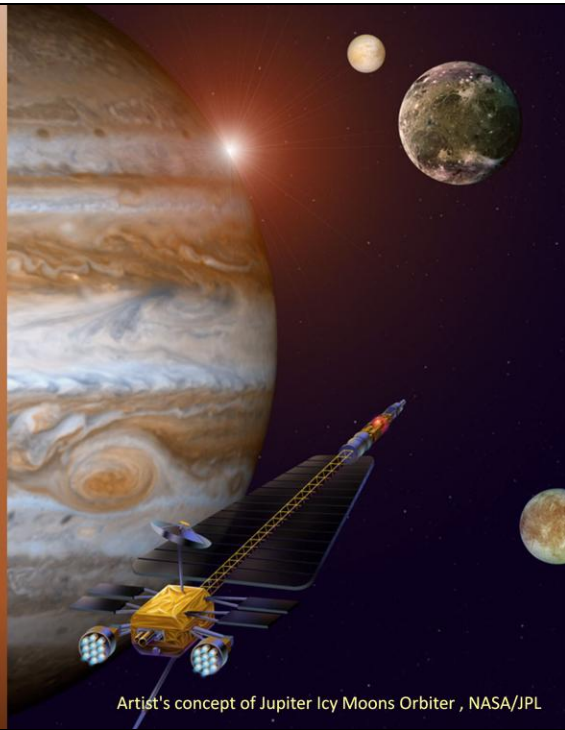


Spacecraft Missions to Jupiter


Chuck Higgins, MTSU



Artist's concept of Jupiter Icy Moons Orbiter , NASA/JPL

This presentation is an overview of the spacecraft that have visited Jupiter and some of the discoveries made.

Jupiter Spacecraft Outline



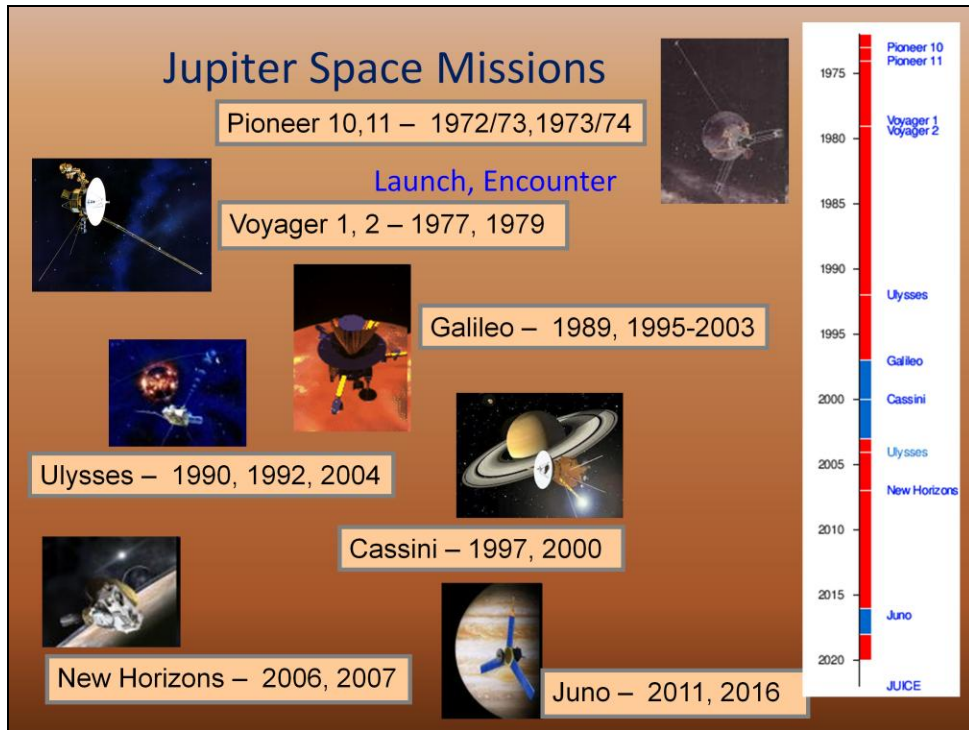
- Pioneer 10 and 11
- Voyager 1 and 2
- Ulysses
- Galileo
- Cassini
- New Horizons

Future Missions

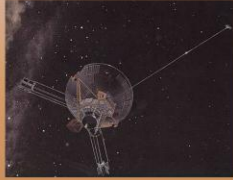
- Juno, JUICE, etc.

