National Aeronautics and Space Administration

Early Observations of Jupiter with Juno's Microwave Radiometer (MWR)

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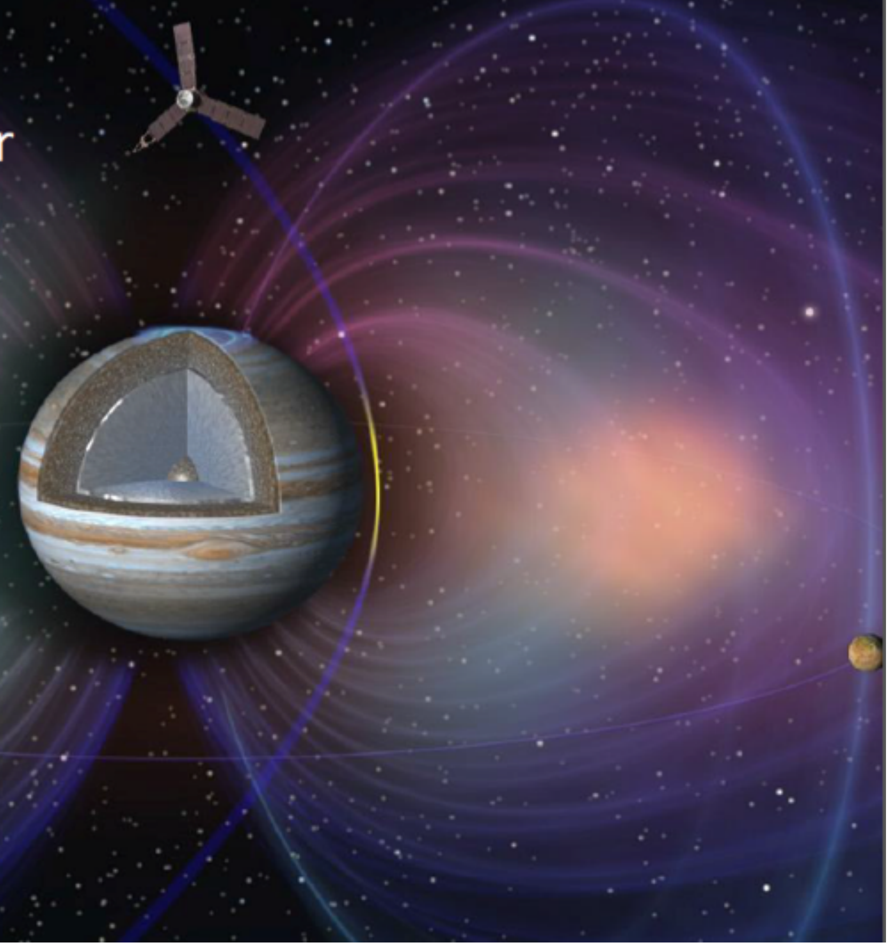
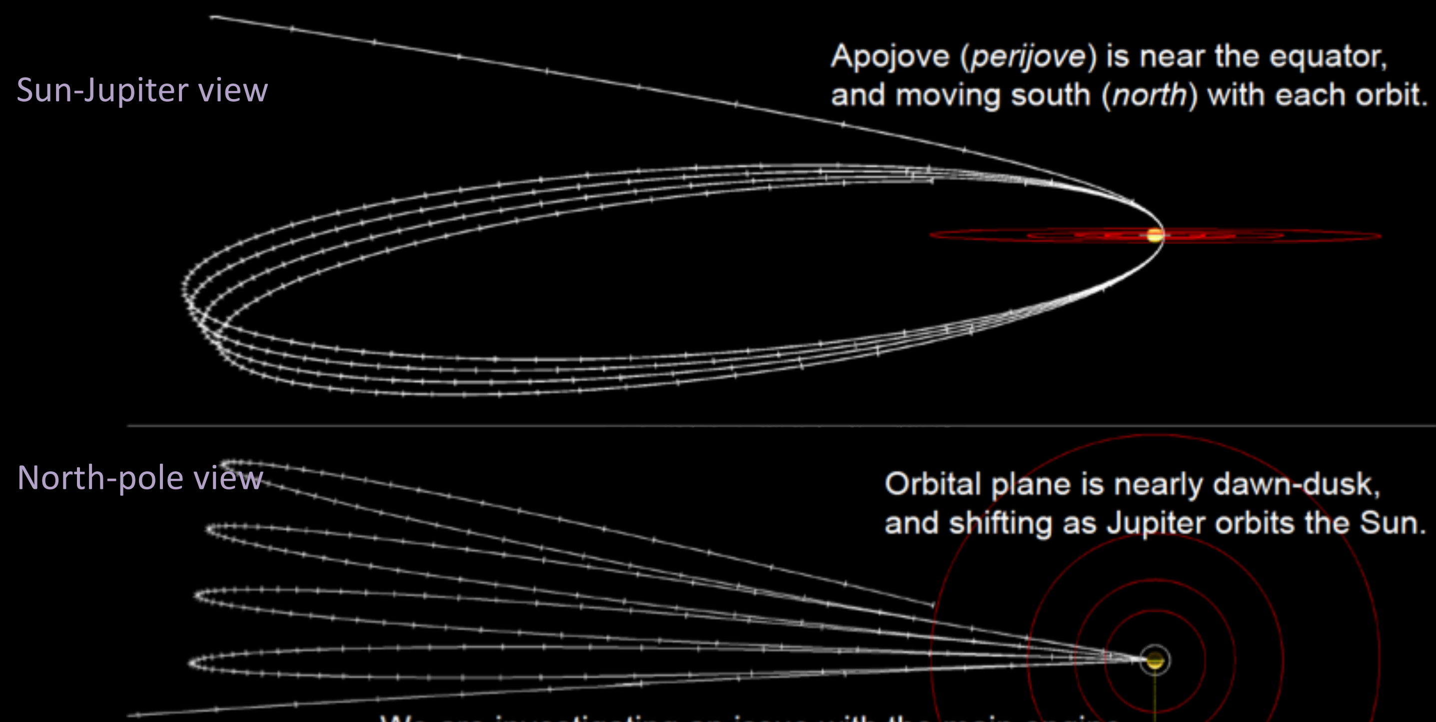
Juno Mission

- First solar powered mission to Jupiter
- Spinning, polar orbiter
- Launch – Aug 5, 2011
- Jupiter Arrival (JOI) – July 4, 2016
- Orbital period is currently 53 days
- Perijove Science
  Aug 27, ~~Oct 19~~, Dec 11, Feb 2,...



Juno's Trajectory



We are investigating an issue with the main engine.

- Orbital period is currently 53 days
- Pending decision whether/when to reduce orbital period
- Primary science (and more) achievable either way.

