Spacecraft Charging Effects

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AGENDA

Jovian Charging Environment

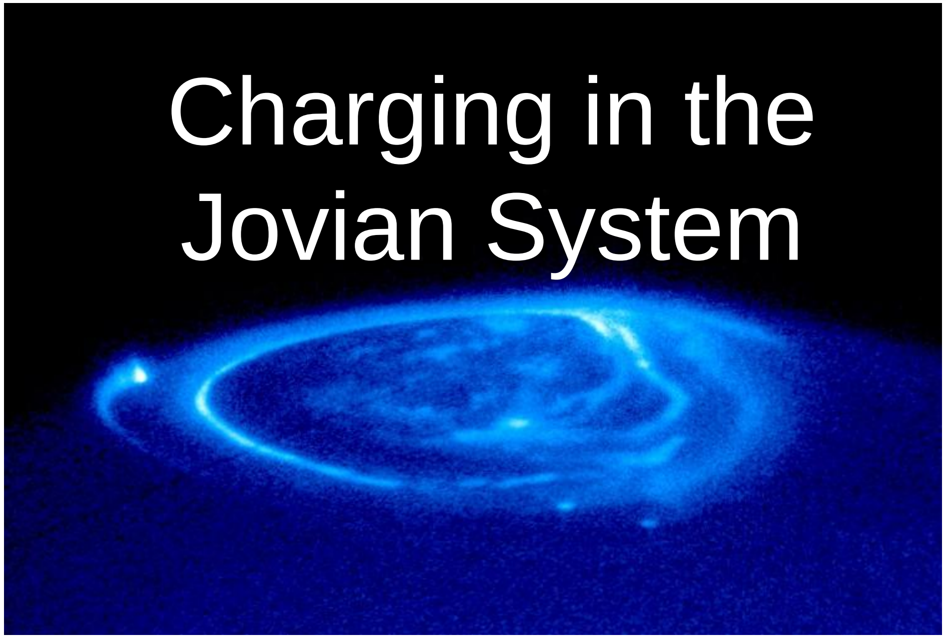
- -Plasma
- -Radiation
- -Aurora
- -VxB

Spacecraft Charging

- -Surface Charging
- -Internal Charging

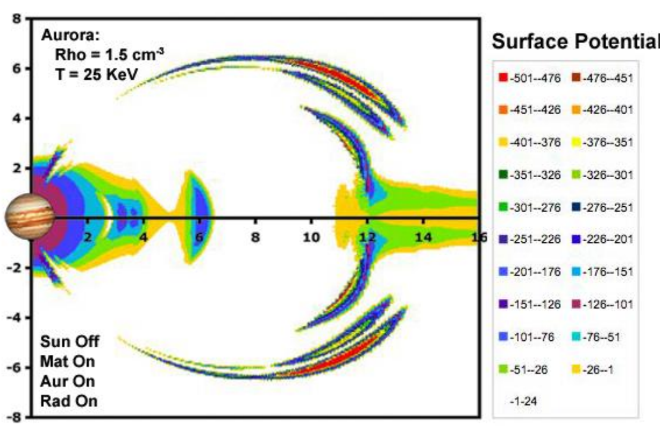
Mitigation Techniques

- -NASA-HDBK-4002A



JOVIAN CHARGING ISSUES

POSSIBLE JOVIAN SURFACE CHARGING REGIONS



Types of Spacecraft Charging

-Surface Charging

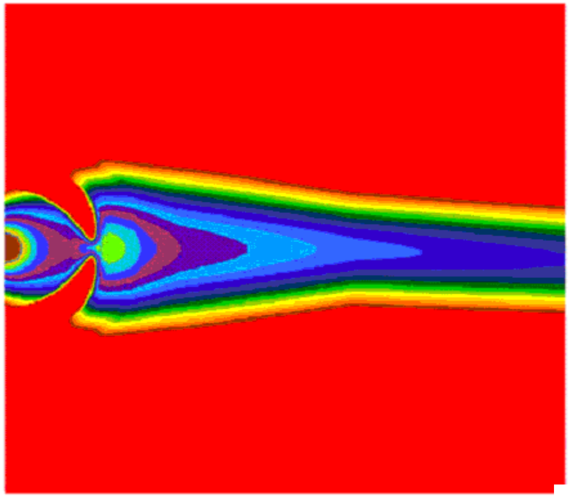
-Internal Charging

Jovian Charging Environment

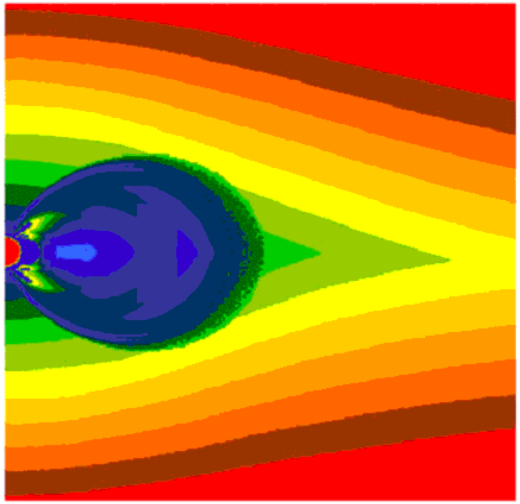
-Plasma	~1000 V Neg
-Radiation	IESD
-Aurora	~5,000 V Neg
-VxB	~30 V/m

