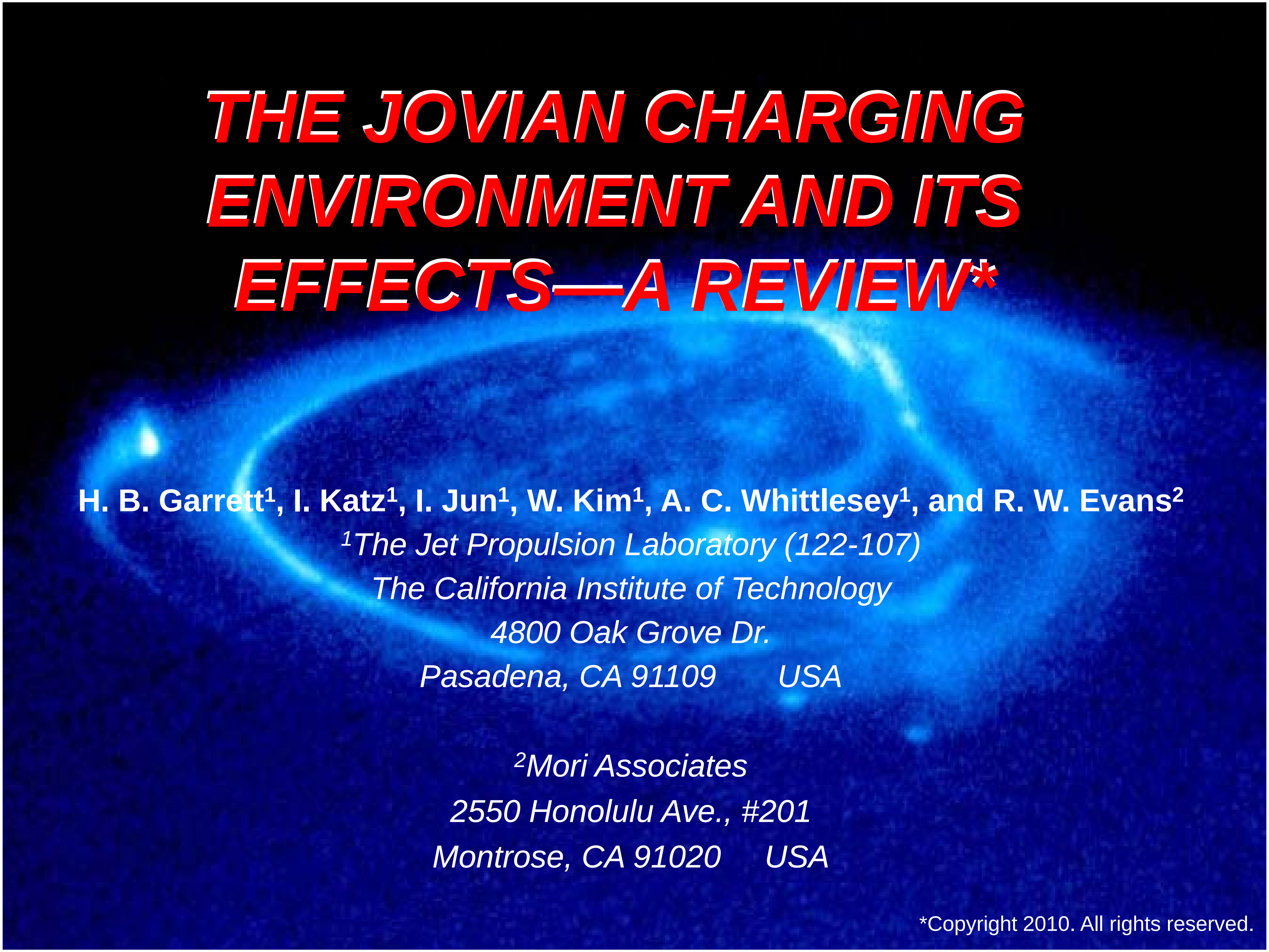


THE JOVIAN CHARGING ENVIRONMENT AND ITS EFFECTS—A REVIEW*

H. B. Garrett[1], I. Katz[1], I. Jun[1], W. Kim[1], A. C. Whittlesey[1], and R. W. Evans[2]

[1]The Jet Propulsion Laboratory (122-107)
The California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109 USA

[2]Mori Associates
2550 Honolulu Ave., #201
Montrose, CA 91020 USA

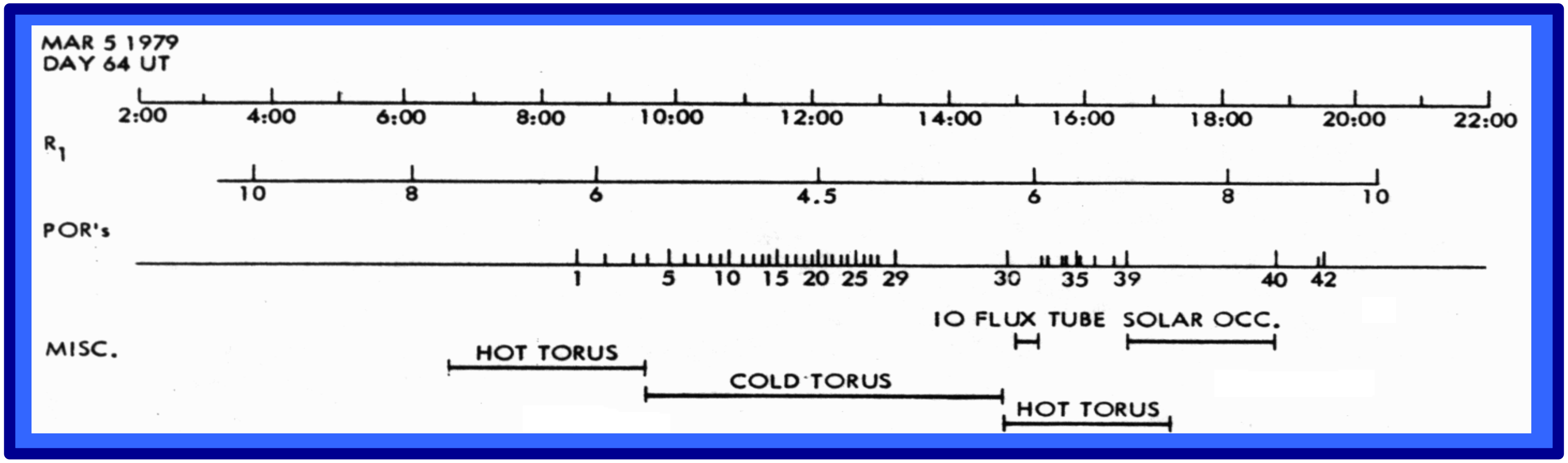
AGENDA

- **Overview-What's the Issue?**
- **Ambient Environment at Jupiter**
  - **Jovian Plasma**
  - **Jovian Auroral Zone**
  - **Jovian Diffuse Aurora**
- **Charging Effects at Jupiter**
  - **Surface Potentials**
  - **IESD at Jupiter**
  - **VxB at Jupiter**
- **Conclusion**

OVERVIEW

WHAT ARE THE ISSUES?

- *Voyager 1 experienced 42 anomalies* during closest approach to Jupiter—believed to be due to charging



- *Jupiter has an extremely severe environment:*
  - Pronounced auroras easily visible from Earth!
  - A complex magnetic field 2x10^4 that of Earth's!
  - The highest intensity electron radiation belts in the Solar System!
- ***IF*** we understand the jovian environment, ***THEN*** proper mitigation techniques should allow us to limit its effects.