Juno Science

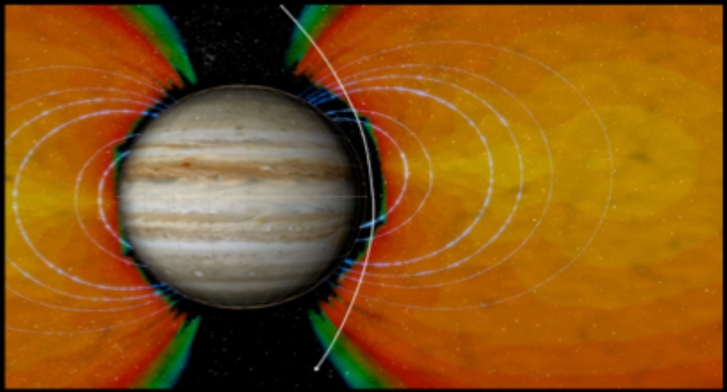
Juno Science Objectives

Origin
Determine the abundance of water and place an upper limit on the mass of Jupiter's dense core to decide which theory of the planet's origin is correct

Interior
Understand Jupiter's interior structure and how material moves deep within the planet 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 Instruments

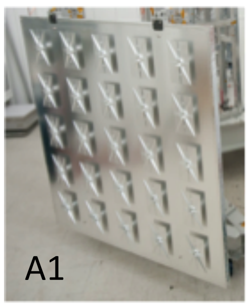
- Gravity Science (JPL, ASI)
- Magnetometer— MAG (GSFC)
- Microwave Radiometer— MWR (JPL)
- Jupiter Energetic Particle Detector— JEDI (APL)
- Jovian Auroral Distributions Exp.— JADE (SwRI)
- Plasma Waves Instrument— Waves (U of Iowa)
- UV Spectrometer— UVS (SwRI)
- Infrared Camera— JIRAM (ASI)
- Visible Camera— JunoCam (Malin)

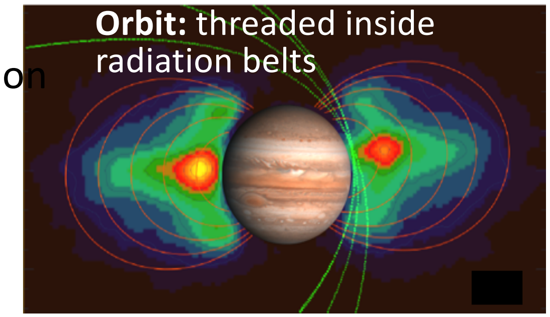
MWR Science Objectives

- Determine the global water and ammonia abundance by sampling to pressures ≥ 100 bars
- Study atmospheric structure and dynamics through the sampled pressure range
- Observe the distribution of synchrotron radiation from inside the magnetosphere

Observations at Jupiter

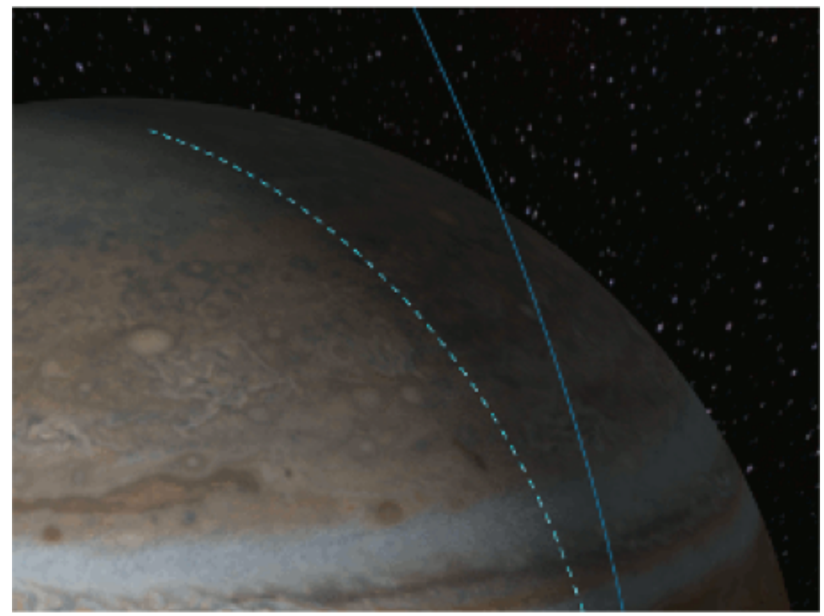
Antennas: mounted on two sides of the spacecraft





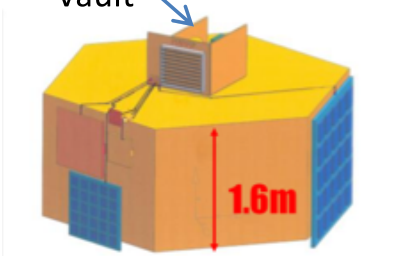
Radiometers: in spacecraft vault

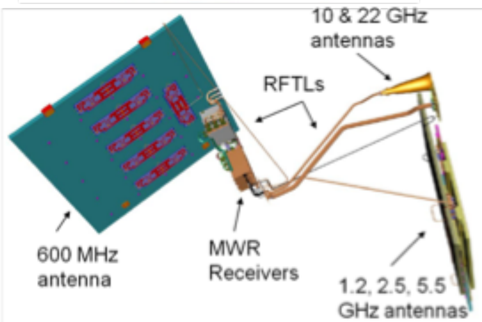
Channel	Wavelength cm	Frequency GHz
1	50	0.6
2	24	1.25
3	11.55	2.6
4	5.75	5.2
5	3	10
6	1.37	21.9



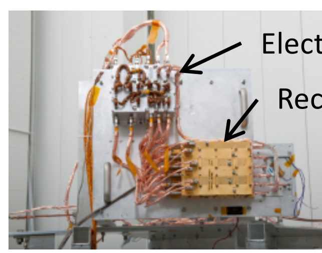
Observations: As the spacecraft spins, each point along the subspacecraft track is observed many times at many emission angles

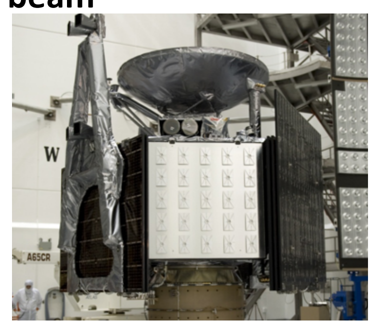
MWR Instrument Description





- **MWR receivers and electronics are installed in a radiation vault**
  - **Receivers include Dicke switch to a load and noise diode injection for calibration**
- **Long RF transmission lines are used to connect to outboard antennas**
  - **>100 K gradient from antenna to receiver**
- **Three antenna types:**
  - **Patch arrays provide 20^o beams at 0.6 and 1.2 GHz**
  - **Slotted wave guide arrays provide 12^o beams at 2.5, 5.5 and 10 GHz**
  - **Feed horn at 22 GHz with 12^o beam**

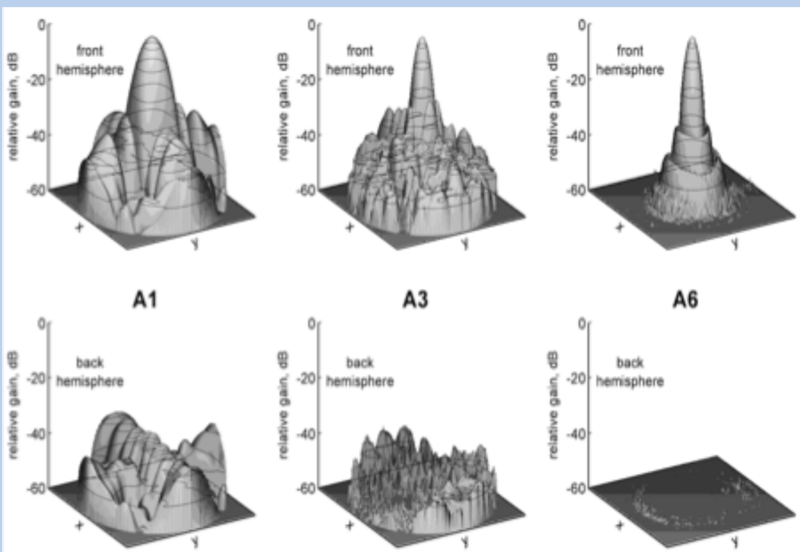




MWR Calibration: Design

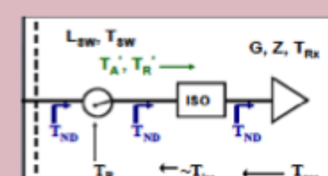
- Ensure capability for relative T_b measurements as a function of emission angle to 1 part in 10^3

