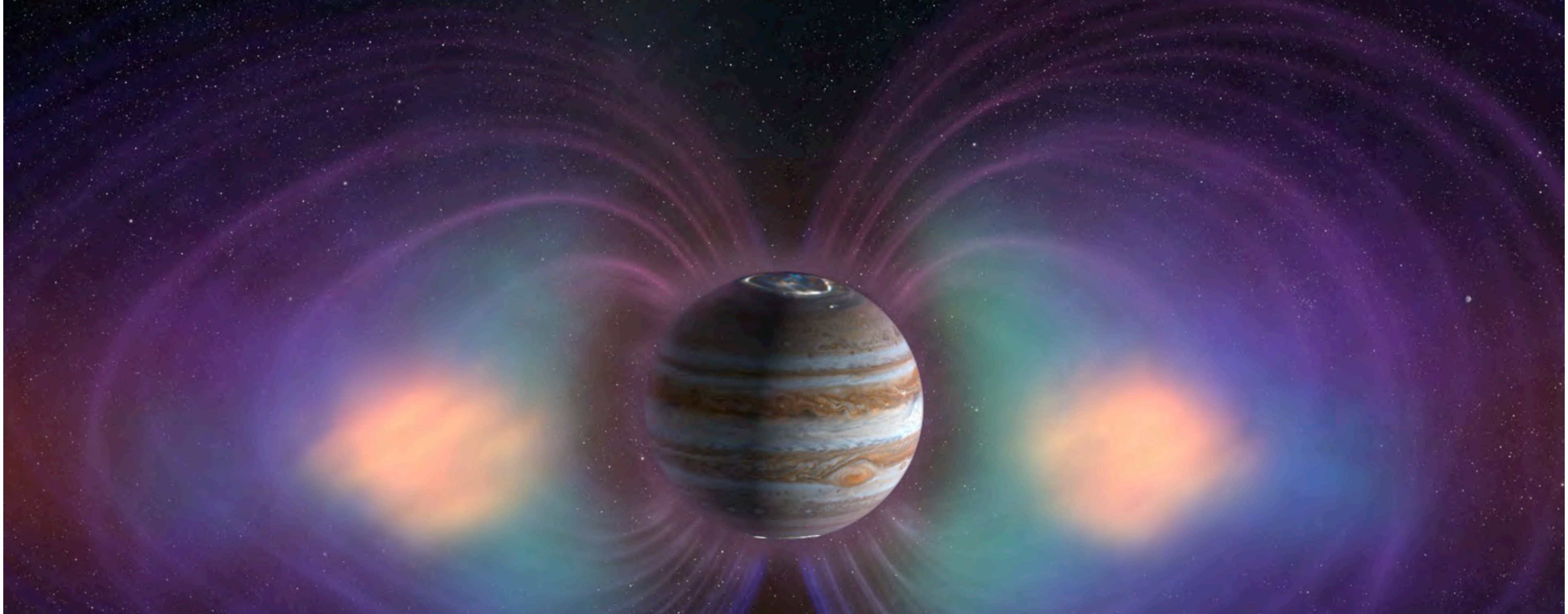
Plasma measurements in Jupiter's magnetosphere



By: Rob Ebert

(and many thanks to Fran Bagenal and George Clark for helping with this talk)

Workshop on Jupiter's Aurora, Anticipating Juno's Arrival – March 8th, 2016

Previous Missions to Jupiter

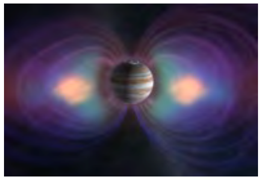
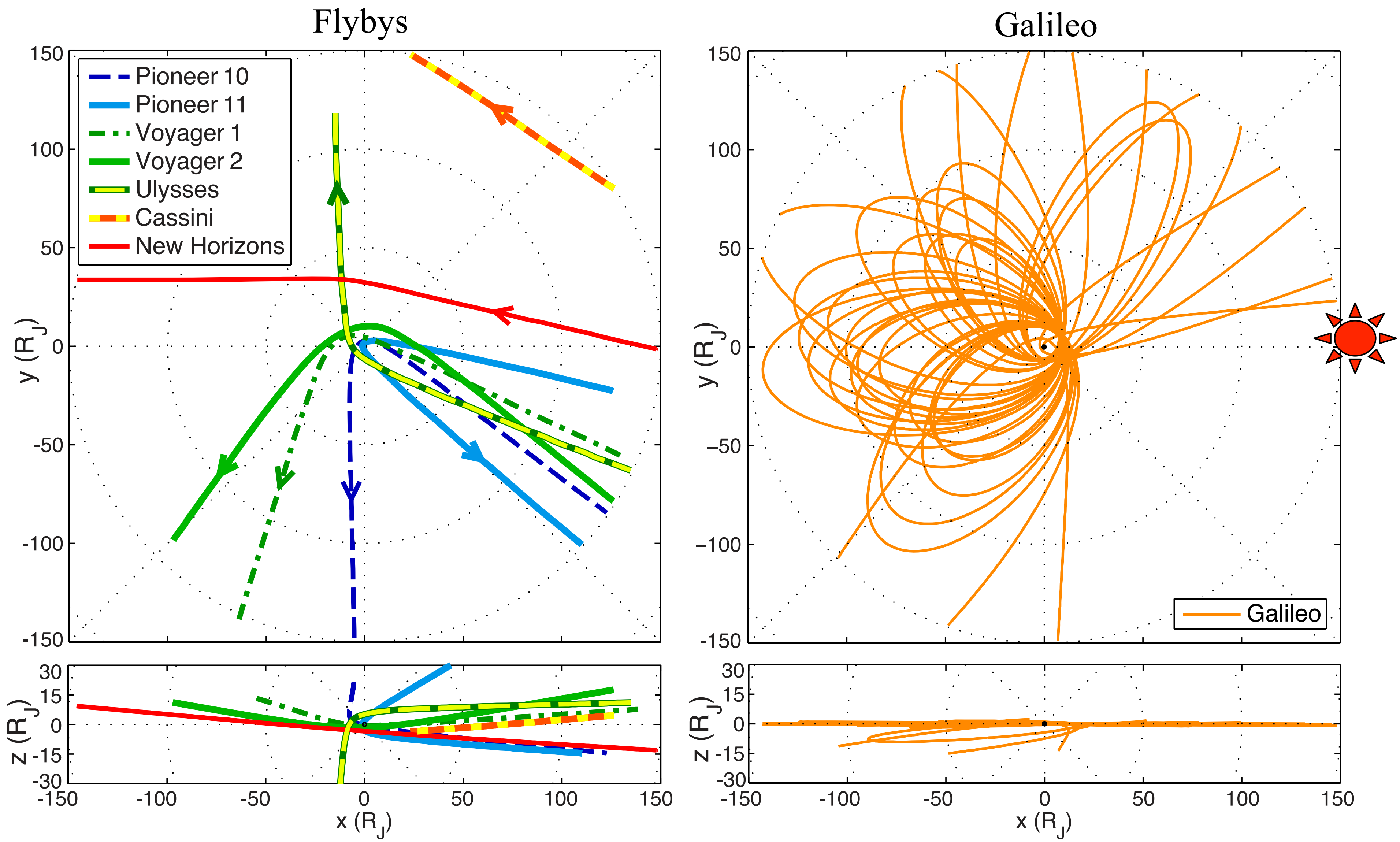
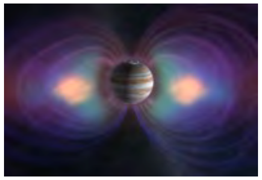
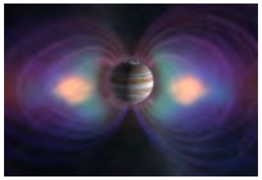



