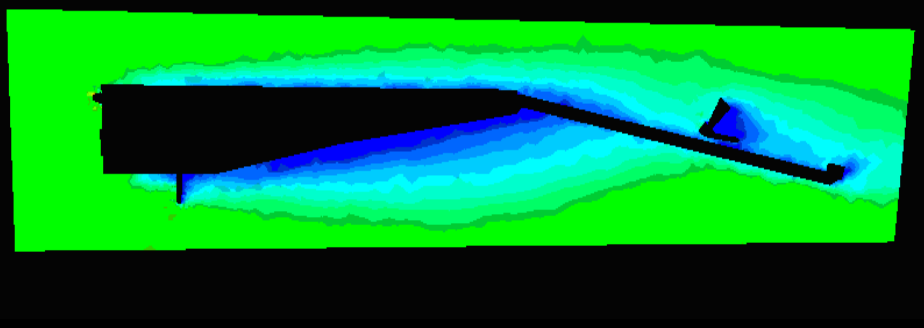

Review of spacecraft plasma interactions

13th SPINE Meeting
28th May 2008
ESTEC

David Rodgers / ESTEC
Simon Clucas / ESTEC
Alain Hilgers / ESTEC

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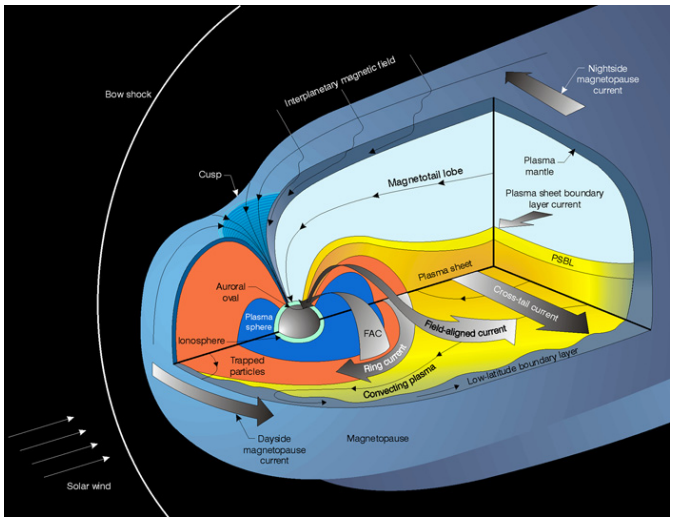
Environment Division – TEC-EES

Geography of the near-earth plasma environment



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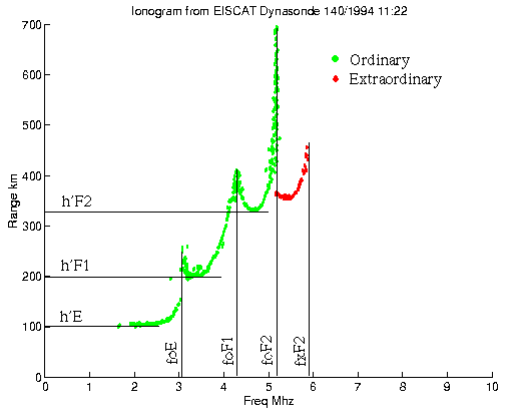

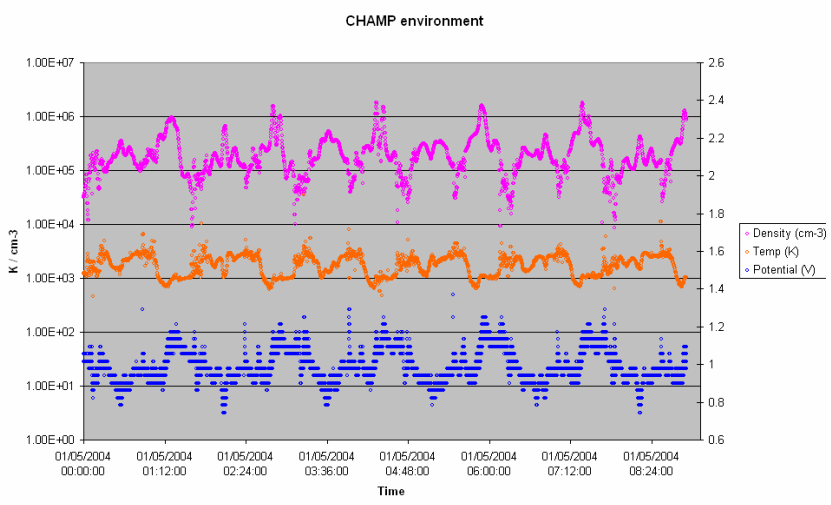

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Plasmasphere
Typically:
L=1 to L=3 to 6
T= 0.5eV
n=10 to 10e4 cm^{-3}