Well measured, low-sidelobe antennas for antenna pattern correction



	Error Allocations, %					
	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6
Measurement Noise (5 sec avg.)	0.038	0.039	0.036	0.042	0.042	0.048
Antenna Temperature Calibration (ATC)	0.053	0.052	0.046	0.067	0.059	0.068
Antenna pattern correction (APC)	0.075	0.075	0.060	0.060	0.060	0.050
Unallocated Error:	0.011	0.013	0.055	0.012	0.034	0.025
MWR Requirement %	0.100	0.100	0.100	0.100	0.100	0.100

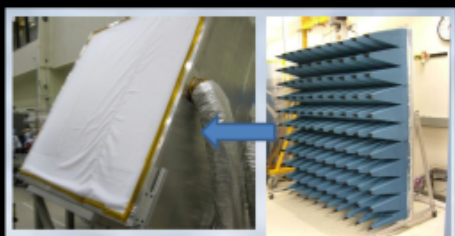
Redundant gain stabilization over second to multiyear time scales



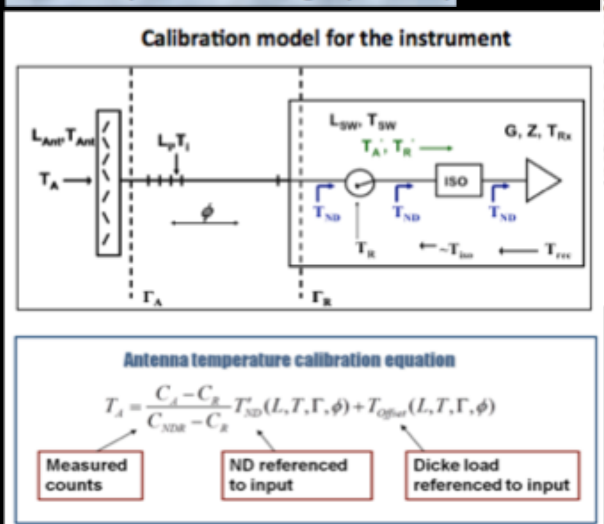
3 noise sources/channel

MWR Calibration: Implementation

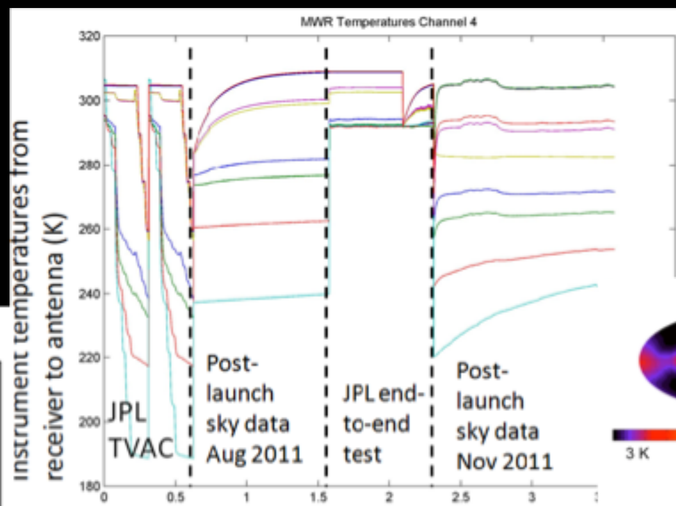
- Carry ground hot/cold load calibration to Jupiter



2.5m temperature controlled blackbody calibration target (24" abs.)

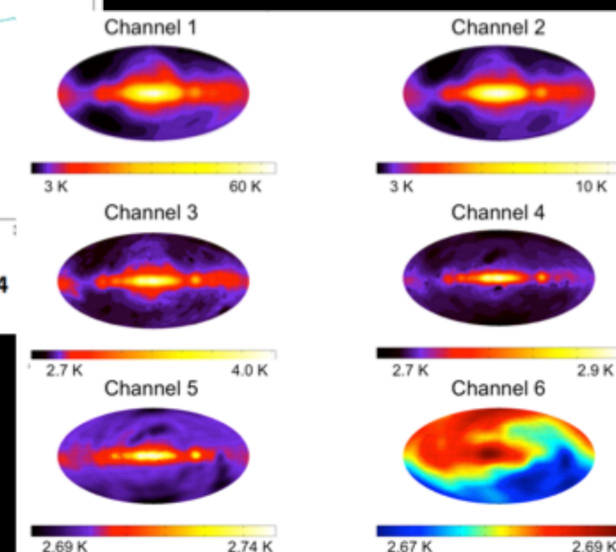


$$T_A = \frac{C_A - C_R}{C_{NDR} - C_R} T'_{ND}(L,T,\Gamma,\phi) + T_{Offset}(L,T,\Gamma,\phi)$$



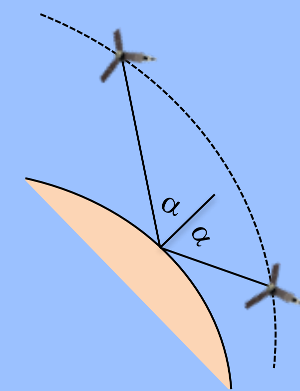
MWR instrument temperatures for Channel 4 in data set used for post-launch tuning

Sky maps accumulated during cruise

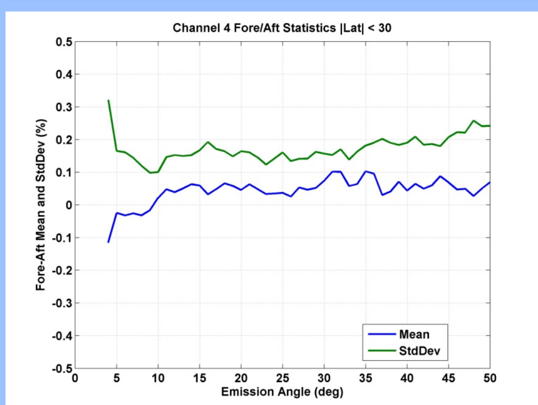


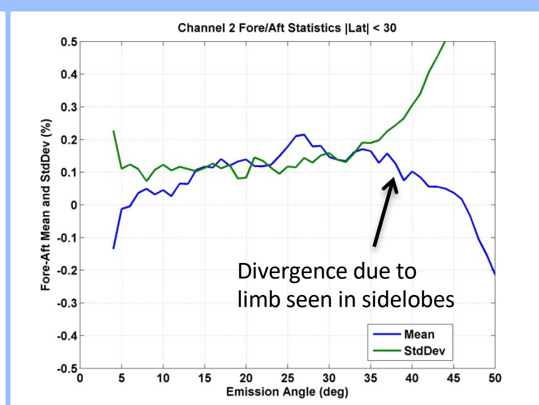
MWR Calibration: Validation in Jupiter Orbit

Fore and aft views: Same footprint, same emission angle, different viewing times. These are very sensitive to systematic errors that depend on viewing geometry, e.g., sidelobe contributions from planet and synchrotron emission, magnetic susceptibility & gain variations.

