Discussion of Magnetosphere-ionosphere coupling at Jupiter

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Applied Physics Laboratory

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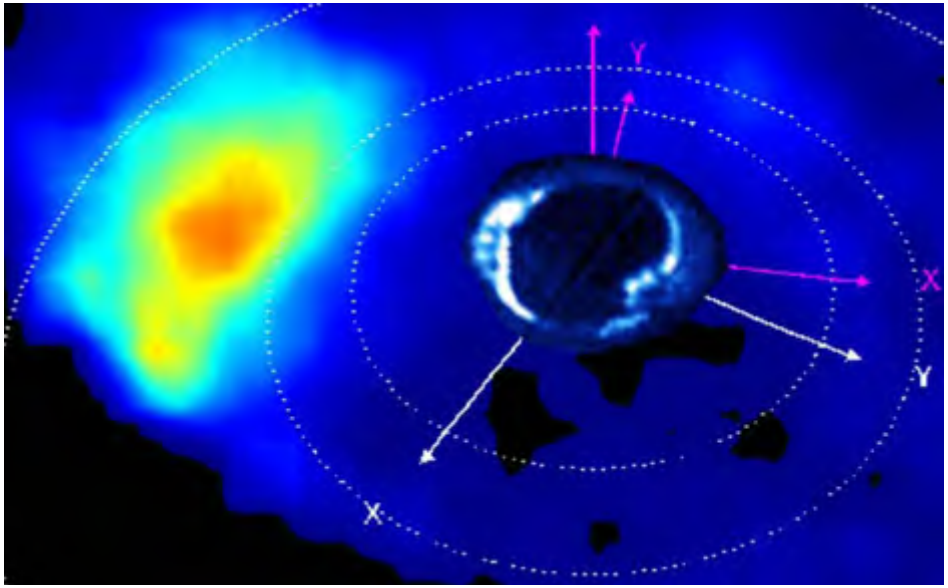
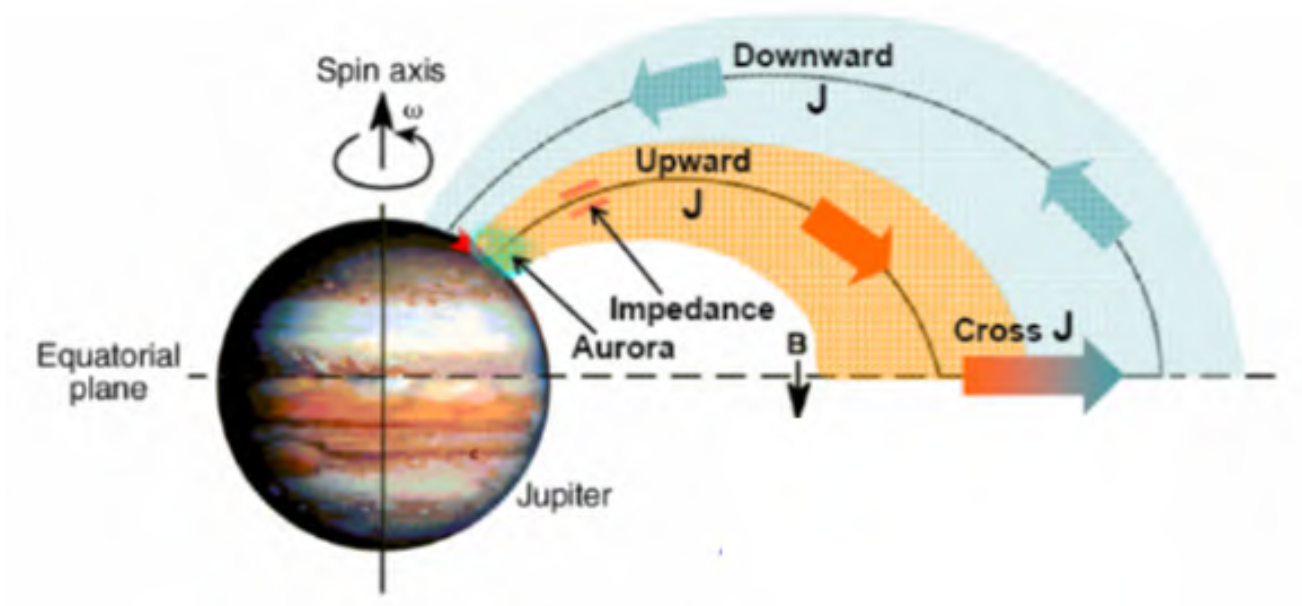
University of Colorado
LASP



Auroral Workshop; 7-8 March 2016; U of C, LASP

How do currents close within the magnetosphere? (1)

- What is the mechanism that carries the radial current (labeled "Cross J" below) in the famous Vasyliunas figure redrawn below?
- Some have answered "ion flows," but that has been unsatisfactory to me.
- Briefly reviewed this subject in the past (Mauk and Bagenal, 2012, Geophysical Monograph 197) and offered in email discussions the explanation on the next slide.



How do currents close within the magnetosphere? (2)

- Guiding Center perpendicular currents (e. g. Parks, 1991)

$$\mathbf{J}_{\perp} = \frac{\mathbf{b}}{B} x \nabla_{\perp}(P_{\perp}) + (P_{\parallel} - P_{\perp}) \frac{\mathbf{b}\, x (\mathbf{b} \cdot \nabla)\mathbf{b}}{B} + (m \cdot n) \frac{\mathbf{b}}{B} x \frac{d\,\mathbf{V}}{dt}$$

- Jump reference frame rotating with the plasmas (not the planet) .
- Assume there are no explicit time dependences

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Centrifugal Term Coriolis Term

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- The Coriolis Term provides the radial current.
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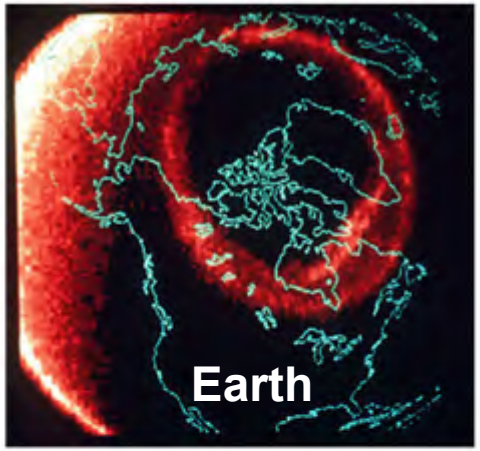
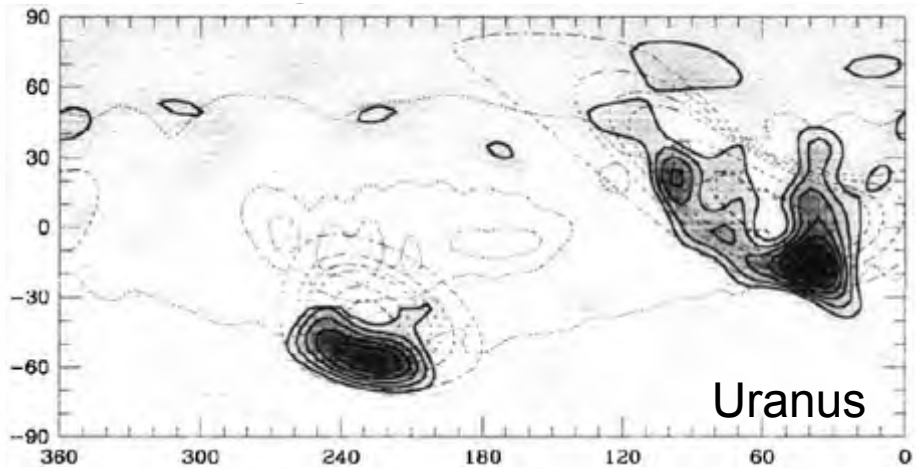
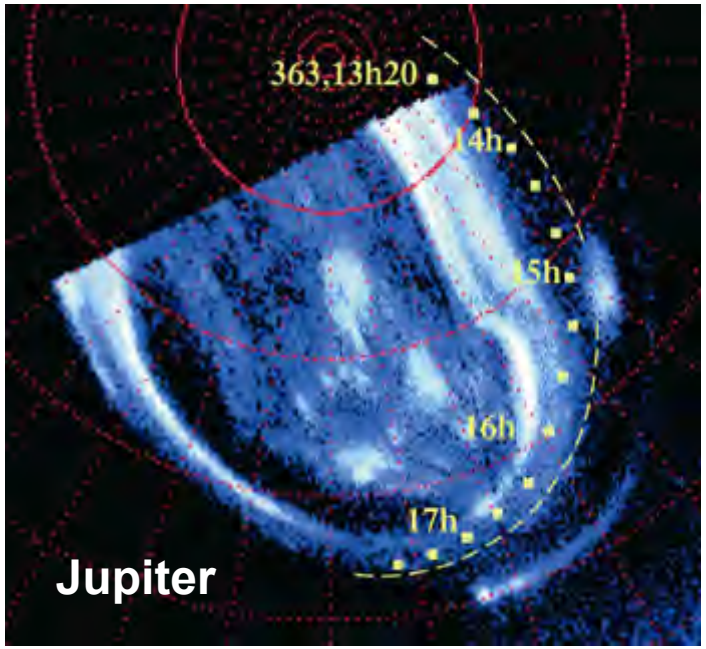
$$\mathbf{J}_{\perp} = \frac{nm}{B^2} \vec{F}\, x\, \vec{B}$$

- Current arises from the "gravitational" F x B drift. This energy independent drift is like the E x B drift, but it carries a current (coupled by mass).

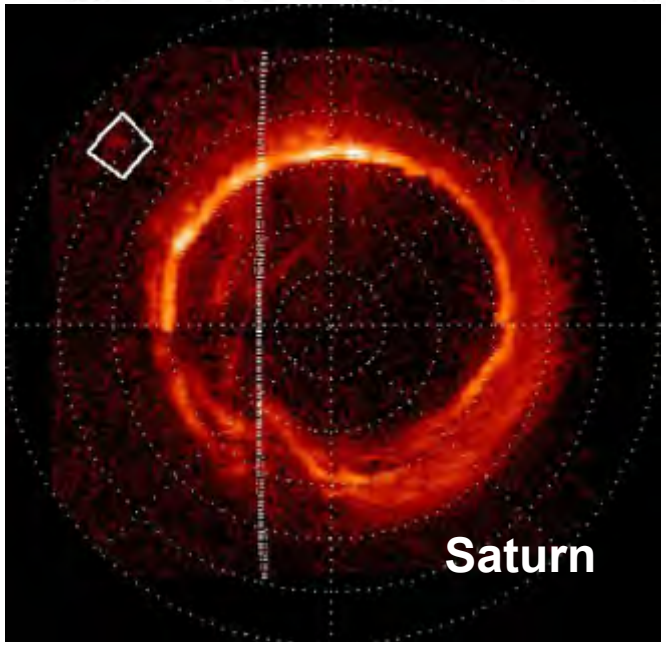
All Strongly Magnetized planets have some level of auroral emissions







Frank and Craven, 1988
Mauk et al., 2002



Herbert, 2009
Pryor et al., 2011

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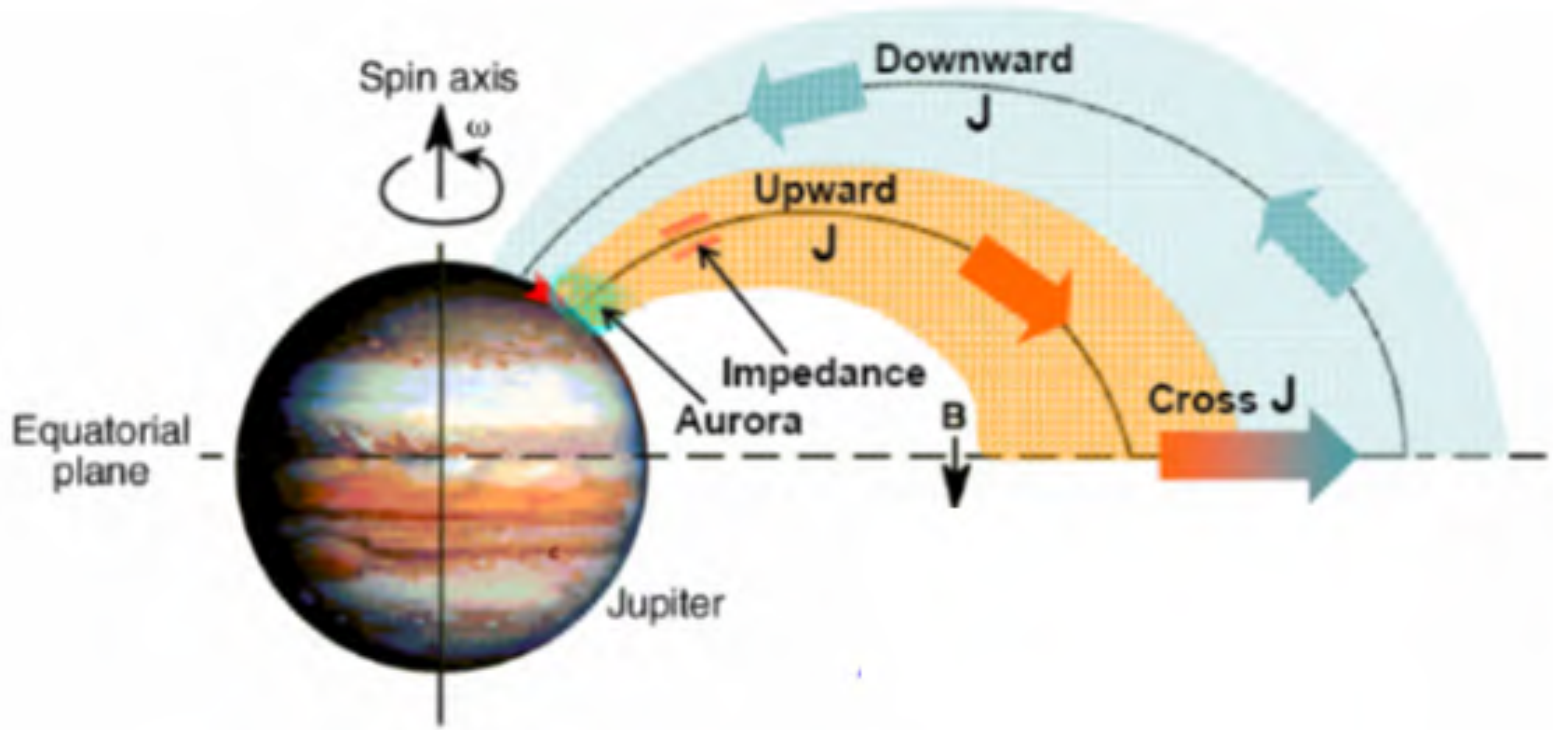
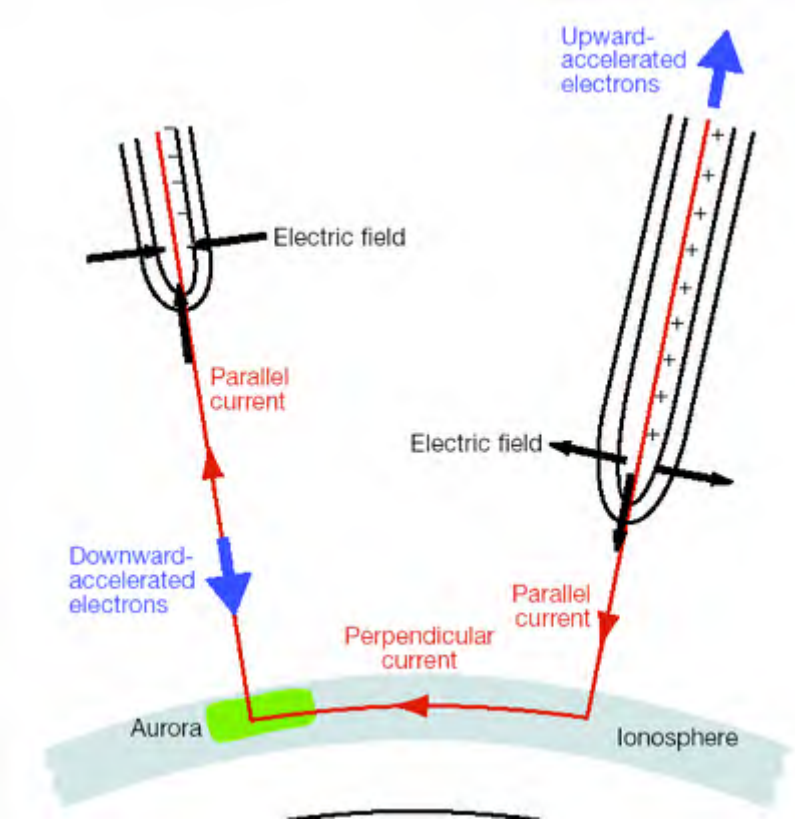
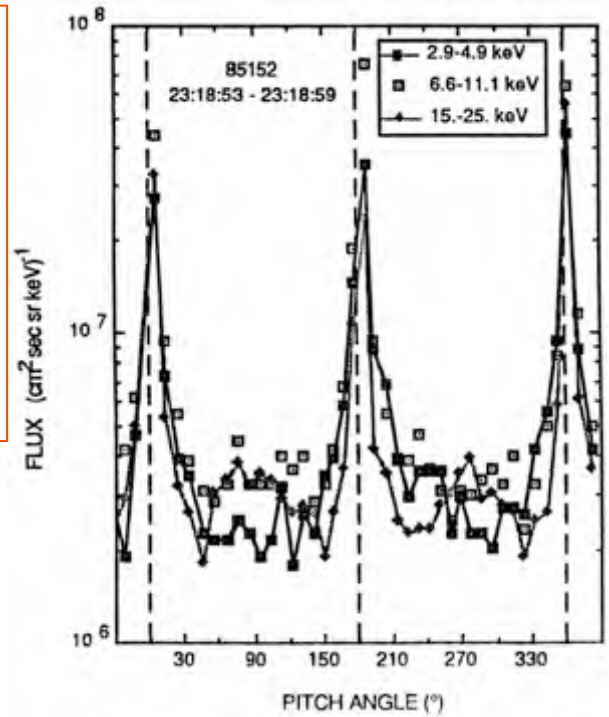
To where do currents map?