Jupiter Charging Environment

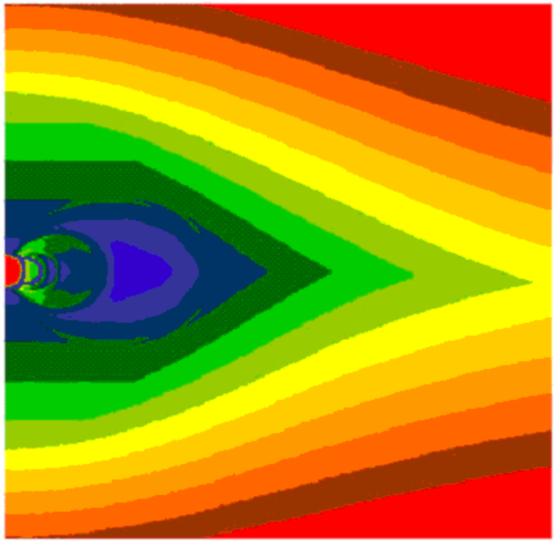
Jovian Plasma Densities



Cold Plasma Density

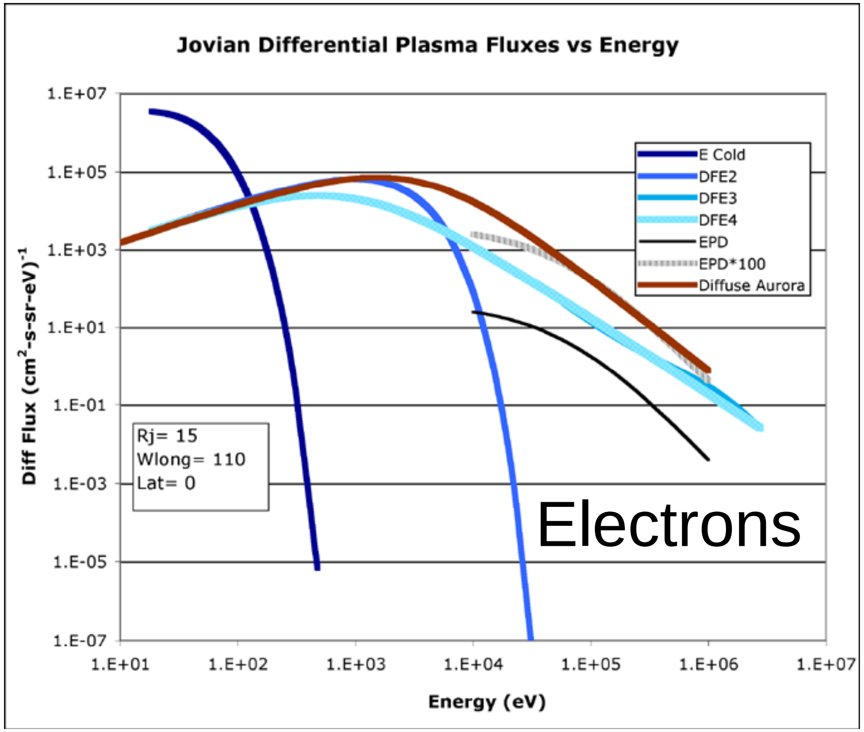


Hot Electron Density

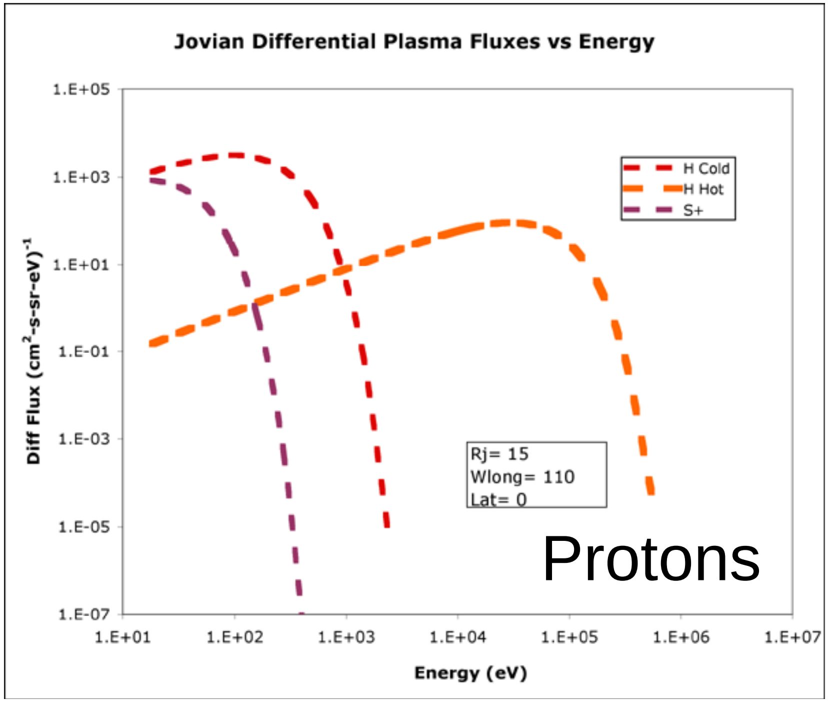


Hot Proton Density

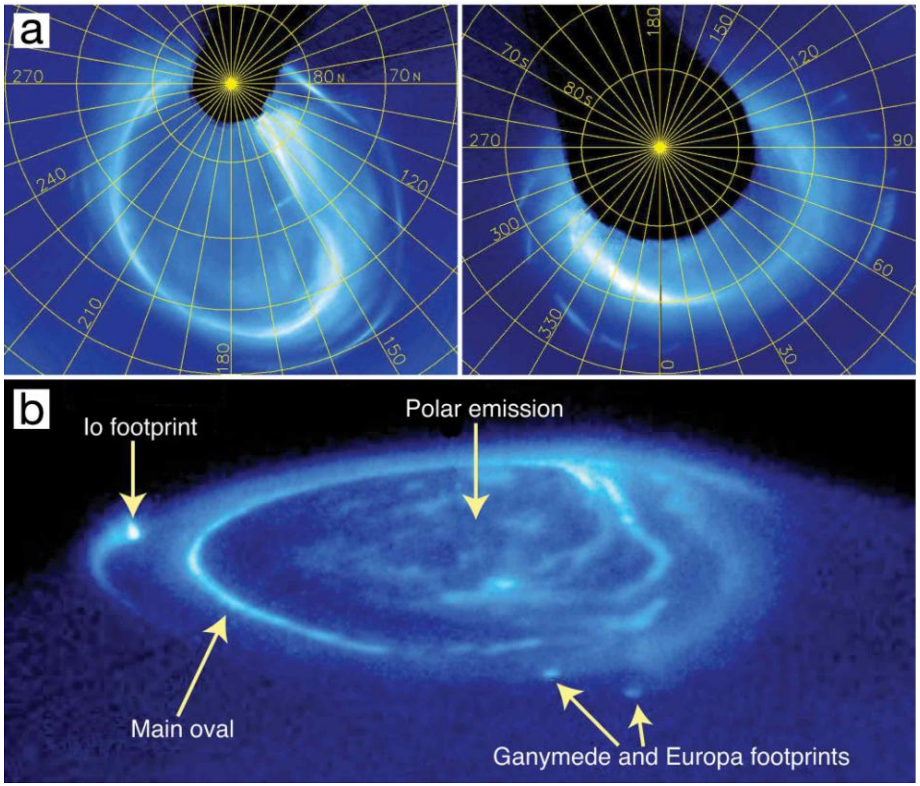
The Ambient Environment at Jupiter



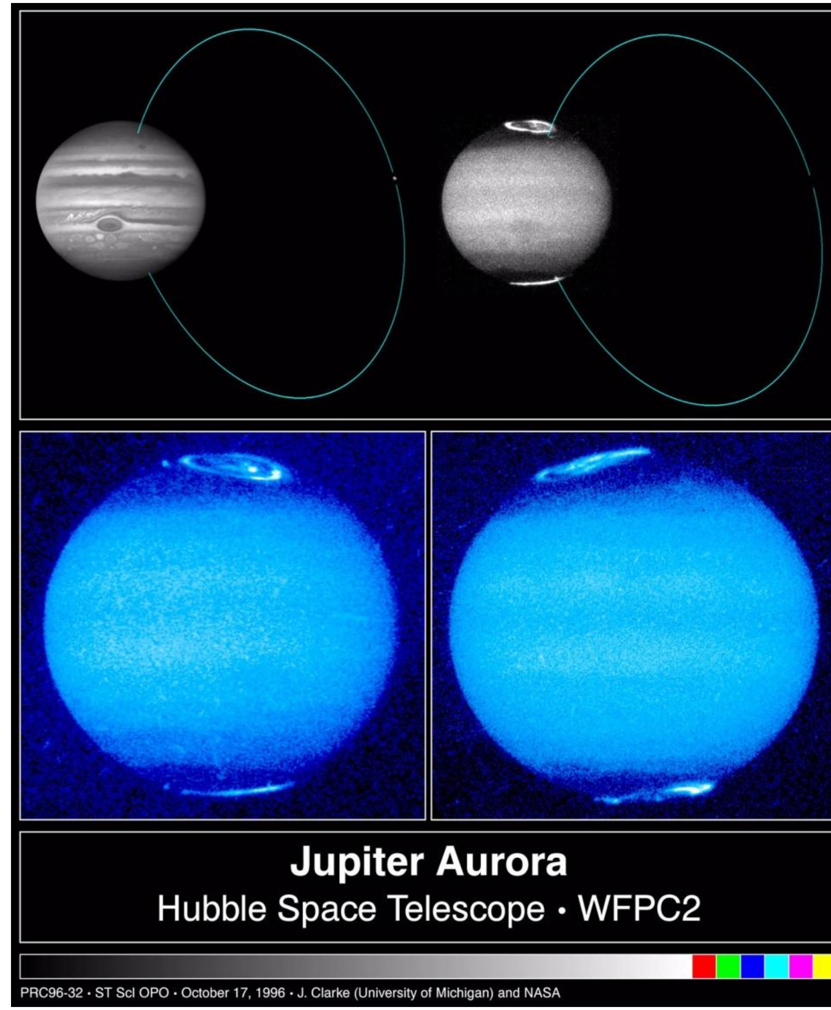
Representative Differential Spectra at 15.0 Rj--0°



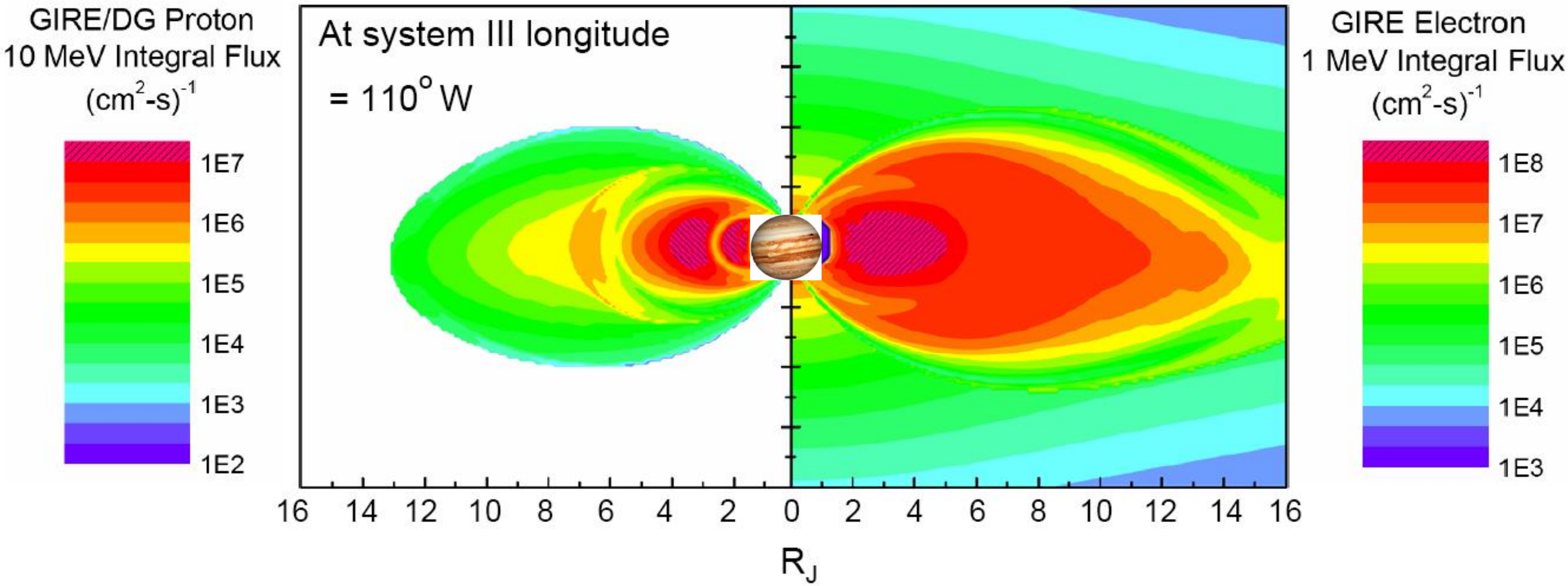
Jovian Aurora



HST UV images of the Jovian aurora. (a) Polar projections of the main auroral ovals, left is for the North Pole, right is for the South Pole. (b) Image of the northern aurora, showing main features: Main oval and polar emissions as well as footprints from three of the Galilean moons.[10]