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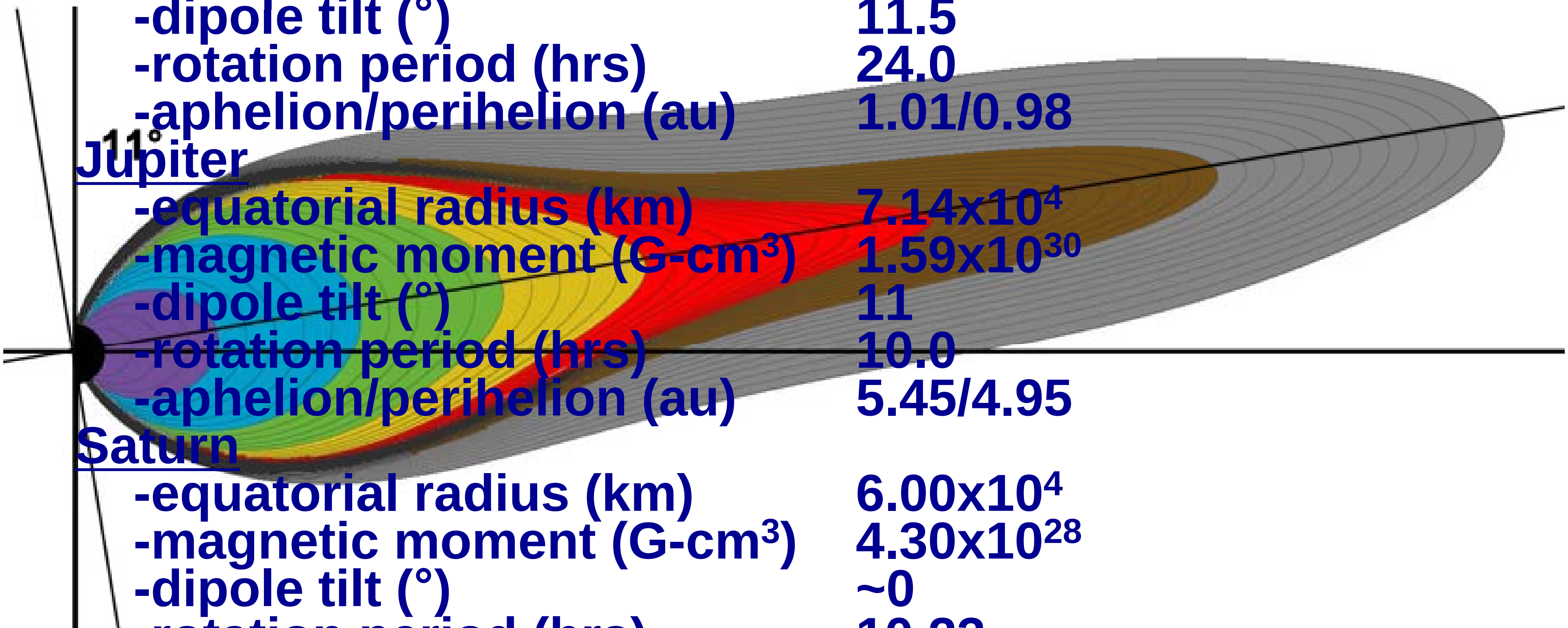
Planetary Characteristics



Earth	
-equatorial radius (km)	6.38×10^3
-magnetic moment (G-cm^3)	8.10×10^{25}
-dipole tilt (°)	11.5
-rotation period (hrs)	24.0
-aphelion/perihelion (au)	1.01/0.98
Jupiter	
-equatorial radius (km)	7.14×10^4
-magnetic moment (G-cm^3)	1.59×10^{30}
-dipole tilt (°)	11
-rotation period (hrs)	10.0
-aphelion/perihelion (au)	5.45/4.95
Saturn	
-equatorial radius (km)	6.00×10^4
-magnetic moment (G-cm^3)	4.30×10^{28}
-dipole tilt (°)	~0
-rotation period (hrs)	10.23
-aphelion/perihelion (au)	10.06/9.01

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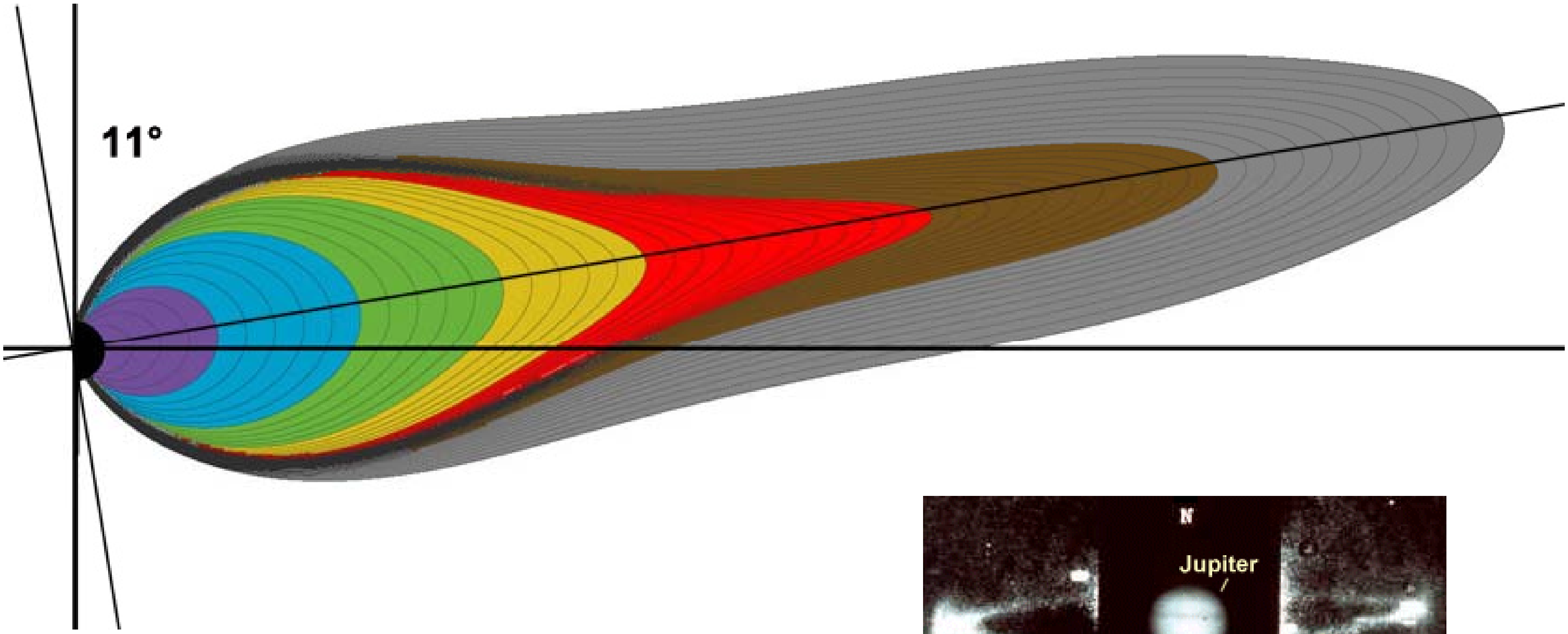
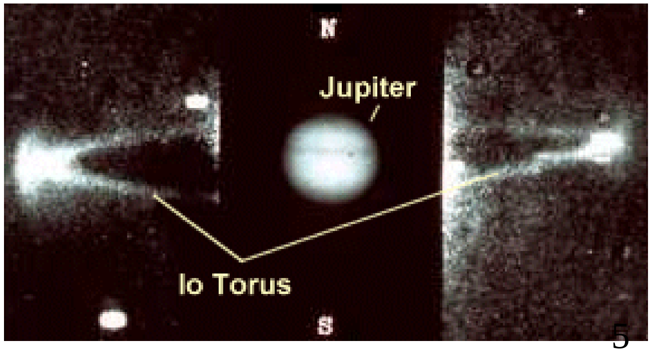
Planetary Characteristics





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Jovian Plasma Environment

The jovian plasma environment is defined by two distribution functions:*

(A) Convected *Maxwell-Boltzmann*:

$$f_i(v) = \frac{N_i}{\pi^{3/2} v_0^3} \exp(-(\vec{v} - \vec{v}_c)^2 / v_0^2)$$

(B) *Kappa* Distribution:

$$f_\kappa(E) = N_\kappa (m_\kappa / 2\pi E_0)^{3/2} \kappa^{-3/2} \frac{\Gamma(\kappa+1)}{\Gamma(\kappa - 1/2)} \frac{1}{(1 + E/\kappa E_0)^{\kappa+1}}$$