Jupiter from NASA's Cassini spacecraft on December 29, 2000

Outline



The spacecraft launch and encounter dates.



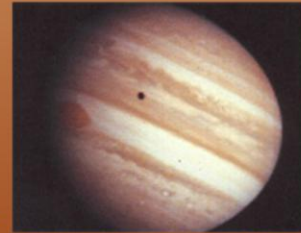
Pioneer 10/11

1973/74



Pioneer mission patch

- Pioneer 10, the first NASA mission to the outer planets
- First vehicle placed on a trajectory to escape the solar system into interstellar space
- First spacecraft to fly beyond Mars
- First to fly through the asteroid belt
- First to fly past Jupiter
- First to use all-nuclear electrical power
- First human-made object to fly beyond the orbit of the outermost known planet in our solar system.



Pioneer 10 image of Jupiter, 1973.

The Pioneers had a lot of “firsts” in their missions.



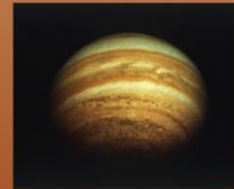
Pioneer 10/11

1973/74

- Scientists identified plasma in Jupiter's magnetic field
- First close-up images of the planet
- Charted Jupiter's intense radiation belts
- Located the planet's magnetic field
- Discovered that Jupiter is predominantly a liquid planet.
- Studied magnetic fields, energetic particle radiation and dust populations in interplanetary space.
- Pioneer 11 obtained dramatic images of the Great Red Spot, made the first observation of the immense polar regions, and determined the mass of Jupiter's moon, Callisto.



On Dec. 4, 1973, Pioneer 10 spacecraft sent back images of Jupiter of ever-increasing size.



The planet Jupiter as seen from above its north pole by Pioneer 11. NASA Ames

Pioneer 11 allowed a first look at the Jupiter polar regions.

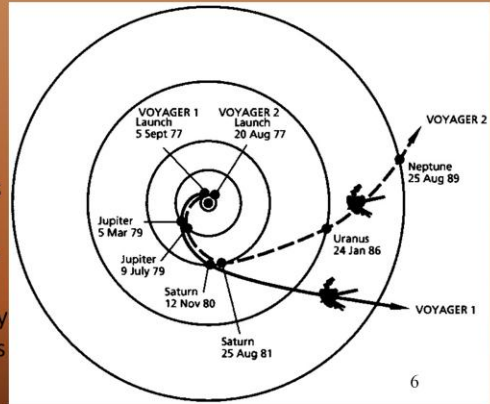
Voyager 1 & 2

Voyager proved to be one of the greatest missions of discovery in history.

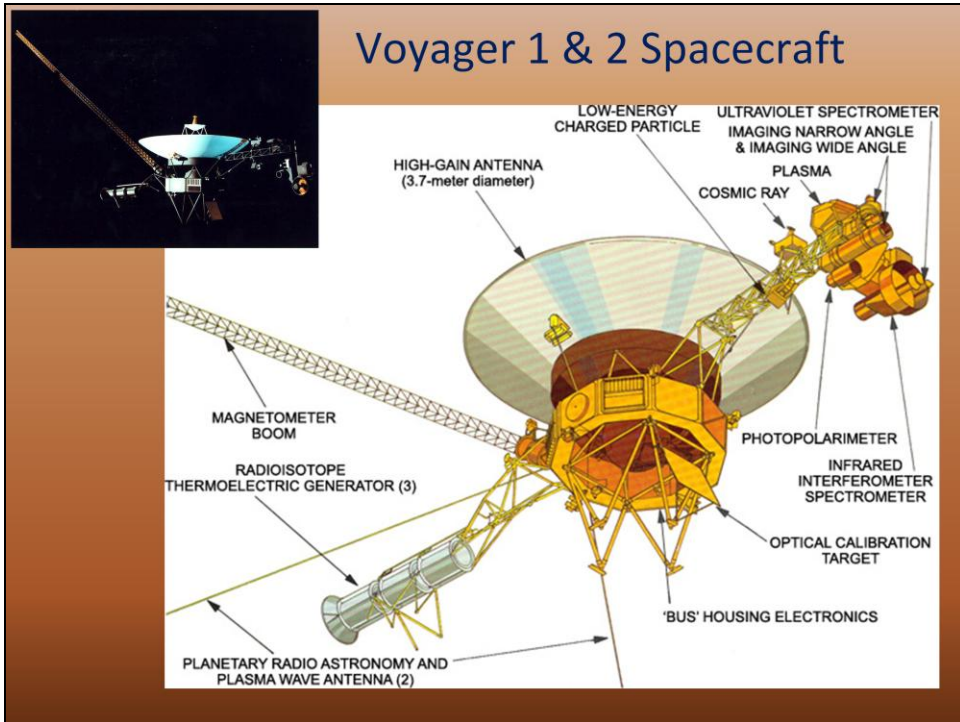
Discoveries:

- Rings around Jupiter
- Volcanoes on Jupiter's moon Io
- Complicated atmospheric dynamics
- Lightning
- Auroras
- Three new moons
- The Great Red Spot rotates once every six days
- Moons of Saturn that shepherd its rings
- New moons of Uranus and Neptune
- Geysers of liquid nitrogen on Neptune's moon Triton
- Voyager 2 is the only spacecraft to study all four of the solar system's giant planets at close range.

Voyager 1 launches from the Kennedy Space Center on Sept. 5, 1977. Credit: NASA



Without a doubt, the Voyagers are the greatest space missions of discovery in history.



An overview of the Voyager spacecraft.

Voyager 1 & 2

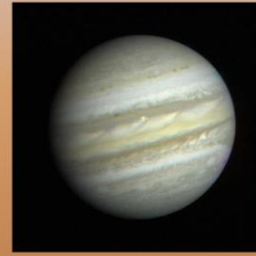
1979

Radio Science (RSS)

Principal Investigator: Prof. G. Leonard Tyler

The science objectives at Jupiter

- Measure physical properties of planetary and satellite ionospheres and atmospheres by examining the propagation effects on a dual-frequency radio signal
- Determine planetary and satellite masses, gravity fields, and densities by precise tracking of a dual-frequency radio signal



First close-up view of Jupiter from Voyager 1.



The approach of Voyager 1 during a period of over 60 Jupiter days.

A few details about some of the radio experiments on Voyager.

Voyager 1 & 2

1979

Planetary Radio Astronomy (PRA)

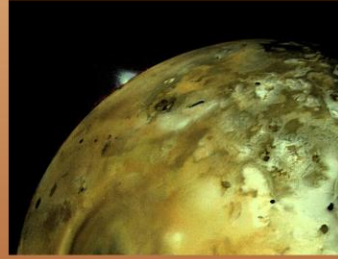
Principal Investigator: Dr. James W. Warwick
Magnetospheric and Radio physics

- Sweep-frequency radio receiver
- Dual polarization states
- 20 kHz and 40.5 MHz
- Orthogonal 10-m monopole antennas

Plasma Wave System (PWS)

Principal Investigator: Prof. Donald A. Gurnett
Electron-density profiles and local wave-particle interactions

- 16-channel, step-frequency receiver
- low-frequency waveform receiver
- 10 Hz to 56 kHz



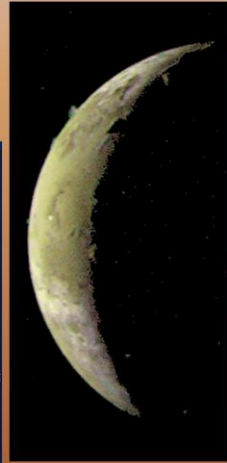
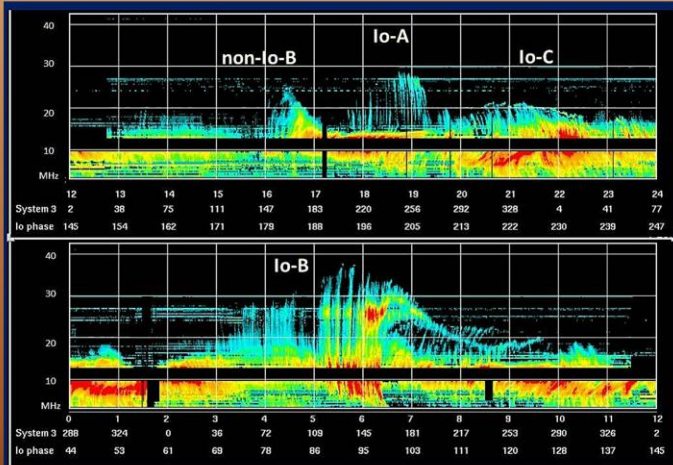
The Very Long Baseline Array (VLBA) imaged the signal of NASA's Voyager 1 spacecraft from 11.5 billion miles (18.5 billion kilometers) away. Feb. 21, 2013.