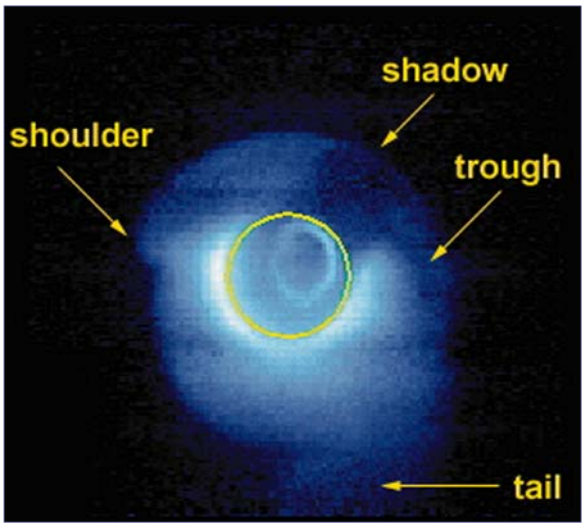
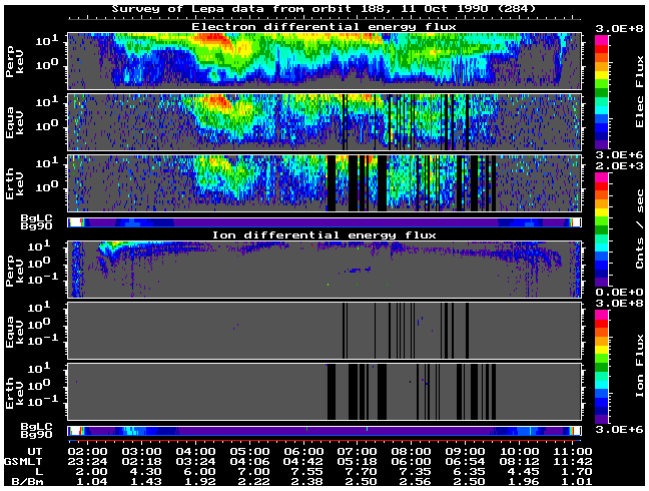


IMAGE UV image



CRRES LEPA

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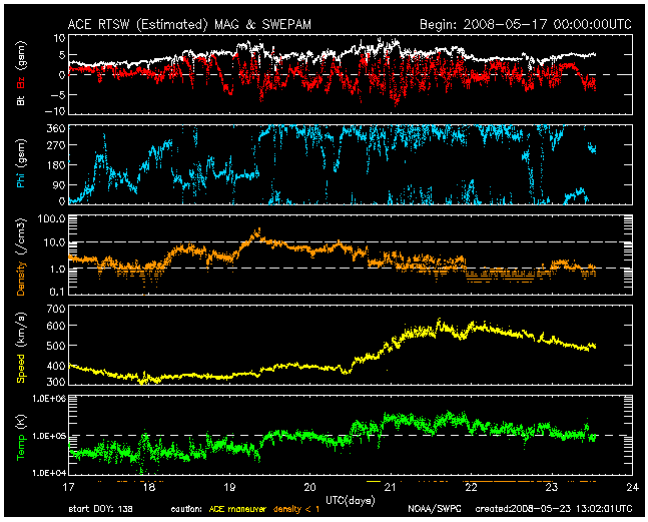
Solar wind

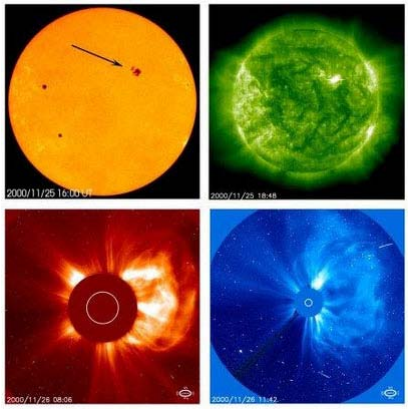


Typical velocity: 400km/s

Enhanced velocities up to 1000km/s

ACE

Sunspot group (MDI) Flare (EIT 195E)



