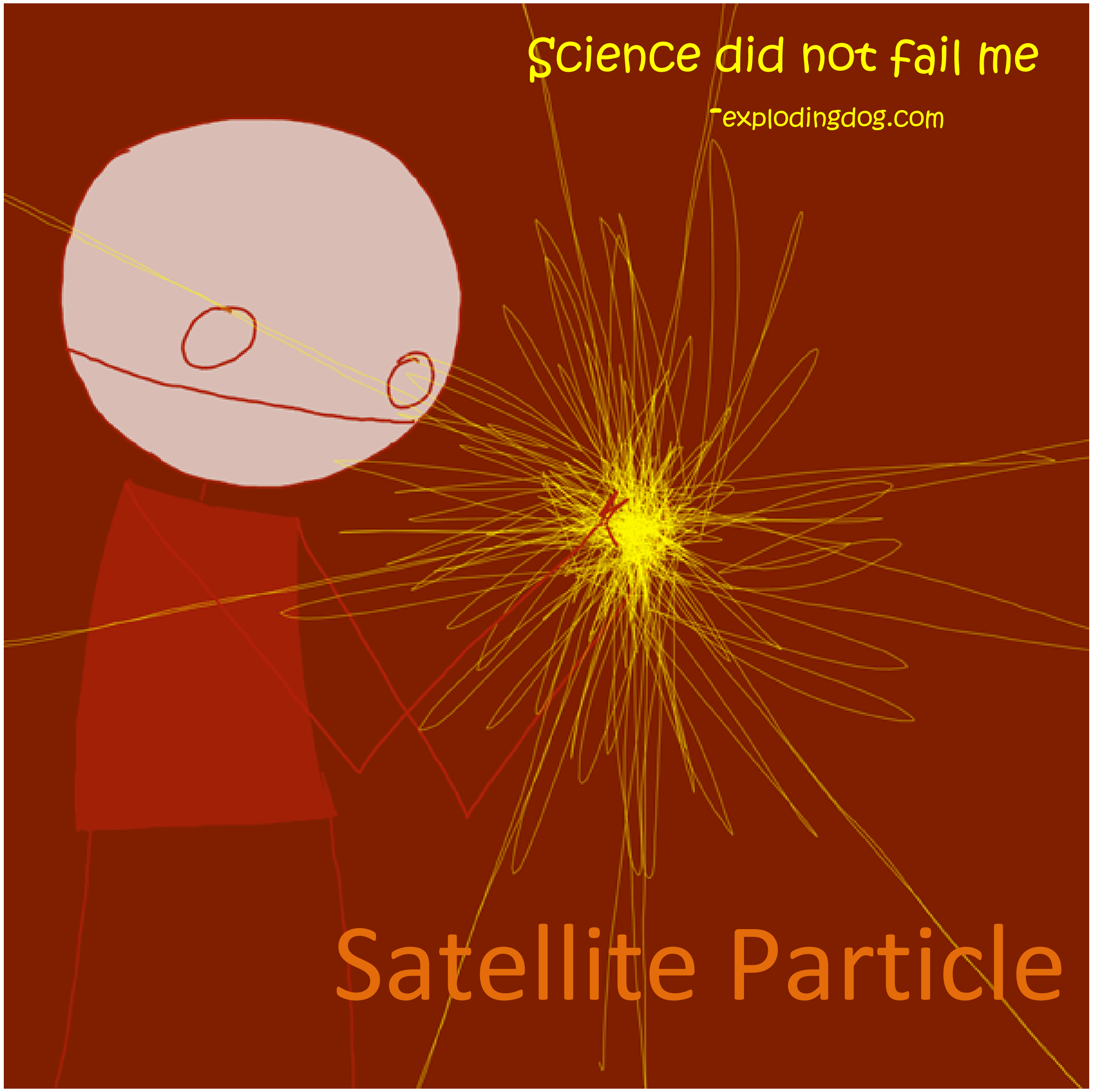


Satellite Particle Data Explained

Janet Green

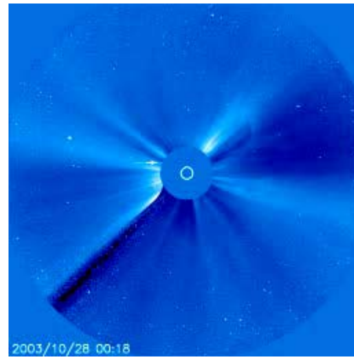
NOAA Space Weather Prediction Center

Outline

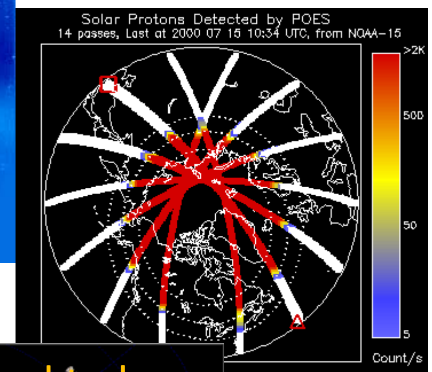
- Intro
  - Space Weather Effects of Energetic Particles
- Satellite Data
- Particle Instruments
- Units
- Interpreting Data
- Instrument Issues

Space Weather Effects of Solar Energetic Particles

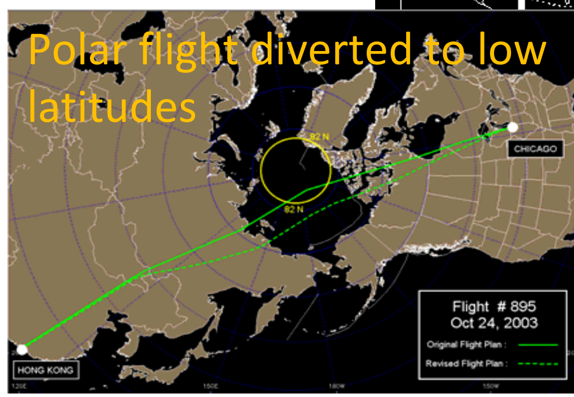
Solar protons hitting camera

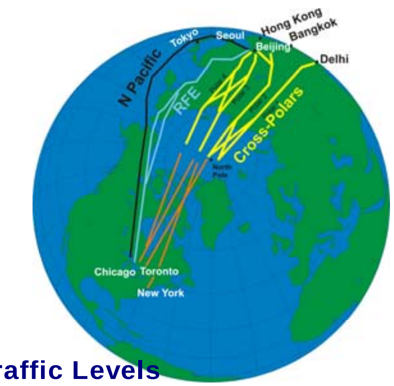


Red marks the area hit by protons



- Effect: High energy (>10 MeV) protons alter the ionosphere and increase absorption of HF communication
- Affected: Polar airline flights
- Impact:
  - Complete loss of communication above 85 degrees.
  - Planes diverted to lower latitude increasing cost (100K/flight) and delays (hours).
  - Radiation health risks.

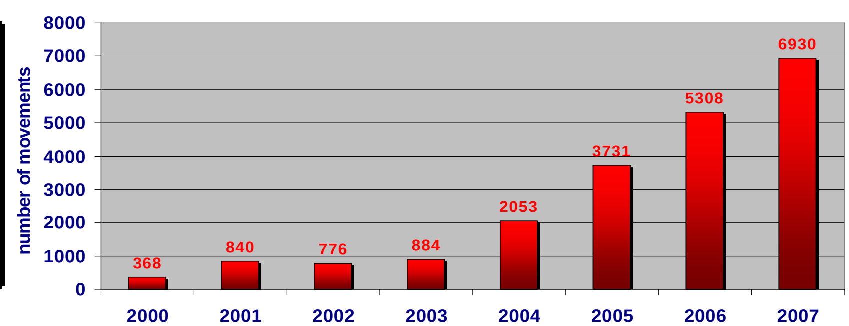




Polar Route Passenger Movement				
	2004	**2009**	**2014**	**2019**
Capacity	228,000	384,000	972,000	1,768,000
AAGR		13.9%	20.4%	12.7%

