Auroral Physics at Jupiter:
Radio and Plasma Wave Observations by Juno

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Juno Science Objectives

Origin
Determine O/H ratio (water abundance) and constrain core mass to decide among alternative theories of origin.

Interior
Understand Jupiter's interior structure and dynamical properties by mapping its gravitational and magnetic fields.

Atmosphere
Map variations in atmospheric composition, temperature, cloud opacity and dynamics to depths greater than 100 bars at all latitudes.

Magnetosphere
Characterize and explore the three-dimensional structure of Jupiter's polar magnetosphere and auroras.
Juno Payload

X and Ka Band Gravity Science (JPL/ASI)
Six Microwave Radiometers— MWR (JPL)
Magnetometer— MAG (GSFC/DTU)
Camera - JunoCam (Malin)
Three Energetic Particle Detectors—JEDI (APL)
Four Jovian Auroral Distributions — JADE (SwRI)
Waves (U of Iowa)
UV Spectrometer— UVS (SwRI)
IR Camera/Spec –JIRAM (ASI)
Location is Key: Juno passes directly through auroral field lines.

A suite of instruments is used to understand the physics:
JADE, JEDI, MAG, Waves, JIRAM, UVS
Outstanding Questions: Polar Magnetosphere

- What structure of the polar magnetosphere? How does it compare to Earth’s?
- Where and how are auroral particles accelerated?
- Where and how are auroral radio emissions generated?
- What causes the transient polar aurora?
- What is the topology of the polar magnetic field? How much connects to the solar wind and how variable is this?
- How do internal magnetospheric dynamics and solar wind variability affect the main aurora?
- How does the polar magnetosphere couple to the distant magnetotail?

After Bagenal et al., *Space Sci. Rev.*, 2014
Other Outstanding Questions

• How are radiation belt particles accelerated and what processes drive the structure and dynamics of the radiation belts?
• How is the magnetosphere coupled to the solar wind? How much mass and momentum are transferred?
• What role does the solar wind play in magnetospheric dynamics and how deep does its influence penetrate?

After Bagenal et al., *Space Sci. Rev.*, 2014
Juno will enable comparisons with terrestrial auroral physics

Paschmann et al. (2002)
Juno Mission Plan

Baseline mission:

32 polar orbits, 12 degree net
Perijove ~5000 km
14 day period
Spinning, solar powered

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

Sun-to-Jupiter View (Jupiter North Pole Up), 1-day Tick Marks for Capture Orbits and Pre-JOI Mission Phases: JOI, Capture Orbits, PRM, Orbits 2-3, Science Orbits, Deorbit

- Flight Direction
- Orbits 4-19
- 53.5-day Capture Orbits
- Orbits 20-35
- 14-day Science Orbits
- Extra Orbit 36
- Increasing Orbit #
- Jupiter North Pole View, Sun Direction Fixed (yellow dashed line)
Juno Waves Science Objectives

- **Waves primary objectives:**
  - Explore radio and plasma waves in Jupiter’s polar magnetosphere
  - Examine the role of plasma waves in the auroral acceleration region
  - Identify source regions for Jupiter’s primary radio emissions and observe these in situ

- **Additionally, Waves will:**
  - Observe the structure and dynamics of the plasmasheet
  - Monitor radio emissions as a proxy for magnetospheric dynamics
  - Measure dust impacts between the ring system and the atmosphere
Juno Waves Overview

**Juno Waves Block Diagram**
- **High Frequency Receiver**
  - ~100 kHz – 40 MHz
- **Low Frequency Receiver (High)**
  - ~10 kHz – 150 kHz
- **Low Frequency Receiver (Low)**
  - ~50 Hz – 20 kHz
- **DPU (Y180, FFT Engine)**
- **To Spacecraft**

**Instrument Characteristics**
- **Spectral Coverage**
  - Magnetic: 50 Hz – 20 kHz
  - Electric: 50 Hz – 40 MHz
- **Spectral Resolution**
  - ~20 Channels/decade
- **Periapsis Mode Cadence**
  - 1 spectrum/s
- **LF and MF Burst Modes**
  - Waveform Captures in all bands to 150 kHz triggered onboard
- **HF Burst Modes**
  - Ability to select a 1-MHz band including $f_{ce}$
Prime Waves Targets

The Three Regions of the Aurora

- **Upward Current Region**
  - $n_e$ Ion holes
  - AKR
  - EIC, EMIC

- **Downward Current Region**
  - VLF Saucers
  - $n_e$
  - EIC

- **Alfvén Aurora**
  - EPSH
  - ELF

Ergun et al.