To where do auroral currents map?
A key signature has been equatorial electron beams.

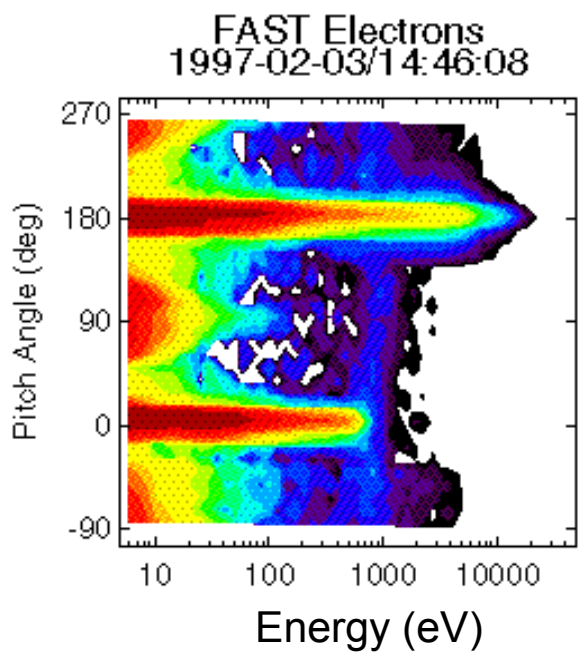


Marklund et al., 2001



~ 9 RE
High Altitude,
Equatorial
Beaming

Klumpar et al. (1988)

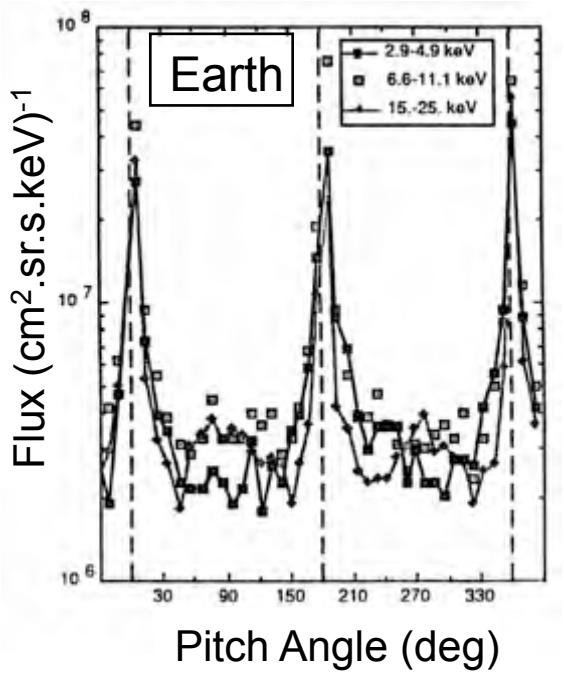


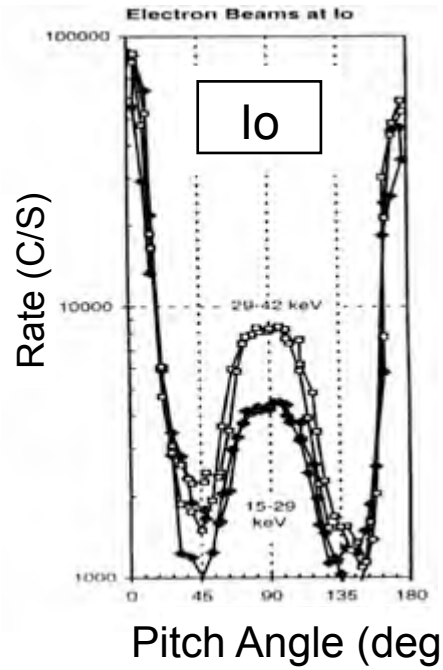
Low Altitude Beaming

Carlson et al. (1998)

Ergun et al. (1998)

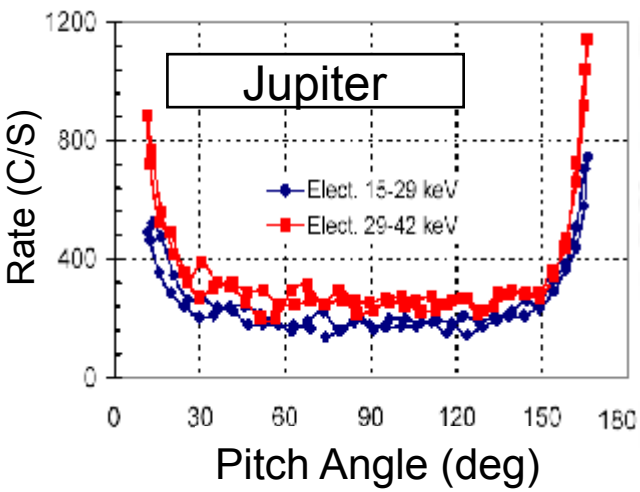
Auroral acceleration signatures are observed in diverse environments

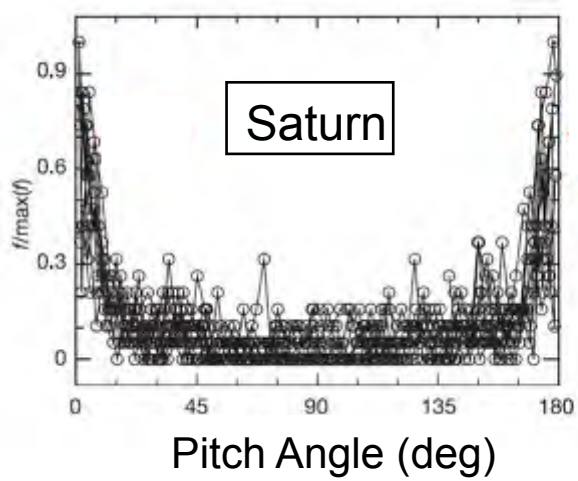




Klumpar et al. (1988)

Mauk and Saur (2007)





Mauk and Saur (2007)

Saur et al. (2006)

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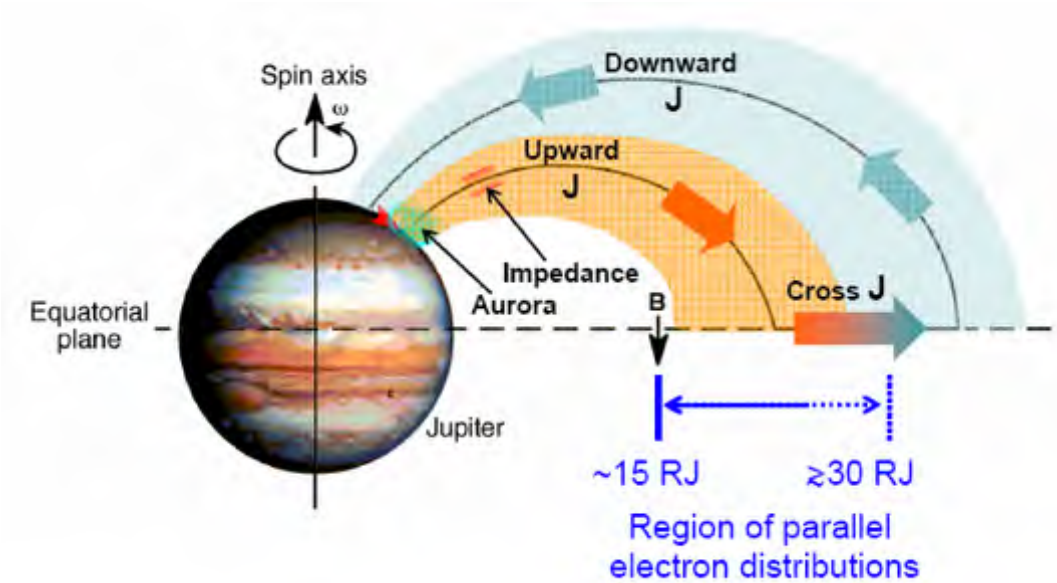
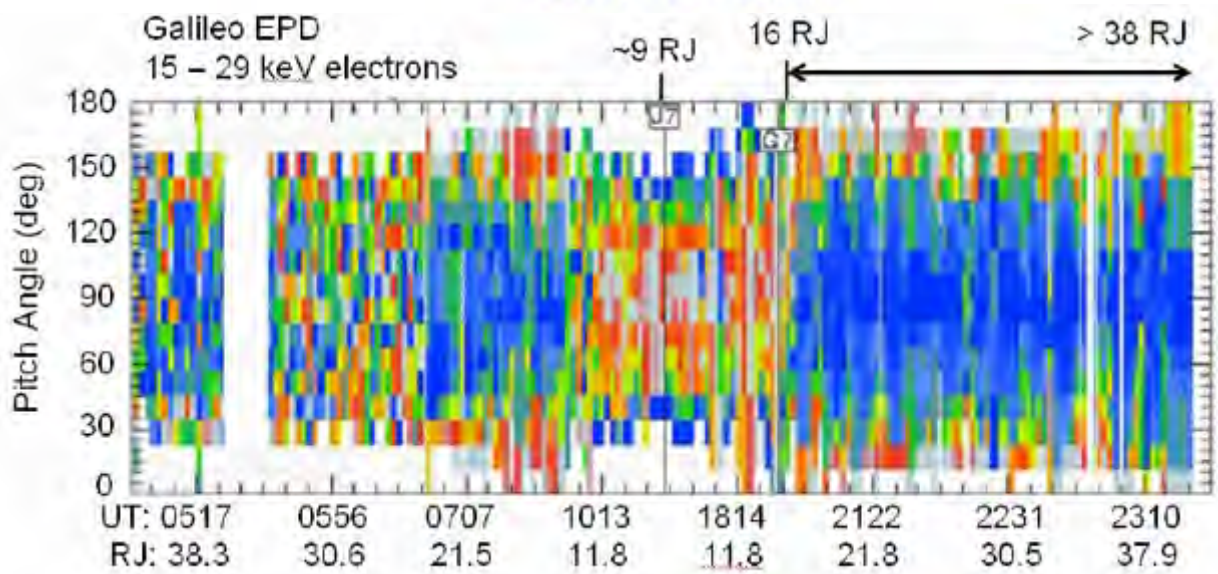
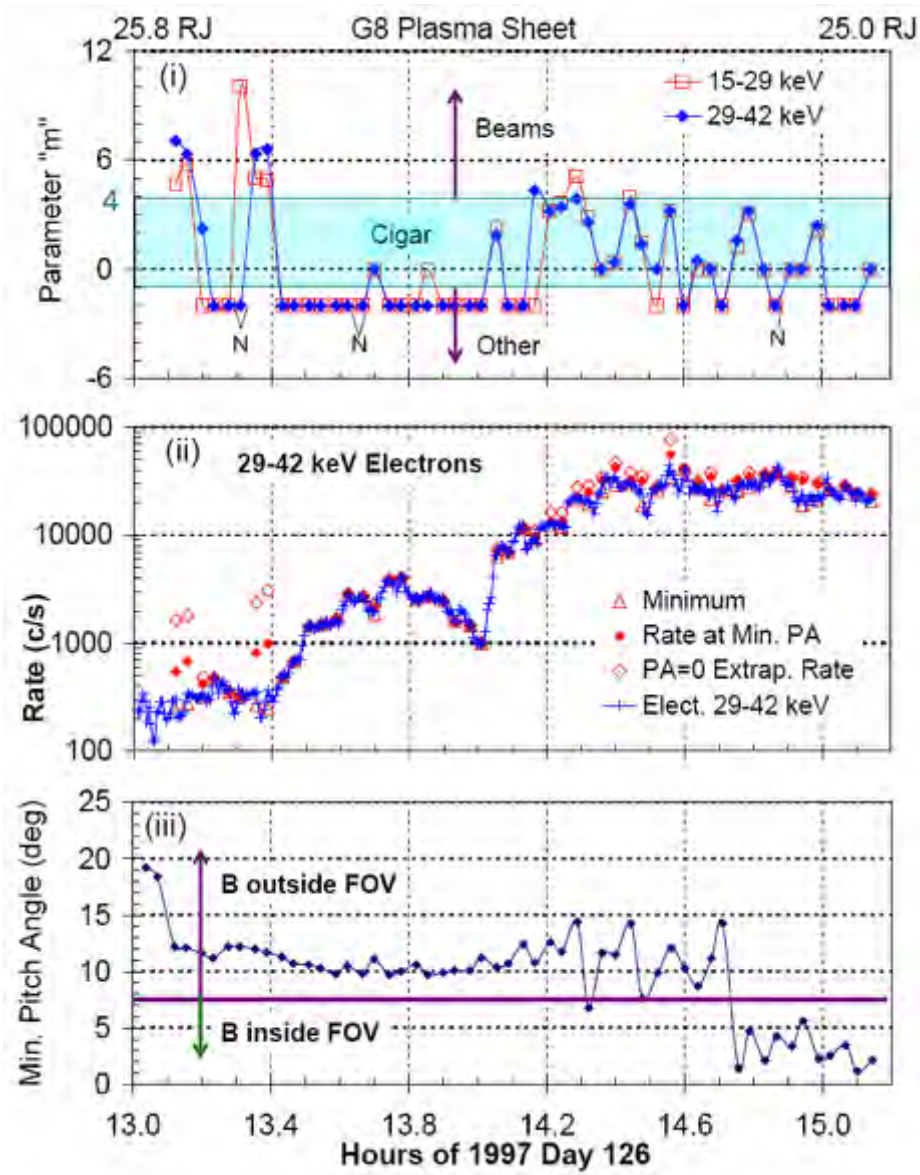


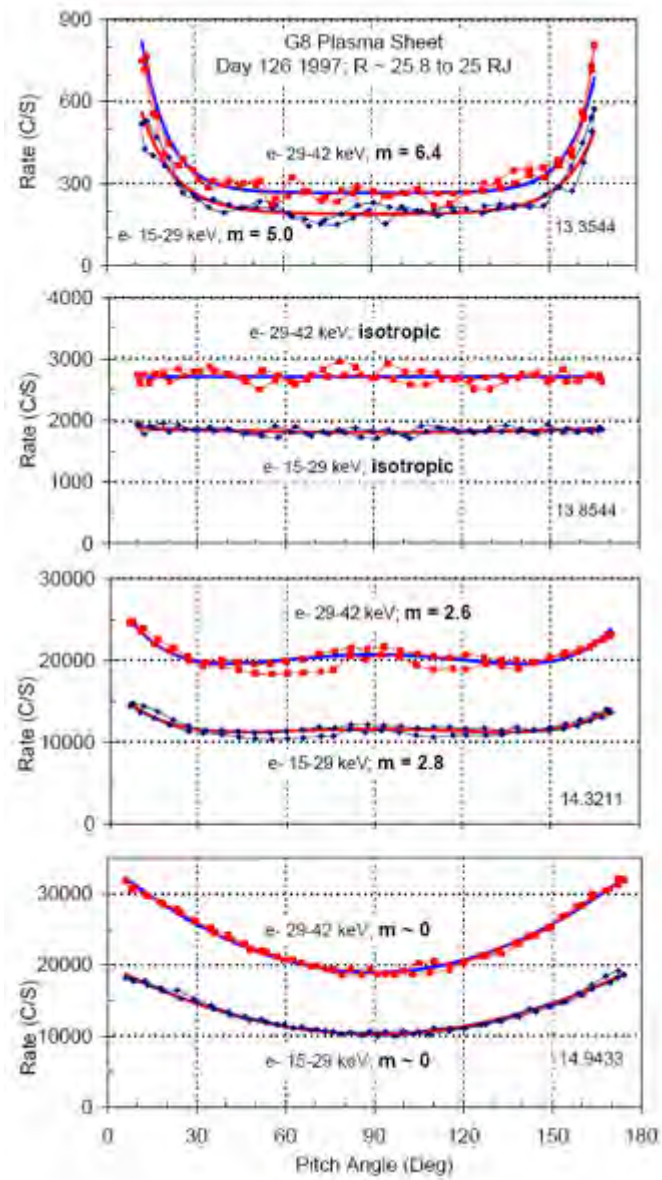
The same region at Jupiter where field-aligned electron distributions prevail, is the region thought to carry upward field aligned currents and that maps to the main auroral oval of Jupiter