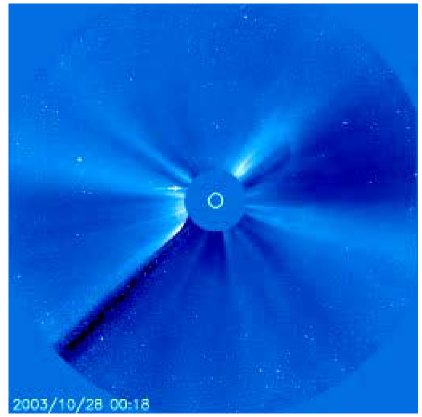
AAGR - Average Annual Growth Rate

Crosspolar Traffic Levels from 2000 through 2007

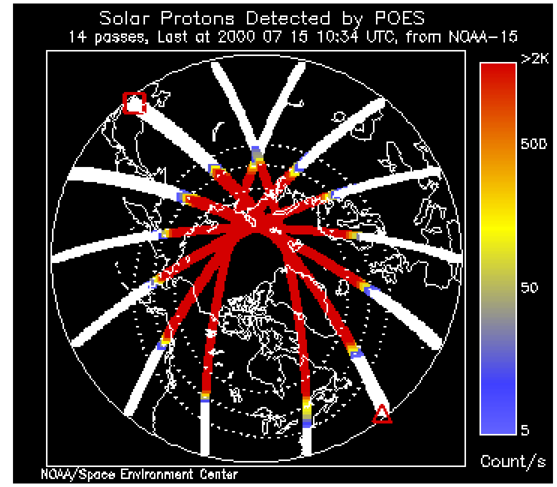


Space Weather Effects of Solar Energetic Particles

Solar protons hitting camera

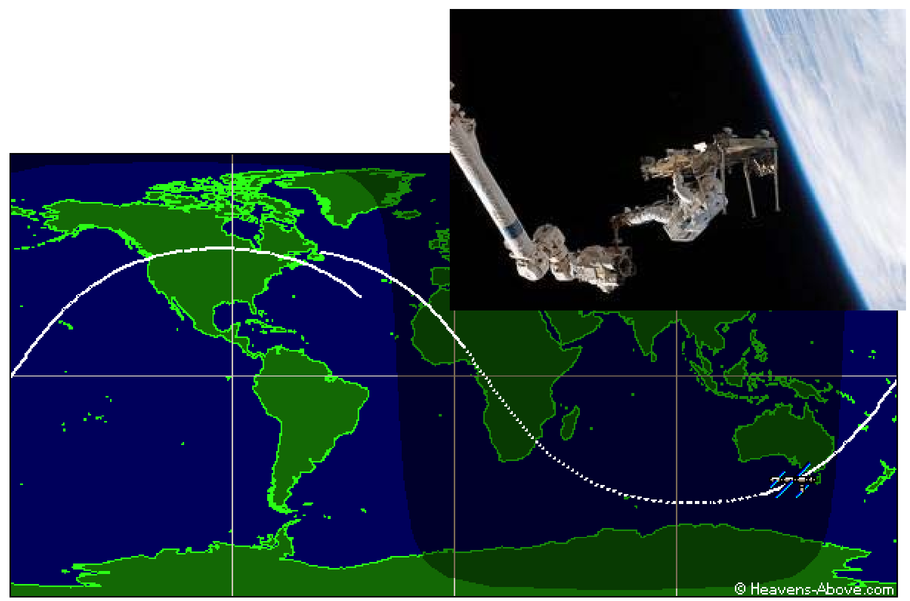


Red marks the polar area hit by protons



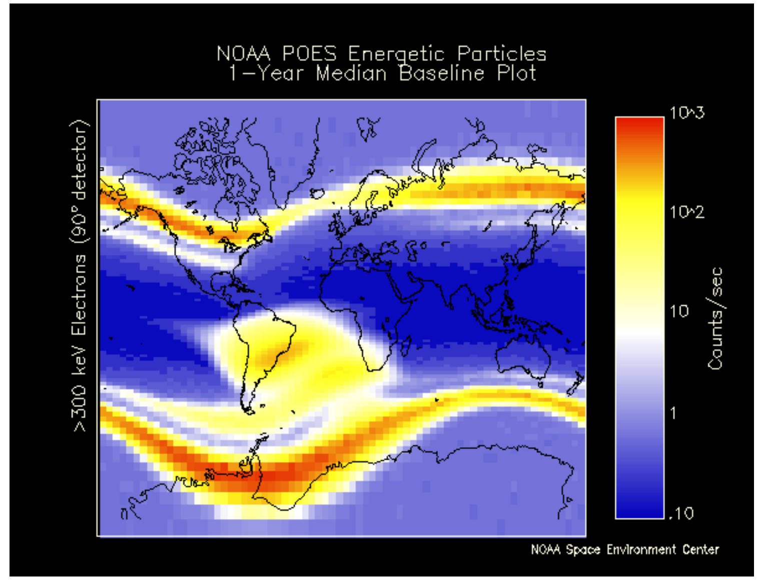
– Effect: High energy protons gain access to low latitudes
– Affected: People in space
– Impact:
  - Health risk to astronauts and space tourists

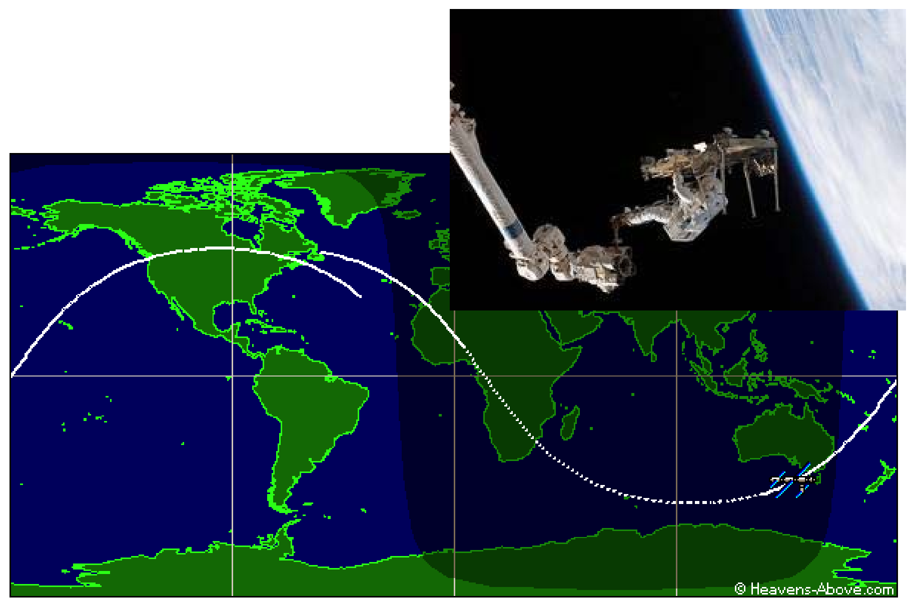
• Virgin Galactic – tourism flights in 2010
• Futron's Space Tourism Market Study: 15,000 passengers and revenues in excess of $1 billion per year by 2021
•Space transportation scenario by 2030 suggests 5 million passengers into space per year **(CNN Science & Space Friday, September 24, 2004**



Space Weather Effects of Trapped Radiation Belts

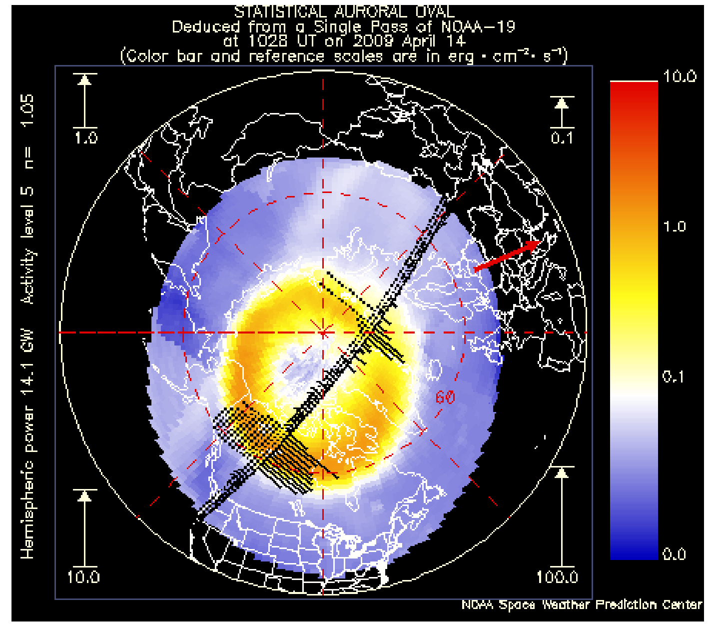
- Effect: High energy protons and electrons penetrate through shielding
- Affected: Satellites and people in space
- Impact:
  - Satellites/Instruments temporarily or permanently malfunction
  - Health risk to astronauts and space tourists





