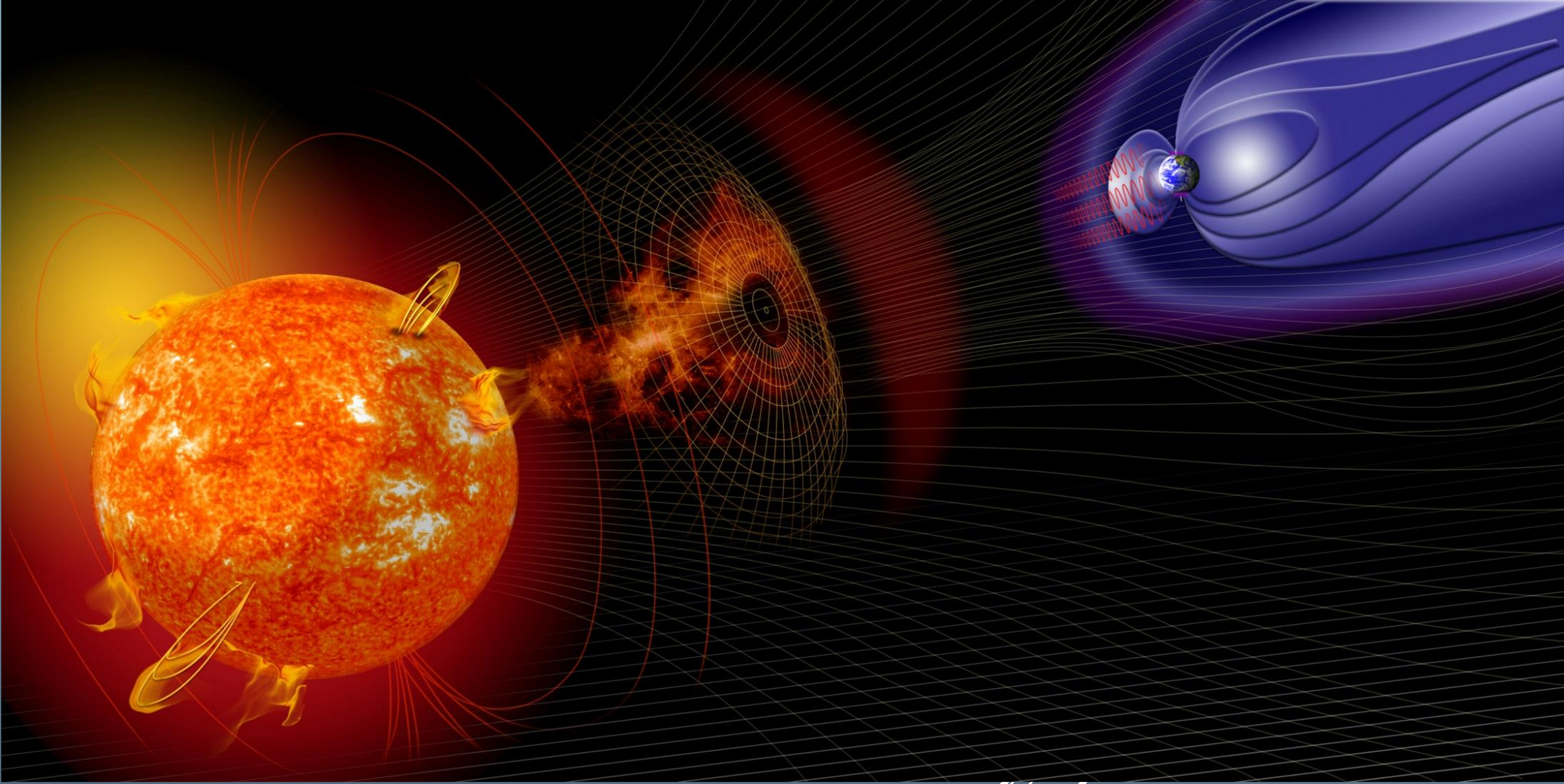

Overview:
Space Weather Launch Constraints

Dr. Linda Neergaard Parker, Jacobs ESSSA Group
EV44 Space Environments Physicist
Deputy for Space Weather, Space Plasma, and Spacecraft Charging to NASA Space Environment Tech Fellow

Outline

- Requirements
- Space Weather Overview
- Environments and Effects
- Examples
- Mitigating Space Weather Effects

Ionizing Radiation for Launch

- Systems that operate at altitudes above 20 km and at or below 200 km altitude will be exposed to the Galactic Cosmic Ray (GCR) and Design Solar Particle Event (Design SPE) environments of Tables 3.2.13-1, -2, and -3. The low altitude atmospheric neutron environment is not a concern for these systems.
- The design limit for systems that operate only at or below 20 km is provided in the Table 3.2.13-4 atmospheric neutron environment for the system maximum operating altitude. The 200 km GCR and Design SPE environments are not applicable.
- From the Design Specification for Natural Environments (DSNE)

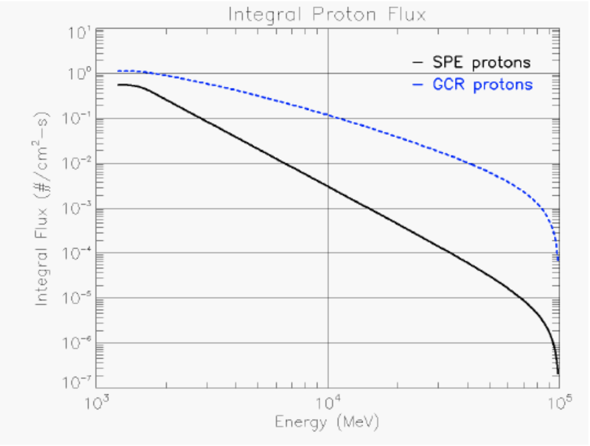

Figure 3.2.13-3. 200 km Integral Proton Flux of Design SPE and Integral GCR Flux as a Function of Energy

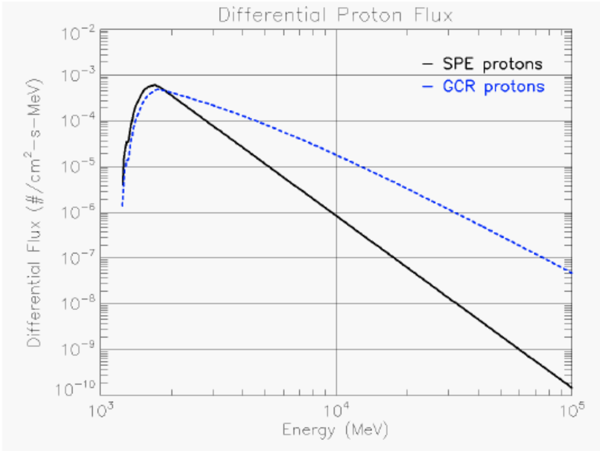

Figure 3.2.13-2. 200 km Differential Design SPE and GCR Proton Flux as a Function of Energy

Charging Environments

- DSNE Section 3.3.3 Plasma Charging gives surface and internal charging environment definition for ALL reference mission in Table 3.3.3-1.

Table 3.3.3.2.2-1
Radiation Belt Transit

Energy (MeV)	Integral Flux (e^-/cm^2 sec)
0.1	3.27e7
0.2	2.67e7
0.4	1.78e7
…	…
5.6	4.62e2
5.8	3.08e2
6.0	2.05e2

Table 3.3.3.3-1 GEO

Parameter	SCATHA "Worst Case" Environment	
	Electrons	Ions
Single Maxwellian		
Density (#/cm^3)	3.00	3.00
Temperature (keV)	12	30
Current density (nA/cm^2)	0.501	0.016
Double Maxwellian		
1. Density (#/cm^3)	0.87	0.97
1. Temperature (keV)	0.6	0.333
2. Density (#/cm^3)	1.73	1.63
2. Temperature (keV)	25.8	25.3

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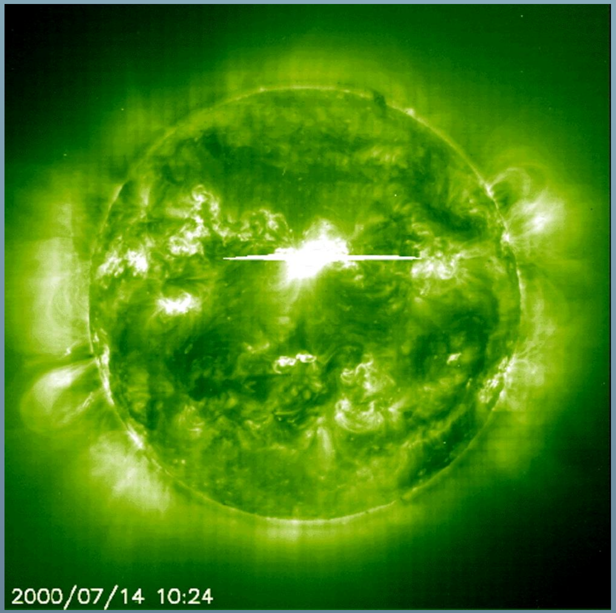
Solar Phenomena

Solar Flares

- Sudden brightening interpreted as a large energy release
- Occurs in active regions around sunspots.
- Flare ejects clouds of electrons, ions, heavy ions, and atoms through the corona to space.

**Flares are used as an alert for possible SEP events



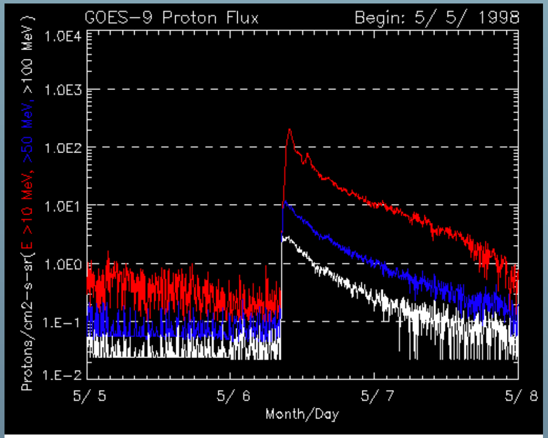
Coronal Mass Ejections (CME)

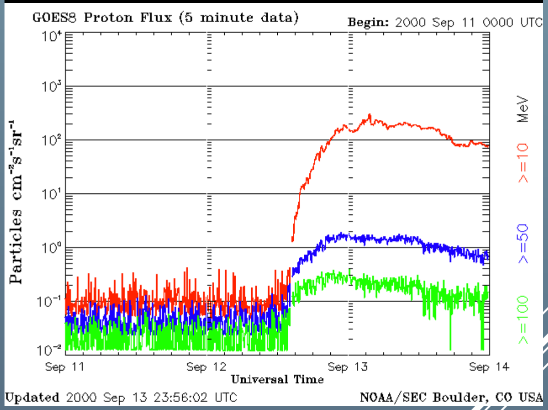
- Massive burst of solar wind
- Associated with solar flares, but causal relationship has not been established
- Solar maximum – 3 a day
- Solar minimum – 1 every five days
- Ejected material is mostly electrons and protons, but may contain heavier ions.