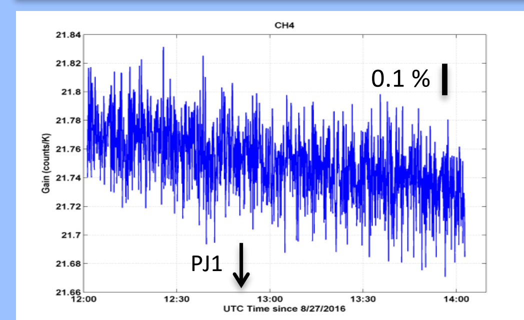


1 part in 10^3 stability demonstrated for emission angle dependence of measured antenna temperatures





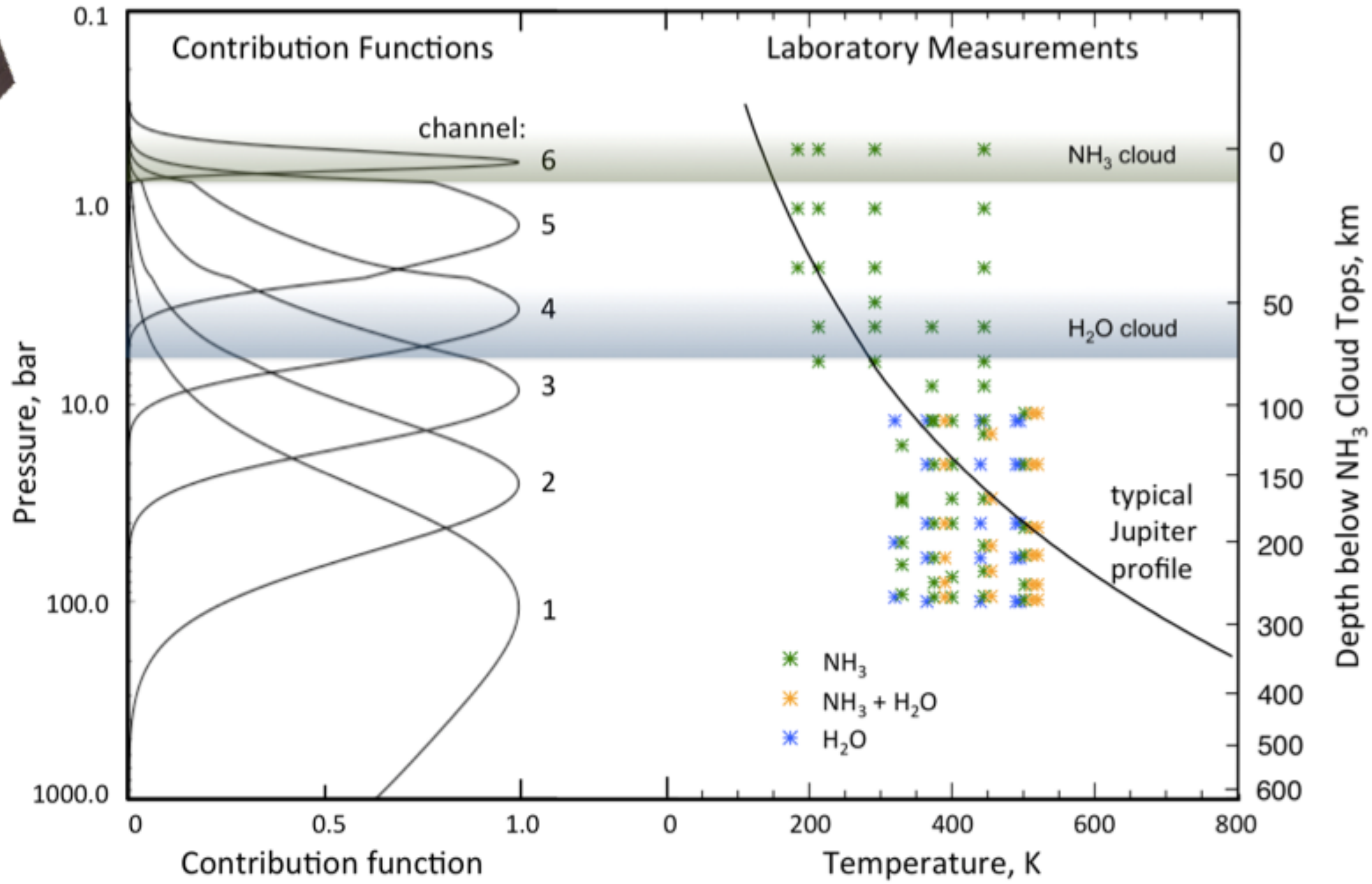
Note: Gain drift << 0.1% during perijove 1 pass after correction



MWR Calibration: Summary

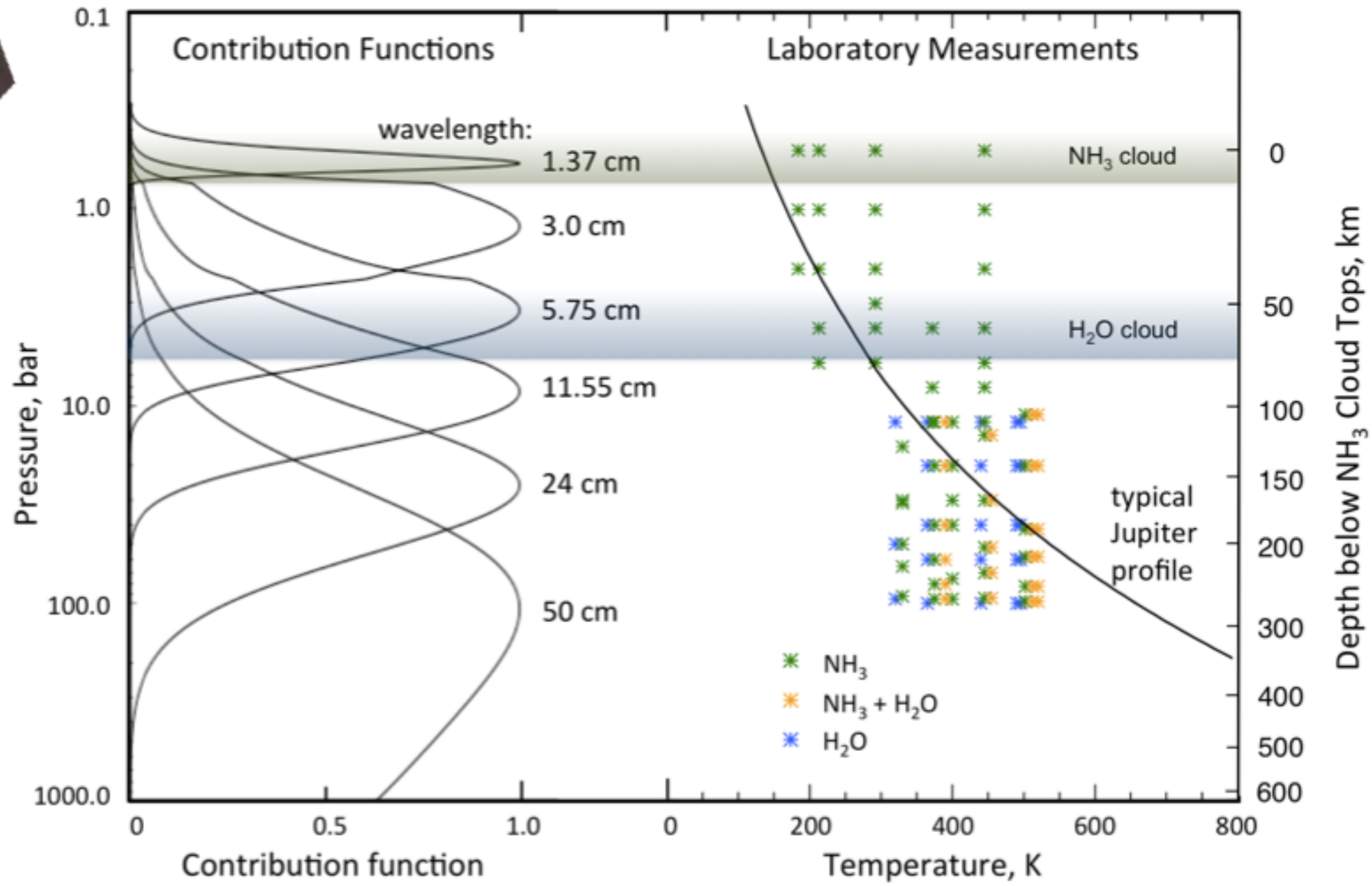
- Current status (for results reported here)
  - Absolute calibration < 2%
  - Relative calibration 0.1%
- We expect absolute calibration to improve when we incorporate emission angle dependence into the analyses