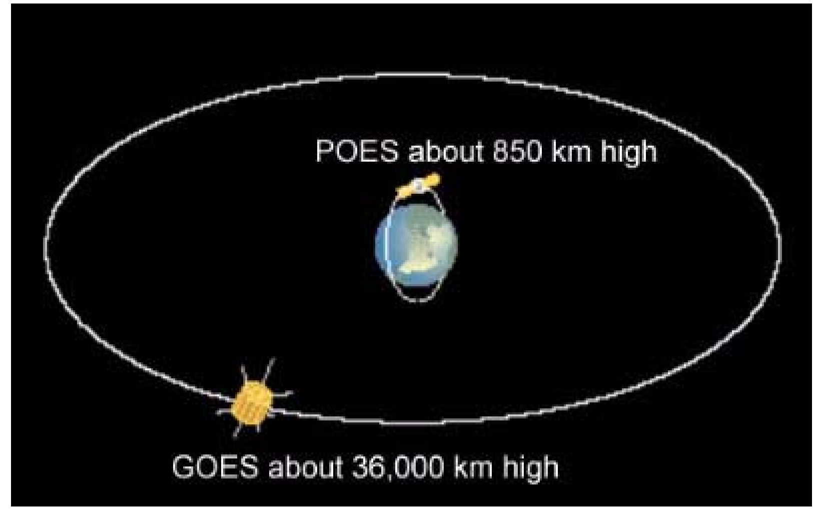
Space Weather Effects of Auroral Particles

- Effect: Auroral energy particle precipitation changes the properties of the ionosphere
- Affected: Polar flights, defense radar, Polar GPS users
- Impact:
  - Planes lose HF communication in limited regions
  - Defense radar looking for incoming missiles returns false signal
  - GPS errors prohibit precise surveying/drilling



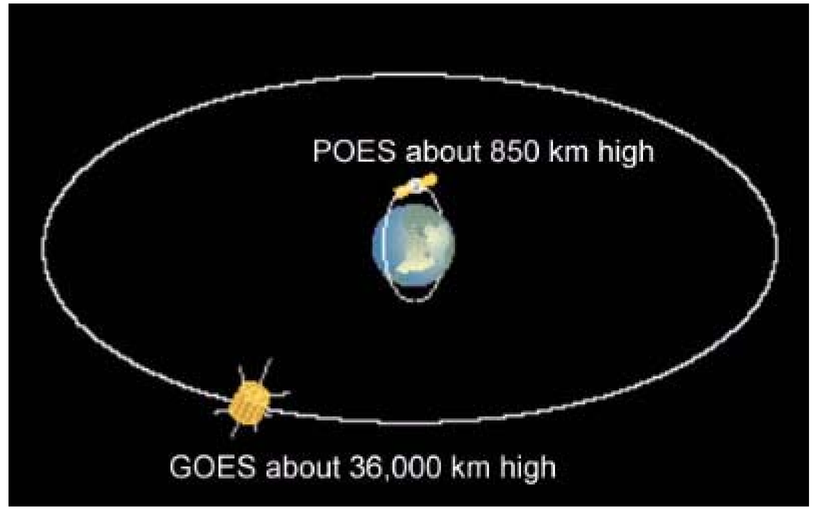
NOAA Satellites

- Geostationary Operational Environmental Satellites (GOES)
- Normally 2 satellites operational and 2 in storage
  - GOES East at 75 deg W (G12)
  - GOES West at 135 deg W (G11)
  - GOES 10 at 60 deg W
- Currently receiving real time data from GOES 10,11,12
  - Electrons >.8 MeV, >2MeV, >4MeV, 1 look direction (G10,G11, G12 is noisy)
  - Protons .8->700 MeV 11 bands, 1 look direction (G10, G11, G12 noisy)
- Archived at the National Geophysical data centerwww.ngdc.noaa.gov
  - from Jan, 1986 - Aug, 2009



- GOES 13, 14 in storage (GOES 15 launched in March)
  - Electrons >.8 MeV, >2MeV, >4MeV, 2 look direction
  - Protons .8->700 MeV 11 bands 2 look direction
  - Electrons 30-600 keV in 5 bands, 9 look directions
  - Protons 80-800 keV, 5 bands, 9 look directions

NOAA Satellites

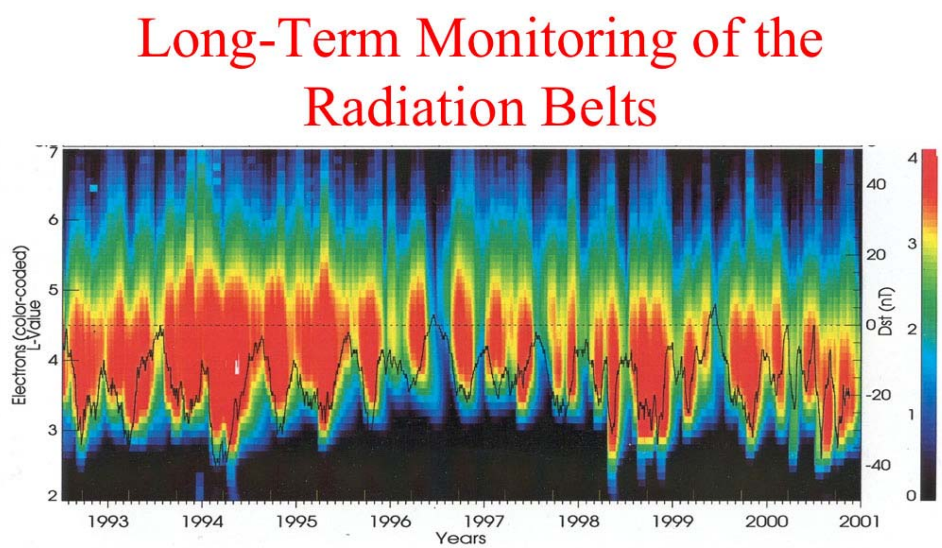


- Polar Operational Environmental Satellites (POES)
- Currently 6 satellites in operation receiving near real time (~1 hour latency) data
  - N15,N16,N17,N18,N19 and METOP
- Total Energy Detector(TED)
  - Proton and electron energy flux 50-eV-20keV, 2 bands, 2 look-directions
- Medium Energy Proton Electron Detector (MEPED)
  - >30 keV, >100keV, >300 keV electrons, 2 look directions
  - 30 keV->6.9 MeV, protons, 6 energy bands, 2 look directions
  - 4 omnis protons > 16 MeV, >35 MeV, >70 MeV, and >140 MeV
- Archived at the NGDC
  - www.ngdc.noaa.gov -1978-present

- NPOESS
  - ~10's min latency
  - SSJ5- protons and electrons 30 eV-30 keV
  - EPM-protons 20 keV- 10 MeV, electrons 25 keV-1 MeV
  - Omnis >10 MeV, >35 MeV, >70 MeV, and >140 MeV

Other Useful Datasets

- Defense Meteorological Satellites Program (DMSP)
  - LEO orbit ~830 km
  - SSJ4/5 particle detector
    - Protons and electrons (30 eV - 30 KeV)
    - 1987-present
    - Available at NGDC
- SAMPEX
  - LEO ~650 km
  - 1992-present
  - 4 instrument
    - PET-protons 19-60 MeV, 2-15 MeV
    - LICA-low energy composition
    - HILT- heavy ions
    - MAST-mass spectrometer
  - Available at the SAMPEX data Center



From the SAMPEX data center

Other Useful Resources

The Virtual Radiation Belt Observatory-http://virbo.org

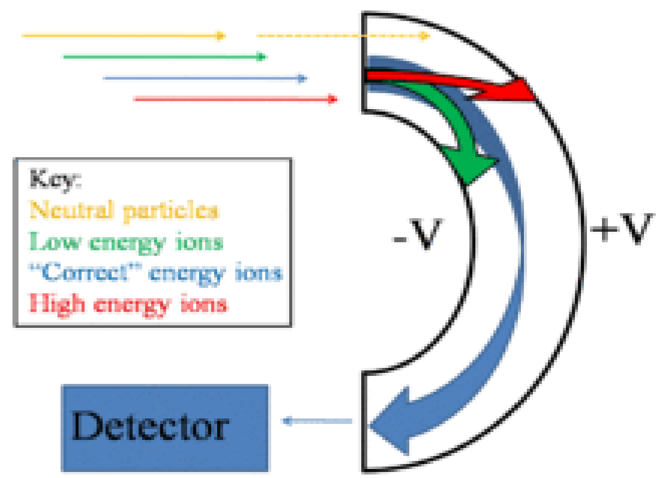
- AMIE-derived indices Inventory Geomagnetic indices derived from the AMIE model.
- Augsburg ULF Index Inventory A ULF index derived from ground magnetometer measurements.
- TSX5 CEASE Electron data from the CEASE instrument on TSX-5 from Aerospace.
- ISGI Inventory Geomagnetic indices aa, am, AE, AL, AU, AO; quiet day index.
- GEO Reanalysis Inventory O'Brien-Lemon GEO Reanalysis data set. OMNI2 Inventory The one-hour-resolution OMNI data set covering 1963-present.
- OMNIHR Inventory The one-minute-resolution OMNI data set covering 1995-present.
- GOES (via NGDC) Inventory GOES 05-12 X-Ray, mag. field, and particle data from NGDC.
- GOES-12 (via ONERA) GOES 12 Processed and corrected GOES 12 particle data from ONERA.
- HEO Data from the HEO-1 and HEO-3 satellites.
- LANL (via LANL) LANL 1991-080, LANL1989-046, LANLLANL-01A particle data from LANL.
- OV OV1-19 and OV3-3 particle measurements from Aerospace.
- PC Index Inventory Thule and Vostok polar cap index.
- POES (via NGDC) Inventory POES 15-18 and MetOp particle and support data from NGDC.
- POES (via CDAWeb) Inventory POES 05-14 particle and support data from CDAWeb.
- SAMPEX (via SRL) SAMPEX Data from the SAMPEX Data Center SAMPEX (via S. Kanekal) Daily-averaged and L-shell-binned SAMPEX MeV electron flux
- SYM- and ASY-H indices Inventory 1-minute SYM and ASY-H indices from Kyoto T05 inputs Inventory Inputs to the Tsyganenko 2001, 2004, and 2005 magnetic field model