Solar Energetic Particle (SEP) Events

SEPs can originate from two processes:

- Impulsive
  - Originate from energetization at a solar flare site
  - Lasts a few hours and has smaller fluences
  - Electron-rich, associated with Type III radio bursts
- Gradual
  - Originate at shock waves associated with CMEs.
  - Lasts several days and has larger fluences
  - Proton-rich, associated with Type II radio bursts
  - Diffusive shock acceleration

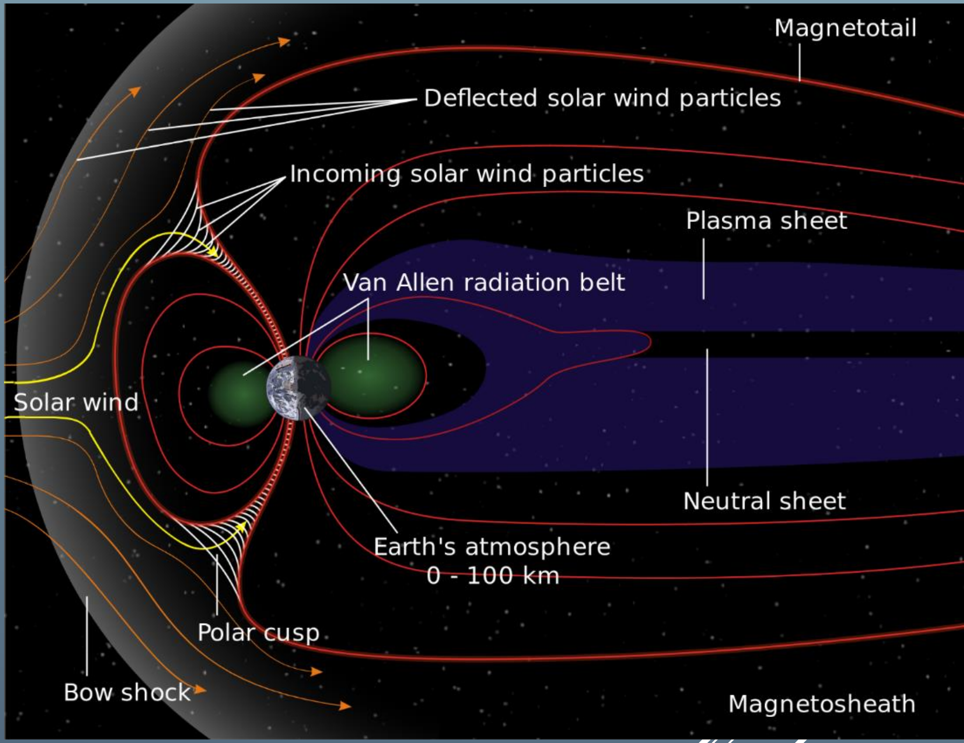




- SEPs can be accelerated to energies of several tens of MeV within 5-10 solar radii
- Can reach Earth in a matter of tens of minutes to a few hours after a flare or an ejection.

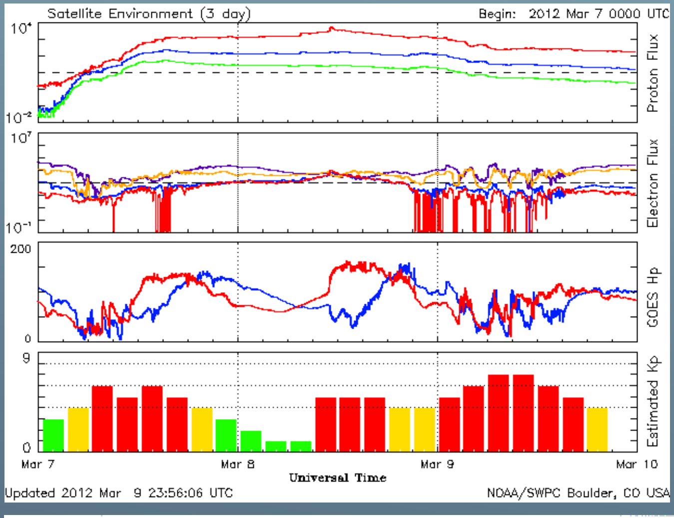
Geomagnetic Storm

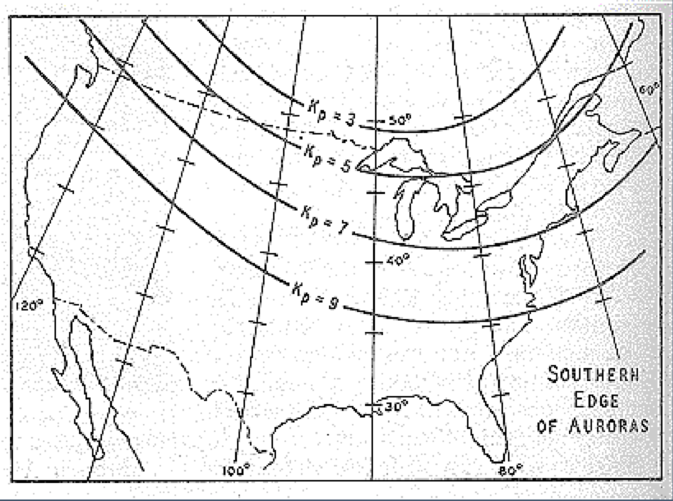
- Temporary disturbance in the Earth's magnetosphere caused by a disturbance in the interplanetary medium.
  - Solar wind shock wave
  - Cloud of magnetic field.
- Increase in the solar wind pressure compresses the magnetosphere, best coupling when $B_z < 0$.
- Weather phenomenon that are associated with or caused by geomagnetic storms:
  - Solar Energetic Particle events
  - Geomagnetically induced currents
  - Ionospheric disturbances which cause radio and radar scintillation
  - Disruption of navigation by magnetic compass and auroral displays at much lower latitudes than normal
  - Aurora



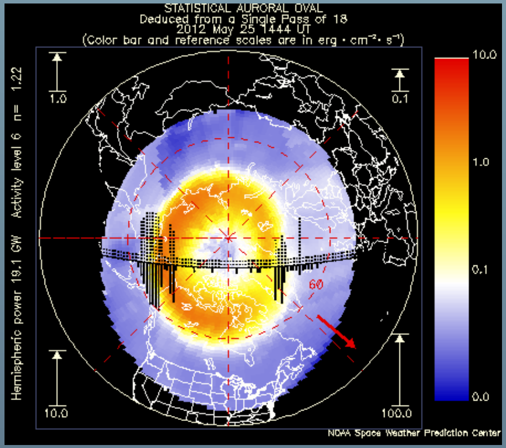
How do we know there's a storm

Kp – Mid latitudes



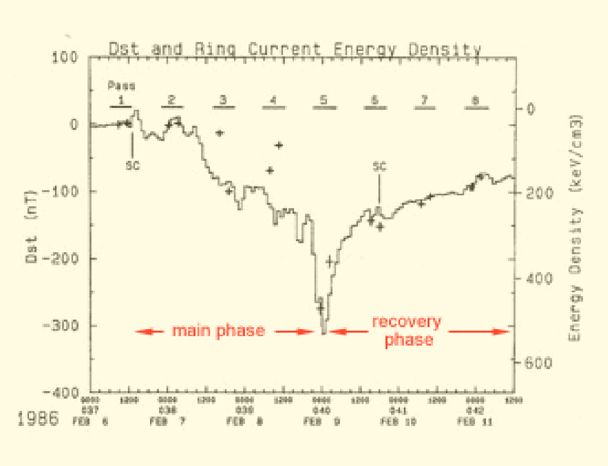


Total Hemispheric Power Data – High latitudes



NOAA/TIROS and DMSP satellites

Dst – Low latitudes



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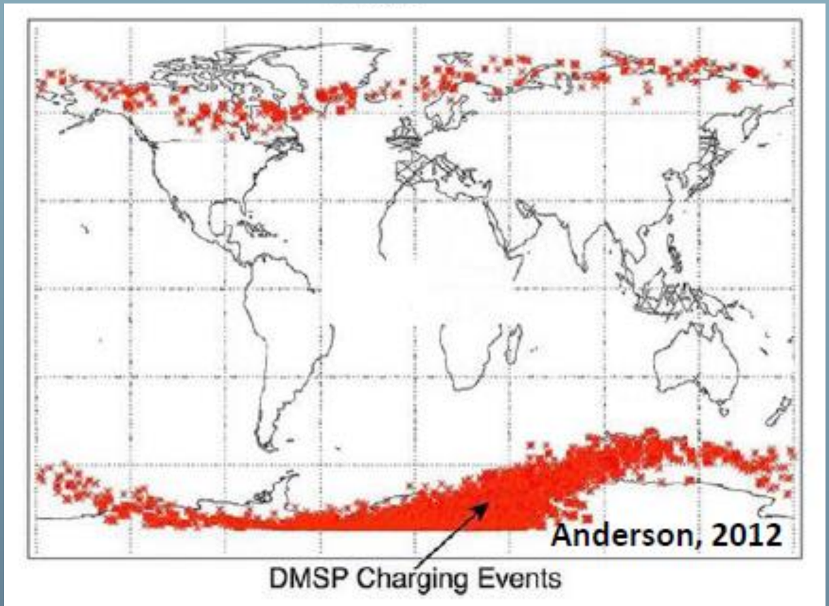
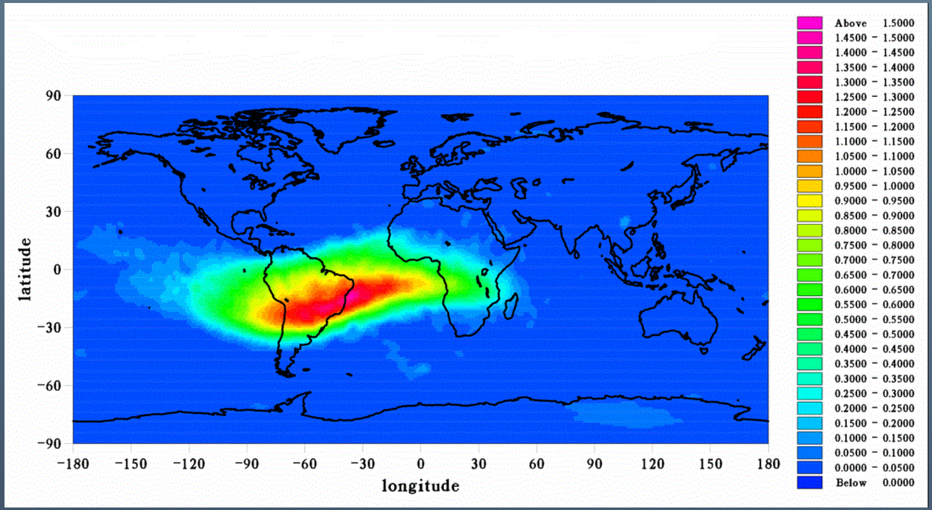
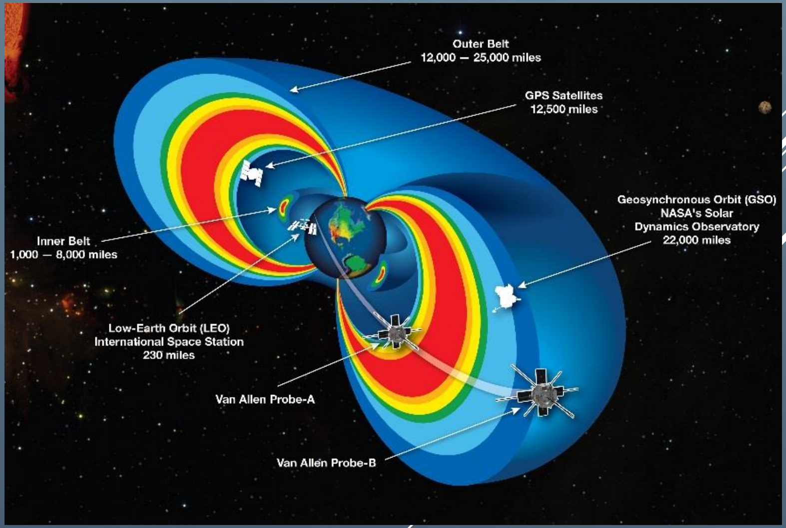
Regions of Concern

- South Atlantic Anomaly
- Polar
- Inner proton belts
- Outer electron belts
- Solar energetic particle event







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eV			keV			MeV			GeV			
1	10	100	1	10	100	1	10	100	1	10	100	
		Surface charging				Internal charging			Radiation effects			