Radiative Transfer in Jupiter's Atmosphere



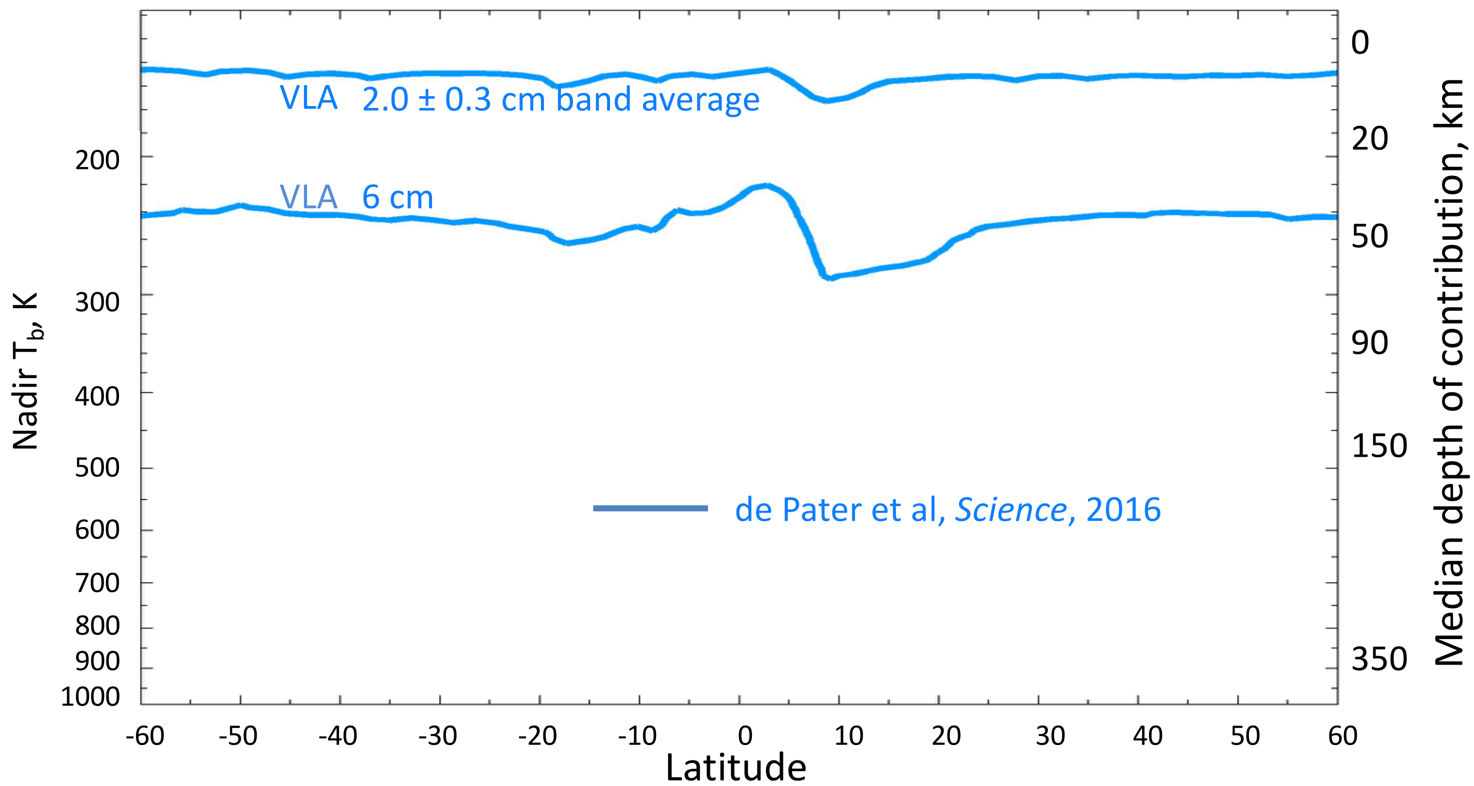
Pressure vessel at Georgia Tech with Steffes and students

