Studying Jupiter's Magnetosphere: Concepts for Discovery Missions

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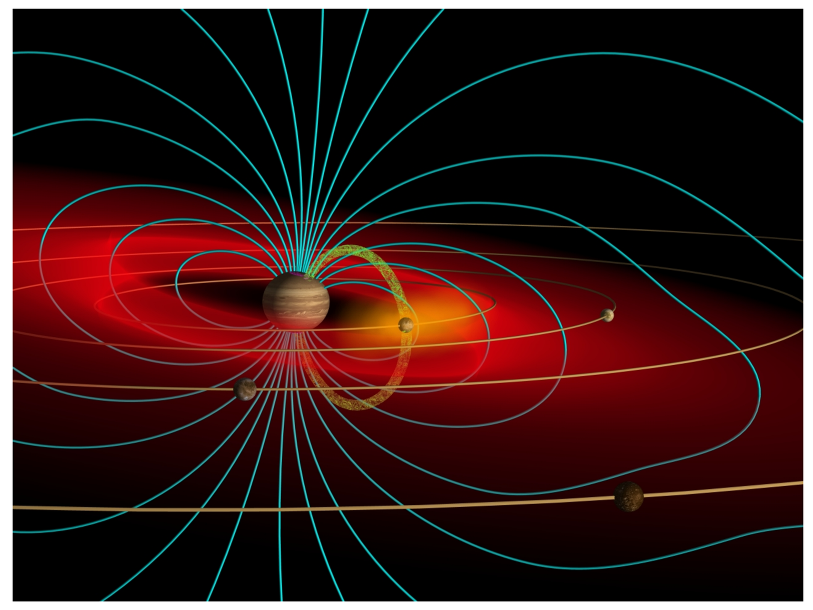
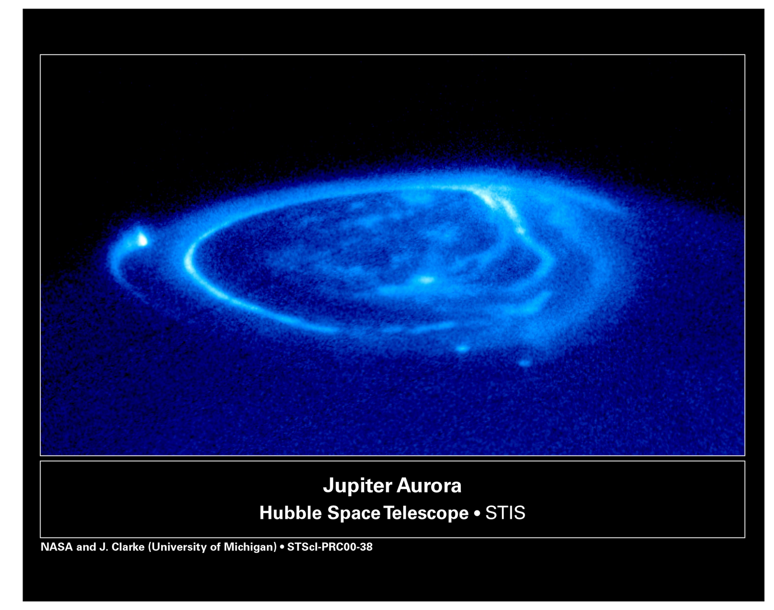
Jupiter's magnetosphere as a Discovery mission target

- According to the Decadal Survey, planetary magnetosphere are
  - Are clues to the conditions to be expected at extra-solar giant planets and their interactions with their stars
  - Only opportunity to study many plasma processes *in situ*
  - Shape our understanding of astrophysical systems
  - Important to understanding the Earth's magnetosphere
- Most modern missions are narrowly focused on a specific target
  - *Galileo* and *Cassini* were broadly multi-disciplinary
  - Discovery and New Frontiers (or even flagship missions like Europa Multiple Flyby) have limited room for this
  - Magnetospheric science goals may require small, dedicate missions, rather than being part of a larger one
- Jupiter is the most accessible, extraterrestrial magnetosphere
- Magnetospheric missions can be small, simple and low resource





