



NASA EDUCATION  
AND OUTREACH



Solar & Planetary Radio Astronomy  
for Schools

1999 - Present

# Introduction to Jupiter Radio Science



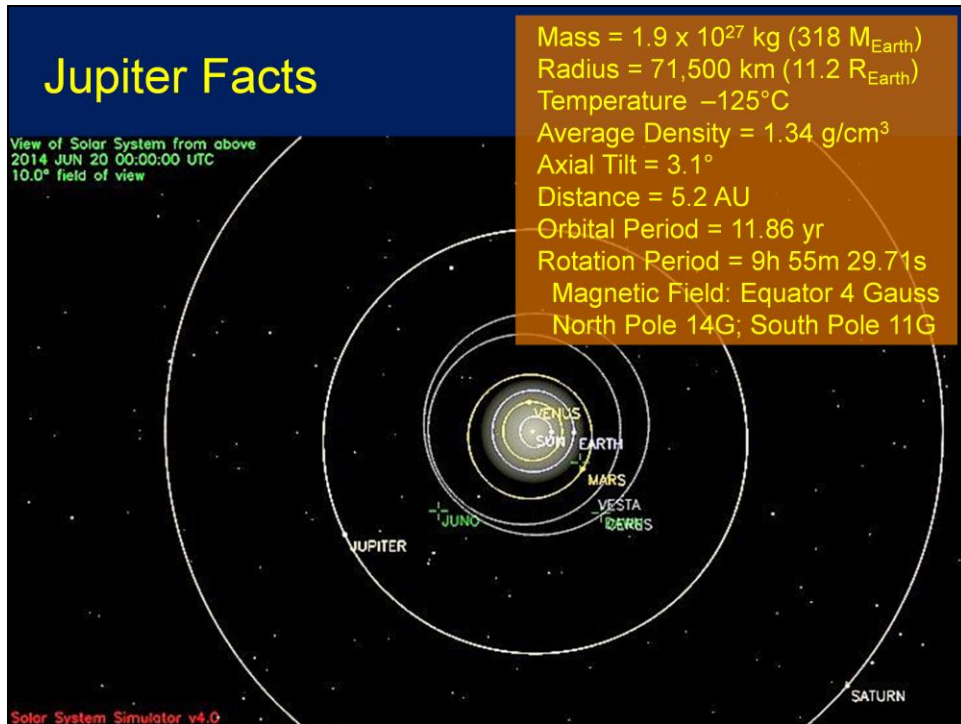
Chuck Higgins, MTSU  
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This presentation is an introduction to the radio science of Jupiter.

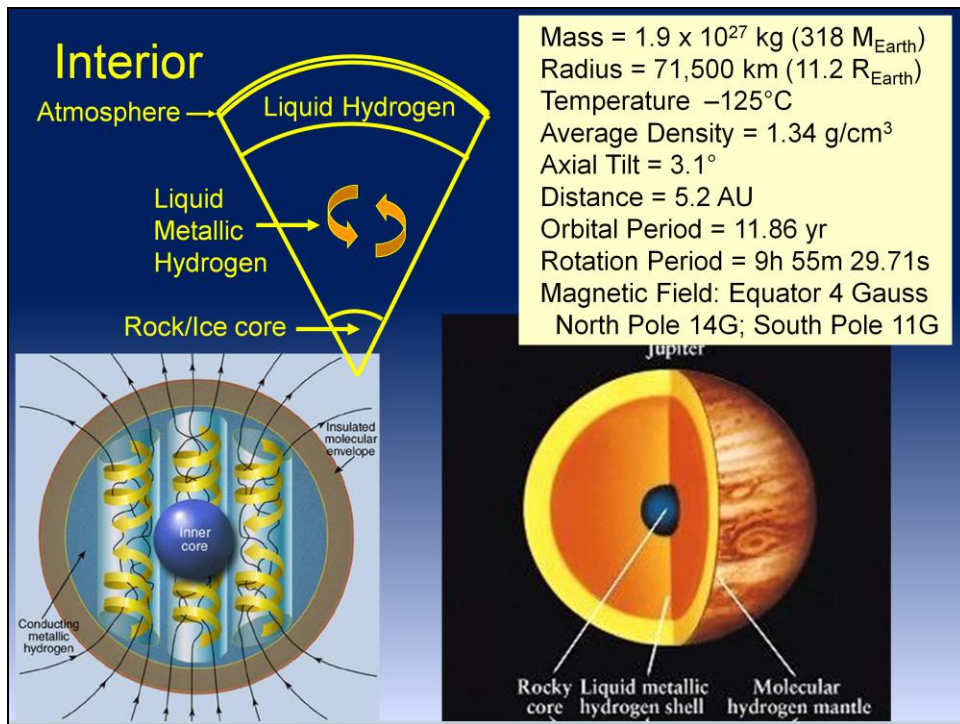
## Jupiter Science Outline

- Jupiter Facts
- Discovery of Jupiter Radio Waves
- Magnetosphere and Io Torus
- Jupiter Radio Sounds
- Io Connection – CML and Io Phase
- Decameter Emission Mechanism
- Summary

Outline



Jupiter, a gas giant planet, is made up of hydrogen and helium and has an average density of  $1.34 \text{ g/cm}^3$ . It is 11 times larger than Earth and is 318 times more massive than Earth. It has an 11.86 yr orbit period and is 5.2 A.U. from the Sun.