Sequence of images of a Coronal Mass Ejection (CME) November 2000

CME (LASCO C2) Expanded CME cloud

SOHO

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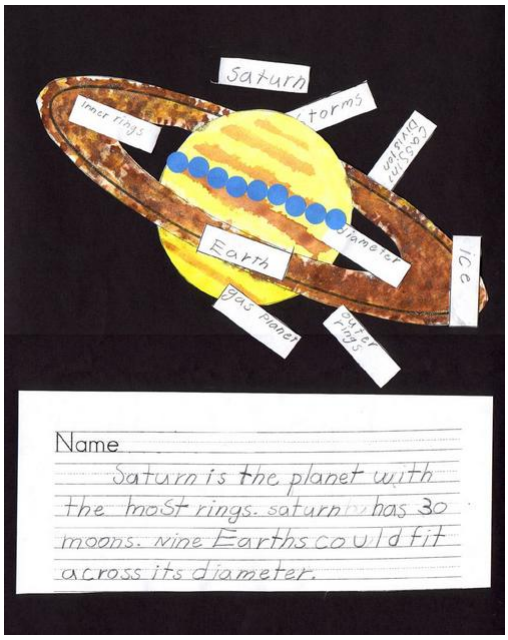
Other planets have magnetic fields:

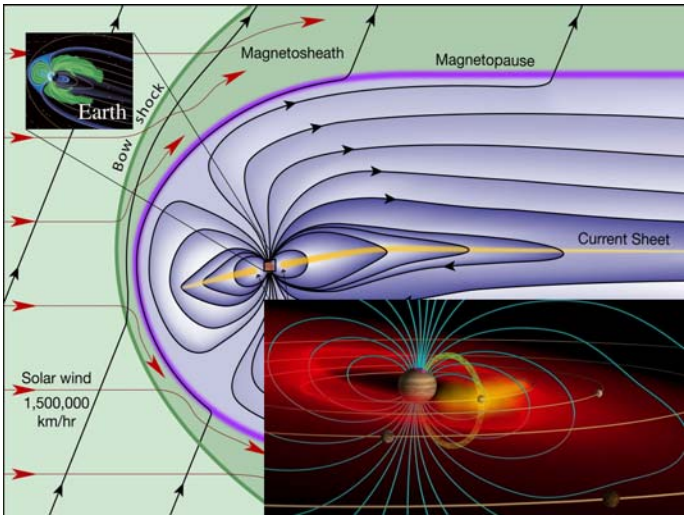
Jupiter
Saturn
Neptune
Uranus

Mercury (weak)
Mars (very weak)
Venus (no field)



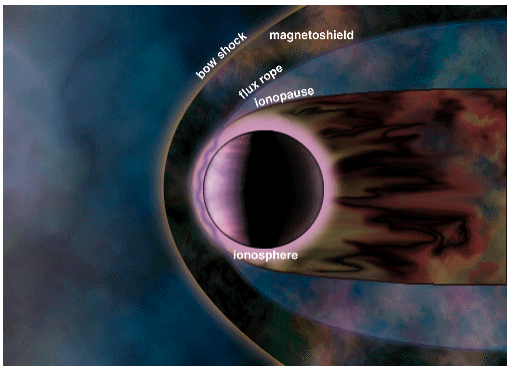
NASA/JPL

Jovian magnetosphere



Bagenal, Colorado Univ.

Venus' magnetosphere



SwRI

Orbit	Plasma environments
Low inclination LEO (<50°)	Ionosphere
High-inclination LEO e.g. Polar orbit	Ionosphere, Auroral zone
Geostationary orbit	Outer magnetosphere, Plasmasphere, Magnetosheath (occasionally)
MEO circular orbit e.g. Galileo	Outer magnetosphere, Plasmasphere, Magnetosheath (possibly at high latitude)
Geostationary transfer orbit	Ionosphere, Plasmasphere, Outer magnetosphere, Magnetosheath (occasionally)
High apogee elliptical orbit	All regions can be encountered, depending on orbit.
L1, L4, L5 Lagrangian points	Solar wind
L2	Solar wind, magnetotail and distant magnetosheath
Interplanetary cruise	Solar wind
Planetary orbit / encounter	Planetary environment