Fig. 4 from Bagenal et al. 2014, SSRv

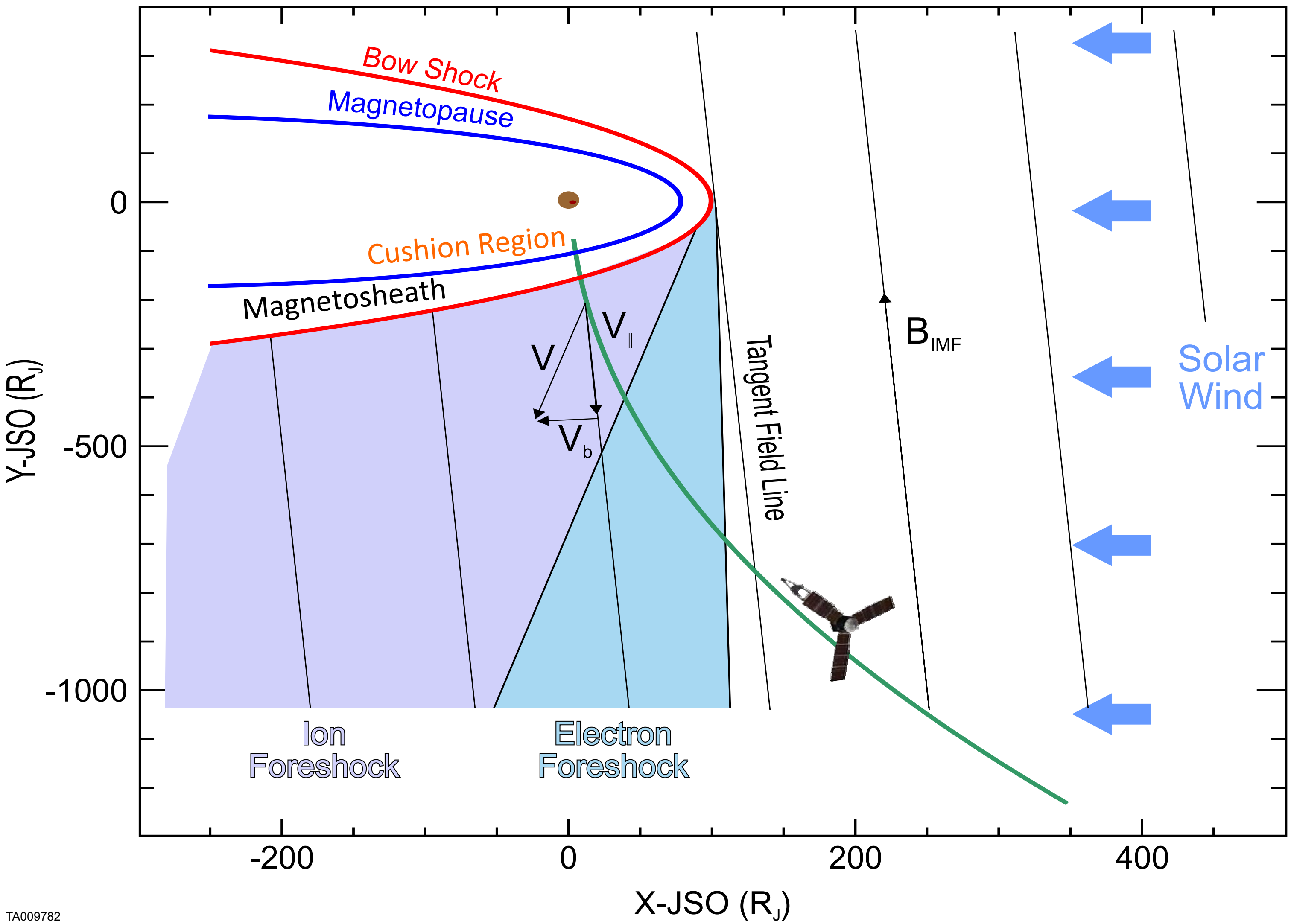


Summary of Plasma Observations

Spacecraft	Instrument	Timeframe	Energy Range	Regions Explored at Jupiter
Pioneer 10	Plasma Analyzer (PA)	DOY 330 – 356, 1973	0.1 – 18 keV (protons) 0.001 – 0.5 keV (electrons)	foreshock, dawn magnetosheath, inner/outer magnetosphere
Pioneer 11	Plasma Analyzer (PA)	DOY 330 – 344, 1974	0.1 – 18 keV (protons) 0.001 – 0.5 keV (electrons)	foreshock, dawn magnetosheath, outer, inner and mid-latitude magnetosphere
Voyager 1	Plasma Science (PLS)	DOY 59 – 81, 1979	0.01 – 6 keV/q (ions) 0.004 – 6 keV(electrons)	foreshock, dawn magnetosheath, outer/inner magnetosphere, magnetotail
Voyager 2	Plasma Science (PLS)	DOY 183 – 225, 1979	0.01 – 6 keV/q (ions) 0.004 – 6 keV(electrons)	foreshock, dawn magnetosheath, outer/inner magnetosphere, magnetotail
Ulysses	Solar Wind Observations Over the Poles of the Sun (SWOOPS)	DOY 33 – 47, 1992	0.255 – 34.4 keV/q (ions) ~0.001 – 0.814 keV (electrons)	foreshock, magnetosheath, boundary layer and outer, inner and mid-latitude magnetosphere
Galileo	Plasma Particle Investigation (PLS)	DOY 341, 1995 – DOY 264, 2003	0.9 – 52 keV/q (ions) 0.9 – 52 keV (electrons)	equatorial inner & outer magnetosphere, satellite flybys
Cassini	Cassini Plasma Spectrometers (CAPS)	October 2000 – April 2001	~0.001 – 50 keV (ions) 0.6 – 28 keV (electrons)	dusk bow shock, magnetosheath, and boundary layer
New Horizons	Solar Wind Around Pluto (SWAP)	DOY 56 – 173, 2007	0.02 – 7.5 keV/q (ions)	dusk magnetosphere, distant magnetotail, boundary layer and magnetosheath
Juno	Jovian Auroral Distributions Experiment (JADE)	JOI 7/4/2016	0.01 – 50 keV/q (ions) 0.1 – 100 keV (electrons)	



Juno Approach



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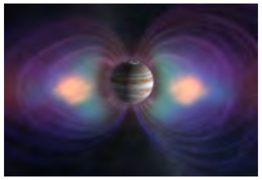
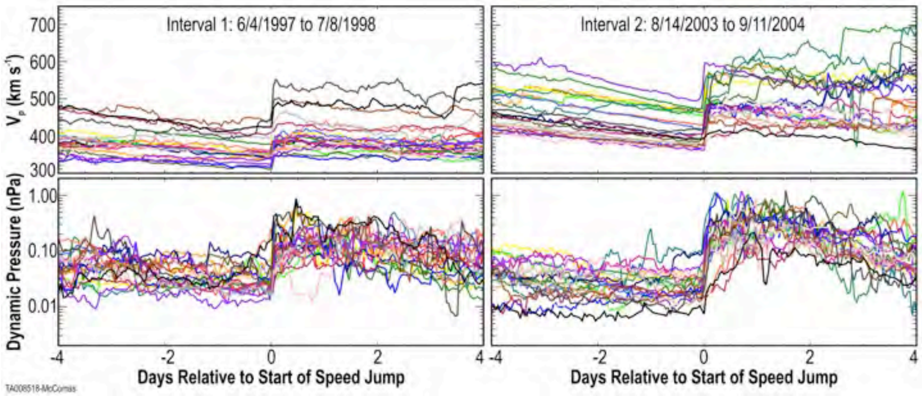
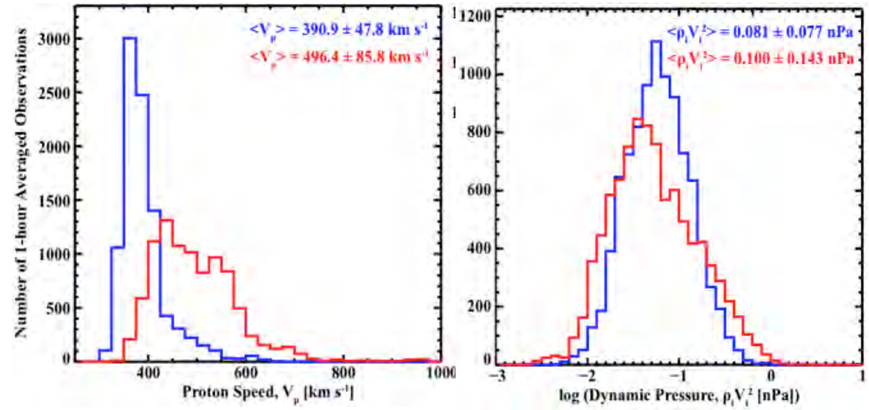


Upstream Solar Wind

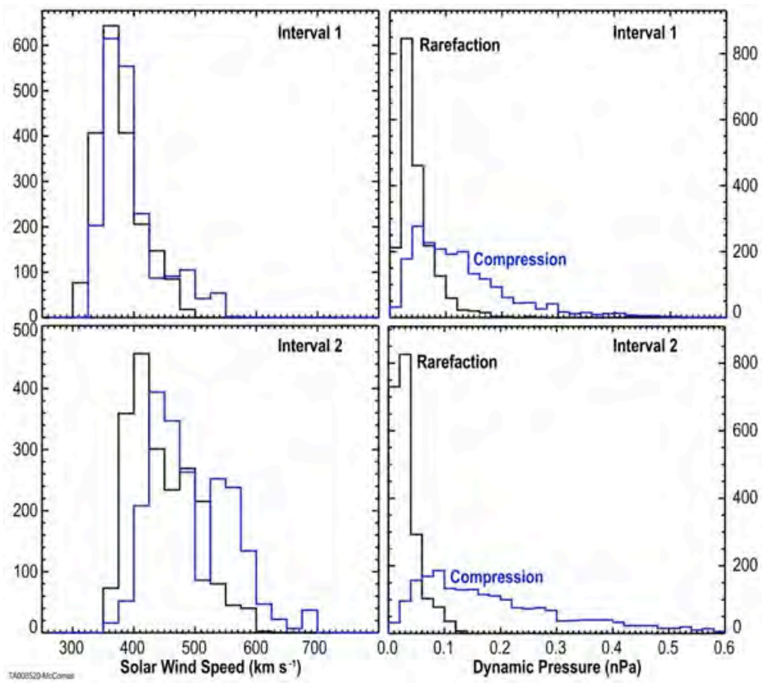
ICME dominated | CIR dominated



All solar wind types combined



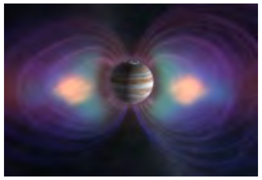
Ebert et al. 2014



McComas et al. 2014

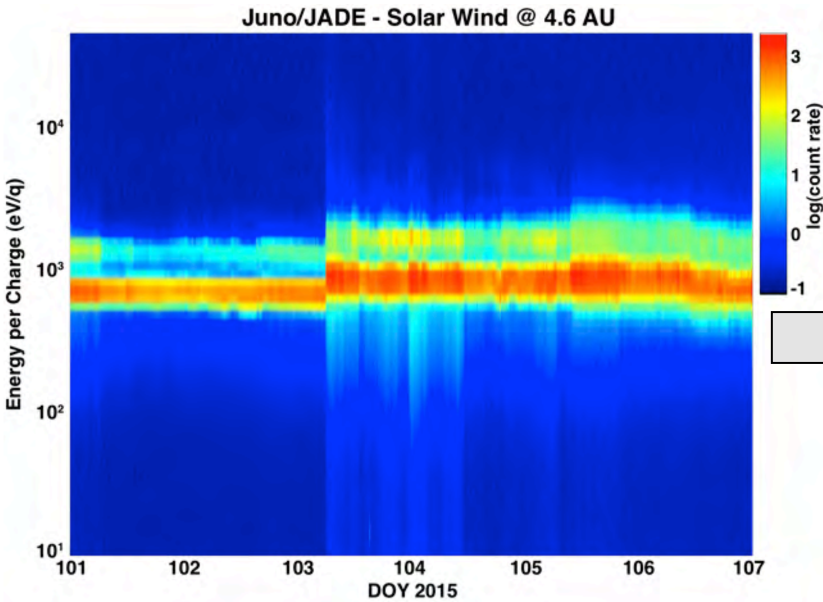
<u>Numerous studies of SW upstream of Jupiter</u>
(e.g. Slavin et al. 1985; Joy et al. 2002, Nichols et al. 2006, Jackman and Arridge, 2011, McComas et al. 2014, Ebert et al. 2014, among others)

- Dynamic pressure distributions of ICMEs and CIRs appear bimodal.
  - Less apparent when considering all SW types.
- SW obs. upstream of Jupiter are needed to infer correlations between SW and remotely observed auroral emissions.

