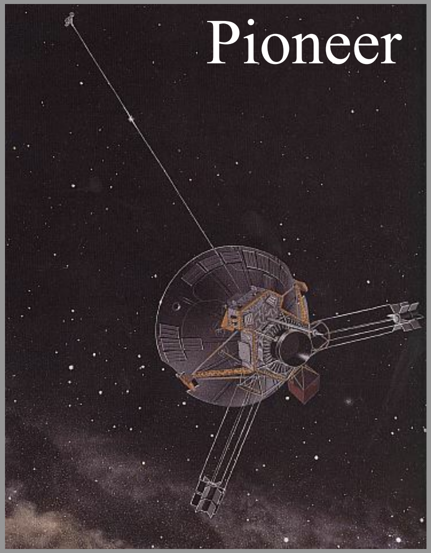
Space Environments
and Effects Section



Surface charging and deep electric charging effects in the Jovian environment

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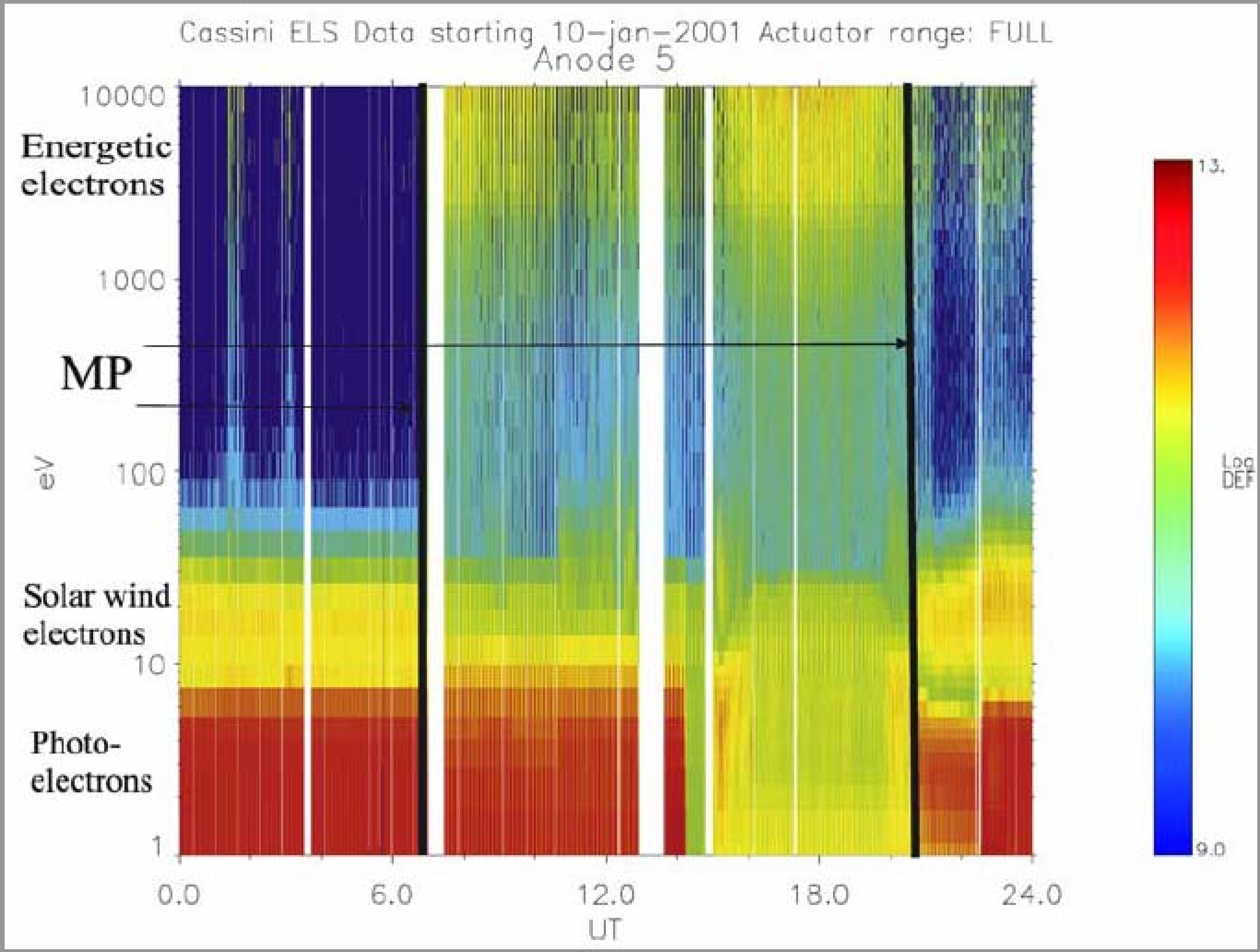
EJSM

- Possible launch 2020
- Spacecraft
  - Jupiter Europa Orbiter
  - Jupiter Ganymede Orbiter
    - Ganymede
    - Callisto
  - Jupiter Magnetospheric Orbiter
- Phases
  - Interplanetary cruise
  - Jupiter magnetosphere
  - Moon orbit