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A few details about some of the radio experiments on Voyager.

Voyager 1 and 2

Voyager 2 July 16, 1979



Voyager 2 at Io: A 2.5 hour period is covered during which Io rotates 7 degrees.

Voyager showed some incredible radio spectra of Jupiter's decameter, hectometer, and kilometer radio emissions.

Voyager 1 & 2

1979

Magnetosphere

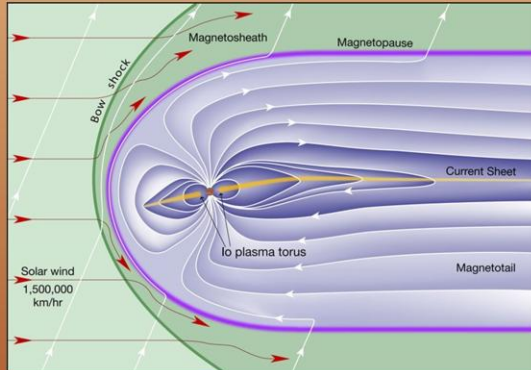
Lightning whistlers in the atmosphere

Plasma-electron densities in some regions of the Io torus

High-energy trapped particles were also detected near Jupiter

Magnetotail extends at least to the orbit of Saturn

Decametric (DAM), Hectometric (HOM), and Kilometric (KOM) radio emission structure



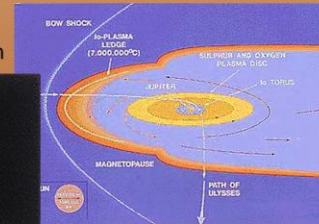
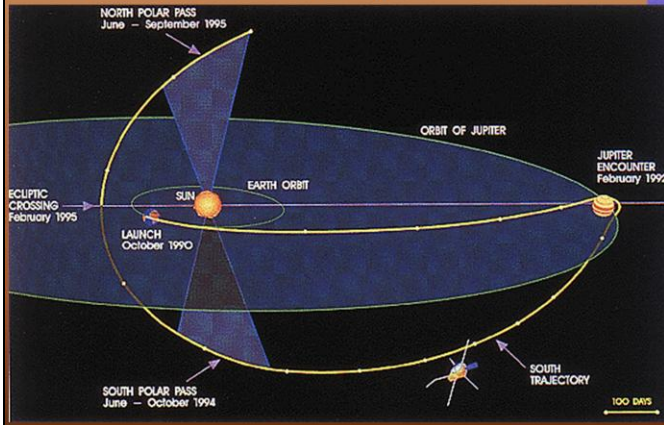
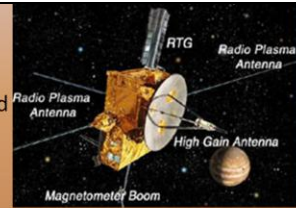
Voyager found that Jupiter's magnetotail extends at least 5 A.U. from Jupiter.

Ulysses

1992

Four radio receivers, which cover two bands (1.25 to 48.5 kHz and 52 to 940 kHz)

- Use the gravity field of Jupiter to redirect the spacecraft to the Sun's polar regions.
- Traveled 12 days through the Jovian magnetosphere
- Reached high northern latitudes and southern latitudes
- Flew through the Io Plasma Torus (IPT), e^- density distribution



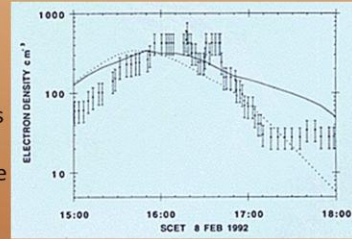
An overview of the Ulysses mission. Too bad the radio instrument peaked at 940 kHz.