Radiative Transfer in Jupiter's Atmosphere

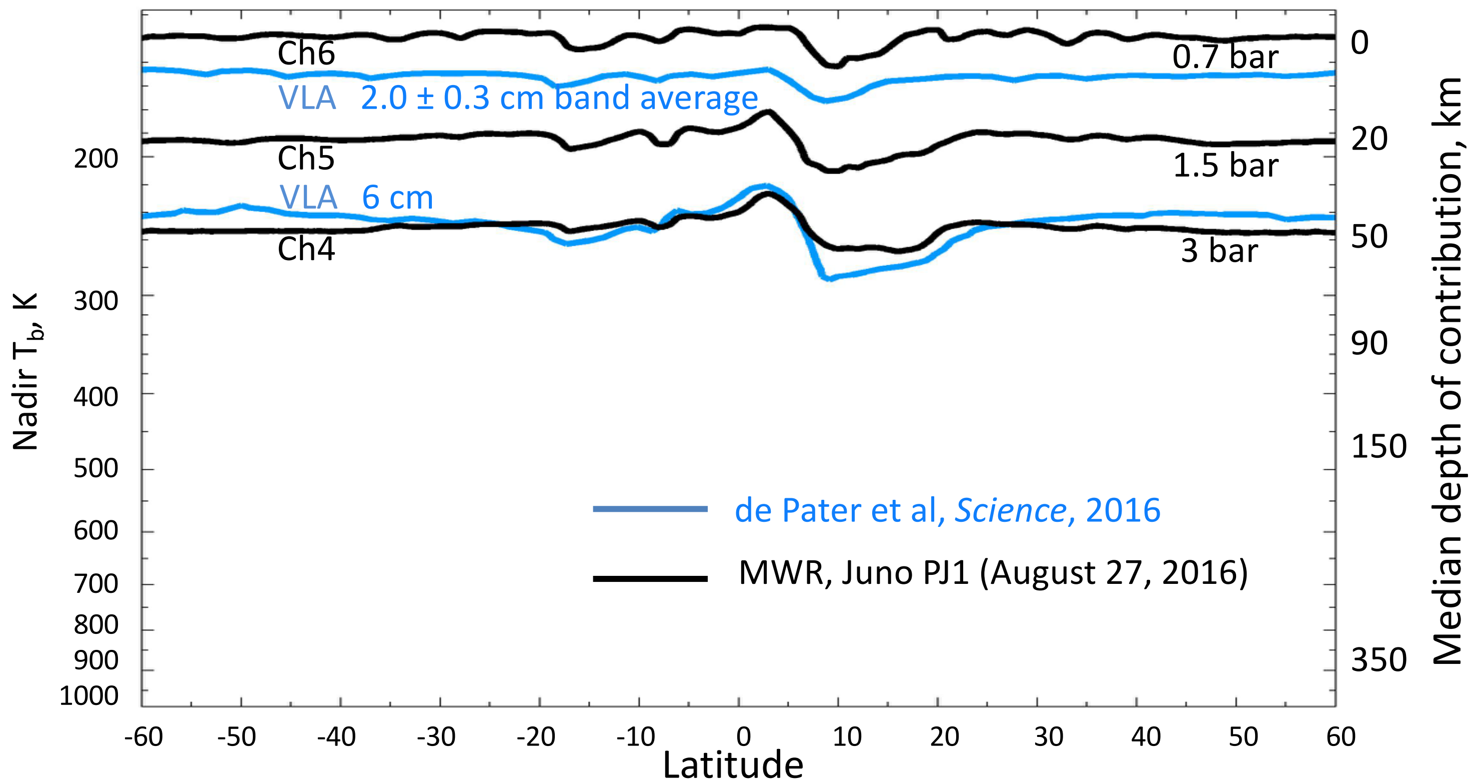


Pressure vessel at Georgia Tech with Steffes and students

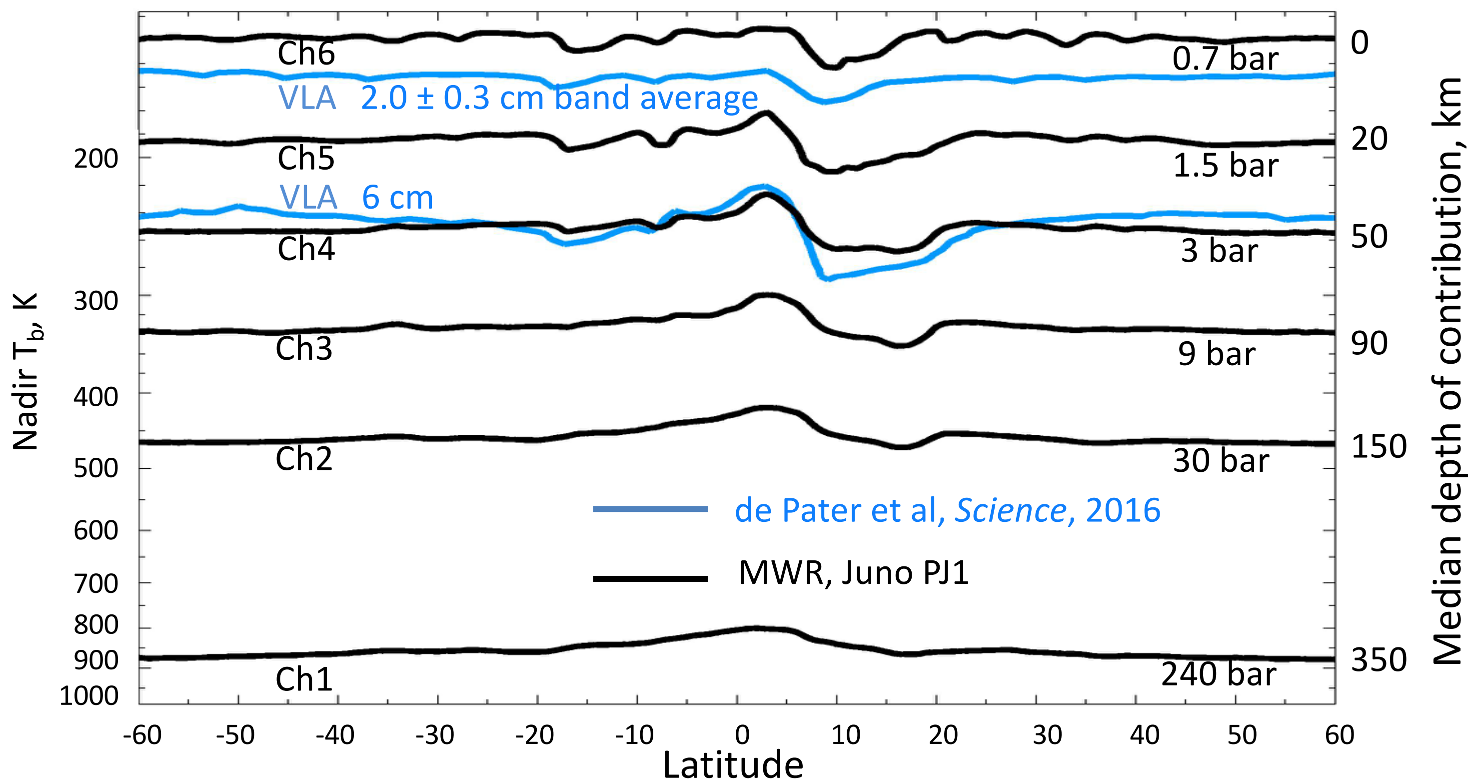
VLA Results and Sounding Depth



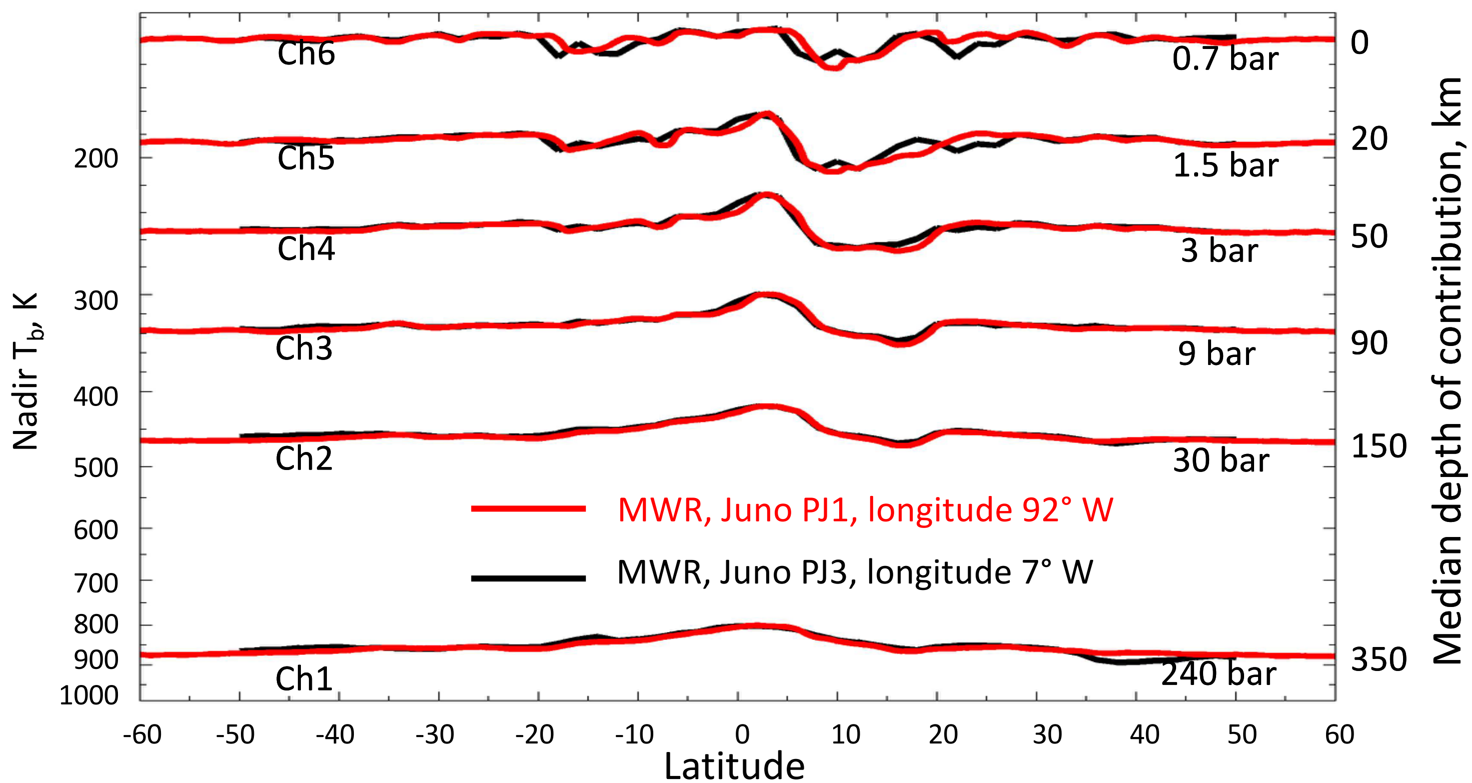
Comparison with Longitudinally-Averaged VLA Results



