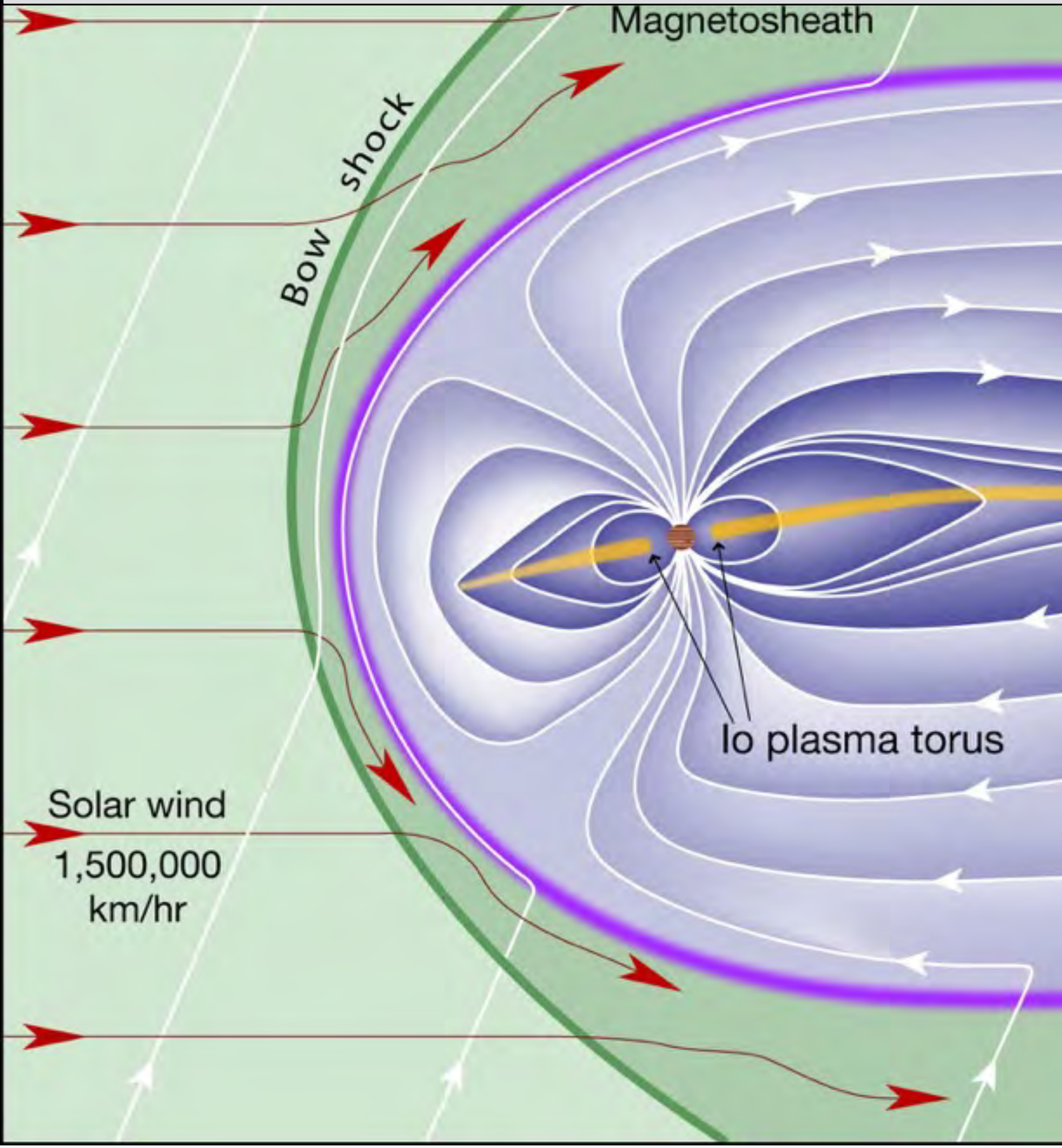
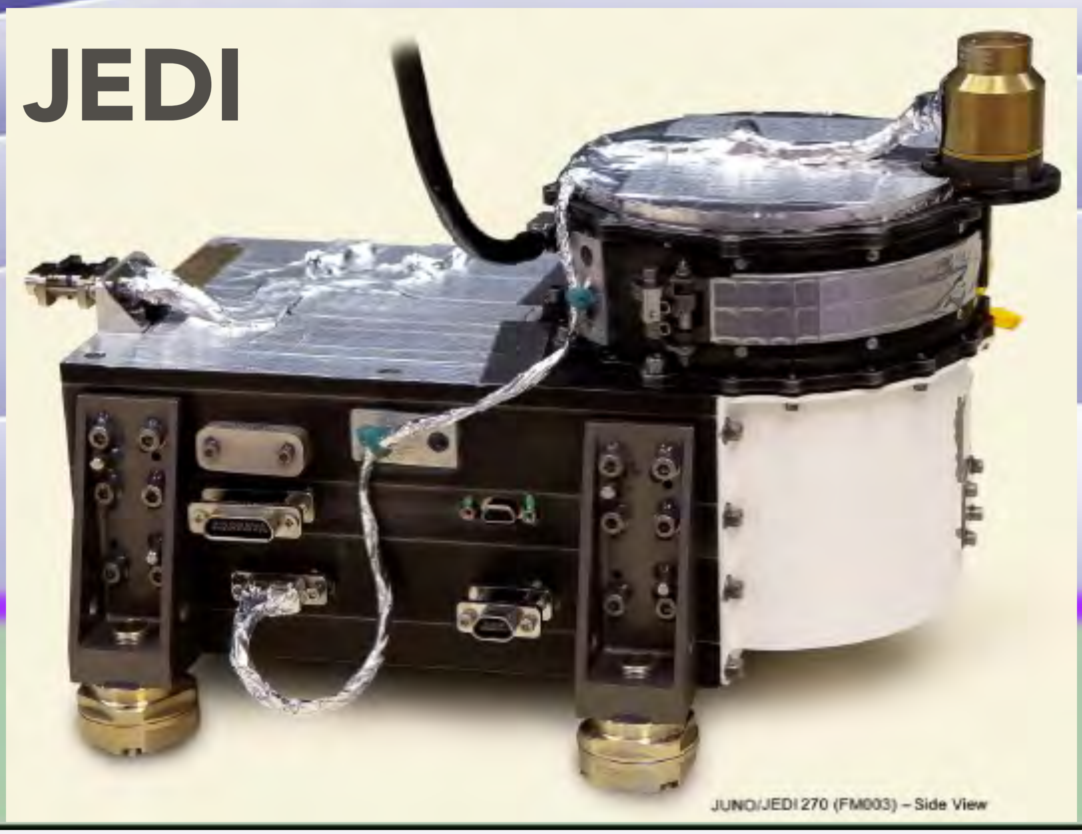
Energetic particle measurements in the magnetosphere

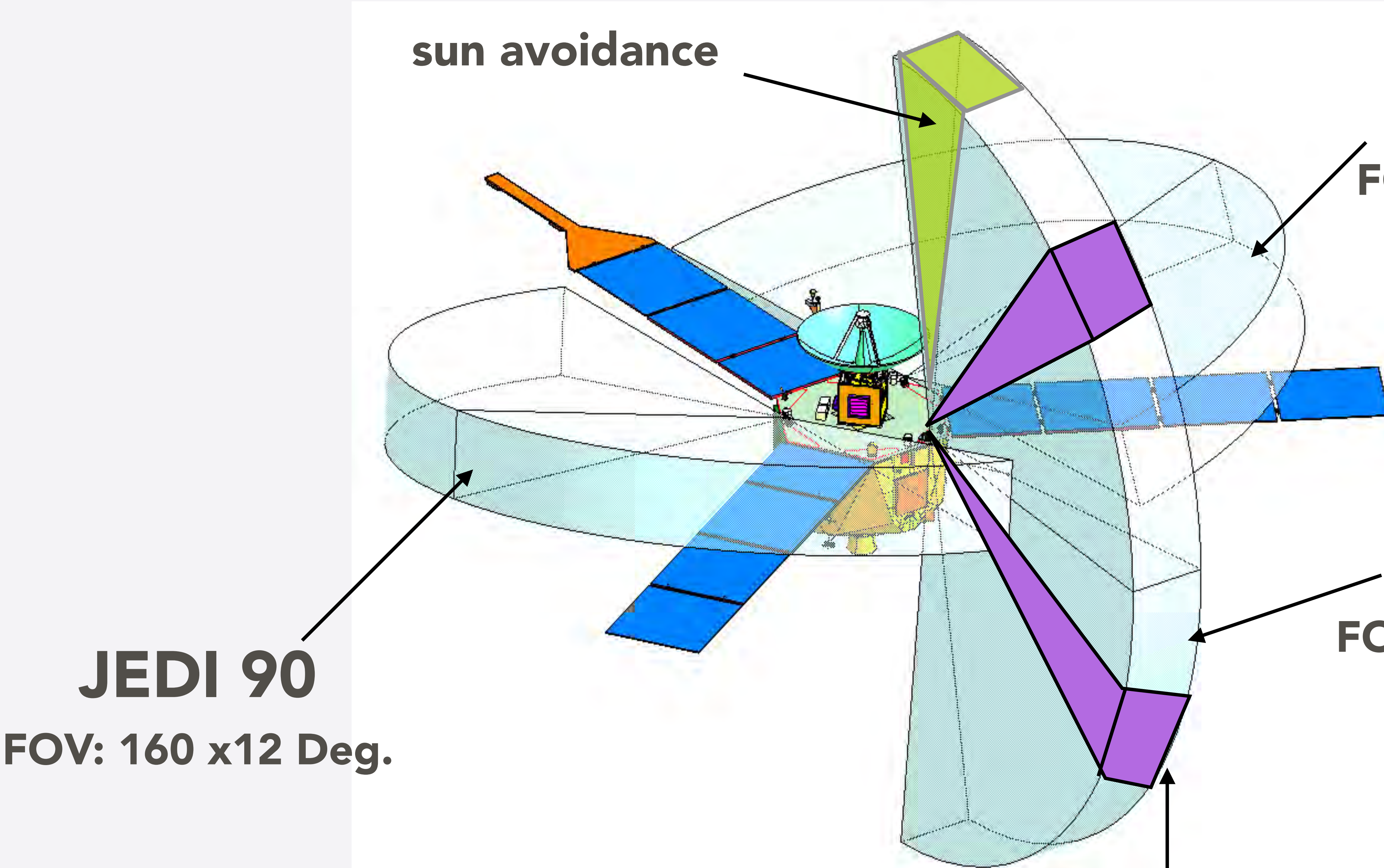


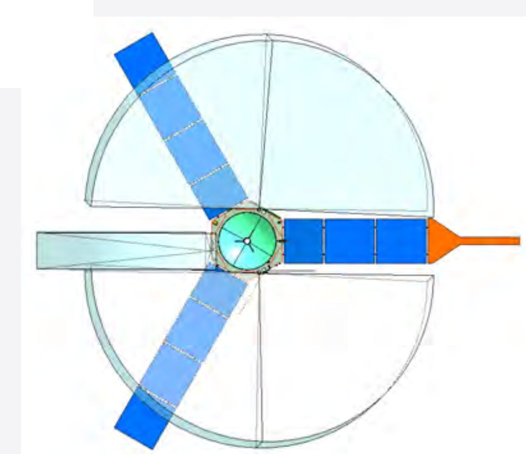
Thank you to Rob, Fran, Chris and Barry for their assistance



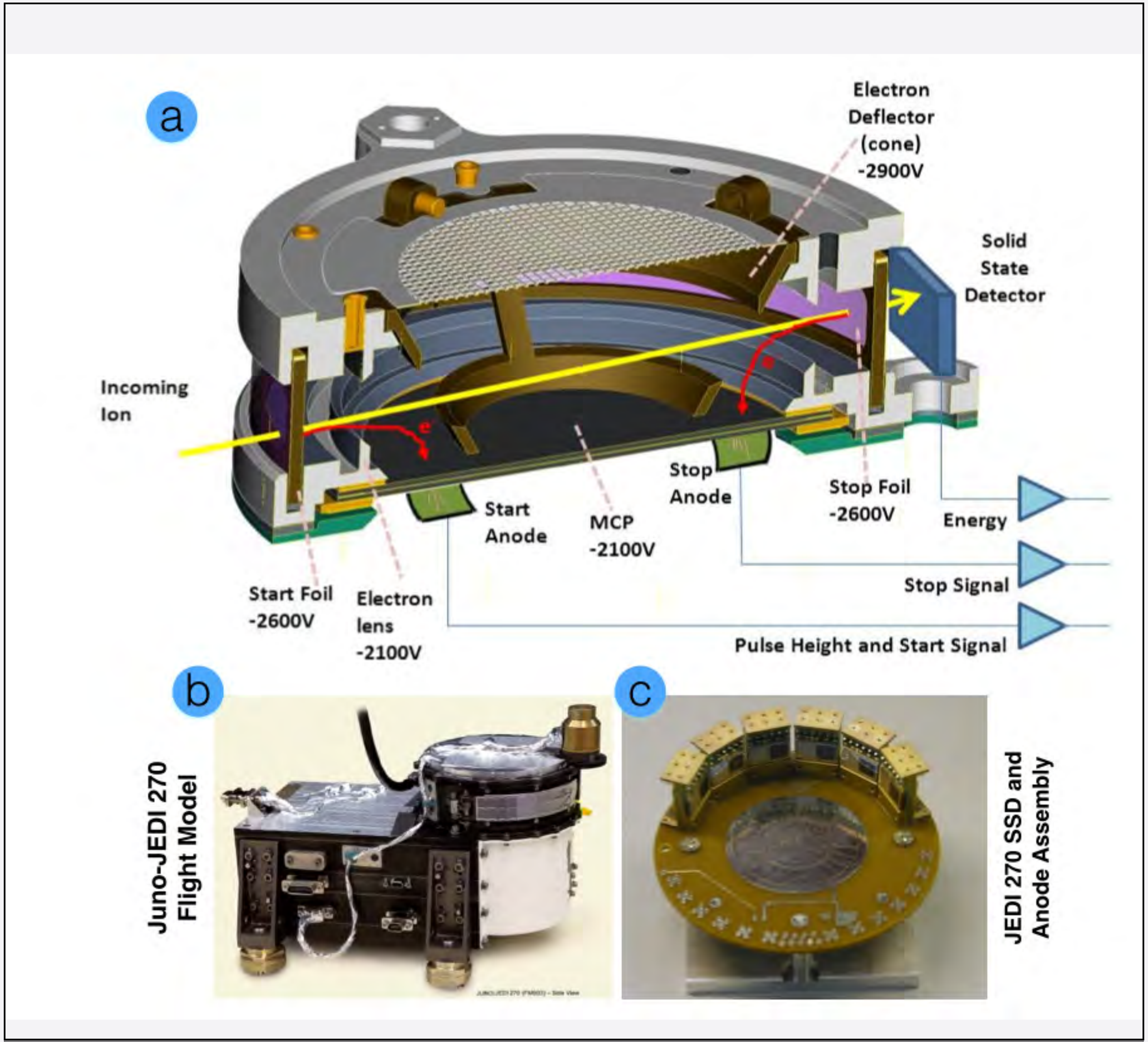
George Clark
george.clark@jhuapl.edu

JEDI


sun avoidance
JEDI 270
FOV: 160 x12 Deg.
JEDI 180
FOV: 148 x12 Deg.
JEDI 90
FOV: 160 x12 Deg.
witness detectors