ECSS-E-10-04B

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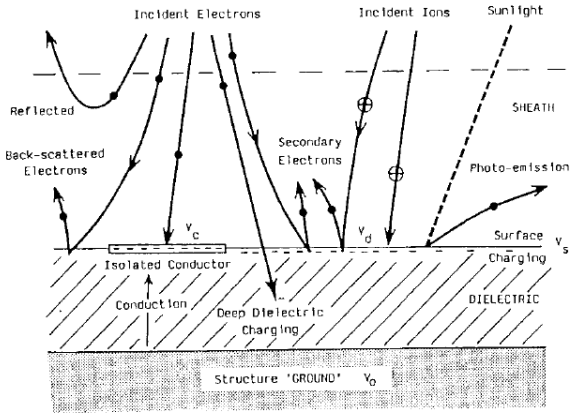
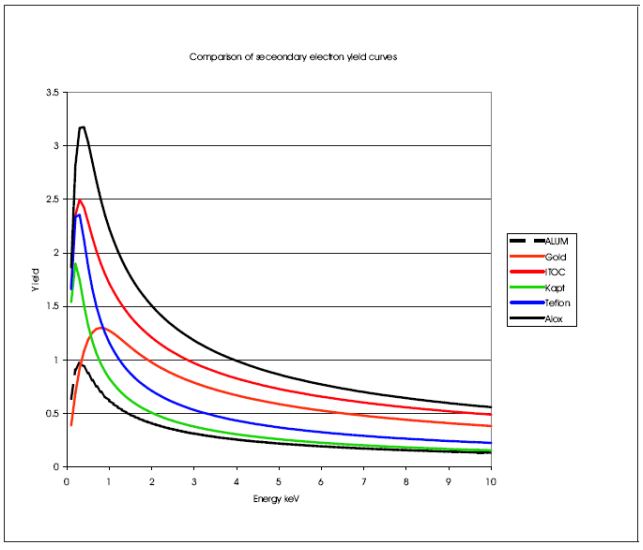
Surface Charging Currents

J=Je-Ji-Jphoto-Jsecond-Jcond-Jbackscatter

J=0 in equilbrium



Wrenn and Sims 1993



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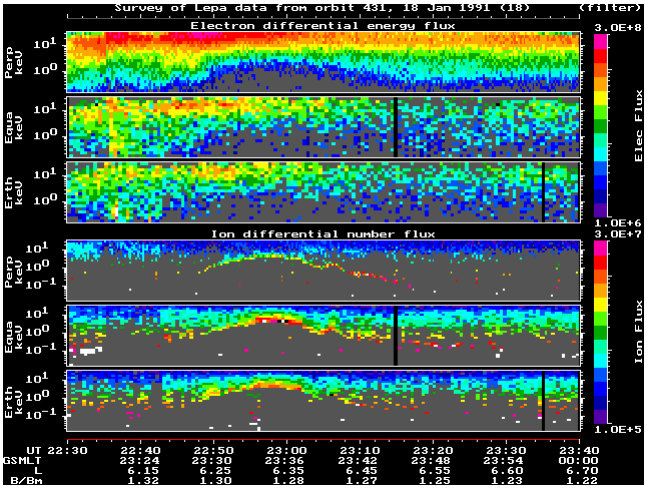
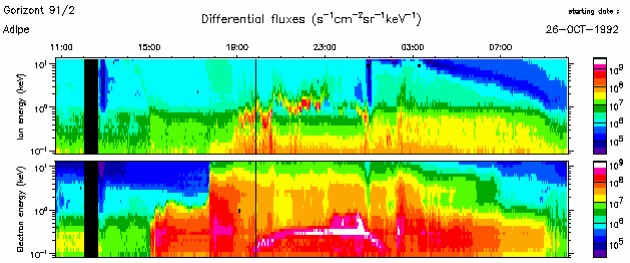


CRRES/LEPA



Gorizont 91/2

Examples of surface charging anomalies

- DSCS-II 9431 (1973)- Mission loss due to ESD induced loss of power to communication system
- Skynet-2B (1974) – 300 telecommand anomalies
- Meteosat-F1 (1977)– many radiometer, power system & attitude control anomalies
- GOES-4 (1980) – radiometer resets, radiometer failure
- MARECS-A (1981) – many small anomalies, safe-mode entry, solar array damage
- TDRSS -1, -3, -4 and -5 (1983, 1988, 1989, 1991) - many anomalies in different subsystems
- ANIK-D2 (1984) - despin control system anomaly

Leach & Alexander 1995

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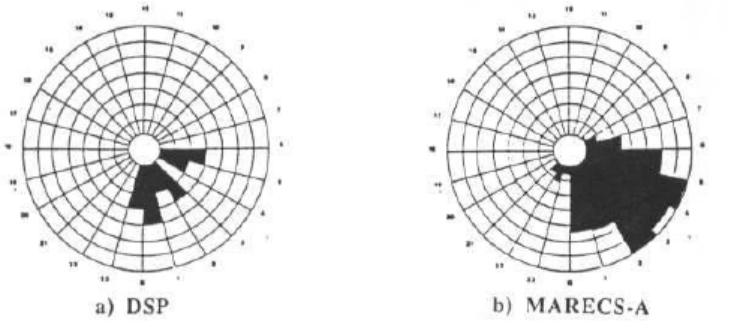

a) DSP b) MARECS-A

Romero and Levy 1993

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SCATHA Transient Pulse Monitor