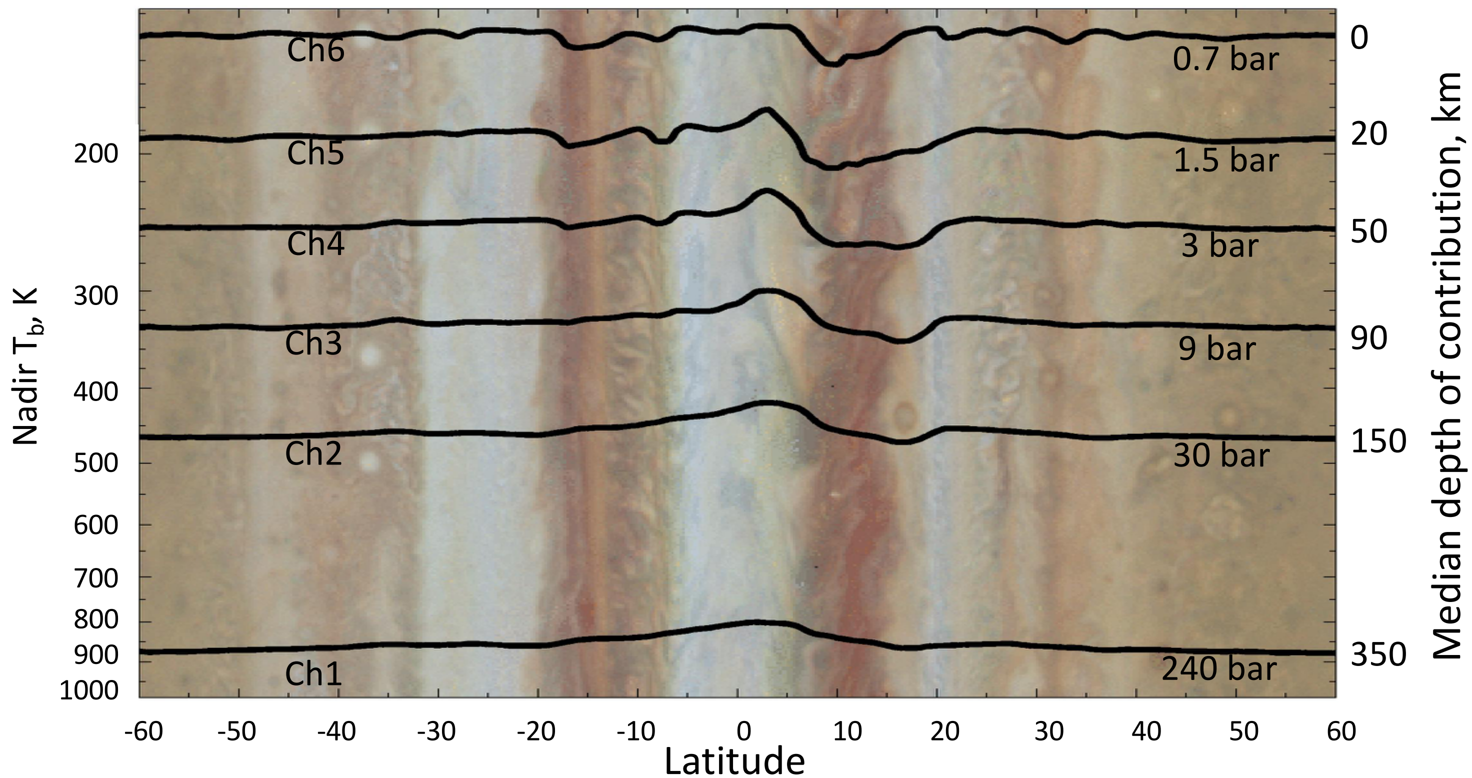
Nadir Brightness Temperatures, PJ1



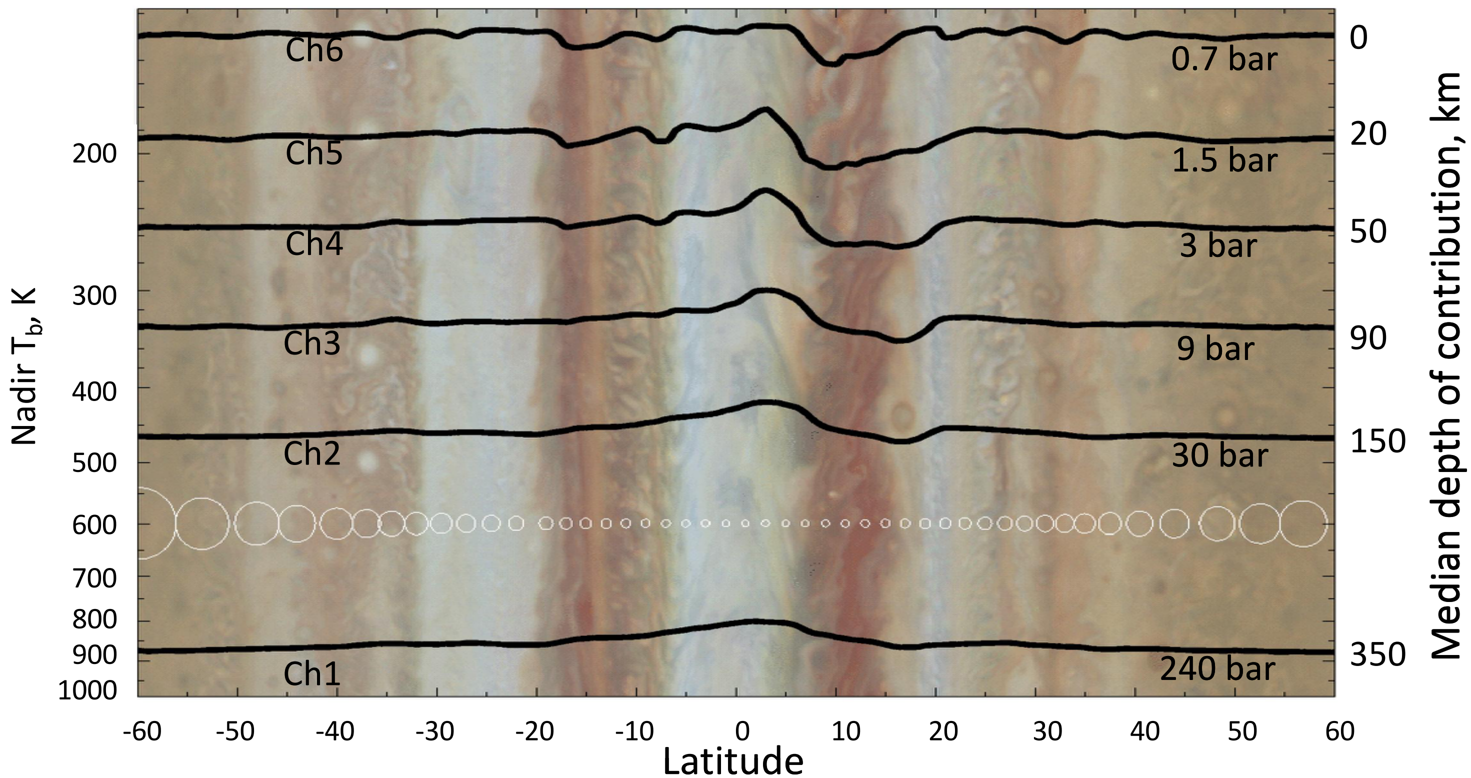
Add PJ3 (December 11, 2016)!