Past missions

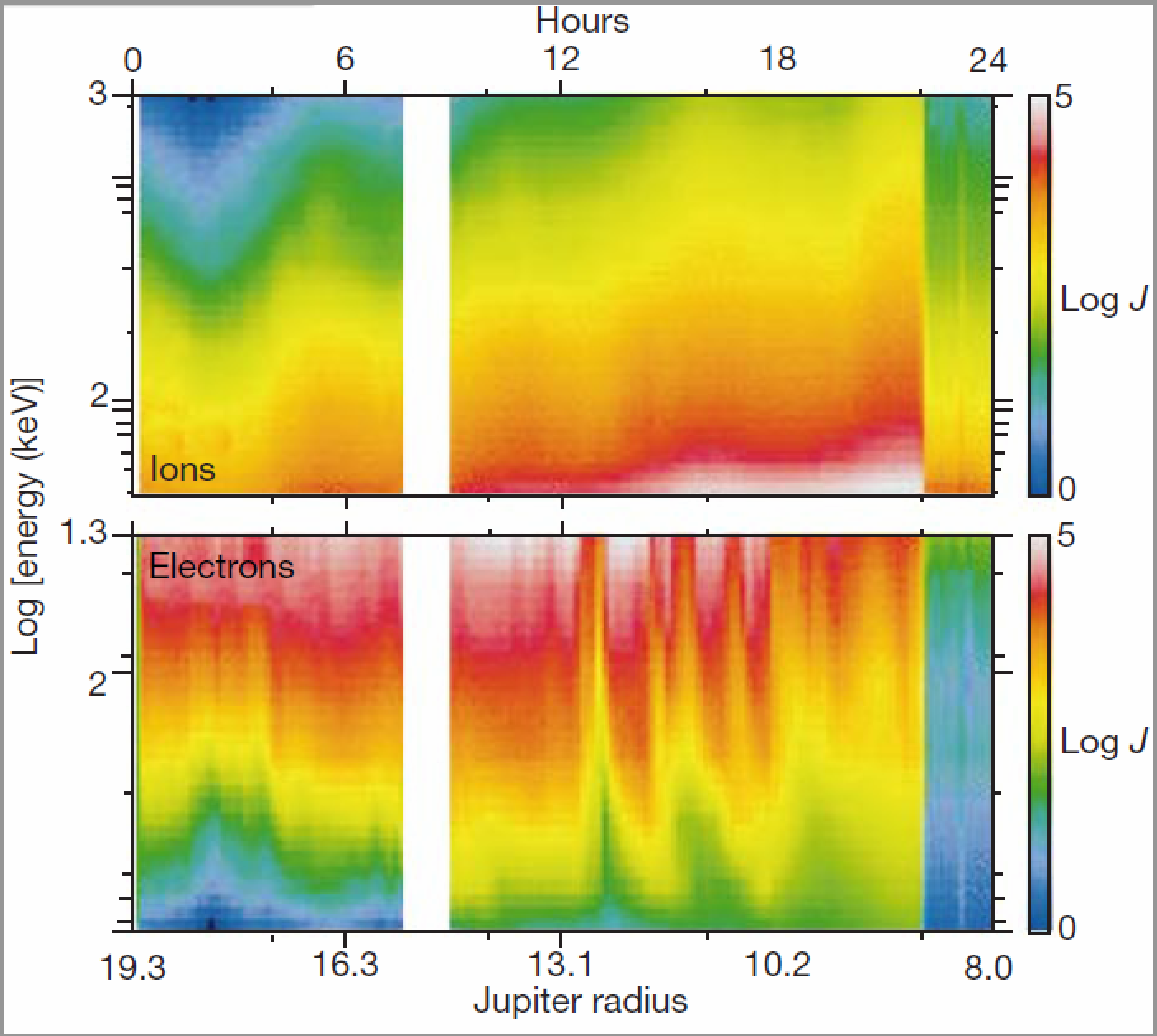
- Pioneer 10,11 (1973, 1974)
- Voyager 1,2 (1979)
- Galileo (1995-2003) (30 fly-bys)
- Ulysses (1992)
- Cassini-Huygens (2000)
- New Horizons (2007)



Transition from cold solar wind to hot plasma can been seen at magnetopause crossing (MP).

Drop-out of photo-electrons during eclipse

Svenes et al 2004 - Cassini/CAPS



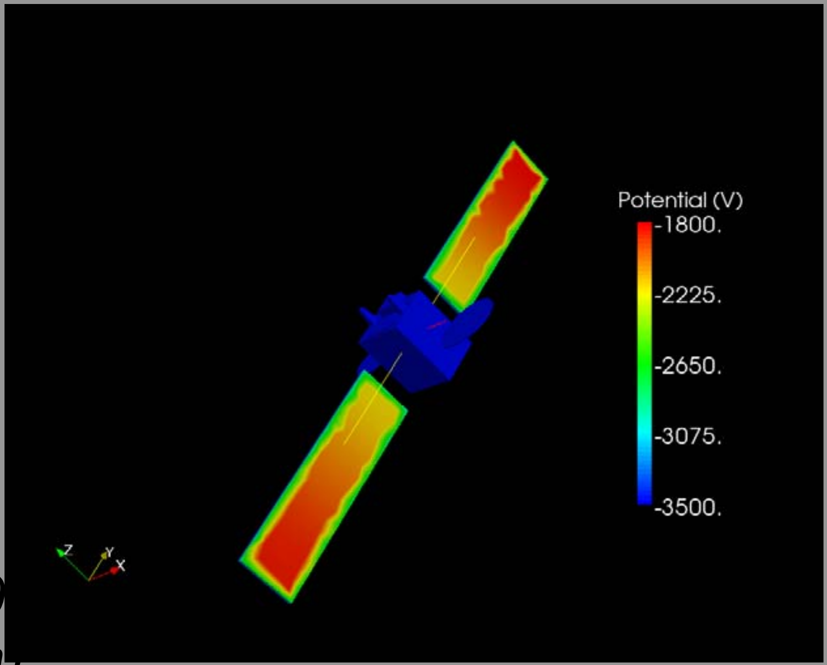
Hot Jovian electron populations experience dynamic changes in flux similar to substorms in the Earth's magnetosphere.

Mauk et al Nature 2002
Galileo

Surface charging

The low-energy electrons cause build-up of electric charge on spacecraft surfaces

- Surface dielectrics
- Ungrounded surface metals



Absolute (Frame) charging
Differential charging

$$J = J_e - J_i - J_{ph} - J_{\sec} - (J_{cond})$$

Je – primary electron current *func(V,geom)*
Ji – primary ion *func(V)*
Jph – photo emission current *func(F_{UV}, mat, geom)*
Je – secondary electron current *func(E_e, mat, geom)*
Jcond – conducted current *func(dV, mat, thickness)*

Equilibrium *J(V, mat, F_{UV},geom,dV,thickness)=0.*

Surface charging

ESD

- Thresholds
  - Normal Voltage Gradient V<-1kV,
  - Inverted Voltage Gradient V>+100V
  - Punch-through E>10MV/m
- Effects
  - Electrical transients (often large but outside Faraday cage)
  - Material damage

Other Effects

- Disturbance to electric field, plasma measurements
- Acceleration of particles towards surfaces (contamination, sputtering, erosion)
- Acceleration/deceleration of particles from active devices

Instruments potentially sensitive to surface charging

- Surface potential
  - Plasma spectrometers,
  - Electric field instruments,
  - Plasma wave instruments,
  - Dust analysers,
  - Magnetometers (via changes in currents)
- ESD
  - All instruments