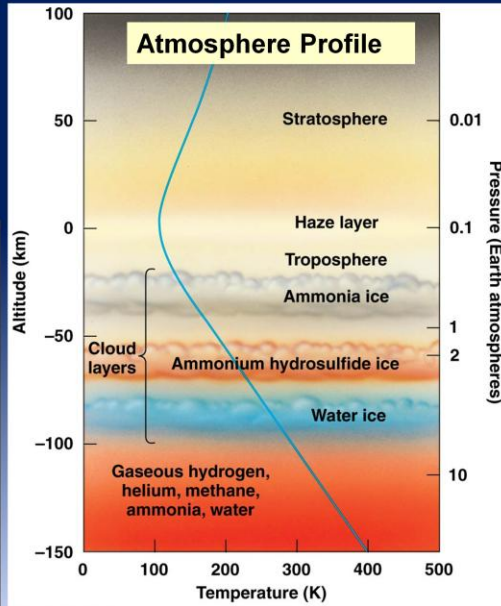
Jupiter's interior structure is not well known, but it has a large magnetic field generated by a planetary dynamo. The dynamo mechanism requires an electrically conducting liquid material that is rotating reasonably quickly; in Jupiter's case the rotation period is about 10 hours. Jupiter's high pressure renders the gaseous hydrogen liquid at increasing depths; at still lower depths the hydrogen changes into a metallic phase able to conduct electricity. This moving electrically conducting material generates a global magnetic field that is about 14 times stronger than Earth's magnetic field (i.e. about 14 Gauss). The core is thought to consist of rock/ice under extreme pressure.

# Jupiter Atmosphere

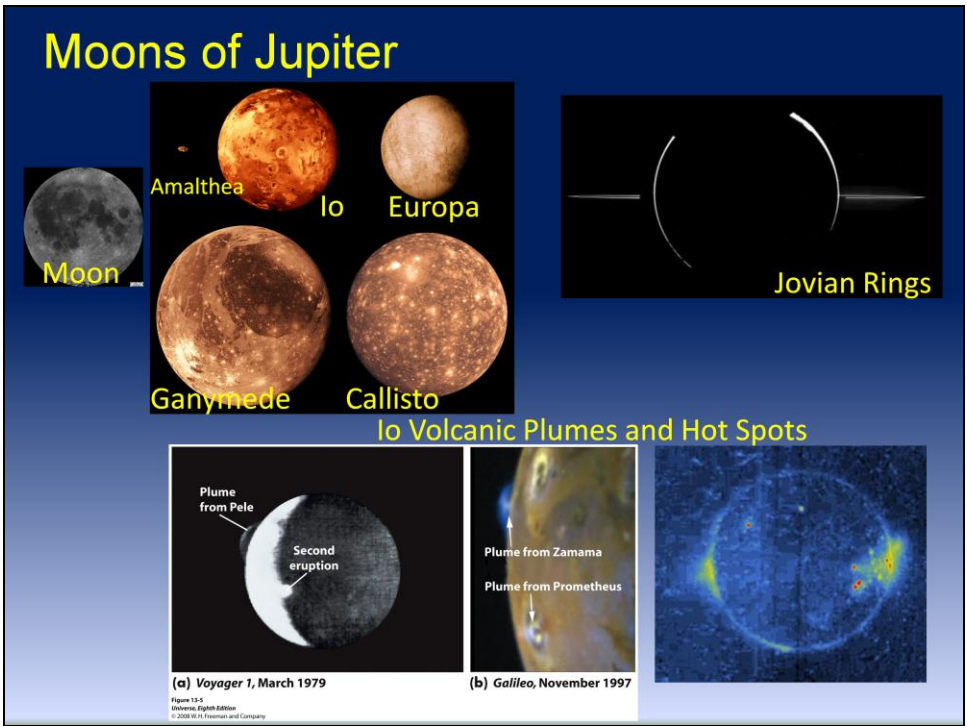
Atmosphere Composition:  
H<sub>2</sub> 78%  
He 21%  
traces of H<sub>2</sub>O, CH<sub>4</sub>, NH<sub>3</sub>



animation



Jupiter's atmosphere is about 78% molecular hydrogen and 21% helium, with trace gaseous elements of water, methane, ammonia. Due to the low atmospheric temperatures (-125 K), the upper cloud layers are ices. Some of the wind speeds are as high as 360 km/hr (223 mi/hr) in the zonal flows. Many vortices form because of the Coriolis forces of a rotating gaseous body.



Jupiter has a faint ring system and has 67 known moons, the four largest are called the Galilean moons. Io the closest Galilean moon, is slightly larger than our Moon, was predicted to have a molten interior in the 1960s due to a large tidal forces from Jupiter. Voyager 1 confirmed the theory in 1979 when volcanic plumes were photographed.

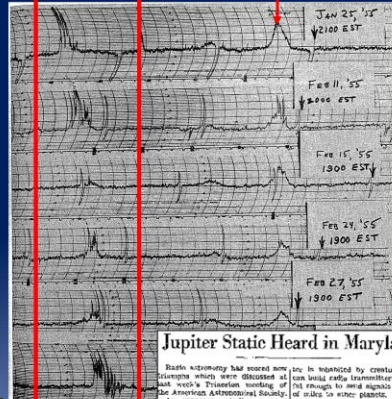


# Discovery

Early 1955 – observing the Crab Nebula, Burke and Franklin noted intermittent bursts of strong radio noise in about a 1/3 of the strip chart records. Burke and Franklin announced their discovery on April 6, 1955 at the AAS meeting in Princeton, NJ.

from Burke and Franklin [1955]

Crab Nebula



## Jupiter Static Heard in Maryland

Radio astronomy has scored new triumphs which were unnoticed at last week's Princeton meeting of the American Astronomical Society. An announcement that aroused special interest came from the Harvard P. Burke and Kenneth L. Franklin of the Carnegie Institution of Washington. Working with a radio "telescope" near Annapolis, Md., they disclosed what, perhaps, bursts of radio waves that come from Jupiter. It may well be, as Dr. Burke and Franklin suspect, that the bursts are static, for they sound just like the static that comes from the loudspeakers of our radio sets when there is a disturbance of the air in a highly charged Jupiter crosses the edge of reception of the radio "telescope" at Annapolis, Md., for the moment. The radio signals come during these disturbances only on one out of every three days.