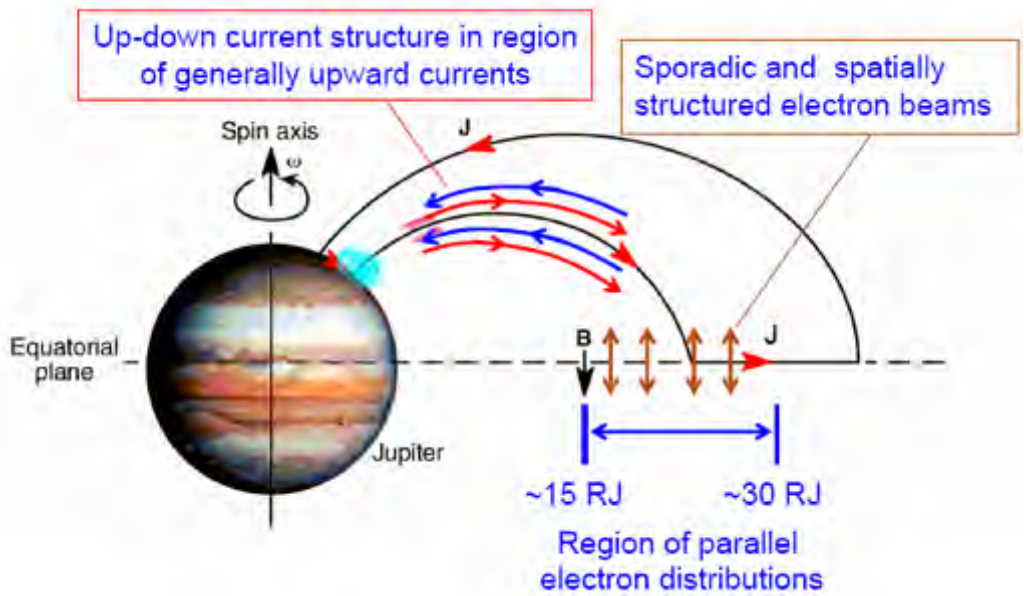
Tamás et al., 2004

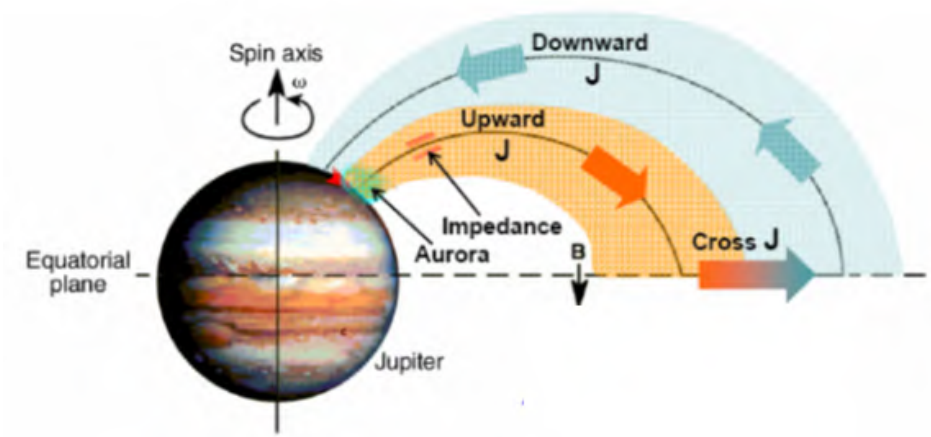
Beams are highly structure and pitch angle distribution types are highly variable in Jupiter's middle magnetopshere

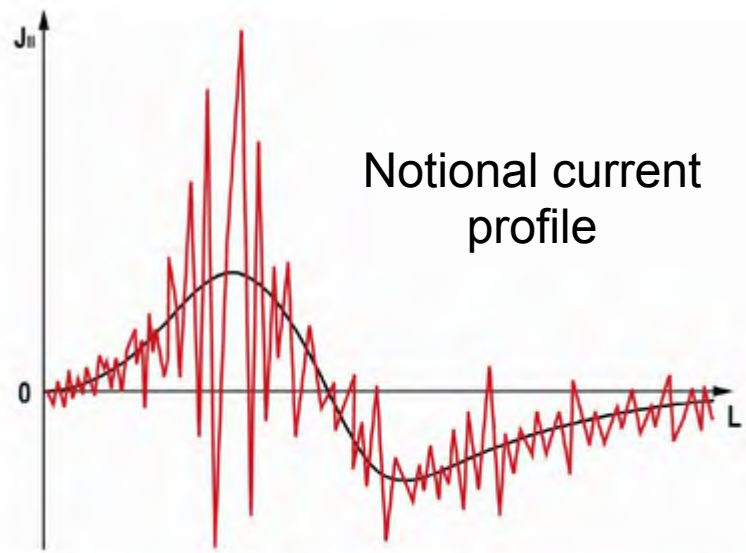




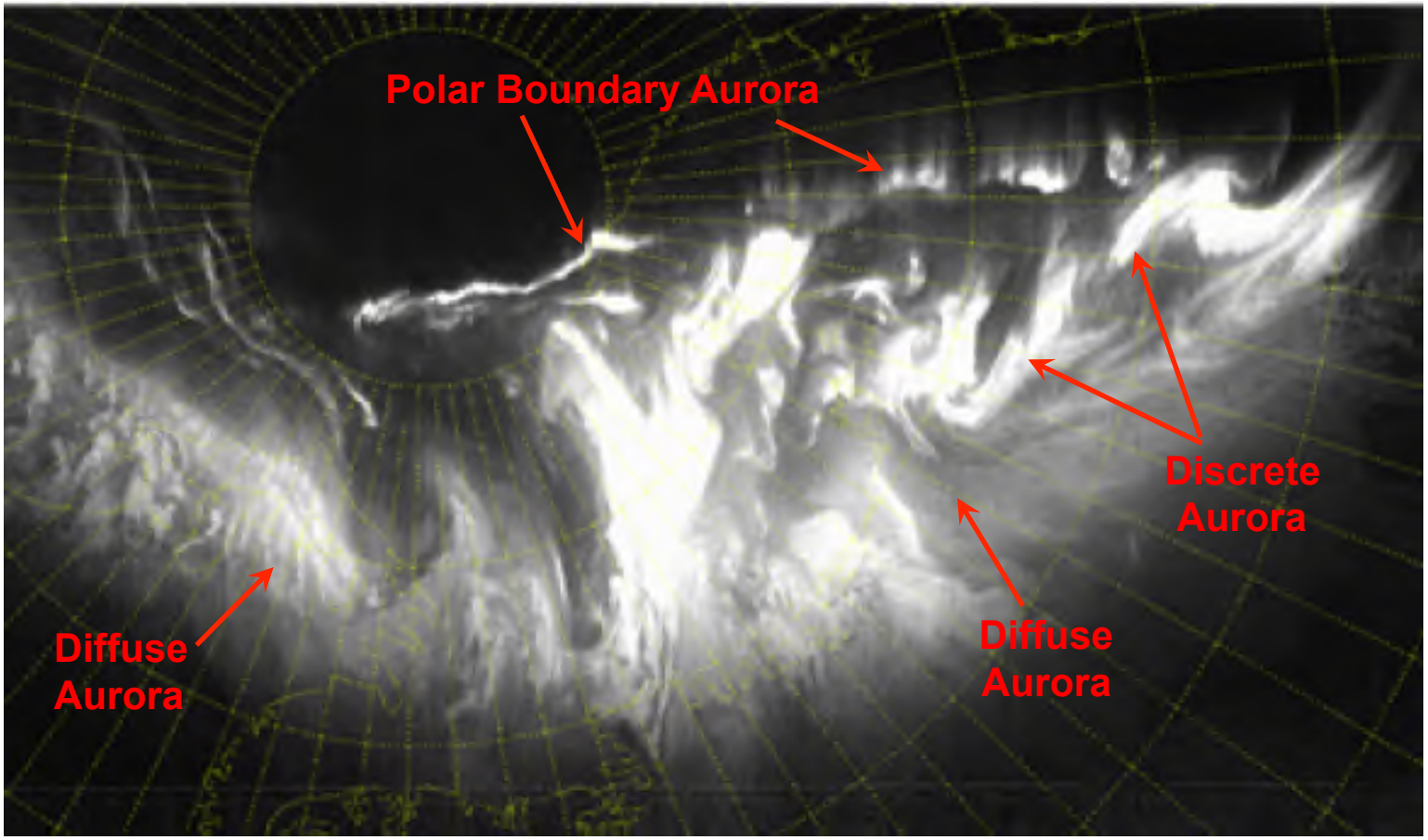
Preliminary Conclusion: Region of generally upward currents associated is highly structured with localized regions of upward and downward currents, similar to Earth's aurora



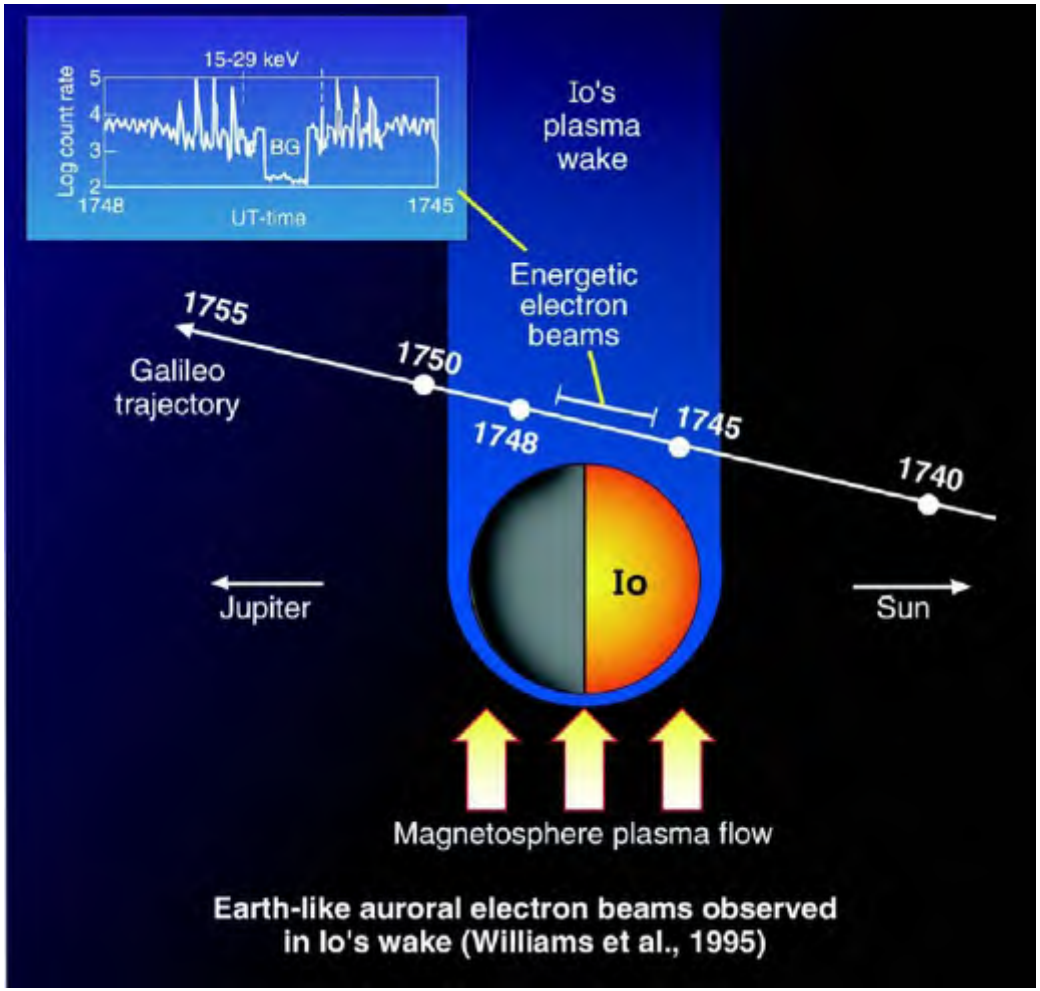


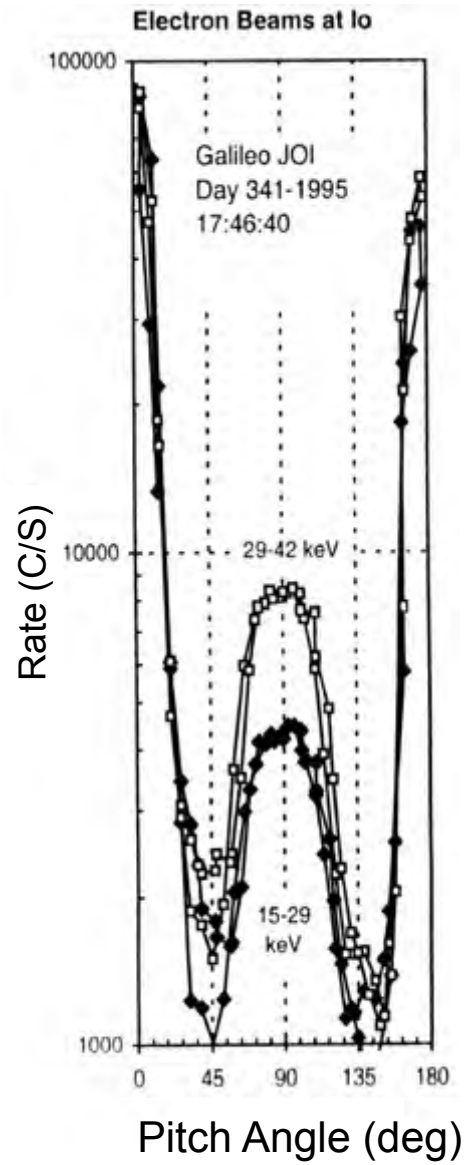


There should be no surprise that the aurora can be highly structured

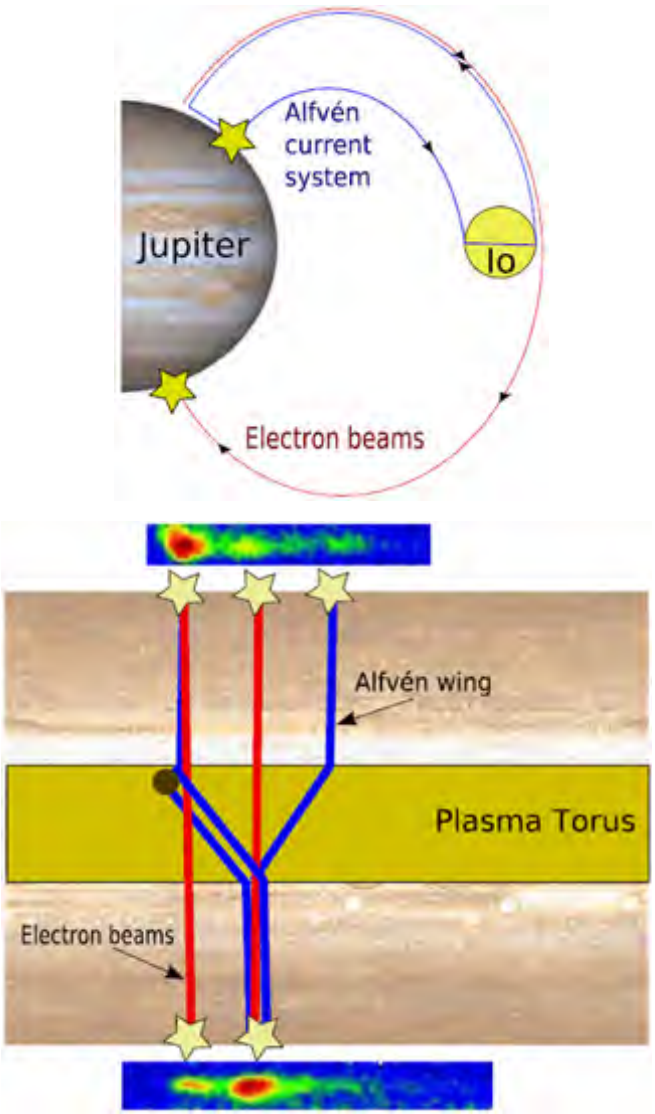


Powerful equatorial electron beams are found within Io's wake

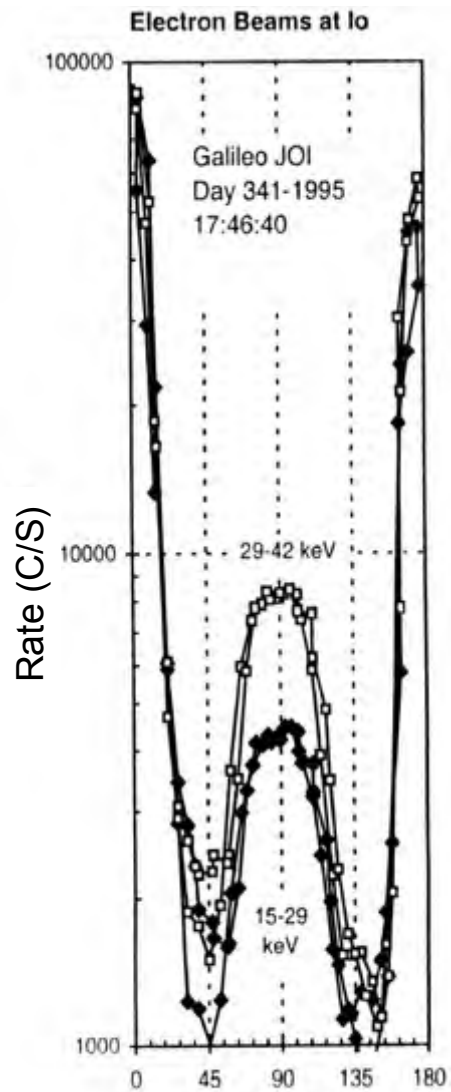




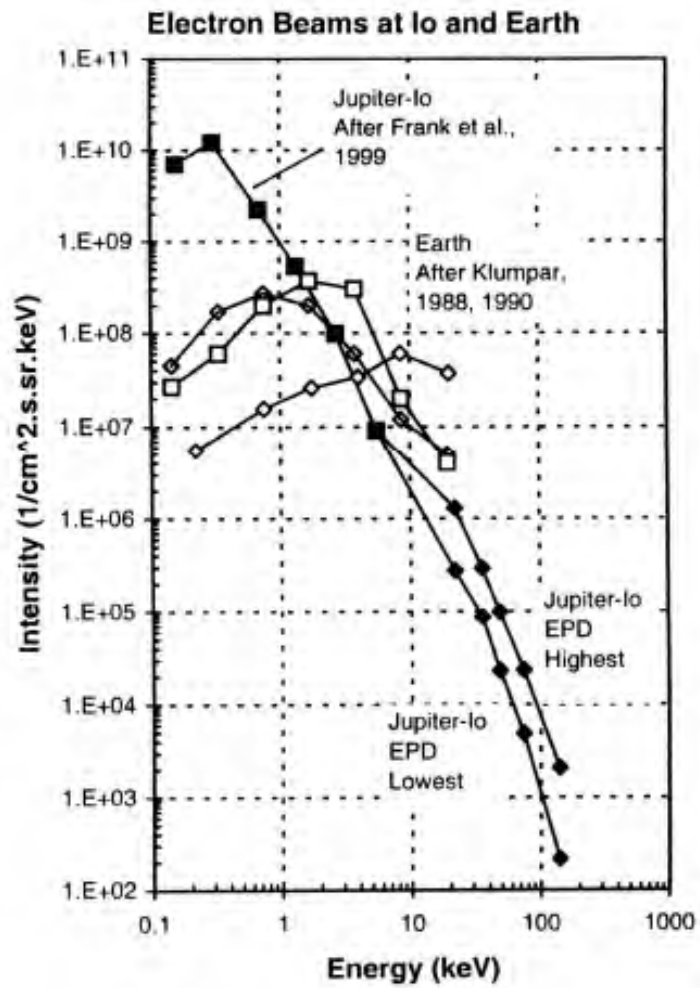
These same beams have been identified as the cause of secondary Io auroral spots.