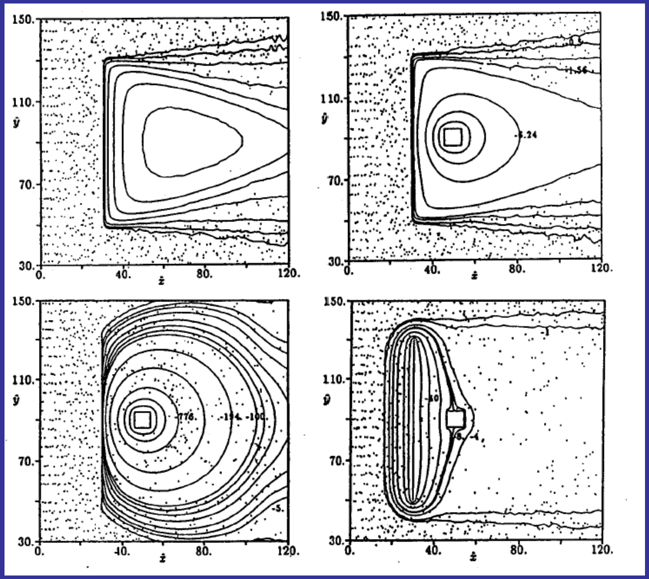


DIVINE/GIRE JOVIAN TRAPPED RADIATION MODELS

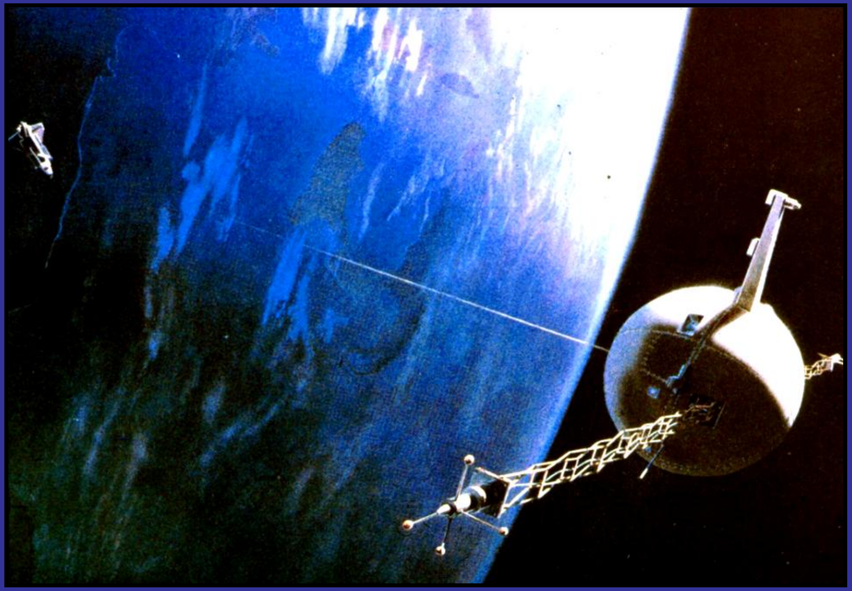


Contour plots of ≥1 MeV electron and ≥10 MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models. Meridian is for System III 110° W.

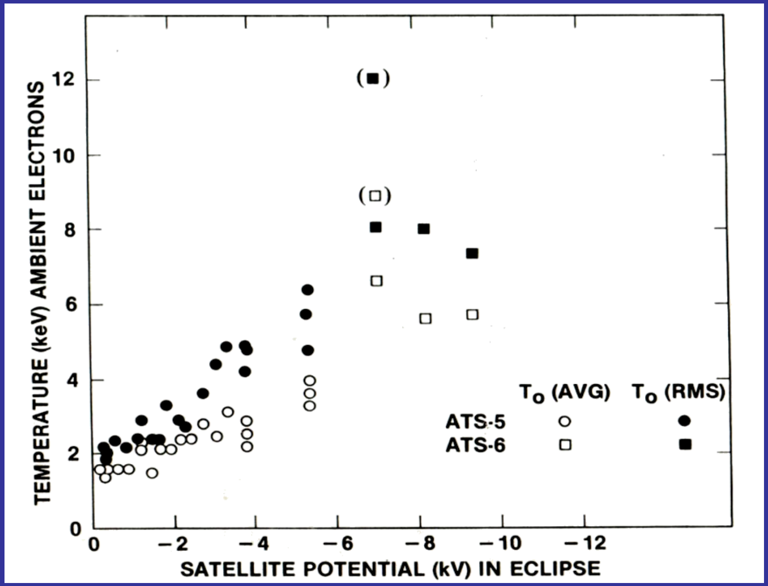
CHARGING EFFECTS



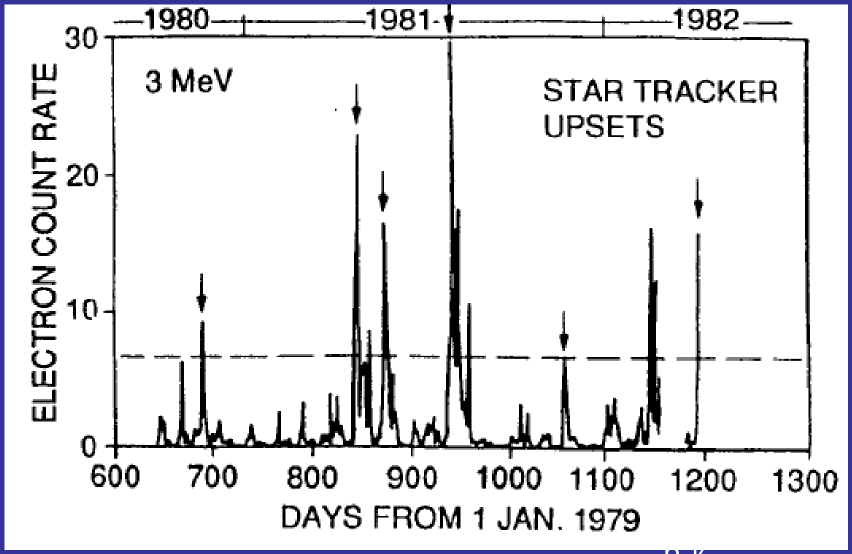
Plasma Interactions



VxB



Surface Charging

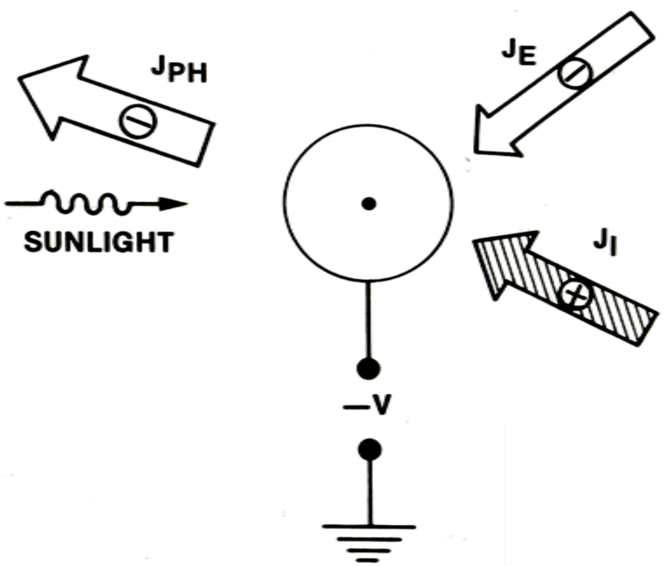


Internal Charging

Spacecraft Surface Charging

THEORY OF SPACECRAFT CHARGING

$$J_E - J_I - J_{PH} = 0$$



FOR A NEGATIVELY CHARGED SPACECRAFT:

$$J_T(V) = J_{Io}\left(1 - \frac{qV}{KT_I}\right) - J_{eo}\left(e^{qV/KT_e}\right)$$