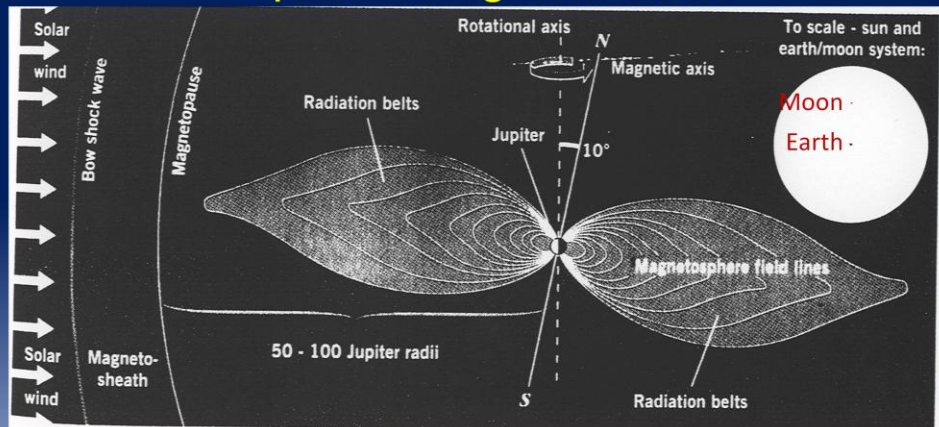
**Nelson Frowe Space**  
Radio noises have also been picked up from the sun and the planets. But this was years ago. The radio noise from the moon is already being picked up.

Thanks to Leonard Garcia QSS Group, Maryland

N.Y. Times April 6, 1955

Jupiter radio emissions were discovered accidentally in 1955 by Burke and Franklin using a “Mills Cross” type array in Maryland. They were observing the crab nebula at low frequencies (22 MHz) and also observed what they thought was local interference. On further observations they confirmed the source of the interference must be Jupiter (see strip chart tracing), and they made their announcement at the American Astronomical Society meeting. A roadside plaque is now erected near the discovery site.