From *Visions and Voyages for Planetary Science in the Decade 2013-2022:*

Haven't we done this? Aren't we about to do it? No

- Voyager, Cassini and New Horizons:
  - Flybys with limited coverage
    1 pass through Io plasma torus, 1 deep down-tail pass (w/o a magnetometer)
  - No ability to study the coupling between regions
- Galileo: No high gain antenna
  - Extremely limited data away from Galilean satellite encounters
- Juno: Focused on polar magnetosphere and aurora
  - Only ~40 hours with latitude < 10° and r < 10 R_J (Io torus)
  - No observations in the magnetotail
- Europa Multiple Flyby and Jupiter Icy Moon Explorer (ESA):
  - Particles/fields instruments designed for ocean induction studies (EMF)
  - Essentially all of the mission inside 50 R_J and outside 10 R_J
  - UV and ENA (JUICE) observations but TBD limited coverage/frequency

"…simultaneous multiple spacecraft measurements of the jovian system to help to address the problem of temporal versus spatial change… and to enhance our understanding of how plasma populations move around…"

"…measurement of the composition of the jovian plasma and concurrent observations of Io's volcanoes and plumes to understand the roles of Io… in populating Jupiter's magnetosphere"

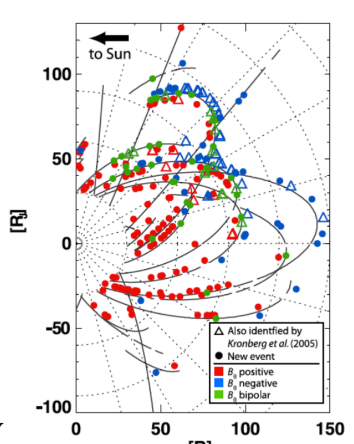
Jupiter's Magnetotail: We haven't seen much of it and what we've seen was not what we expected to see

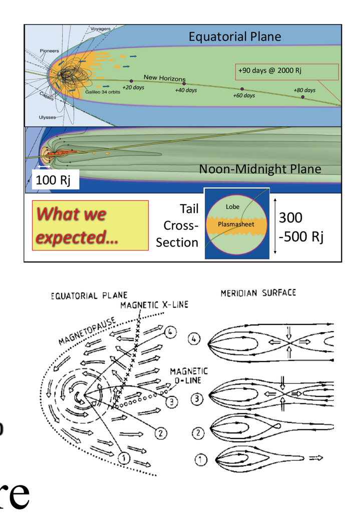
How is plasma transported out of Jupiter's magnetosphere?

~1000 kg of plasma produced near Io, transport inside ~25 R_J is understood (probably)

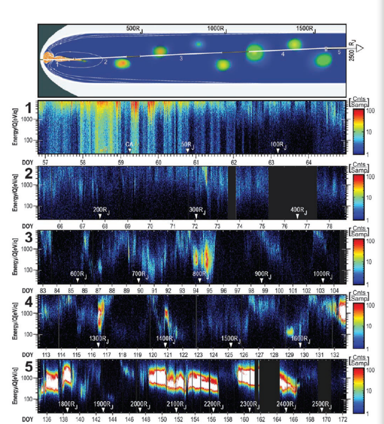
What controls the dynamics of the magnetotail? How does it drive the polar aurora?

- Plasma moves from Io by diffusion and interchange
- Observed by Galileo (and Cassini at Saturn)
- At 75-100 R_J plasma breaks free and flows down tail
- Earth experience and theory predicted well-organized, large scale structure



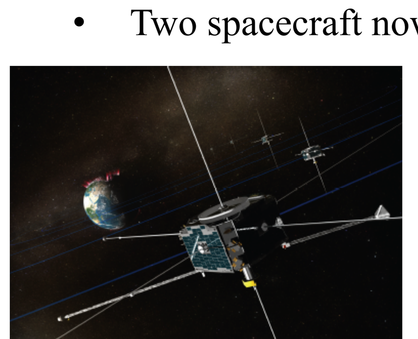


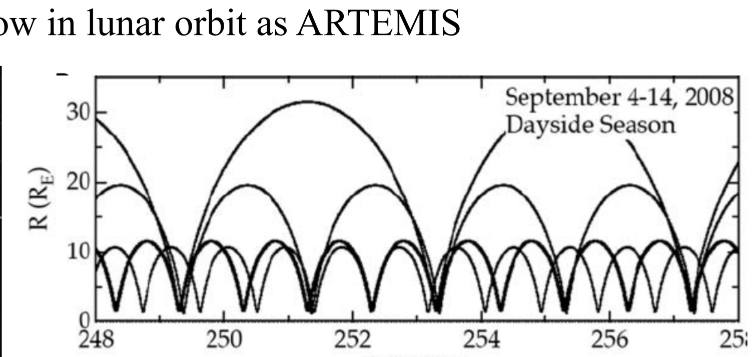
- New Horizons observations showed nothing of the sort
- Deep tail is patchy, with disorganized blobs of plasma
- "Drizzle" rather than large (width of tail) plasmoids?
- Magnetotail dynamics drive polar auroral activity