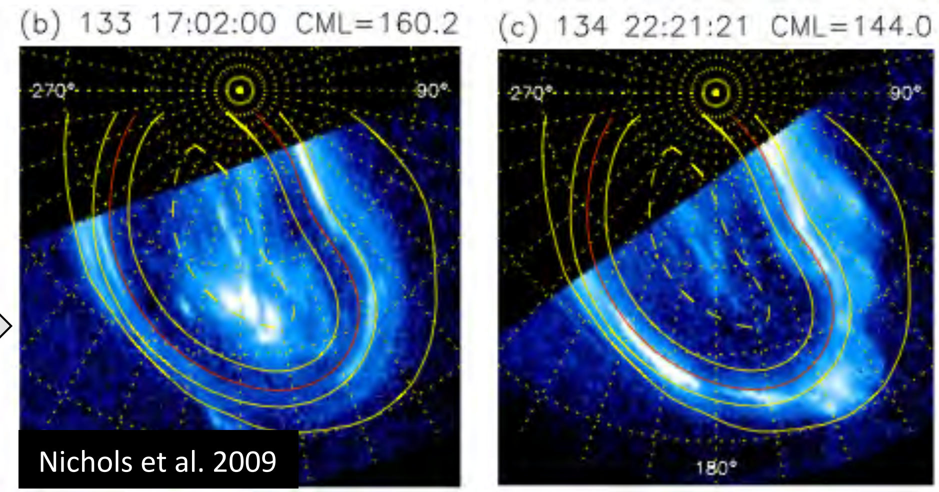


Upstream SW + Remote Sensing

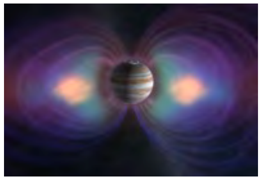
JADE-I SW observations



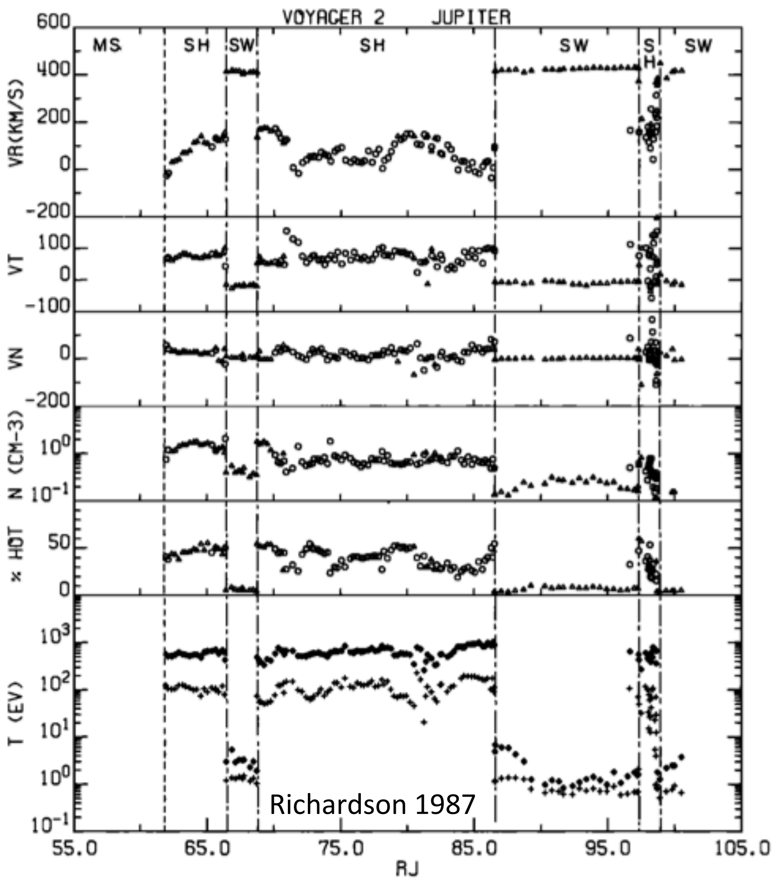
Jovian Auroral Emissions

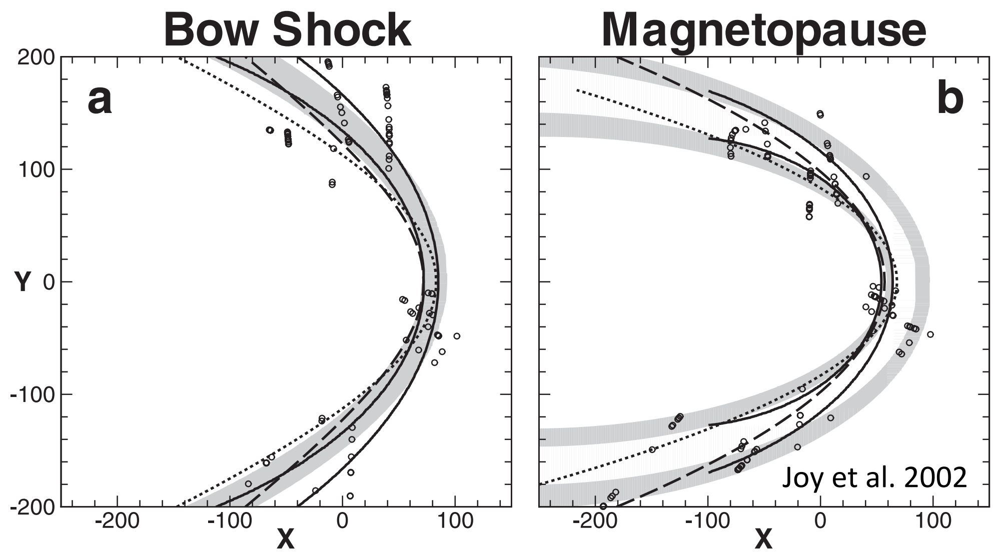


- Plenty of discussion regarding role of solar wind in driving variations in auroral emission features.
- Simultaneous observations of upstream solar wind/IMF and remotely sensed auroral emissions are needed to accurately identify correlative relationships.
- Understanding gained from these studies will help guide interpretation of the auroral observations when Juno is inside the magnetosphere.

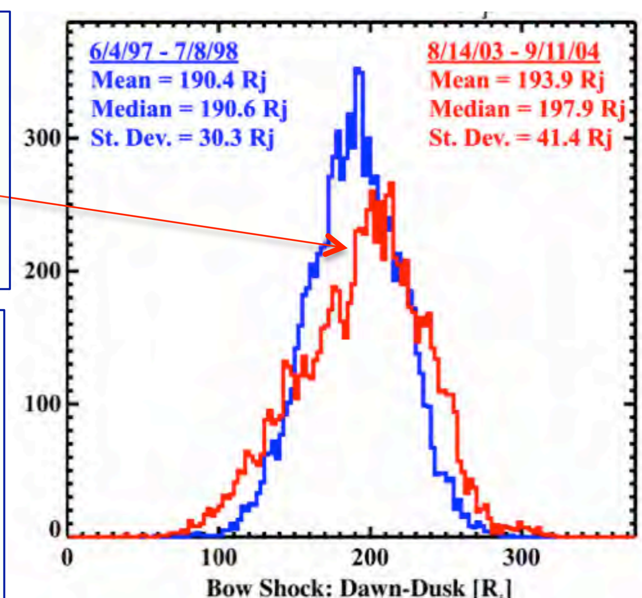


Magnetospheric Boundaries



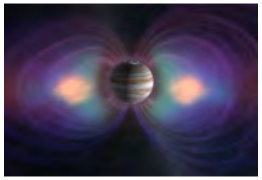


Estimated bow shock distance distribution during Juno



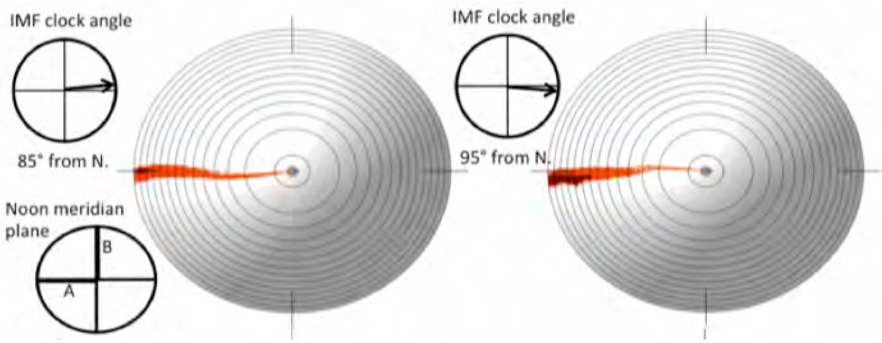
Ebert et al. 2014

- Plasma observations provide a definitive signature of magnetospheric boundaries.
- Location of boundaries constrain the shape and extent of the magnetosphere.
- Aurora emissions may vary with boundary motion.