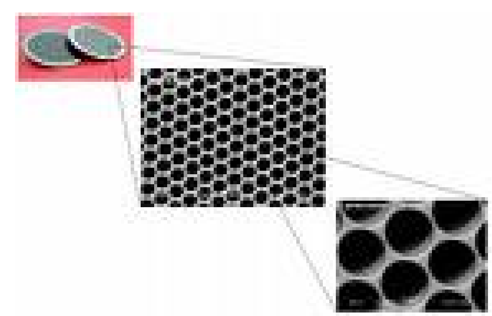
HEO 1 and 3 - Make available as browse product and put in CDF
OV1-19 and OV3-3 - Make available as browse product and put in CDF
S33 - Make available as browse product and put in CDF
SCATHA – Make available as browse product and put in CDF
CRRESS – Make available as browse product and put in CDF
GOES < 12 Develop or obtain PRBEM-formatted data
SYM-H and ASYM-H geomagnetic indices – complete metadata
LANL_1989_046 – Make available as interactive browse product
LANL_1991_080 - Make available as interactive browse product
LANL_LANL_01A - Make available as interactive browse product
Polar - Make available as interactive browse product
SAMPEX - Make available as interactive browse product and in CDF

Other data we are looking into:
TWINS ES – Metadata work
SAMPEX post-mission
Full resolution NOAA-14- data – Conversion to CDF and metadata work
THEMIS-SSD – Metadata and implementation and make available as a browse product
AFRL DSX – Metadata and make available as a browse product
International Space Station dosimeter data
DEMETER
Orsted
CHAMP
ROSAT
TOPEX
Any data not on the above list but listed here:
http://www.ukssdc.ac.uk/sedat/datasets.html

Instruments: low energy

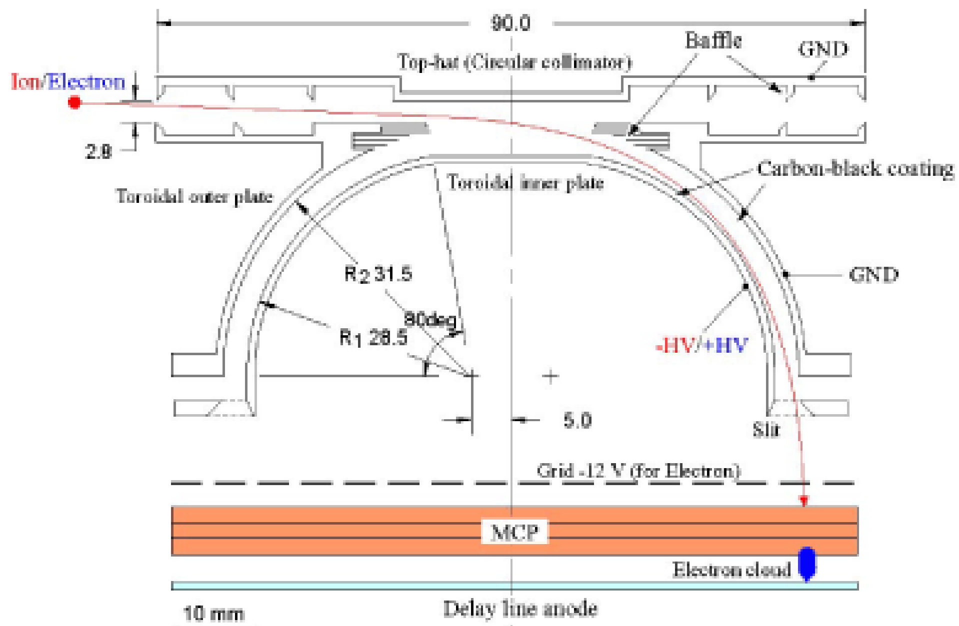
- Low energy (eV-10's KeV) typically measured with electrostatic analyzers (ESA)
- The instrument selects particles within a given energy range by applying a voltage across curved plates.
- The voltage alters the trajectory of particles entering the instrument such that only those with the right energy make it through the curved plates to be counted.
- After navigating through the plates, the particle hits a microchannel plate (MCP) that creates secondary electrons.
- The electron cascade from the MCP is translated to a voltage pulse. All pulses above a set threshold are counted.
- The plate voltage is stepped to measure particles with different energy.





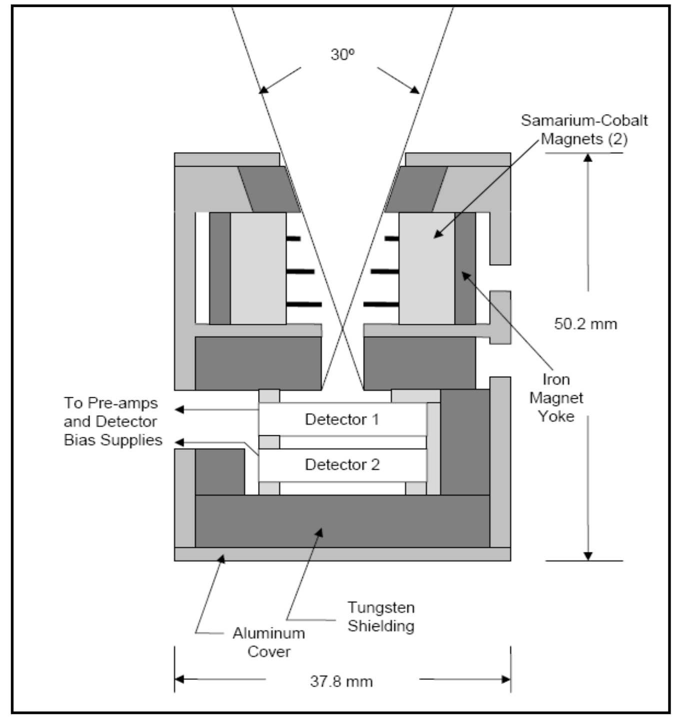
Instruments: low energy

- Angular measurements can be made with individual telescopes or a top-hat design.



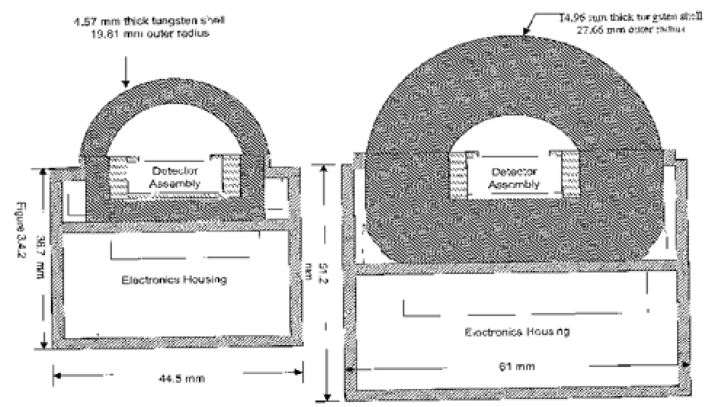
Instruments: Medium Energy

- Solid State Telescope
  - Measures energy and species by the amplitude of a voltage pulse generated as a particle passes through one or more silicon detectors.
  - Angular measurements are either made by multiple telescopes or by spinning the satellite.



Instruments: High Energy

- Omni-directional detectors allow only particles with energy greater than the external shielding to penetrate and be counted.



P8 Omni-directional (Dome) detector

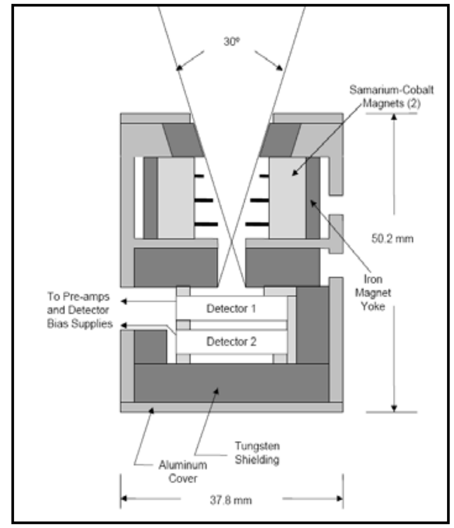
P9 Omni-directional (Dome) detector

Units

- Ultimate quantity is differential particle flux $J(E,\alpha)$ (#/cm^2-s-str-keV)
- All particle detectors integrate flux (#/cm^2-s-str-keV) over some time, energy range, area, and opening angle (str) and output total counts.

$$counts = \iiint J(E, A, \alpha, t)\, dE\, d\Omega\, dA\, dt$$

- Different methods are used to translate counts back to flux J.