Surface charging

Mitigation

- •Grounding strategy
    - •Grounding floating metals (<1MΩ)
    - •Metallic coatings
    - •Avoiding metal/dielectric/vacuum boundaries
- •Apertures smaller than Debye length
- •Material selection
    - •High photo/secondary emission yield
    - •High conductivity or thin
- •Potential control
    - •Electron/ion guns
    - •Plasma contactors

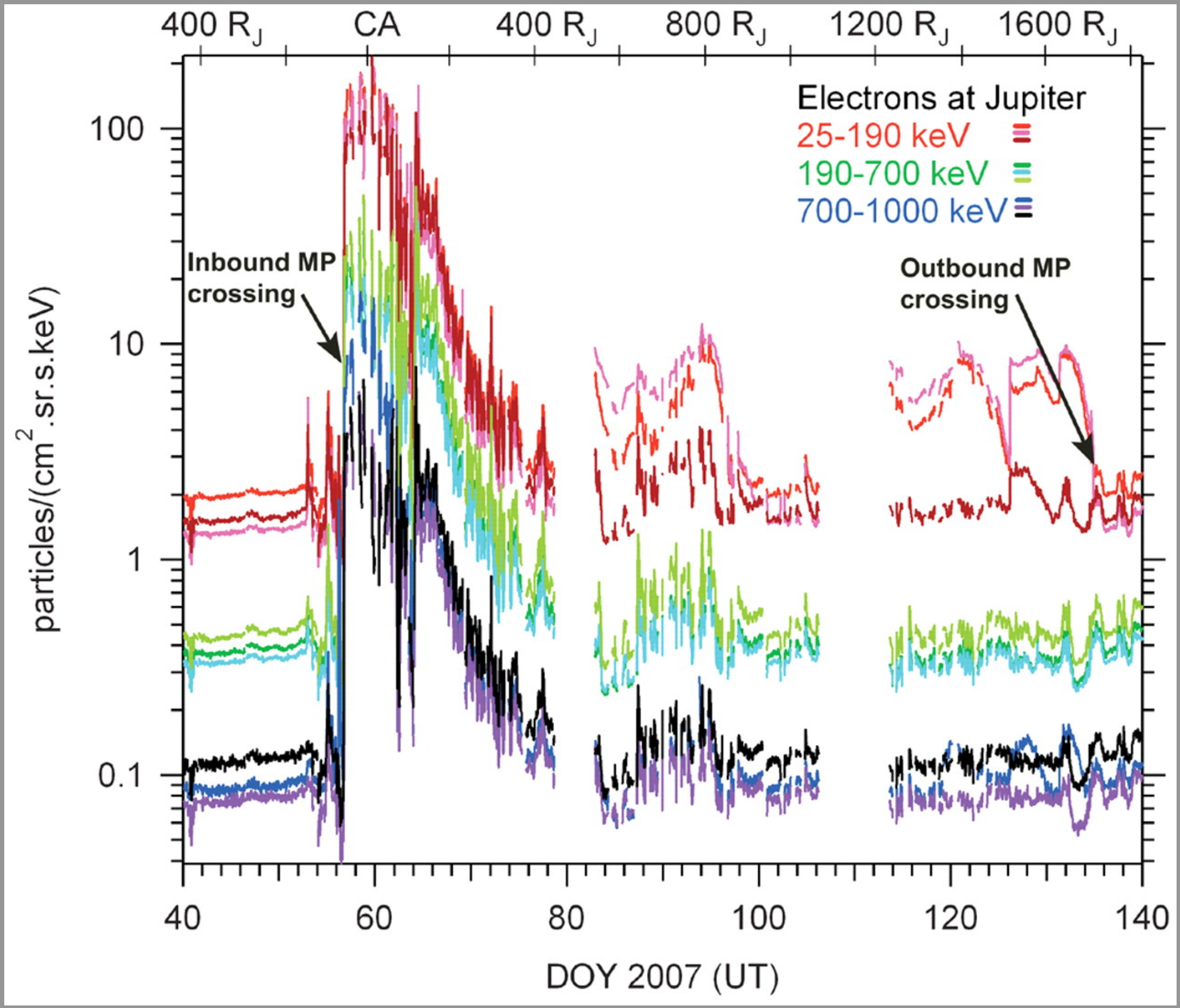
Surface charging analysis

Geometric tools (not exclusive)

- SPIS (EU)
- NASCAP/GEO (US)
- NASCAP-2k (US)
- Spacecraft charging handbook (US)
- MUSCAT (J)

Simple tools

- EQUIPOT (EU)
- MATCHG (US)



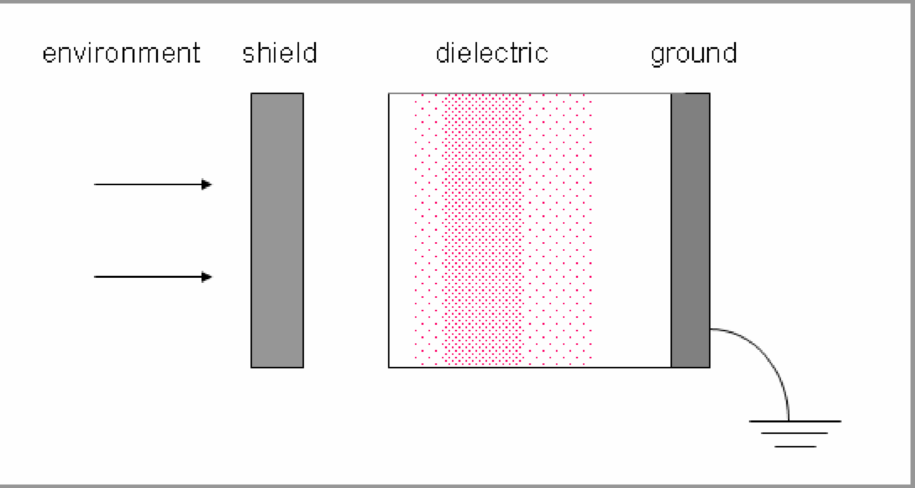
High energy electron population is seen on crossing the magnetopause. This mission started at the front of the magnetosphere and passed down the tail.