TYPICALLY AT GEOSYNCHRONOUS ORBIT:

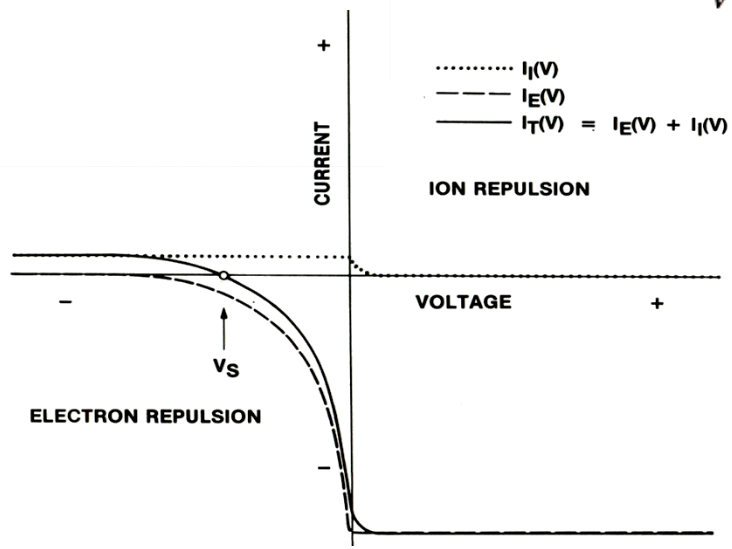
$$\frac{qV}{KT_I} \sim 0$$

FOR CURRENT BALANCE:

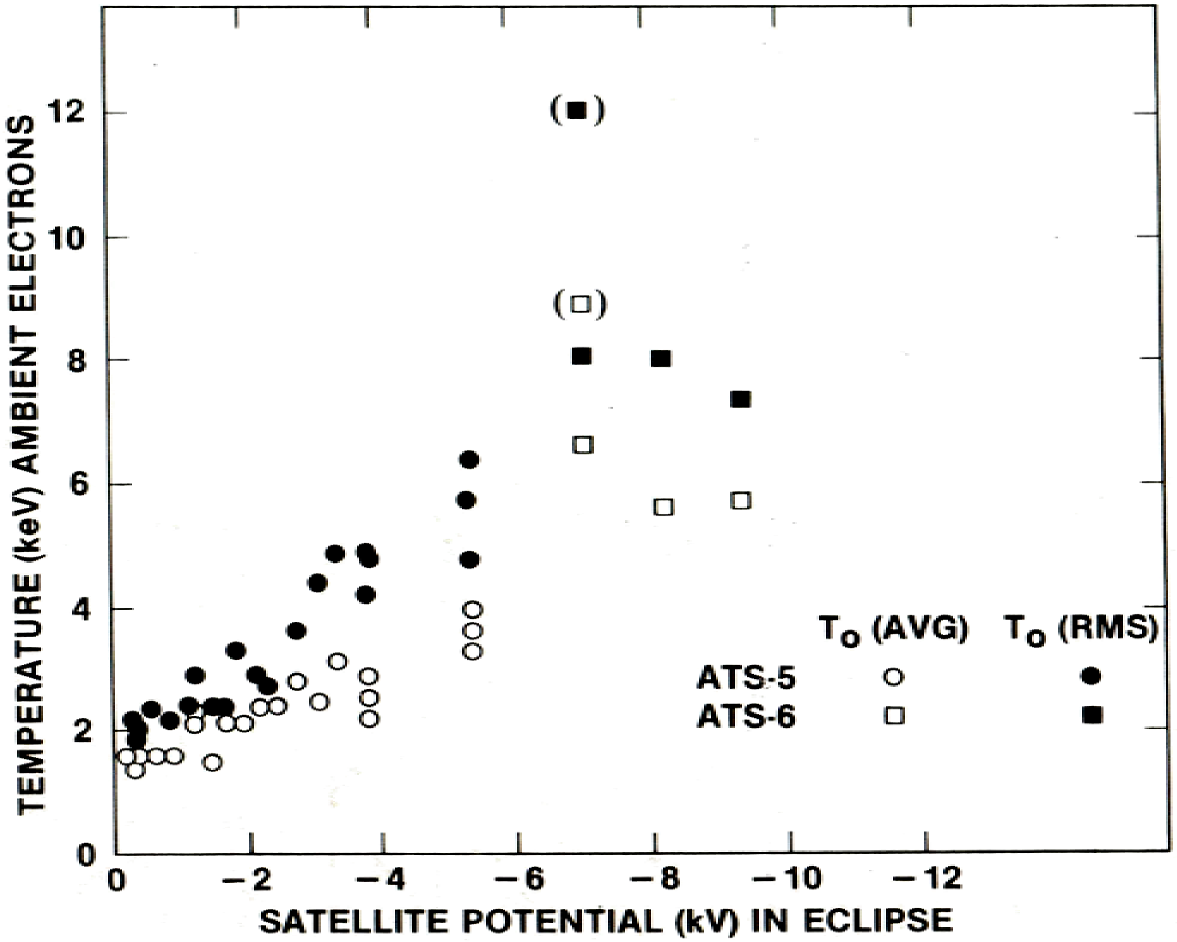
$$J_T(V) = 0$$

THIS IMPLIES:

$$V = \frac{-KT_e}{q}\ln\left(\frac{J_{eo}}{J_{Io}}\right)$$



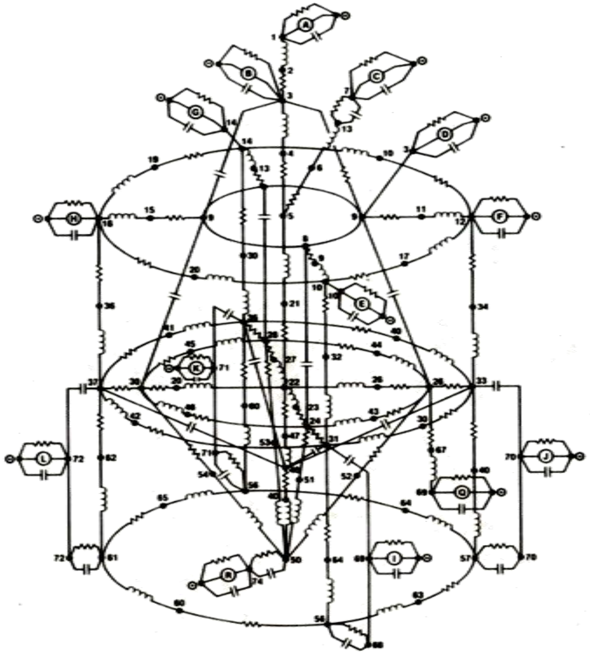
SPACECRAFT CHARGING OBSERVATIONS
PLASMA TEMPERATURE VS POTENTIAL



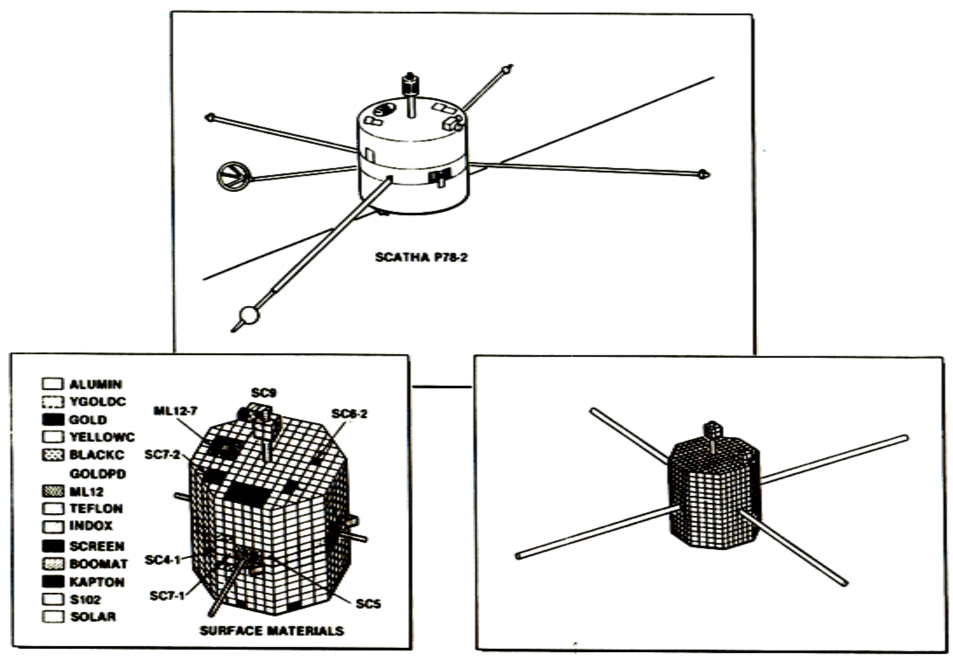
PRE-DECISIONAL DRAFT— For planning and discussion purposes only