Ulysses

Results at Jupiter

- Longitudinal asymmetries in of the Io plasma torus
- Presence of counter-streaming ions and electrons, field-aligned currents, and energetic electron and radio bursts in the dusk sector on high-latitude magnetic field lines
- Identification of the direction of the magnetic field in the dusk sector, which is indicative of tailward convection.

Credit: Science. 1992 Sep 11;257(5076):1503-7.

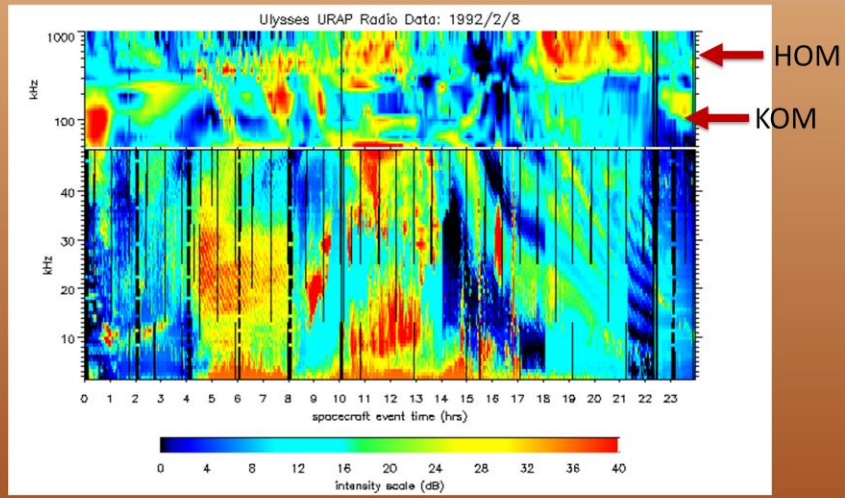


- Unique direction-finding capability for Jupiter's hectometer (HOM) radio sources
- HOM revealed narrow latitudinal beaming along the magnetic equator
- "Narrow-band kilometric" (nKOM) radiation – originates from the Io Plasma Torus
- "Jovian type III" events showing a characteristic rapid drift in frequency (Voyager, Ulysses)

Credit: ESA Bulletin No.72 November 1992, by R.G. Marsden and K.-P. Wenzel, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands.

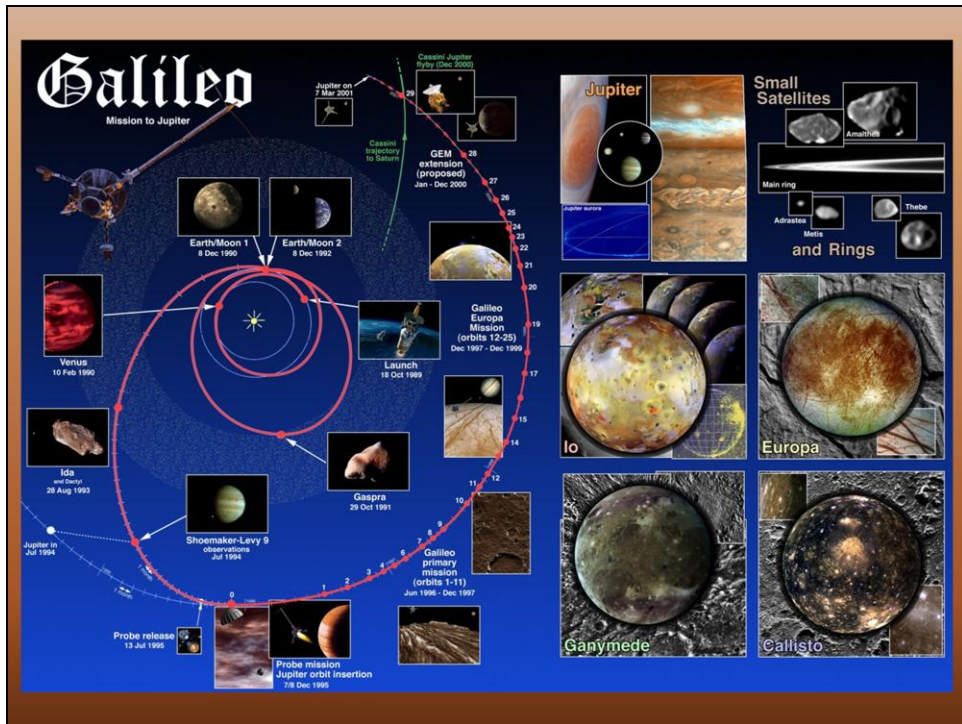
A few good discoveries at Jupiter by Ulysses.