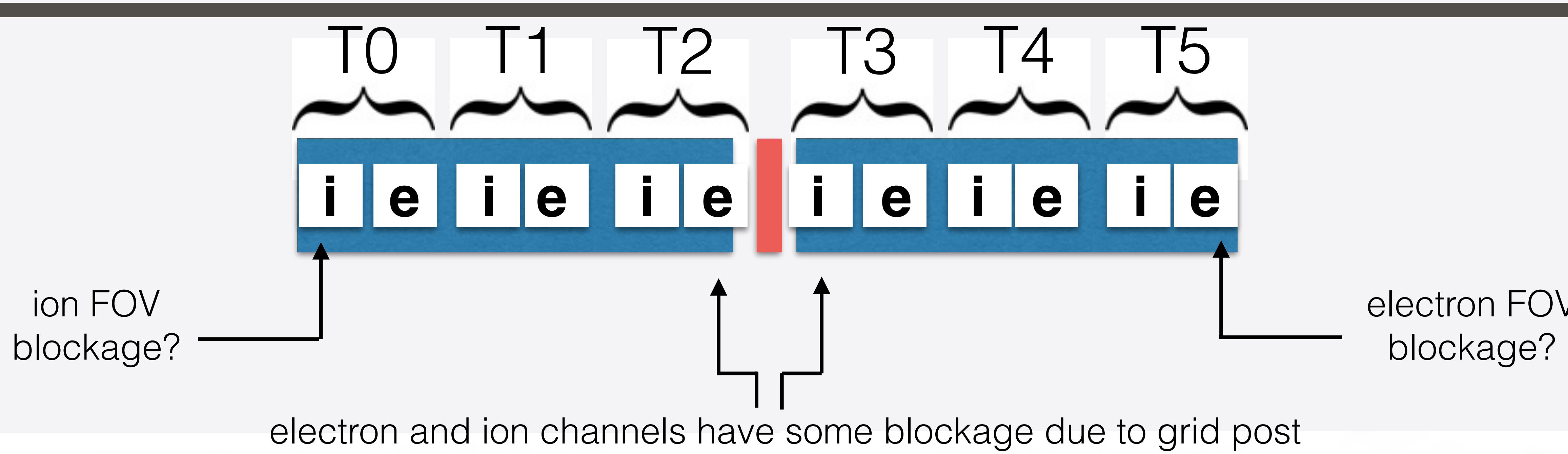
JEDI DESIGN PRINCIPAL

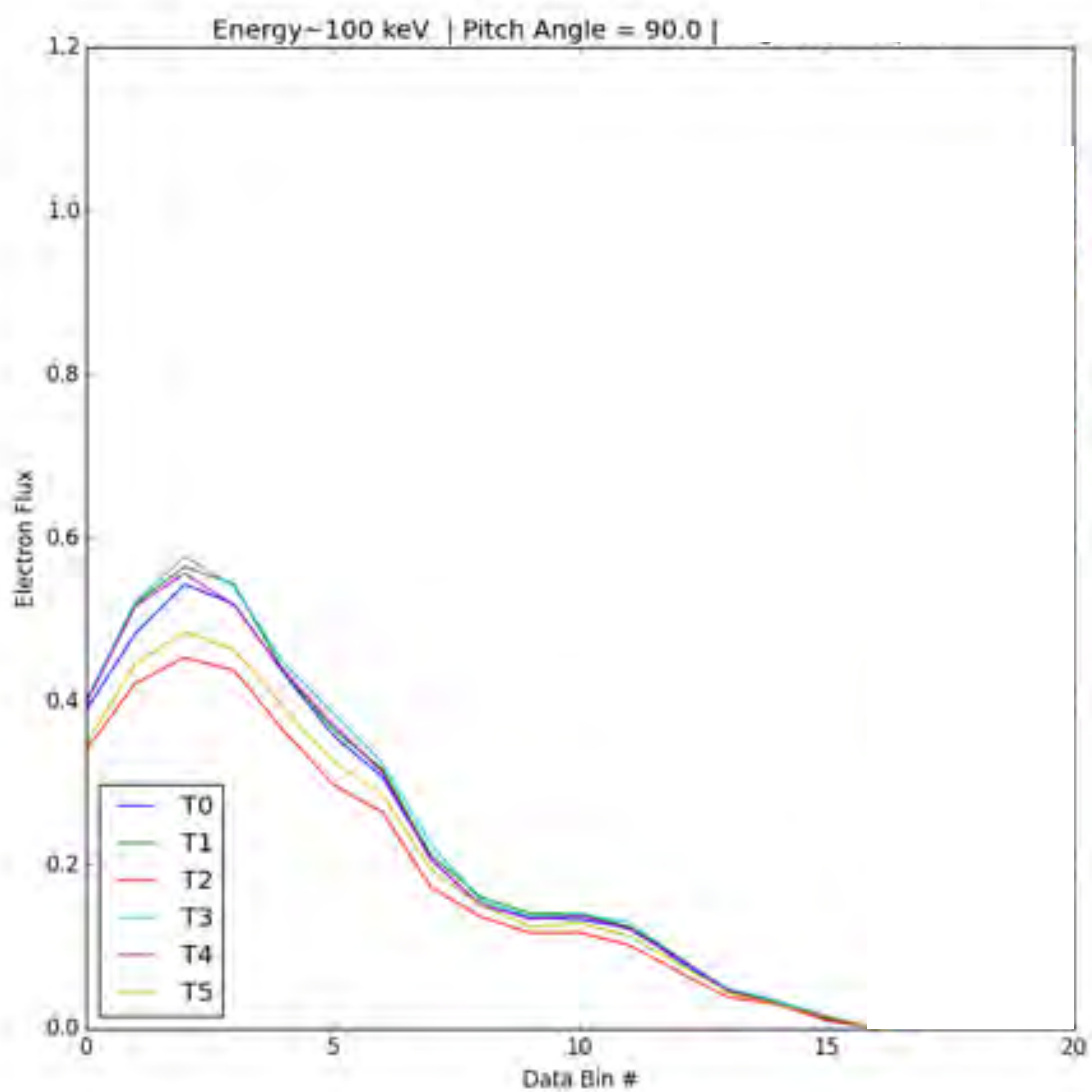


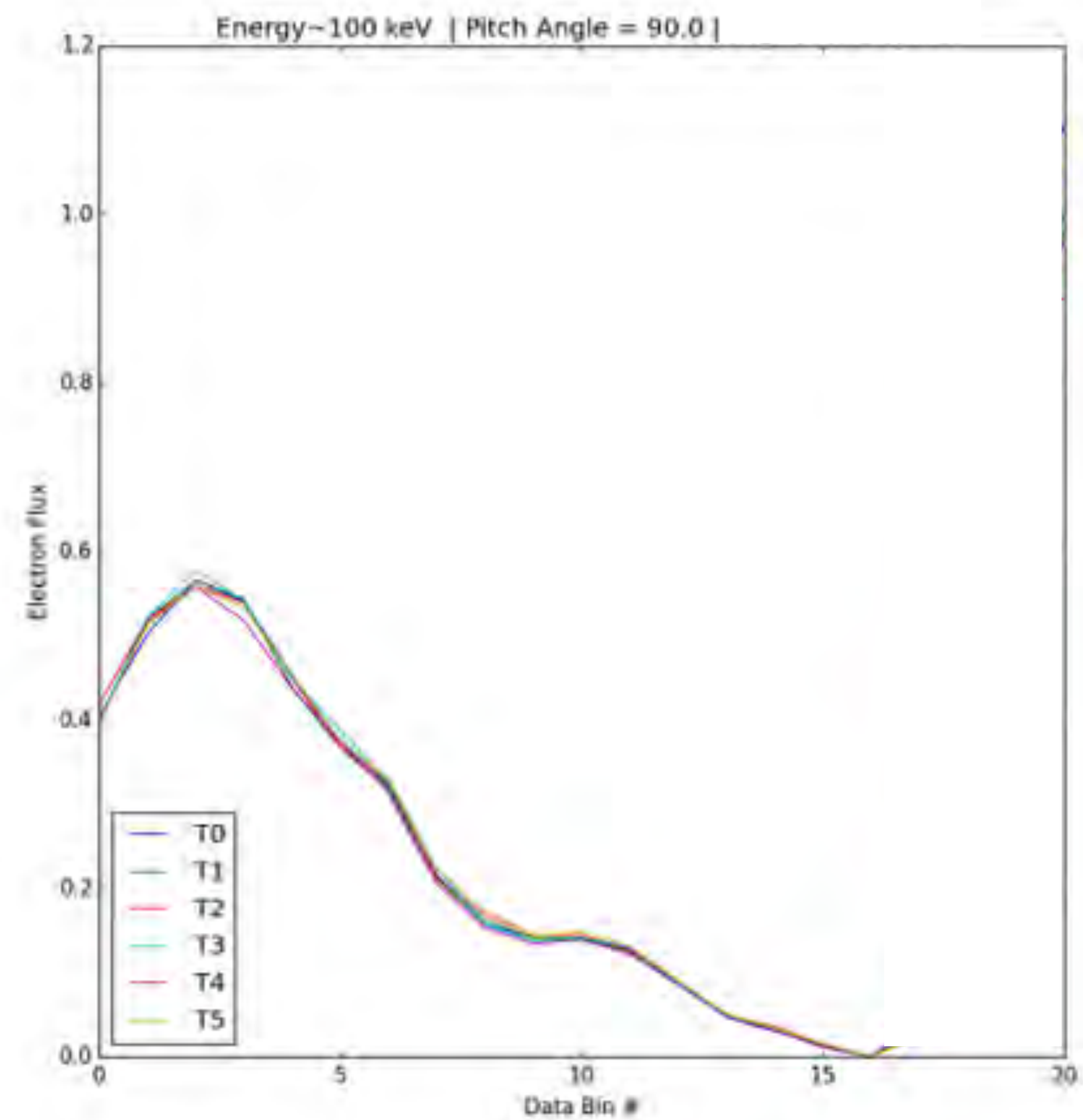
JEDI PERFORMANCE

Parameter	Required	Capability	Comment
Electron Energies	40–500 keV	25–1000 keV	Abuts JADE
Ion Energies (Measured, not discriminated)	H: 20–1000 keV He: 30–1000 O: 50–1000	H + 10–2000 keV He: 25–2000 O/S + 45–10000 keV	Abuts JADE
Energy Resolution	Ions $< 25\%$ ($< 30\%$ for $E < 40$ keV); Electron $<$ larger of 25 % and 15 keV	20 %	Earth aurora spectra driver
Time sampling	0.6 s	0.5 s	$\leq$ 30 km auroral sampling/
Angle resolution	30°	18° using rotation	Resolve loss cone for $R < 2/3$ RJ
Pitch Angle (PA) Coverage	0–360 degrees for whole orbit	0–360 degrees for whole orbit	Requires 3 JEDI heads with 160° × 12° fans
Time for Full PA near Periapsis	2 s	1.25 s	For high energy/angle resolution
Ion Composition	H and S/O over required energies. He: 70–1000 keV	H above 15 keV He above 50 keV O above 45 keV	Separate S from O for $E > 200$ keV
Electron Sensitivity: Measure energy spectra	I = 3E5–3E9 1/cm^2 s sr	Sensor-G: 0.0036–0.00018 Pixel-G: 0.0006–0.00003 Up to 5E5 1/s counting	I = Intensity (1/cm^2 sr) G = geom. factor × eff. (cm^2 sr) Variable G; 6 pixels/sensor
Ion Sensitivity Measure energy spectra	I = 1E4–1E8 1/cm^2 sr	Senso-G: 0.002–0.0002 Pixel-G: 0.0003–0.00003 Up to 5E5 1/s counting	I = Intensity (1/cm^2 sr) G = geom. factor × eff. (cm^2 sr) Variable G; 6 pixels/sensor