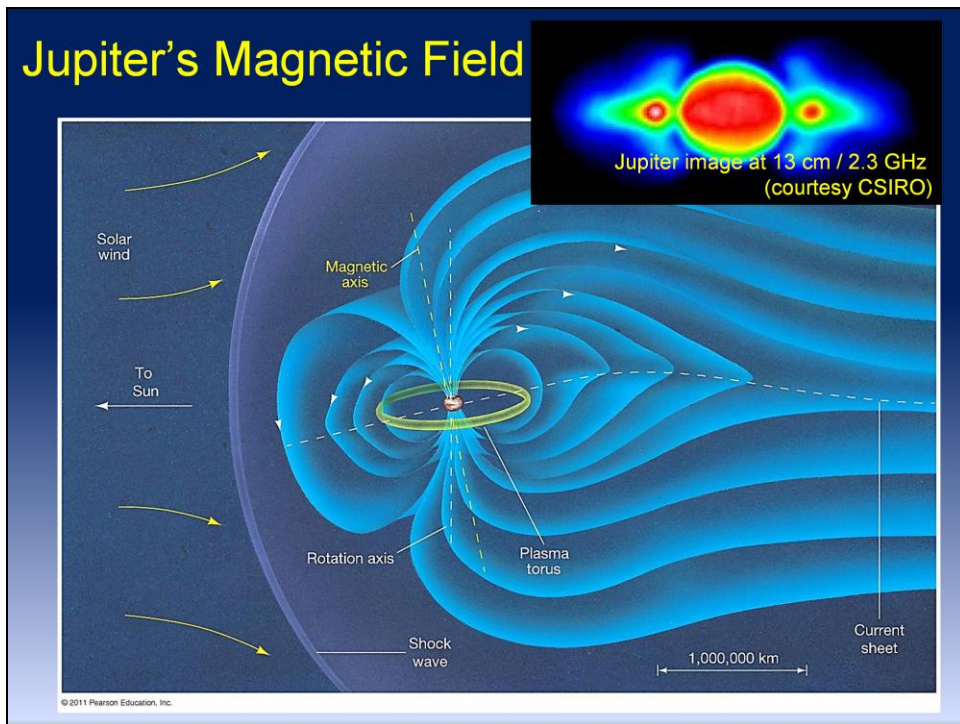
# Jupiter's Magnetic Field



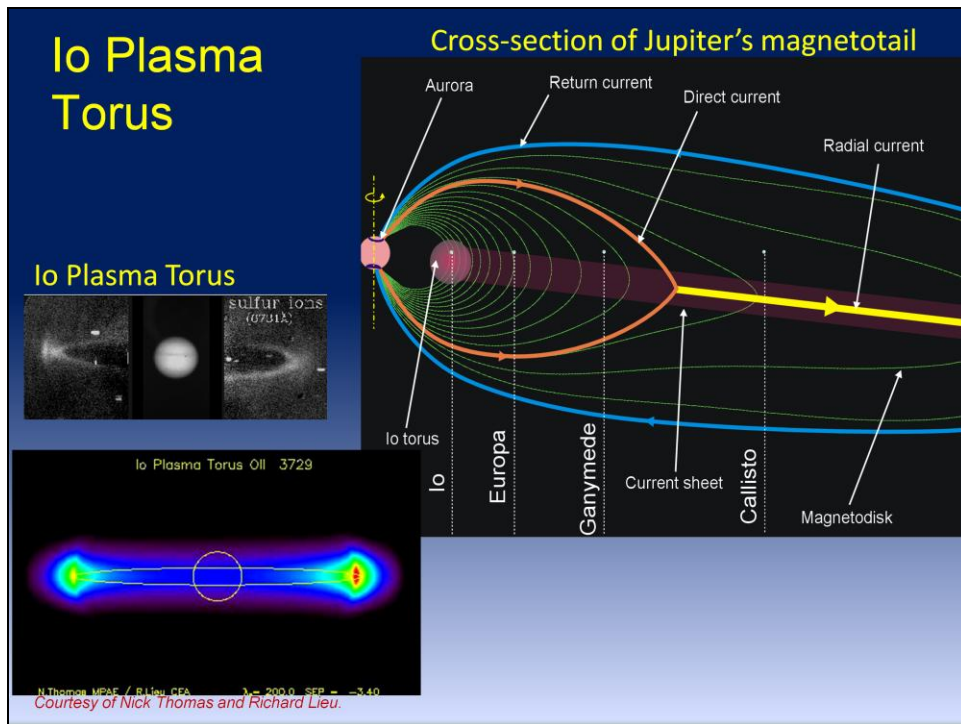
- 1955 Jovian radio emission discovered by Burke and Franklin
- 1959 Radiation belts discovered
- 1964 Jupiter's moon Io strongly influences the radio emission
- 1979 Aurora discovered
- 1998 – 2008 Callisto, Ganymede and Europa shown to influence Jupiter radio emissions

Jupiter's magnetosphere is huge! It spans about 100 Jovian radii and is 4 times larger than the Sun. The magnetic pole is tilted about 10 degrees from the rotational axis causing the entire magnetosphere to wobble back-and-forth on a 10 hour rotation period. After the initial discovery of radio emissions in 1955, the radiation belts were discovered by radio astronomers in 1959 (the same year Explorer 1 confirmed Earth's radiation belts). Soon after Io's influence on the radio emissions were discovered and after the Galileo spacecraft mission the other moons were shown to have a small influence on the radio emissions. Voyager 1 discovered the aurora on Jupiter in 1979.

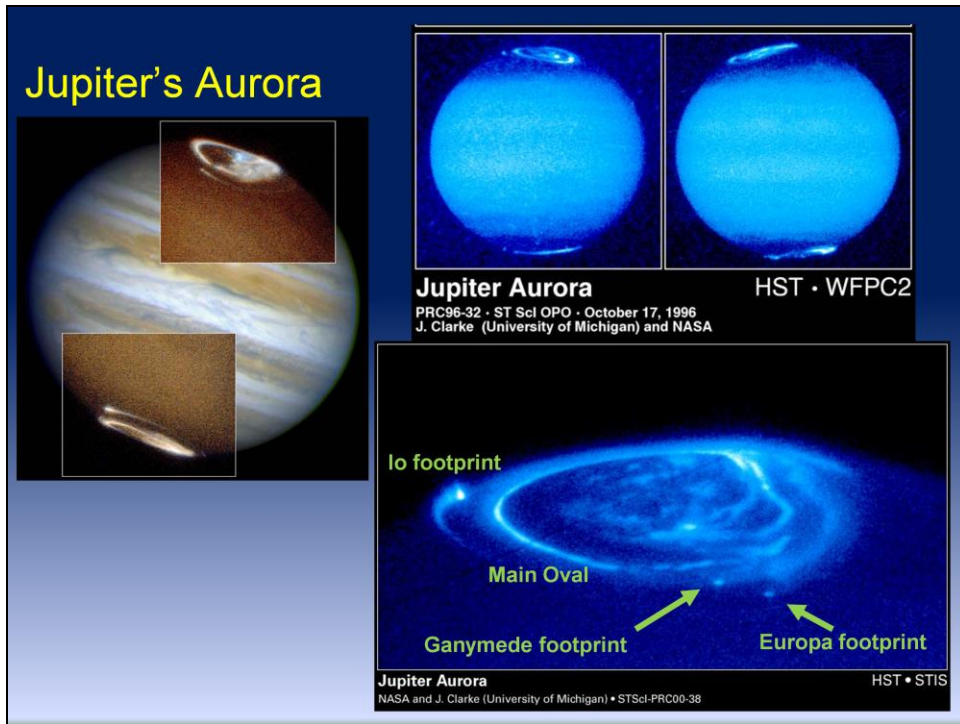




Jupiter's magnetic field is shown with the dayside bow shock and the nightside magnetotail. The current sheet provides an outward radial current flow connected back to Jupiter along high latitude magnetic field lines to close the "circuit". The Io plasma torus caused by the volcanism of Io is shown at 6 Jovian radii. A 13 cm / 2.3 GHz map of Jupiter's radiation belts is shown in the upper right.



Jupiter's magnetic field is shown with the dayside bow shock and the nightside magnetotail. The current sheet provides an outward radial current flow connected back to Jupiter along high latitude magnetic field lines to close the "circuit". The Io plasma torus caused by the volcanism of Io is shown at 6 Jovian radii. The sulfur, sodium, and oxygen neutrals emitted from Io are ionized by the solar UV light and become trapped as a torus of plasma at Io's orbit.