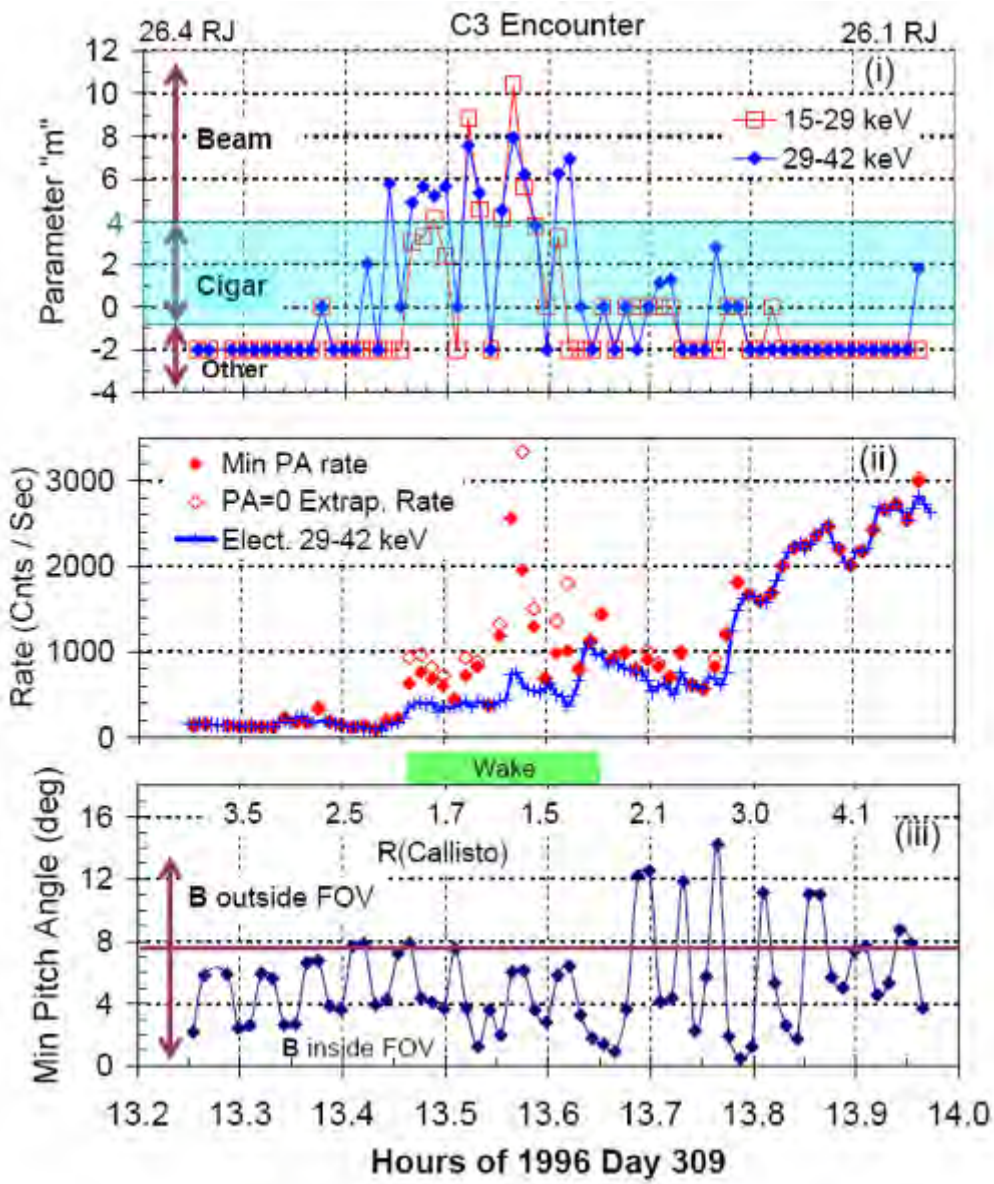
Bonfond et al., 2008

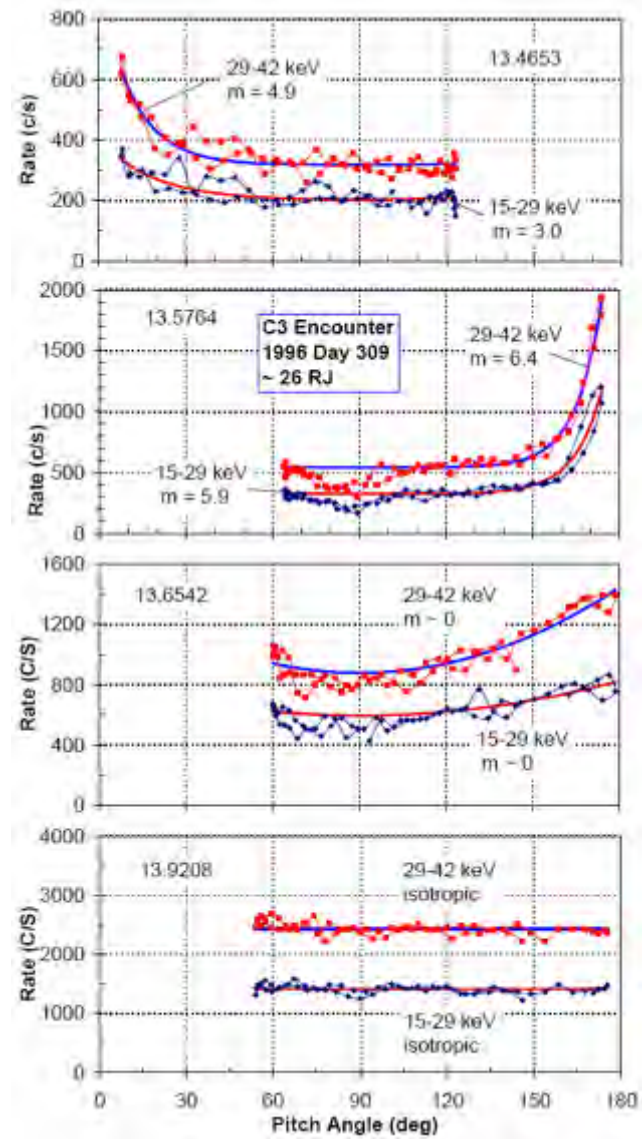


Pitch Angle (deg)



As at Io, some beams appear circumstantially to be generated by satellite interactions, here at Callisto





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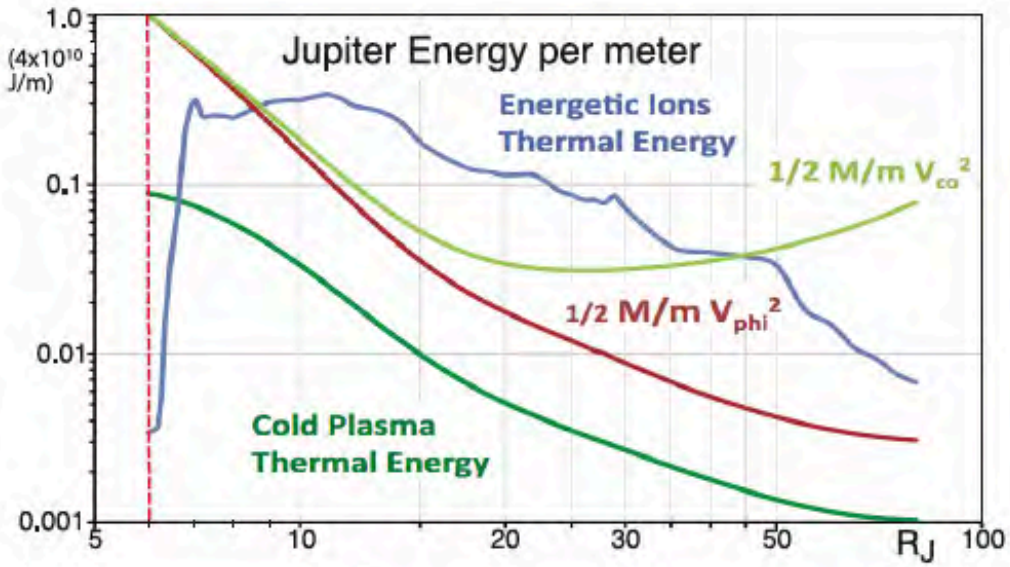
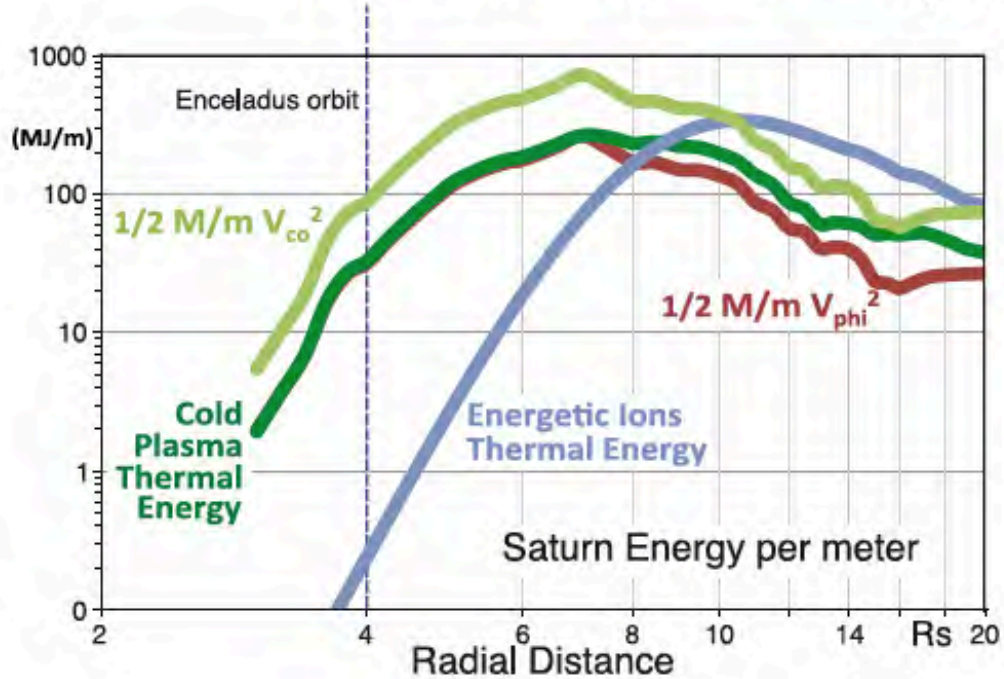
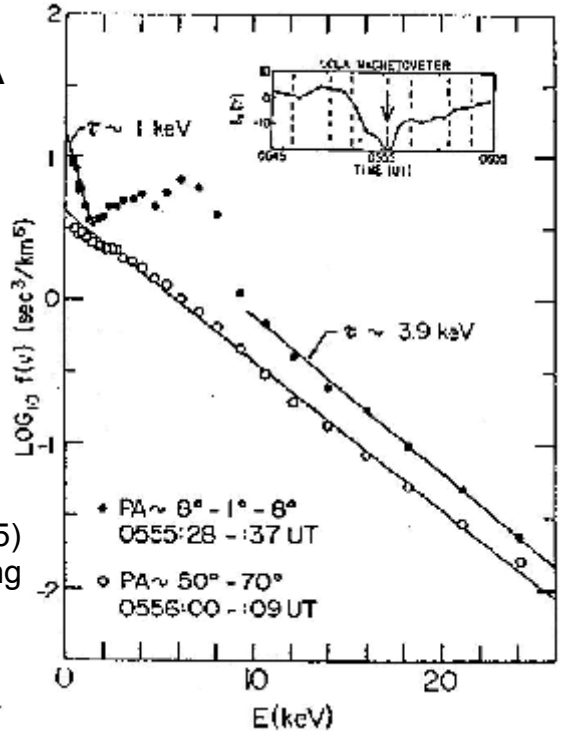

Jupiter Energy per meter
(4x10^10 J/m)
1.0
0.1
0.01
0.001
5
10
20
30
50
100
R_J
Energetic Ions Thermal Energy
1/2 M/m V_co^2
1/2 M/m V_phi^2
Cold Plasma Thermal Energy


(MJ/m)
1000
100
10
1
0
Enceladus orbit
1/2 M/m V_co^2
1/2 M/m V_phi^2
Cold Plasma Thermal Energy
Energetic Ions Thermal Energy
Saturn Energy per meter
2
4
6
8
10
14
20
Rs
Radial Distance

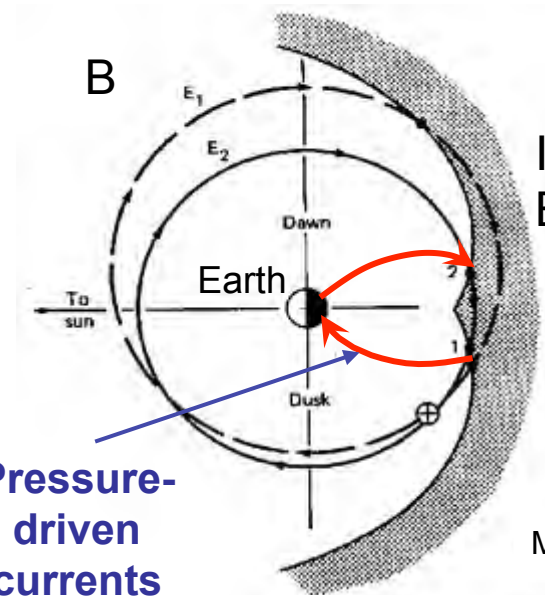
Injections commonly drive magnetic field-aligned electrodynamics

A



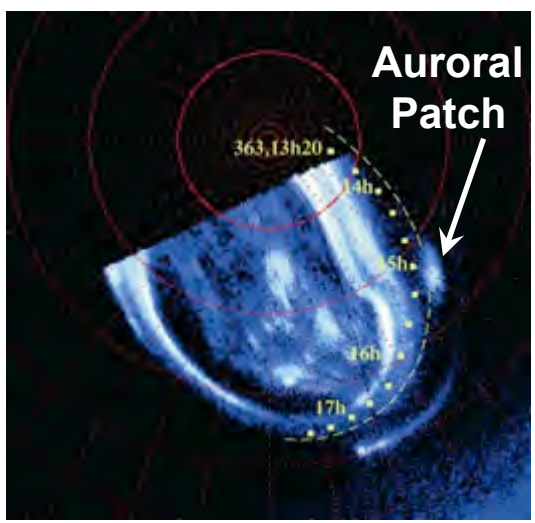
McIlwain (1975)
Mauk and Meng (1991)