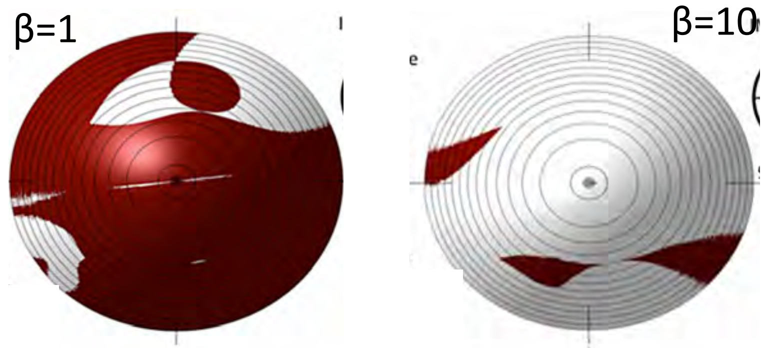


SW-Boundary Interactions

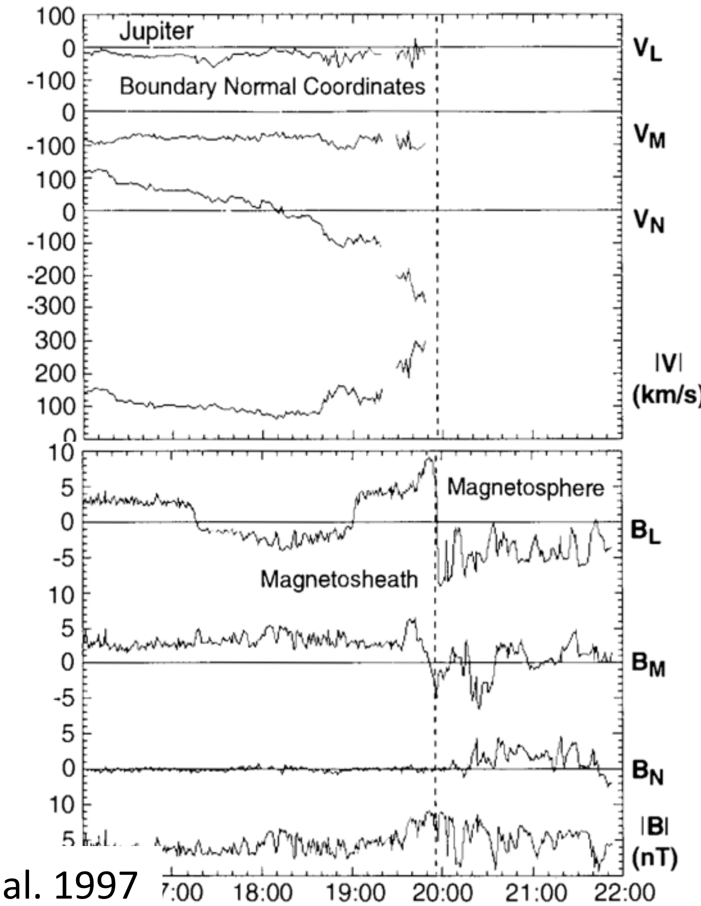
<u>Where KH instabilities are probable</u>



<u>Where magnetic reconnection is probable</u>

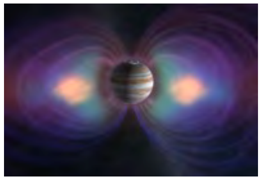


Desroche et al. 2012



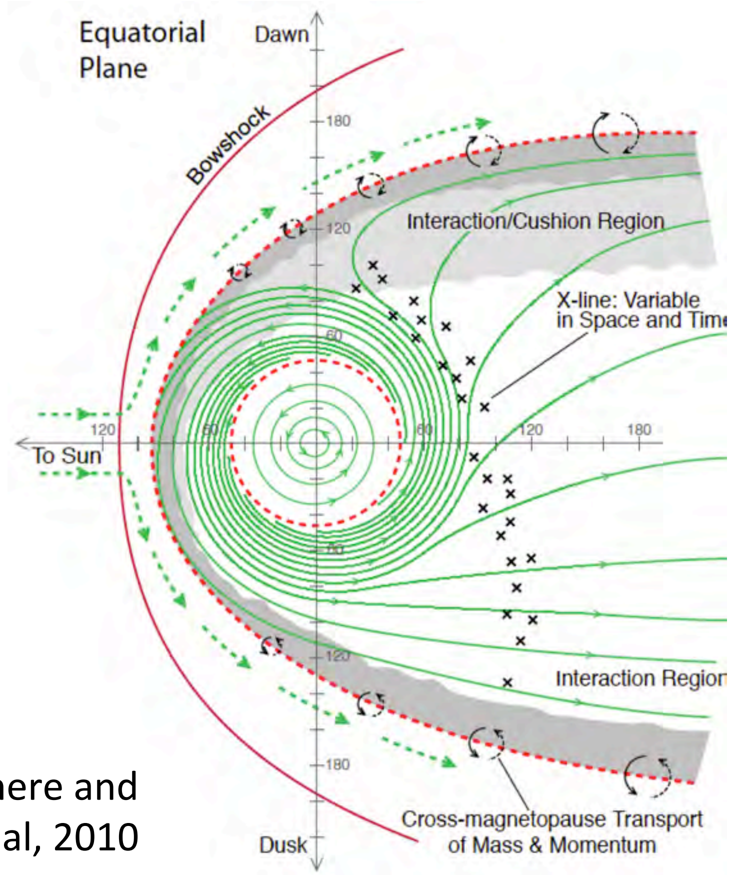
Huddleston et al. 1997

- There are several theoretical models describing SW-magnetospheric interactions at Jupiter but **few observational constraints.**
- Additional observations of the plasma flow, density, temperature and composition inside the magnetopause and in the outer magnetosphere are needed.



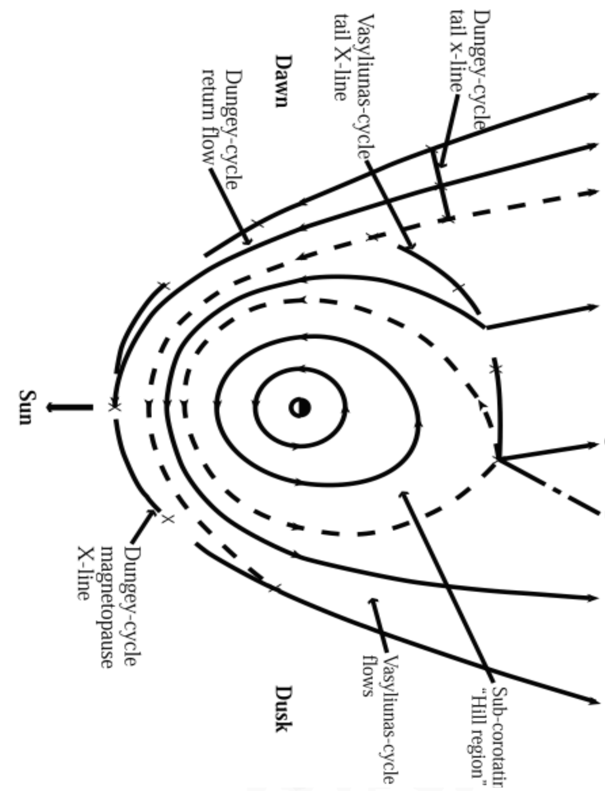
SW-Boundary Interactions

SW interaction mediated by KH instabilities



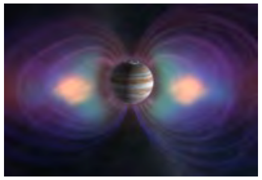
Delamere and Bagenal, 2010

SW interaction mediated by reconnection

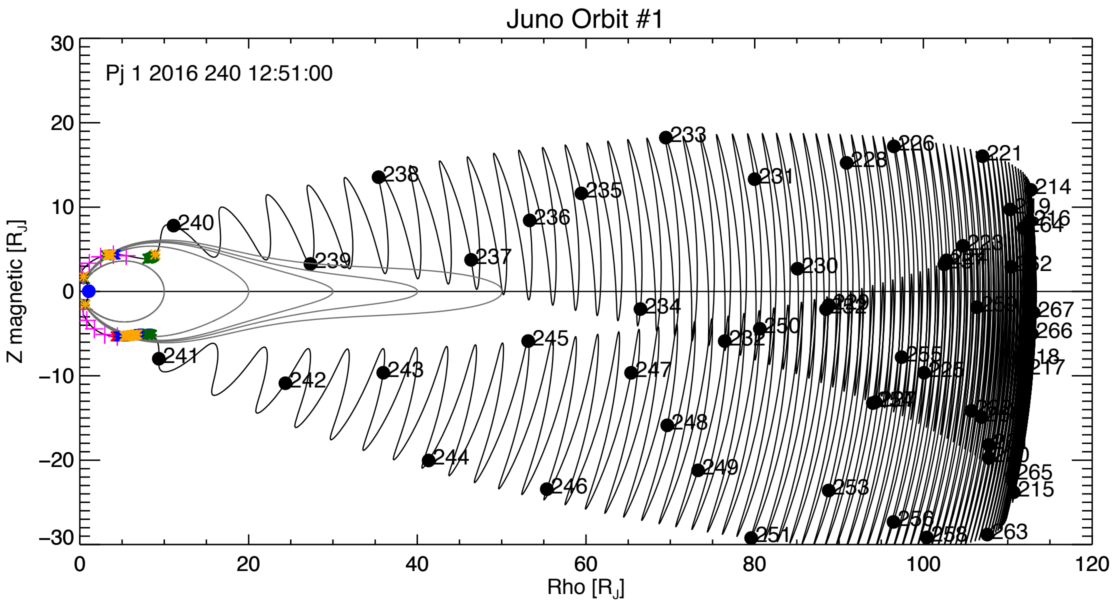


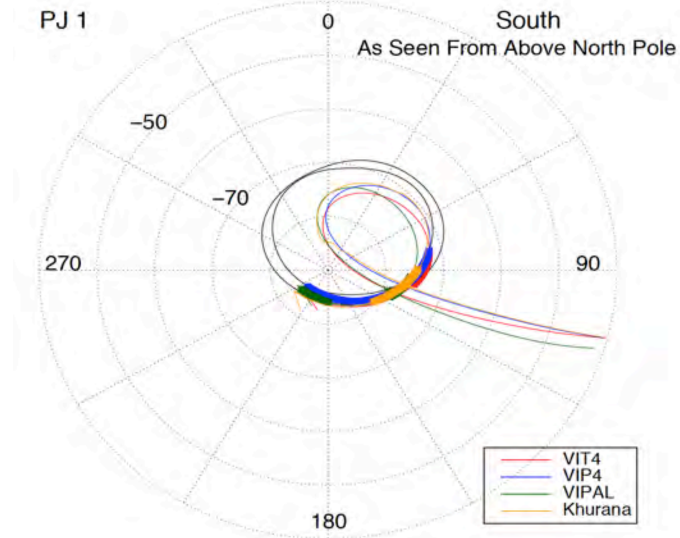
Cowley et al. 2003

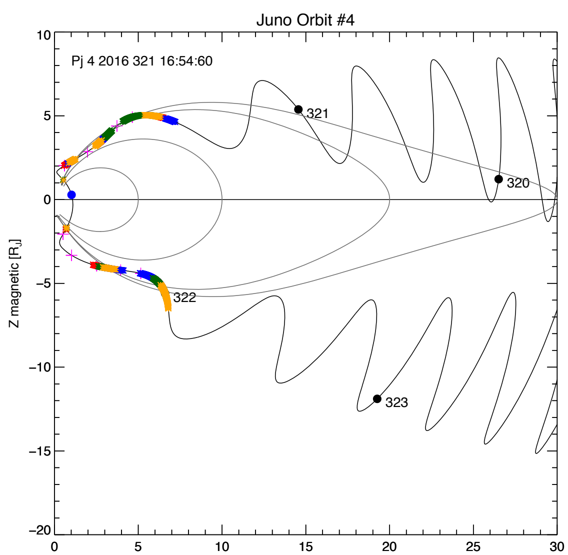
- Understanding how the SW couples to the magnetosphere has important implications for global magnetospheric dynamics.