FLAT FIELDING



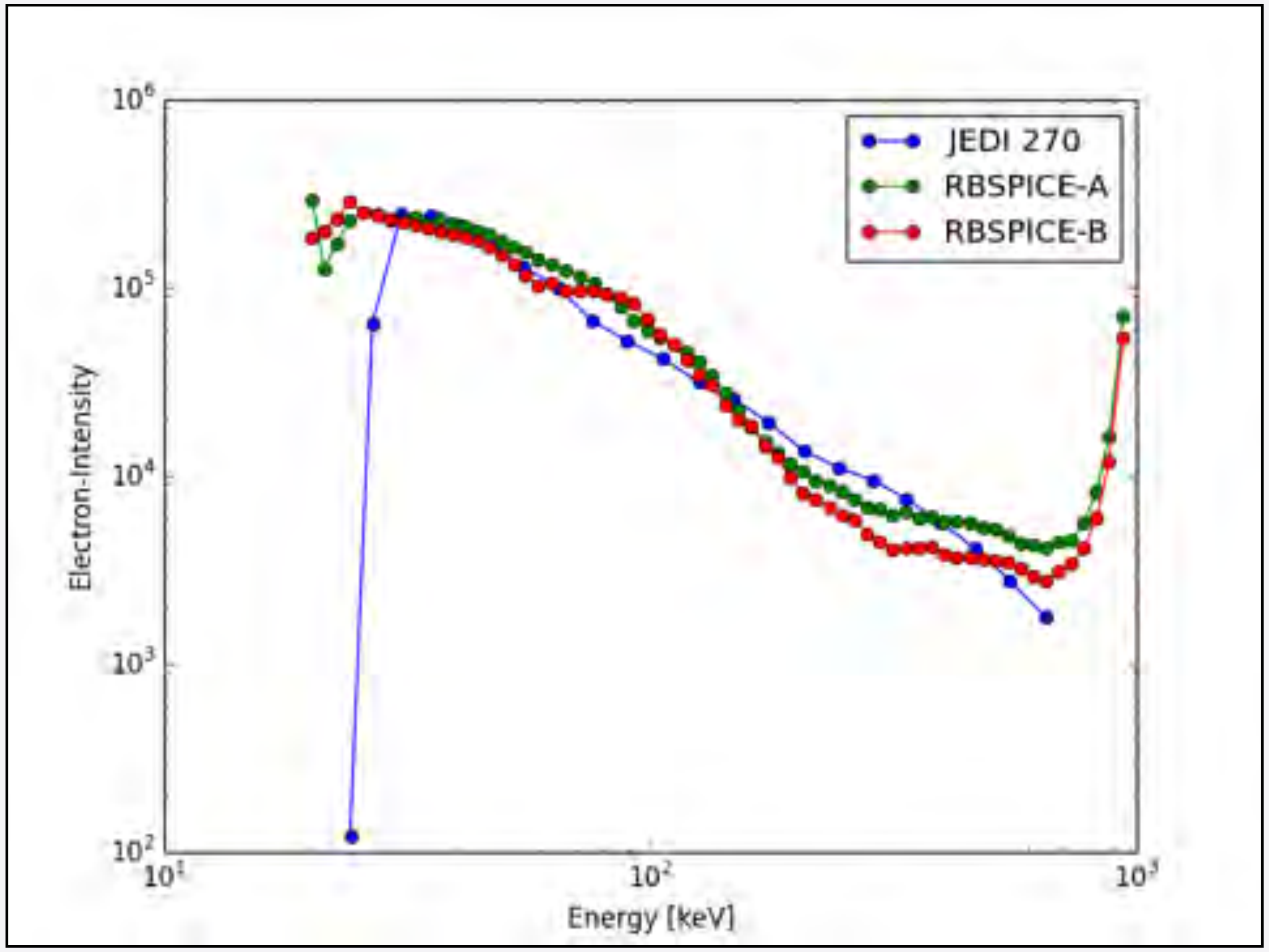




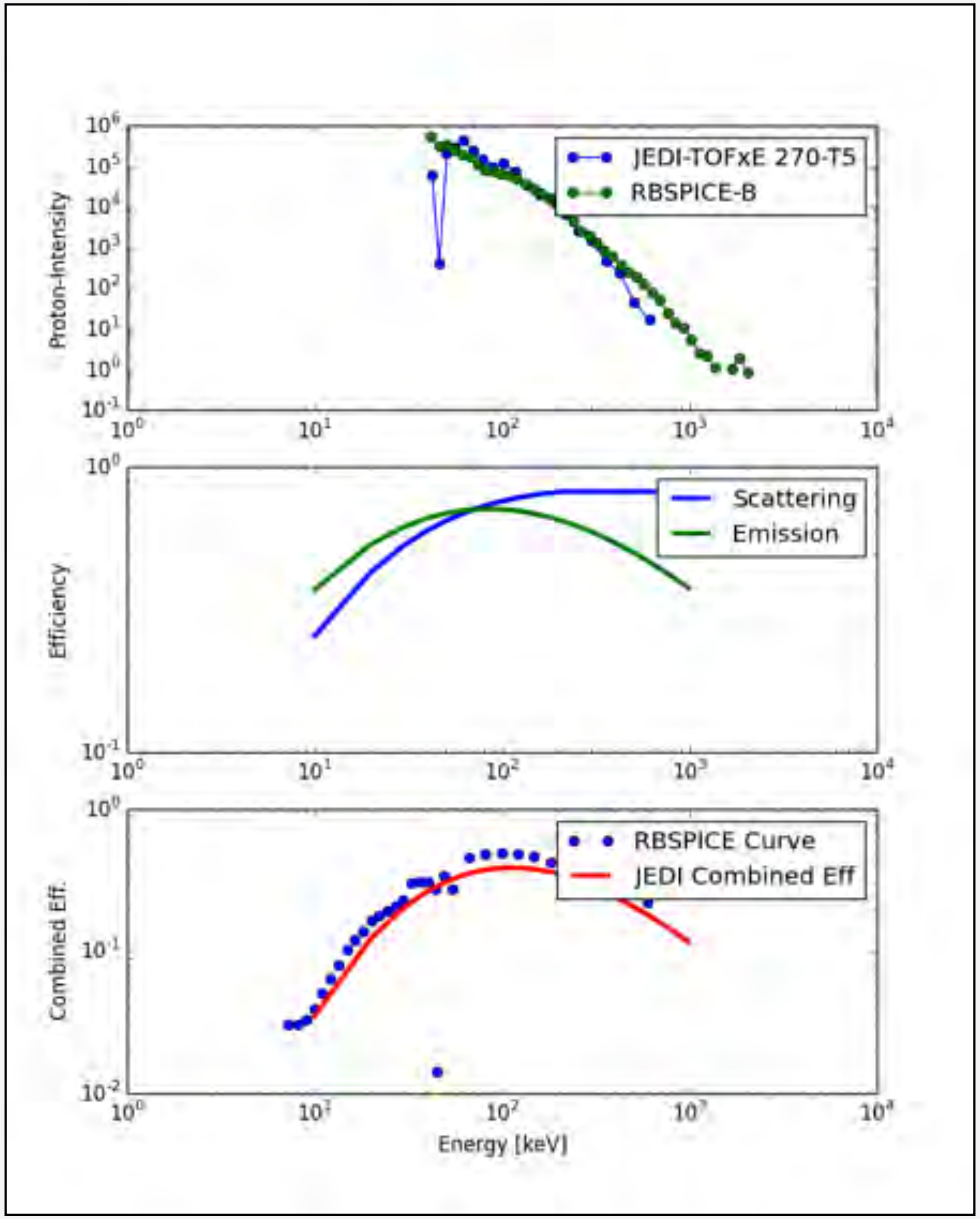
CROSS CAL WITH RBSPICE

Cross-calibration efforts with RBSPICE on Van Allen probes proved fruitful

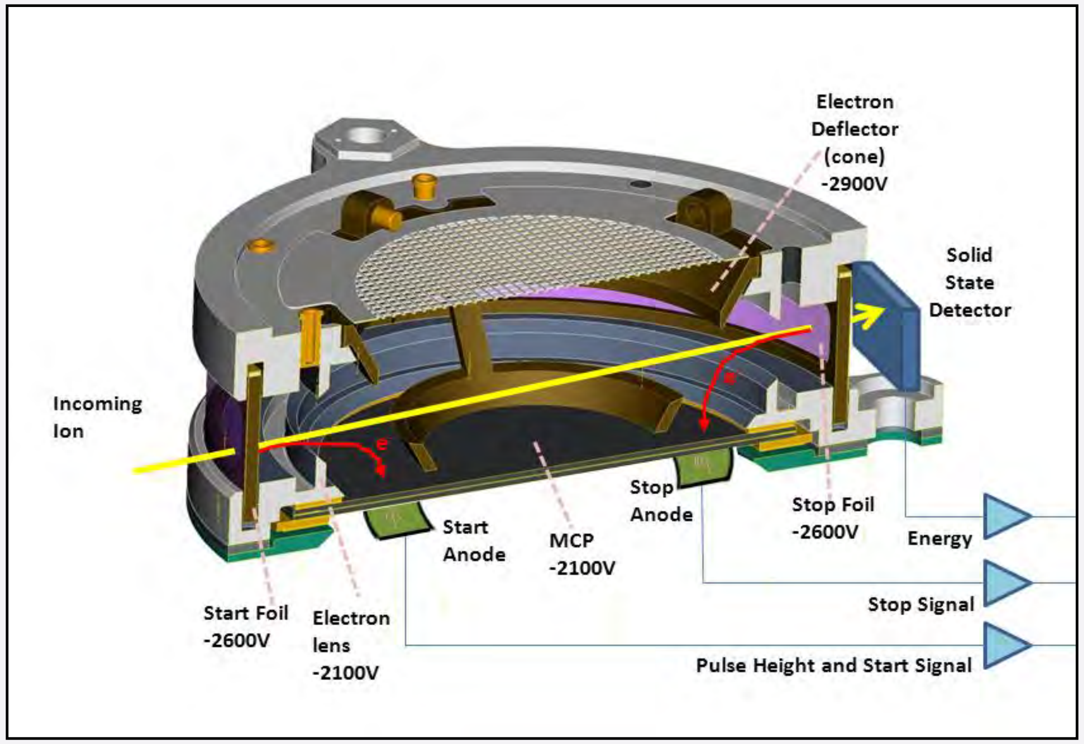
Electrons

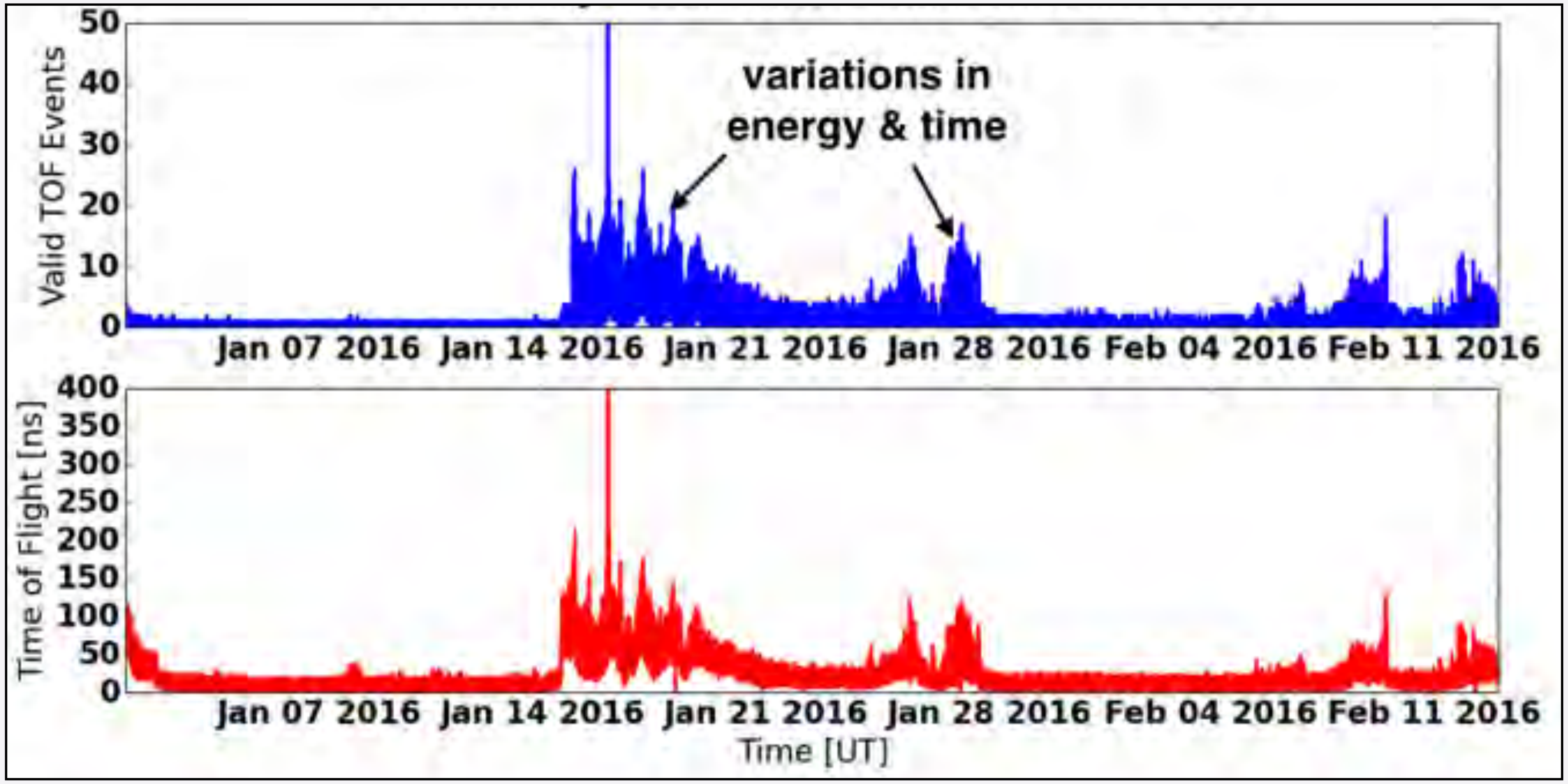


Protons



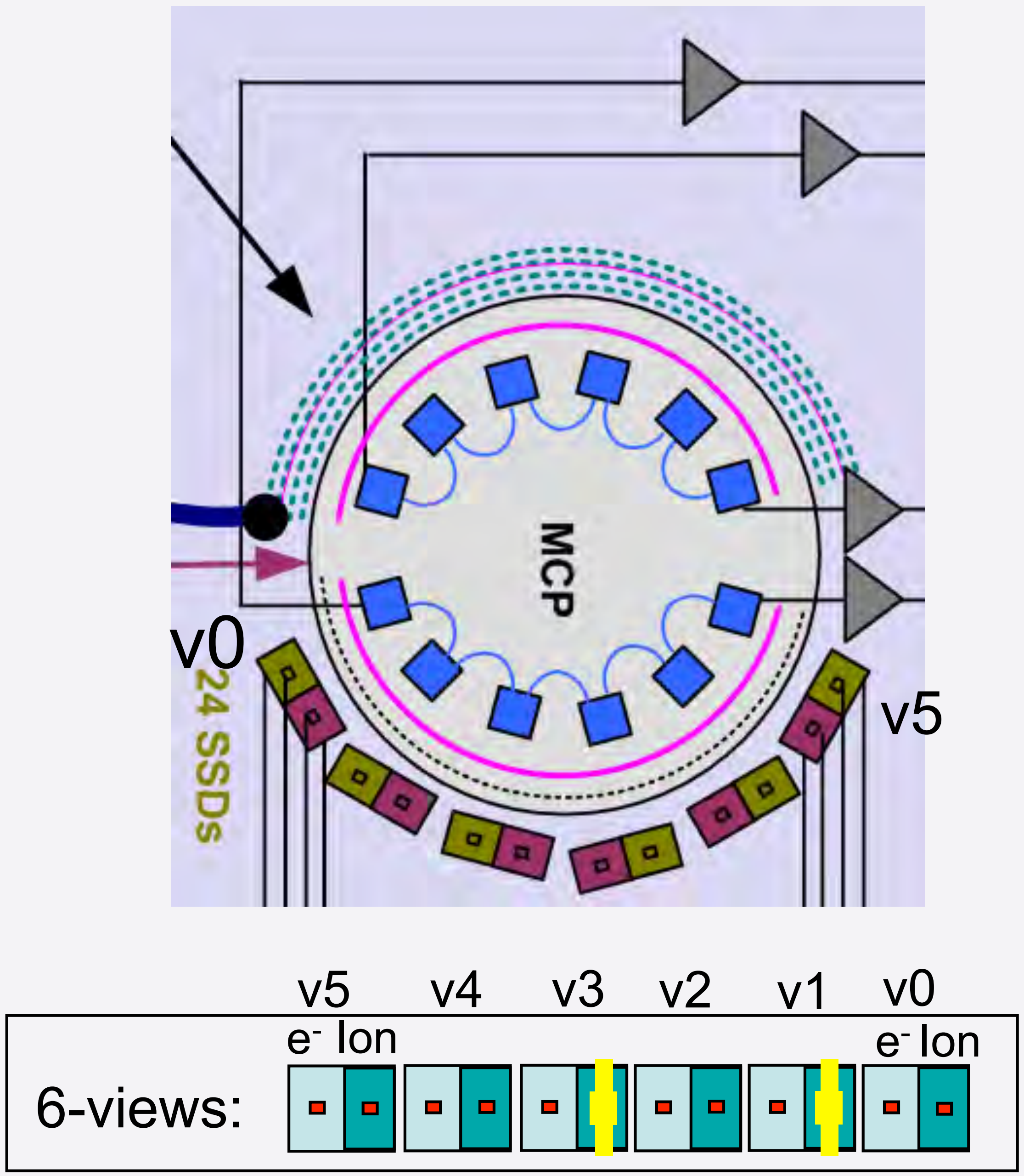
SUPRATHERMAL SW IONS

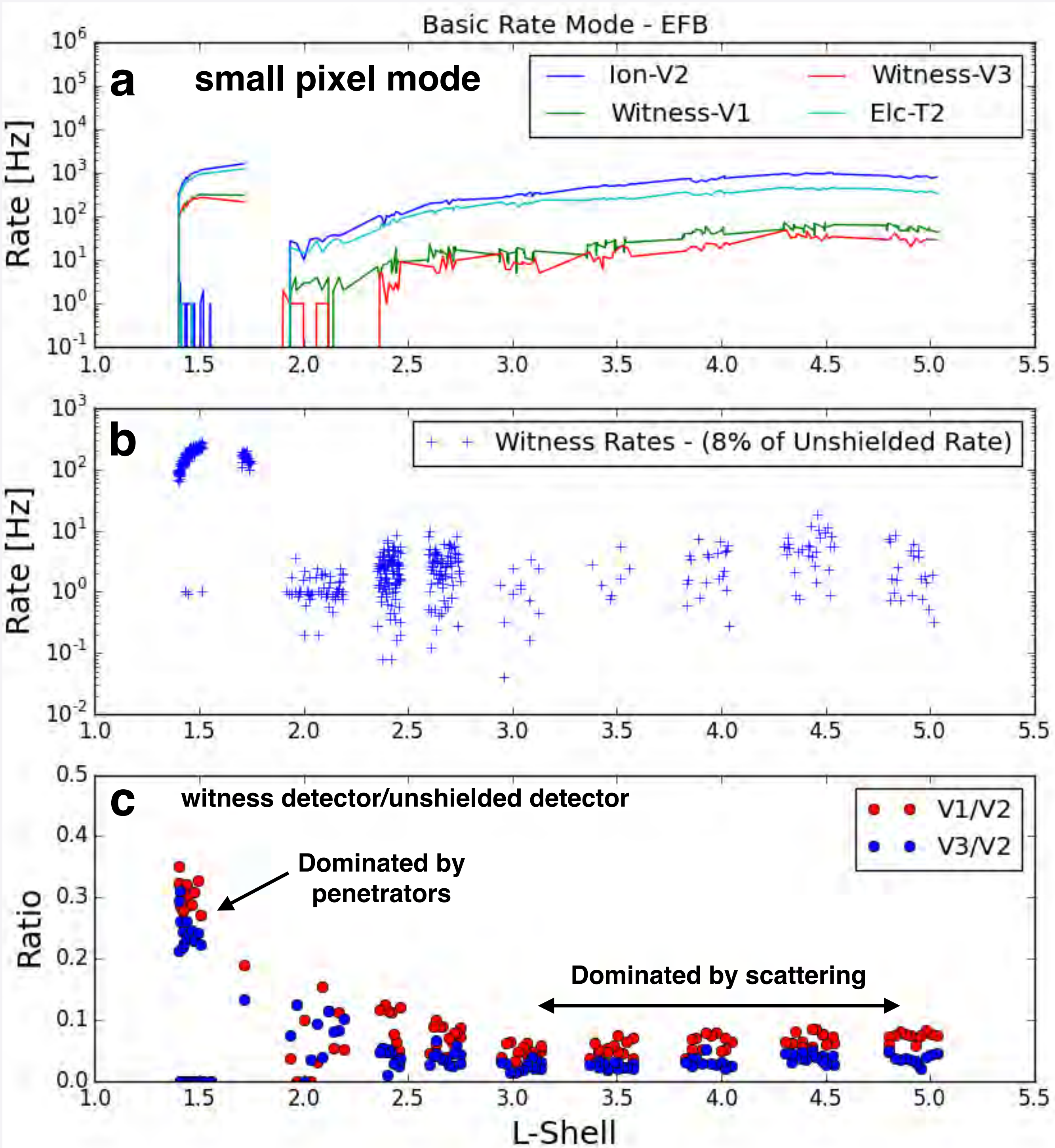




- Preliminary analysis suggest that JEDI can measure approx. 10 keV/nuc ions in the solar wind