Ulysses



URAP radio and plasma wave data during the flyby displayed as frequency vs. time dynamic spectra, with relative intensity indicated by the color bar.

A Ulysses radio spectrum at Jupiter.



The Galileo mission launch and orbital trajectory.



Galileo

1995 - 2003



Launch: Oct. 18, 1989 from Kennedy Space Center, Fla., on space shuttle Atlantis on mission STS-34

Primary Mission: October 1989 to December 1997

Extended Missions: Three, from 1997 to 2003

Number of Jupiter orbits during entire mission: 34

Number of flybys of Jupiter moons: Io 7, Callisto 8, Ganymede 8, Europa 11, Amalthea 1

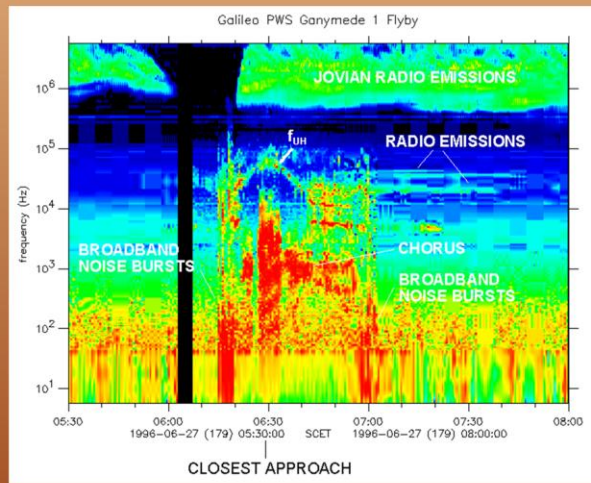
Major scientific results of the *Galileo mission* include:

- First observation of ammonia clouds in another planet's atmosphere
- Confirmation of extensive volcanic activity on Io
- Evidence supporting the theory that liquid oceans exist under Europa's icy surface
- First detection of a substantial magnetic field around a satellite (Ganymede);
- Magnetic data evidence suggesting that Europa, Ganymede and Callisto have a subsurface liquid-saltwater layer
- Formation of the rings of Jupiter (by dust kicked up as interplanetary meteoroids)
- Observation of two outer rings
- Global structure and dynamics of the magnetosphere

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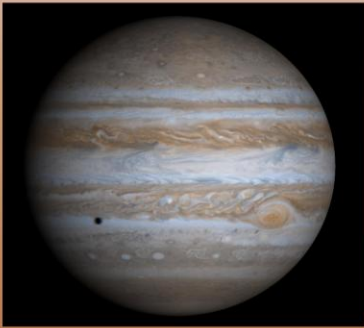
Highlights of the Galileo mission.

Galileo 1995 - 2003



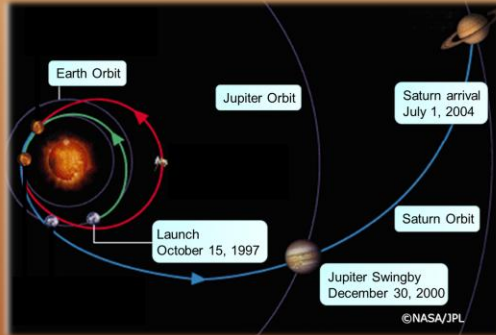
The HFR provides 42 frequencies from 100.8 kHz to 5.645 MHz with a fractional frequency spacing of $\Delta f/f \sim 10.0\%$ and a bandwidth of 2 kHz. One spectral sweep is provided every 18.67 seconds with a dynamic range of 100 db.

Galileo discovers the moon Ganymede has its own magnetosphere.