COMPUTER MODELING OF SURFACE CHARGING

FINITE ELEMENT MODEL
OF PIONEER-VENUS SPACECRAFT



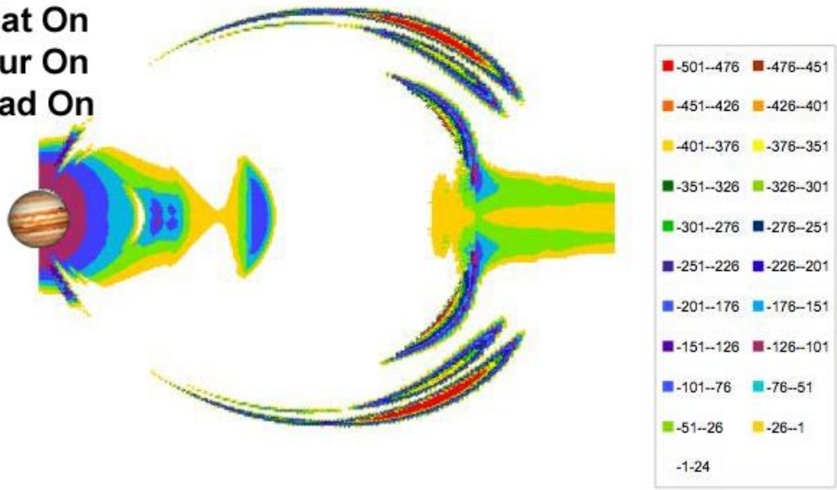
THE "NASCAP" SPACECRAFT CHARGING CODE



NASCAP MODELS

PREDICTED JOVIAN CHARGING ENVIRONMENT

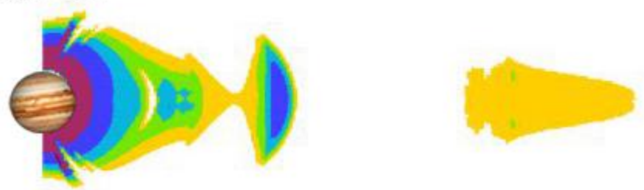
Sun Off
Mat On
Aur On
Rad On



POTENTIALS IN SHADOW

POTENTIALS IN SUNLIGHT

Sun On
Mat On
Aur On
Rad On



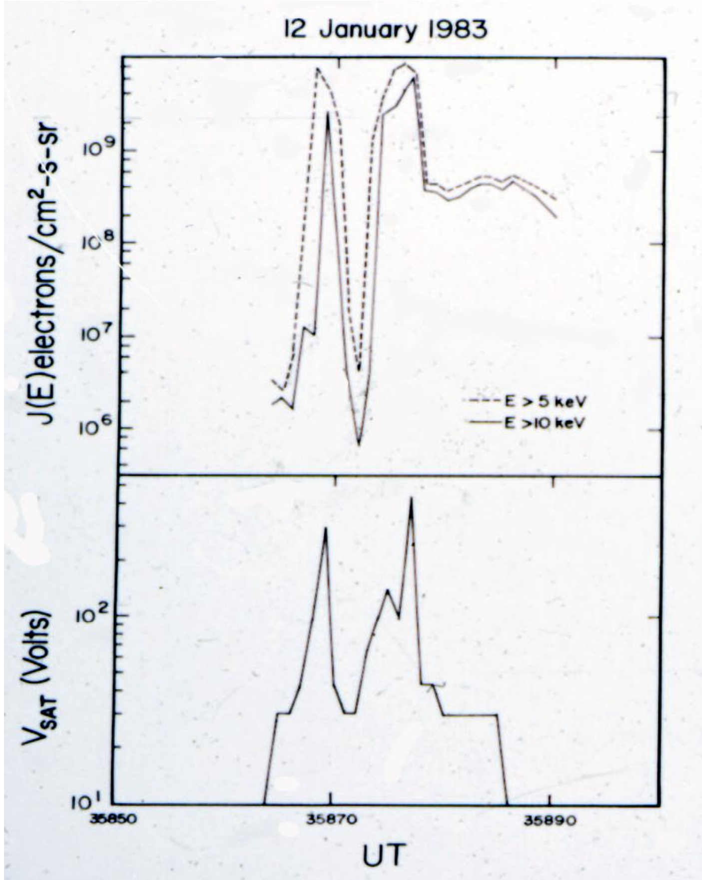
AURORAL CHARGING OVERVIEW

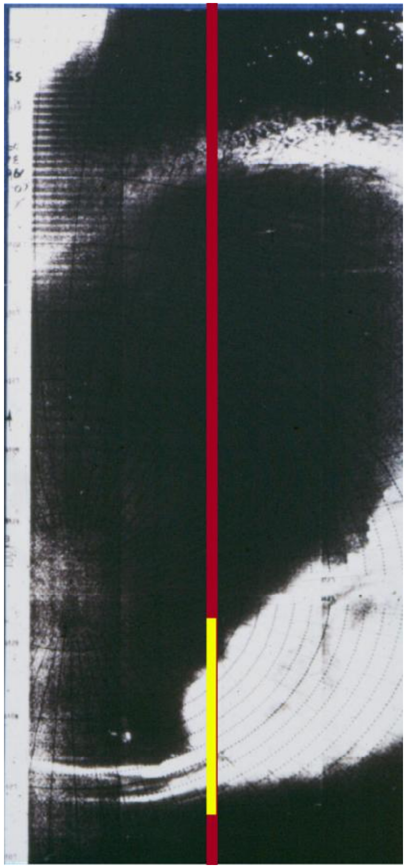
AURORAL CHARGING OVERVIEW

<u>WHAT IS THE CONCERN?</u>

- Auroral charging is a major concern for polar orbiting spacecraft at Earth
- Jupiter has pronounced auroral features:
  - A narrow auroral zone at high latitudes
  - A complex and variable environment over the poles
  - Aurora-like features associated with the main jovian moons and their magnetic flux tubes
- ***<u>IF</u>*** we understand the environment, ***<u>THEN</u>*** proper mitigation techniques should allow us ot limit their effects…