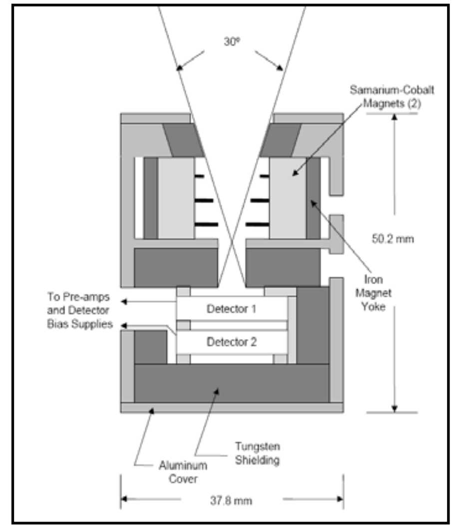
Counts to flux

$$counts = \iint\iint eff\,(E,\alpha)J(E,A,\alpha,t)dEd\Omega dAdt$$

1. Divide counts by integration time.

$$counts = \Delta t\iiint eff\,(E,\alpha)J(E,A,\alpha)dEd\Omega dA$$

$$\frac{counts}{\Delta t} = \iiint eff\,(E,\alpha)J(E,A,\alpha)dEd\Omega dA$$



2. Divide by the area of the detector.

$$\frac{counts}{\Delta t} = A\iint eff\,(E,\alpha)J(E,\alpha)dEd\Omega$$

$$\frac{counts}{\Delta tA} = \iint eff\,(E,\alpha)J(E,\alpha)dEd\Omega$$

Counts to flux

3. Divide by the steradians spanned by the opening angle.

$$\frac{counts}{\Delta t A} = \Delta\Omega \int eff(E) J(E) dE \qquad \frac{counts}{\Delta t A \Delta\Omega} = \int eff(E) J(E) dE$$

   Assuming the flux does not vary with angle is not entirely valid if you have an omnidirectional detector. Often the efficiency of the detector varies with the angle.

4. Divide by the energy width.

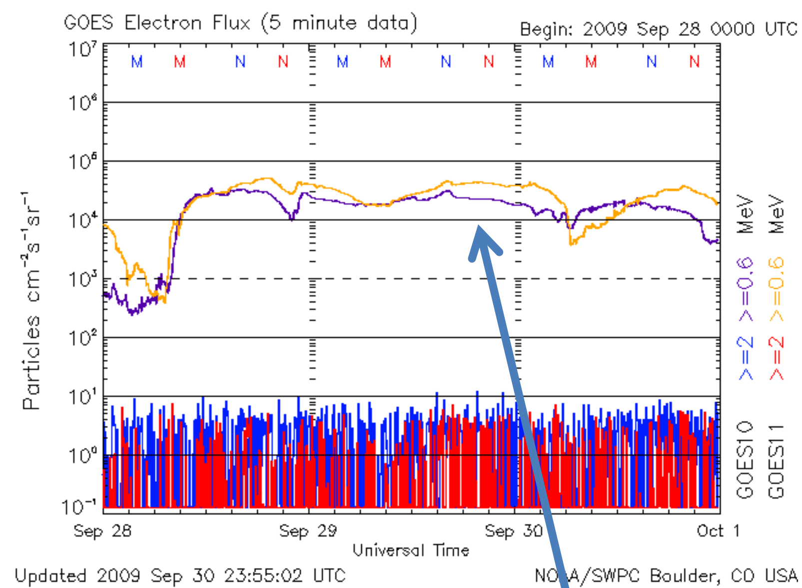
$$\frac{counts}{\Delta t A \Delta\Omega} = J(E)\Delta E \qquad \frac{counts}{\Delta t A \Delta\Omega \Delta E} = J(E)$$

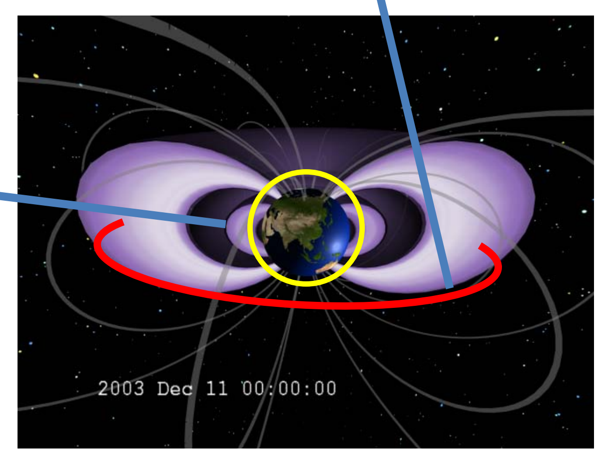
   Assuming the flux does not vary with energy over the range of the detector is generally not valid. Often the efficiency of the detector varies with the angle.

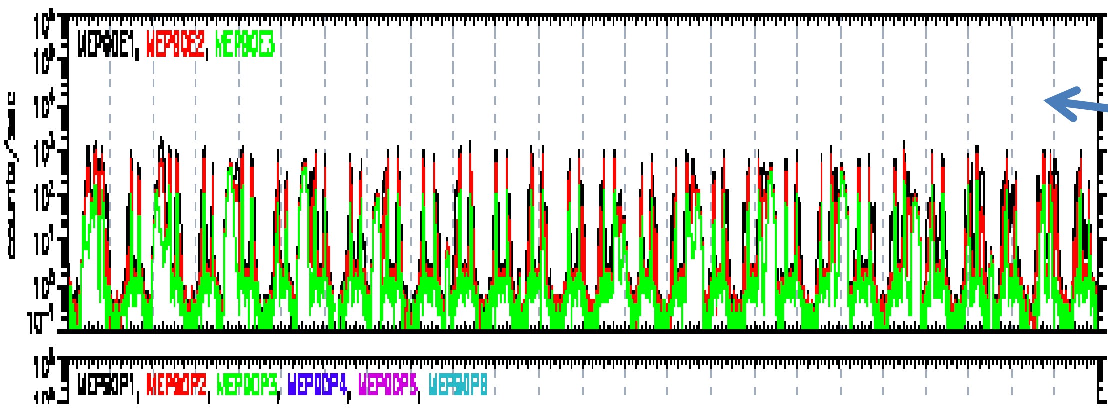
Some instruments report energy flux which integrates flux multiplied by the particle energy.

Interpreting Data

- Data looks very different from geosynchronous satellites and low earth satellites.