*[Divine and Garrett, 1983]

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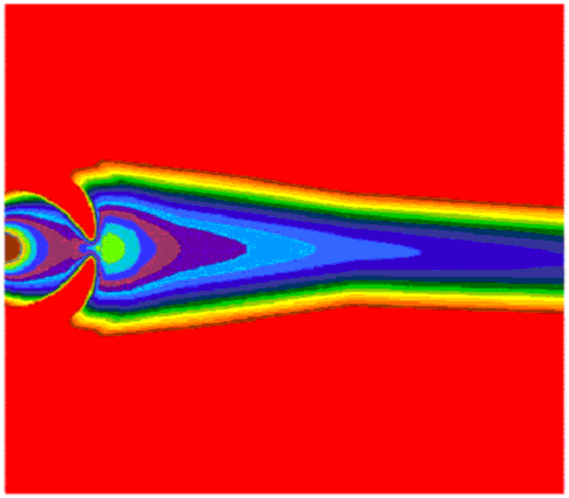
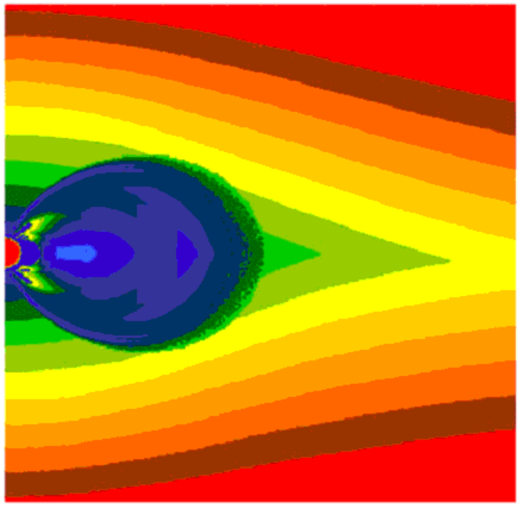
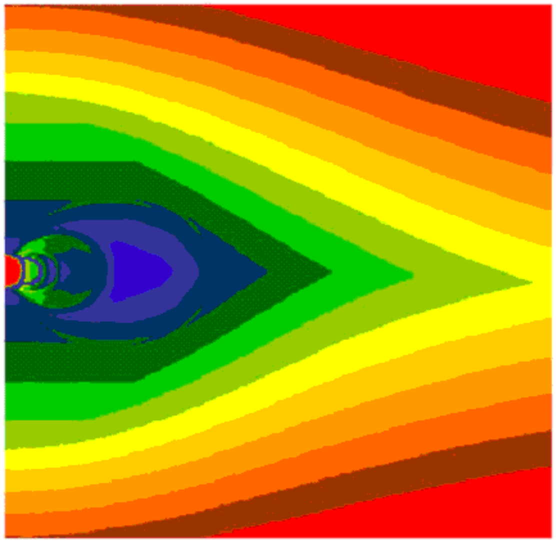
Jovian Plasma Environment



Cold Plasma Density



Hot Electron Density



Hot Proton Density

**Based on [Divine and Garrett, 1983]*

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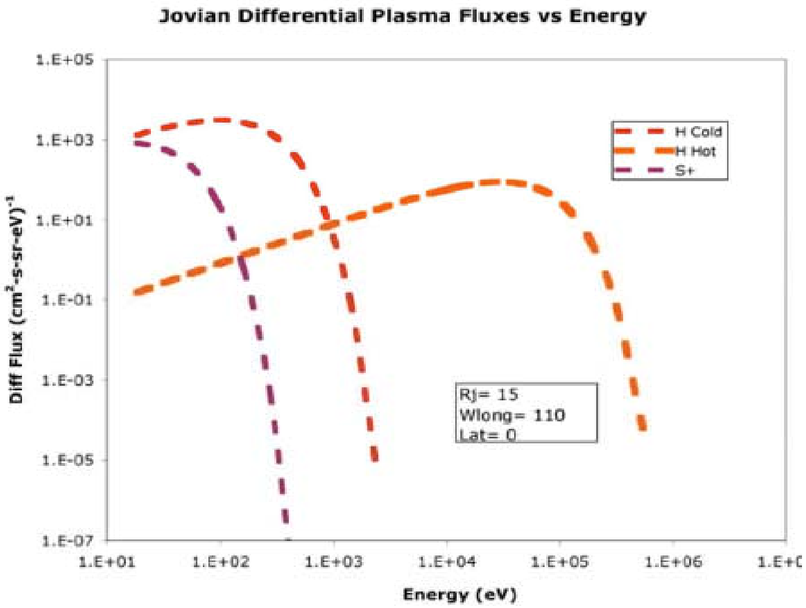
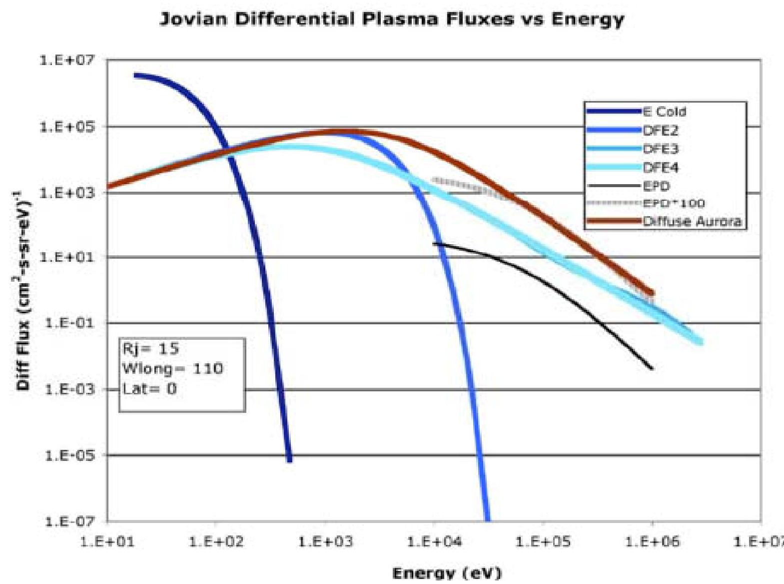
Jovian Plasma Environment

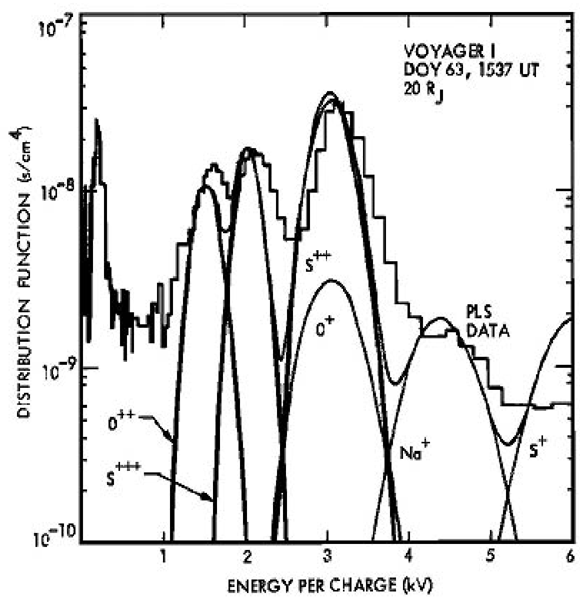


Proton Plasma
110°W, 15 Rj, 0°λ



Electron Plasma*
110°W, 15 Rj, 0°λ

*Diffuse spectrum based on [Bhattacharya et al., 2001] and [Divine and Garrett, 1983] “Warm Electron” spectrum. See [Garrett et al., 2008] for details