Aurora at the Earth

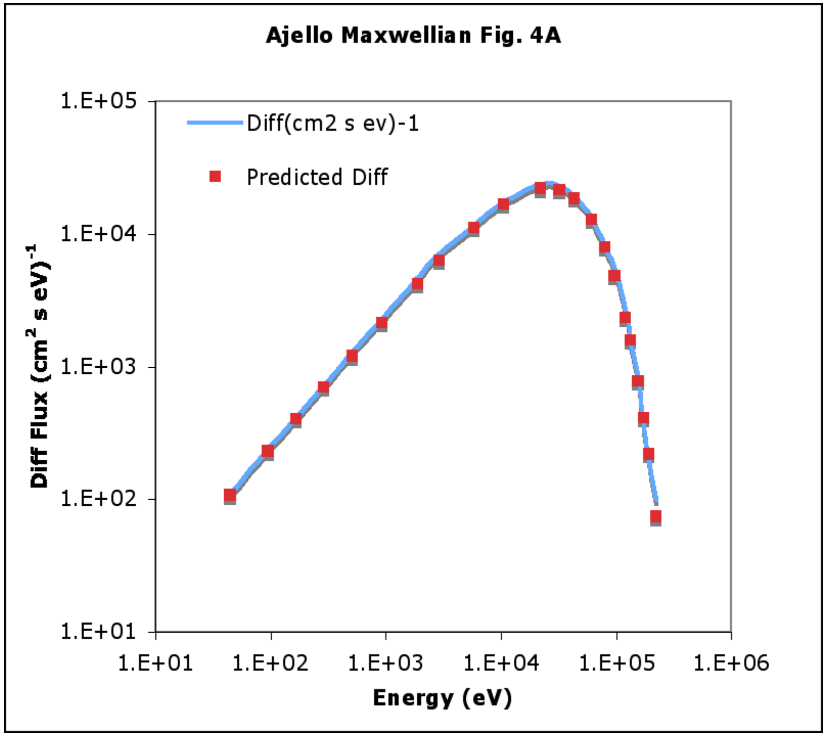


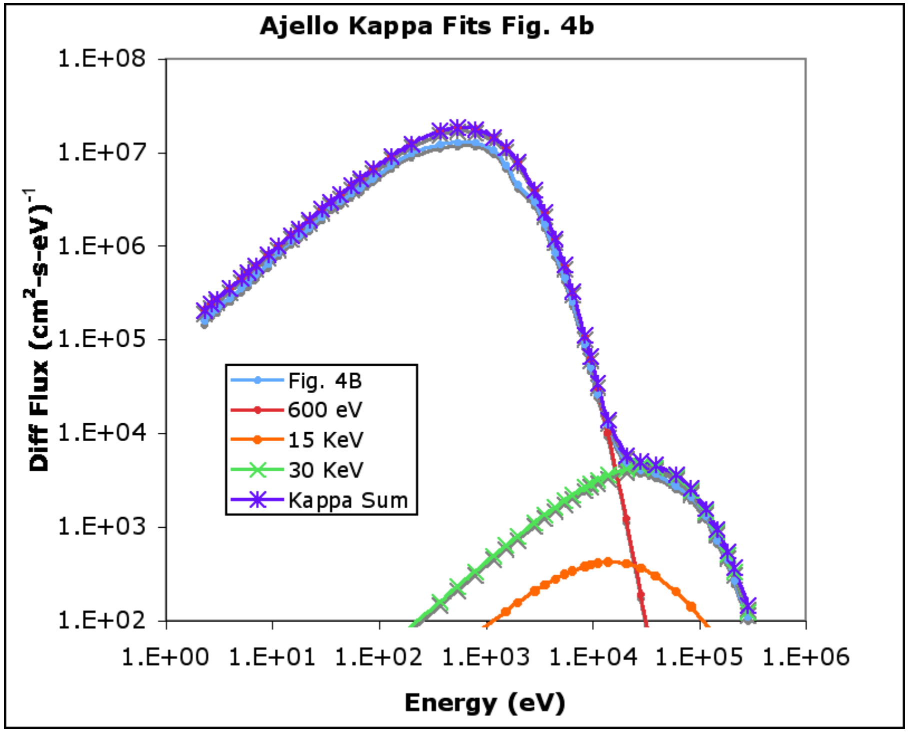


DMSP low altitude charging in Earth's auroral zone. Left side plots electron fluxes and spacecraft potentials along nadir track of spacecraft at 800 km (red-yellow line on right). Left hand data correspond to passage through auroral arc along yellow segment (right side).

(Courtesy AFRL)

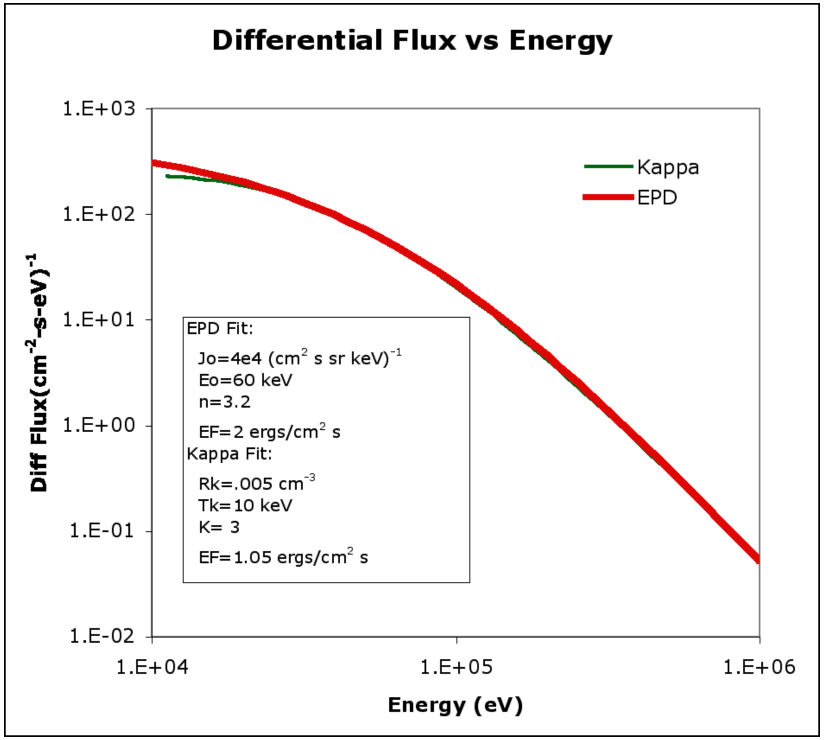
Jovian Auroral Zone Spectra





Ajello et al., "Spectroscopic Evidence for High-Altitude Aurora at Jupiter from Galileo Extreme Ultraviolet Spectrometer and Hopkins Ultraviolet Telescope Observations", Icarus, 152, pp. 151-171, 2001.

Jovian Diffuse Aurora



Observed EPD electron spectrum at 18.4 Rj*. As Energy Flux varies from ~1 to ~100 ergs/cm^2-s, we assumed a "Worst Case" of ~100 ergs/cm^2-s.

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*Bhattacharya et al., "On the energy source for the diffuse Jovian auroral emissivity", Geophys. Res. Lttrs., 28, 2715-2754, 2001.

Surface Potentials at Jupiter-A Simple Estimate

Assumed simple current balance for spherical Aluminum probe 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
15	0	-8		-2212		-1934	-3984	-4834		-1318	-24	-9
25	0	-24		-		-	-	-		-4658	-1567	-81

Estimates of potentials in jovian magnetosphere for: "A Max"--Ajello Maxwellian; "A κ"--Ajello Kappa ("+I/1, +I/10, +I/100"=> 100%, 10%, 1% of ion plasma currents); "Diffuse WC"--diffuse fluxes varied from 100 ergs/cm^2-s to 1 erg/cm^2-s (tabulated as "WC", "WC/10", and "WC/100").

Summary

WE FIND:

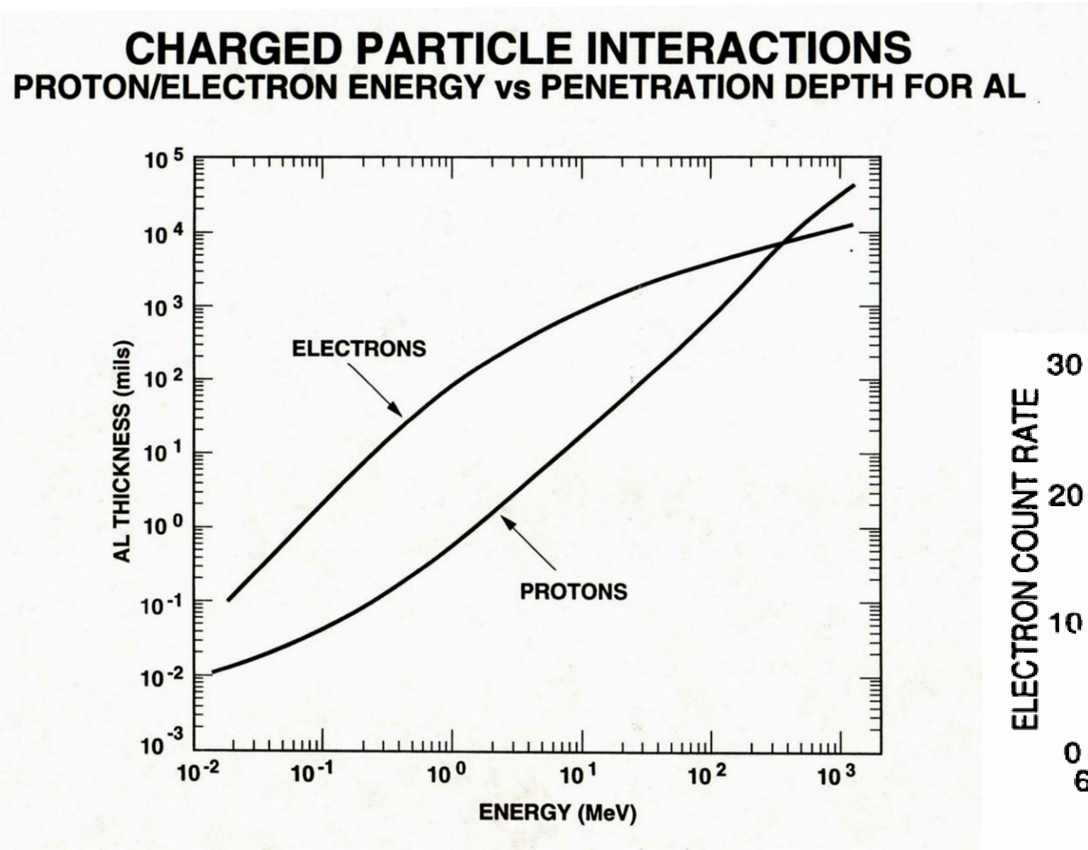
- At base of auroral field lines, "Worst Case" auroral zone fluxes ***may*** cause charging (***-2-5 kV***) in the 15-25 Rj equatorial region on shadowed surfaces.