Space Weather Radiation Effects

Mechanism	Cause	Effect	Impact
Single Event Effects	**Inner belts, SAA, beyond inner belt** • GCR heavy ions • Solar protons and heavy ions • Trapped protons • Neutrons	Soft Errors: • Transient pulses in logic or support circuitry • Bitflips in memory cells or registers	Single Event Upsets –generally non-destructive
		Hard errors: • High operating current, above device specifications. • Burnout of power MOSFETS • Gate Rupture • Frozen bits • Noise in CCDs	Single Event Latchup – potentially destructive Require power reset to clear.
Total Ionizing Dose (TID)	**On the Pad** **SEPs, SAA** • Trapped protons • Trapped electrons • Solar energetic particles	• Degradation of microelectronics • Cumulative long term ionizing damage	• **Issue for launches with radioactive sources.** • Devices can suffer threshold shirts, increased leakage and power consumption, timing changes, decreased functionality
Displacement Damage Dose (DDD)	**Inner belts, outer belts, on the pad** • Trapped protons and electrons • Solar protons • Neutrons	• Incident proton will create defects by colliding with an atom of the crystal which provokes damage to the electrical characteristics of certain components	Issue for launches with radioactive sources. • Degradation of optical components and some electronics • Degradation of solar cells

Space Weather Radiation Effects

Mechanism	Cause	Effect	Impact
Single Event Effects	**Inner belts, SAA, beyond inner belt** • GCR heavy ions • Solar protons and heavy ions • Trapped protons • Neutrons	Soft Errors: • Transient pulses in logic or support circuitry • Bitflips in memory cells or registers	Single Event Upsets –generally non-destructive
		Hard errors: • High operating current, above device specifications. • Burnout of power MOSFETS • Gate Rupture • Frozen bits • Noise in CCDs	Single Event Latchup – potentially destructive Require power reset to clear.
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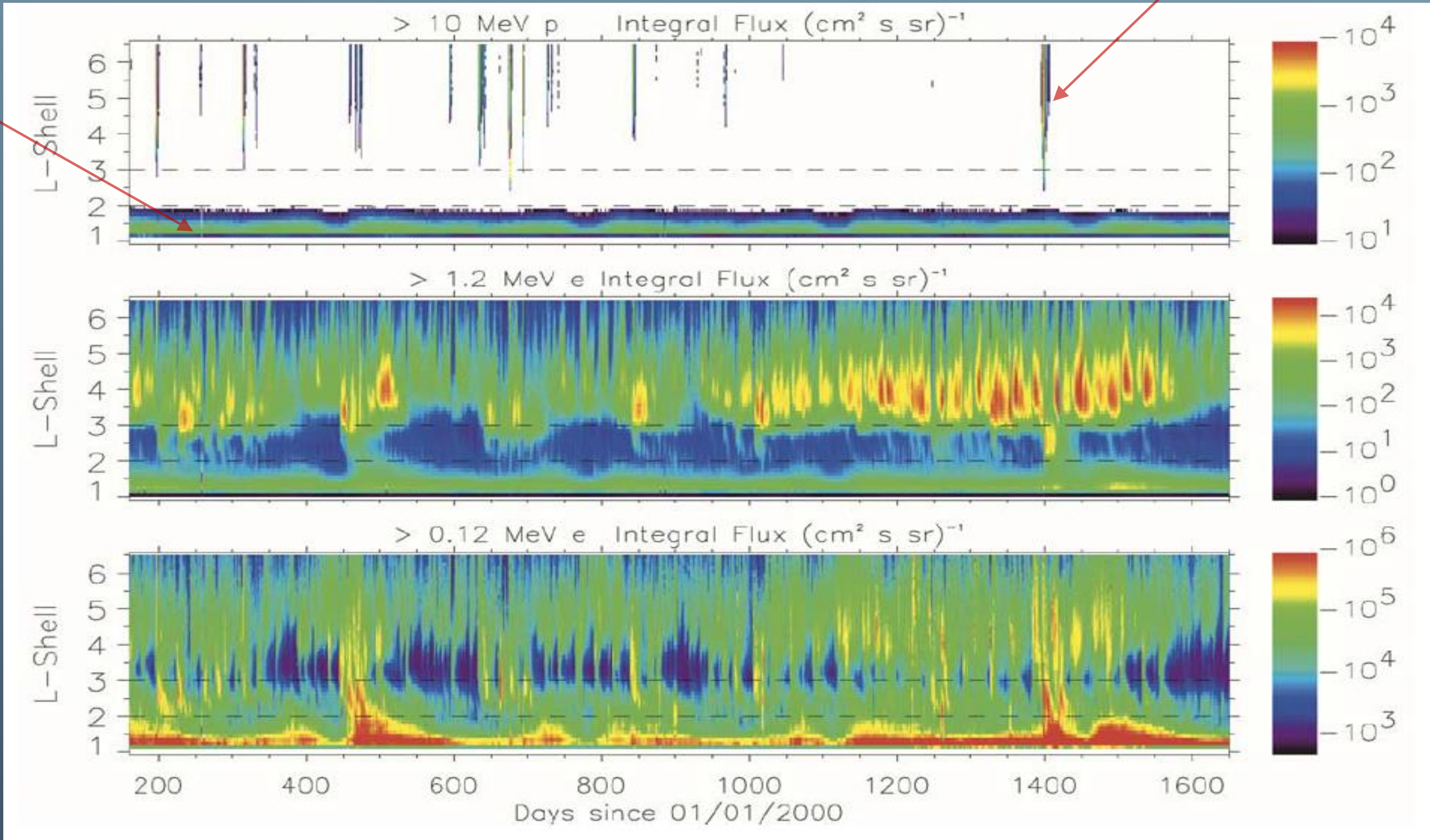
Relative stability of inner belt e-, proton populations compared to strong variability in outer belt electron populations

Solar energetic particle event

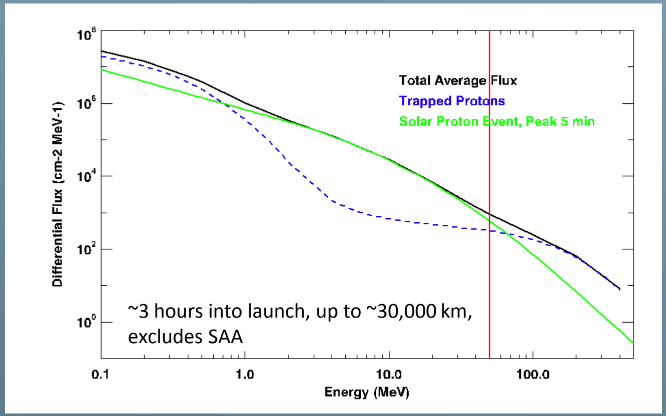
TSX-5: 410 km x 1710 km x 69⁰ inclination

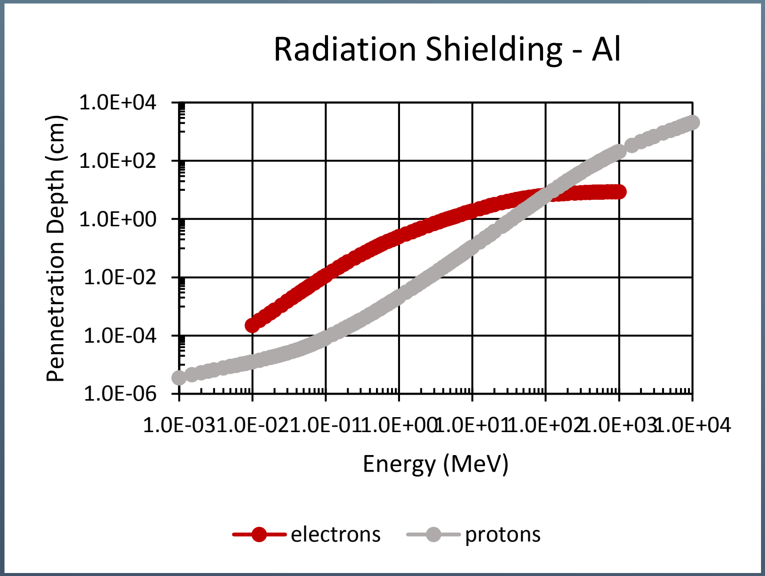
Inner proton belt

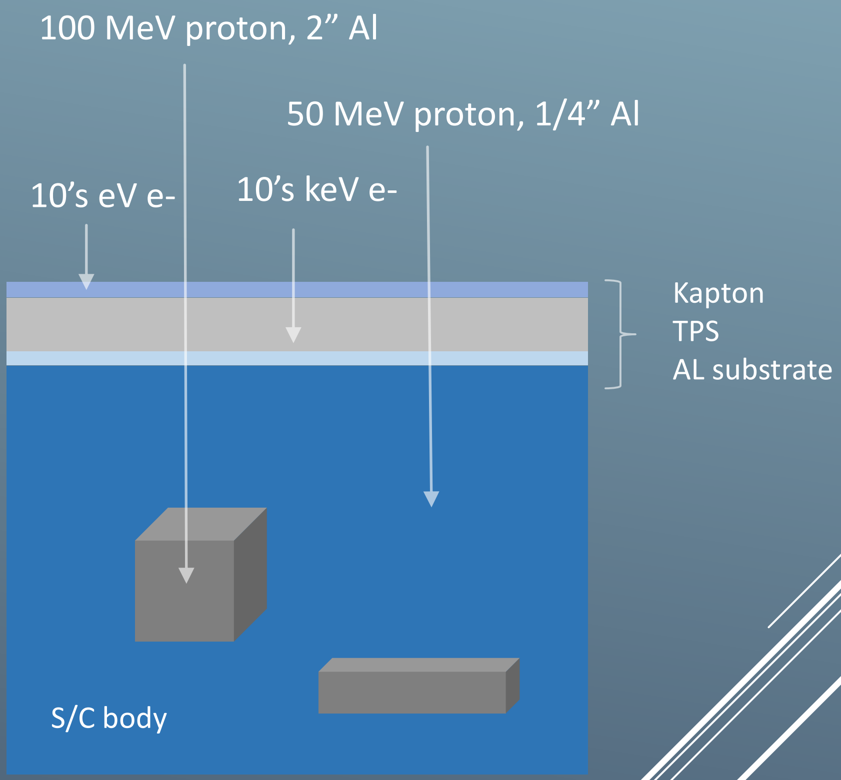


Brautigam et al., 2004

Radiation and Penetration Depth







300 MeV proton, 10" Al

1 GeV proton, 80" Al

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Single Event Effects (SEE)

Single Event Effects (SEE): current generated by ion passing through the sensitive volume of a biased electronic device changes the device operating state

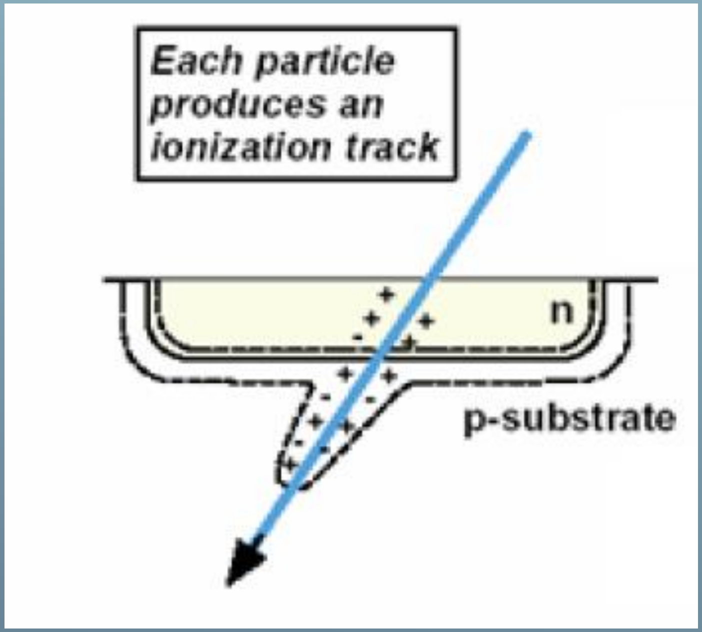
- SEE is caused directly by ionization produced by incident heavy ion particles