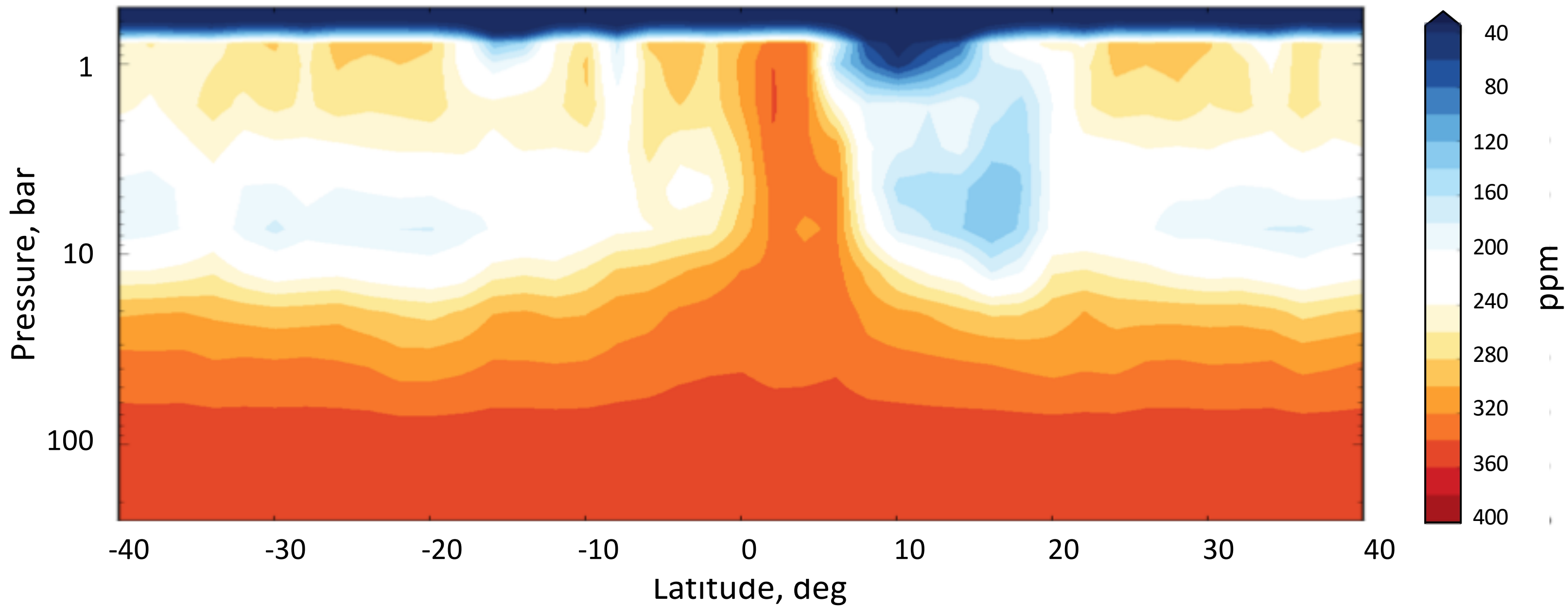
Comparison to Visible Cloud Tops



Spatial Resolution



Retrieved NH_3 Concentration



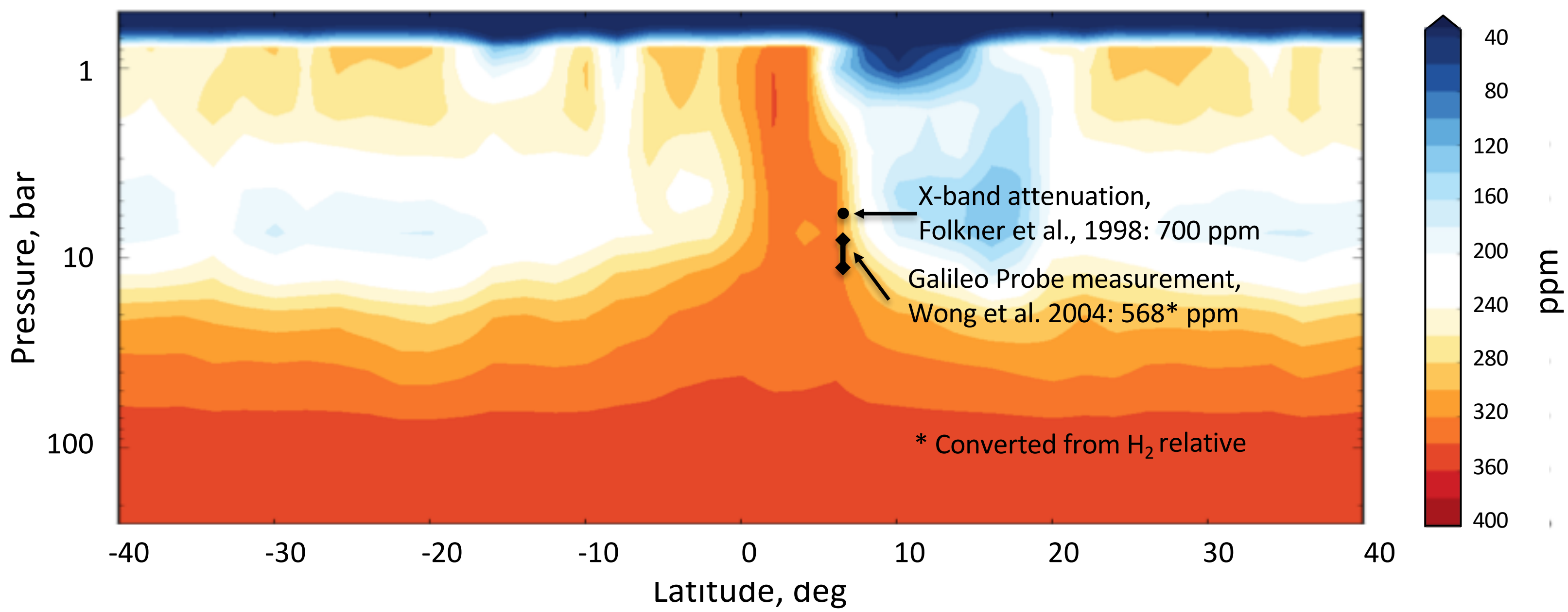
Summary

- Designed MWR instrument performance achieved in Jupiter's environment
- Accurate radiances obtained in channels sounding from NH_3 cloud to 100+ bar pressure level
- Primary result is NH_3 distribution with latitude, showing highly variable distribution below saturation level
  - Deep concentration is ~2.7 x solar (below ~50 bars)
  - Equatorial Zone shows narrow column of enhanced concentration reaching cloud top
  - North Equatorial Belt shows deep column of depleted NH_3
  - Mid-latitude NH_3 depleted from 2 to 30 bars relative to regions above and below
- Conclusion: NH_3 traces the deep circulation of Jupiter's atmosphere and provides the basis for a new generation of circulation models

Backup Slides

NH_3 result in context with Galileo Probe Results

Probe measurements are marginally consistent with our results



MWR Contribution Functions

For nominal atmosphere with 4xsolar NH_3 and H_2O