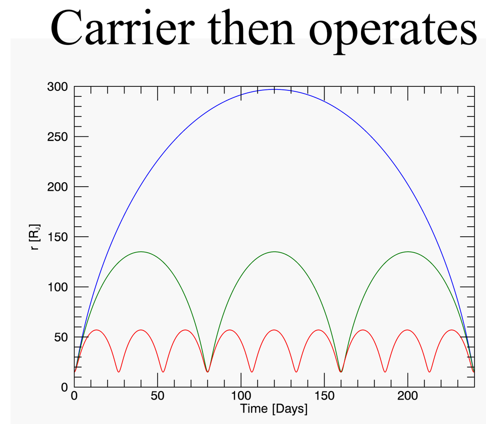
From McComas et al., 2007

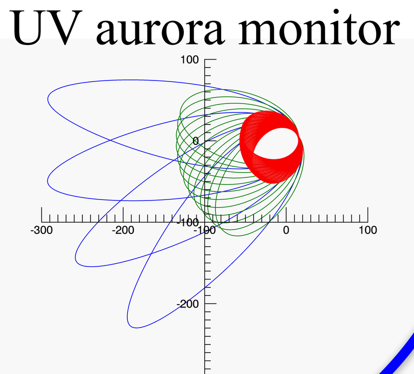
- **A similar problem has been solved at Earth**
- THEMIS (Time History of Events and Macroscale Interactions during Substorms)
- Coupling between magnetotail reconnection, substorms, plasmasphere, radiation belts and aurora
- Five small spacecraft in three resonant orbits (1:2:4 day)
  - Periodic conjunctions and alignments between spacecraft
  - Observed transient events propagate across magnetosphere
- Spinning, 77 kg (dry) spacecraft with 5 particles & fields instruments
  - Flux gate magnetometer, search coil magnetometer, electric field instrumnet, plasma analyzer and energetic particle telescope
  - Also included ground-based aurora program
- Low data rate (down to 1 kbps plus burst data for microphysics)
- MIDEX mission (<$180 million) launched in 2007, still operating
  - Two spacecraft now in lunar orbit as ARTEMIS





- **The same solution will work at Jupiter**
- 3 spacecraft plus one carrier vehicle
- Add high gain antenna (1-m) and solar panels (5.75 m^2, 50W) to THEMIS design
- Spacecraft mass increases to 145 kg each
- 5.5 kbps downlink direct to Earth (34m, Ka)
- Launch on Atlas 431, 5 year cruise (w/ EGA)
- Carrier vehicle preforms Jupiter orbital insertion at 15 R_J (never in radiation belts)
- Releases s/c into 240, 80 and 26.7 day orbits
- Carrier then operates as UV aurora monitor





Io's atmosphere, the Io plasma torus and Jupiter's radiation belts and aurora as a coupled and variable system

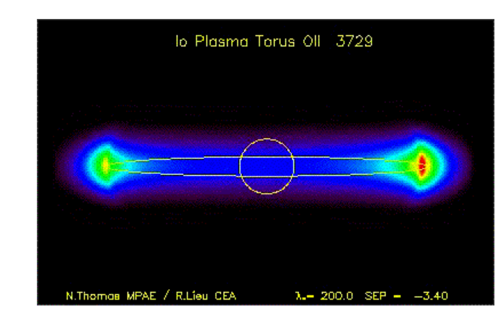
All these components have been studies and all interact with each other

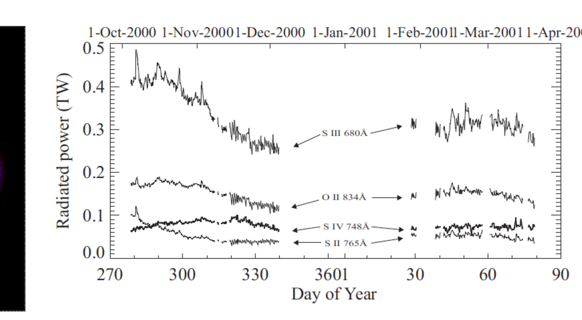
There are very few observation of the coupling and interaction between them

How do changes in Io's atmosphere (volcanos) change the torus and radiation belts?