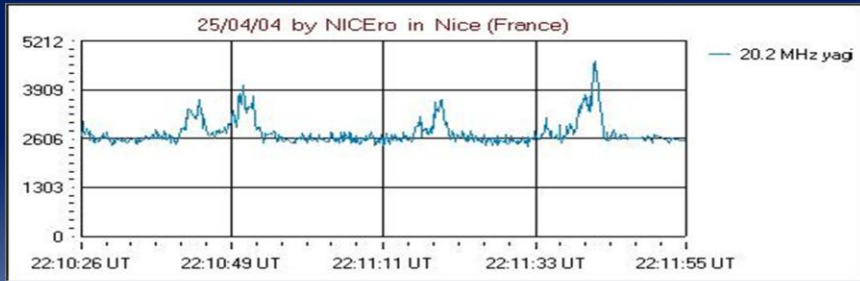


The solar wind interaction with Jupiter causes incredible aurora as seen in these UV images. Notice the vast difference in the dawn-side and dusk-side aurora. Also seen in some images are the electrical footprints of the plasma interactions with the satellites Io, Europa, and Ganymede.

# Jupiter L-bursts



L-type bursts from Jupiter-Io sound like waves crashing on the beach

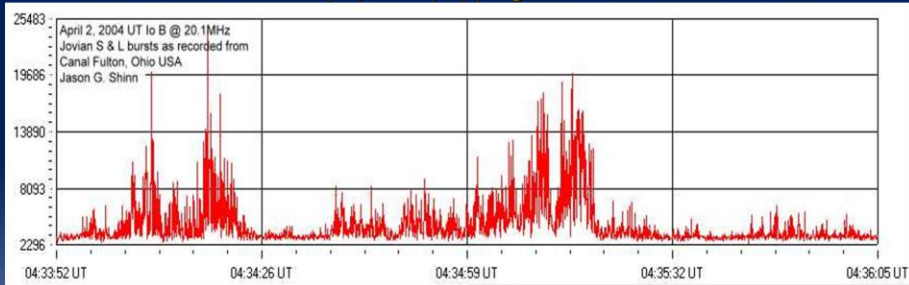


This is a strip chart recording of some 20 MHz radio L-burst emissions from Jupiter. These L-bursts sound like waves crashing on an ocean shore and the modulation is due to interplanetary scintillation of the radio waves.

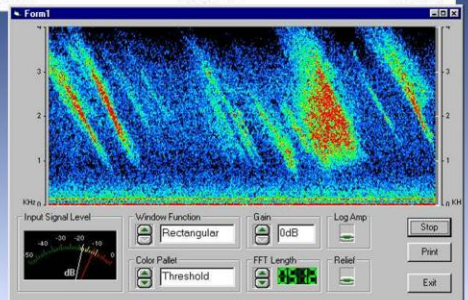
# Jupiter S-bursts



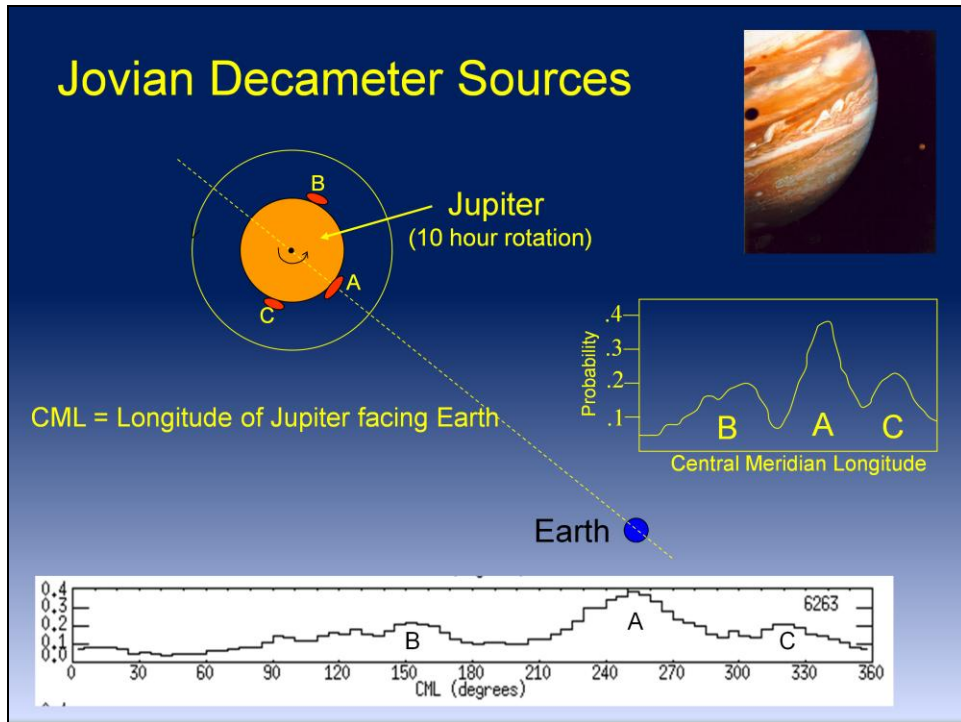
S bursts are the short popcorn popping sounds in this lo-B storm



These are recordings of the same bursts, except that the second file played 128 times slower.



