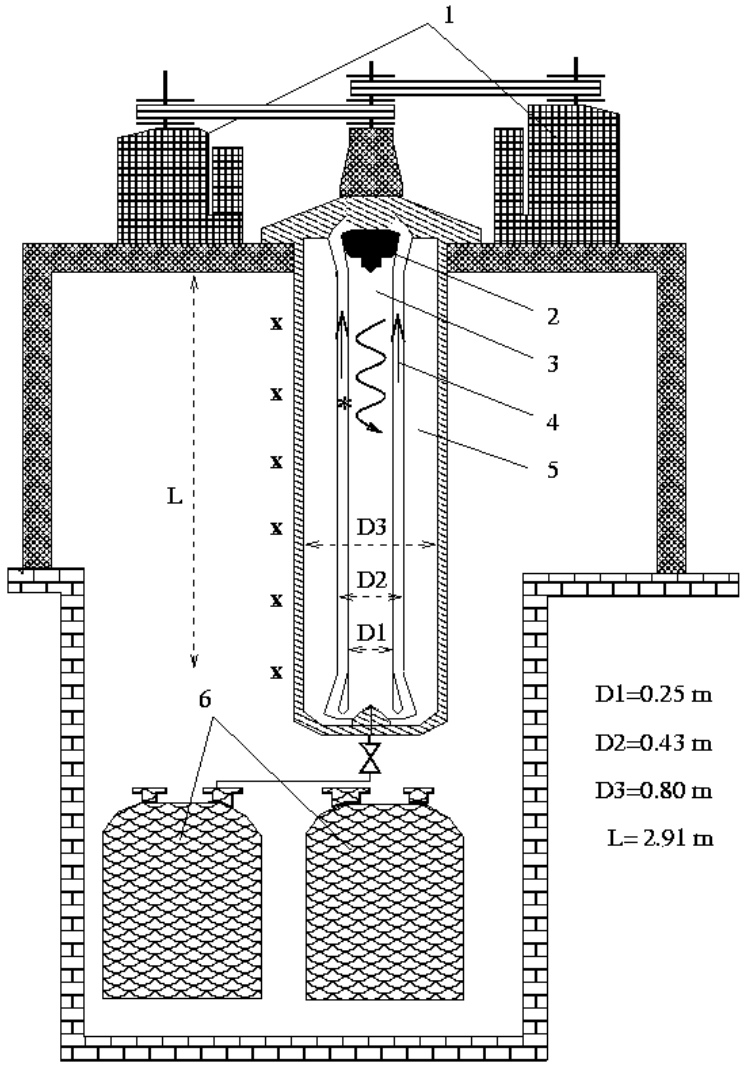
http://science.gsfc.nasa.gov/695/images/Picture1.jpg

Magnetic field self-excitation in the Riga dynamo experiment

- Experiment by Agris Gailitis, Olgerts Lielausis, Ernests Platacis, Gunter Gerbeth, Frank Stefani in 2000
- Motivation: experimentally demonstrate a magnetic field self-excitation in a moving liquid