McNutt et al 2007
New Horizons

Internal charging

High energy electrons (>300keV) penetrate surface layers and cause the build-up of charge in internal structures, affecting

- Dielectrics
- Ungrounded metals



$$J = J_e - J_{cond}$$

J_e – primary electron current *func(shielding)*
J_{cond} – conducted current *func(E, mat)*

Equilibrium $J_{cond}=J_e$

$$E = J_{cond}.r(T,\dot{D},mat)$$

Internal charging

Material conductivity σ is crucial in determining charging levels.

$$E = J / \sigma \qquad \text{(at equilibrium)}$$

Time-scale τ for hazardous charging is typically days

$$\tau = \varepsilon / \sigma$$

J increases with material thickness
σ increases with temperature and radiation dose rate

Hence cold thick dielectrics are most likely to charge

Internal charging

ESD

- Threshold
  - Punch-through E>10MV/m
  - Surface discharges also possible (<-1kV)
- Effects
  - Electrical transients (usually small but close to components)
  - Material damage

- Other effects
  - Disturbance to electric field sensitive devices
  (Instruments with MEMS components, Microgradiometers)

Internal charging analysis

Geometric tools

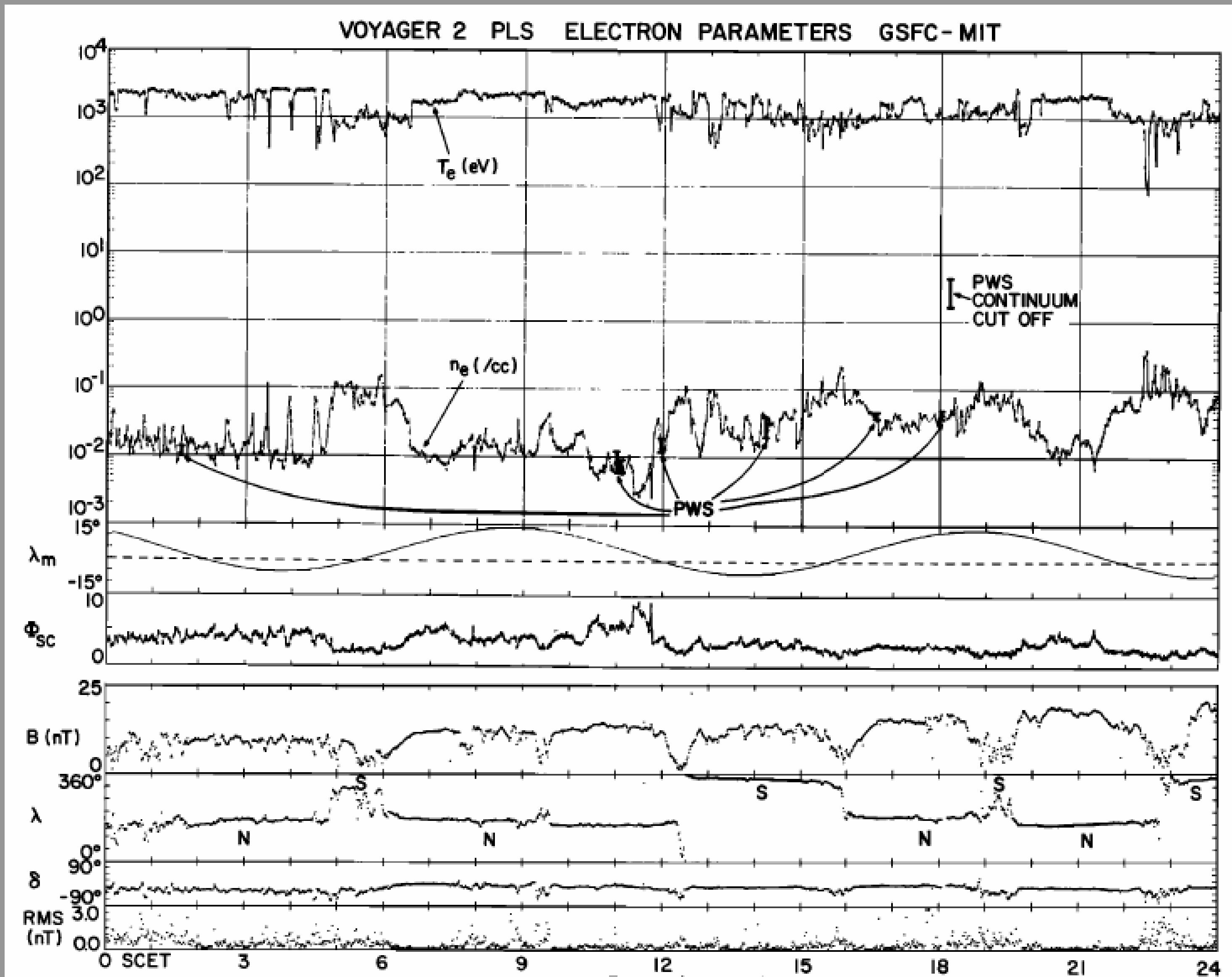
- Radiation transport tools (but don't do the whole job)
  - GEANT-4 etc.
- 3-d internal charging tool now starting development as part of ESA study

1-D Tools

- DICTAT (EU)
- NUMIT (US)

Observed Charging Effects

- Voyager 1&2
  - 42 Power-On resets during belt passage – attributed to internal charging ESD(MeV electrons in cable)
  - Few V positive to 10s V negative (-130V once) (McNutt, Scudder et al)
  - May have experienced 10s KV surface charging (Voids in plasma fluxes)
  - No surface ESD
- Galileo (carefully designed in light of Voyager experience)
  - No Internal charge anomalies



This shows that charging levels were generally low in Voyager 2, however, very low density periods, originally attributed to Ganymede wake may be due to kV charging (Khurana et al 1987)