This is a strip chart recording of some 20 MHz radio S-burst emissions from Jupiter. These S-bursts sound like popcorn popping in a microwave. Also shown/heard are the S-bursts recorded at high speeds over a few MHz bandwidth and played back at 128 times slower. The high-to-low frequency whistling demonstrates that the electrons are moving up magnetic field lines, away from Jupiter after reflecting at the mirror points.

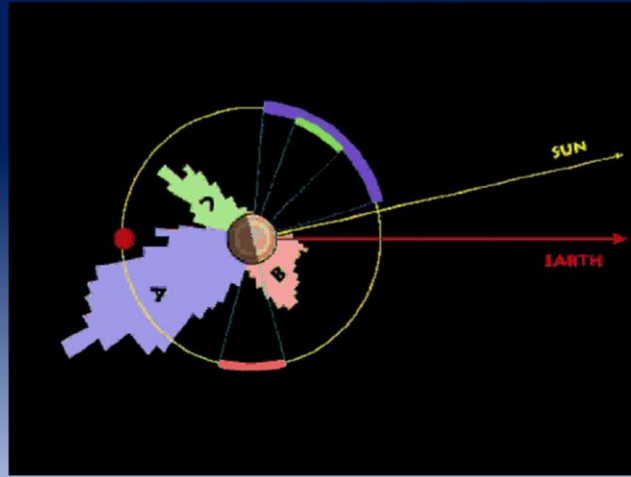


Jupiter's radio emission probability of occurrence has been mapped over many months and years of observations. Three main source areas have been found and are labeled A, B, and C in Jupiter's longitude system. The Central Meridian Longitude (CML) is defined to be the longitude of Jupiter that is facing the observer (usually Earth) based on a fixed rotation period. Actual occurrence probability data from 1962-63 is shown in the lower graph.