THIS IMPLIES:

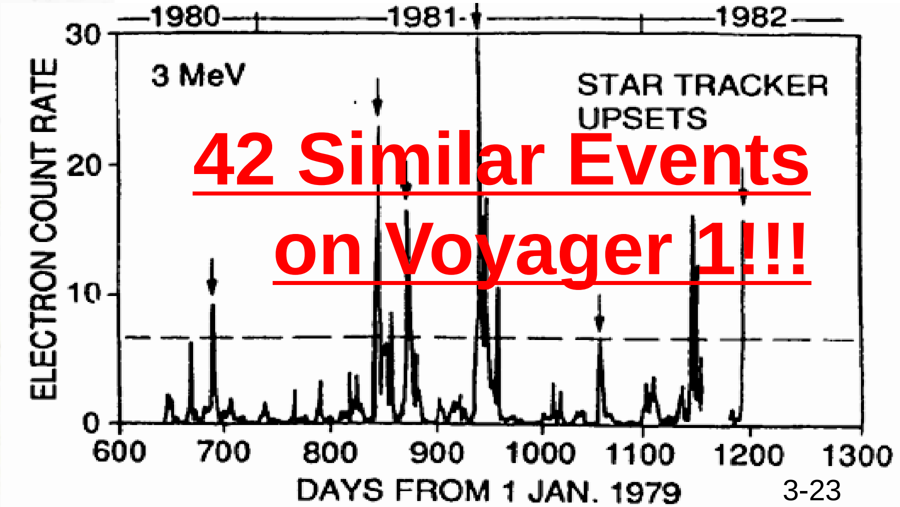
- Equatorward extension of aurora will be of concern to missions passing through the 15-25 Rj equatorial region--again, however, these levels are well within levels we protect geosynchronous spacecraft against.
- ***Surface charging will not be of concern at Jupiter if standard mitigation procedures are followed!***

INTERNAL ELECTROSTATIC CHARGING

INTERNAL ELECTROSTATIC DISCHARGE--ATTACK OF THE KILLER ELECTRONS…

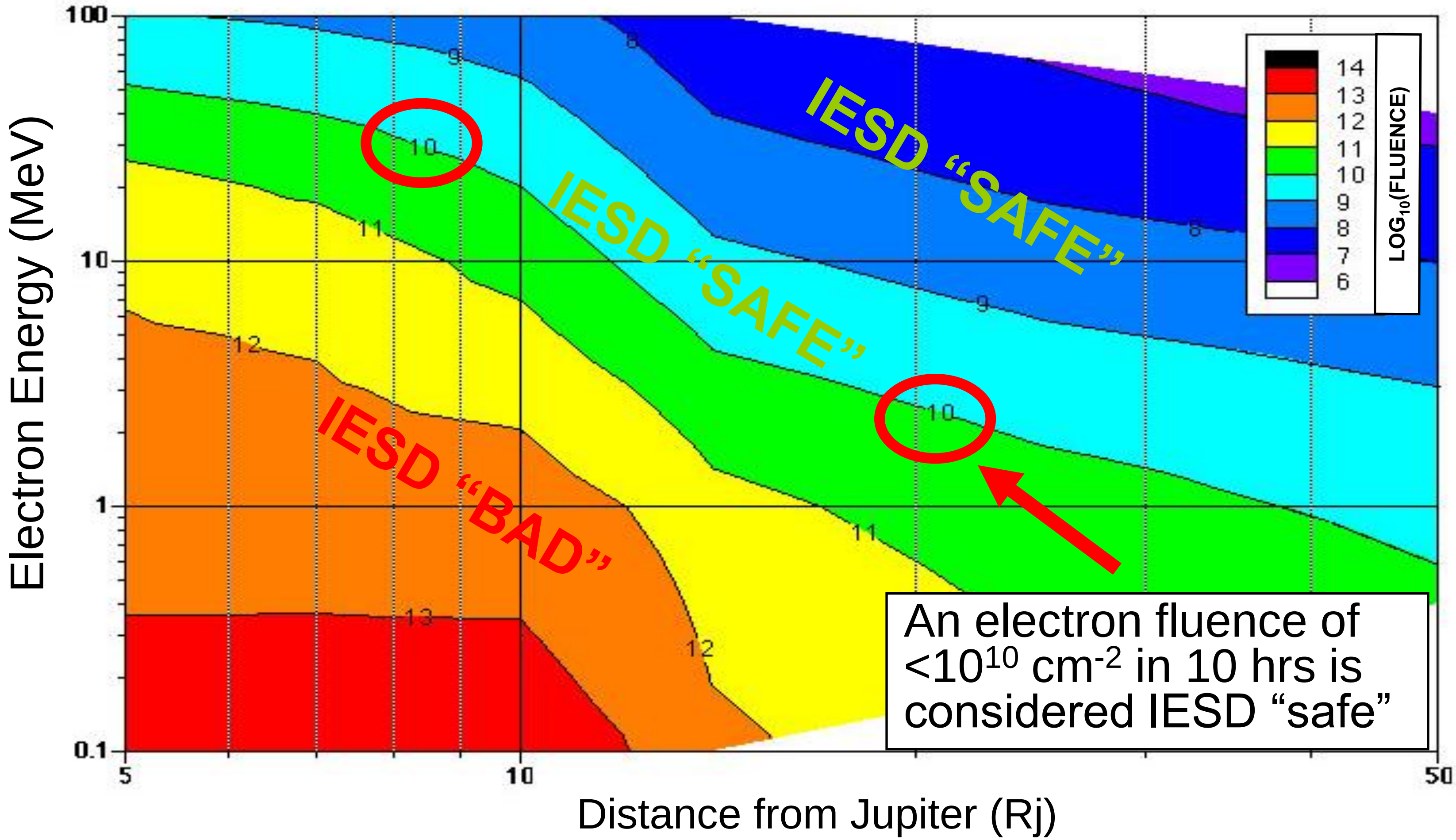


DISCHARGE PATTERN



42 Similar Events on Voyager 1!!!

REGIONS OF IESD CONCERN FOR FLYBYS



Contour plot of ***total electron fluence*** (Log) versus flyby perijove distance and energy (note: all flybys are assumed to be in the jovian equatorial plane). Units are (cm^{-2}).

VxB

THE ELECTRIC FIELD INDUCED BY A MAGNETIC FIELD

$E = 0.1\,(v \times B)$ V/m

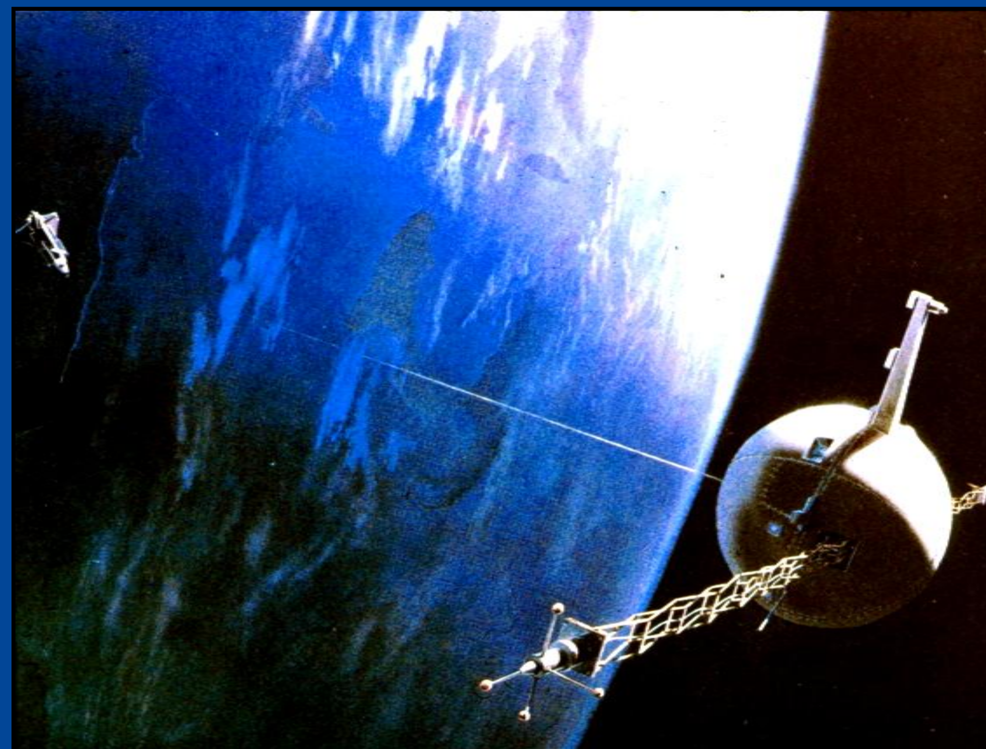
$v \sim 7.6$ Km/s

$B \sim 0.3$G

$E \sim 0.3$ V/m

SHUTTLE —

15m x 24m x 33m



At Jupiter, E ~ 20-30 V/m!!!