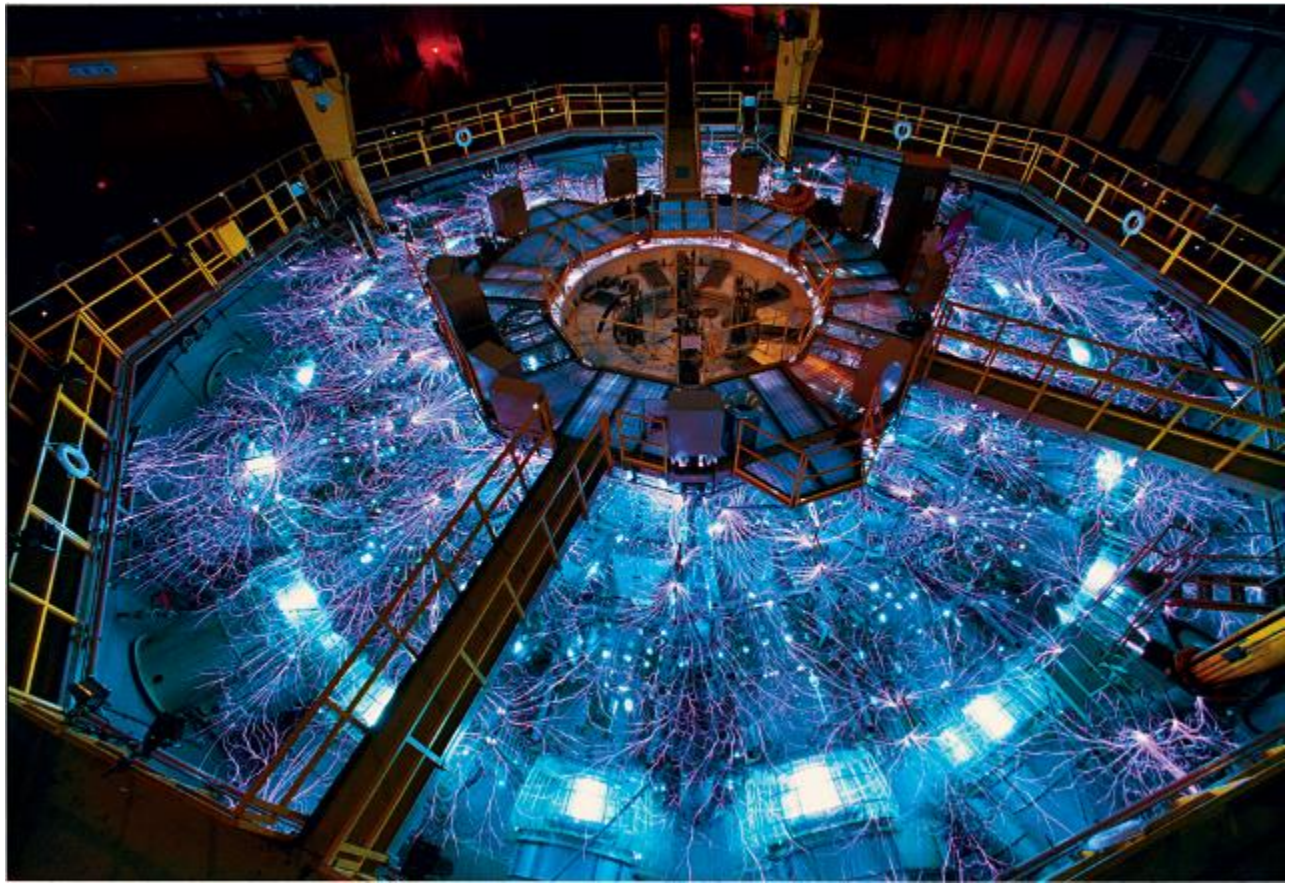


http://www.hzdr.de/FWS/FWSH/Stefani/idurch0.064gail.gif



https://www.hzdr.de/FWS/FWSH/Stefani/facility.gif

The Sandia Z Machine



https://nycnews.net/sites/default/files/field/image/Sandia-Z-machine-Age-Saturn.png

General

- Largest X-Ray generator in the world
- Test materials under condition of high temperature and pressure
- 80 Trillion Watts of electrical power (5-6 times than all power plants in world combined)
- 2 Billion Kelvin (15 Million in Sun)

Function

- intense electrical pulses (~20 million amperes) and large magnetic field densities (~10 million gauss)
- magnetic pressures of several hundred GPa
- reflectivity of a 532-nm laser light is measured using a spectrometer (450- to 650-nm bandwidth).
- increase in reflectivity of the deuterium samples

4. Summary

- Giant Planets contain a lot of hydrogen in different states
- are not massive enough to let nuclear fusion processes happen
- magnetic fields result from inner rotation of ionized hydrogen
- conditions can be reproduced on earth to verify either theoretical presumptions or experimental observations in space

5. Sources

Title	Link	Date	Time
Models and Outstanding Questions	http://arxiv.org/pdf/astro-ph/0502068v1.pdf	04.11.15	03:11
Inside and Outside the Solar System	https://www.sciencemag.org/content/286/5437/72.full.pdf	04.11.15	03:14
Models and Outstanding Questions PPT	https://solarsystem.nasa.gov/docs/28_guillot.ppt.pdf	04.11.15	03:19
The Sandia Z machine	http://mappingignorance.org/2015/07/10/the-sandia-z-machine-unveils-the-interior-of-gas-giant-planets/#note-2617-2	04.11.15	03:11
The Outer Planets	http://lasp.colorado.edu/education/outerplanets/giantplanets_interiors.php	04.11.15	03:13
Planets	http://www.space.com/25986-planet-definition.html	12.11.15	00:03
Planets	http://www.iau.org/news/pressreleases/detail/iau0603/	12.11.15	00:11
Jovian Planets	http://www.universetoday.com/33061/jovian-planets/	17.11.15	18:46
Terrestrial Planets	http://space-facts.com/terrestrial-planets/	17.11.15	18:57
Sandia Machine	https://share.sandia.gov/news/resources/releases/2006/physics-astron/hottest-z-output.html	17.11.15	20:02
JUNO Overview	http://www.nasa.gov/mission_pages/juno/overview/index.html	19.11.15	17:42
Dynamo	http://onlinelibrary.wiley.com/doi/10.1002/phbl.19760321003/pdf	26.11.15	02:33
Neptune	http://voyager.jpl.nasa.gov/science/neptune_magnetic.html	26.11.15	02:53