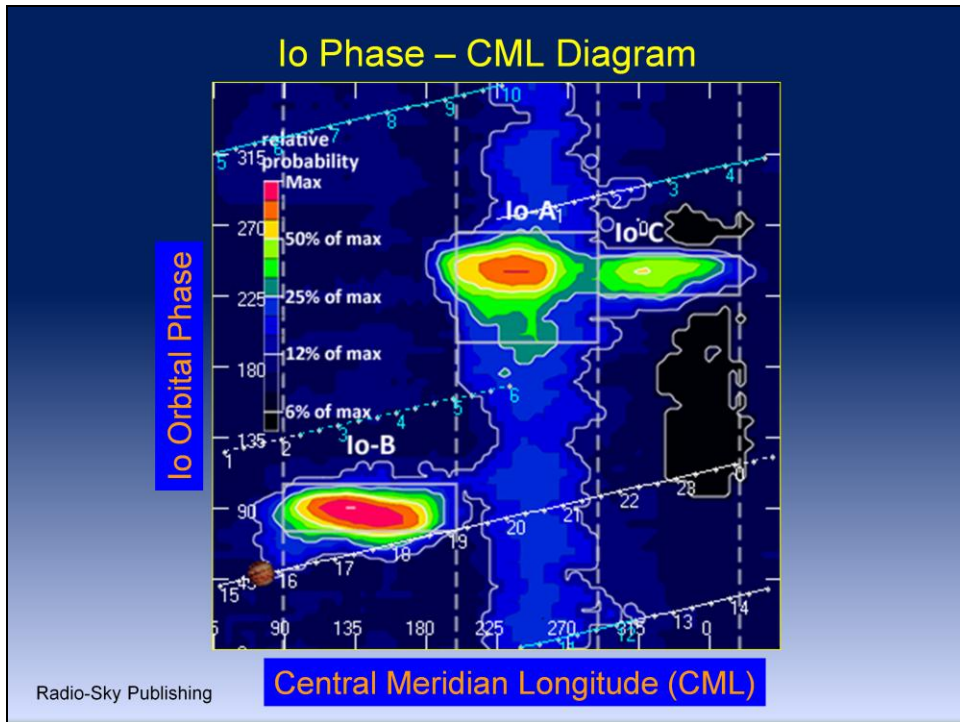
# Jovian Radio Storms

Source A, B, and C dependence on the position of Io

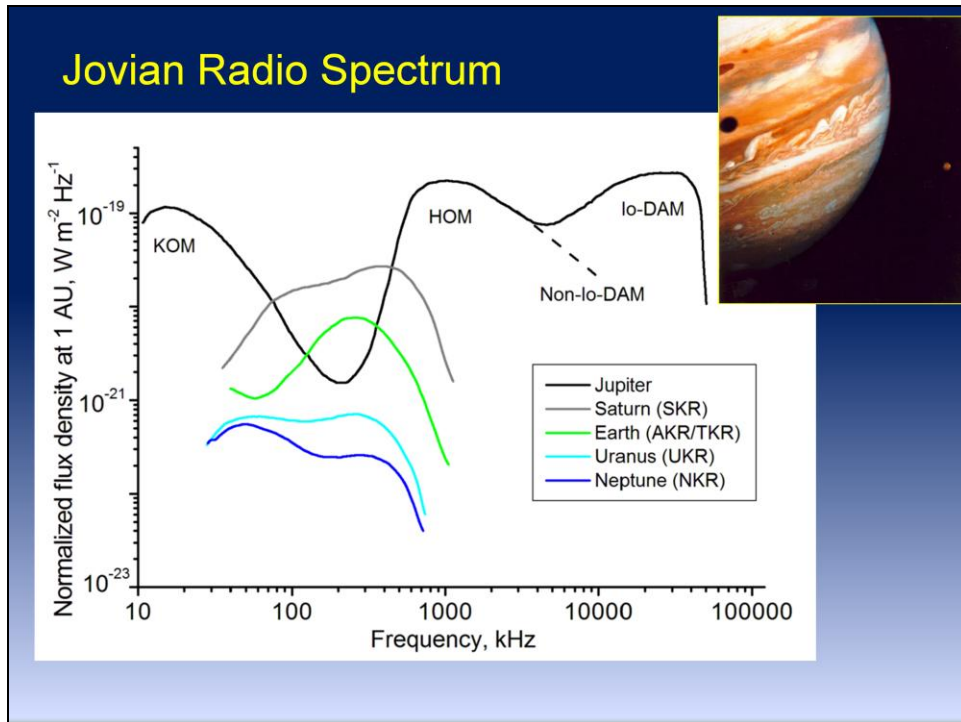


This video clip illustrates the sights and sounds of the various types of Jovian radio storms, including Io and non-Io events. Listen to the difference in signal between L-burst and S-burst events.

As mentioned earlier, it was also found that the orbital position of Io influence the radio emission. This is a video animation of the A, B, and C source geometries and their dependence on Io.

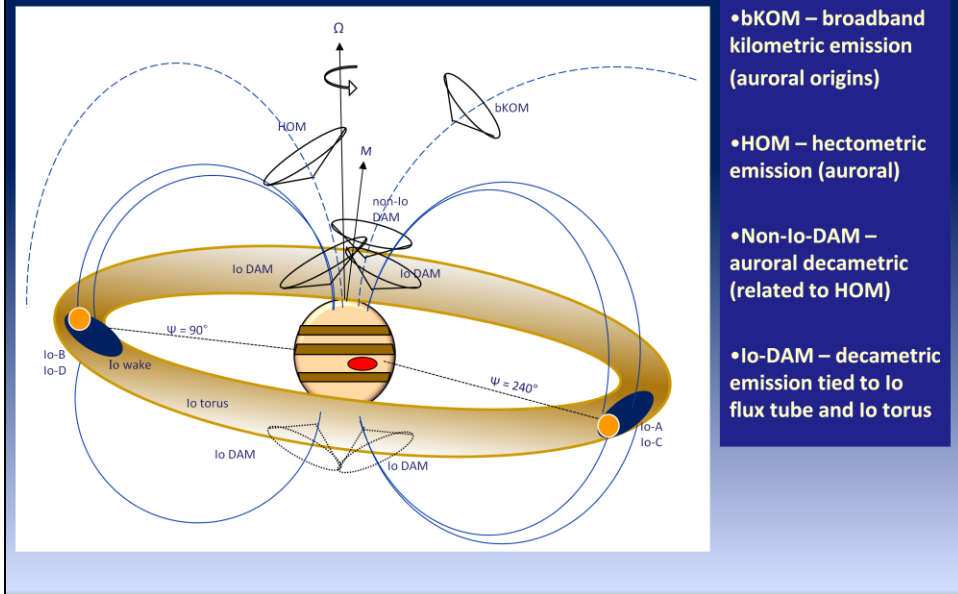


This is a map of the probability of receiving Jupiter's radio emissions at and near 20 MHz. The y-axis shows the Io orbital position and the x-axis is the Jupiter longitude. High probability regions are shown in red and yellow; they are labeled Io-B, Io-A, and Io-C.



This graph shows the radio spectrum of Jupiter from about 10 kHz to 40 MHz. Plotted is the normalized flux density of the radio emission (at 1 AU distance) versus frequency. Jupiter kilometric radio emissions (KOM) and hectometer emissions (HOM) are shown along with the decameter emissions (DAM). DAM emissions are further separated as Io-dependent and non-Io dependent emissions. Also plotted for comparison are the radio spectra of Saturn, Earth, Uranus, and Neptune.

## Jupiter Radio Emission Overview



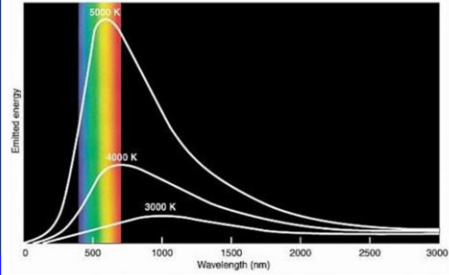
This overview shows the basic picture of many of the source regions of Jupiter's radio emissions. Due to the emission mechanism, the radio waves are emitted in a hollow cone-like beam around active magnetic field lines – some of these are tied to Io while others are tied to higher latitude field lines influenced by the solar wind (auroral field lines). The Io-B and Io-D sources come when Io is about 90 degrees phase, and the Io-A/C sources come from the other side. Io-related emission occurs from both the northern and southern magnetic field regions. Non-Io-DAM, HOM, and broadband KOM (bKOM) come from auroral field lines.

# Mechanisms of Radio Emission

Thermal Emission  
Non-thermal Emission

## Thermal

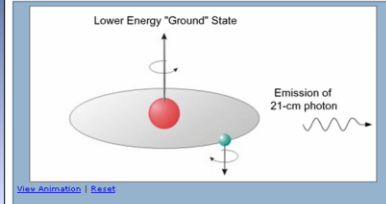
- Blackbody Radiation
- Free-free emission – thermal ‘bremsstrahlung’ radiation (for LTE)
- Spectral Line Emission – i.e. 21 cm line of neutral hydrogen