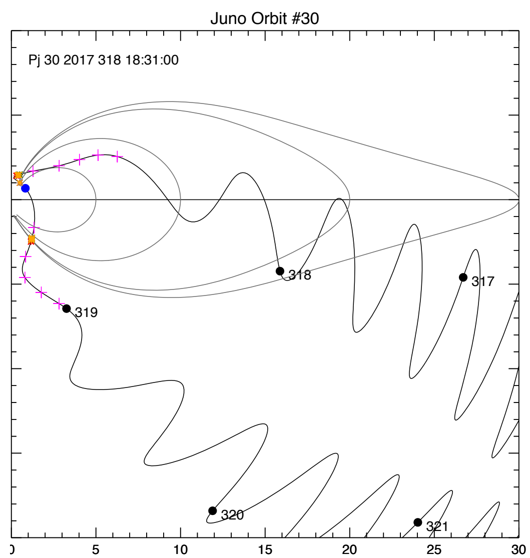


Juno: Capture Orbits and Prime Mission

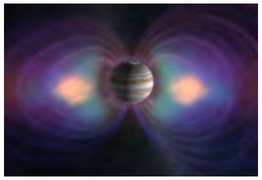




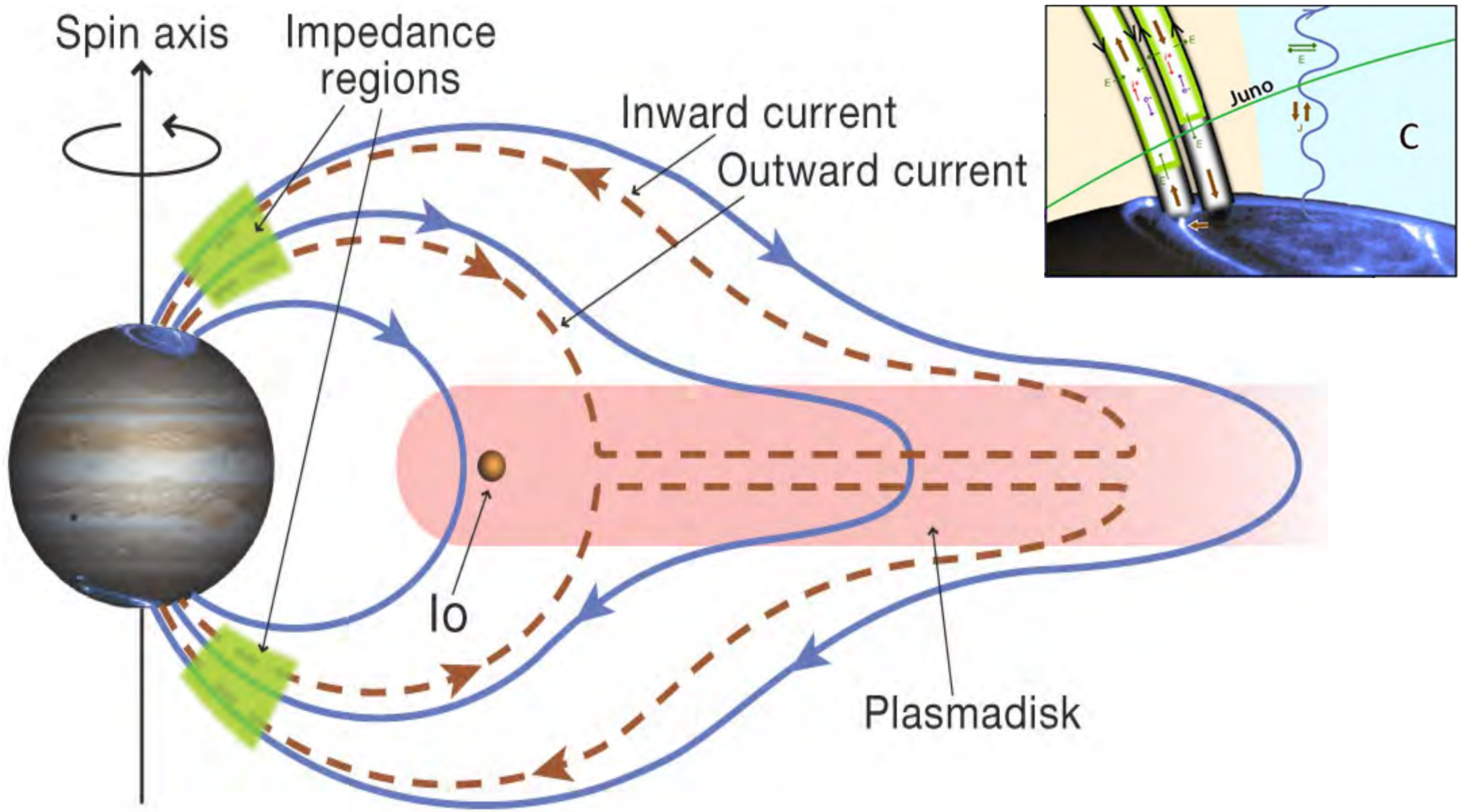


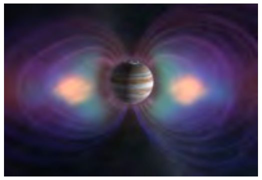


- Juno will explore Jupiter's:
  - Auroral regions
  - Polar magnetosphere
  - Plasma sheet
  - Outer magnetosphere/ cushion region
- Little to no *in situ* plasma observations in many of these regions.