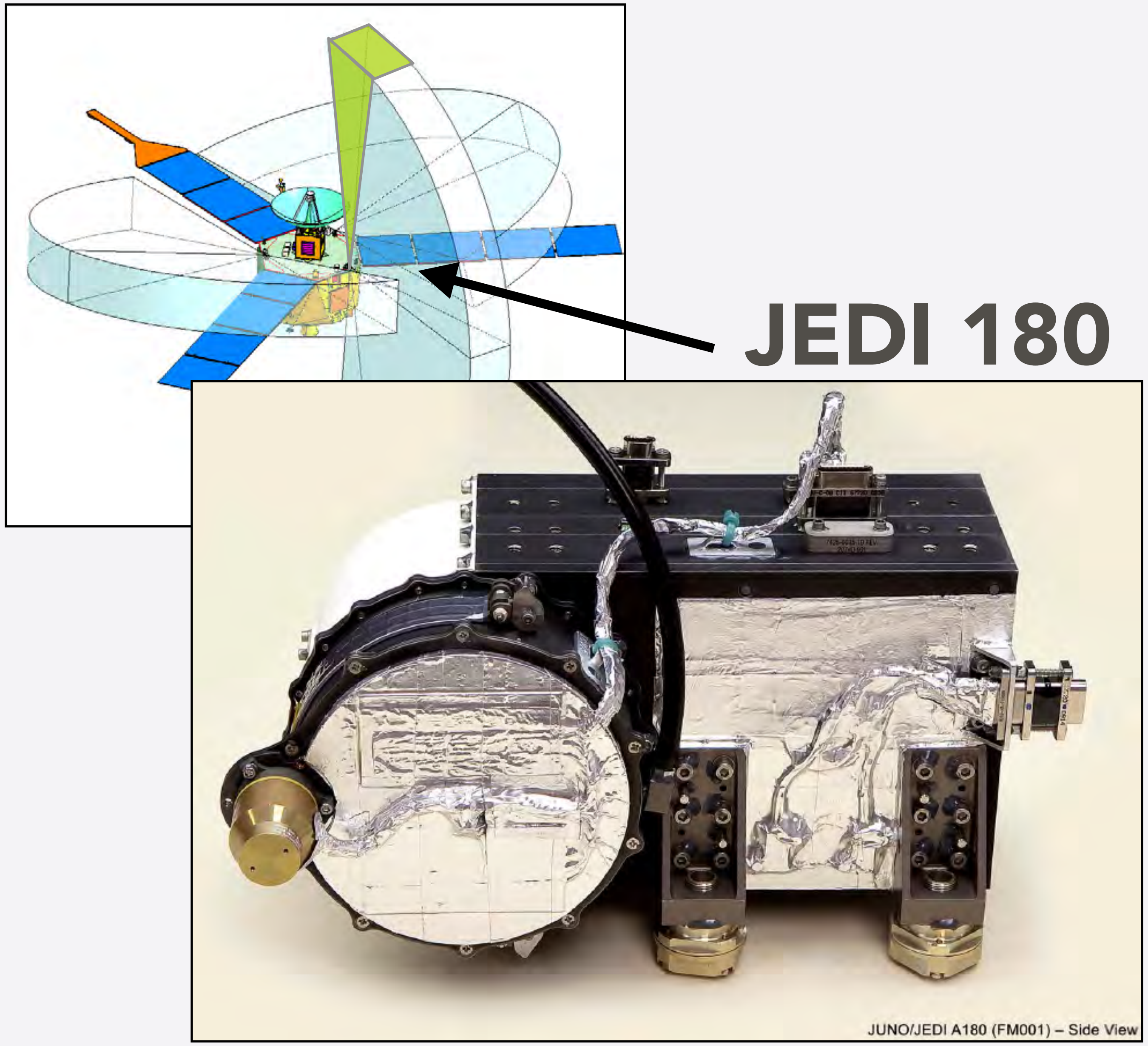
WITNESS DETECTORS

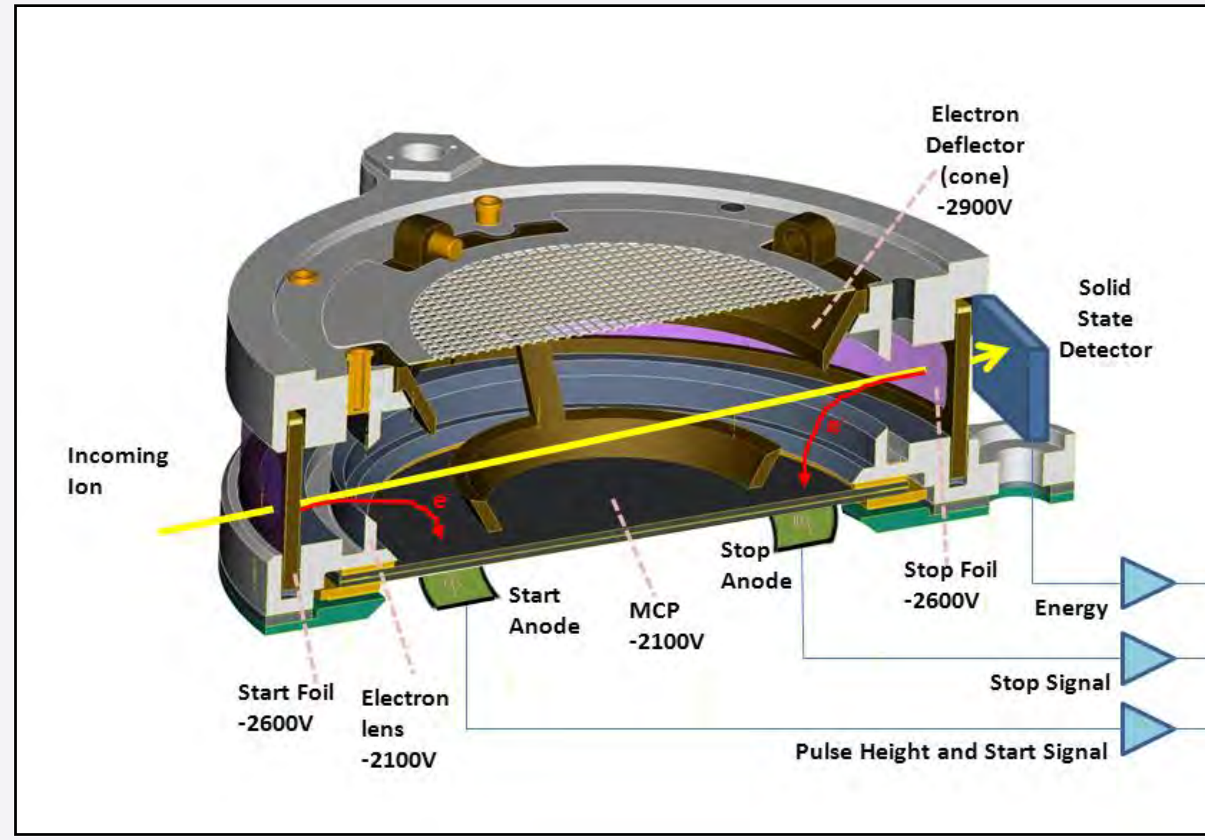




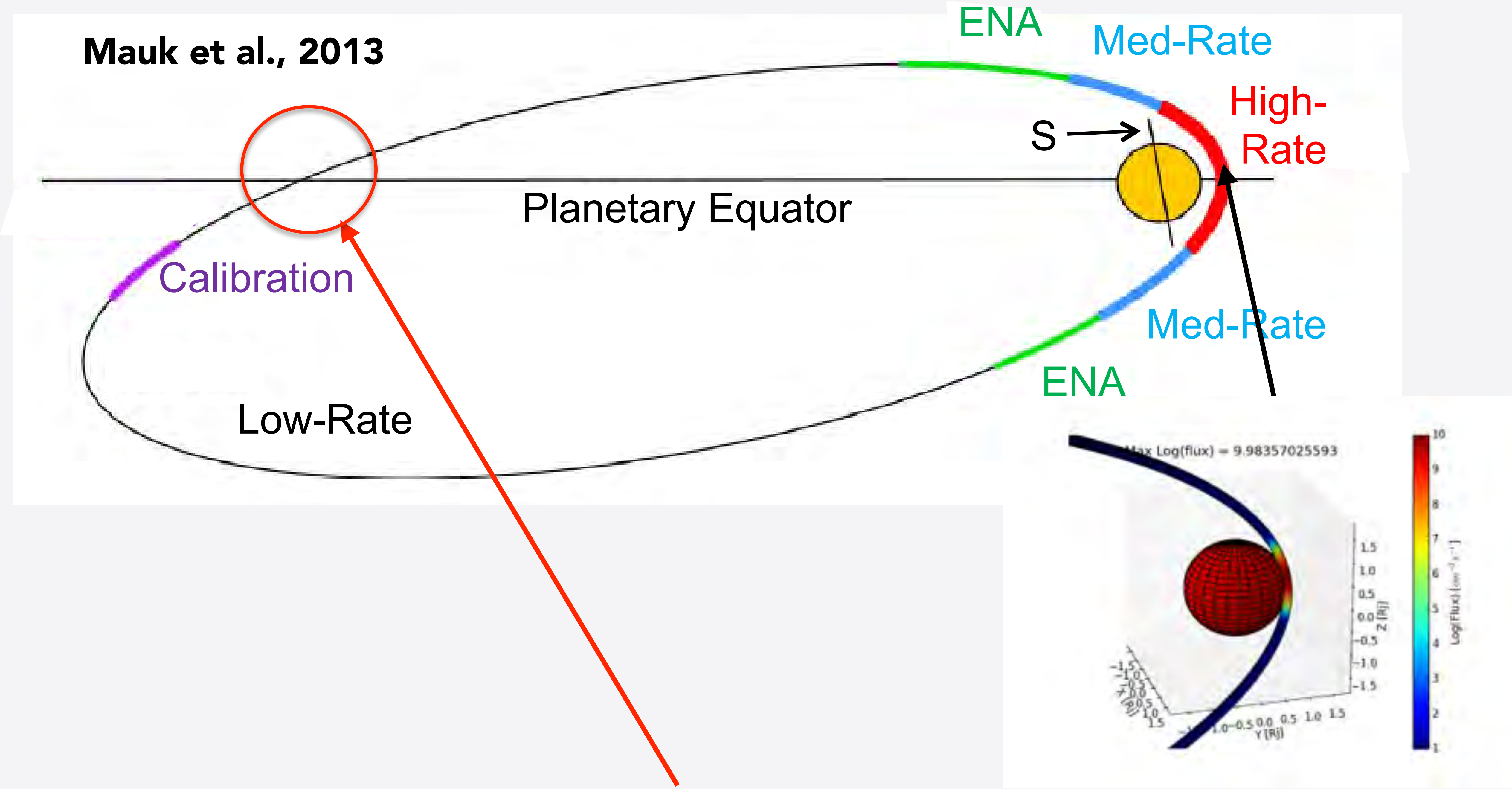
Identified scattering contribution and developed a method to determine penetrators exclusively

JEDI-A180



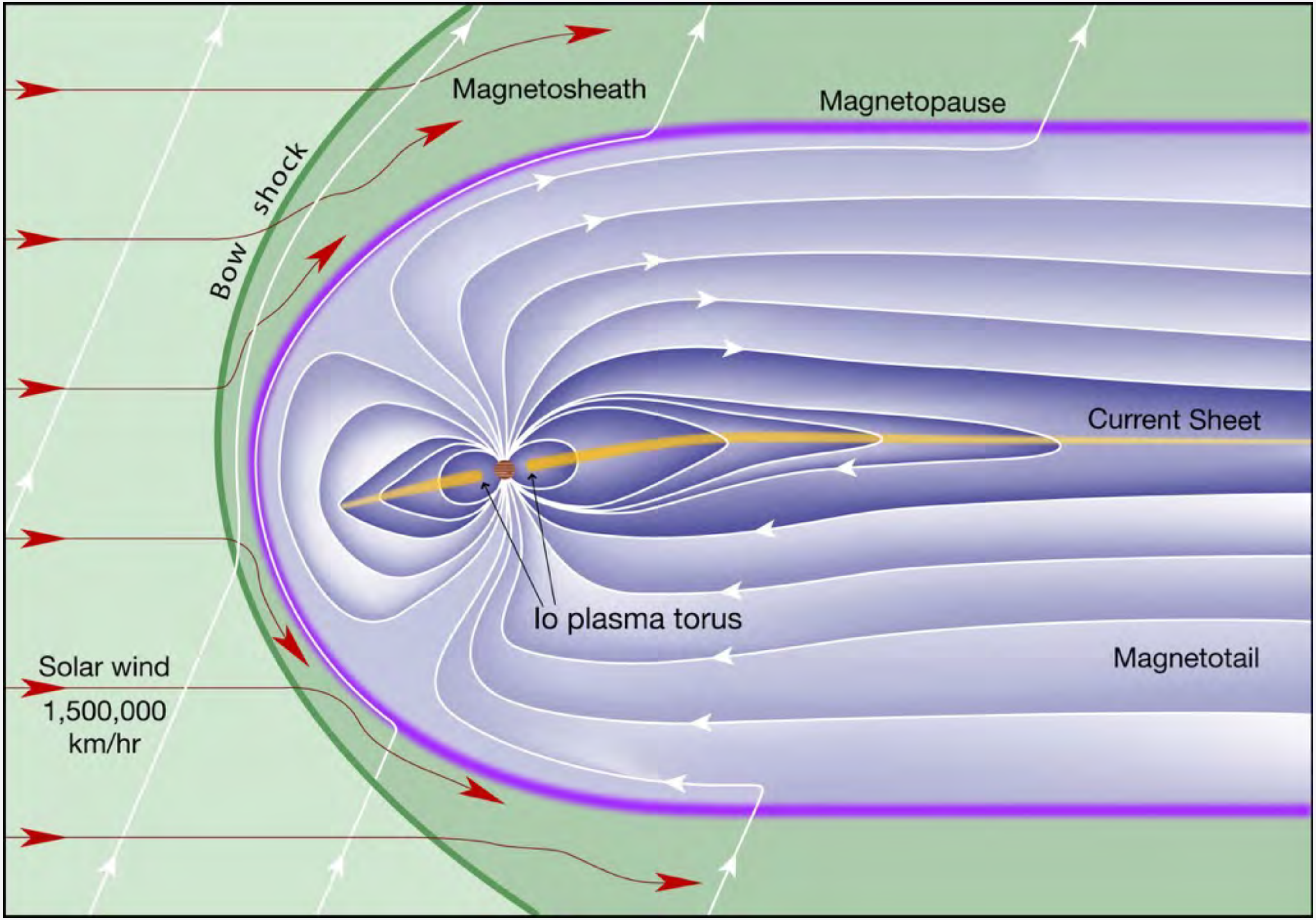


- Currently not operating HV on the microchannel plate
- Can not distinguish heavy ions from protons
- Will measure incident ion and electron energies



JEDI has identified regions of scientific interest in the current sheet —> increase data rates and tailor specific "modes"….**WHY?**

JUPITER'S MAGNETOSPHERE



How does Jupiter maintain its magnetodisk shape?

$$-\nabla\left[p_\perp + \frac{B^2}{2\mu_0}\right] + \left(p_\parallel - p_\perp - \frac{B^2}{\mu_0}\right)\frac{\hat{\mathbf{n}}}{R_C} - \rho\Omega^2 r\sin(\vartheta)(\hat{\mathbf{z}}\times\hat{\boldsymbol{\varphi}}) = 0$$