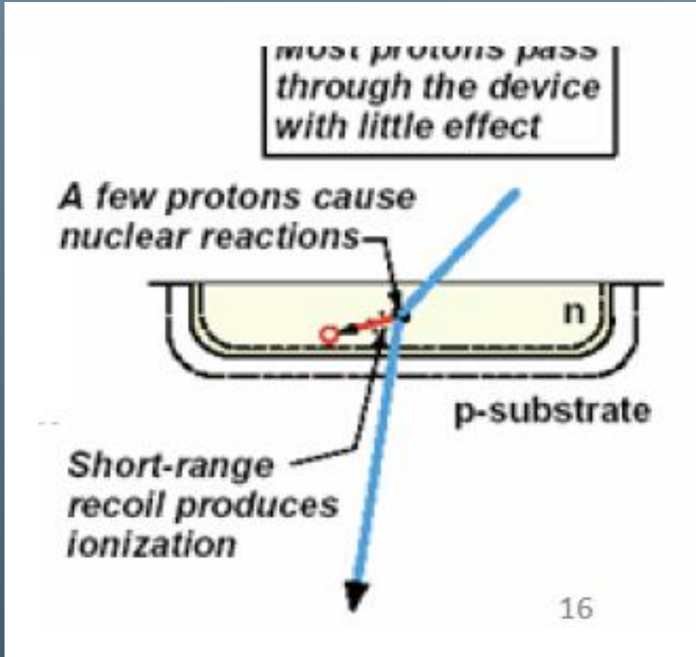
SEE Generated by Heavy Ions (2 < Z < 92)

- High linear energy transfer (LET) rate of heavy ions produces ionization along track as ion slows down
- Dense ionization track over a short range produces sufficient charge in sensitive volume to cause SEE

SEE Generated by Protons (Z = 1)

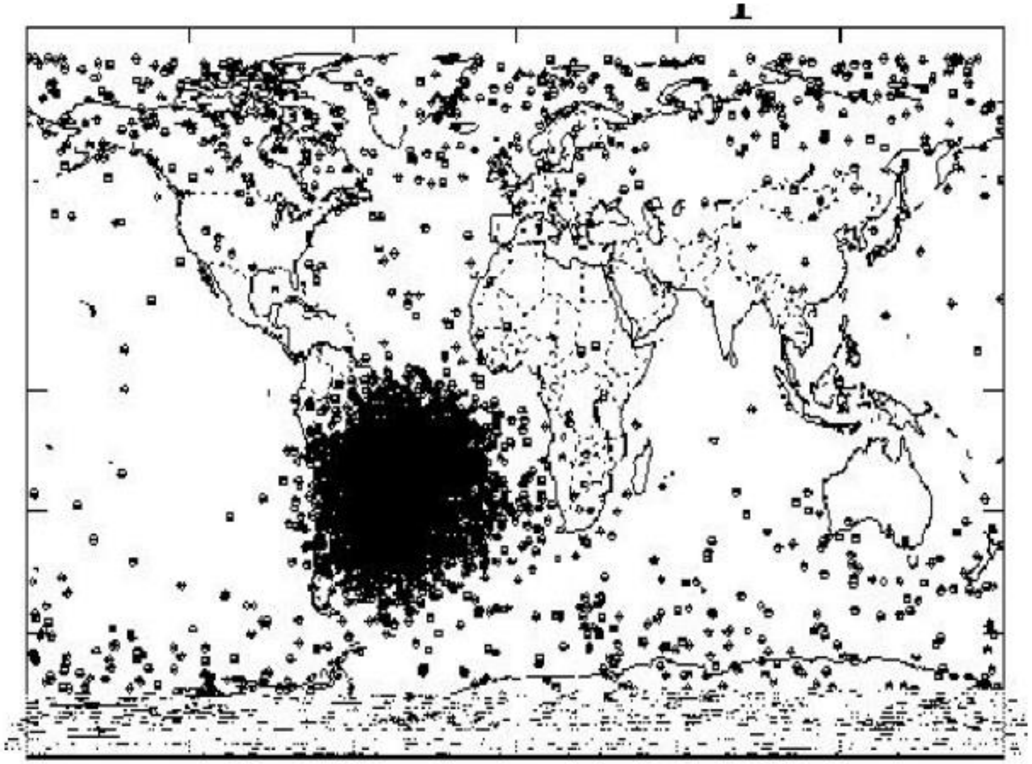
- Proton LET is too low to generate SEE, but secondary heavy ions are produced in nuclear reactions with nuclei of atoms (usually silicon) inside electronics. Energy is transferred to a target atom fragment or recoil ion with high LET and charge deposited by recoil ion(s) is the direct cause of SEE.
- Only a small fraction of protons are converted to such secondary particles (1 in 10^4 – 10^5).





UoSAT-3 Single event upsets

University of Surrey Satellite (UoSAT)



780 km, 98° inclination

[http://www.esa.int/TEC/Space_Environment/SEMQ95T4LZE_0.html]

Space Weather Charging Effects

Mechanism	Cause	Effect	Impact
Surface Charging	**Polar, Outer radiation belts, GEO, GTO** • Dense, cold plasma • Hot plasma	Currents from electrostatic discharges (ESD)	• Compromised function and/or catastrophic destruction of sensitive electronics • Solar array string damage (power loss), solar array failures • Un-commanded change in system states (phantom commands) • Loss of synchronization in timing circuits • Spurious mode switching, power-on resets, erroneous sensor signals • Telemetry noise, loss of data
		Electromagnetic interference	• EMI noise levels in receiver band exceeding receiver sensitivity • Communications issues due to excess noise • Phantom commands, signals
		Power drains	• Parasitic currents and solar array power loss (LEO
		Physical damage from ESD	• ESD damage to mission critical materials including thermal control coatings, re-entry thermal protection systems, optical materials (dielectric coatings, mirror surfaces) • Re-attracted photo ionized outgassing materials deposited as surface contaminants
		Biasing of instrument readings	• Compromised science instrument, sensor function • Photoelectron contamination in electron spectrum
Internal Charging	**Polar, Outer radiation belts, GEO, GTO** • High energy electrons	Electrical discharging causing physical damage	• ESD damage to mission critical materials including thermal control coatings, re-entry thermal protection systems, optical materials (dielectric coatings, mirror surfaces)
		Biasing of instrument readings	• Compromised science instrument, sensor function
		Charging of circuit boards, cable insulation, and ungrounded metal faster than charge can dissipate	• Material damage, discharge currents inside of spacecraft Faraday cage on or near critical circuitry, and RF noise.

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Mechanism	Cause	Effect	Impact
Surface Charging	**Polar, Outer radiation belts, GEO, GTO** • Dense, cold plasma • Hot plasma	Currents from electrostatic discharges (ESD)	• Compromised function and/or catastrophic destruction of sensitive electronics • Solar array string damage (power loss), solar array failures • Un-commanded change in system states (phantom commands) • Loss of synchronization in timing circuits • Spurious mode switching, power-on resets, erroneous sensor signals • Telemetry noise, loss of data
		Electromagnetic interference	• EMI noise levels in receiver band exceeding receiver sensitivity • Communications issues due to excess noise • Phantom commands, signals
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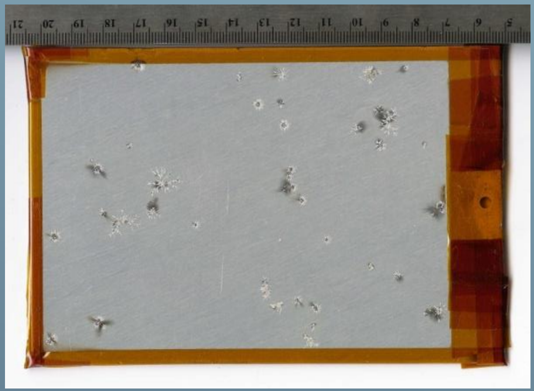
		Biasing of instrument readings	• Compromised science instrument, sensor function
		Charging of circuit boards, cable insulation, and ungrounded metal faster than charge can dissipate	• Material damage, discharge currents inside of spacecraft Faraday cage on or near critical circuitry, and RF noise.

Charging Anomaly and Failure Mechanisms

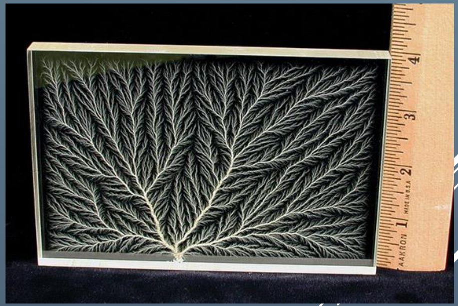
- Accumulation of excess negative charge or inductive re-distribution of charge generates potential differences between spacecraft and space (frame potential) or between two points on the spacecraft (differential potential)
- An electrostatic discharge (ESD) results when electric fields associated with potential differences (**E** = $-\nabla\Phi$) exceed the dielectric breakdown strength of materials allowing charge to flow in an arc
- Damage depends on energy available to arc

$$E = \frac{1}{2}CV^2 \qquad C = \varepsilon\frac{A}{d}$$

- Charging anomalies and failures depend on
  - Magnitudes of the induced potentials and strength of the electric fields
  - Material configuration (and capacitance)
  - Electrical properties of the materials
    - Surface and volume resistivity, dielectric constant
    - Secondary and backscattered electron yields, photoemission yields
    - Dielectric breakdown strength



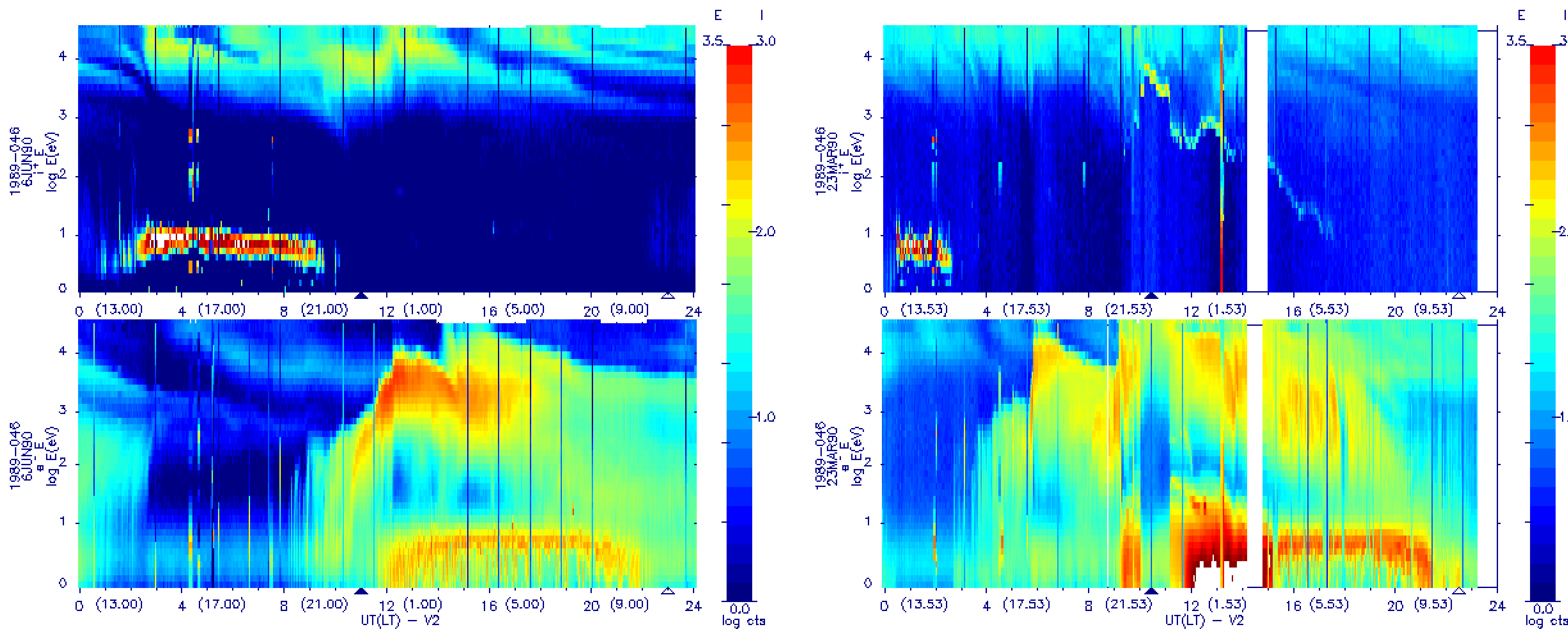
ISS MMOD shield 1.3 μm chromic acid anodized thermal control coating (T. Schneider/NASA)