Voyager 1 Data Compared to Model

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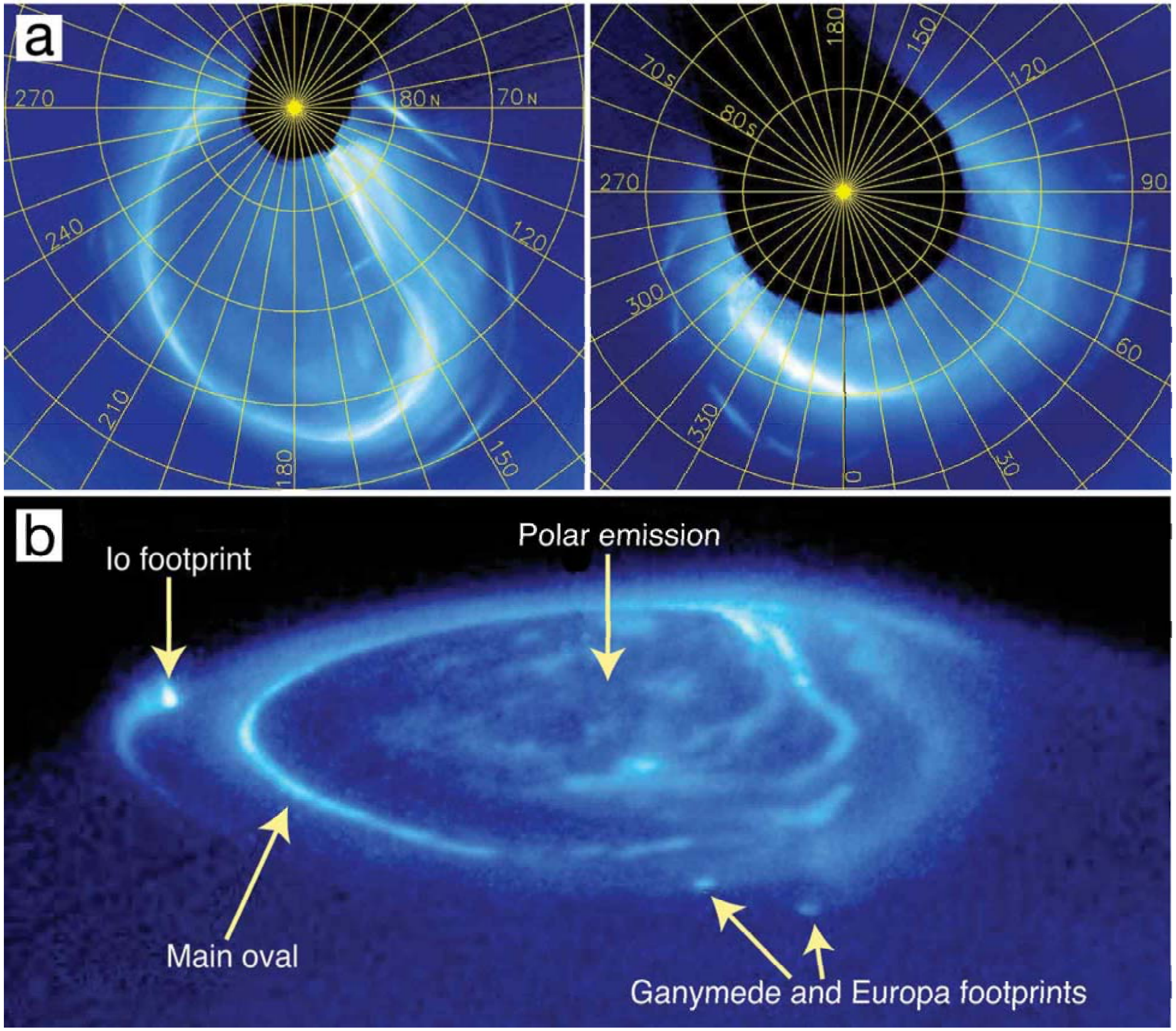
The Jovian Aurora



HST UV images of Jovian aurora. (a) Polar projections of main auroral ovals (left North Pole, right South Pole) (b) Image of northern aurora, showing: Main oval and polar emissions as well as footprints from three of the Galilean moons (c) Io field line.

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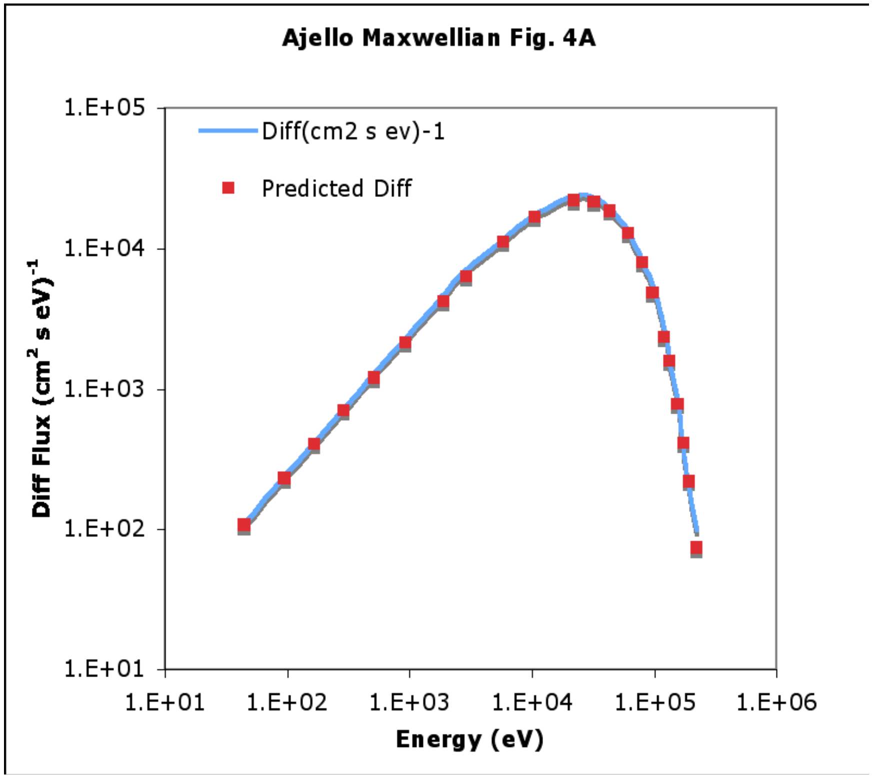
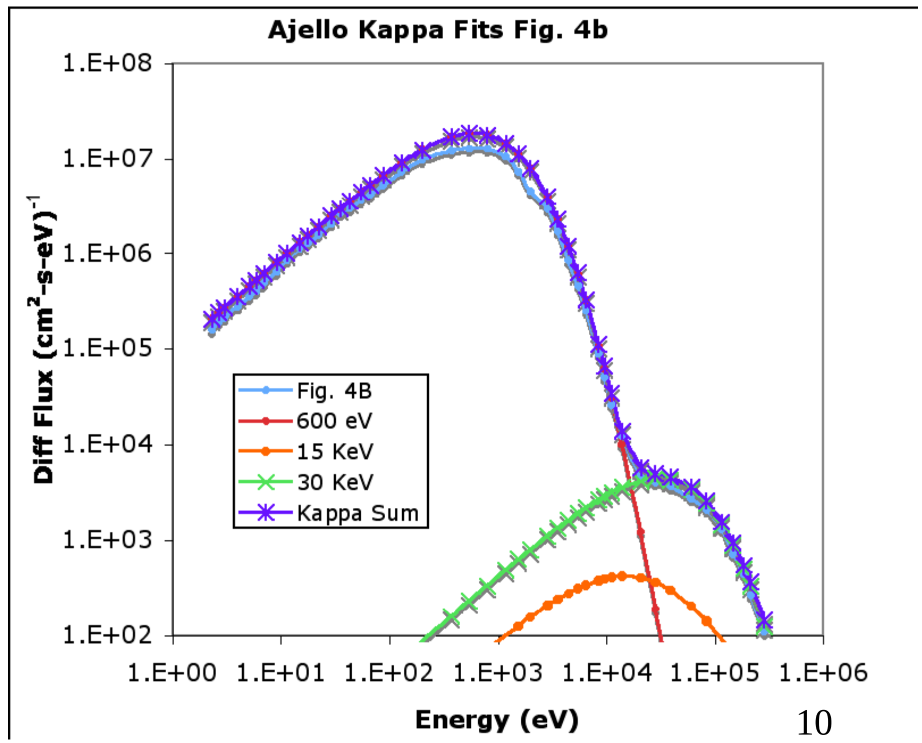
*Jovian Auroral Zone Spectra**





*Ajello et al., 2001

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Jovian Surface Potentials

Assume current balance for Aluminum in shadow:

$$I_E(V) - [I_I(V) + I_{SE}(V) + I_{SI}(V) + I_{BSE}(V)] = I_T \sim 0$$

SURFACE CHARGING CONCERNS!!