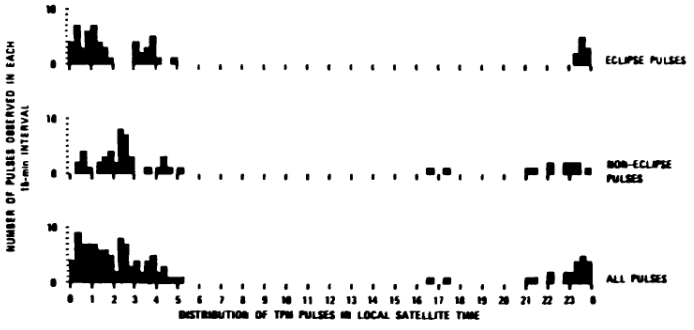


FIGURE 2 DISTRIBUTION OF PULSES OBSERVED BY THE SRI TPM

Damron et al. 1980

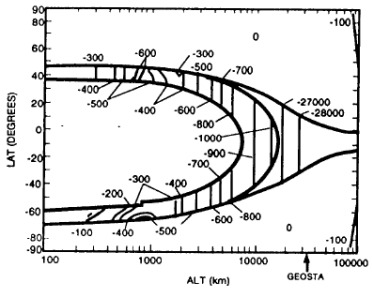


Fig. 2 Surface potential contours (in the absence of sunlight) in volts as a function of altitude and latitude for the Earth (Evans et al., 1989).

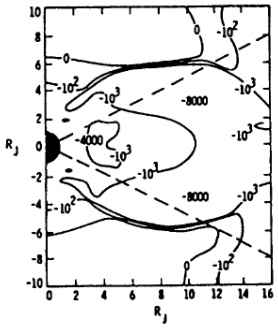
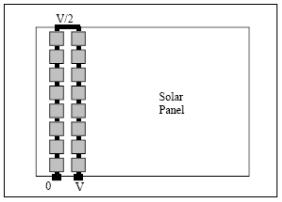


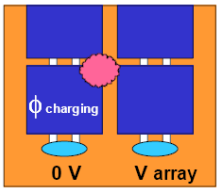
Fig. 5. Spacecraft-to-space potential contours for the thick sheath approximation (Divine and Garrett, 1983) as in Fig. 3. No photoelectron or secondary currents are included.

Garrett et al. 1998

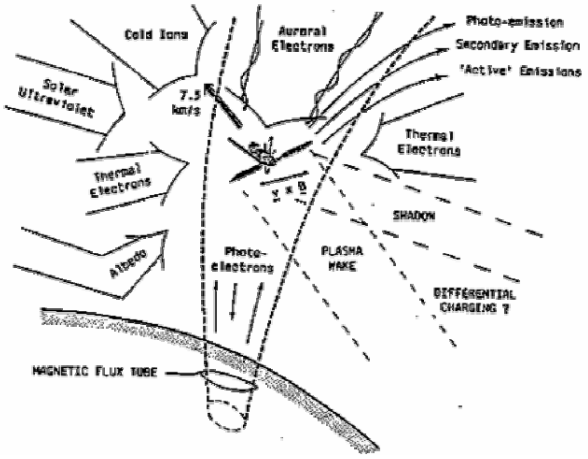
Secondary arcing

- TEMPO-2 and PAS-6 (1997)
  - Solar array string failures
  - Substorm environment
  - Spacecraft charging on LANL spacecraft





Katz et al 1998



Martin 1991

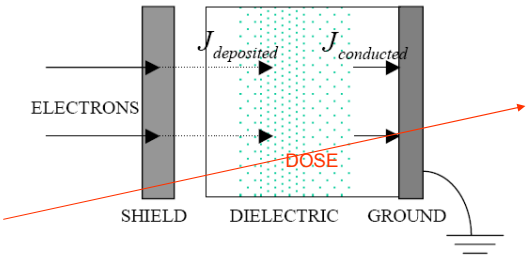
LEO charging

- Potential of floating Langmuir probe ~ <|1V|
- Additional factors
  - Current collection to solar arrays
  - VxB effect on differential potentials
  - High-energy electrons in auroral zone
  - Ram/wake effects
    - Ion ram current
    - Ion depletion in wake
- DMSP F13 micro-processor lock-up, -460V potential (Cooke 2000)

Other LEO effects

- Sputtering/Atomic Oxygen erosion
  - Modifies surface properties
- Paschen discharge
  - Limits exposed high voltages
- Snap-over effect
  - Can dramatically increase solar array current collection