PMMA (acrylic) charged by ~2 to 5 MeV electrons

GEO Satellite Surface Charging

LANL 1989-046 6 June 1990 | LANL 1989-046 23 March 1990



no charging

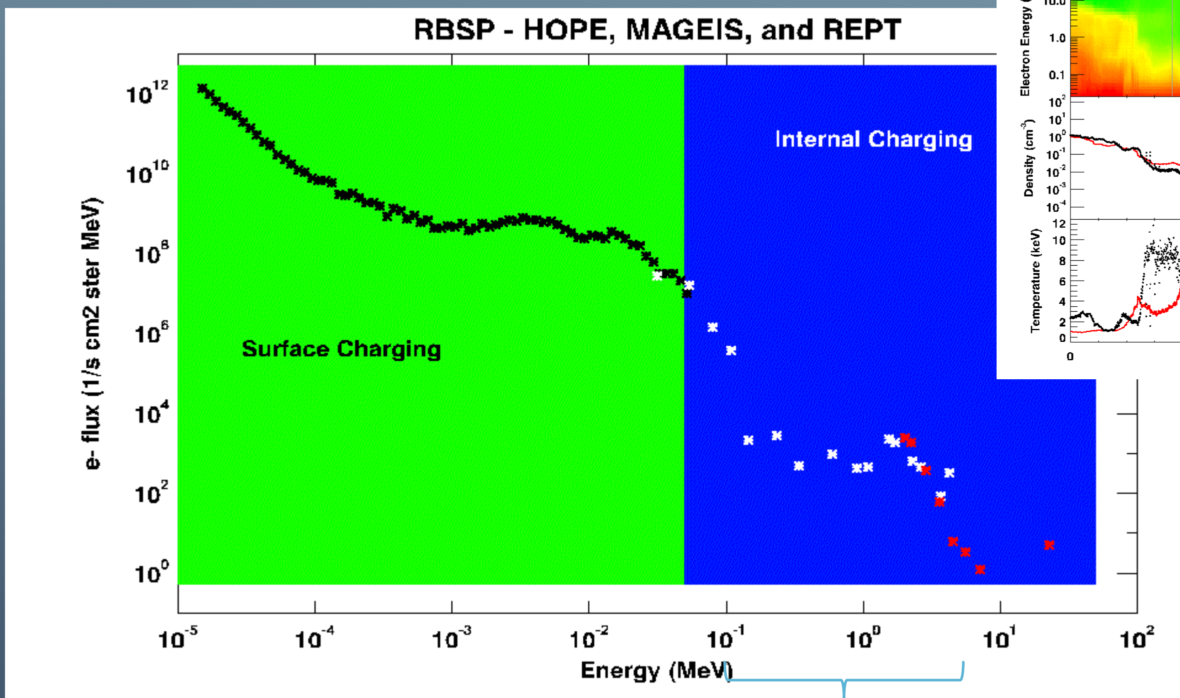
~ 10 kV in eclipse

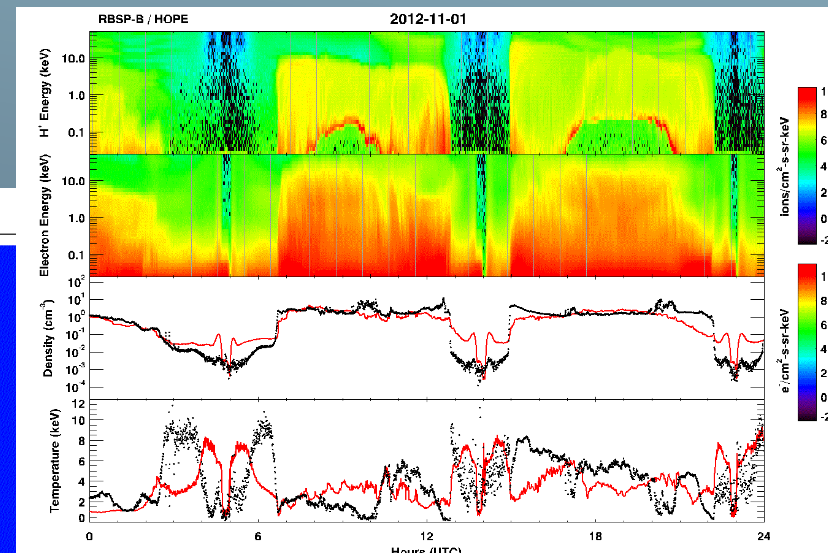
~ 1 kV post midnight

During periods of significant hot plasma injection, spacecraft may become significantly charged relative to background plasma

Radiation Belts

- Radiation effects
- internal charging
- surface charging





AE8

SPM

AE9

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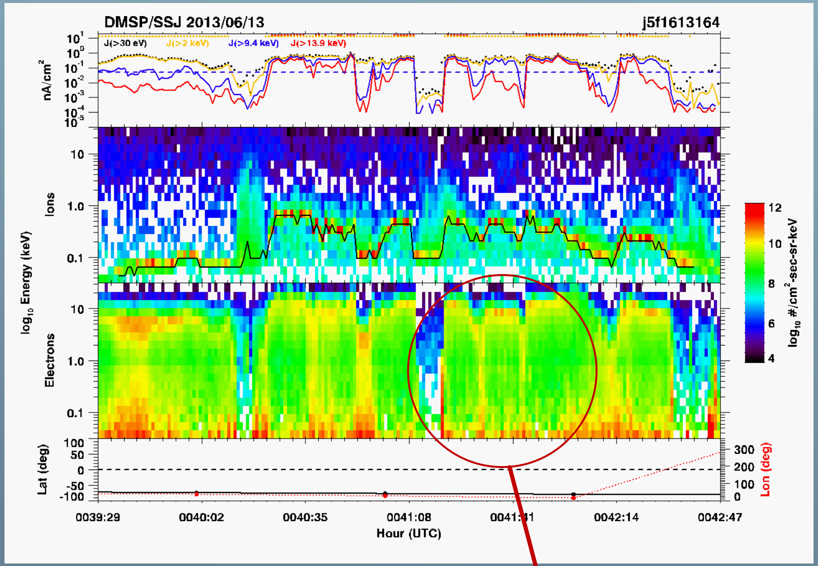
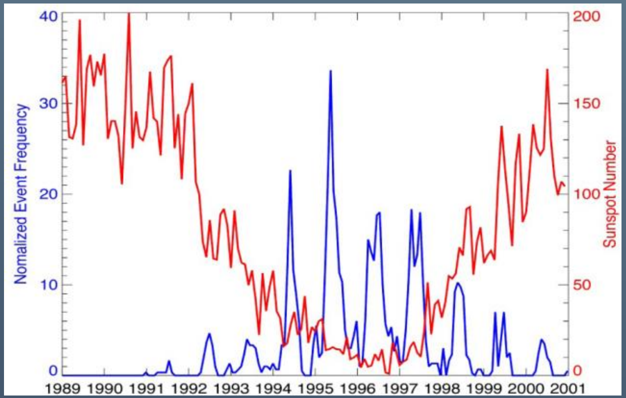
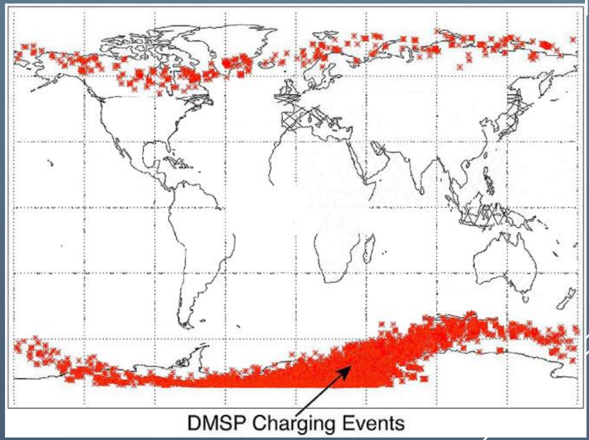
Auroral Oval

- Surface, internal, radiation
- Rule of thumb
  - Satellite is in darkness
  - An intense, energetic electron (> 14 keV population) precipitation event is required (flux > 10^8 electrons cm^{-2} s^{-1} sr^{-1})
  - Locally depleted (< 10^4 cm^{-3}) ambient plasma density



Inverted V





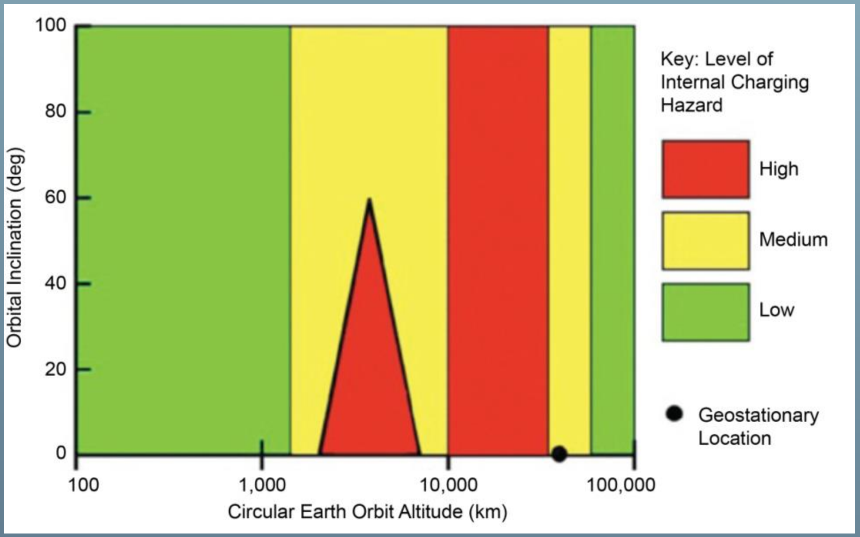
(from *Anderson*, 2001)

Satellite Charging

- Accumulation of charge (current) on or within the outer material of a spacecraft
  - Surface
  - Internal
- Charging can cause significant damage to spacecraft resulting in loss of mission, loss of functionality, loss of revenue
- Complicated physical process that is dependent on spacecraft configuration, material selection, and orbit (environment)
- Characterize charging environment and build spacecraft to withstand or avoid charging events
- Types of Discharges
  - Flashover – discharge from one outer surface to an adjacent surface
  - Punch through – discharge from outer surface to underlying ground
  - Discharge to space – discharge from outer surface of spacecraft to ambient plasma

Internal (deep dielectric) Charging

- Charging time scales of ~hours to days (even months depending on the material), typically low threat for launch vehicles
- Multiple GTO phasing orbits or complete radiation belt transits should be evaluate as special cases
- Questions to ask:
  - Insulation on exposed or lightly shielded signal and power cables?
  - Cryotank insulation, paints, decals?
  - Are sensitive electronics located near the insulation materials?
  - Will RF noise interfere with critical up/down communications?