Scudder et al 1981

Interplanetary Plasma Environment Summary

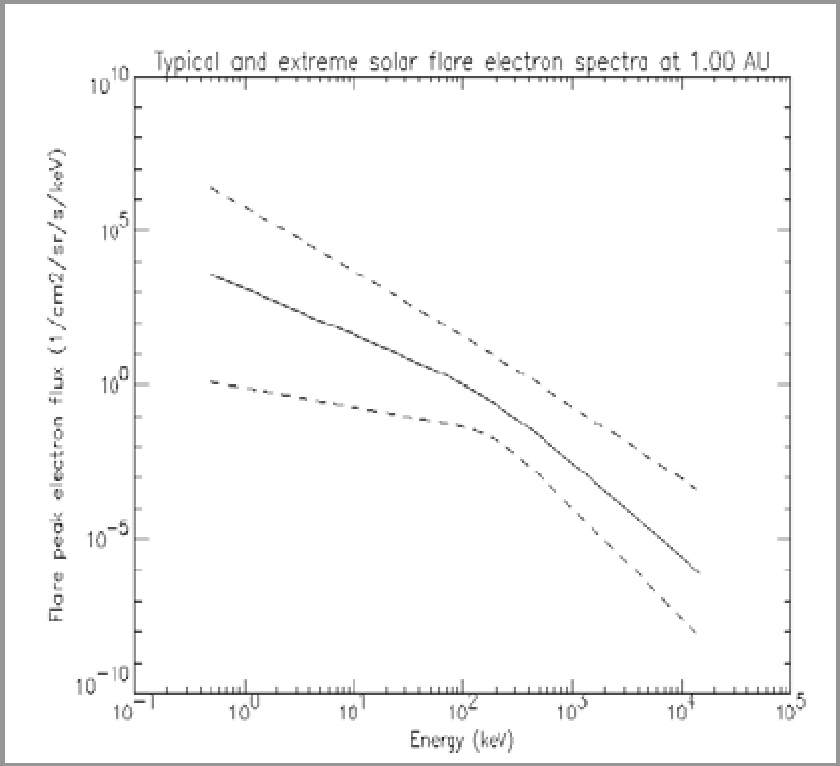
- ECSS solar wind environment based on 1AU

Table 8-2: Solar wind parameters

Parameter	Mean	5-95 % Range
Speed (km s^{-1})	468	320 - 710
Density (cm^{-3})	8,7	3,2 - 20
T_p (K)	1,2 x10^5	1 x10^4 - 3 x 10^5
T_e (K)	1,0x10^5	9 x 10^4 - 2 x 10^5
N_{alpha}/N_{proton}	0,047	0,017 - 0,078

  – $1/r^2$ mapping of density
  – $1/r^{0.64}$ mapping of electron temperature
  – No change in ion velocity

Solar electron events



An ESA study to create a model of Solar Electron Events, for use in internal charging analysis has begun.

Nieminen 1999

Jupiter Environment Summary

Distance to the Sun	5.2AU
Sunlight intensity	50.5 W/m2 (3.6% of 1AU)
Magnetopause	60-100Rj
Magnetotail	>200Rj
Regions	Inner magnetosphere 1 to 6Rj Middle magnetosphere 6 to 40Rj –Neutral sheet –Plasma disk –Equatorial currents Outer magnetosphere 40Rj –Dynamic fluctuations
Magnetic tilt angle	10.8°
Io, Europa, Ganymede Callisto	5.9, 9.4, 15.0, 26.4 Rj

Trapped Radiation Models

- Divine &Garrett (1983)
  - Based on Pioneer and Voyager data
- GIRE (Galileo Interim Radiation Environment) (1995)
  - Limited coverage (8-16Rj)
- Salammbo-3D (1998)
  - <9.5Rj (electrons), <6 Rj (protons)
- Combined model

DIVINE AND GARRETT: THE MAGNETOSPHERE OF JUPITER

TABLE 1. Data Sources for Jupiter Charged Particle Models

Instrument	Data Type	References
	Pioneers 10 and 11	
Helium vector magnetometer (HVM)	vector magnetic field	*Smith et al.* [1976]
Flux gate magnetometer (FGM)	vector magnetic field	*Acuna and Ness* [1976*a*, *b*]
Plasma analyzer (PA)	electrons and protons, 0.1 to 4.8 keV	*Frank et al.* [1976]
Geiger tube telescope (GTT)	electrons >0.06, 0.55, 5, 21, 31 MeV protons 0.61–3.41 MeV	*Van Allen et al.* [1974, 1975], *Van Allen* [1976], and *Baker and Van Allen* [1977]
Trapped radiation detector (TRD)	electrons >0.16, 0.26, 0.46, 5, 8, 12, 35 MeV protons >80 MeV	*Fillius and McIlwain* [1974], *Fillius et al.* [1975], and *Fillius* [1976]
Low-energy telescope (LET)	protons 1.2–2.15 and 14.8–21.2 MeV	*Trainor et al.* [1974, 1975] and *McDonald and Trainor* [1976]
Electron current detector (ECD)	electrons >3.4 MeV	*Simpson et al.* [1974, 1975]
Fission cell (F1)	protons >35 MeV	*Simpson and McKibben* [1976]
	Voyagers 1 and 2	
Flux gate magnetometer (MAG)	vector magnetic field	*Ness et al.* [1979*a*, *b*]
Planetary radio astronomy (PRA)	electric vector, 1.2 kHz to 40.5 MHz	*Warwick et al.* [1979*a*, *b*] and *Birmingham et al.* [1981]
Plasma wave (PWS)	10 Hz to 56 kHz	*Scarf et al.* [1979] and *Gurnett et al.* [1979]
Plasma science (PLS)	electrons 10–6000 eV ions 10–6000 V	*Bridge et al.* [1979*a*, *b*], *Bagenal and Sullivan* [1981], and *Scudder et al.* [1981]
Low-energy charged particle (LECP)	electrons >15 keV ions >30 keV	*Krimigis et al.* [1979*a*, *b*, 1981]
Cosmic ray telescope (CRT)	electrons 3–110 MeV ions 1–500 MeV/nucleon	*Vogt et al.* [1979*a*, *b*]
	Earth	
Radio telescopes	UHF intensity and polarization	*Berge and Gulkis* [1976] and *dePater and Dames* [1979]