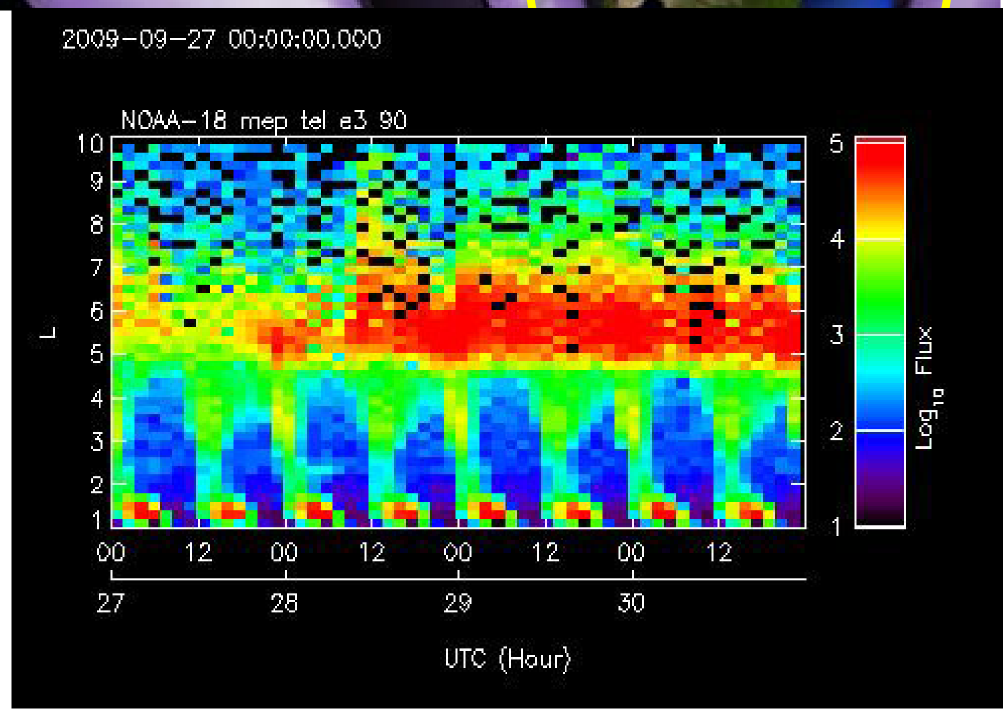






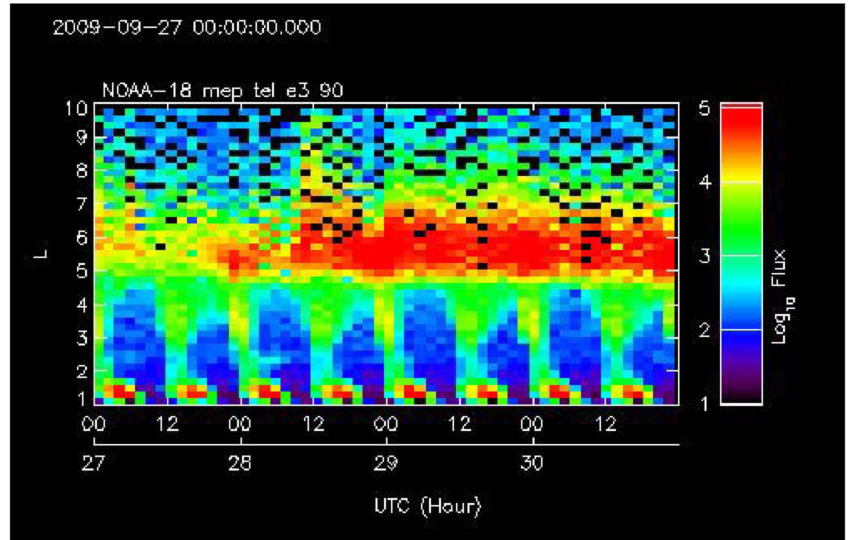
Interpreting Data

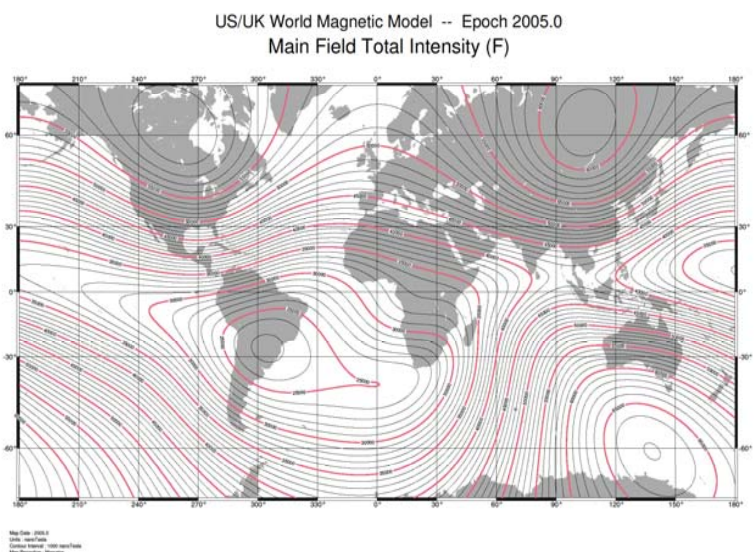
- Lbin plots of low altitude data are easier to interpret than time traces.

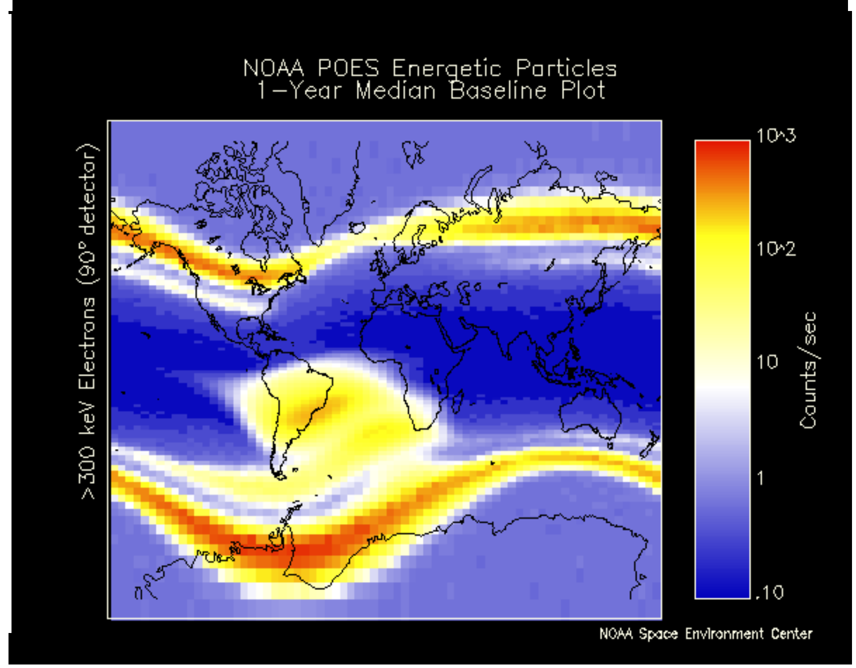


Interpreting Data

- The intensity of flux varies with the strength of the magnetic field.

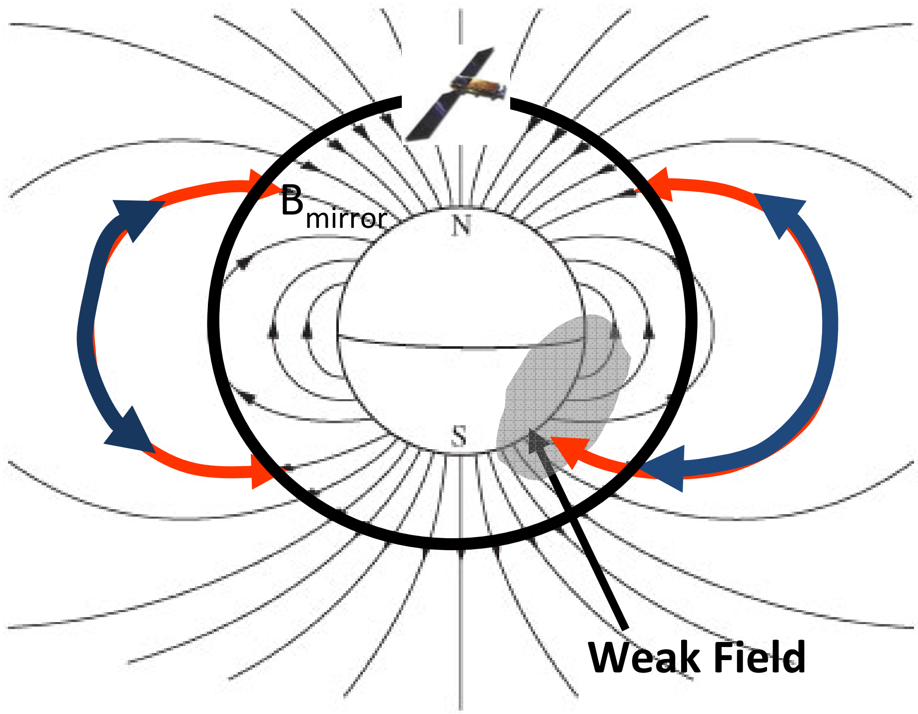






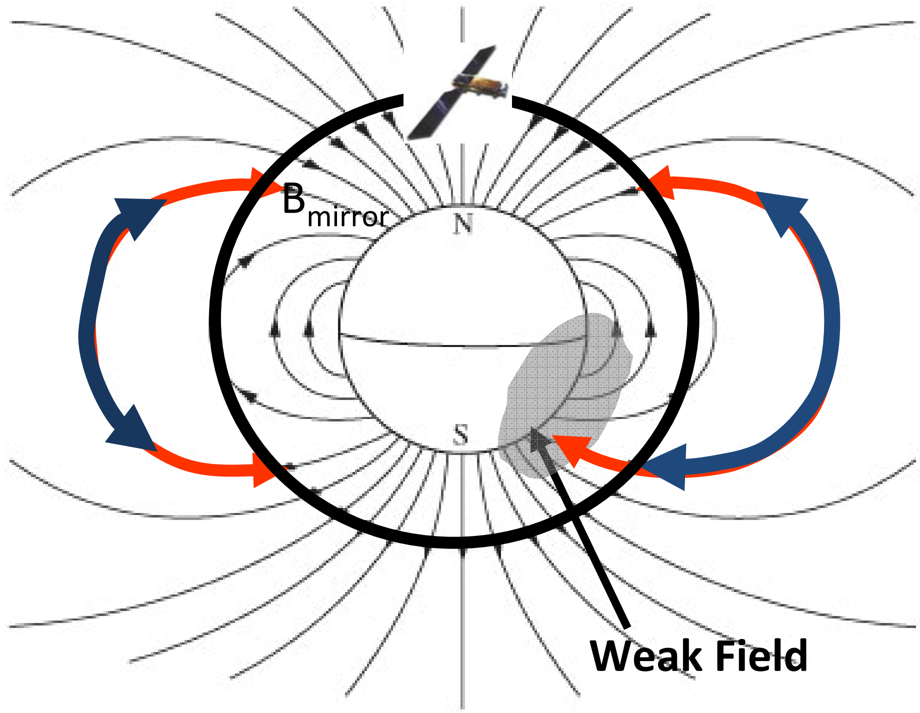
Earth's non-uniform internal magnetic field

- A satellite at a fixed radial distance will measure particles with different pitch angles in regions of different field strength.