B



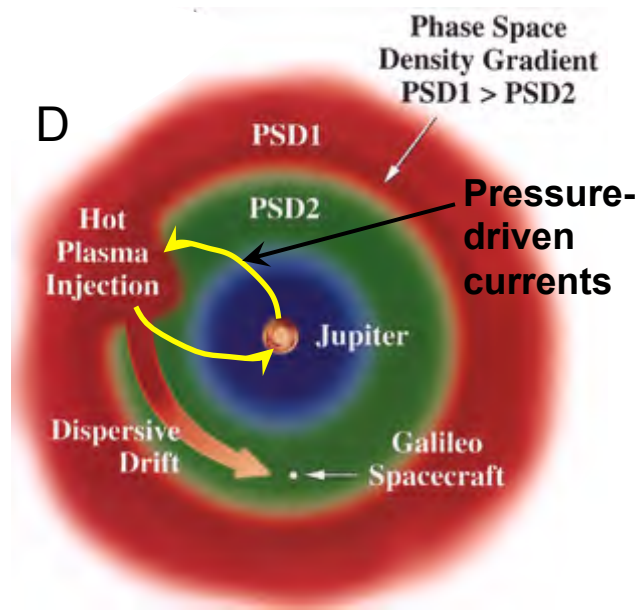
Mauk and Bagenal (2012)

C

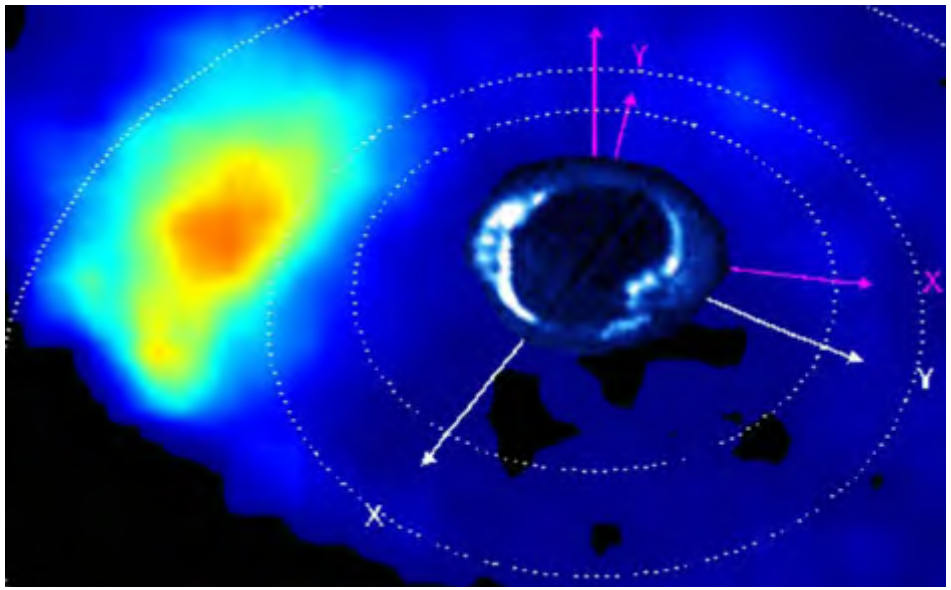


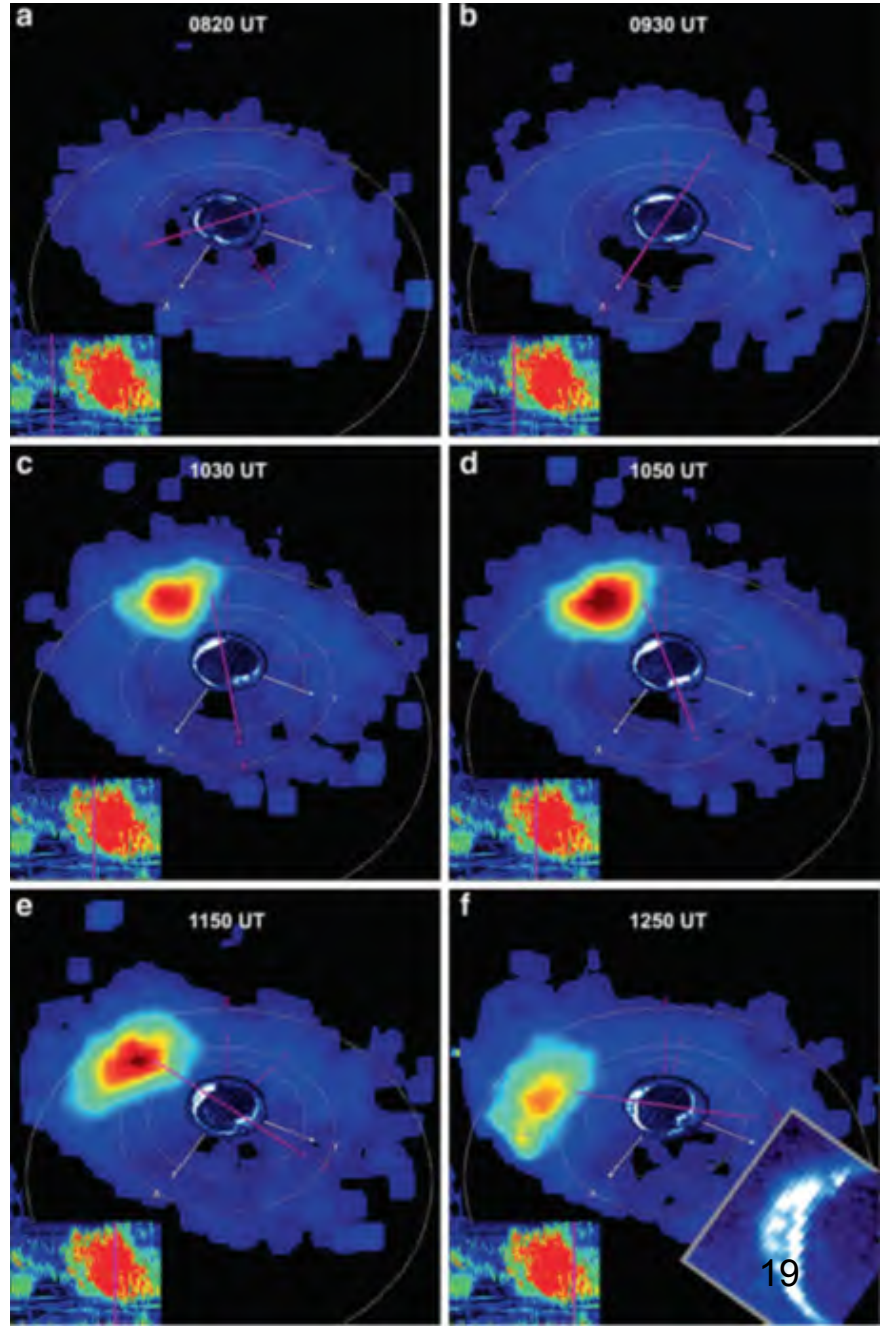
Mauk (2002)

D



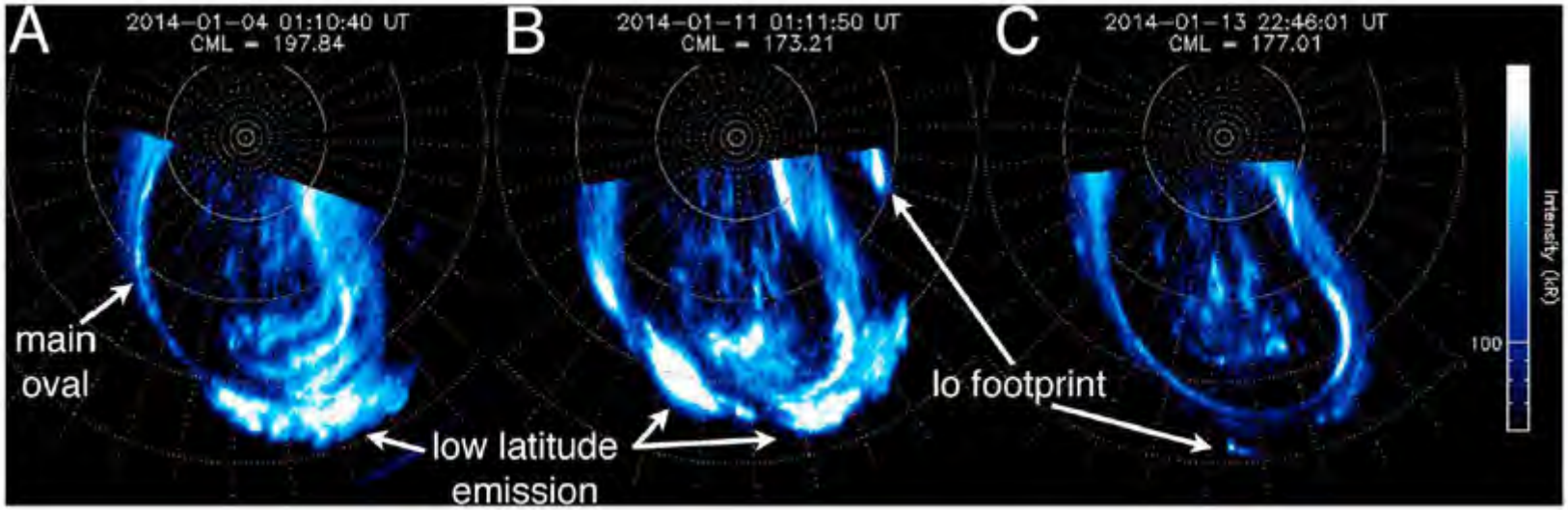
Injections at Saturn are major drivers of aurora

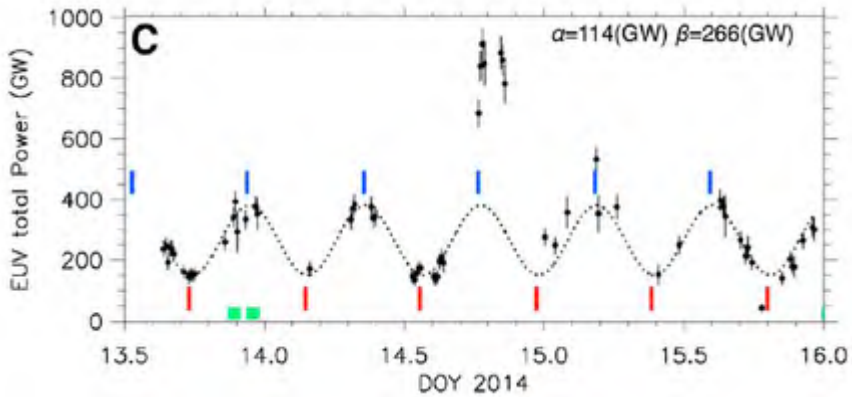


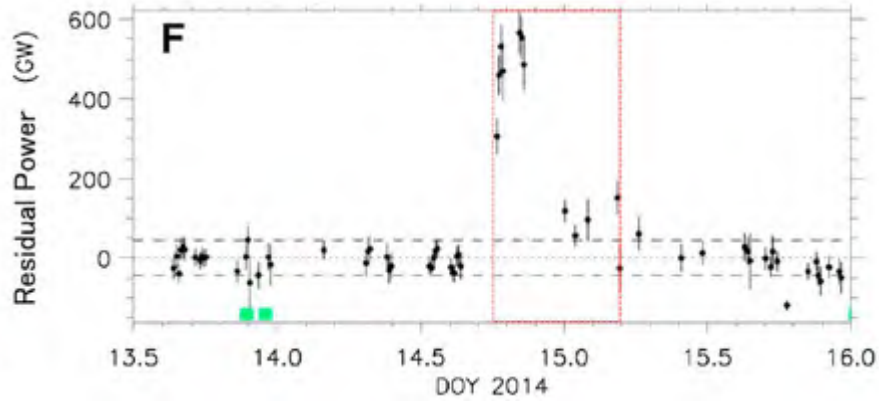


Mitchell et al., 2009

One might guess that the dramatic high auroral power transients are also closely related to dynamic injection events





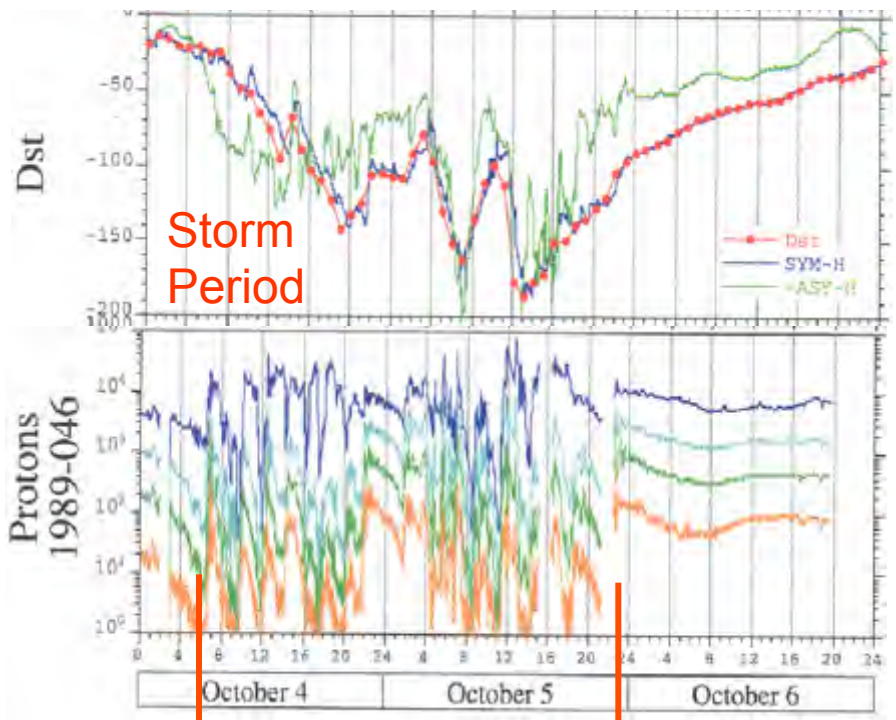


Kimura et al., 2015

Like Earth, Jupiter and Saturn have have quiet and active periods of injections

At Earth:

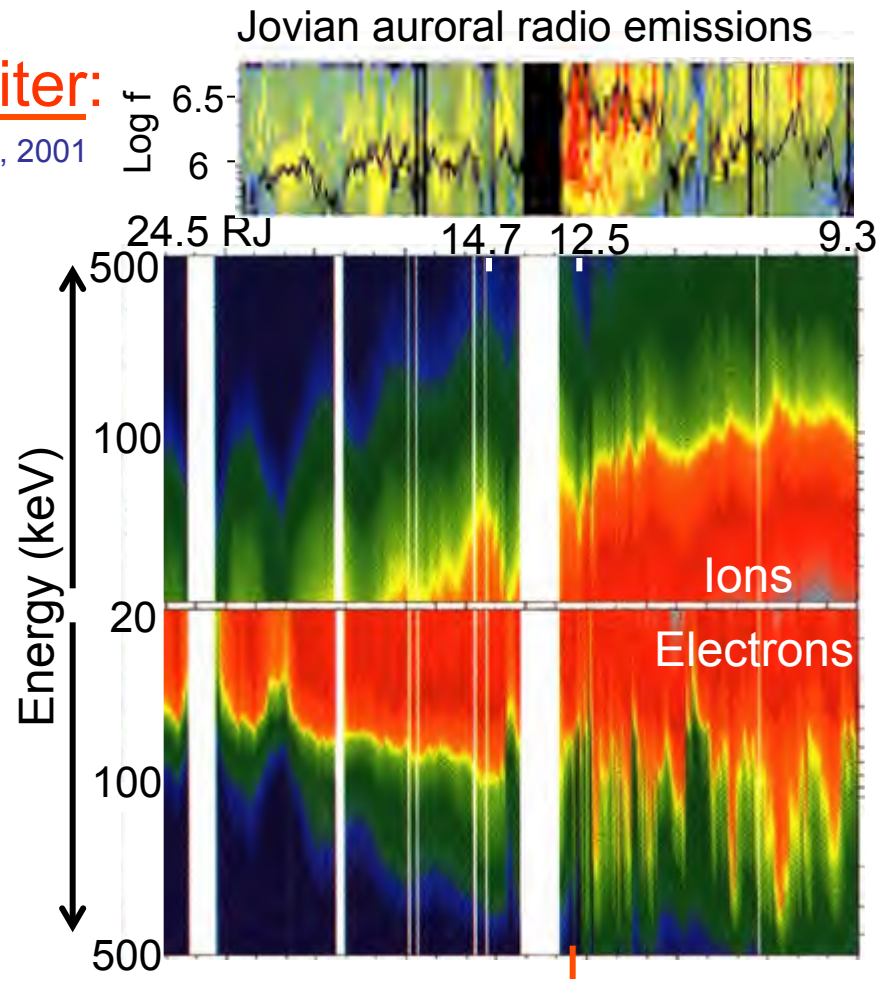
Reeves et al., 2003



Storm Associated Injections

At Jupiter:

Louarn et al., 2001



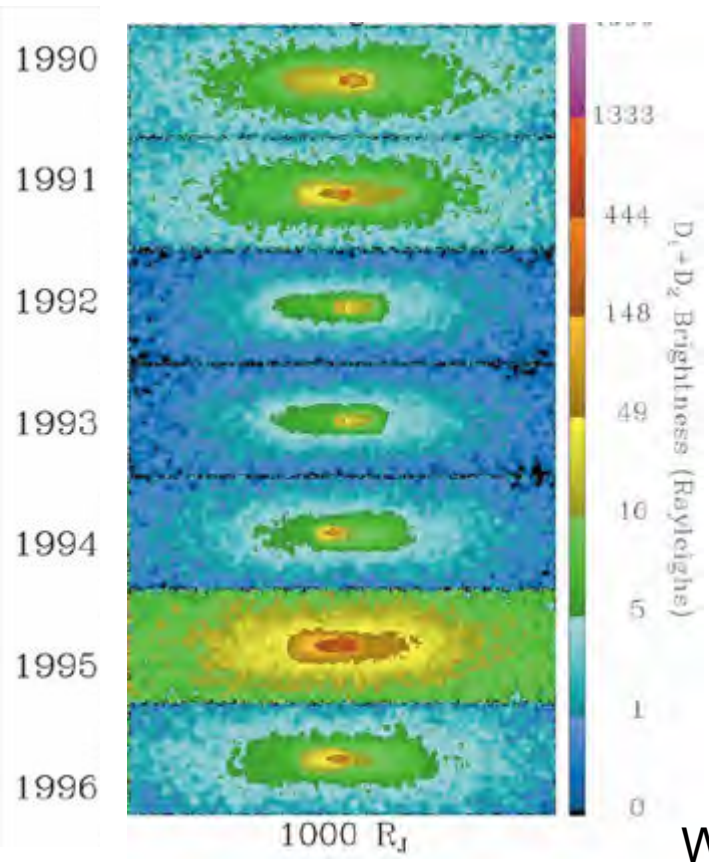
"Quiet" Period | **"Storm" Period**

Mauk et al., 1999

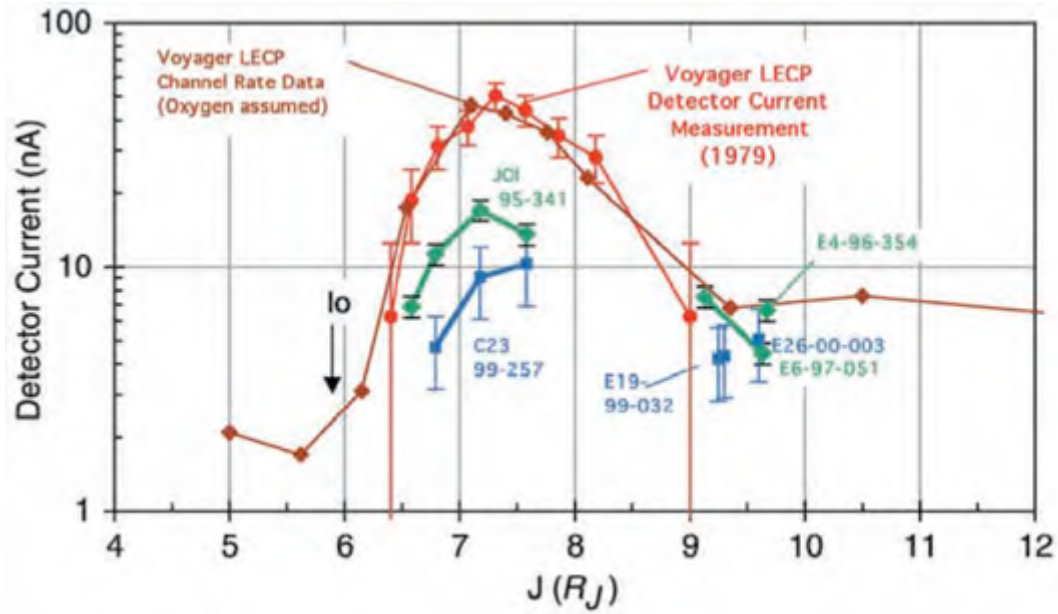
Jupiter has changed. Has Jupiter's aurora?

Why did Voyager researchers thing that Jupiter's aurora mapped to the near Io regions?

Was it bad mapping or did Jupiter's system change?

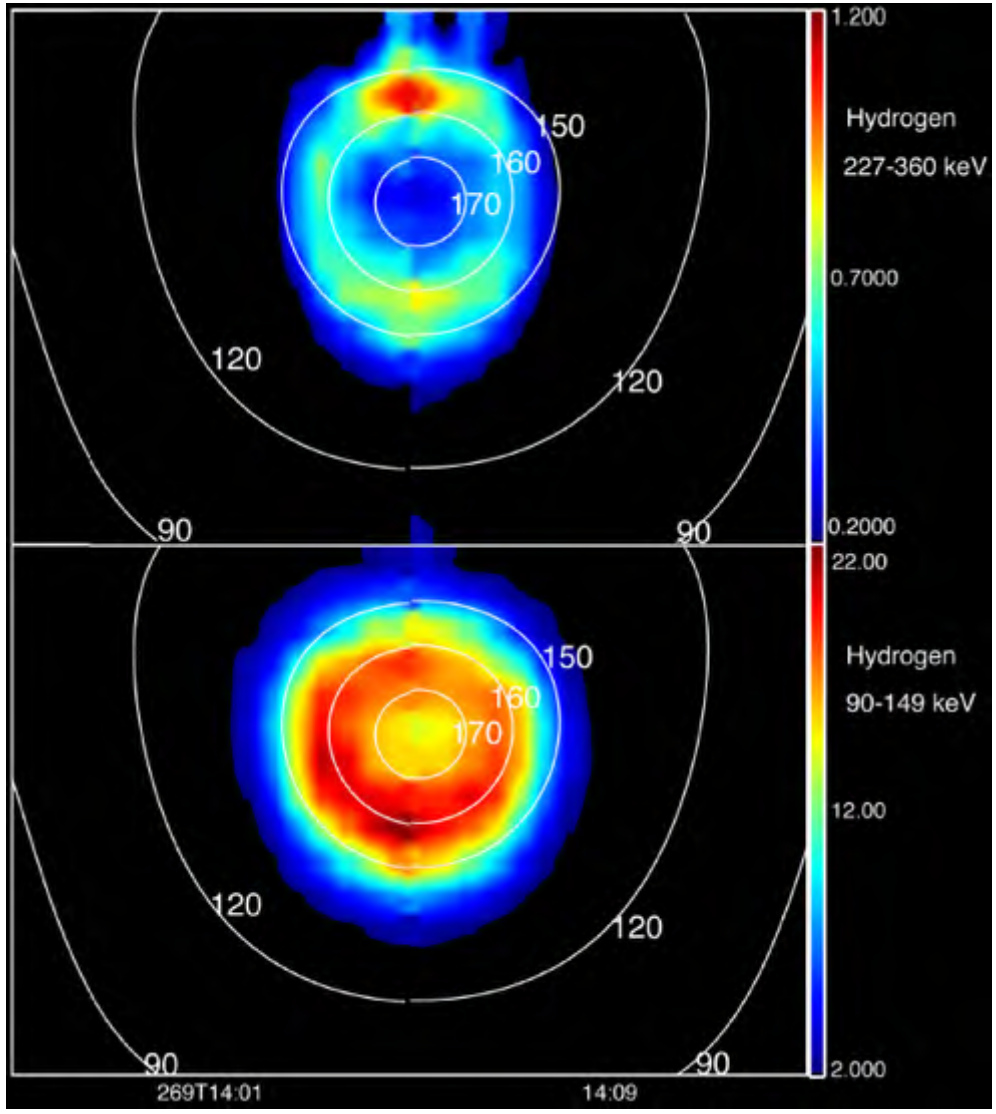


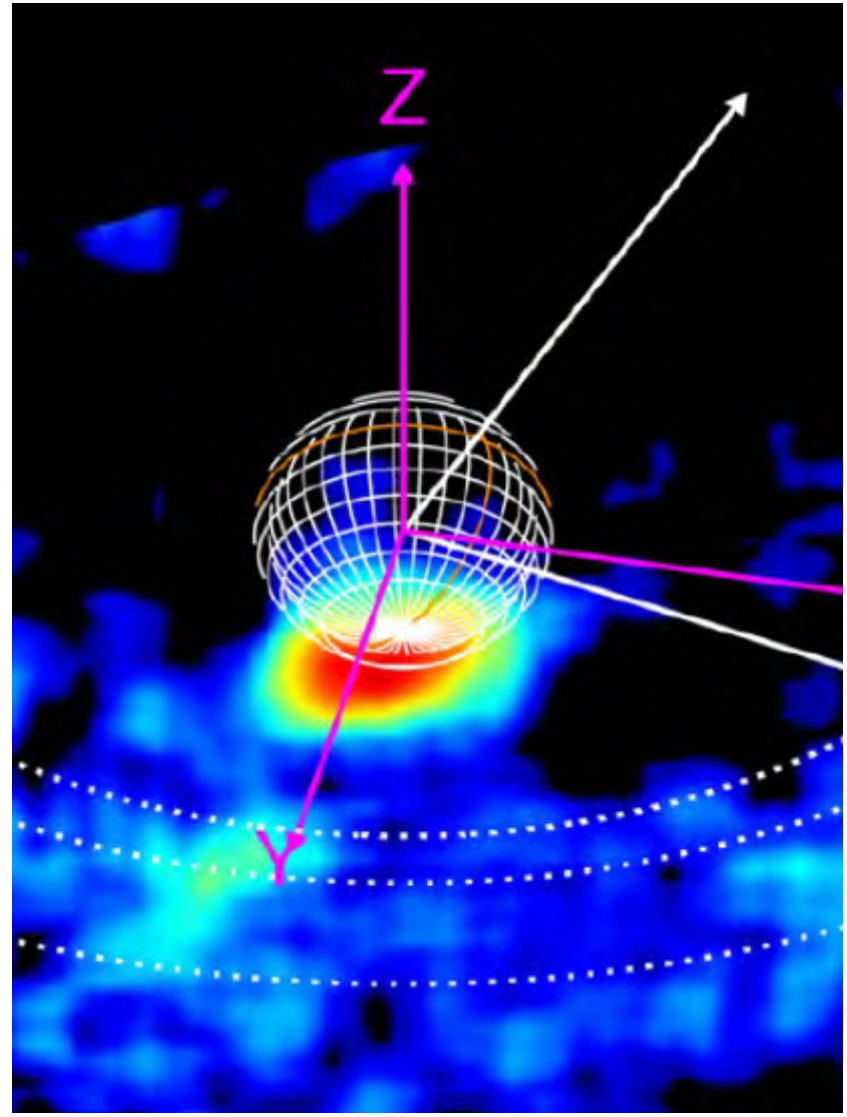
Wilson et al., 2002



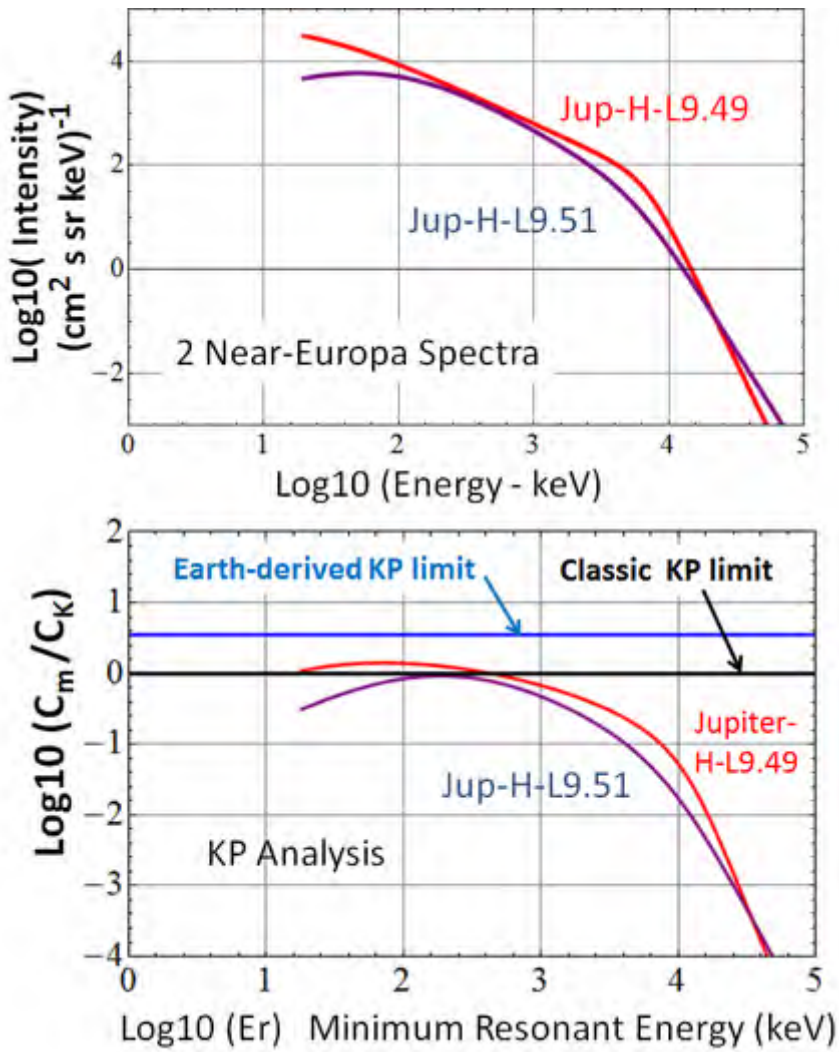
Mauk et al. 2004

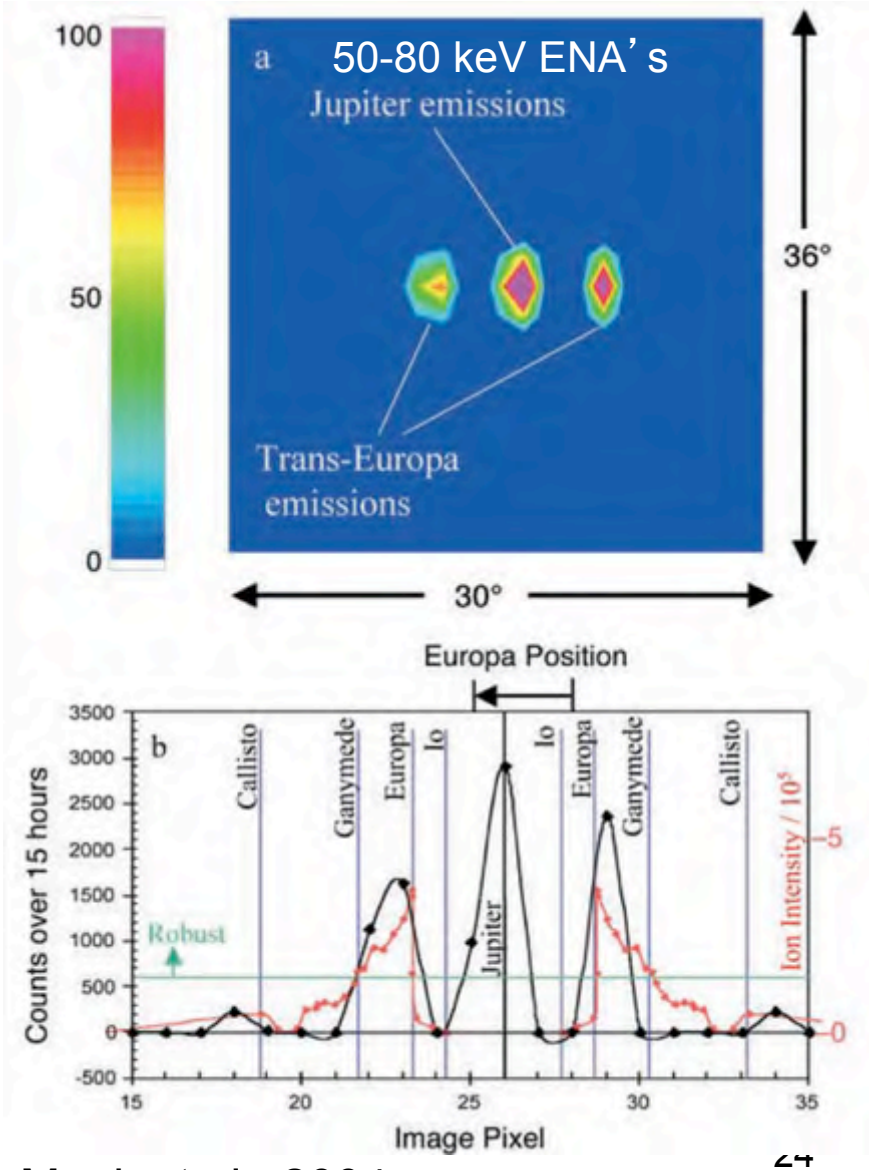
Ion auroral processes were an important aspect of Saturn's auroral regions





Ion precipitation has likely been observed directly at Jupiter

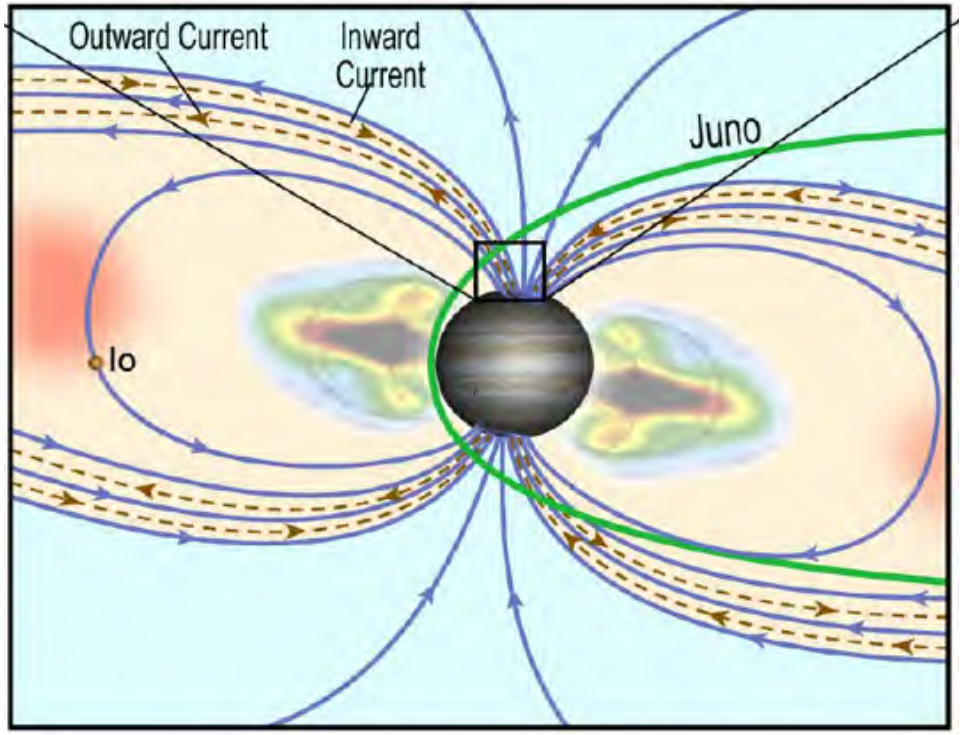




Mauk et al., 2004

Juno is location, location, location

- Diffuse precipitation versus pressure-driven currents as an explanation of transient equatorward phenomena.
  - Electric currents associated with precipitation.
- What mechanisms close the auroral currents within the magnetosphere?
- More specifically, what roles do pressure driven currents play?
- What is the interplay between flow and pressure driven currents?
- Degree of structuring. Is full structuring unresolved at this time.