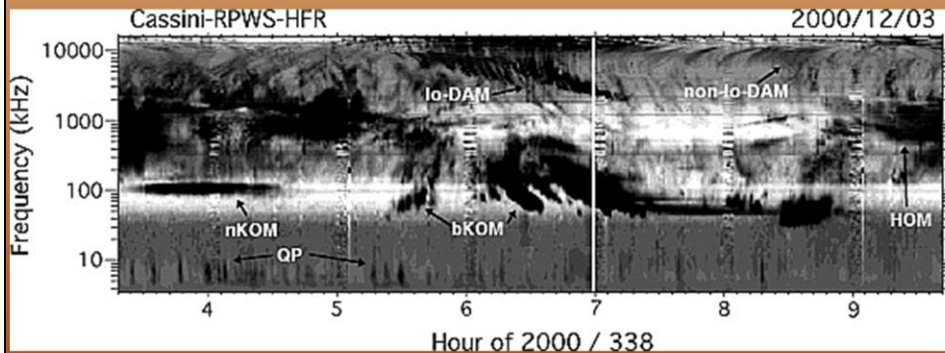
Cassini

2000



Cassini

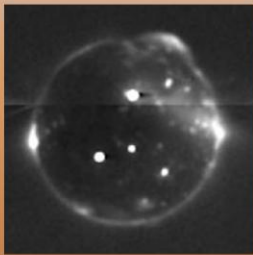
Jupiter's low-frequency radio spectrum from Cassini/Radio and Plasma Wave Science (RPWS) absolute flux density measurements
Frequency range is 3.5 kHz to 16.1 MHz.



Journal of Geophysical Research: Space Physics
Volume 109, Issue A9, A09S15, 14 AUG 2004 DOI: 10.1029/2003JA010260
<http://onlinelibrary.wiley.com/doi/10.1029/2003JA010260/full#figra17267-fig-0011>

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Jovian low-frequency radio emissions detected on 3 December 2000 by the RPWS experiment onboard Cassini approaching Jupiter. Frequency range is 3.5 kHz to 16.1 MHz. The Io-DAM emission appears here down to about 2 MHz, while weaker Io-independent (non-Io-DAM) arcs merge with the hectometer component (HOM) detected down to ~ 400 kHz. The auroral broadband kilometer component (bKOM) is detected down to ~ 40 kHz. The narrowband emission (nKOM) about 100 kHz is generated at or near the plasma frequency f_{pe} in Io's torus. The quasi-periodic (QP) bursts, spaced by 5 to >15 min, are detected in the ~ 5 to 20 kHz range. Distance to Jupiter was $383 R_J$ (2.7×10^7 km) at the time of this observation.



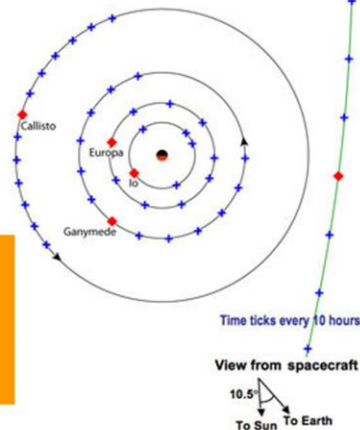
This image of Io eclipsed by Jupiter's shadow, Feb. 27, 2007
Credit: NASA/JHU/APL/SWRI

New Horizons

2007



Jupiter Flyby Geometry	
Closest Approach Date	Feb 28, 2007
Closest Approach Range	2.3 million km 1.4 million miles 32.2 R_J
Speed	21 km/s



Studies of Jupiter's

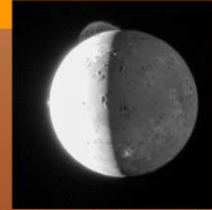
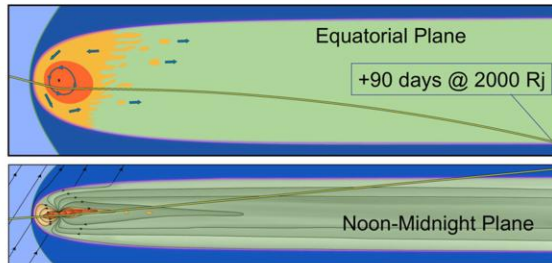
- 1) Atmospheric structure and storm behavior.
- 2) Major satellites and search for new moons
- 3) Ring composition
- 4) Magnetosphere

New Horizons 2007



- Pictured heat induced lightning strikes in the polar regions and "waves" that indicated violent storm activity
- Imaged up close the Little Red Spot
- Imaged the faint ring system discovering debris left over from recent collisions within the rings
- No new moons discovered
- Magnetospheric "bubbles" of plasma were noticed in the magnetotail, believed to be ejected by the moon Io

New Horizons Flies Down Jupiter's Magnetotail - 2007



This dramatic image of Io was taken on Feb. 28, 2007
Credit: NASA/JHU/APL/SWRI

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New Horizons very quickly flew by Jupiter in 2007. On to Pluto!