- In weak field regions the satellite measures particles that would normally mirror closer to the equator so the flux appears to increase in this region.

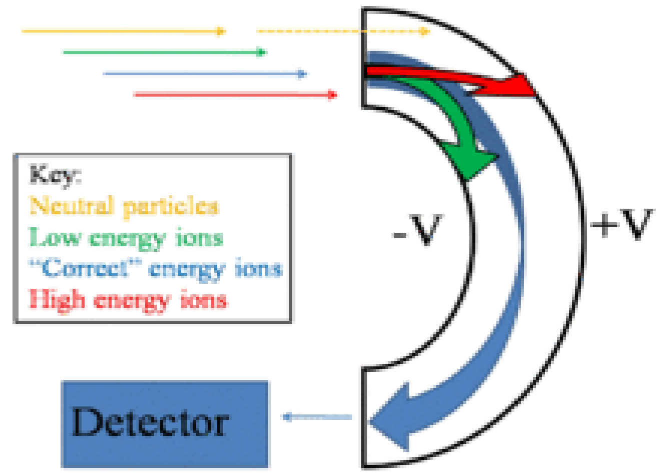
Earth's non-uniform internal magnetic field

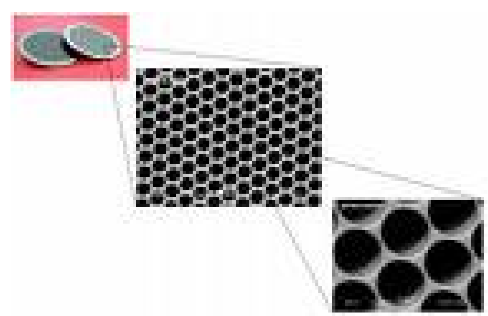


- Particles in the bounce loss cone are ones that are currently mirroring at the location of the satellite but will hit the atmosphere when they bounce to the opposite hemisphere.
- Particles in the drift loss cone are ones that are currently mirroring at the location of the satellite but will eventually be lost as they drift about Earth.

Issues with ESA's

- Degradation of the MCP
  - Over time the emission of secondary electrons from the MCP is reduced. Degradation can be sudden.
  - The voltage pulse created by incoming particles is reduced.
  - Not all particles are detected.
  - Some instruments allow the voltage across the MCP to be increased. Some do not.



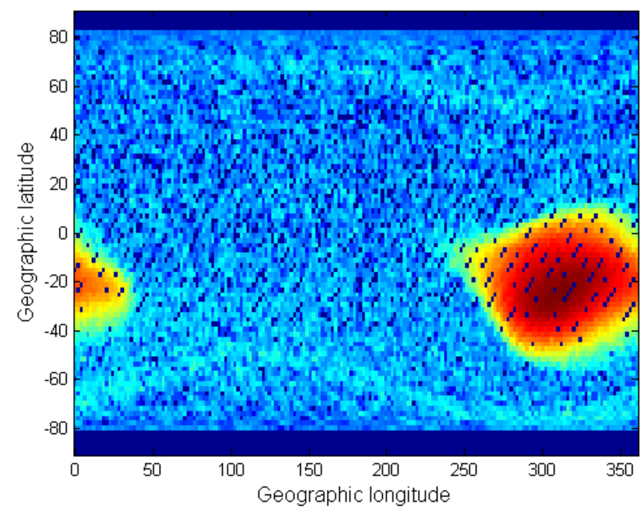


Spacecraft charging

- Often satellites will charge to some negative potential ~keV.
- Low energy protons will be drawn towards the satellite and energized to the potential of the satellite.
- Satellite charging will appear as a mono-energetic beam of particle flux.

Penetrating Radiation

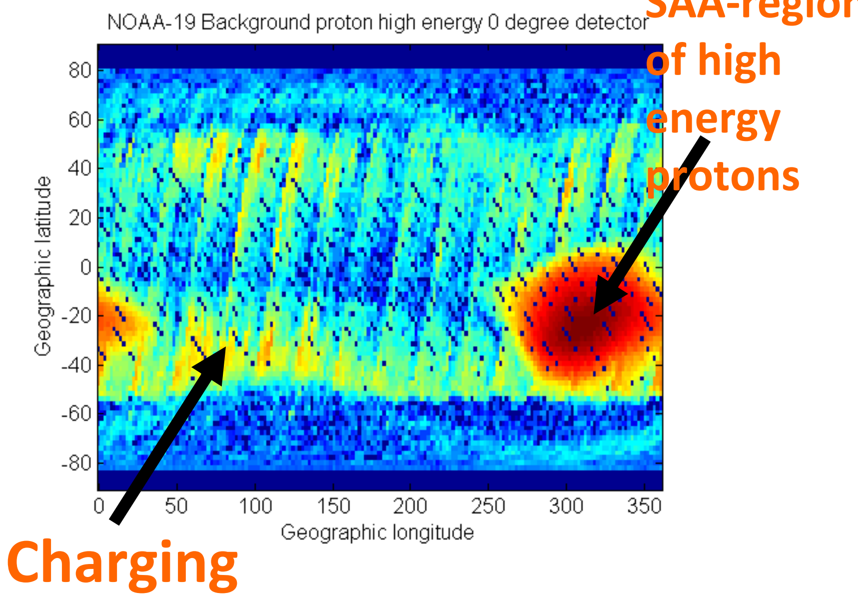
- High energy protons can penetrate through the instrument causing anomalous counts.
- Most instruments make a background measurement that can be subtracted.
  – POES/TED measures the background by setting the plate voltage to zero.



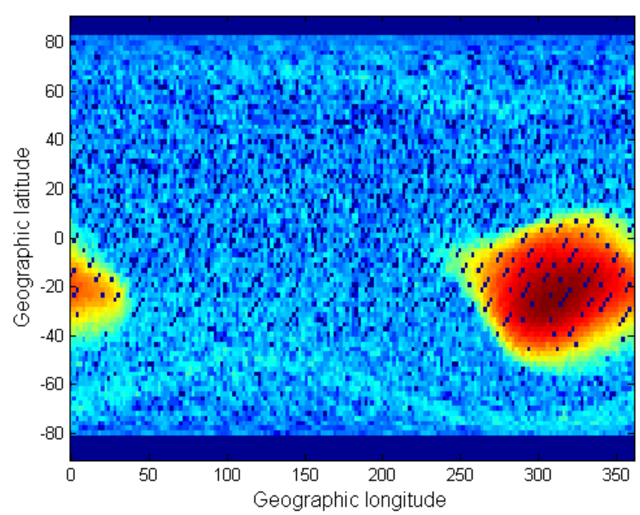
Spacecraft charging Problem unique to POES/TED

- TED often measures anomalously high background counts due to spacecraft charging.
  - The satellite charges to several -keV on the night side.
  - The plate voltage is not quite 0 during the background measurement.
  - The background measurement is actually accelerated low energy protons instead of penetrating radiation.