RJ	ALAT	No Aurora		A Max		A κ +I/1	A κ +I/10	A κ +I/100		Diffuse WC	Diffuse WC/10	Diffuse WC/100
1.2	70	-106		-114		-119	-308	-1025		-113	-107	-106
2	70	-293		-652		-732	-1465	-1699		-396	-45	-37
15	0	-8		-2212		-1934	-3984	-4834		-1318	-24	-9

Estimates of surface potentials for: (1) Maxwellian or Kappa ("+I/1, +I/10, +I/100" => 100%, 10%, 1% of ion plasma); Diffuse aurora varied from 100 ergs/cm^2-s to 1 erg/cm^2-s

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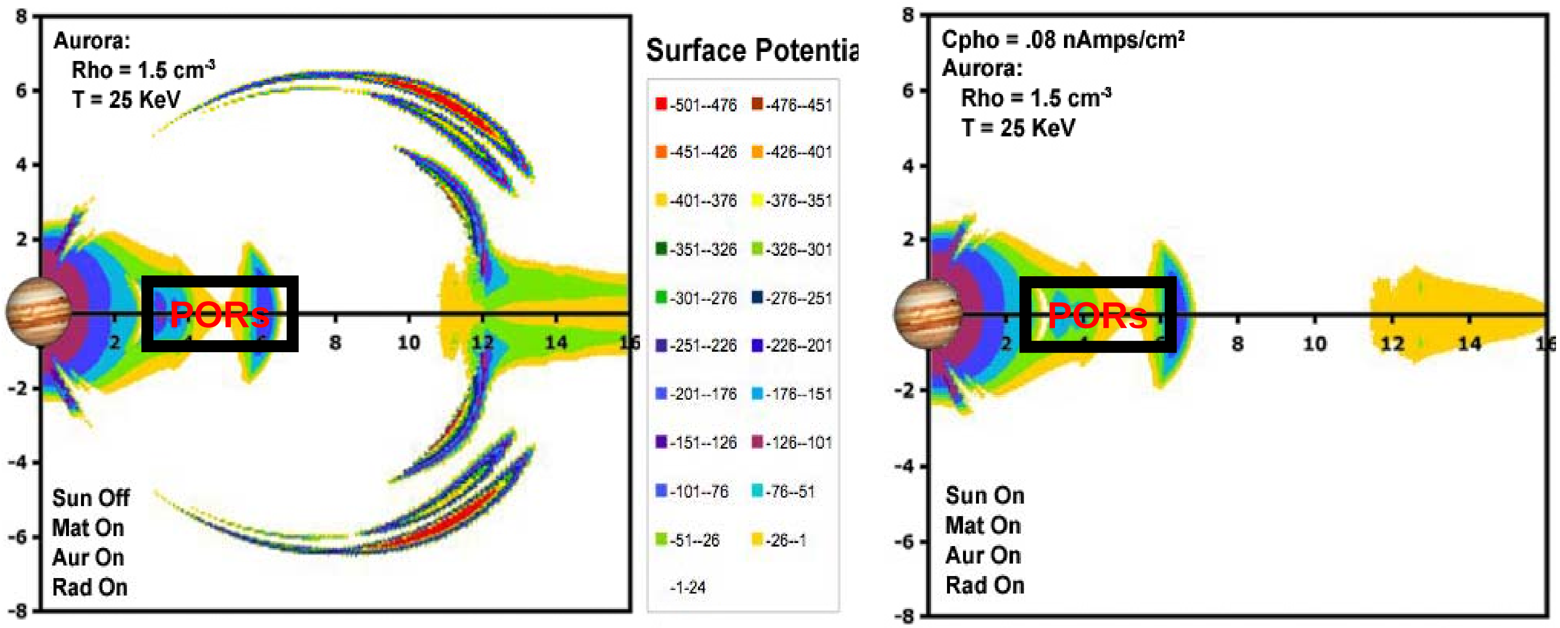
Auroral Charging



A. Dark Side **B. Sunlit Side**

Meridional plots of the charging potentials in darkness and sunlit for nominal auroral and plasma environments.

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Surface Charging

WE FIND:

- Jovian auroral zone can cause ~300 V charging above background levels over poles--charging is moderated by cold plasmasphere.
- Lowering jovian cold plasma density (as observed for Earth aurora) increases charging to ~1-2 kV.
- For diffuse aurora, potentials are barely above the background levels (~100-400 V) over poles.
- At equatorial crossing of auroral field lines, “Worst Case” auroral fluxes may cause significant charging (-2-5 kV) in the 15-25 Rj equatorial region.

THIS IMPLIES:

- Surface charging is a potential problem for spacecraft crossing through the auroral zone though levels are within current mitigation techniques.
- Equatorward extension of aurora will be of concern to missions passing through the 15-25 Rj equatorial region--again, however, these levels are well within levels we protect geosynchronous spacecraft against.
- ***<u>Surface charging will be of concern at Jupiter if standard mitigation procedures are not followed!</u>***

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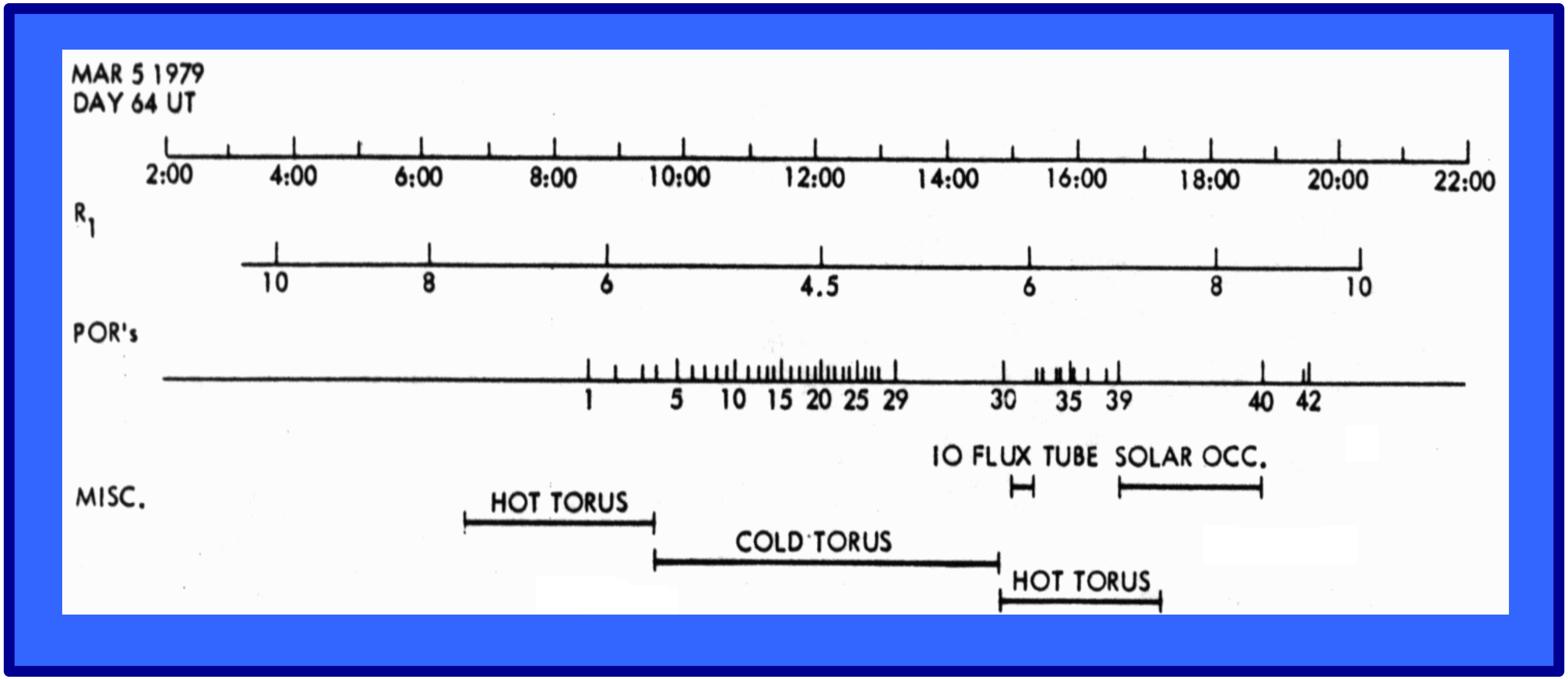
Voyager 1 PORs