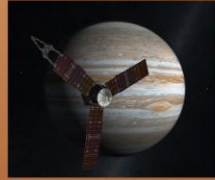
Juno to Jupiter



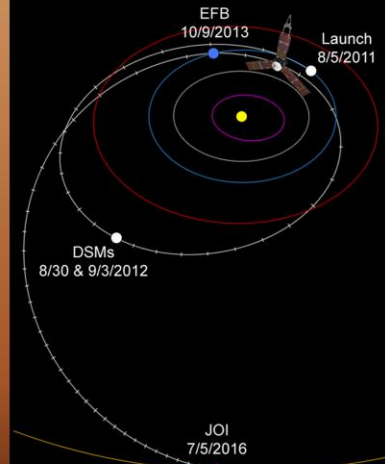
Roman goddess who could see through the clouds



- Launch: Aug 2011
- Earth Flyby: Oct 2013
- Cruise: 2013 - 2016
- Arrival: Jul 2016
- Mission: 1 year



Jupiter Juno Galileo



Tilted ecliptic pole view, vernal equinox up; launch at start of 8/5-26 launch period; 30-day tick marks

The Juno mission launch and orbital trajectory.

Juno Spacecraft

National Aeronautics and Space Administration

Juno's Instruments

Gravity Science and Magnetometers
Study Jupiter's deep structure by mapping the planet's gravity field and magnetic field

Microwave Radiometer
Probe Jupiter's deep atmosphere and measure how much water (and hence oxygen) is there

JEDI, JADE and Waves
Sample electric fields, plasma waves and particles around Jupiter to determine how the magnetic field is connected to the atmosphere, and especially the auroras (northern and southern lights)

UVS and JIRAM
Using ultraviolet and infrared cameras, take images of the atmosphere and auroras, including chemical fingerprints of the gases present

JunoCam
Take spectacular close-up, color images

SPACEDRAFT DIMENSIONS
Diameter: 68 feet (20 meters)
Height: 15 feet (4.5 meters)

For more information:
mission.juno.swri.edu &
www.nasa.gov/juno

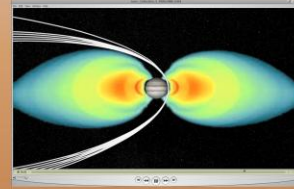
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

A summary of the Juno spacecraft.

Juno Science Questions

Juno's primary science goal

the formation, evolution, and structure of Jupiter
→ the conditions in the early solar system
→ the formation of our planetary system



Origins – Interior – Atmosphere – Magnetosphere

How did Jupiter form?

How much water or oxygen is in Jupiter?

What is the structure inside Jupiter?

Does Jupiter rotate as a solid body, or is the rotating interior made up of concentric cylinders?

Is there a solid core, and if so, how large is it?

How is its vast magnetic field generated?

How are atmospheric features related to the movement of the deep interior?

What are the physical processes that power the auroras?

What do the poles look like?

The major science questions to be addressed by the Juno mission.

Jupiter Icy Moon Explorer (JUICE)

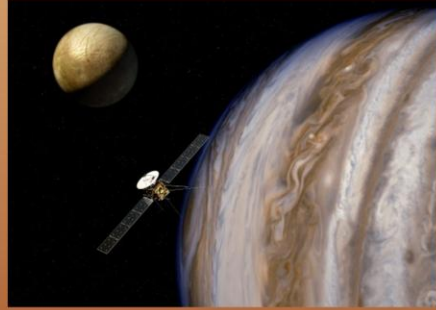
Proposed Launch 2022

Proposed Arrival 2030

Study Ganymede, Callisto,
and Europa

Proposed Science:

- Study the ocean layers
- Investigate the potential for life
- Surface mapping and geology
- Study of the physical properties of the icy crusts
- Study the internal structure and evolution of the interiors
- Investigate Ganymede's atmosphere and magnetosphere
- Study interactions with the Jovian magnetosphere



Credit ESA

A summary of the proposed JUICE mission.