Night side background

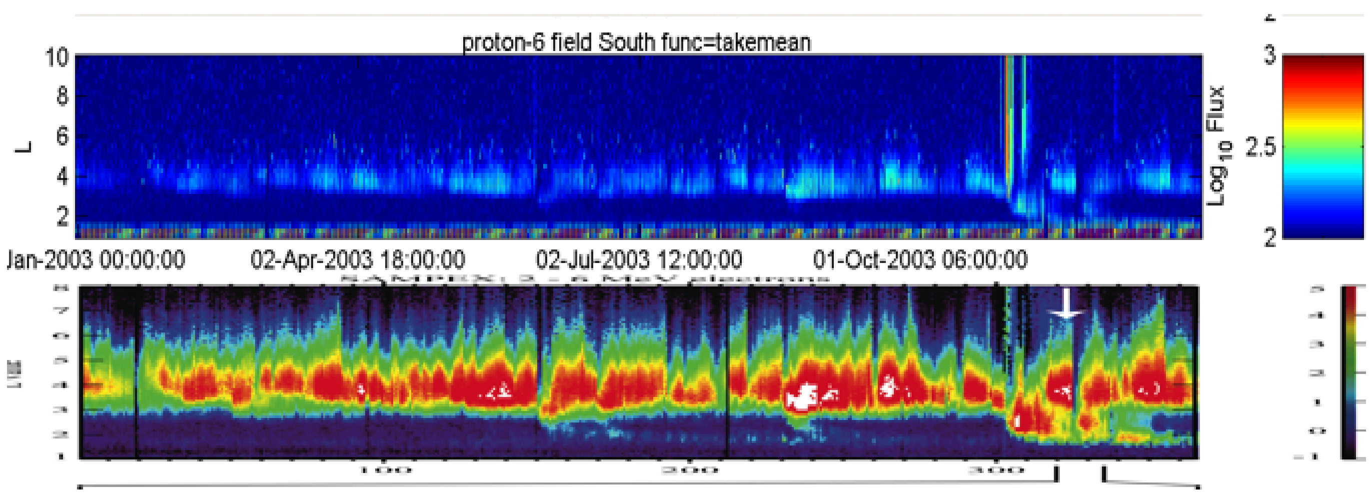


Day side background



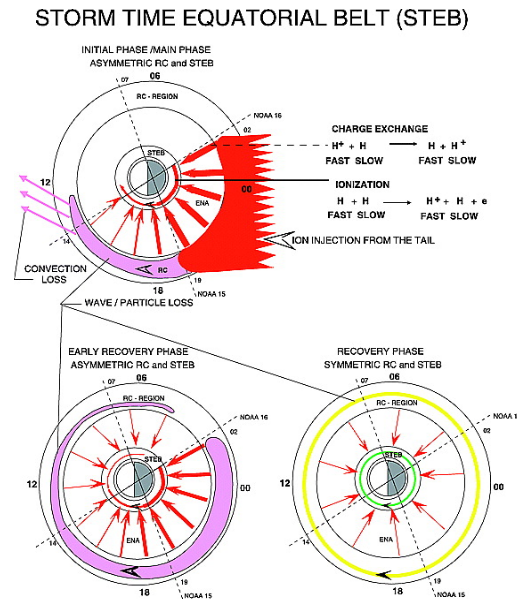
Solid State Telescope Issues

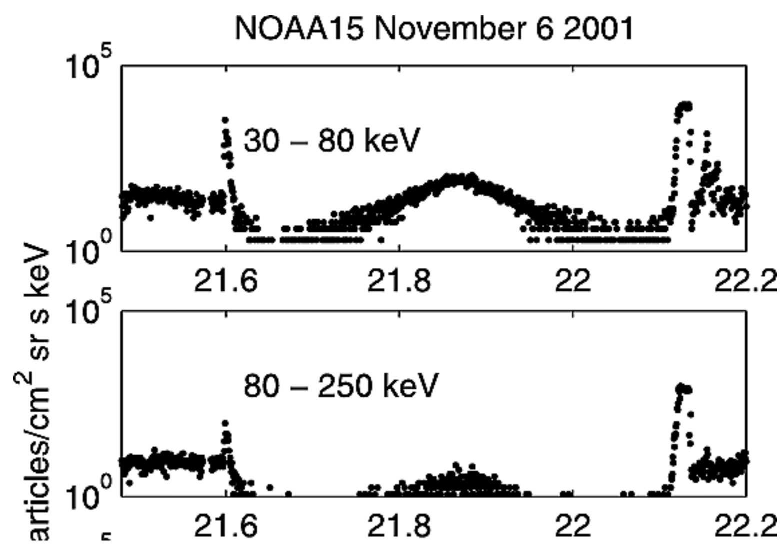
- Contaminating particles
  - Protons sometimes misidentified as electrons and vice versa.
  - Sometimes an advantage
    - POES/MEPED P6 telescope and p6 omnis can be used as ~1 MeV electron detectors when there are no solar proton events.
  - Sometimes not
    - POES/MPEED >30 keV, >100 keV, >300 keV electrons channels are contaminated by ~>100 keV protons. The contamination is overwhelming during storms on the duskside.



Energetic Neutral Atom Contamination

- During a storm, a ring current forms around Earth.
- Charge exchange between the energetic ions and neutrals of the atmosphere produce energetic neutral atoms (ENA).
- ENA’s appear in the POES MEPED detectors.





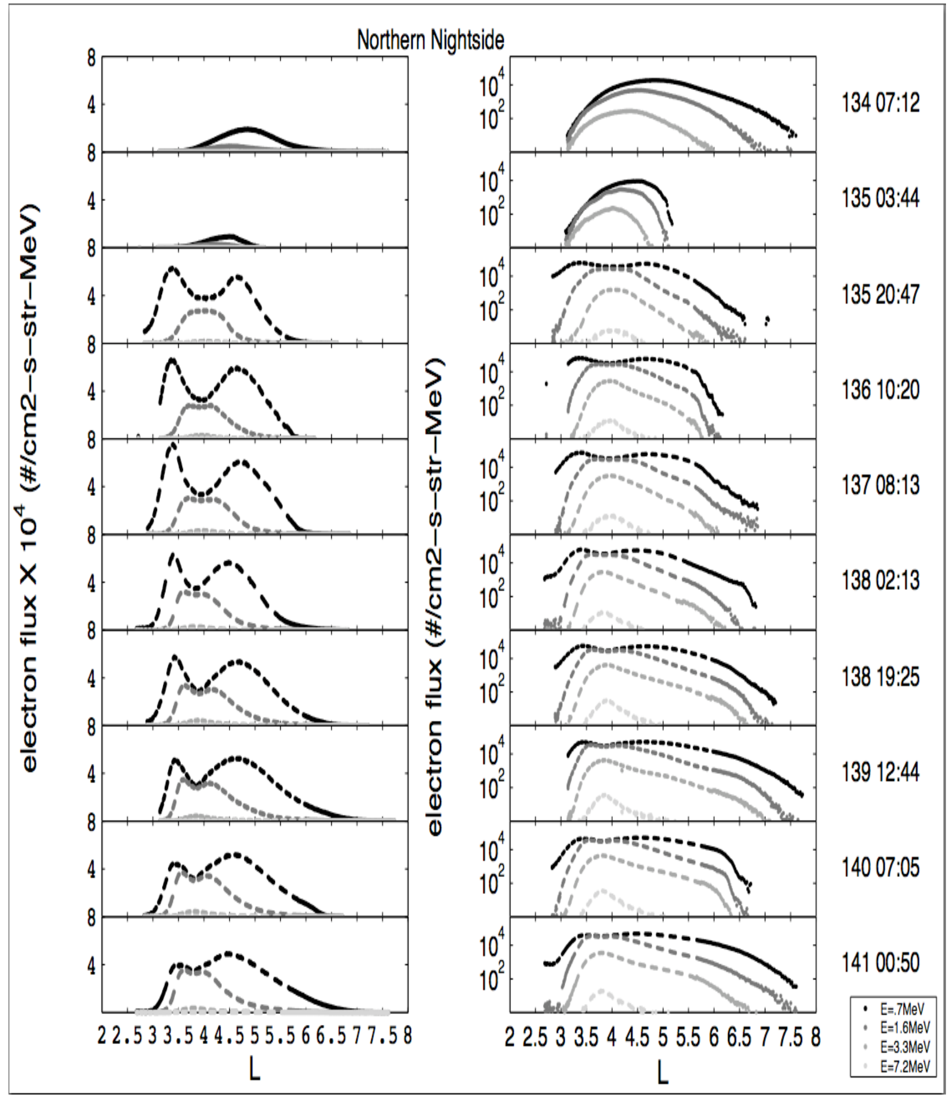
[Soraas, 2003]

Radiation Damage

- Over time the solid state detector become less sensitive.
- The voltage pulse created by a passing particle decreases effectively increasing the energy range of the particles measured.
- Example: Fluxes from the POES 90 degree detector drop below those from the 0 degree detector.

Dead time

- The detector electronics are not fast enough to count all particles when the fluxes are high.
- Sometimes the dead time is variable.
  - Measured flux may actually decrease as the real flux increases.
  - Variable dead time may affect pitch angle distributions.



Summary

- Geosynchronous and low altitude satellite measurements are invaluable to science and space weather.
- 3 data repositories
  – National Geophysical Data Center
  – SAMPEX Data Center
  – Virtual Radiation Belt Observatory
- Data is imperfect, clean-up efforts are often underfunded, so use it with caution.
- When uncertain consult the instrument scientist.

Instruments: Medium Energy

- Magnetic Spectrometer
  - Uses a magnetic field to bend particle trajectories to silicon detectors.