Temporal and spatial occurrences of the 42 Voyager 1 POR anomalies during the March 5, 1979 flyby [Leung et al., 1986]

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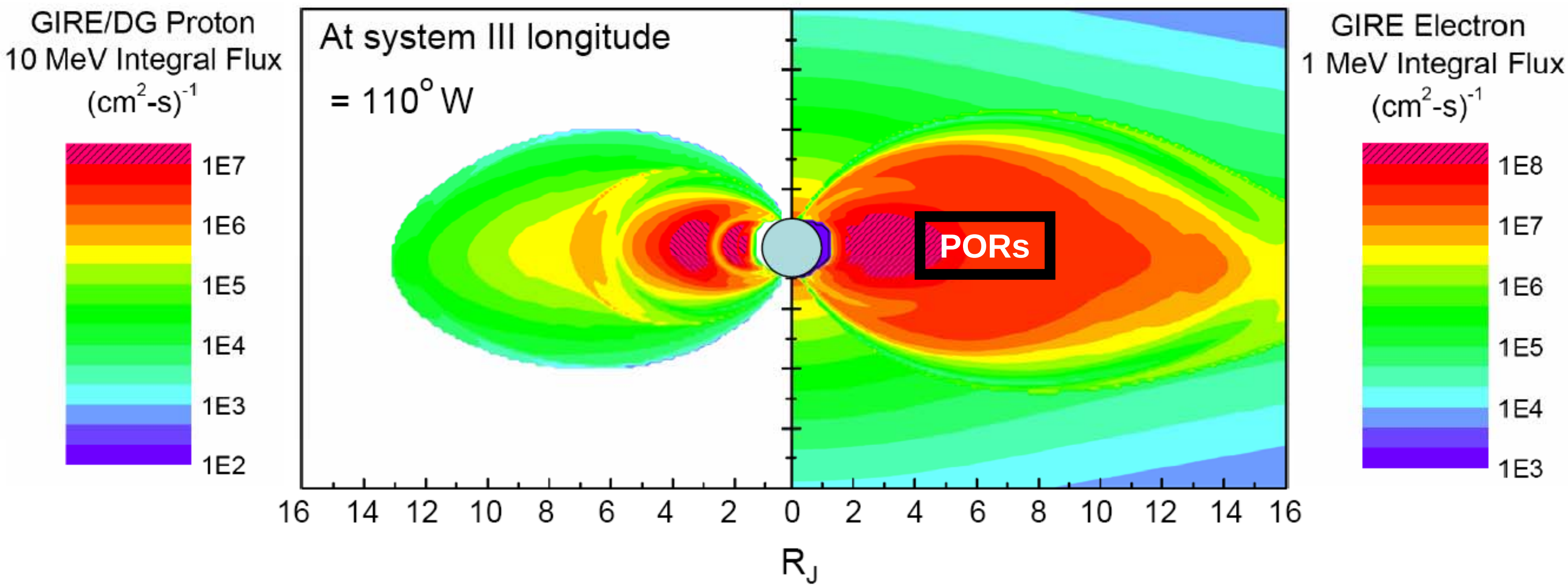
JOVIAN RADIATION MODELS



Contour plots of ≥1 MeV electron and ≥10 MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models*. Meridian is for System III 110° W.

***[Divine and Garrett, 1983], [Garrett et al., 2003]**

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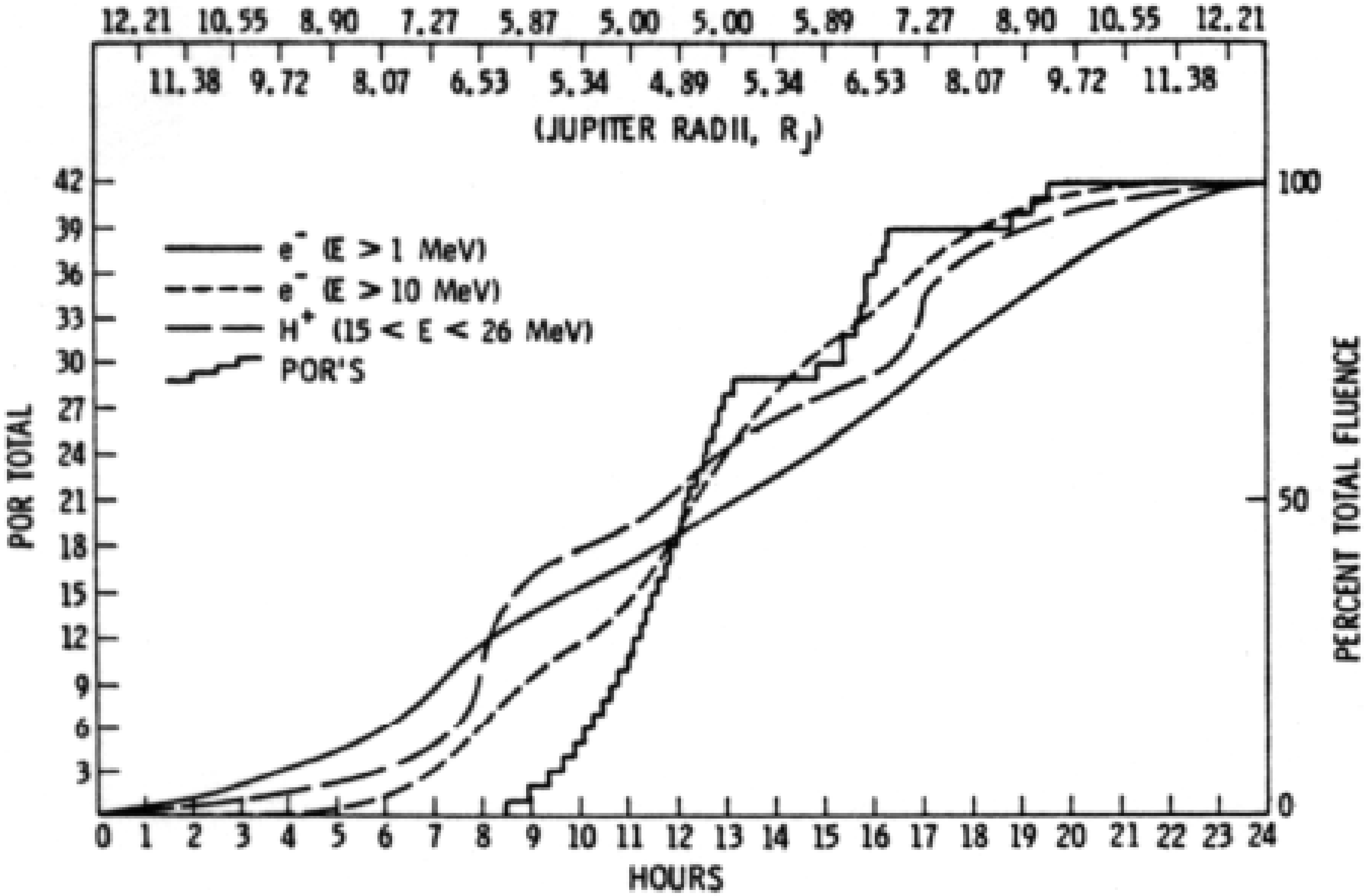
Voyager 1 PORs



Cumulative occurrence frequency of 42 Voyager 1 POR anomalies vs cumulative high energy electron (E>1 MeV and E>10 MeV) and proton (15 MeV<E< 26 MeV) fluences [Leung et al., 1986].