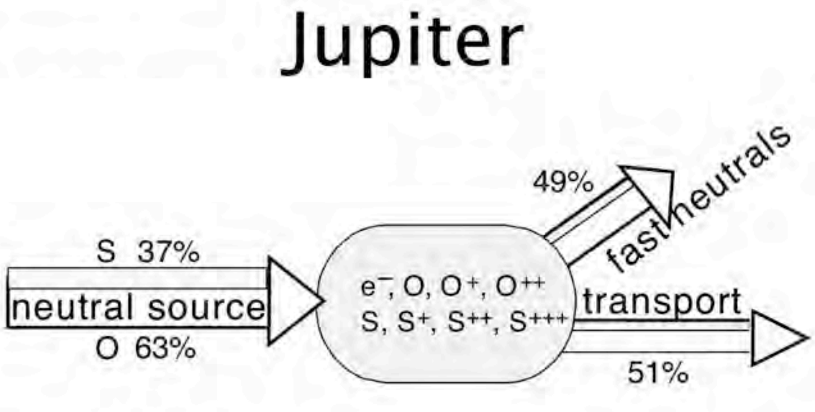


The Big Picture





Plasma Sheet



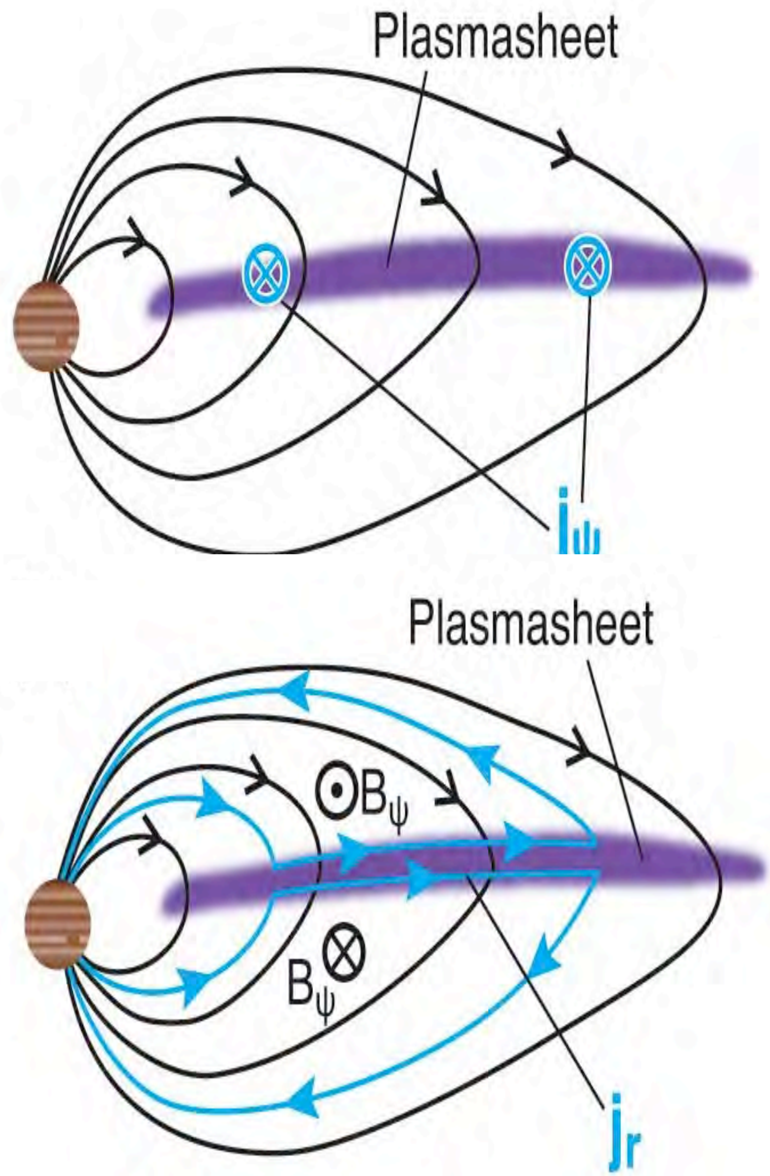
Half lost as fast neutrals

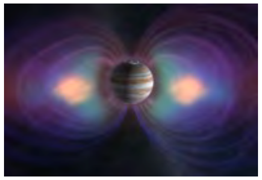
-> extended neutral cloud

Half transported out to plasma disk

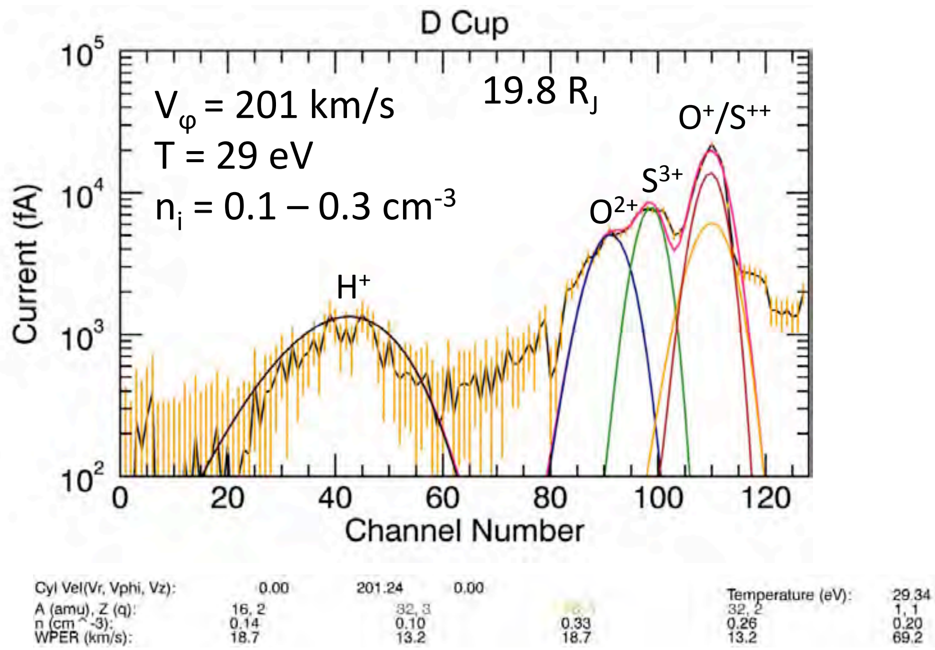
Delamere & Bagenal 2003

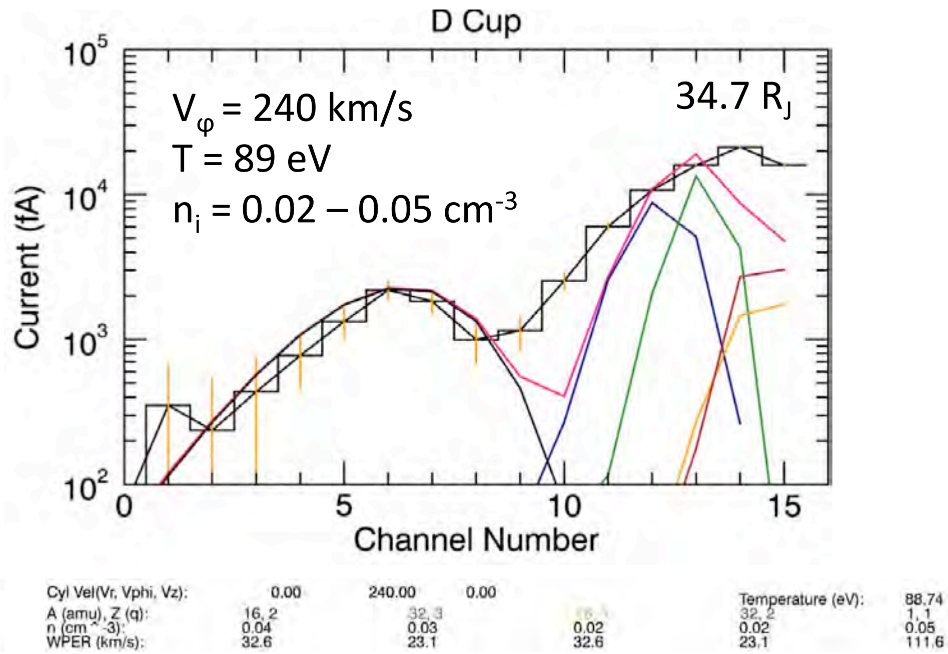
- Ions are picked up by Jupiter's magnetic field, spun up to the planet's rotation rate and transported radially outward.





Plasma Sheet

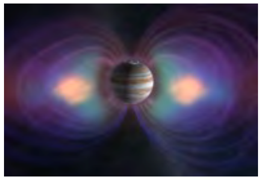




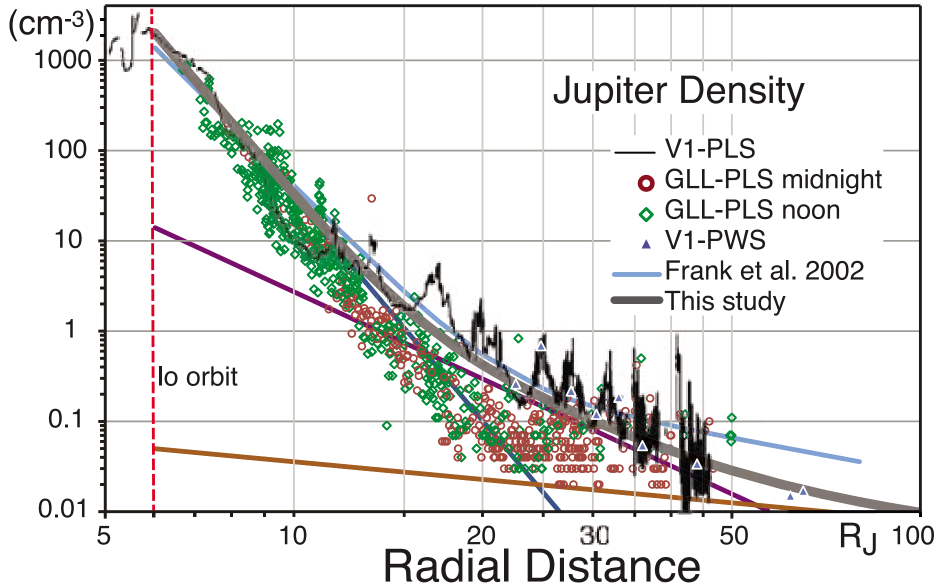
Bagenal et al. 1981, reprocessed data shown here by Bodisch et al. 2015; Dougherty et al. 2015

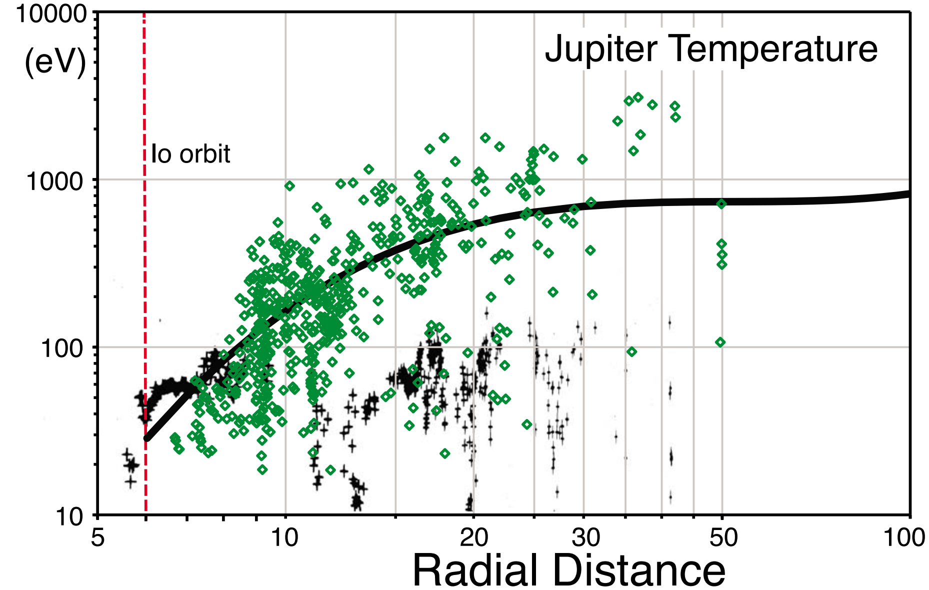
- Plasma mass density dominated by heavy ions.