Divine & Garrett Model

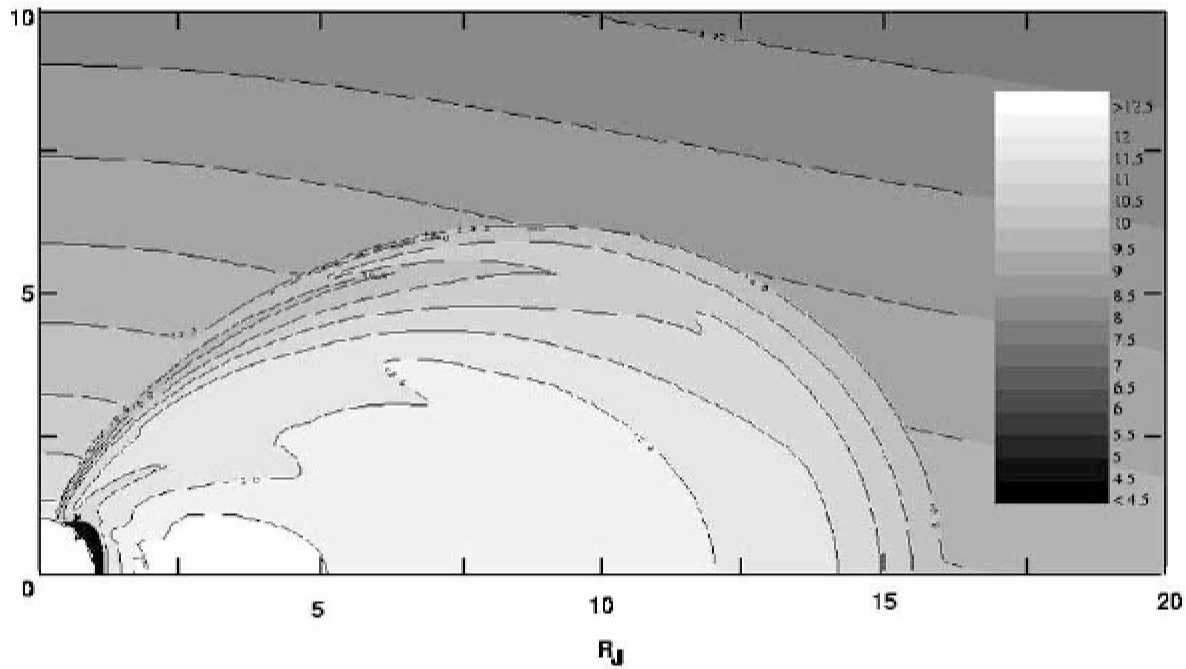
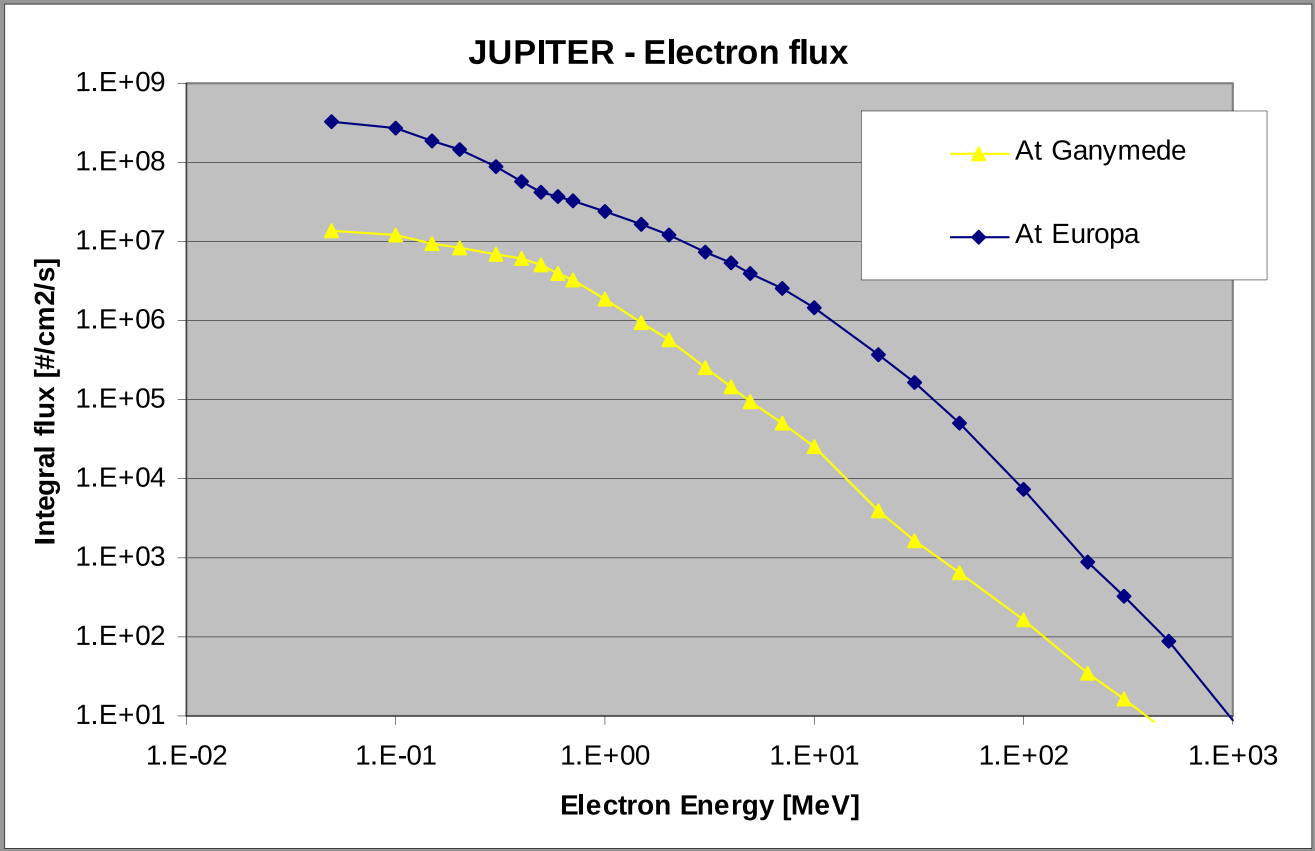


Fig. 4. Contour plot of the E>1 MeV high energy electron fluence (Log) at Jupiter as estimated from the Divine model. Fluences (cm^{-2}) are for a 10 hr period.