How do these changes affect the aurora and magnetosphere-ionosphere coupling?

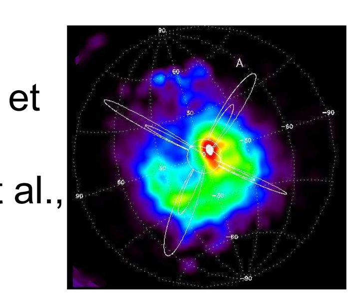
- The neutral SO_2 from Io supplies mass (ions) and energy to the Io plasma torus and the jovian magnetosphere
- This mass and energy flux drives magnetospheric dynamics, which drives the radiation belts and aurora
- Simultaneous observations of these systems are rare
  - Changes in one should produce changes in another
  - Mauk et al., 2002 (Energetic particles and aurora)
  - Steffl et al., 2006 (Torus UV emission) is more typical
    Clear changes in torus brightness and composition
    May be associated with a volcanic event Io, but event was not observed (just before/after images)
- Understanding Io's variability
  - Disk-integrated UV spectroscopy
- Understanding energy and mass flux in the Io torus
  - The energy is primarily lost through UV emissions
  - The mass is primarily lost (we think) through charge exchange and production of energetic neutral atoms
  - EUV imaging spectroscopy (as done by Cassini)
  - 0.25-1.25 keV energetic neutral imaging
- Understanding the effects on the radiation belts
  - >50 keV energetic neutral imaging (as done by Cassini)
- Understanding the effects on the aurora, through FUV imaging and radio emissions

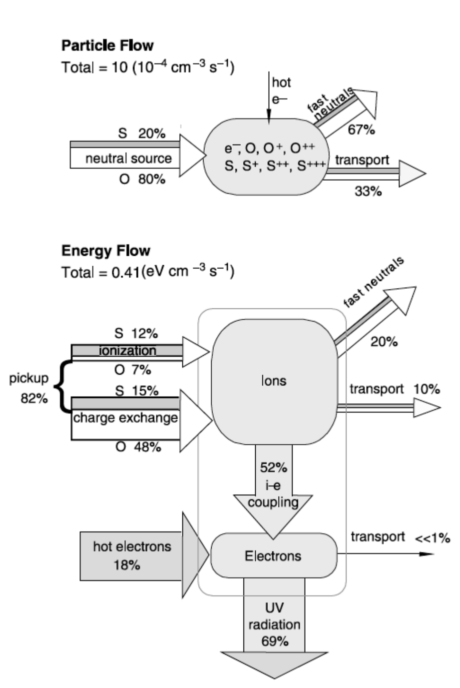


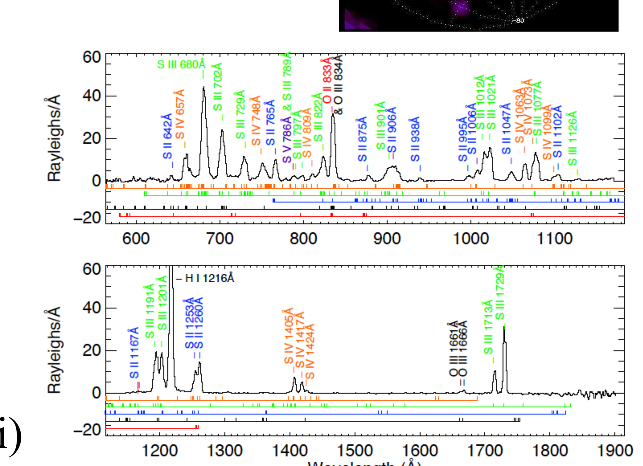


Io plasma torus image (from Thomas et al.) and torus variability (from Steffl et al., 2004)

From Pollock et al., 2001
From Steffl et al., 2004







- **A dedicated Io atmosphere/torus/radiation belt/aurora observer in Jovian orbit**
  - Spatially resolved UV observations not possible from Earth (w/o HST class telescope)
  - ENA observations not possible from Earth
  - Near continuous and simultaneous measurements require dedicated mission