Cassini Radio and Plasma Wave Science

- Decametric Radiation
- Hectometric Radiation
- Narrowband Kilometric Radiation
- Broadband
- Quasi-Periodic Bursts

FAST ORBIT 1747

- LF E OMNI (kHz)
- Log 2Hz/Level

Time (UT) Minutes from 1997-01-30 00:03:00

Coupling the Middle Magnetosphere to the Aurora

Barbosa et al., 1981
Auroral Radio Emissions

Zarka et al., 2004.
Auroral Radio Emission Source

Cassini Orbit 89
October 17, Day 291, 2008

Saturn Kilometric Radiation

Narrowband Z-mode Emissions

Auroral Hiss

RS
Inv. Lat
Lat
LT
L

04:00 06:00 08:00 10:00 12:00

R_s 3.95 4.21 4.75 5.45 6.21
Inv. Lat 60.68 71.24 76.42 82.29 83.73
Lat -13.34 -39.03 -59.25 -71.76 -74.20
LT 22.77 23.39 0.37 2.33 5.32
L 4.17 6.97 18.15 55.56 83.86
Solar Wind/Magnetospheric Interactions

Galileo PWS, Dec. 3, Day 338 to Dec. 20, Day 355, 2001

Interplanetary Shock (Cassini)

Onset (Event B)

Hectometric Radiation

Magnetospheric Compression

Trapped Continuum Radiation

Frequency (kHz)

dB

Day

0.1
340
345
350
355

Inside Magnetosphere

Outside Magnetosphere

A-G01-163-4
Observation Planning
Plasma Waves in Earth’s Radiation Belts

Juno Waves October 9, Day 282, 2103

Electric

Magnetic

$R_e$ 5.637 4.798 3.756 2.721 1.739 1.100 1.496
Terrestrial Lightning Whistlers
Interplanetary Shock Associated with X4.9 flare on 2/25/2014

- Class X4.9 flare occurred early on 25 February
- Associated with coronal mass ejection
- Juno/Waves observed type III solar radio emission
- Disturbance propagated to Juno as an interplanetary shock shown here
- Upstream plasma oscillations caught in Waves burst mode.
Juno Dust Impact

Juno Waves  December 2, Day 336, 2011  20:38 SCET

~ 200 mV
Earth-based Supporting Observations

- Glenn Orton is responsible for organizing Earth-based observations in support of the Juno mission
  - Amateurs
  - Professionals

- Specifically for auroral physics, professional support is expected from:
  - HST UV (e.g. Nichols Cycle 23 coinciding with Juno’s orbit insertion)
  - IRTF H$_3^+$
  - Giant Telescopes: COMICS, VISIR, CanariCam (Mid-IR)

- Philip Zarka was asked to coordinate ground-based decametric radio observations under an ad-hoc group named “Juno Ground Radio”:
  - Nançay Decameter Array (France)
  - LOFAR (various European locations)
  - UTR-2, URAN 1-4 (Ukraine)
  - LWA, LWA1 (USA)
  - Others
Summary

• The exploration of the polar magnetosphere is a basic objective of Juno.
• The polar orbit with very low periapsis is ideal to survey the expected auroral acceleration region.
• Juno has a well-balanced payload allowing a comprehensive examination of auroral processes at Jupiter
• Juno Waves investigation should allow comparisons with the terrestrial auroral situation, thereby advancing our understanding of Jupiter’s polar magnetosphere.
• Arrival on July 4, 2016!
UVS and JIRAM observe auroral emissions on approach & departure

In situ instruments measure particles & fields over poles and in plasma disk
The aurora is the signature of Jupiter’s attempt to spin up its magnetosphere.

Hill; Cowley et al.,