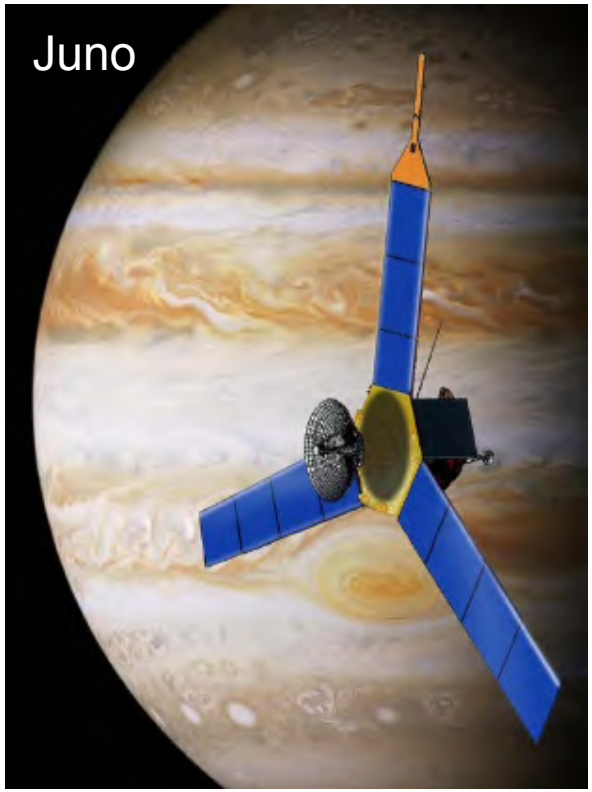


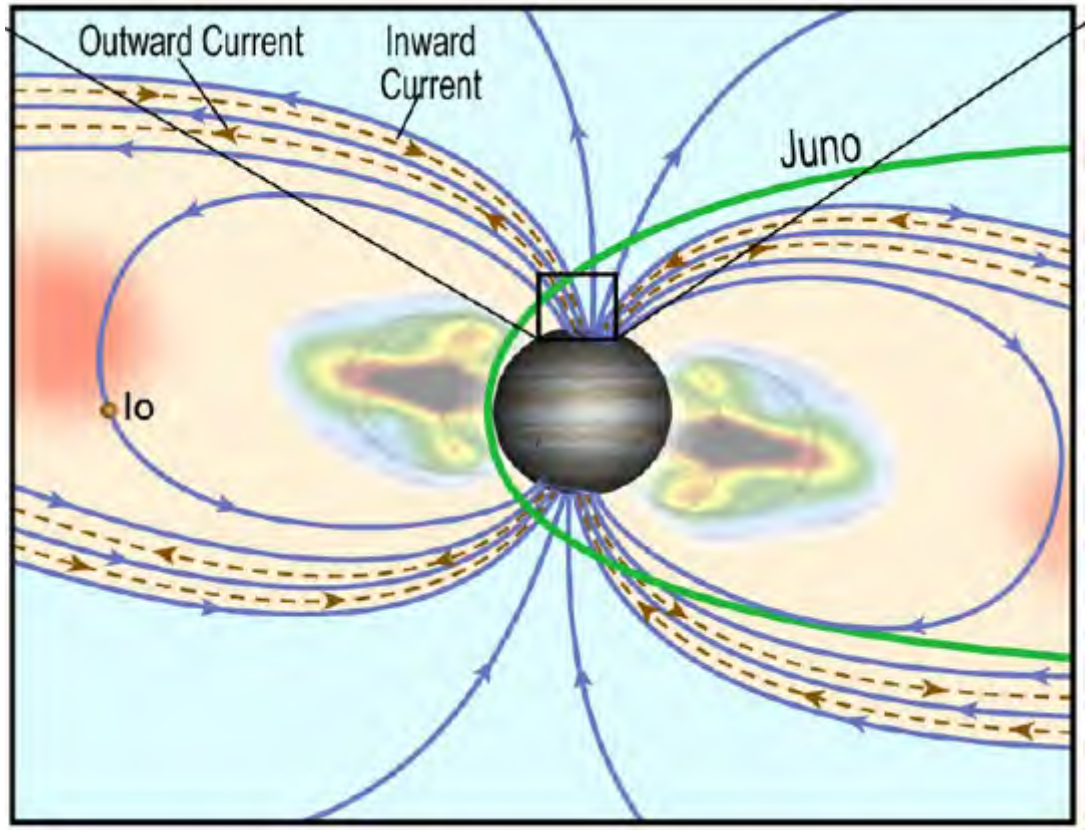
Nature of downward and upward acceleration / precipitation as a function of position and auroral structures

Backup

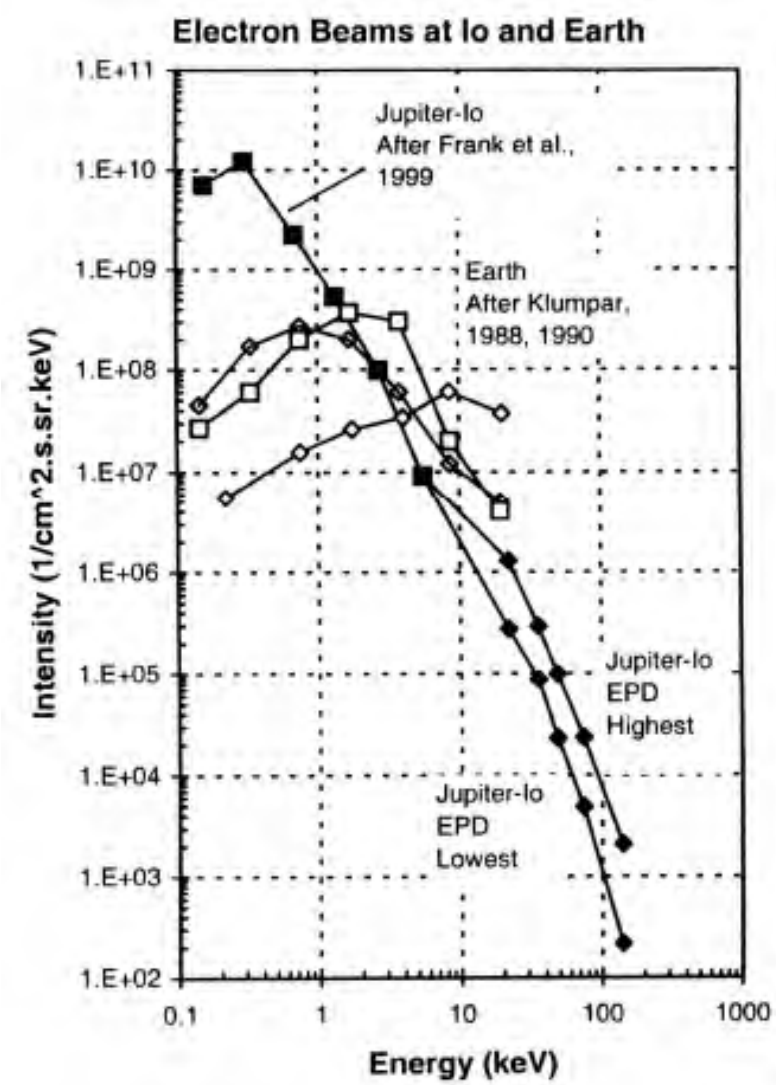
The next 2 decades will see a heightened focus on the space environment of Jupiter

- Juno arrives at Jupiter in July 2016 to study Jupiter's polar regions
- ESA's JUICE mission, with a robust magnetospheric suite including UV, Particles and radar insturments from the US, will arrive in the late 2030. NASA's Clipper mission will arrive in the late 2028 to focus on the Europa regions (some magnetospheric instruments, although not robust)

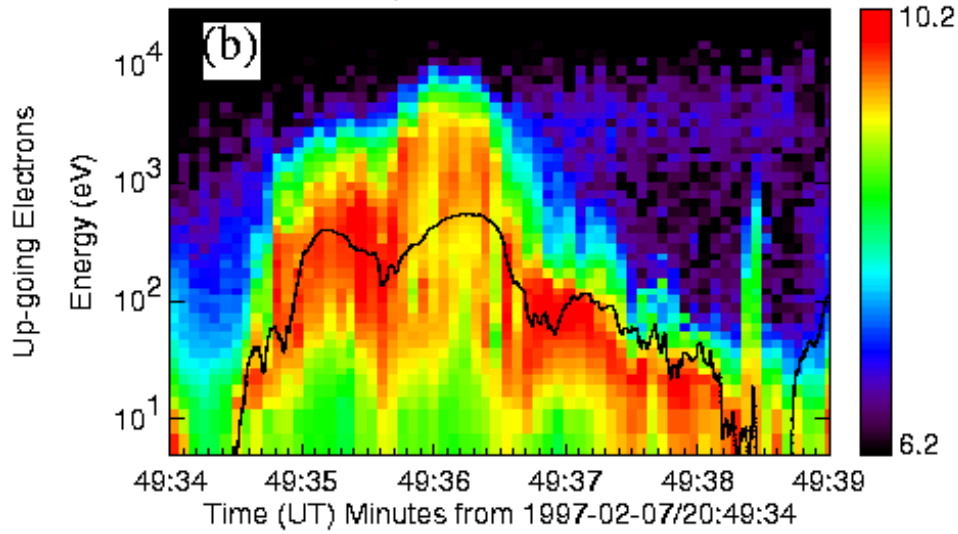


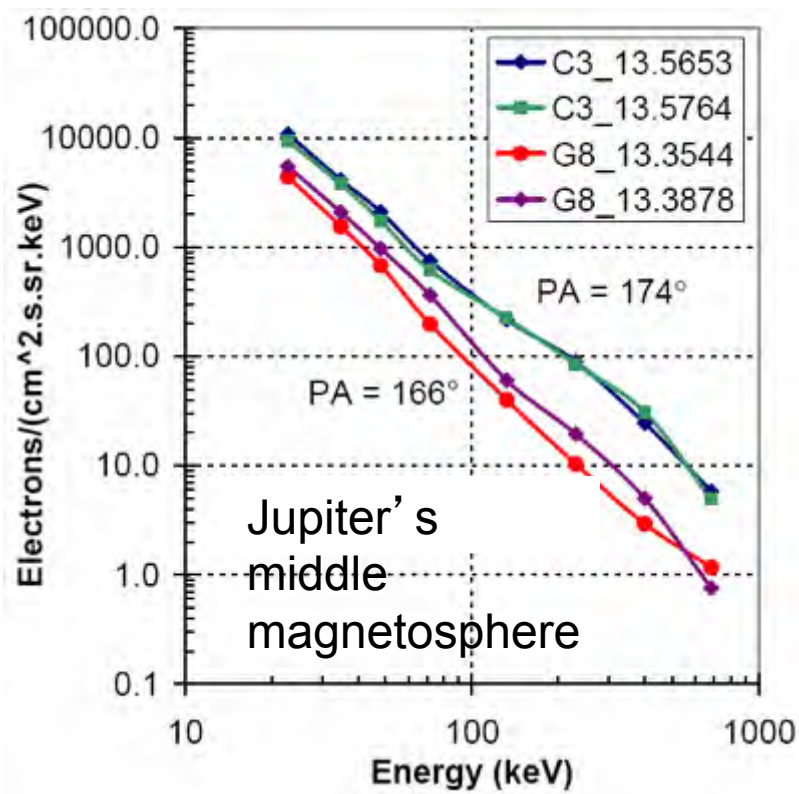


Beams at Earth, Jupiter, and Saturn show un-peaked phase space density distributions

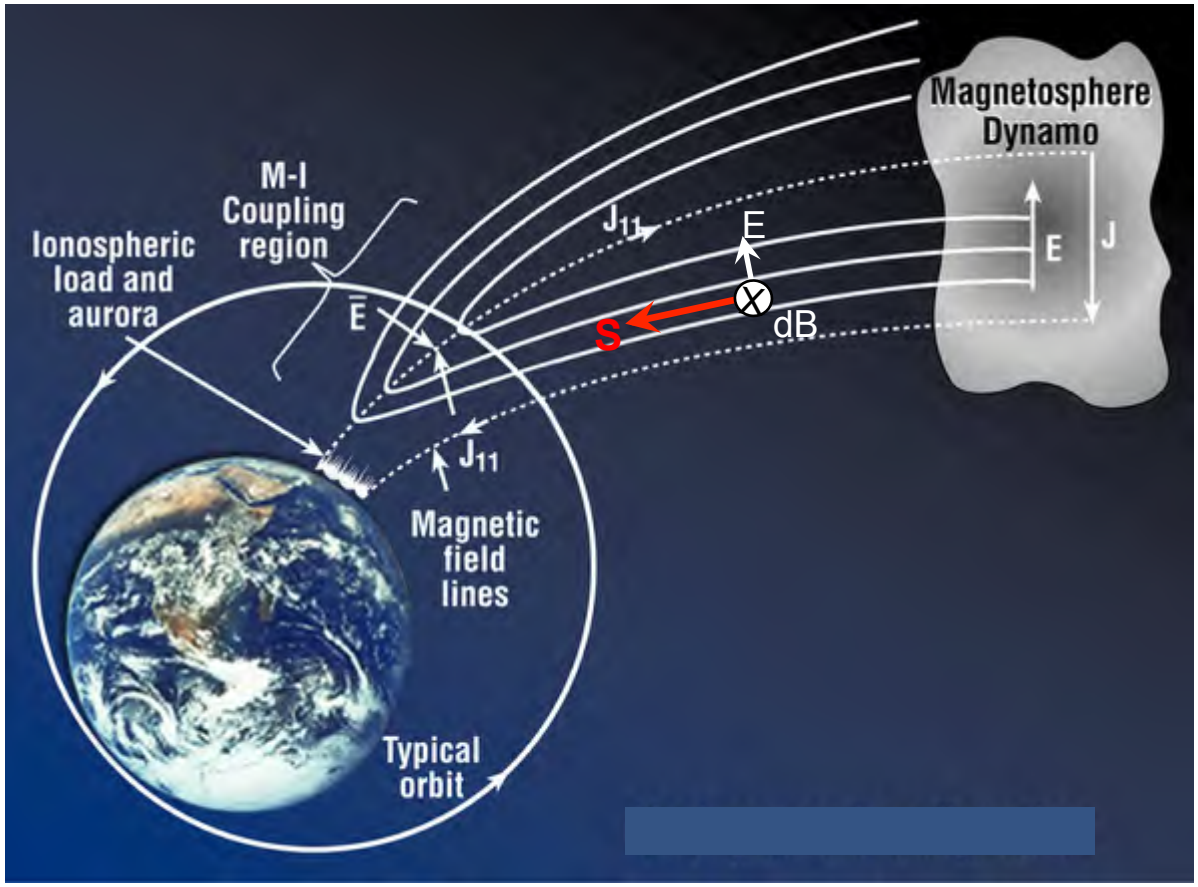


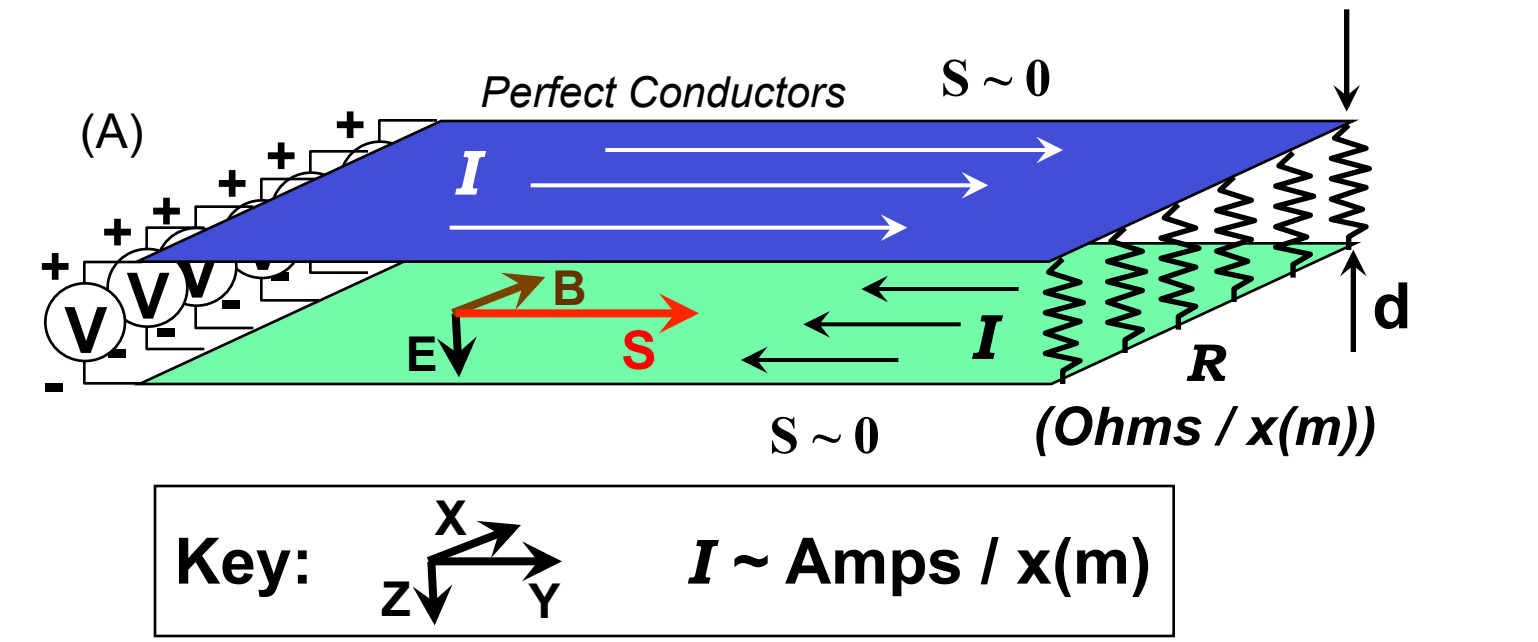
Ergun et al. (1998)