Internal charging



$J=J_{deposited}-J_{conducted}$

$J=J_{deposited}-E.\sigma(bulk+radiation\text{-}induced)$

J=0 in equilbrium

Examples of internal charging anomalies

- Intelsat K (1992) – momentum wheel
- Anik E-1, E-2 (1991) – momentum wheel
- FLTSATCOM (1987) – logic anomalies
- DRA-δ – more than 100 minor anomalies
- Voyager – 42 power-on re-sets around Jupiter

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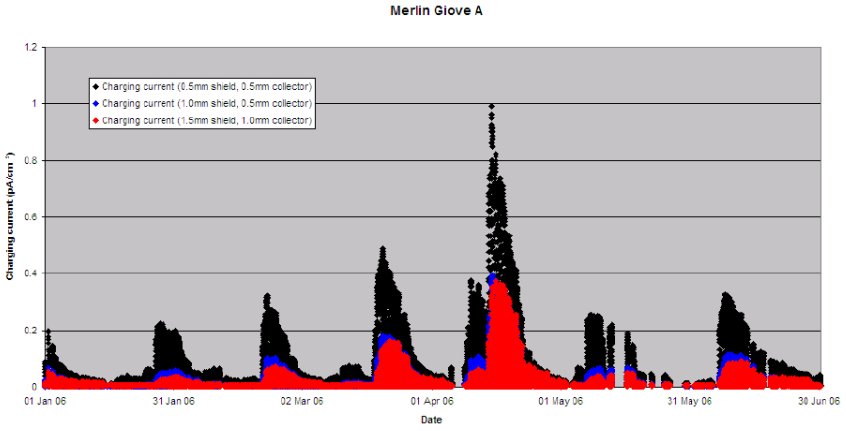

Ryden et al 2007

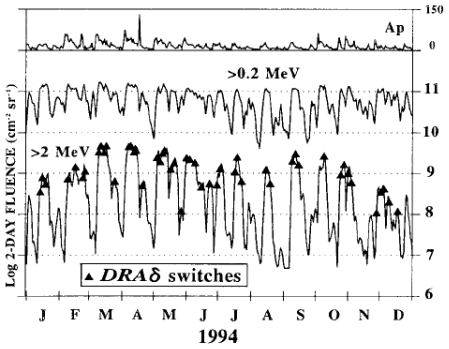

Figure 1. DRA δ anomalies during energetic electron enhancements

Wrenn et al 1997

Interaction with active sources

e.g. electric propulsion systems and charge alleviation devices

- FEEPs in LEO can be neutralised by natural currents
- Electrostatic sheath can control space-charge limitation on ion and electron guns
- Charge-exchange ions provide additional currents for charging and contamination

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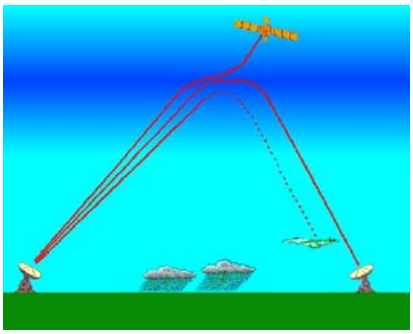
Radio propagation effect in plasmas



- Critical frequency
  - Barrier to communications / radar imaging
  - typically MHz for ionosphere
- Refraction
  - Errors on GNSS
- Fade-out/Scintillation
  - Communication degradation
- Includes active plasma sources

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Measurement contamination

- Sheath effects/wake effects
  - Plasma observed has been modified
- Photoelectron contamination
- Re-deposition of sputtered material
- Natural and induced electric field variations
  - e.g. Debie – Debris/micrometeoroid impact detector

    Direct interference + charged particulates

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Finally - other effects

- Dust charging and sticking
- Electrostatic sticking (e.g. inflatables, solar sails, solar arrays)
- Docking, EVA discharges
- Material modification by ESD
-

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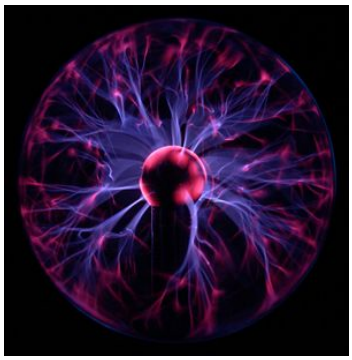
Finally - other effects

- Dust charging and sticking
- Electrostatic sticking (e.g. inflatables, solar sails, solar arrays)
- Docking, EVA discharges
- Material modification by ESD