pressure gradient

magnetic tension

pressure anisotropy

centrifugal force

McNutt et al., 1983

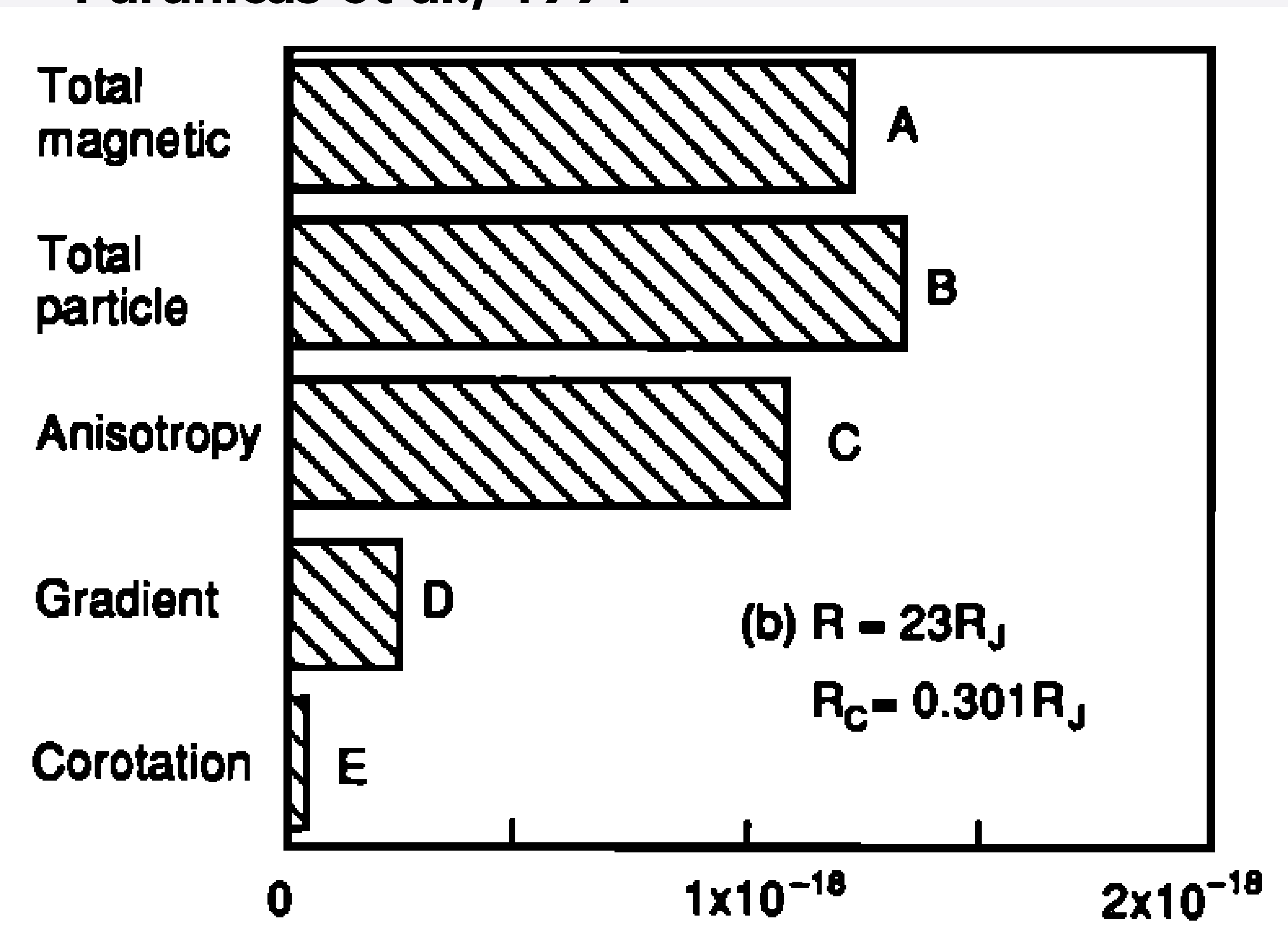
Connerney et al., 1981

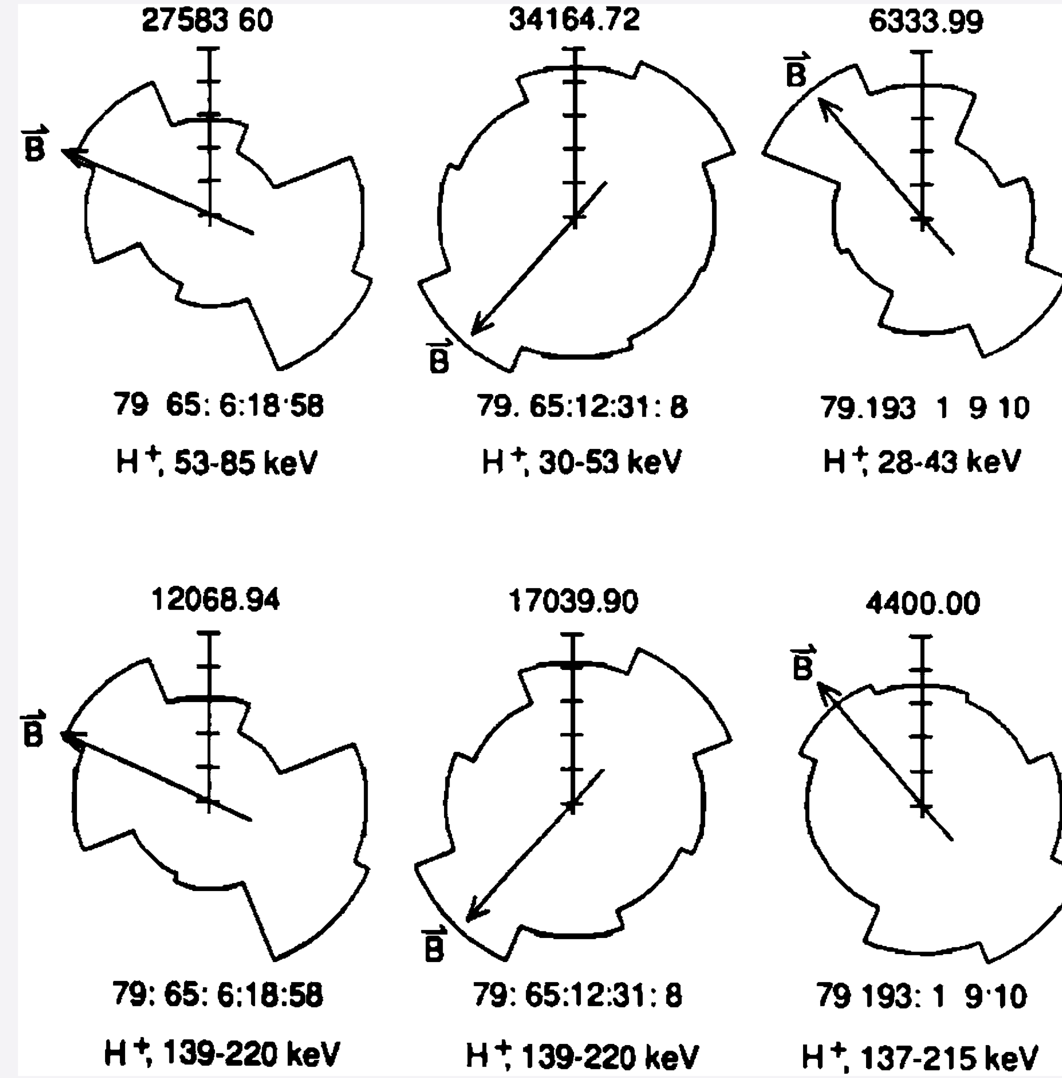
Mauk and Krimigis 1987

Paranicas et al, 1991

Nichols et al., 2015

Paranicas et al., 1991

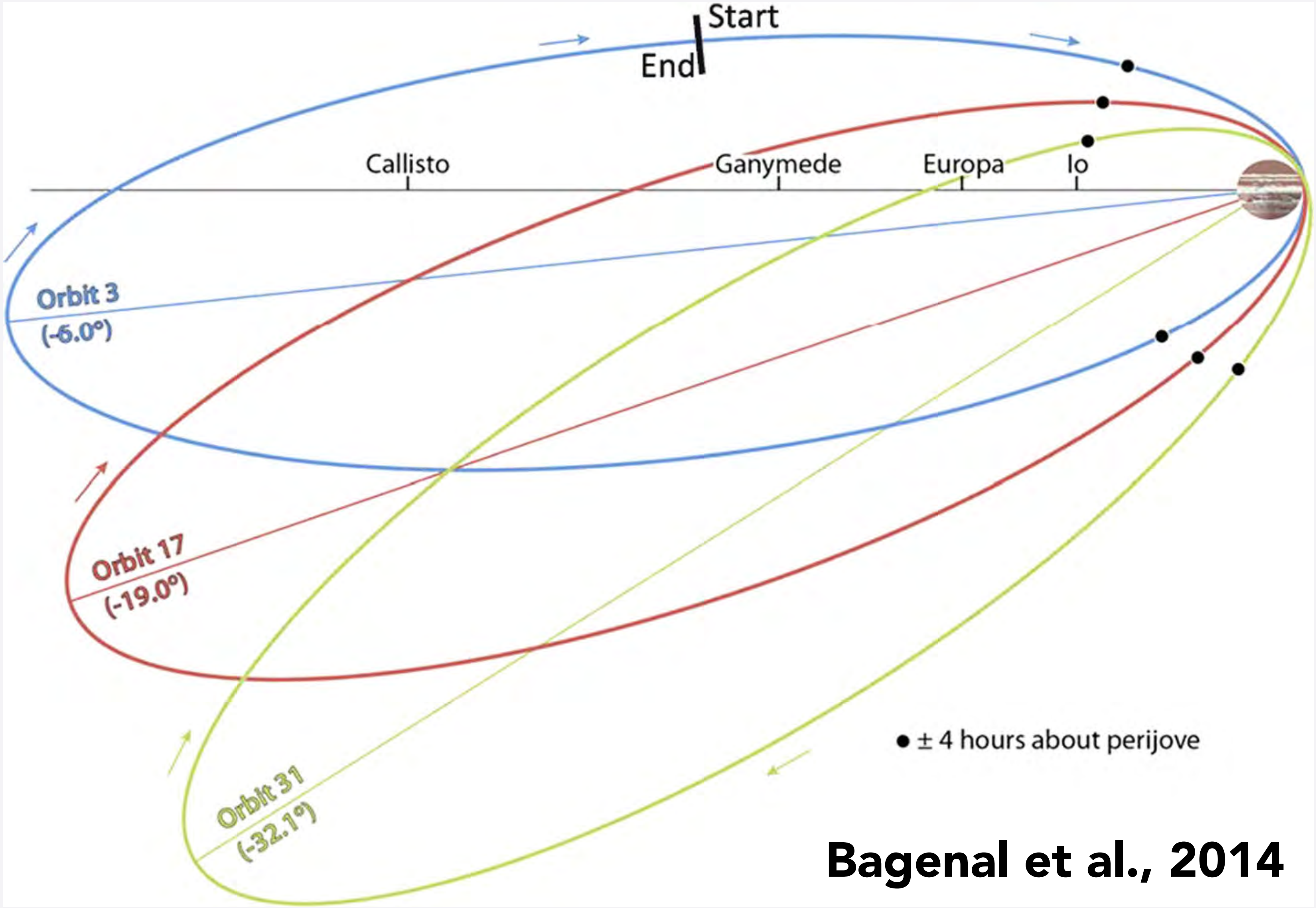




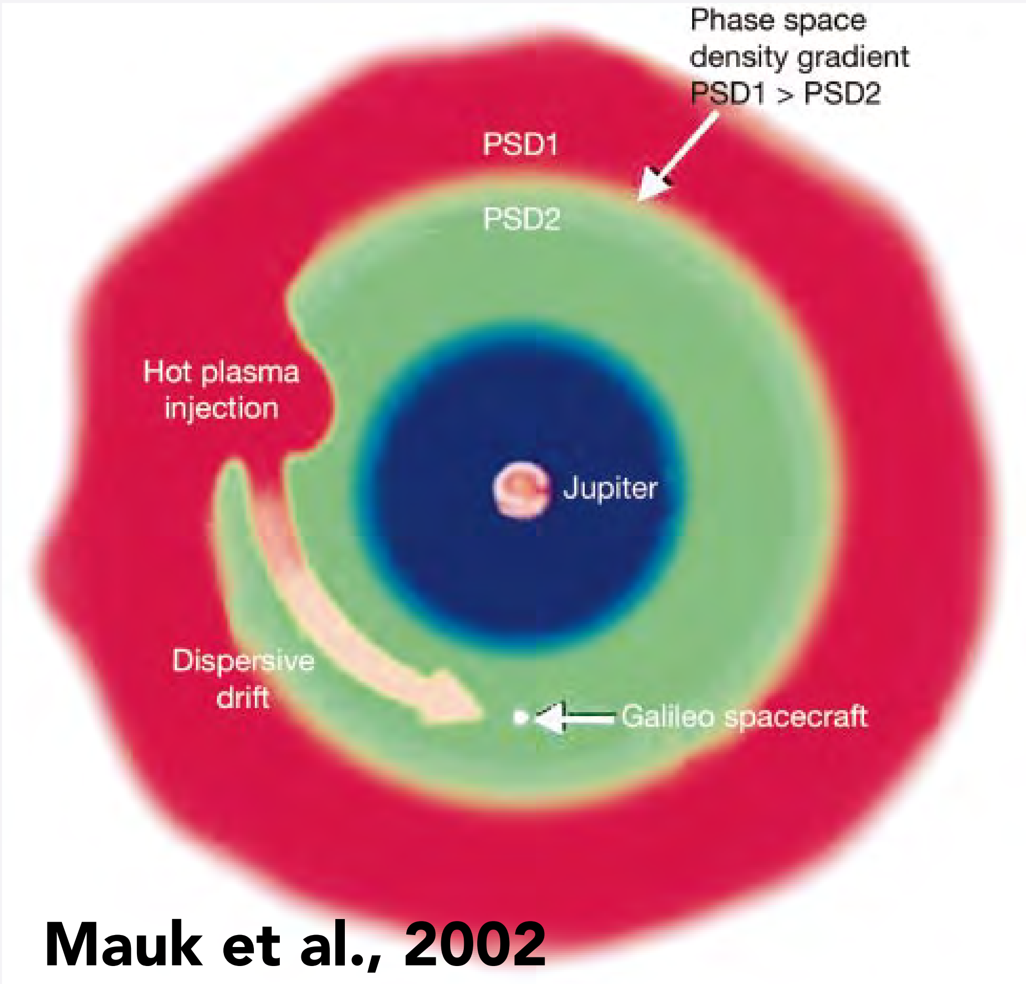
Conclusions

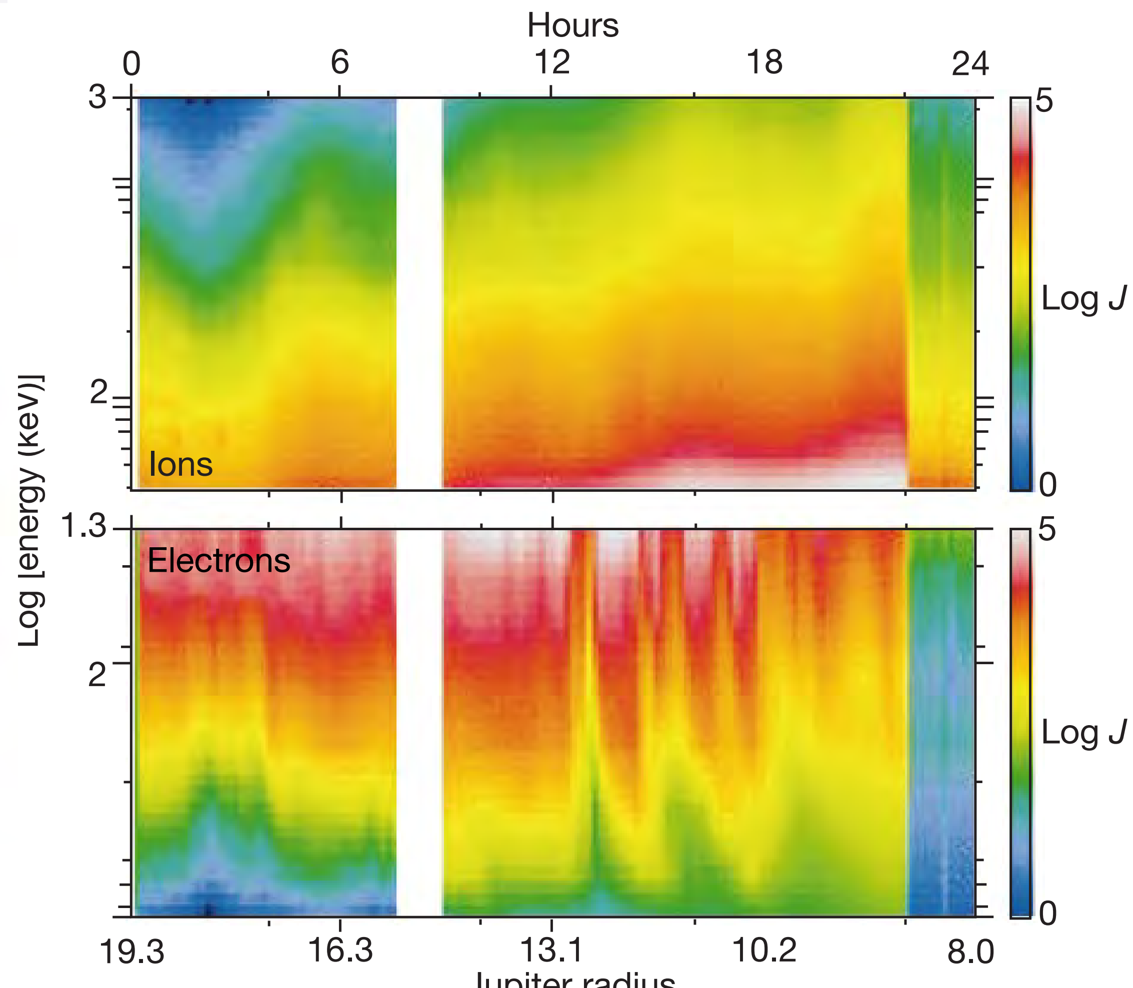
- **Parallel pressure is larger than perpendicular**
- **Outside of ~20 R$_J$ the pressure anisotropy force plays a dominant role**
- **Process that generates these anisotropies is still an open topic**