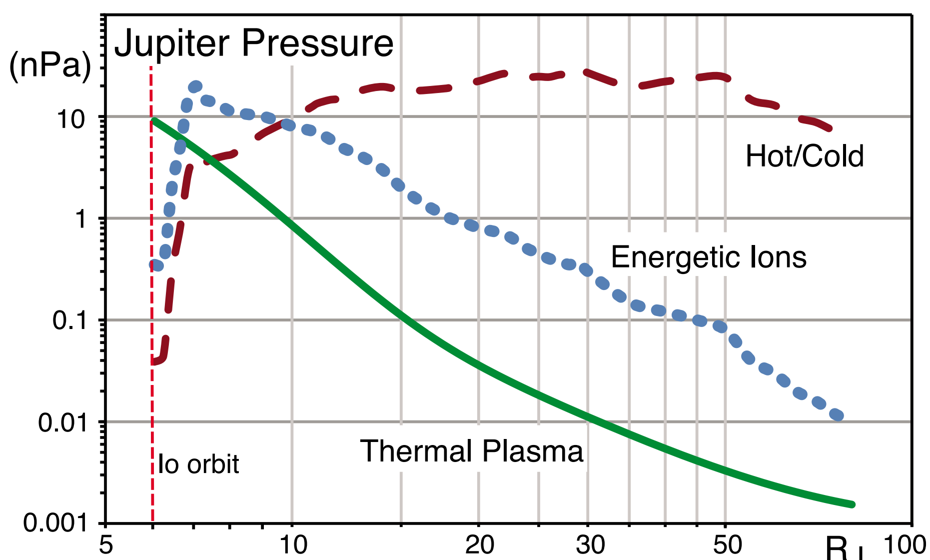
- Data shown here reprocessed to include estimates for O^+/S^{++} based on Cassini UVS observations + physical chemistry model (e.g. Delamere, Steffl, and Bagenal, 2005).



Plasma Sheet

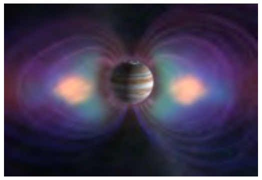




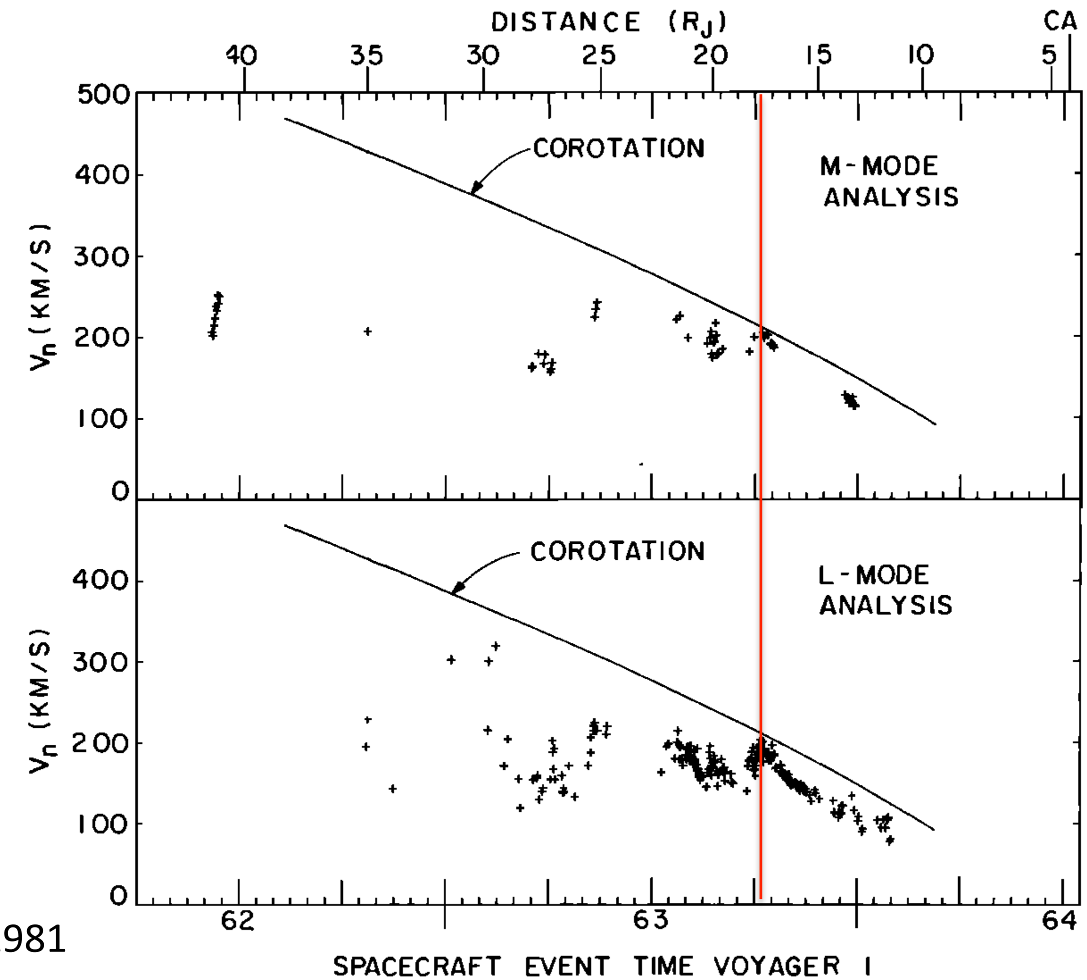


Bagenal and Delamere, 2011; Bagenal et al. 2014

- Juno can provide new insight into the vertical and radial profiles of the plasma sheet, including measuring the conditions within days of the perijove passes through the auroral region.

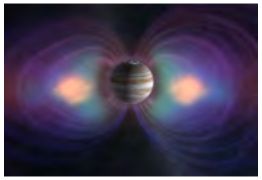


Plasma Sheet

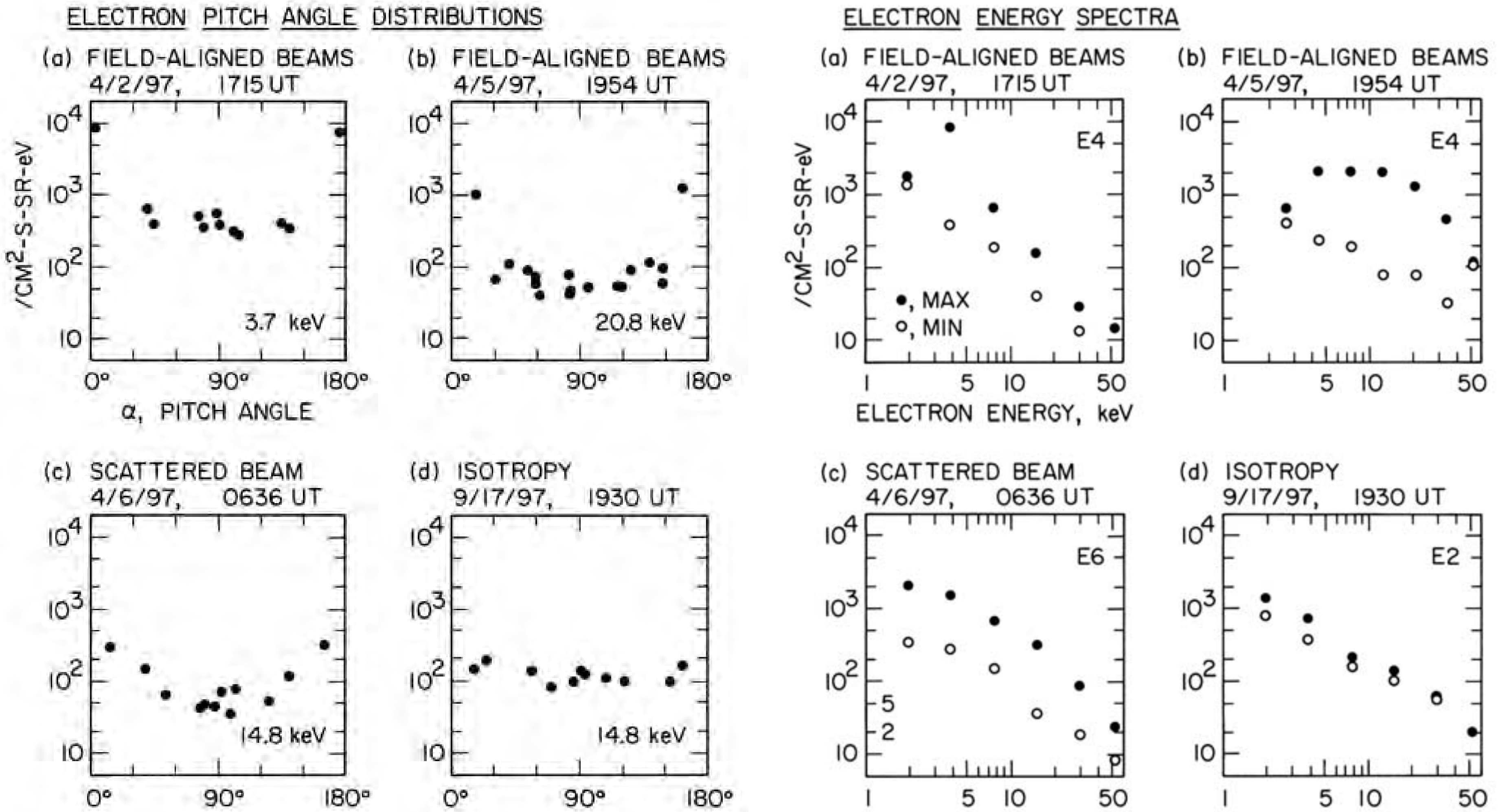


McNutt et al. 1981

- Plasma co-rotation starts to break down at ~17 - 20 R_J (e.g. McNutt et al. 1981).
- Coupling currents and corresponding aurora are stronger in region where plasma slips behind cororation (e.g. Hill 1979).

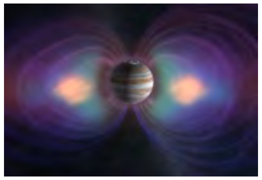


Plasma Sheet



Frank and Paterson, 2002

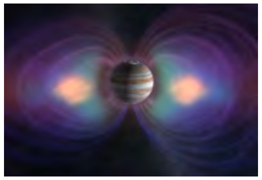
Electron pitch angle and energy distributions provide information about these currents.