R. W. Evans, et al., SCTC, November 1989.
A. Whittlesey, et al., *IEEE International EMC Symposium*, 1992.

$$\vec{\nabla}\cdot\vec{D} = \vec{\nabla}\cdot\varepsilon\vec{E} = \vec{\nabla}\cdot\varepsilon(-\vec{\nabla}\phi) = \rho$$

$$\nabla^2\phi = -\rho/\varepsilon$$

$$\frac{\partial\rho}{\partial t} = -\nabla\cdot J \quad \text{where } J = J_R + J_C$$

$$J = \sigma E = (\sigma_{dark} + \sigma_{RIC})E$$

$$\sigma_{RIC} = k\left(\frac{d\gamma}{dt}\right)^{\alpha} \quad 0.5 < \alpha < 1.0$$

Solution to Poisson, continuity equation involves two problems:

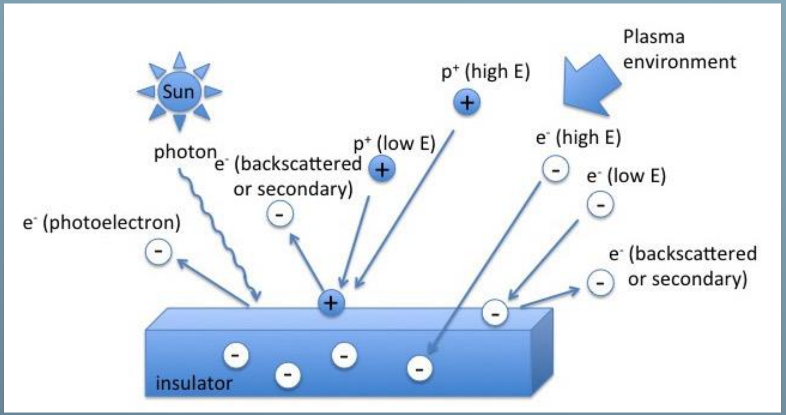
- Radiation penetration with charge and energy deposition in material
- Electrostatic solution of fields from motion in insulator

Surface Charging

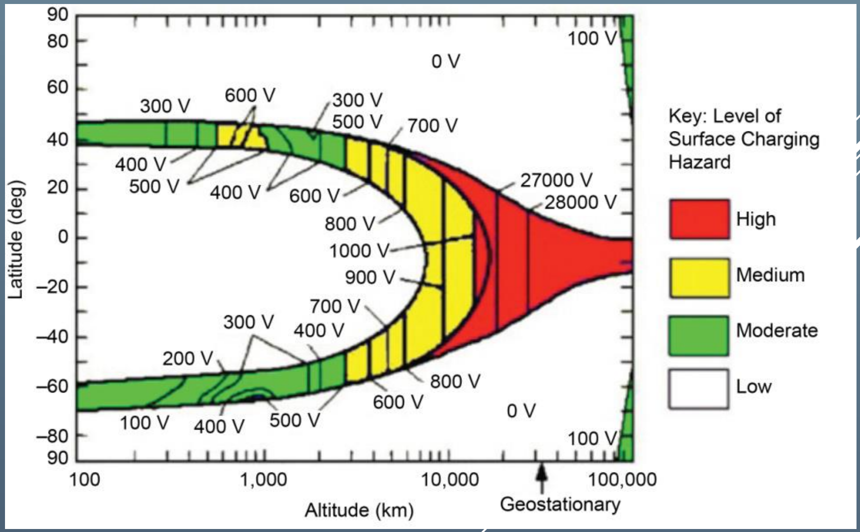
- The net charge is due to the sum of the incident currents.

$$\frac{dQ}{dt} = \frac{d\sigma}{dt} A = C\frac{dV}{dt} = \sum_k I_k \approx \; 0 \text{ (at equilibrium)}$$

- Charging time scales ~seconds.
- Insulating materials on spacecraft surfaces increase the threat of differential charging
- Questions to ask:
  - Will launch trajectory encounter regions of auroral charging threat?
  - Will the encounter be in sunlight or darkness?
  - Are sensitive electronics located near the insulation materials?
    Will RF noise interfere with critical up/down communications?



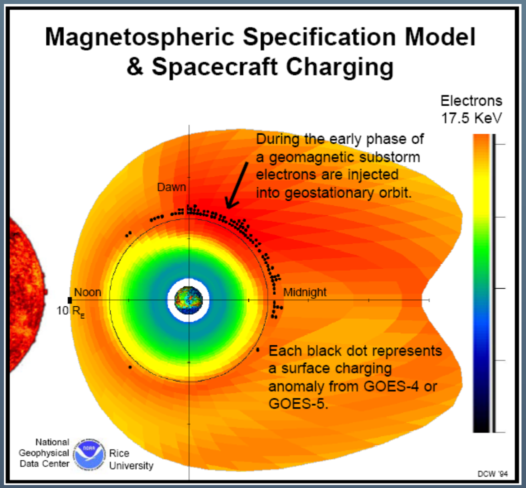
Adapted from Garrett and Minow, 2004

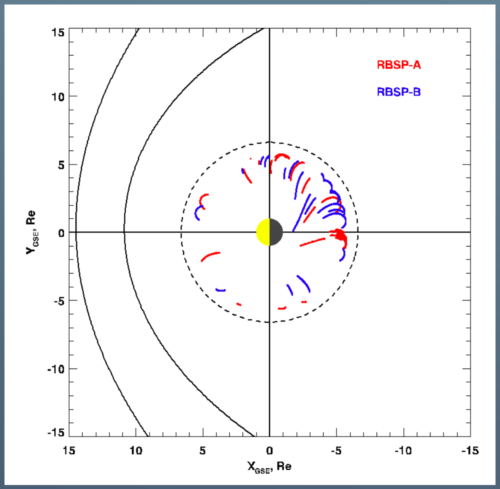


Surface Charging Locations

- GEO charging is more prevalent in the midnight to dawn sector.
- GTO, larger number in midnight-dawn sector, but sizable number at other local times
- Auroral charging occurs in the night time hemisphere of auroral regions.
- Internal charging independent of local time.

GOES 4, 5





RBSP A, B

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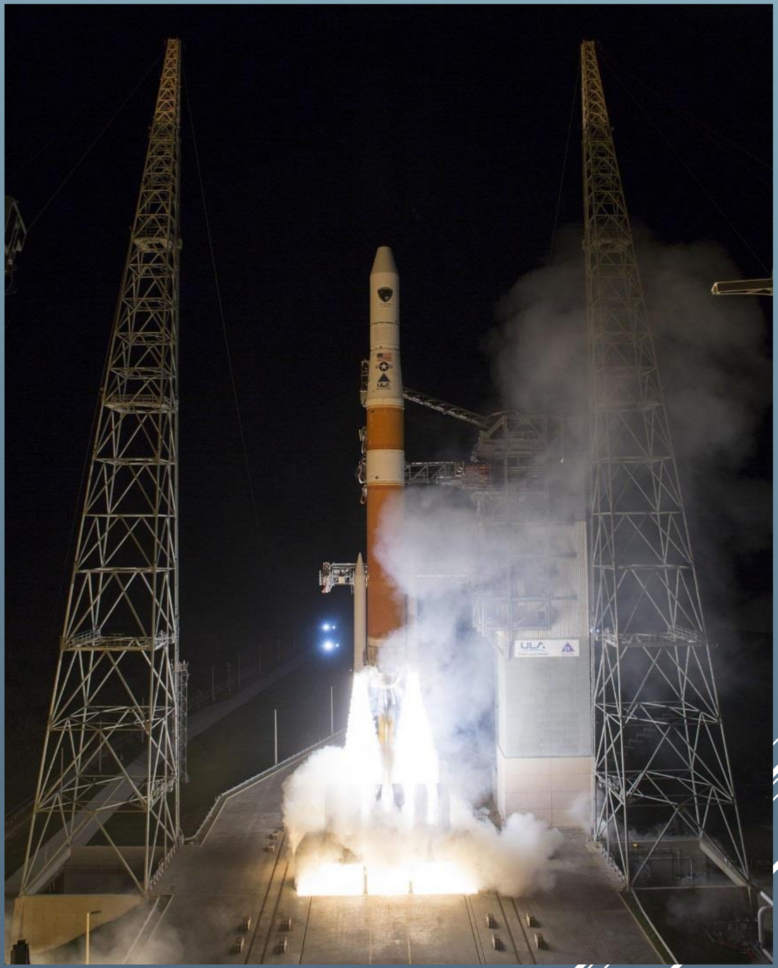
Delta IV/GPS IIF-5: Launch Delay

- Cape Canaveral Air Force Stations Delta IV launch operations on Feb 20-21, 2014 briefly delayed due to concern over solar proton event.
- All system consoles report "GO" at T-4 minute hold except Space Weather which reported a violation of launch criteria.
- Launch teams determined the proton flux levels were very close to acceptable limit, represented no danger to LV, and decided Space Weather was "GO."
- Launch successful at end of window

    Window: Feb 21, 1:40 UT – 1:59 UT

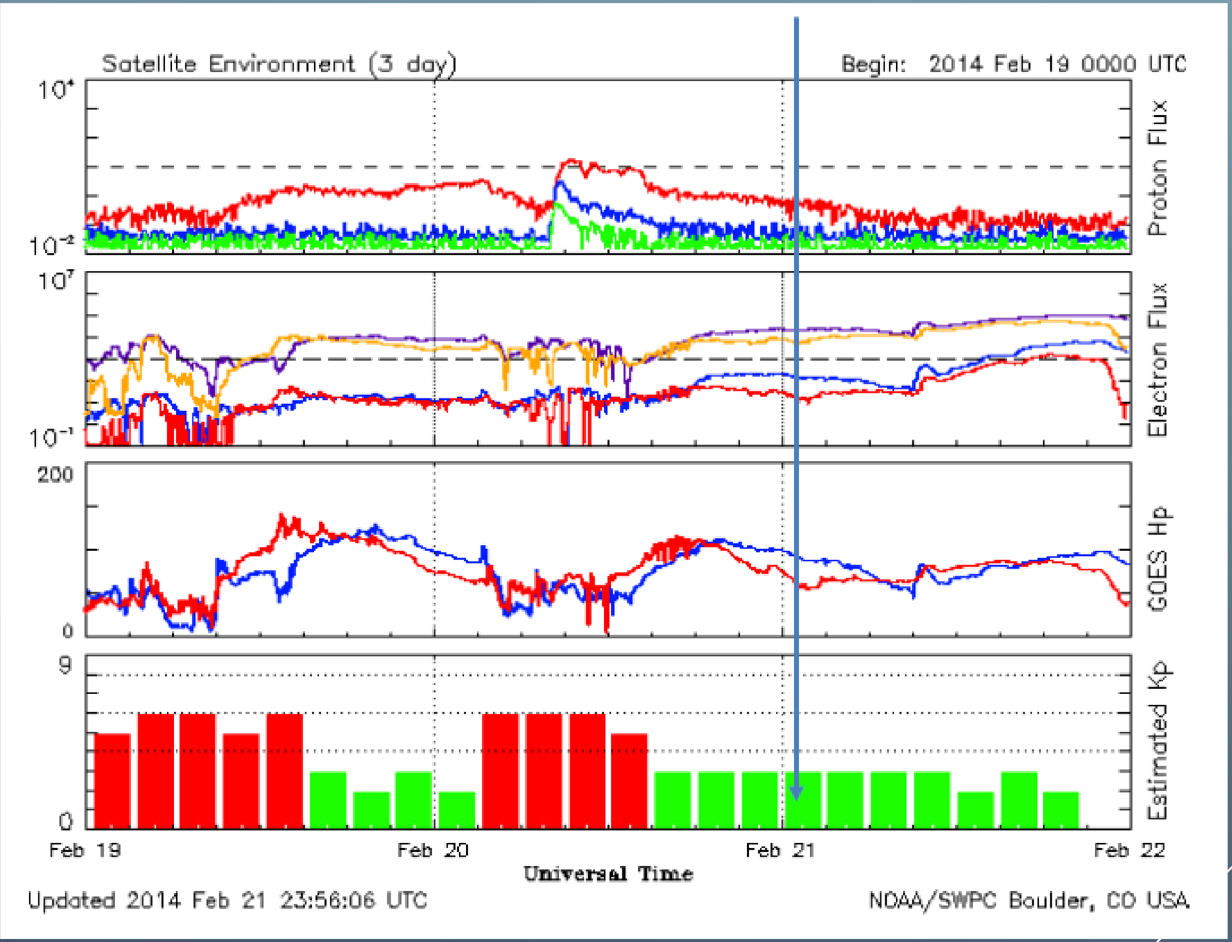
    Launch: Feb 21, 1:59 UT



http://www.spaceflight101.net/delta-iv-gps-iif5-launch.html
http://gpsworld.com/new-gps-iif-satellite-launched/