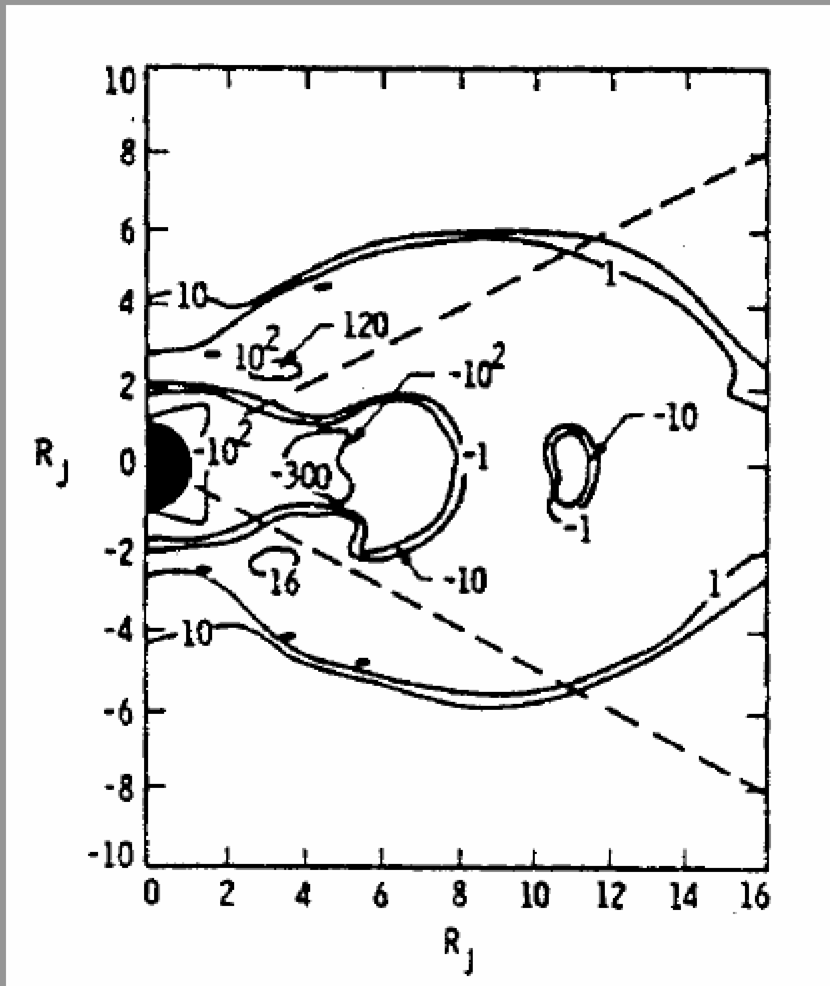
Model spectrum

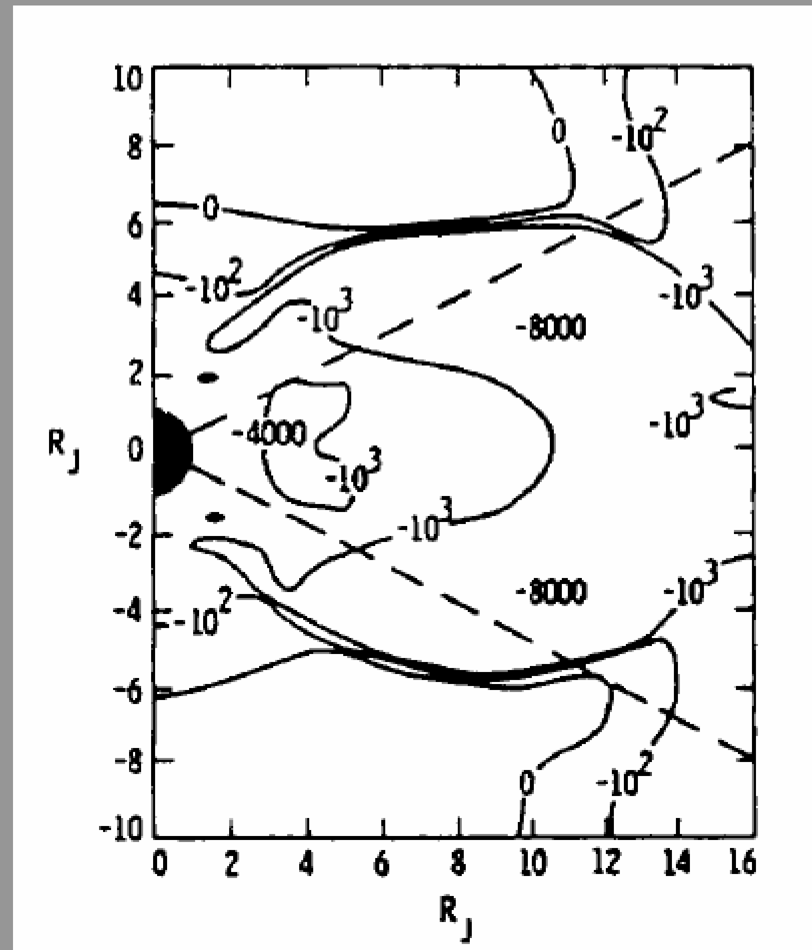


Surface charging environment

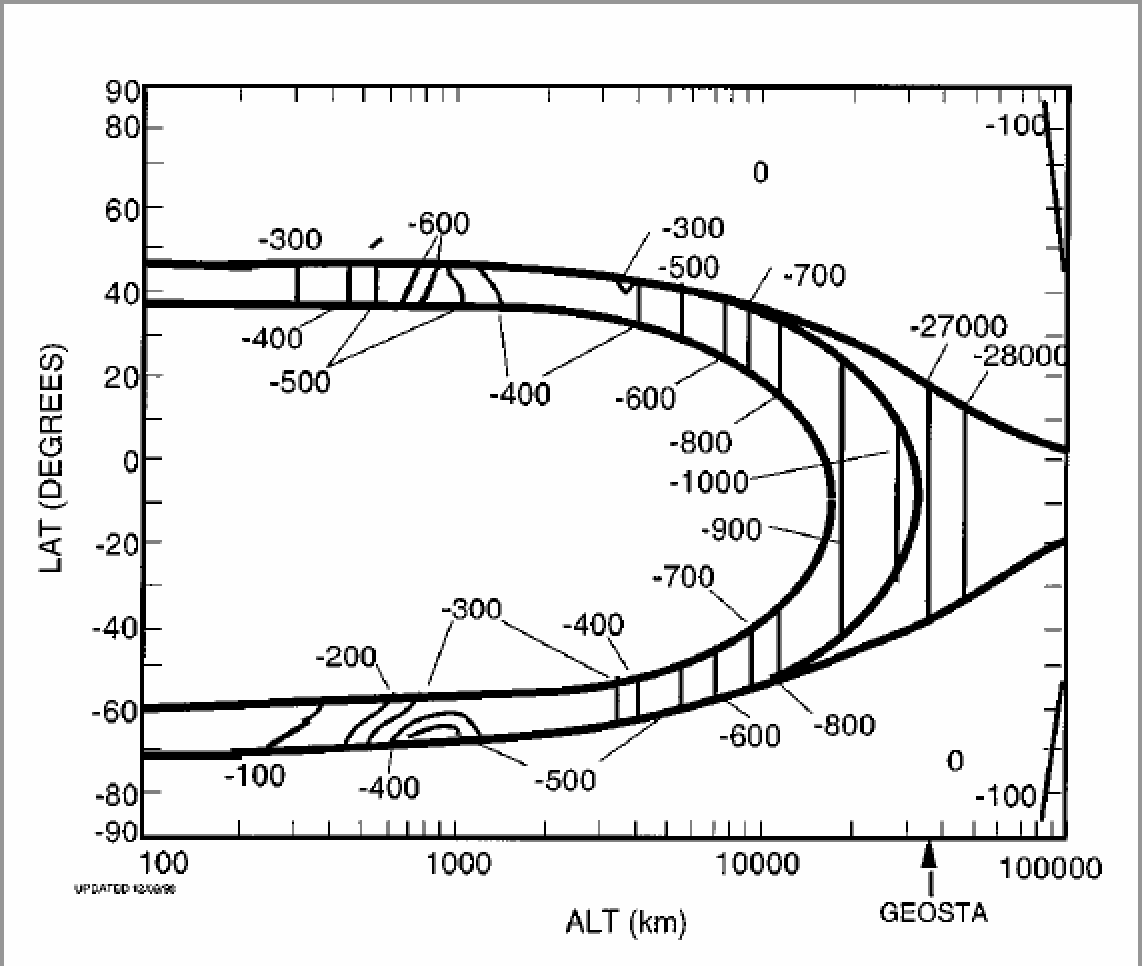
Region	Jph	re1	te1	re2	te2	rek	tek	ak	rhk	thk	hk	Vc	rhc	thc	Am	roc	toc	eV(H)	eV(Am)
Jupiter																			
cold torus 3.5 Rj	0.08	50	0.5	-	-	5	1000	2.1	1	30000	2.0	44	-	-	32	50	0.5	10	325
warm torus 5.5 Rj	0.08	1000	1	-	-	10	1000	2.0	1	30000	3.0	69	-	-	24	1000	2	25	600
hot torus 7 Rj	0.08	1000	10	-	-	5	500	2.0	5	50000	4.2	85	-	-	24	1000	40	38	911
plasmasheet 8 Rj	0.08	12	50	-	-	2	500	2.0	5	40000	3.5	100	-	-	16	12	50	53	840
outer mag 20 Rj	0.08	-	-	-	-	0.01	1000	2.0	-	-	-	250	0.01	1000	1	-	-	328	328

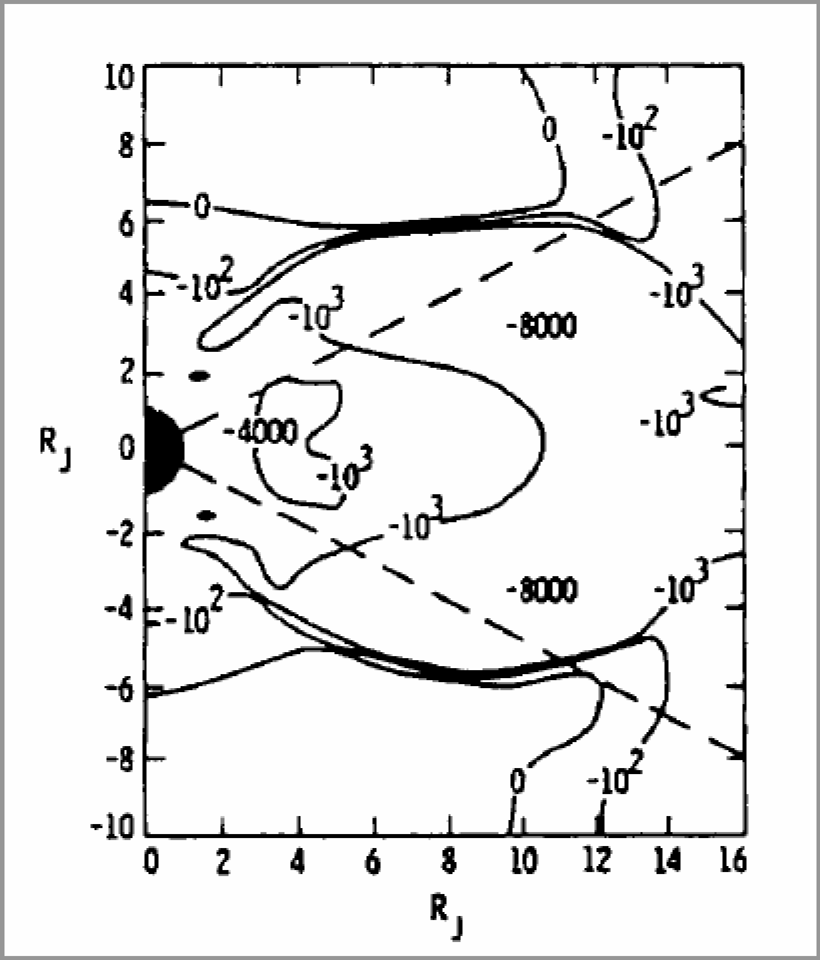
Garrett & Hoffman 2000





Garrett & Hoffman 2000- a conducting aluminium sphere (best case – worst case eclipse/potential barrier)





Garrett & Hoffman 2000- worst case comparison with Earth.

Conclusions

- Surface and internal charging both need consideration in the Jovian environment
- They could cause ESD and contaminate scientific measurements
- Despite the larger magnetosphere and decreased sunlight, the surface charging environment is less hazardous than near the Earth
- Hotter (radiation belt) electrons may mean that internal charging effects are seen deeper inside a spacecraft.
- Mean models exist for radiation belt electrons but possible enhancements are not well known

THE END