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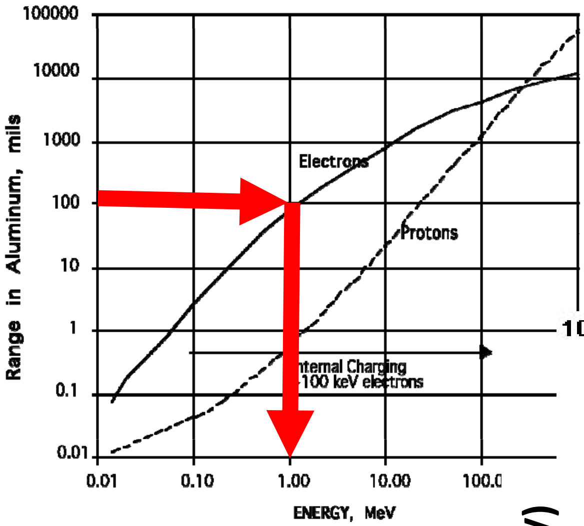
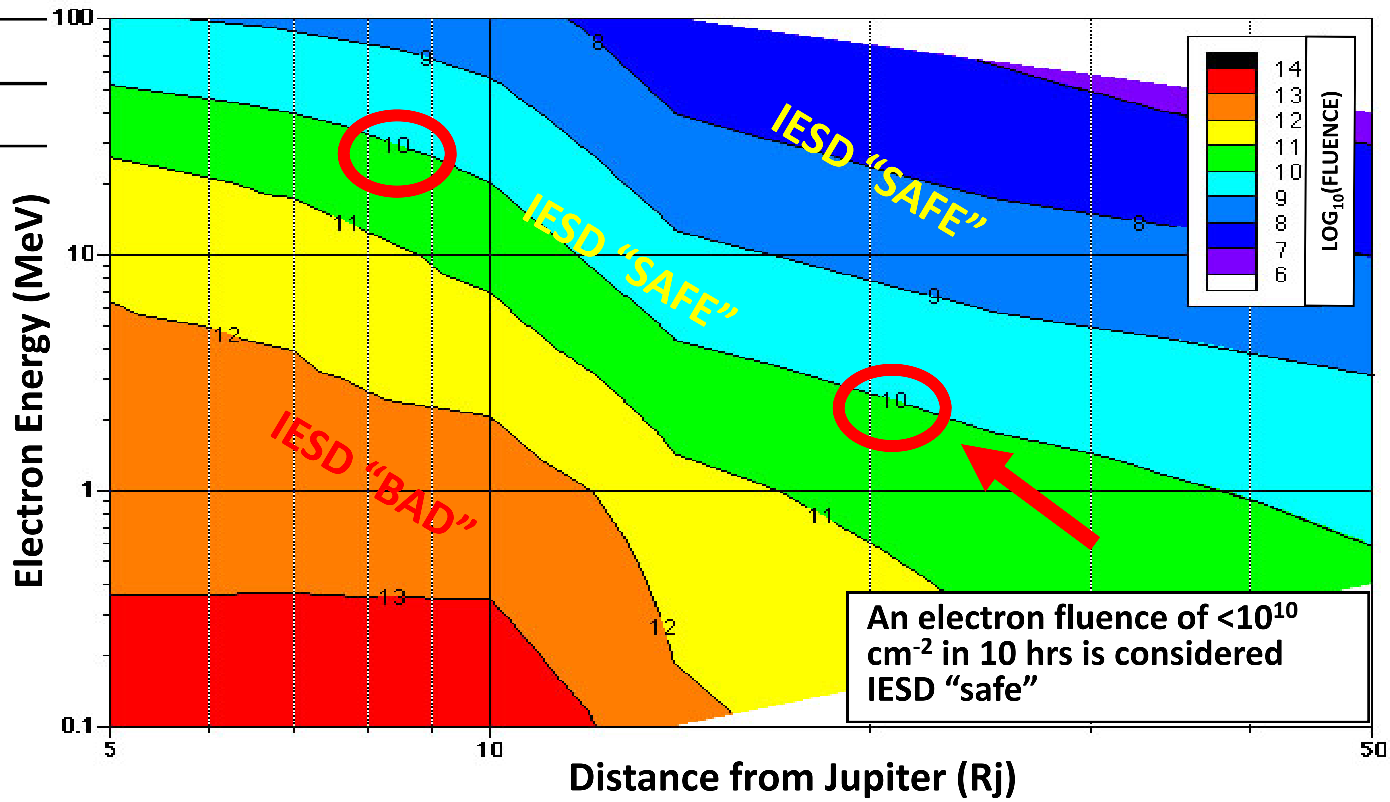
Jovian IESD



e$^-$, H$^+$ ranges in Al [Whittlesey, 1999].



Contour plot of *Log electron fluence* in (cm^{-2}) versus flyby perijove distance and energy [Evans and Garrett, 2002].

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Jovian IESD

We find:

•The main radiation belt at Jupiter is dominated by 1-100 MeV electrons

•The time integrated flux of the high energy electons (e.g, the fluence vs time) is consistent with the pattern of Voyager 1 PORs.

This implies:

•PORs were likely caused by IESD on Voyager 1

•The IESD threat is potentially very severe at Jupiter due to its intense, high energy electron belt

•***<u>A thorough IESD mitigation program is a critical component of any mission to regions inside ~16 Rj at Jupiter</u>***

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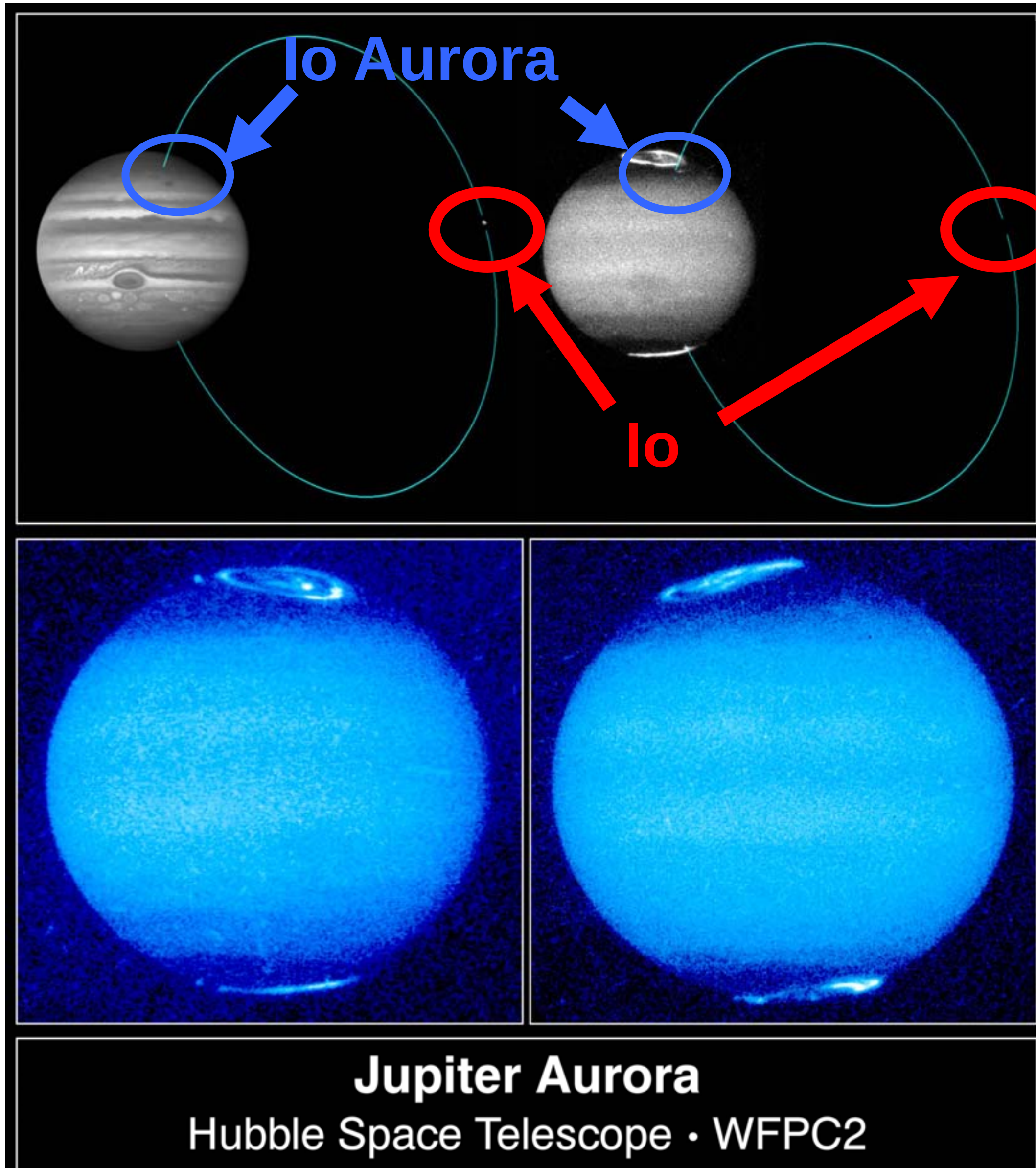
VxB Effects at Jupiter