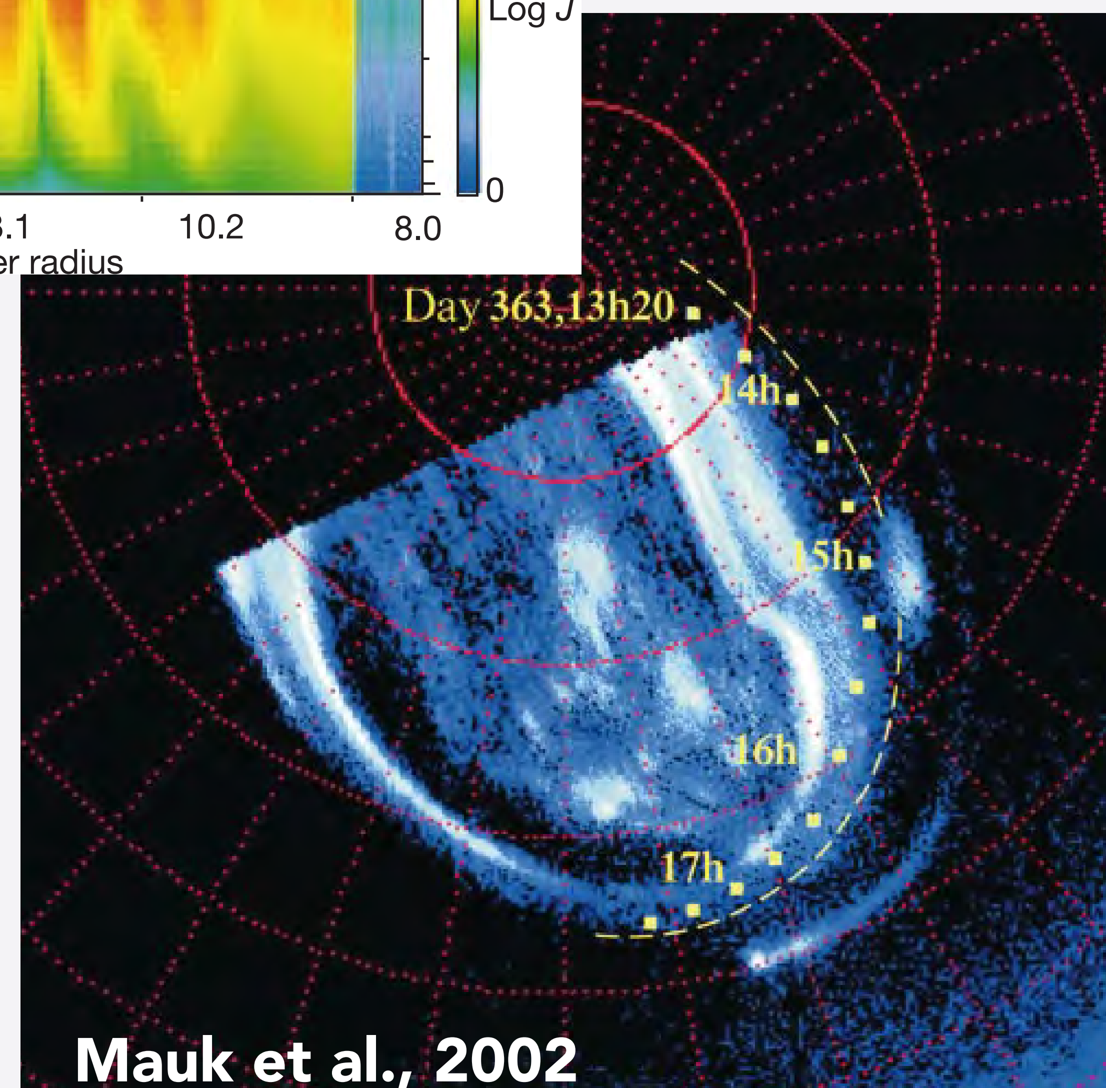
PRESSURE ANISOTROPY



- **JEDI will measure the ion PADs and determine composition in the equatorial region**
- **More complete measurements of the anisotropies**
- **Also, See J. Nichols [2015], model of force balance with anisotropies included!**

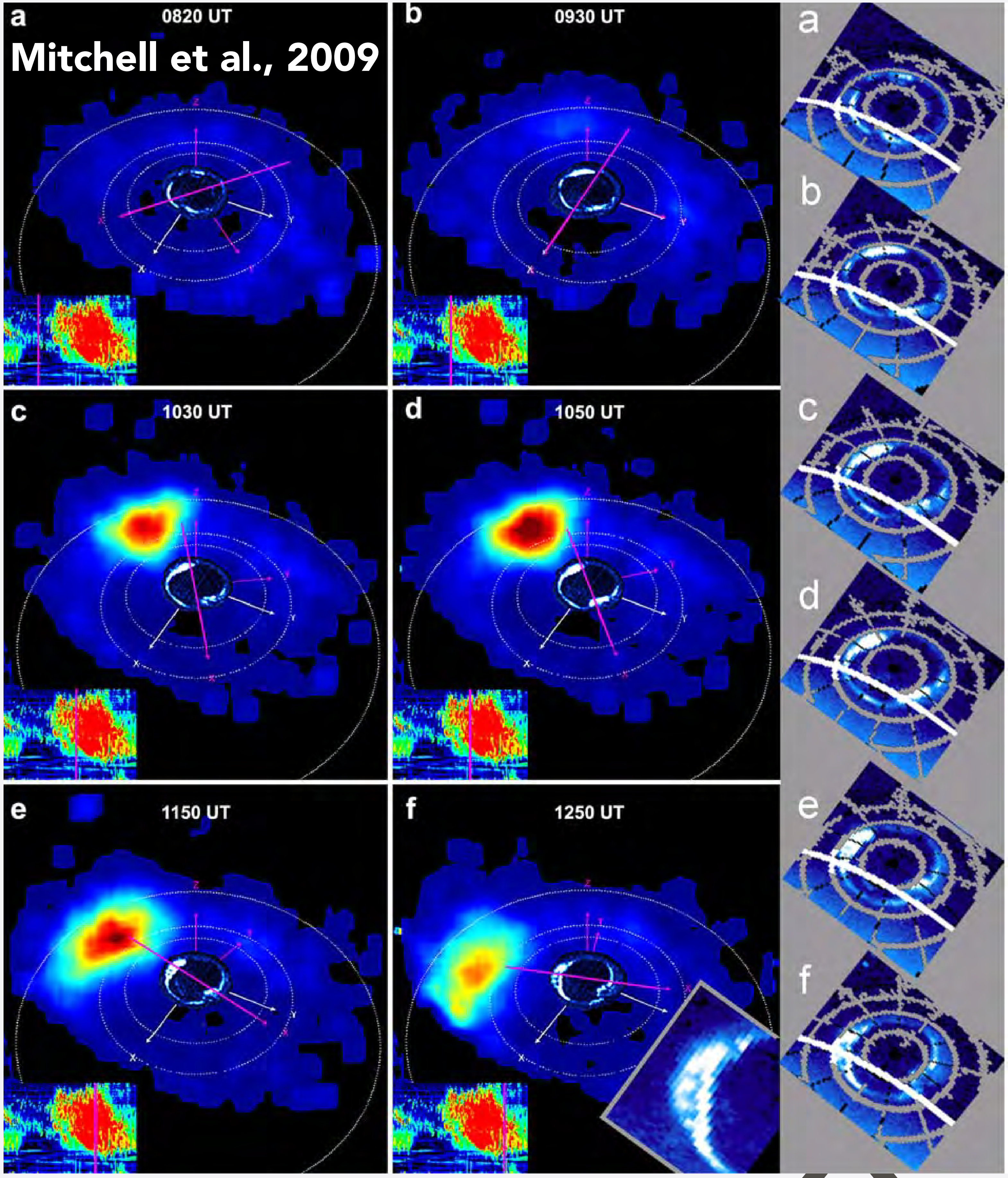






Conclusions

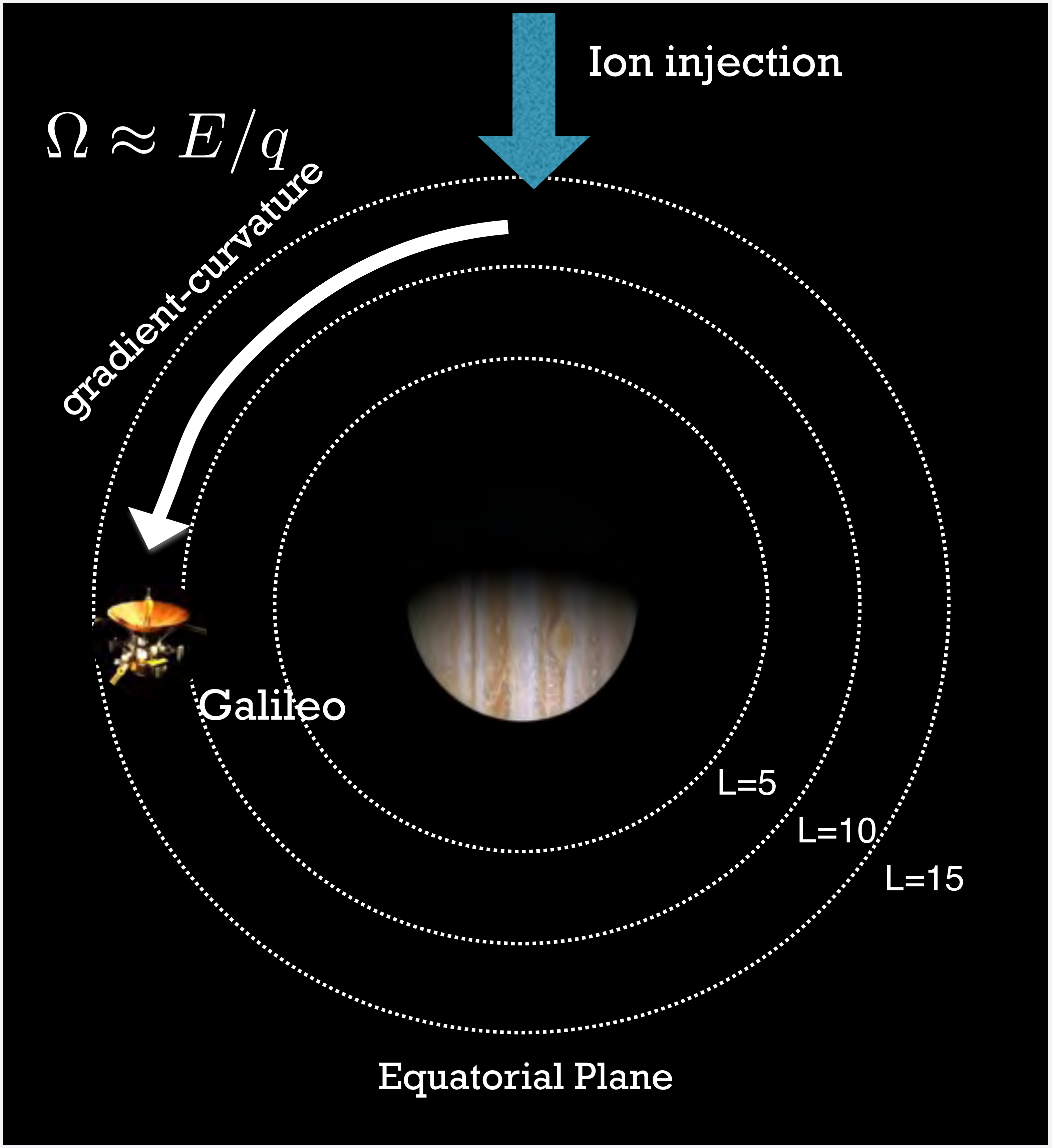
- **Observational campaign between Galileo and Hubble revealed relationships between transient injections and auroral brighting.**
- **Particle distributions are modified during the injection and perhaps scatter particles into the loss cone**

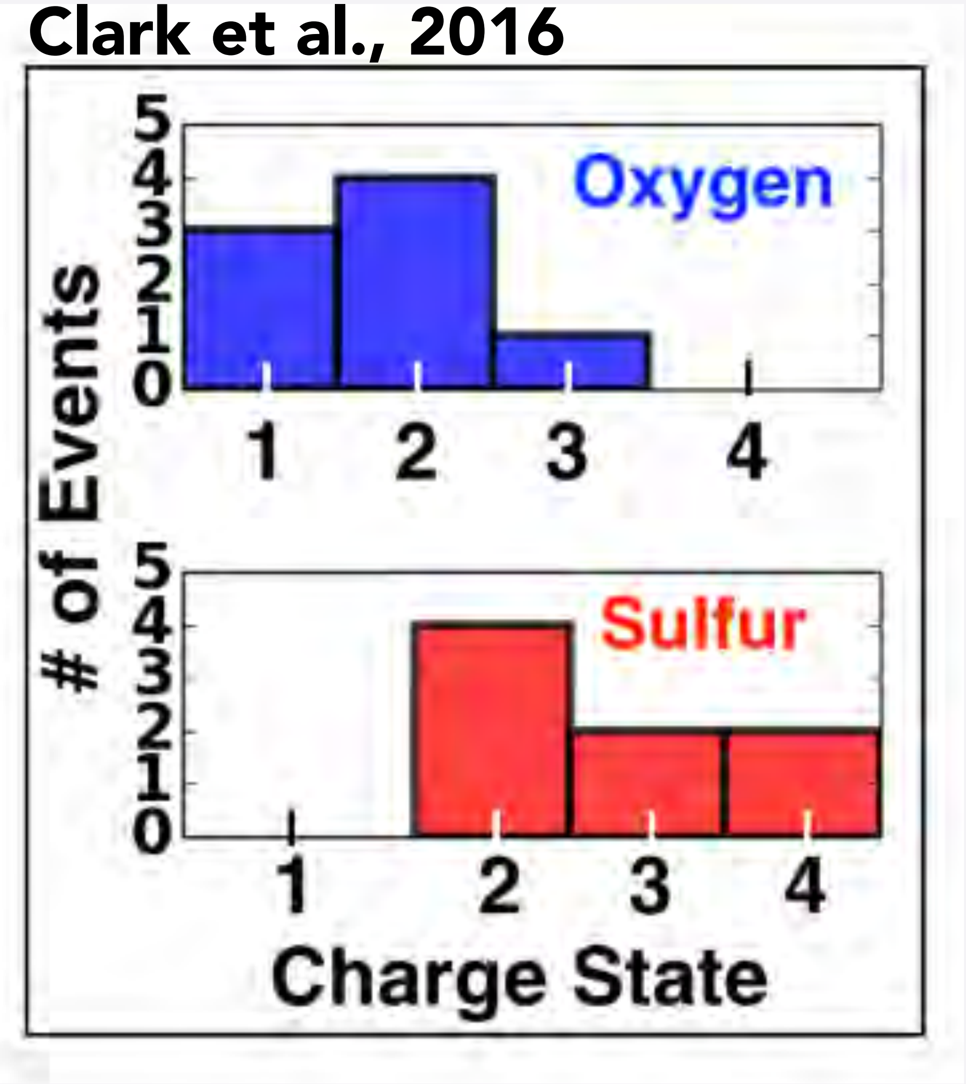


Conclusions

- ~50 - 250 keV ENAs measured by Cassini INCA
- Local time enhancements in ENAs indicative of injection of energetic electrons & ions
- Simultaneous observations from HST and Cassini UVIS reveal a strong correlation between transient magnetospheric phenomenon and auroral enhancements