Delta IV/GPS IIF-5: Launch Delay

ULA Delta IV
GPS IIF-5
Feb 21, 2016 @ 1:59 UTC



ISS Commercial Resupply: Launch Delay

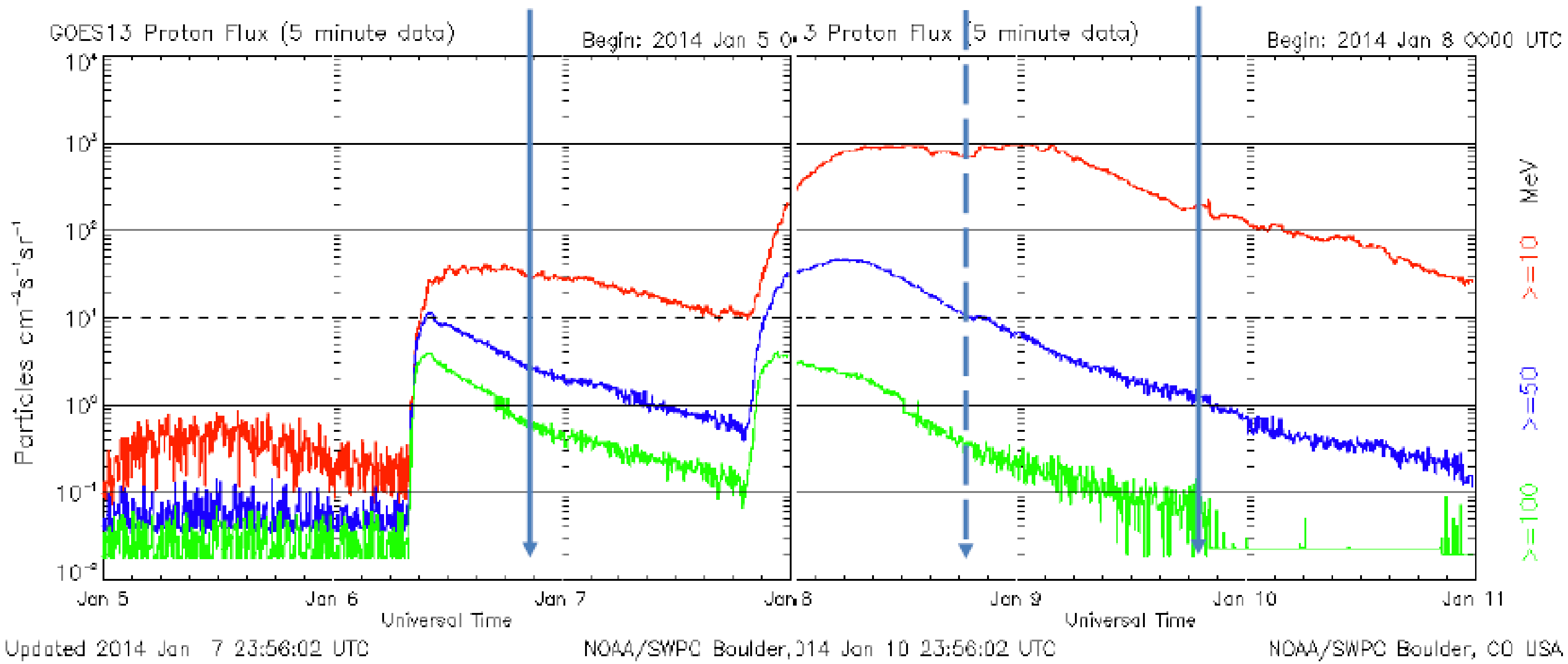
- Massive solar flare scrubbed the launch of Orbital Space Corp ISS re supply on an Antares rocket from Wallops Island on 1-8-14
- Delayed 24 hours due to solar proton event.
- Space radiation exceeded LCC that were in place to ensure the rocket's electronic system was not impacted.
- "[The proton-flux levels] exceeded by a considerable margin the constraints imposed on the mission to ensure the rocket's electronic systems are not impacted by a harsh radiation environment." – Orbital officials
- "Prior to beginning the countdown, we decided we did not have a path forward to ensure we'd have a safe launch so we decided to scrub for the day to do further analysis and evaluate both the event itself and our hardware to make sure we could in fact execute the mission," added Frank Culbertson, Orbital vice president and a former astronaut.
- After analyzing the risks for the day - "Upon a deeper examination of the current space weather, Orbital's engineering team, in consultation with NASA, has determined the risk to launch success is within acceptable limits established at the outset of the Antares program."

http://www.collectspace.com/news/news-010814a-orbital-launch-scrub-solarflare.html

ISS Commercial Resupply: Launch Delay

SpaceX, Falcon 9
Thiacom 6 satellite
6 Jan, 22:06 UT

Orbital ATK, Antares
Cygnus (ISS cargo resupply)
1st window: 8 Jan, 18:32 UT, launch delayed
2nd window: 9 Jan, 18:07 UT. launched



NASA/DoD Kodiak Star: Launch Delay

Kodiak Star scheduled for September 2001 launch from Kodiak

Launch criteria: J(10>MeV) < 10 particles/cm^2 s sr

16 Sept: launch operations start, launch approved for 21 Sept

21 Sept: scrub due to terrestrial weather

22 Sept: scrub due to range tracking radar hardware problems, next attempt deferred to 24 Sept

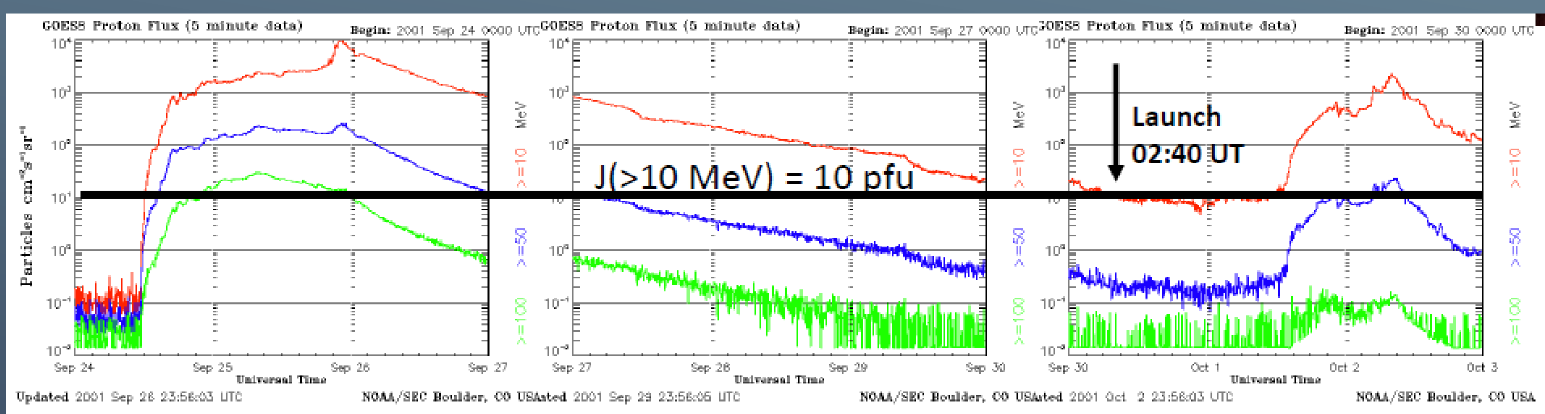
24 Sept: scrub due to solar proton event

25 Sept: scrub due to solar proton event, next attempt deferred to 27 Sept

27 Sept: scrub due to solar proton event and terrestrial weather, next attempt deferred to 29 Sept

29 Sept: attempt begins with radar issues and proton flux out of limits; radar problem is corrected

30 Sept: proton flux decreases to less than constraint value allowing launch at 2:40 UT on Sept 30.



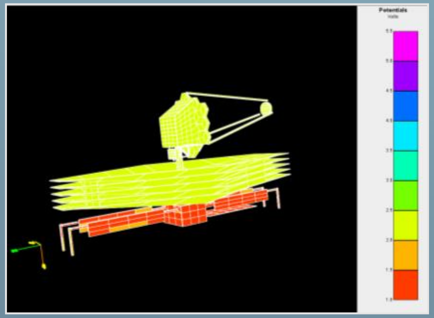
L. Neergaard Parker/DOLWG 2016

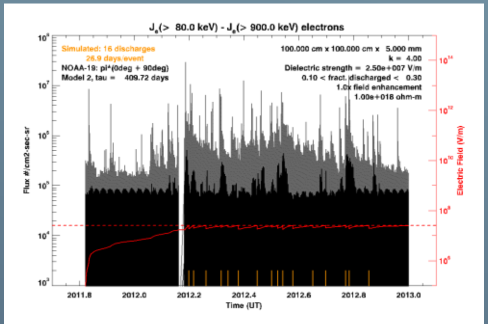
Outline

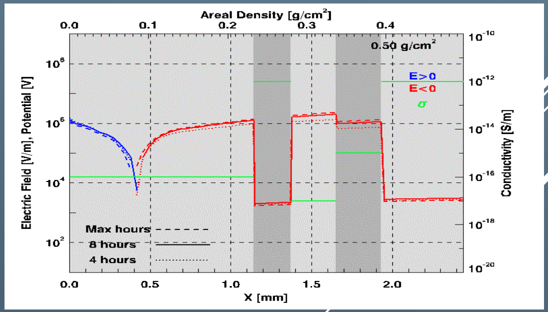
- Requirements
- Space Weather Overview
- Environments and Effects
- Examples
- Mitigating Space Weather Effects

Design Strategies

- **Design your spacecraft to withstand the environment.**
- Follow good EMC, grounding/bonding and charging design practices
  - Ground conductive materials to assure an equipotential (eliminate differential charging)
  - Use static dissipative materials when conductors can not be used
- Analyze spacecraft configuration in charging environment - modeling
  - Nascap-2k, In.cam, NUMIT
- Test insulating materials with electron beams at relevant energy (10's keV) and current (~1-10 nA/cm^2) to determine if (a) arcing will occur and (b) if it will result in damage
- Perform radiation testing on sensitive parts.