- Nice lamps



The end

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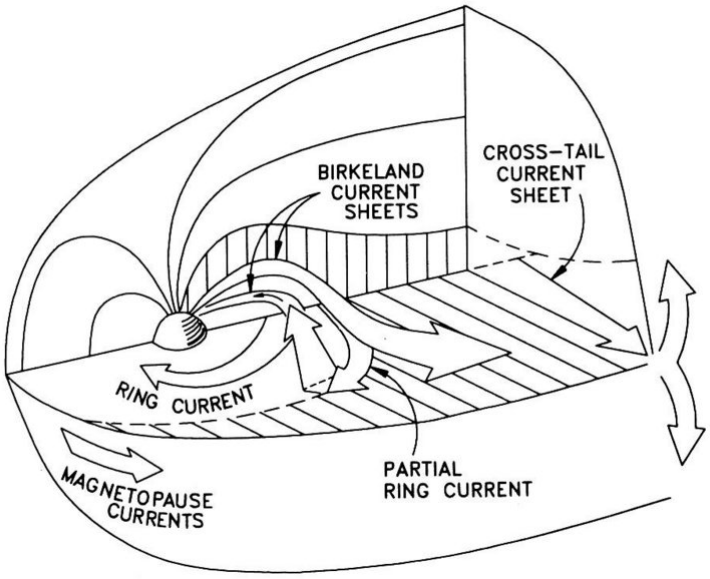
Internal charging

- Examples
- Process
- Role of material properties (saviour electrons)
- ESD
- Instruments to observe
- observations

Surface charging

- Absolute
- Differential (+esd hazard, triggered esd)
- Secondary arcing on solar arrays
- Floating potentials in different environments
- Observations + plasma effects instruments



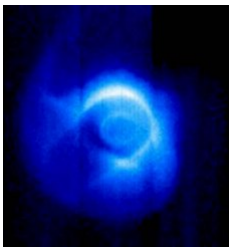


IMAGE view of plasmasphere

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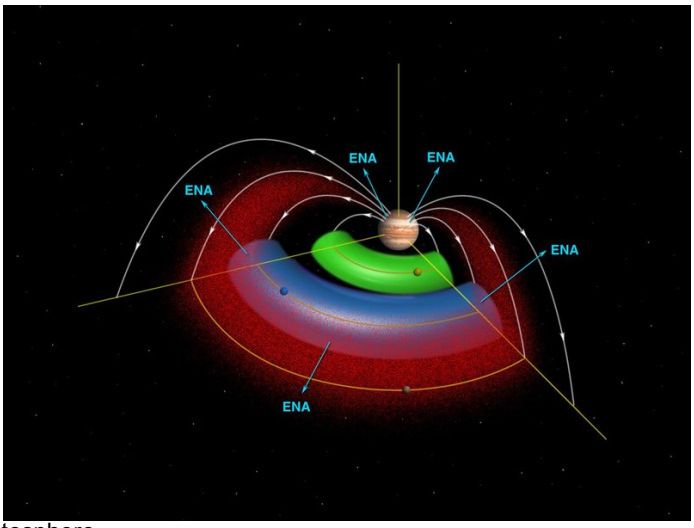
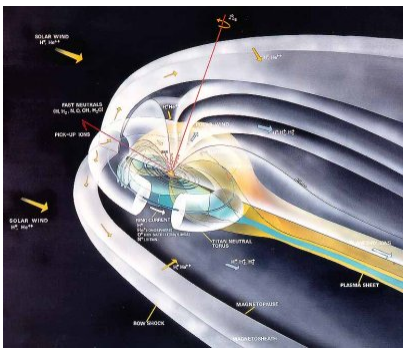


Jovian magnetosphere

Saturn magnetosphere



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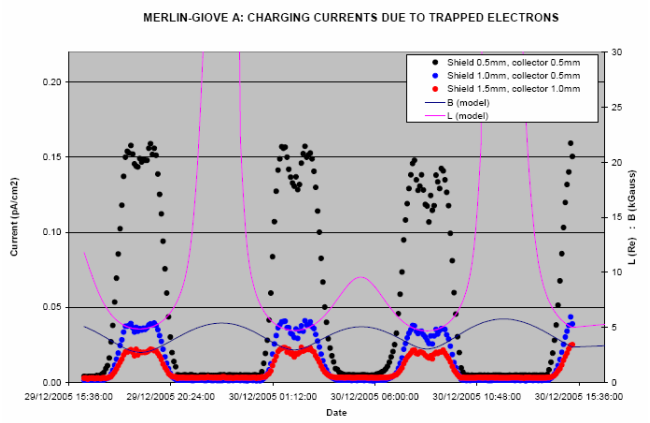
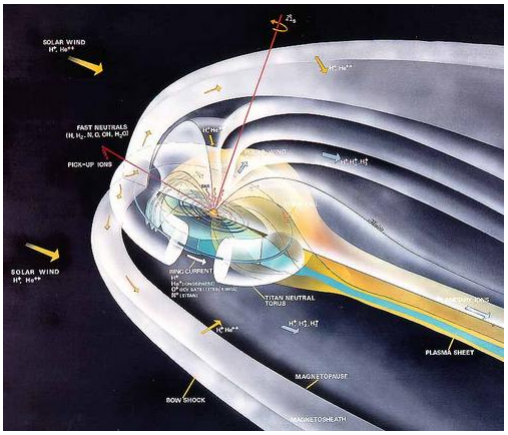
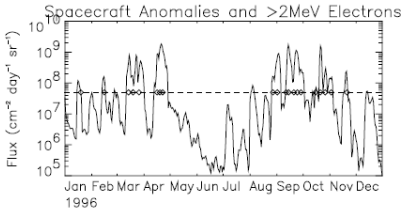