MITIGATION TECHNIQUES FOR CHARGING

MATERIAL CONSIDERATIONS IN CONTROLLING CHARGING

SURFACE COATINGS AND MATERIALS TO BE AVOIDED FOR SPACECRAFT USE

Material	Comments
Anodyze	Anodyzing produces a high-resistivity surface to be avoided. The surface is thin and might be acceptable if analysis shows stored energy is small
Fiberglass	Resistivity is too high
Paint (white)	In general, unless white paint is measured to be acceptable, it is unacceptable
Mylar (uncoated)	Resistivity is too high
Teflon (uncoated)	Resistivity is too high. Teflon has a demonstrated long-time charge storage ability and causes catastrophic discharges
Kapton (uncoated)	Generally unacceptable, due to high resistivity. However, in continuous-sunlight applications if less than 0.13 mm (5 mils) thick, Kapton is sufficiently photoconductive for use
Silica cloth	Has been as antenna radome. It is a dielectric, but because of numerous fibers, or if used with embedded conductive materials, ESD sparks may be individually small
Quartz and glass surfaces	It is recognize that solar cell coverslides and second-surface mirrors have no substitutes that are ESD acceptable. Their use must be analyzed and ESD tests performed to determine their effect on neighboring electronics.

SURFACE COATINGS AND MATERIALS ACCEPTABLE FOR SPACECRAFT USE

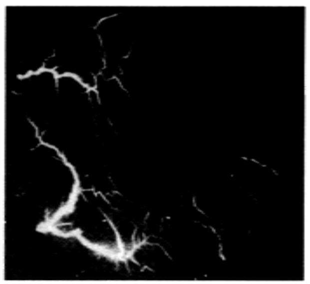
Material	Comments
Paint (Carbon black)	Work with manufacturer to obtain paint that satisfies ESD conductivity requirements of section 3.1.2 and thermal, adhesion, and other needs
GSFC NS43* paint (yellow)	Has been used in some applications where surface potentials are not a problem (apparently will not discharge)
Indium tin oxide (250 nm)	Can be used where some degree of transparency is needed; must be properly grounded; for use on solar cells, optical solar reflectors and Kapton
Zinc orthotitanate paint (white)	Possibly the most conductive white paint; adhesion difficult without careful attention to applications procedures
Alodyne	Conductive conversion coatings of magnesium, aluminum etc., are acceptable

FROM "MITIGATING IN-SPACE CHARGING EFFECTS—A GUIDELINE", NASA HANDBOOK 4002A

*GSFC denotes Goddard Space Flight Center

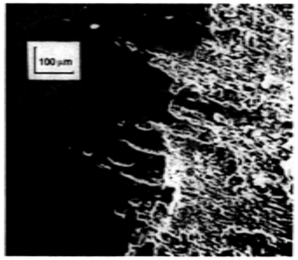
Testing for Spacecraft Charging Effects

SURFACE DISCHARGE EFFECTS (K.G. BALMAIN, 1980)

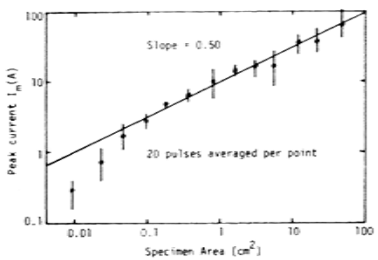


ARC DISCHARGE ON MYLAR (area=48 cm^2)

MAGNIFIED VIEW OF ELECTRON MICROSCOPE IMAGE

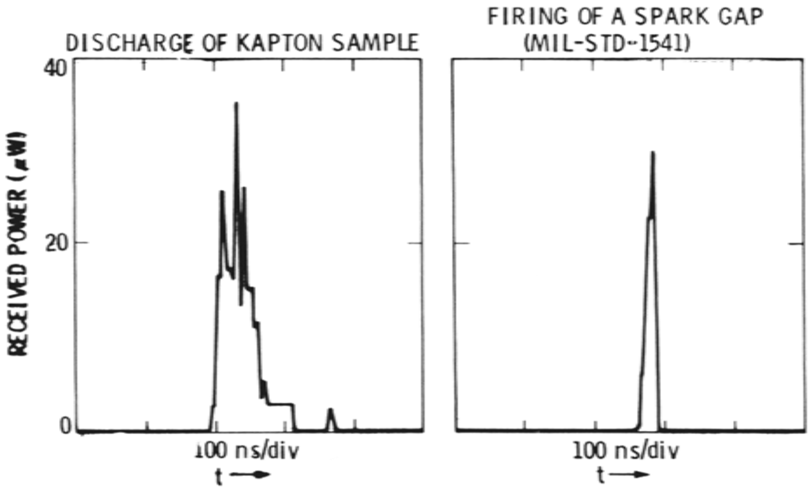


ELECTRON MICROSCOPE IMAGE OF ARC DAMAGE



PEAK ARC CURRENT VS AREA (CURRENT~LENGTH)

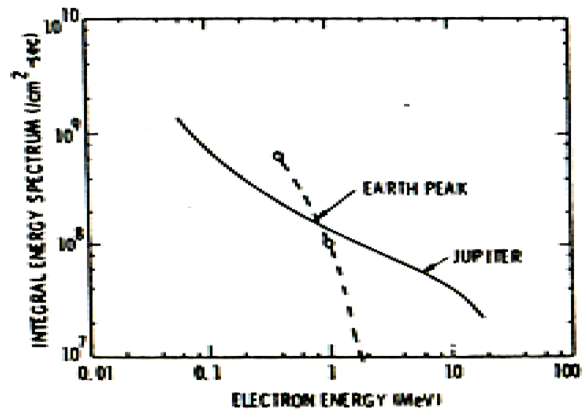
COMPARISON OF RF PULSES GENERATED BY THE DISCHARGE OF KAPTON SAMPLE AND BY THE FIRING OF A SPARK GAP



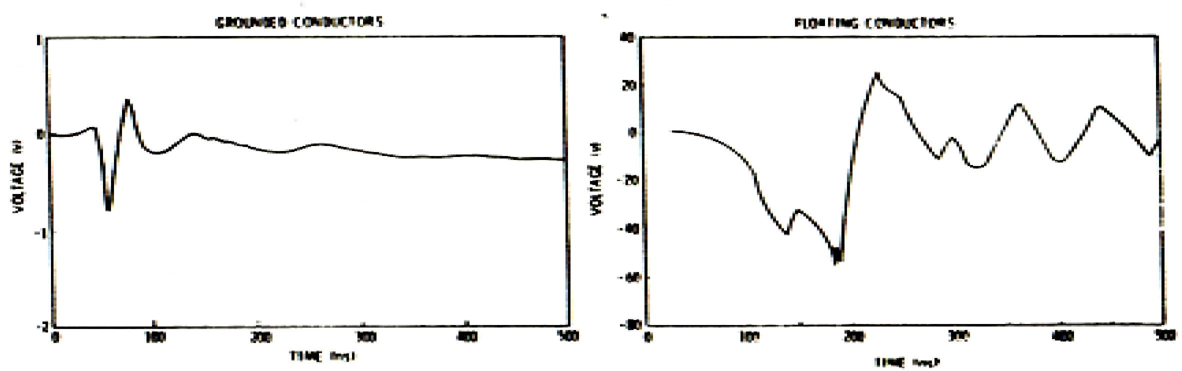
f = 2000 MHz
BW = 400 MHz

GALILEO INTERNAL ELECTROSTATIC DISCHARGE GUIDELINES

- PHENOMENON – ENERGETIC ELECTRONS >0.1 MeV CAN PENETRATE S/C SHIELDING AND DEPOSIT THEIR CHARGE ON COMPONENTS
- CONCERN – PROBABLE CAUSE OF POR's DURING VOYAGER 1's ENCOUNTER WITH JUPITER
- THREAT – ESD EVENTS OCCUR RIGHT AT THE COMPONENTS, EFFICIENT COUPLING OF EMI INTO CIRCUITS
- APPROACH – R&D TEST AND ANALYSIS PROGRAM TO IDENTIFY THE THREATS
- DESIGN GUIDELINES – ALL CONDUCTIVE SURFACES SHOULD HAVE A RESISTANCE $<10^{12}$ ohm TO GROUND
    - CONDUCTORS WITH SURFACE AREA $> 3\ cm^2$ NOT ALLOWED
    - CONDUCTORS WITH A LENGTH OF > 25 cm NOT ALLOWED



COMPARISON OF ENERGETIC ELECTRON ENVIRONMENTS



SIGNALS INDUCED ON VICTIM CIRCUITS

Design Guidelines for Assessing and Controlling Surface Charging Effects

GENERAL DESIGN GUIDELINES:

- Ground all conductive spacecraft elements
- Use conductive surface materials
- Shield all circuitry (Faraday Cage Concept)
- Filter circuits near ESD sources
- Develop, document and follow procedures
- Test spacecraft systems and circuits for sensitivity to arc discharges
- Follow "Mitigating In-Space Charging Effects—A Guideline", NASA Handbook 4002A

Questions & Answers