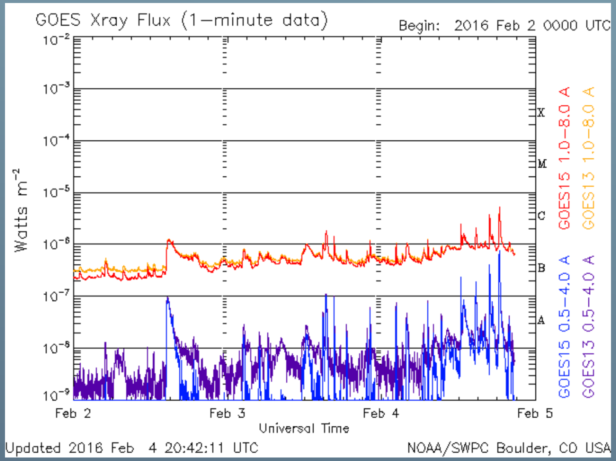


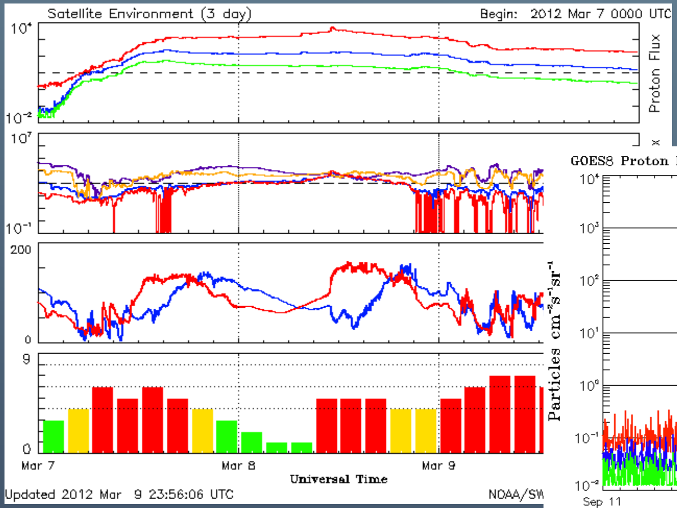


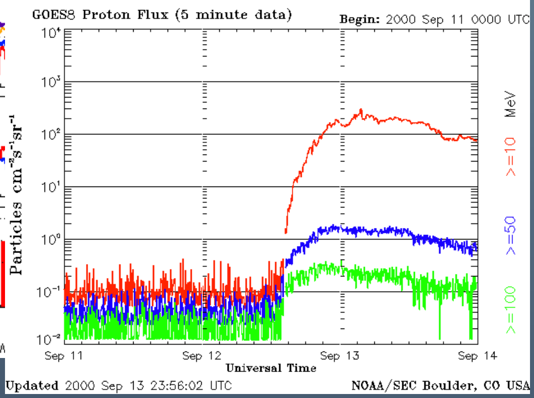
Monitoring for Space Weather

- GOES data from NOAA
- A flare does not mean there will be a solar energetic particle

Classification	Peak Flux Range at 100-800 Picometer (Watts/m^2)
A	$< 10^{-7}$
B	10^{-7} - 10^{-6}
C	10^{-6} - 10^{-5}
M	10^{-5} - 10^{-4}
X	$> 10^{-4}$







Example of false negative

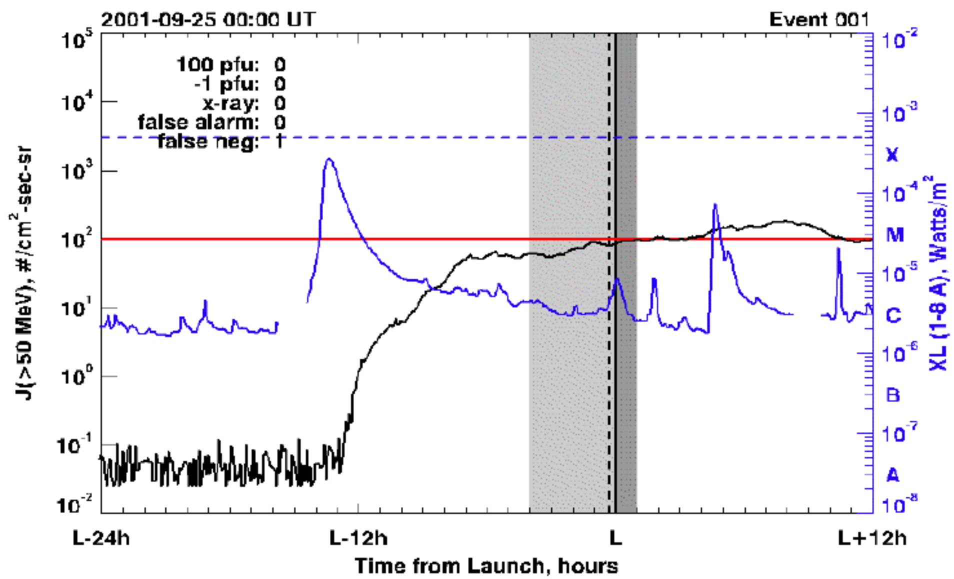


Figure 1. Example False-Negative Solar Proton Event. This figure shows a false-negative example from an evaluation of solar x-ray (blue line) and energetic proton (black line) launch constraints used during the 4 hours preceding launch. The software determines whether the constraint would require holding launch and checks for possible exposure to protons exceeding the constraint for an hour following launch. The launch decision was "go" for space environment at the simulated launch decision time. However, the solar proton flux increased to levels exceeding the constraint level in the hour following launch.

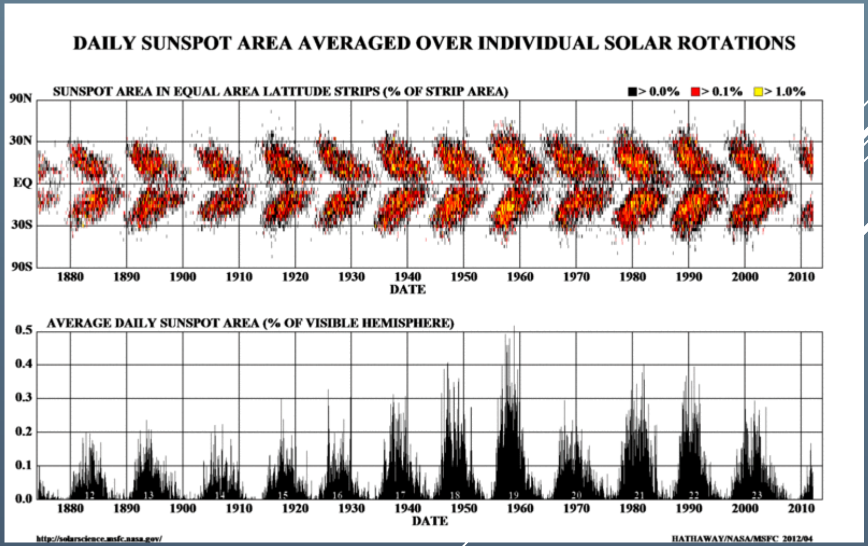
Summary

- Need to understand the environment you're launching into
- Understand if the launch vehicle/payloads have any component issues
  - Radiation / SEE
  - Internal or surface charging
- Monitor the space environment

BACKUP CHARTS

Solar cycle

- Why do we care about solar cycle
  - Maximum – more geomagnetic storms, CMEs, solar flares, electron radiation environment
  - Minimum – GCR, auroral charging, LEO proton radiation environment, coronal holes
- Approximately 11 years in length, sun's polarity changes with each cycle.
- F10.7 - Represents a measure of diffuse, nonradiative heating of the coronal plasma trapped by magnetic fields over active regions.
- Solar Sunspot number - Measure of the area of solar surface covered by sunspots. Possible geomagnetic storms because CMEs and SEPs can come from those regions



Environment Models

- IRI
  - Statistical
  - 50-2000 km
  - Monthly averages in the non-auroral ionosphere for magnetically quiet conditions
  - Uses data from ionosondes, ISR, topside sounders, satellite and rocket observations
  - Electron density, electron Temperature, ion temperature, ion composition (O^+, H^+, He^+, NO^+, O_2^+), ion drift, TEC
- AE8 / AP8
  - Statistical
  - e^- is 0.1-7 MeV
  - Protons is 0.1-400 MeV
- AE9 / AP9
  - Monte Carlo model
  - Electrons: 40 keV - 10 MeV
  - Protons: 100 keV – 2 GeV
  - Standard Plasma Model (SPM): electrons 1-40 keV, protons 1.15-164 keV

Analysis Models

- Internal Charging - NUMerical Intergration (NUMIT)
  - 1D internal charging code that iteratively solves a set of equations.
  - Estimates currents, voltages, and electric fields as a function of depth in dielectrics
- Surface Charging - Nascap-2k
  - 3D analytic surface charging code that calculates the interaction of the spacecraft with the surrounding plasma environment
  - PIC calculations are used when required
  - Estimates surface currents, potentials, and electric fields on the outer surface of the spacecraft
- Radiation Effects
  - CRÈME – 1D radiation transport model (SEUs)
  - Novice – 3D radiation model that calculates dose

Example: Internal Charging Radiation Belt Transit

- NASA-HDBK-4002A recommended thresholds evaluated for flight periods of 2, 4, and 8 hours.
- SLS/Orion Design Specification for Natural Environments (DSNE) internal charging spec is an orbit averaged flux, needs to be multiplied by exposure period to evaluate internal charging threat.
- DSNE specifies no less than 4 hours.
- Design environment exceeds internal charging threshold for energies less than a few MeV
- Credible threat for internal charging requires additional analysis and/or testing.

Energy	Integral Flux	2-hr Integral Fluence	4-hr Integral Fluence	8-hr Integral Fluence
MeV	1/cm^2-sec	1/cm^2	1/cm^2	1/cm^2
0.1	3.27E+07	2.35E+11	4.71E+11	9.42E+11
0.2	2.67E+07	1.92E+11	3.84E+11	7.69E+11
0.4	1.78E+07	1.28E+11	2.56E+11	5.13E+11
0.6	1.18E+07	8.50E+10	1.70E+11	3.40E+11
0.8	7.88E+06	5.67E+10	1.13E+11	2.27E+11
1	5.25E+06	3.78E+10	7.56E+10	1.51E+11
1.2	3.50E+06	2.52E+10	5.04E+10	1.01E+11
1.4	2.33E+06	1.68E+10	3.36E+10	6.71E+10
1.6	1.55E+06	1.12E+10	2.23E+10	4.46E+10
1.8	1.04E+06	7.49E+09	1.50E+10	3.00E+10
2	6.90E+05	4.97E+09	9.94E+09	1.99E+10
2.2	4.60E+05	3.31E+09	6.62E+09	1.32E+10
2.4	3.06E+05	2.20E+09	4.41E+09	8.81E+09
2.6	2.04E+05	1.47E+09	2.94E+09	5.88E+09
2.8	1.36E+05	9.79E+08	1.96E+09	3.92E+09
3	9.06E+04	6.52E+08	1.30E+09	2.61E+09
3.2	6.04E+04	4.35E+08	8.70E+08	1.74E+09
3.4	4.02E+04	2.89E+08	5.79E+08	1.16E+09
3.6	2.68E+04	1.93E+08	3.86E+08	7.72E+08
3.8	1.79E+04	1.29E+08	2.58E+08	5.16E+08
4	1.19E+04	8.57E+07	1.71E+08	3.43E+08
4.2	7.93E+03	5.71E+07	1.14E+08	2.28E+08
4.4	5.28E+03	3.80E+07	7.60E+07	1.52E+08
4.6	3.52E+03	2.53E+07	5.07E+07	1.01E+08
4.8	2.35E+03	1.69E+07	3.38E+07	6.77E+07
5	1.56E+03	1.12E+07	2.25E+07	4.49E+07
5.2	1.04E+03	7.49E+06	1.50E+07	3.00E+07
5.4	6.94E+02	5.00E+06	9.99E+06	2.00E+07
5.6	4.62E+02	3.33E+06	6.65E+06	1.33E+07
5.8	3.08E+02	2.22E+06	4.44E+06	8.87E+06
6	2.05E+02	1.48E+06	2.95E+06	5.90E+06