Theory: An inductor moving across an electric field generates a potential difference across the inductor:

$$\phi = v \times B \cdot l$$

For Io:

- B **~ 0.02 G**
- v **~ 17.3 km/s**
- l **~ 3640 km**
- ϕ **~ 125,000 V!!**



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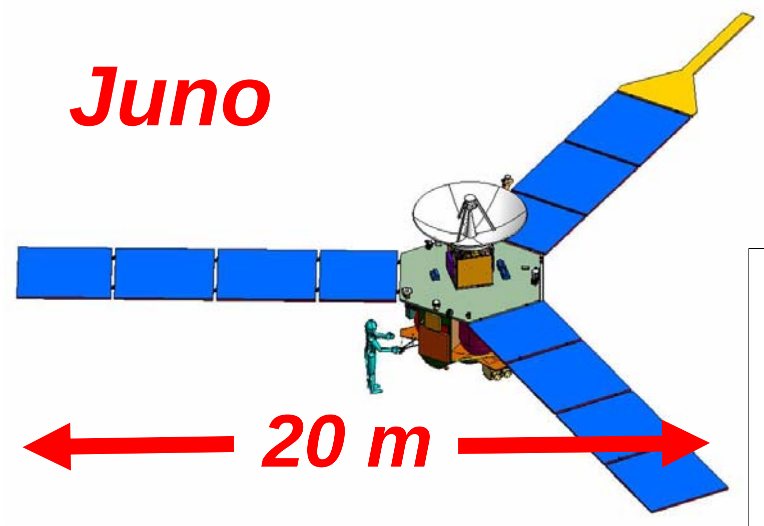
Juno VxB



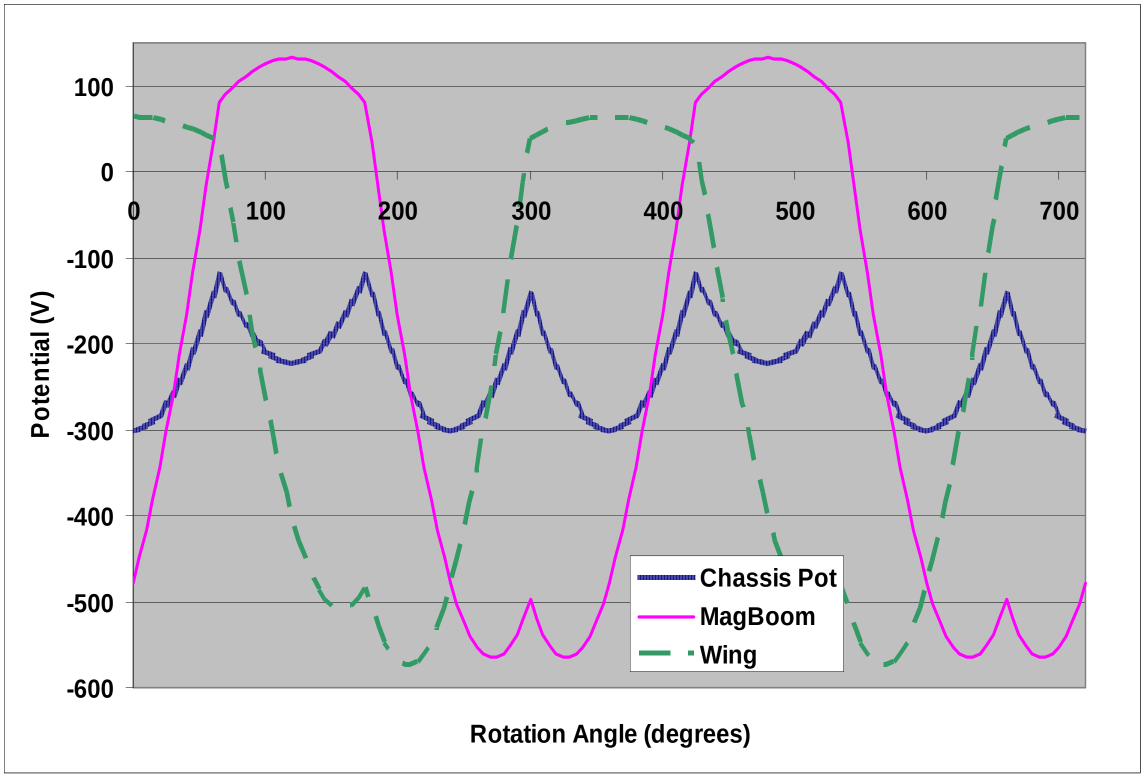
For Juno:

B ~ 10 G

v ~ 60 km/s

l ~ 20 m

ϕ ~ 1200 V



Angular dependence of vxB potentials for Juno surfaces

Jovian VxB

We find:

•vxB induced electric fields at Jupiter are real and readily visible—Io has a field of over 125,000 V!

•A polar orbiter skimming the upper atmosphere of Jupiter like Juno could see fields of 60 V/m producing as much as a 1200 V drop across the spacecraft

This implies:

•vxB effects will be measurable on Juno and will potentially affect low energy plasma and electric field measurements (magnetic field measurements will not be affected)

•***Care must be taken in grounding the solar arrays though the likelihood of arcing is limited***

Conclusion

We Found:

•Charging effects in Jupiter's environment first became of interest as a result of 42 POR events during the Voyager 1 flyby.

•Surface potentials of ~1-5 kV might indeed be possible due to jovian auroras but the PORs did not appear to be connected to surface charging.

•The jovian electron radiation environment using the Divine radiation models implied that Voyager PORs were most likely the result of IESD which could be a real problem at Jupiter.

•Visual observations of auroral spots associated with the jovian moons from the Earth prove that vxB-induced electric fields are real.

•Estimates of the vxB fields showed that for the Juno mission the field will reach 60 V/m giving potentials of ~1 kV across the 20 m structure.

•Finally, none of these effects has proven to be so severe that standard charging mitigation techniques wouldn't be adequate to limit them**—*there should be no serious show stoppers due to spacecraft charging at Jupiter as long as care is taken in preparing spacecraft for this harsh, challenging environment!***

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