## Free-Free Emission



## Spectral Line Emission

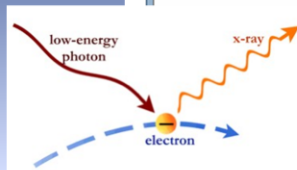
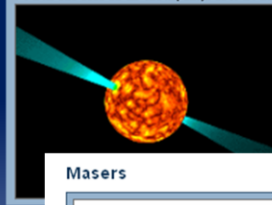
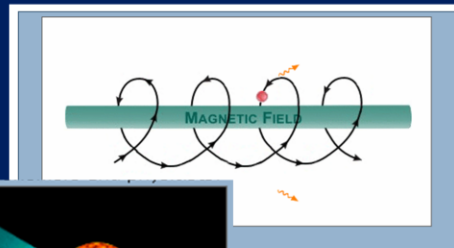


Radio waves can be generated by thermal and non-thermal sources. Thermal radio emissions are generated by blackbody radiation, electron-proton/nuclei interactions called free-free emission, and from spectral line emission from electronic transitions within the atom. The most famous radio emission is the 21 cm emission line from the electron “spin flip” transition in the hydrogen atom.

# Mechanisms of Radio Emission

## Non-thermal Emission

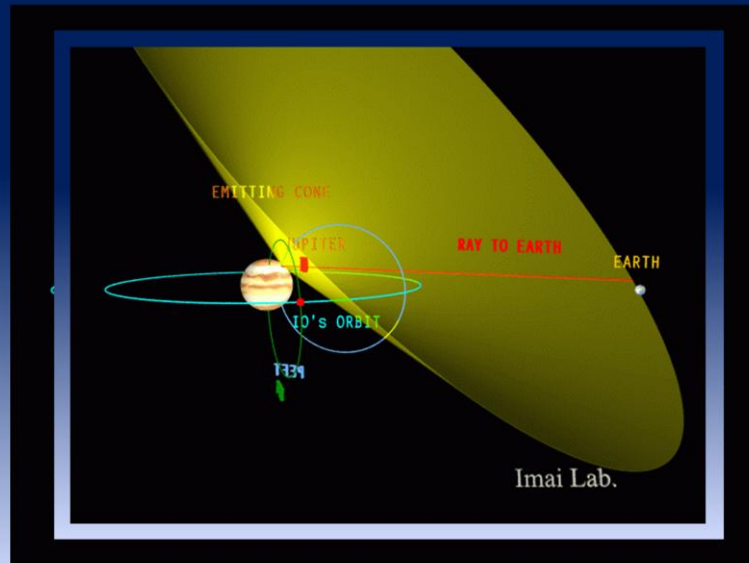
1. Cyclotron/Synchrotron emission – magneto-bremsstrahlung radiation
2. Gyrosynchrotron – pulsars
3. Masers – stimulated emission associated with molecules (in molecular clouds or envelopes of old stars)
4. [Inverse Compton Scattering – high energy emission, not really radio energies]



Non-thermal radio emissions are caused by spiraling electrons in a magnetic field. This magneto-bremsstrahlung radiation can come at non-relativistic (cyclotron) and relativistic (synchrotron) energies. Jupiter's emission is caused by the cyclotron emission mechanism. Other types of non-thermal emissions are masers in molecular clouds. Inverse Compton scattering is a non-thermal emission mechanism, but it is mainly an x-ray source.



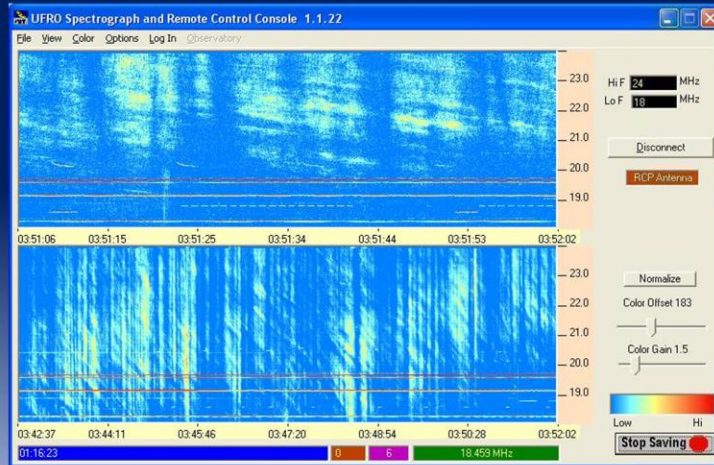
## The Jovian Hollow Cone



This is an animation of Jupiter's emission as a hollow cone emanating from the source in the northern hemisphere. This example is one of an Io-related emission where the instantaneous flux tube (IFT) and previously energized flux tube (PEFT) are shown. These flux tubes carry electrons from Io to Jupiter and stimulate the radio emission.

# Jupiter Spectral Structures

L & S bursts  
Polarization  
Io Arc structure  
Modulation Lanes  
N-events  
S-N events  
Faraday Lanes



March 26, 2004 Io-B event  
shows beautiful modulation lanes

The spectrograph allows scientists to analyze the nature of Jupiter's radio emission. This example shows a 6-MHz wide display of radio emissions versus time. The intensity is given as the color on the diagram. Many types of fine structures are seen in a spectrograph including L and S burst structures, arc-structures, modulation lanes, and N events, S-N event interactions, and Faraday lanes. These will be explained in a later talk.

## Summary

- Jupiter Radio waves were accidentally discovered in 1955
- Radio Discoveries
  - Longitude System
  - Rotation Period
  - Satellite influences
  - Emission Mechanism / Auroral connection
  - Spectral signatures: L- and S-bursts, N-events, modulation lanes, arc structures, etc.
  - Emission cone structure
  - Long-term periodicities
  - Solar wind interactions
- Many questions remain ... more in the Advanced Science Summary



A summary of Jupiter radio science.