Polar Magnetosphere

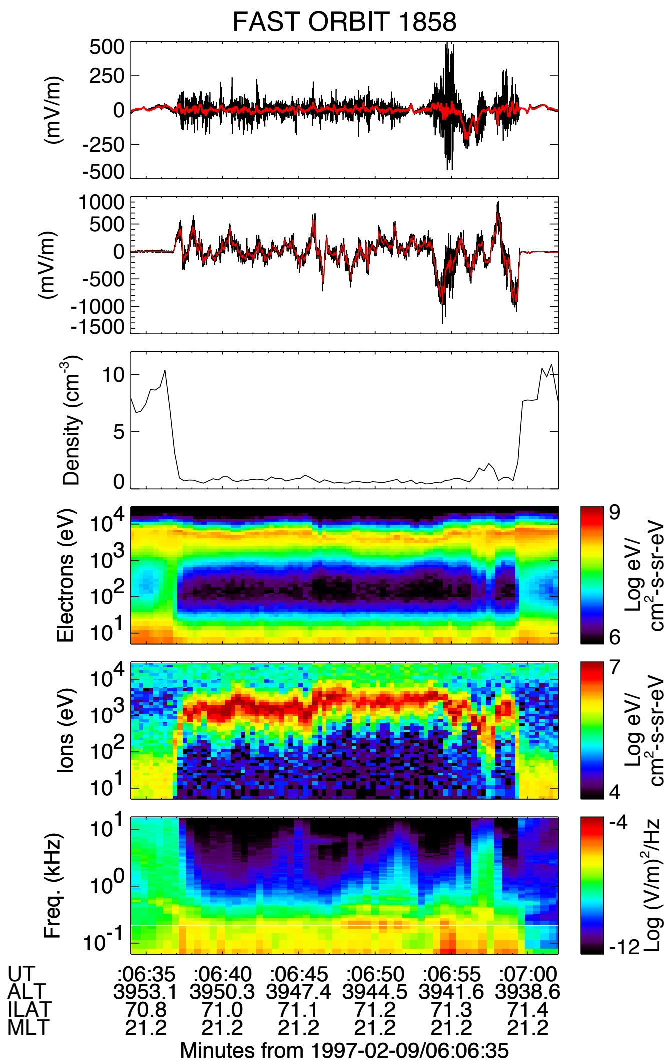
Little to no *in situ* plasma measurements, many fundamental questions:

- What is the high latitude structure of the magnetosphere? Is it fundamentally similar or different than Earth?
- Where and how are the particles that excite the aurora generated?
- How do the currents close between the plasma disk and the aurora region?
- What causes the transient polar aurora?
- How open is the magnetosphere to the IMF?
- What is the size and the variability of Jupiter's polar cap?
- How is the main aurora related to magnetospheric dynamics and/or changes in the solar wind?
- Is there significant outflow from Jupiter's ionosphere? How much does it contribute to Jupiter's plasma environment?

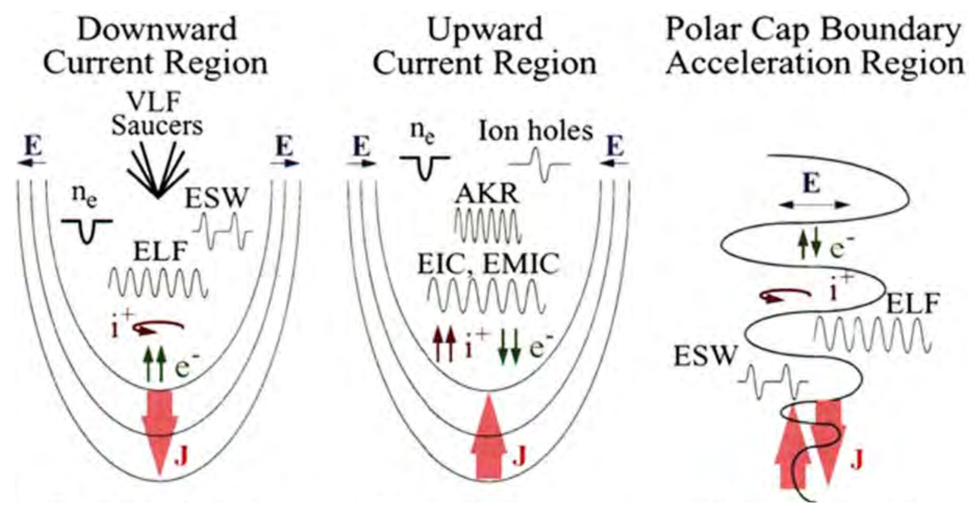


Acceleration Region

Upward Current Region at Earth

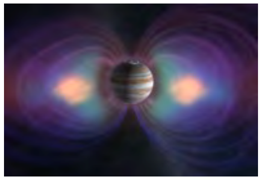


Sketch of Auroral Acceleration Regions at Earth

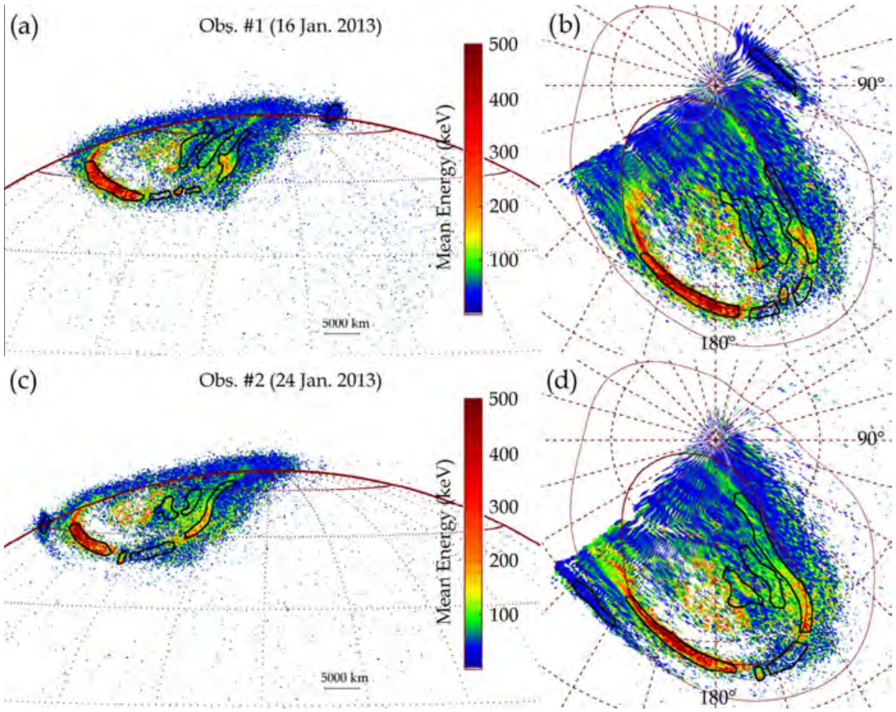


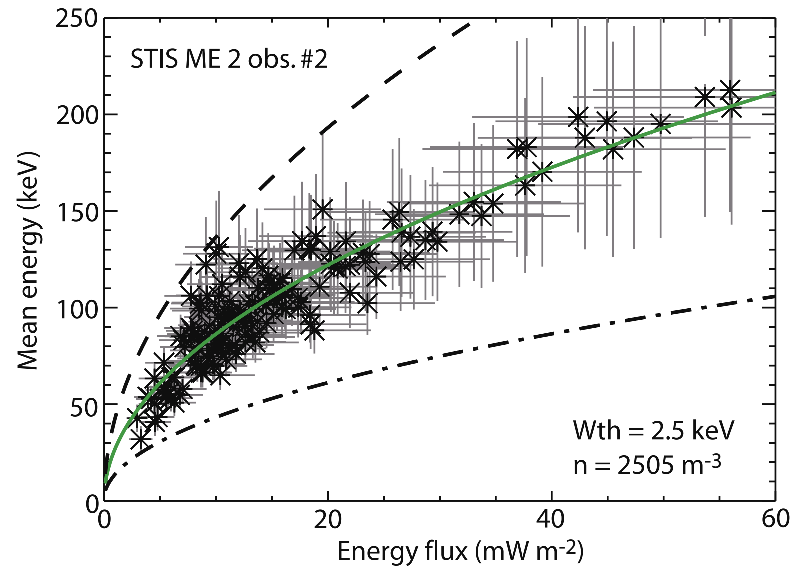
- Electron and ion observations are needed to help discover the structure and location of the auroral acceleration regions at Jupiter.
- What will this sketch look like for Jupiter?

From Ergun talk at 2015 Juno/Cassini Workshop

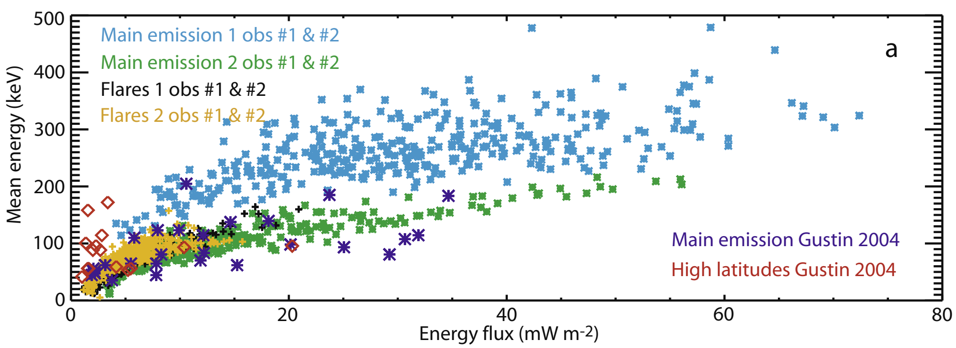


Precipitating Electrons

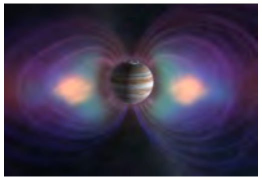




Gustin et al. 2016



- Remote sensing observations used to estimate mean energy and energy flux of precipitating electrons; suggest spatial variability.
- Observations from Juno will provide ground truth.



Conclusions

- Plasma measurements from 8 previous missions have revealed a lot about the structure of and dynamics within Jupiter's magnetosphere.
- There are still many open questions.
- Juno's orbit provides an opportunity to makes observations in several regions of the magnetosphere that are either under-sampled or completely unexplored.
- Key objective is to determine the structure of the region that accelerates the particles that produce the aurora.
- Many other high impact science opportunities during mission.