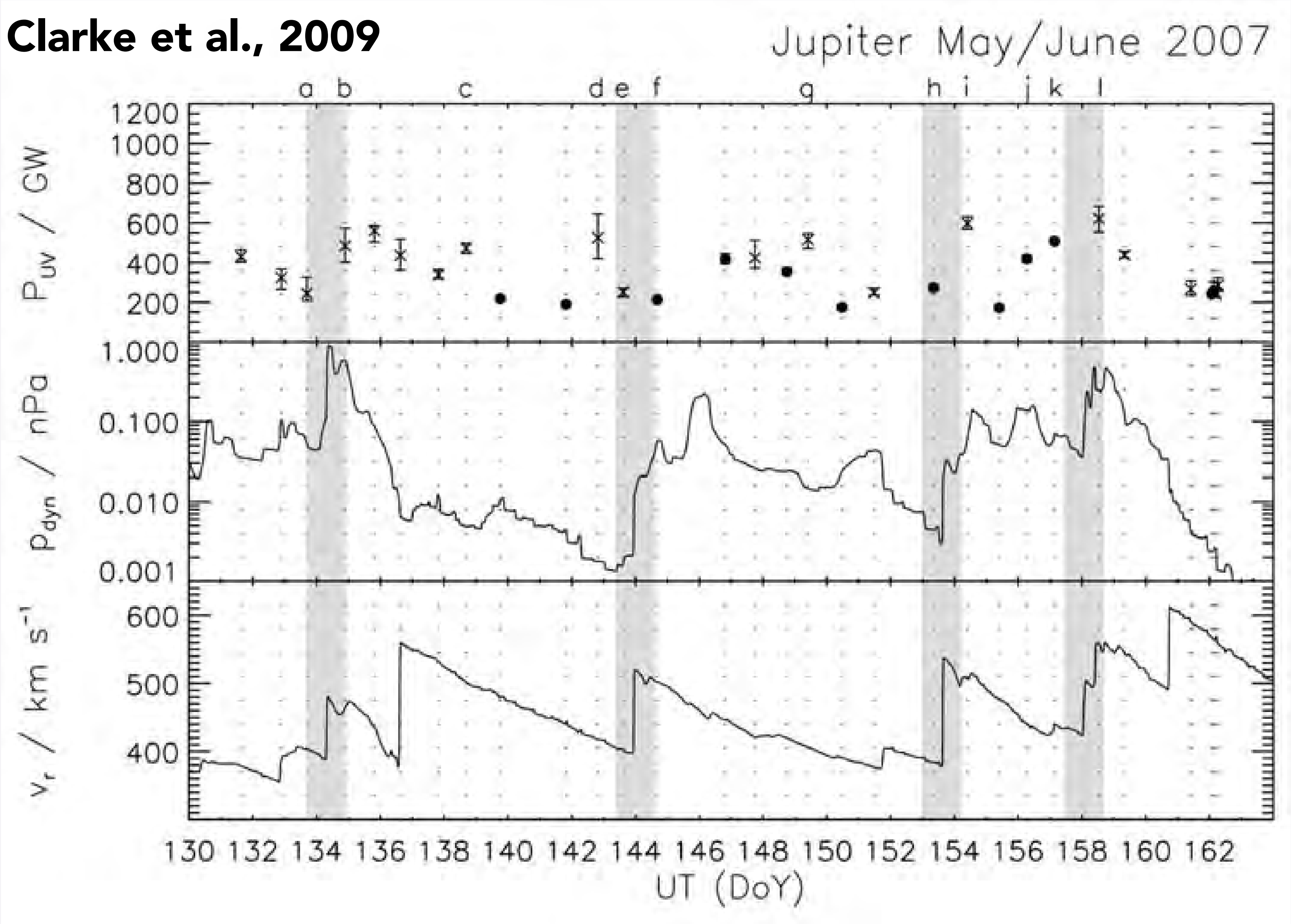
CHARGE STATE ANALYSIS W/ INJECTIONS





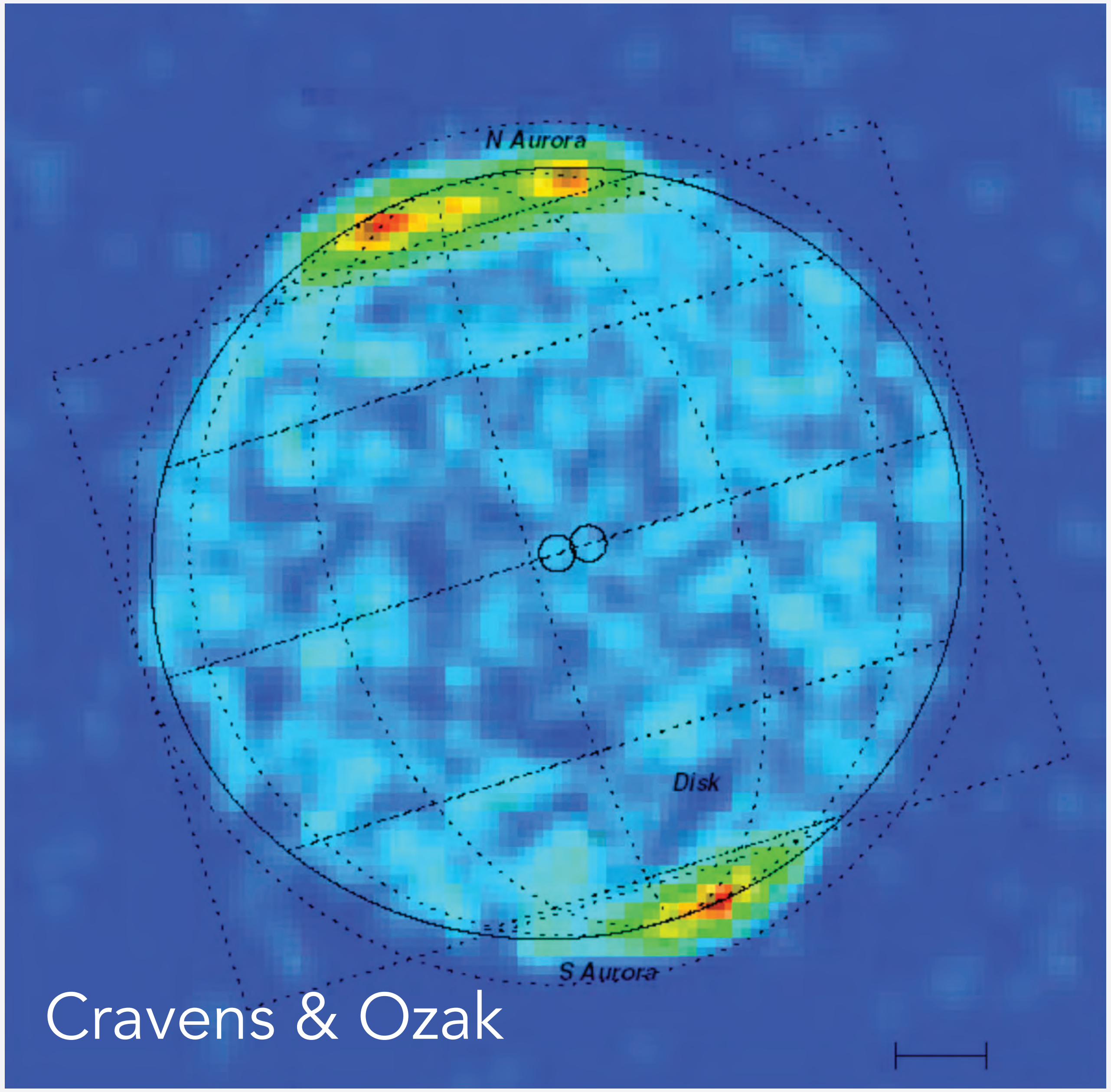
- JADE-Ion may be able to tell us more about the distribution of O^+ & S^{++} in Jupiter's magnetosphere
- Important to understanding heavy ion dynamics

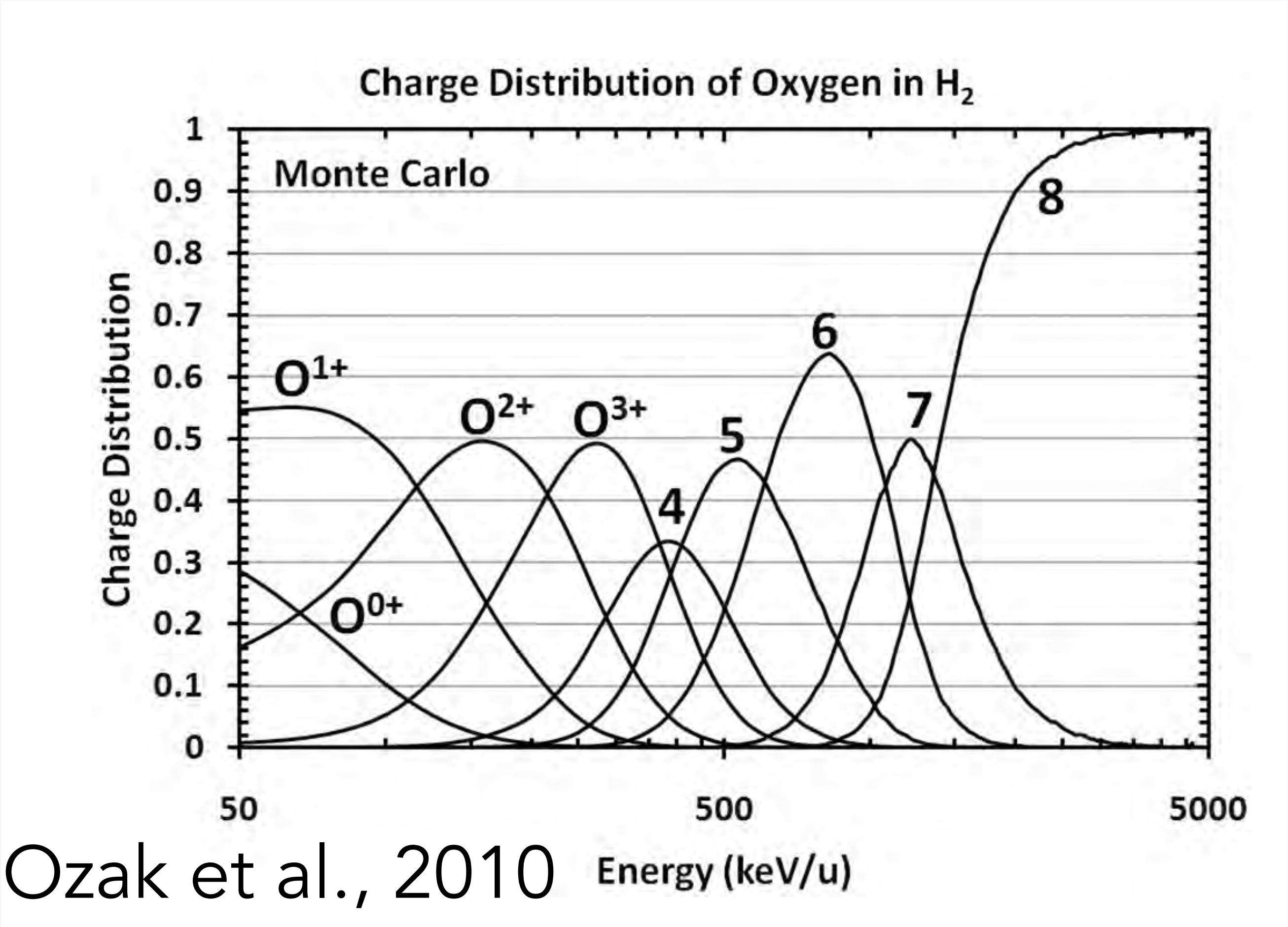
SOLAR WIND VARIABILITY



- Can JEDI infer crude solar wind variations from our TOF only measurements?
- It would be very interesting to compare with *in situ* data from JADE and remote observations from Hasaki & HST

PRECIPITATING HEAVY IONS

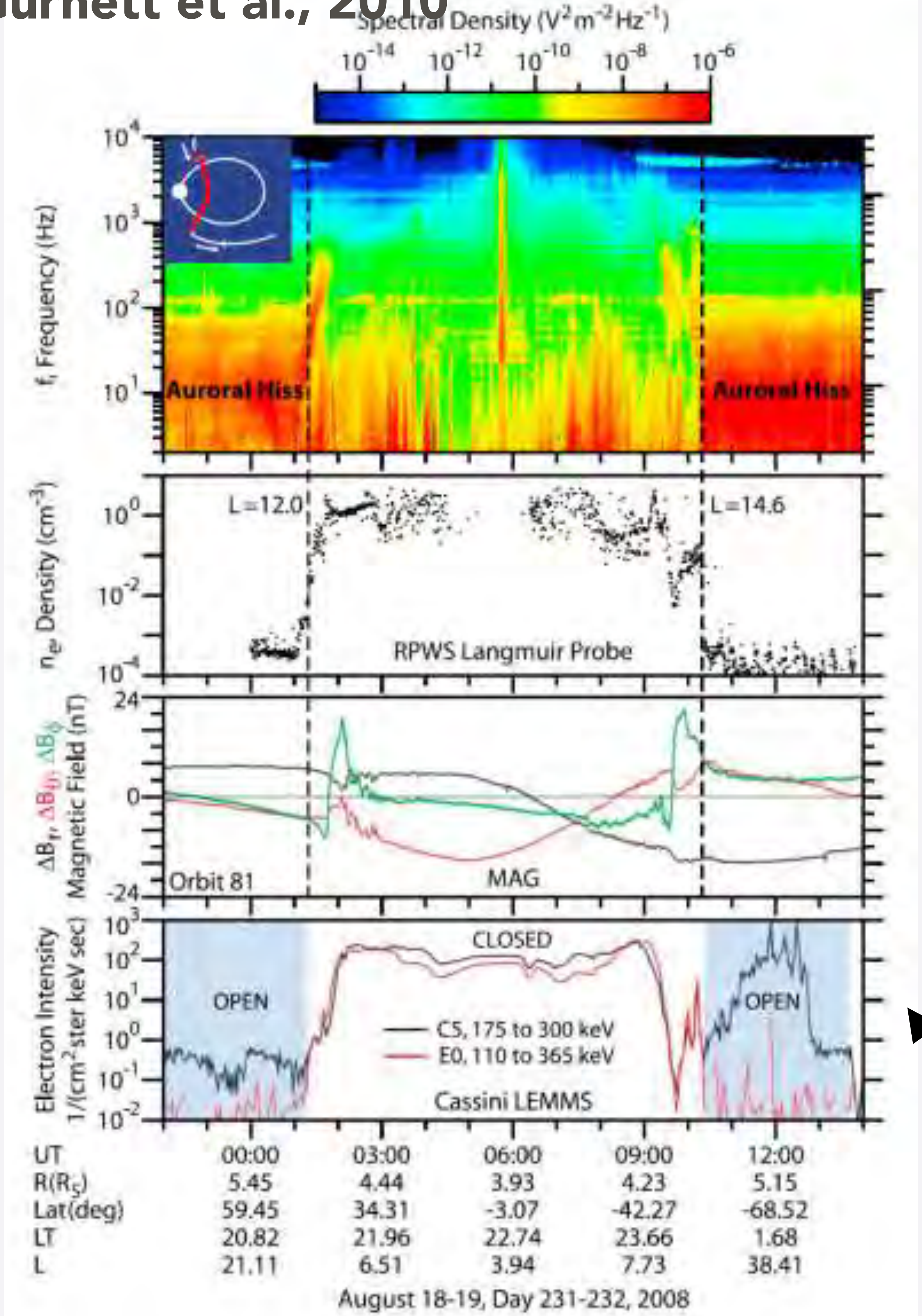


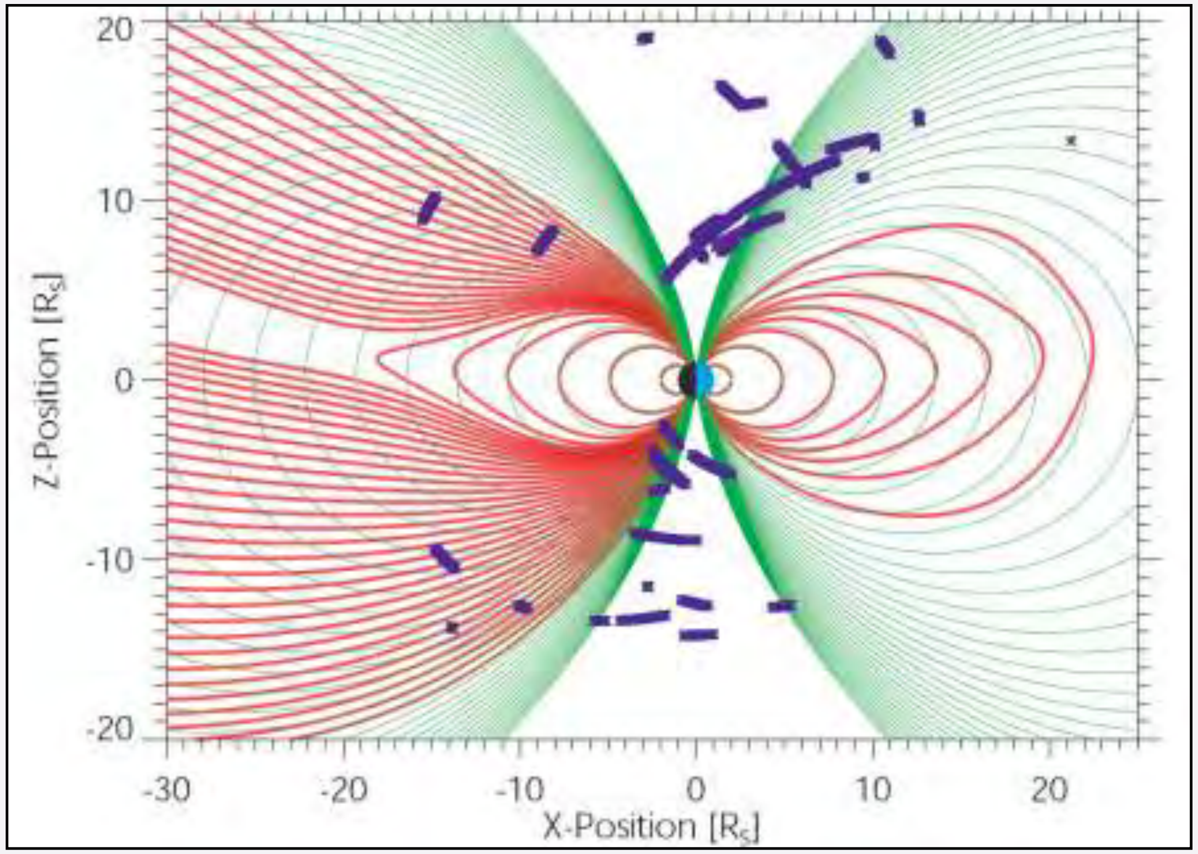


- JEDI will measure several 100 keV/nuc precipitating heavy ions
- If these heavy ions are present, then how are they accelerated?