Ryden et al 2007





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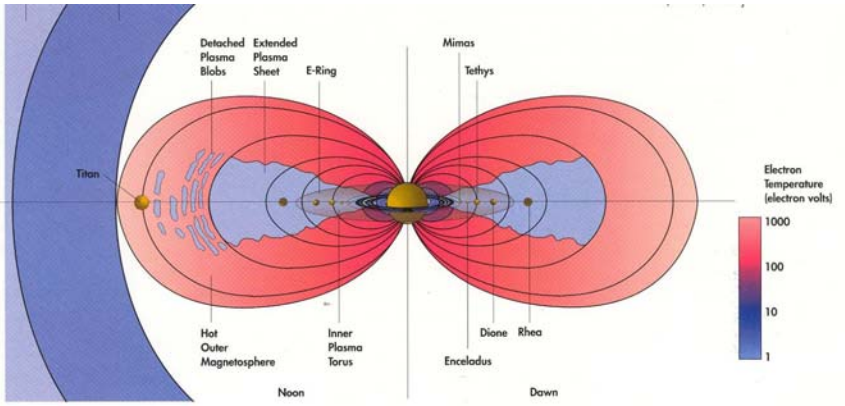

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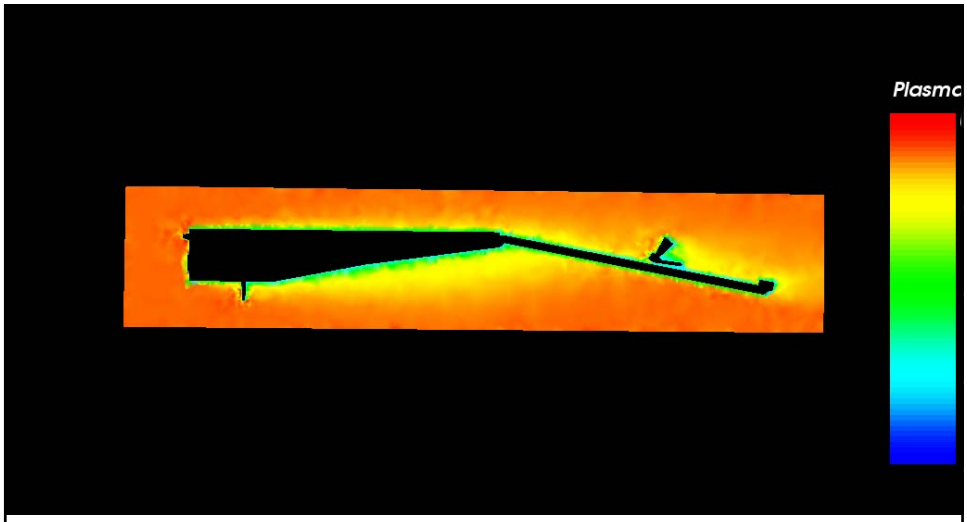

	V_c(km/s)	Potential (V) Sun	No Sun/Sec
Earth			
-ionosphere	8	-0.7	-4.4
-plasmasphere	3.7	-1.6	-3.8
-auroral zone	8	-0.7	-500
-geosynchronous	3	2.0	-28,000
Jupiter			
-cold torus	44	-.59	-1.2
-hot torus	100	-60	-70
-plasma sheet	150	-94	-130
-outer mag-sph	250	9.5	-2500
Saturn			
-inner plasma sheet	100	~5	-30
-outer plasma sheet	100	~5	-500
-hot outer mag-sph	100	~5	-500

Garrett et al. 1998

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Effects contents

- Surface charging
- Internal charging
- Beam propagation effects
- Current collection
- Sputtering
- Instrument contamination
- Environment modification e.g. charge exchange