Jupiter's middle magnetosphere


Magnetosphere
Dynamo
M-I
Coupling
region
Ionospheric
load and
aurora
J_{11}
E
E
J
$\bar{E}$
S
dB
J_{11}
Magnetic
field
lines
Typical
orbit


(A)
Perfect Conductors
S ~ 0
I
B
E
S
I
R
d
S ~ 0
(Ohms / x(m))
Key:
X
Z
Y
I ~ Amps / x(m)

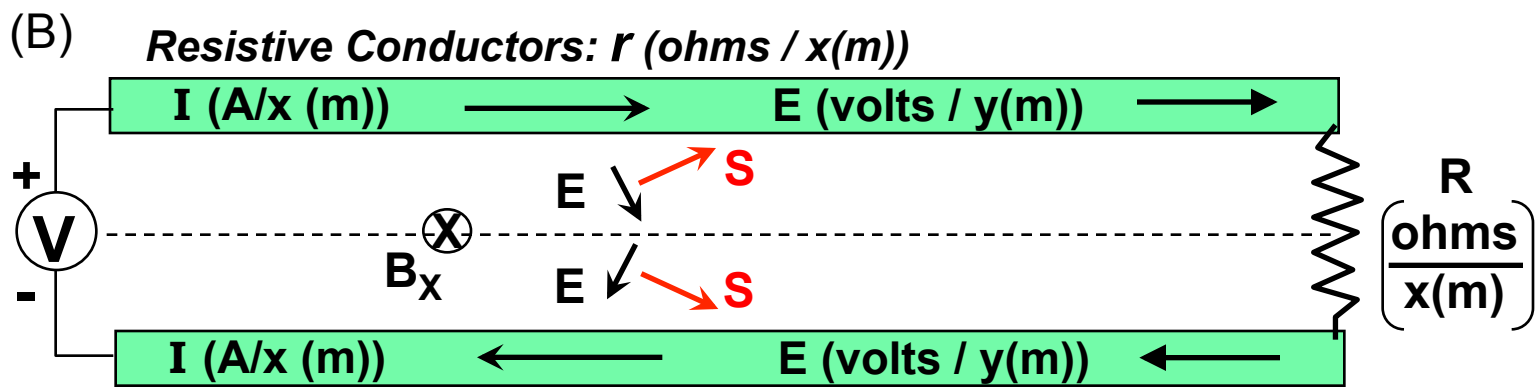

(B)
Resistive Conductors: r (ohms / x(m))
I (A/x (m))
E (volts / y(m))
E
S
Bx
E
S
R
ohms
x(m)
I (A/x (m))
E (volts / y(m))

Figure 3

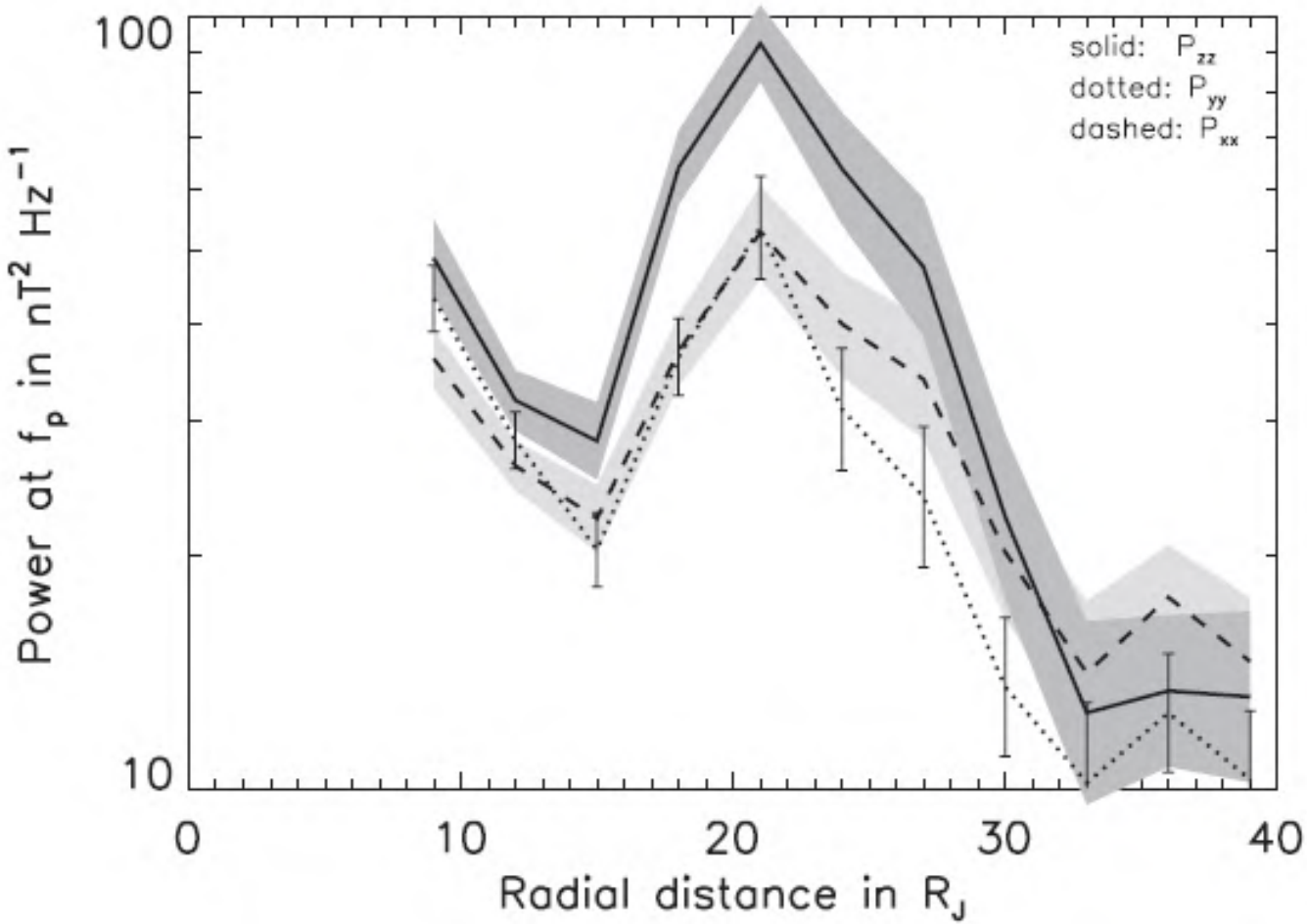
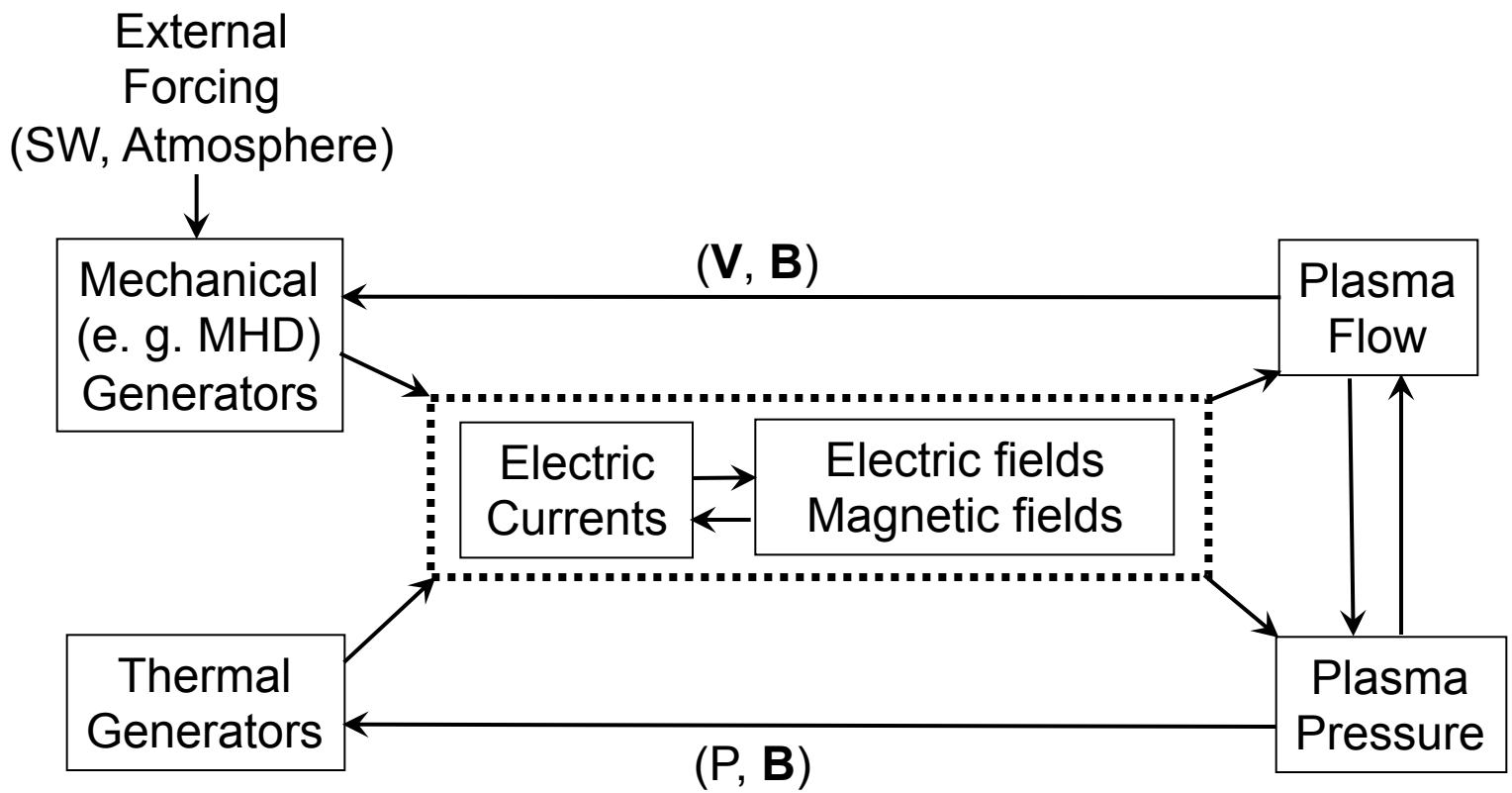

solid: P_{zz}
dotted: P_{yy}
dashed: P_{xx}
100
10
0
10
20
30
40
Power at f_p in nT^2 Hz^{-1}
Radial distance in R_J

Figure 10


External
Forcing
(SW, Atmosphere)
Mechanical
(e. g. MHD)
Generators
(**V**, **B**)
Plasma
Flow
Electric
Currents
Electric fields
Magnetic fields
Thermal
Generators
Plasma
Pressure
(P, **B**)

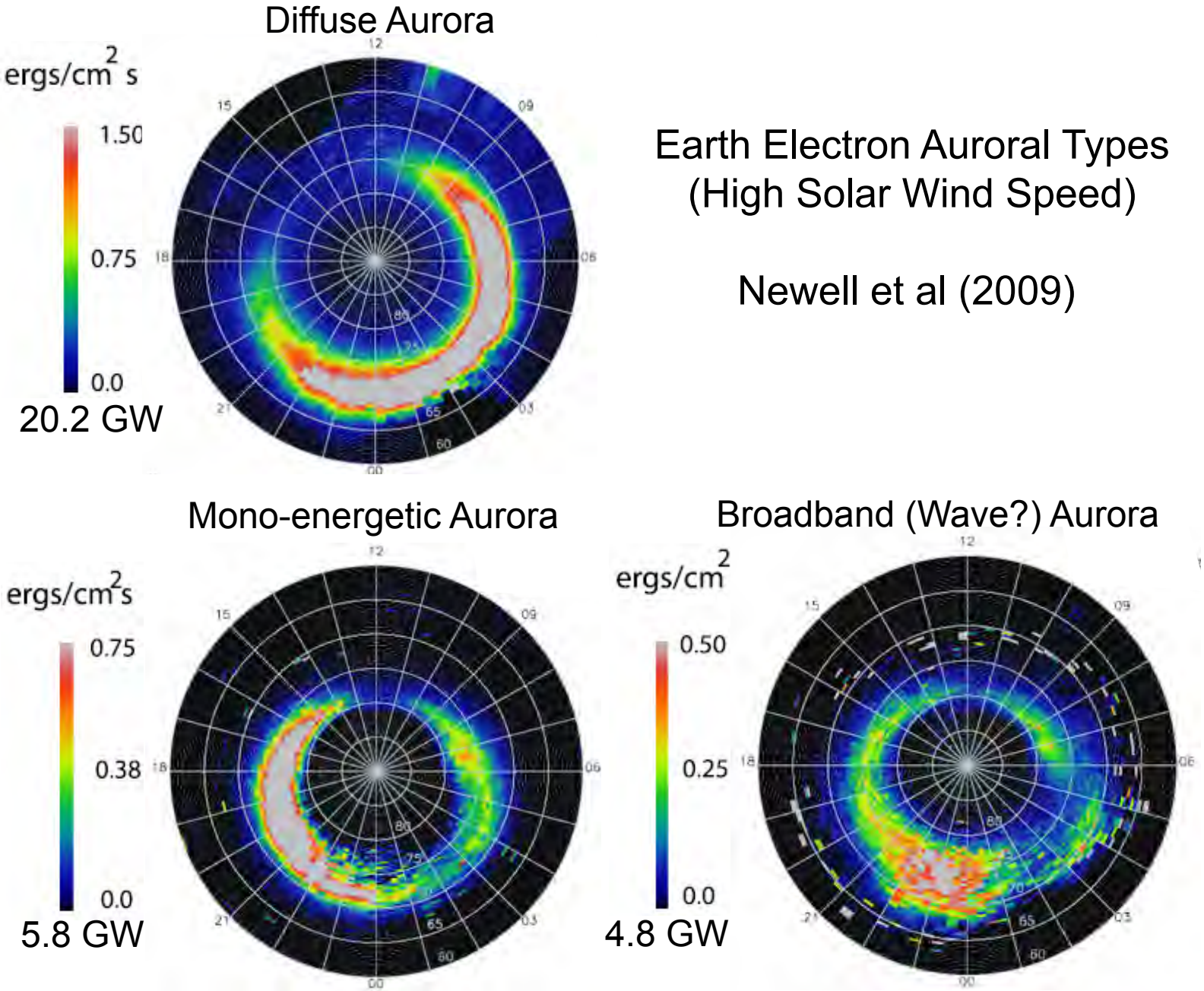

Diffuse Aurora
ergs/cm2 s
1.50
0.75
0.0
20.2 GW
Earth Electron Auroral Types
(High Solar Wind Speed)
Newell et al (2009)
Mono-energetic Aurora
ergs/cm2s
0.75
0.38
0.0
5.8 GW
Broadband (Wave?) Aurora
ergs/cm2
0.50
0.25
0.0
4.8 GW

Figure 5