OPEN/CLOSED FIELD LINES

Gurnett et al., 2010





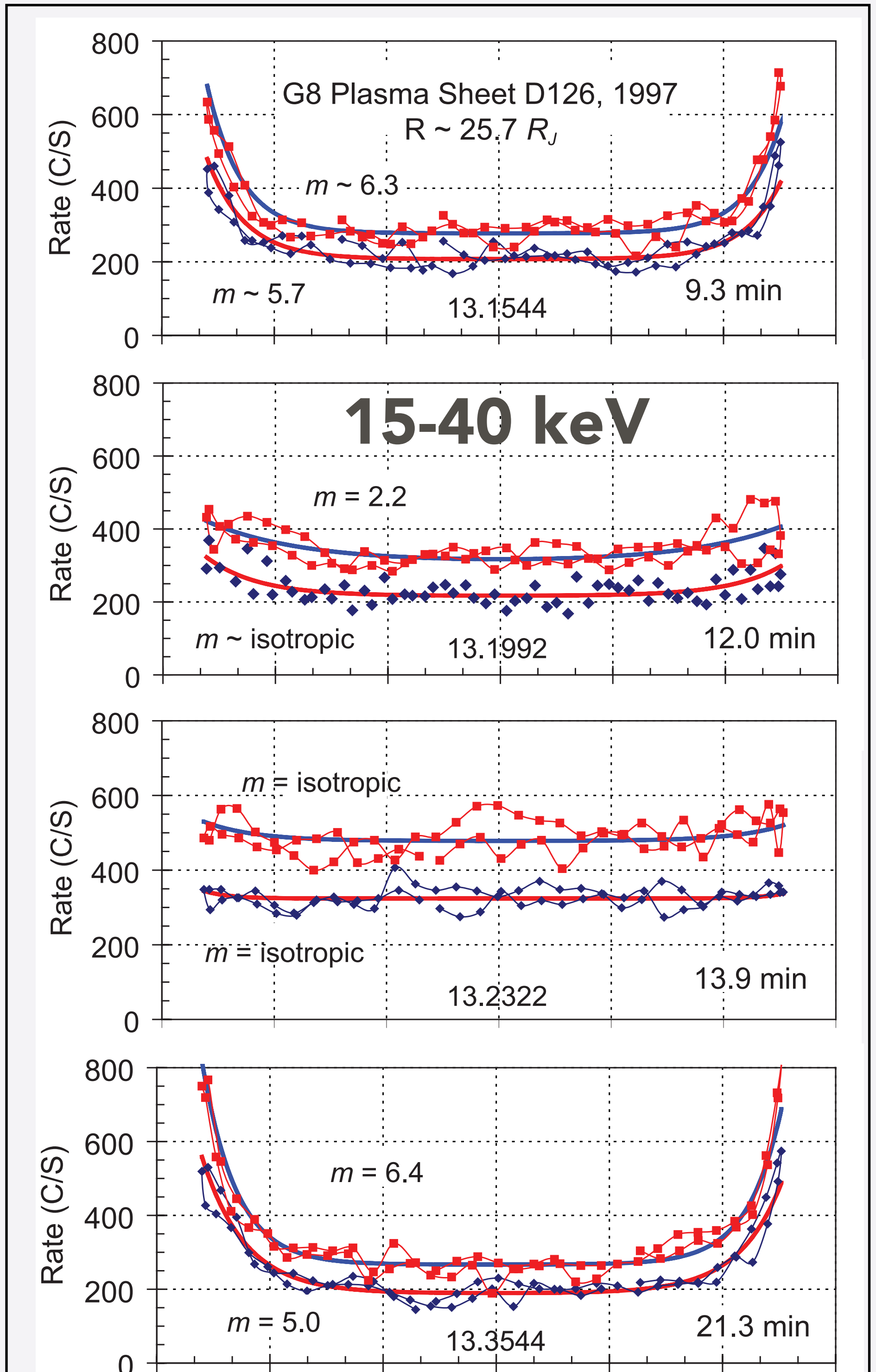
Krupp et al., 2011 MOP

- Ratio of energetic electron fluxes parallel and anti-parallel to the field
- What will the open field line configuration look like at Jupiter? How does it compare to Saturn?

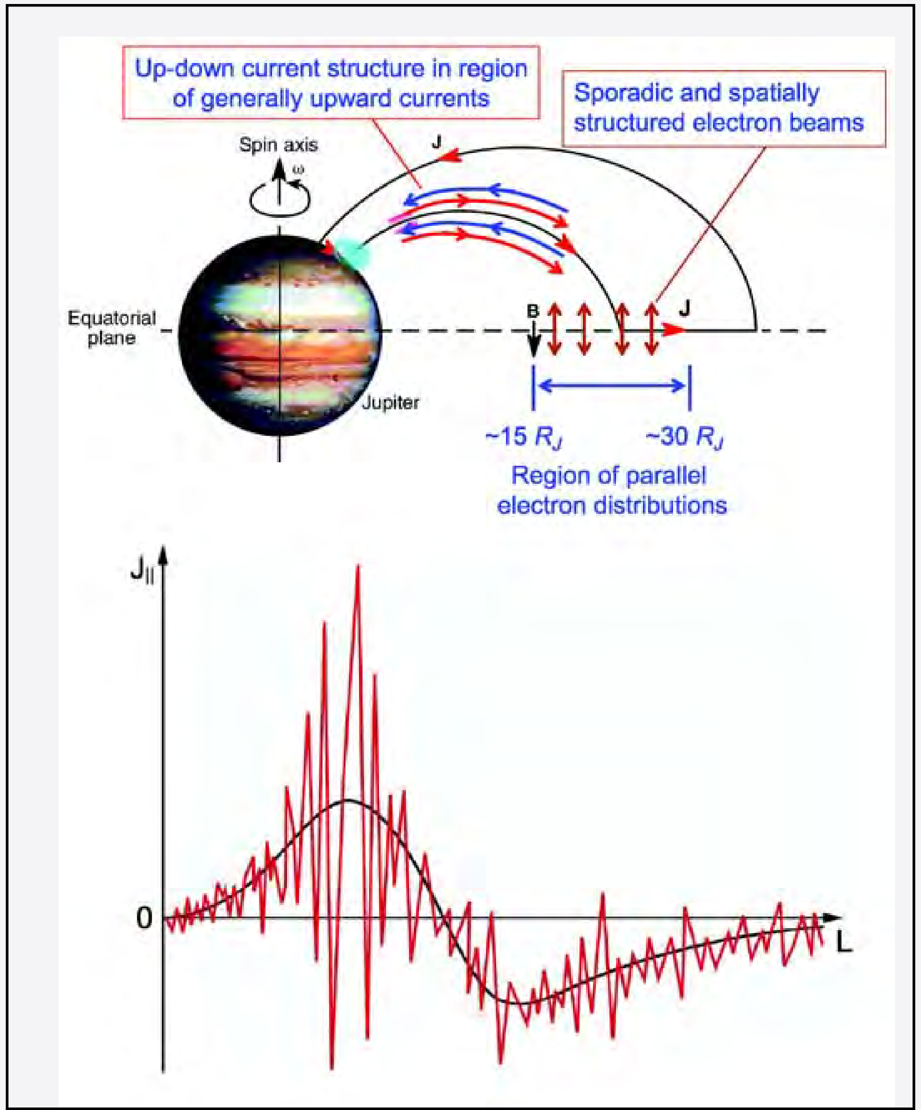
JEDI?

FIELD ALIGNED ELECTRONS

Variability



FAC system



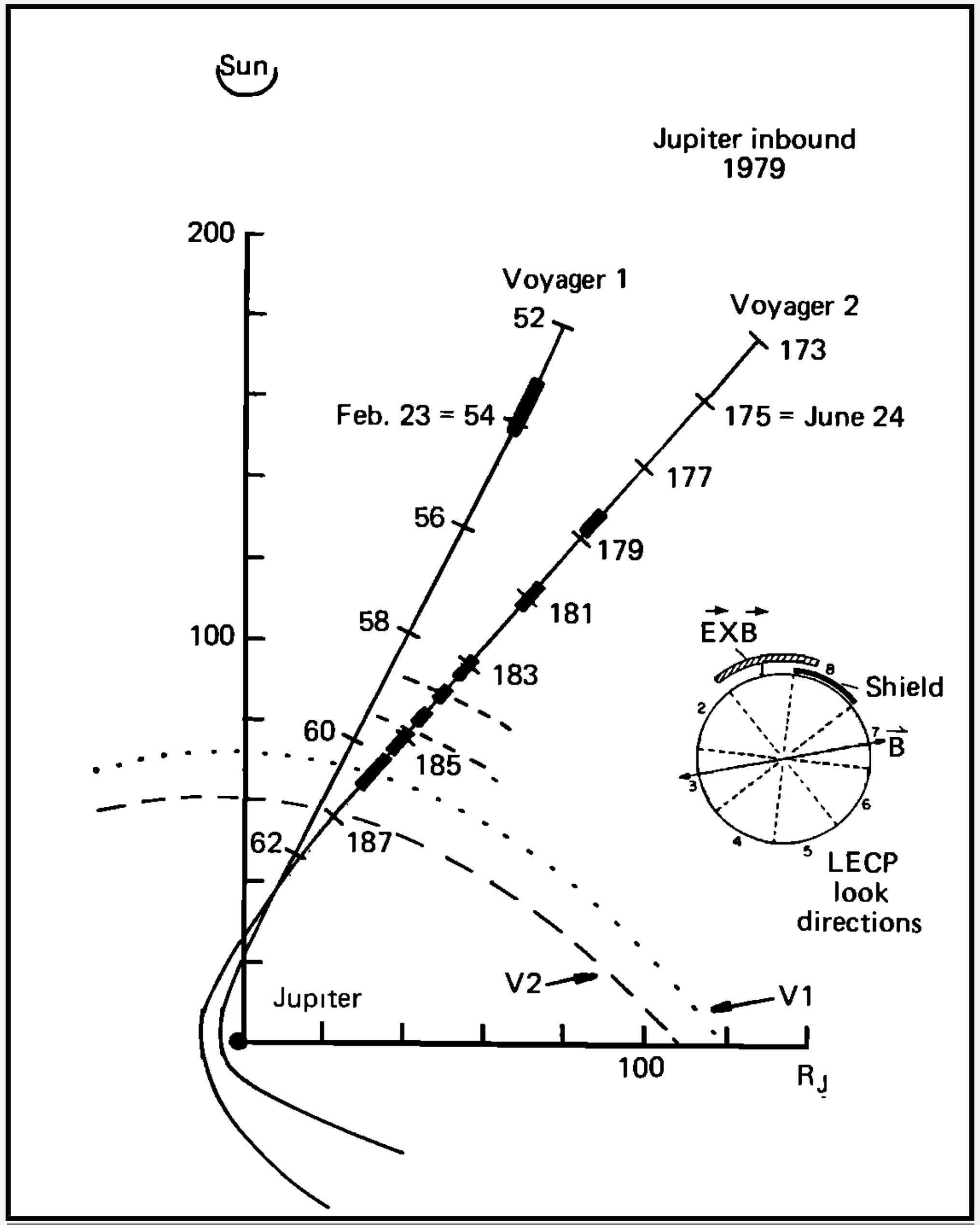
Conclusions

- **Temporal (few mins.) and/or spatial (< 20 km) variability**
- **Angular scattering between source location and equatorial magnetosphere**
- **Magnetic field signatures suggest turbulent Alfven waves**

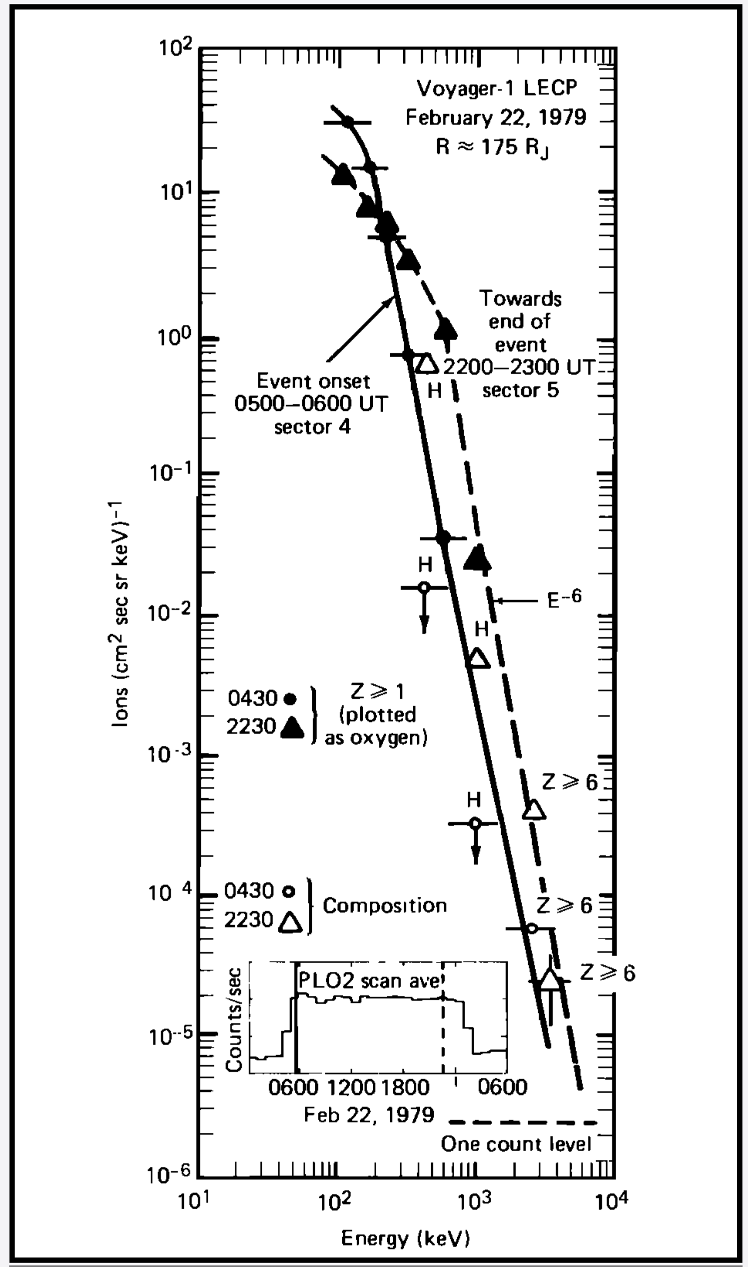
Mauk & Saur, 2007

UPSTREAM ION EVENTS

Trajectory



Data



Conclusions

- **Source of ions appear to originate form Jupiter**
- **Ions are accelerated along bow shock**
- **First order fermi acceleration does not play a role**

Krimigis et al., 1985
Haggerty & Armstrong 1999

JUNO'S SOLAR PANELS

- Juno will be the first spacecraft to use solar panels in Jupiter's magnetosphere
- Can we learn something about the performance of Juno's solar arrays in Jupiter's harsh radiation environment
- JEDI witness detectors can help diagnose the high energy radiation environment

SUMMARY

- JEDI is in great shape to make energetic particle measurements throughout Jupiter's magnetosphere
- Detailed analysis of the JEDI EFB and cruise data are revealing new and interesting opportunities

- In addition to the high-latitude measurements, we have identified several science questions that can be addressed with JEDI
- This list is not exhaustive however
- In some ways, JEDI is uniquely positioned to test hypotheses (e.g., Cravens et al., 2003)

Thank you!

PAST EPD INSTRUMENTS

Instrument	Measurements	Region	Discoveries
CPI $^{\alpha}$	> 0.5 MeV protons > 3 MeV electrons > 10 MeV/nuc heavy ions	Foreshock Dawn magnetosheath Inner/outer magnetosphere	Periodicities in particle flux Upstream Jovian ions Particle trapping Moon effects
LECP $^{\beta}$	> 10 keV electrons > 15 keV protons > 50 keV/nuc heavy ions	foreshock dawn magnetosheath Outer/inner magnetosphere	
HI-SCALE $^{\eta}$	> 30 keV electrons > 50 keV ions		
EPD $^{\gamma}$	> 15 keV electrons > 20 keV protons >10 keV/nuc heavy ions	Equatorial inner & outer magnetosphere Satellite flybys	
MIMI $^{\delta}$	> 20 keV electrons > 30 keV protons >7 keV/nuc heavy ions charge state 2 < E < 200 keV	Bow shock Magnetopause on dusk flank	
PEPSSI $^{\epsilon}$	>20 keV electrons > few keV protons >10s of keV heavy ions	Flank Distant magnetotail	
JEDI $^{\zeta}$	>20 keV electrons > few keV protons >10s of keV heavy ions	Dawn magnetopause/sheath Polar magnetosphere Inner/outer equatorial crossings	

α Pioneer: Simpson et al. 1975

β Voyager: Krimigis et al., 1977

γ Galileo: Williams et al., 1994

δ Cassini: Krimigis et al., 2004

η Ulysses: Lanzerotti et al., 1992

ϵ New Horizons: McNutt et al., 2008

ζ Juno: Mauk et al., 2013