

Solar Energetic Particles (SEP's)

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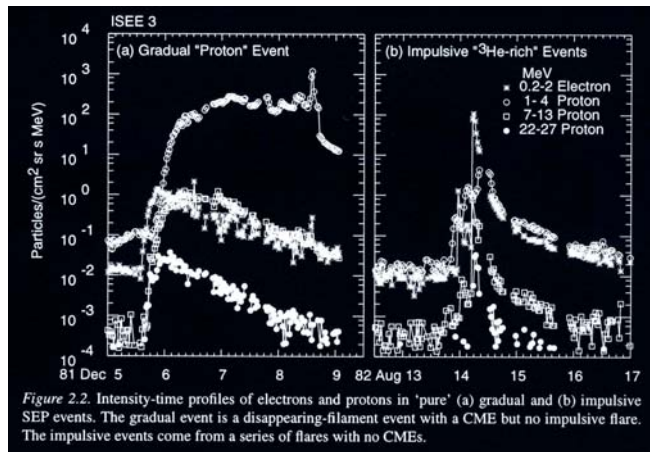
High-Energy Charged Particles:

Topics to be covered in 2 lectures

- Lecture 1:
 - Overview of energetic particles in the solar system
 - Basic theory of energetic particle distributions 1
 - Transport concepts, fluctuations, magnetic scattering
- Lecture 2:
 - Basic theory 2: Acceleration Mechanisms
 - Shock acceleration (CMEs and flares)
 - Stochastic acceleration (flares?)
 - Non-diffusive treatment

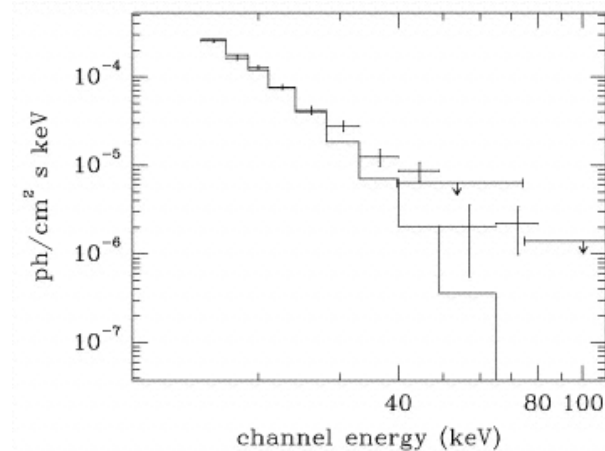
Cosmic rays or energetic charged particles are present in space wherever collisions are rare enough to permit them to exist.

Sun

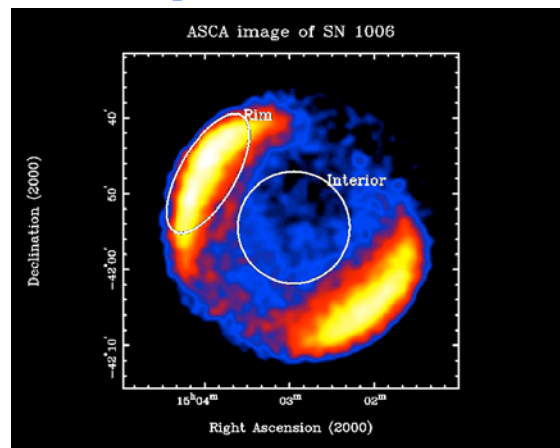


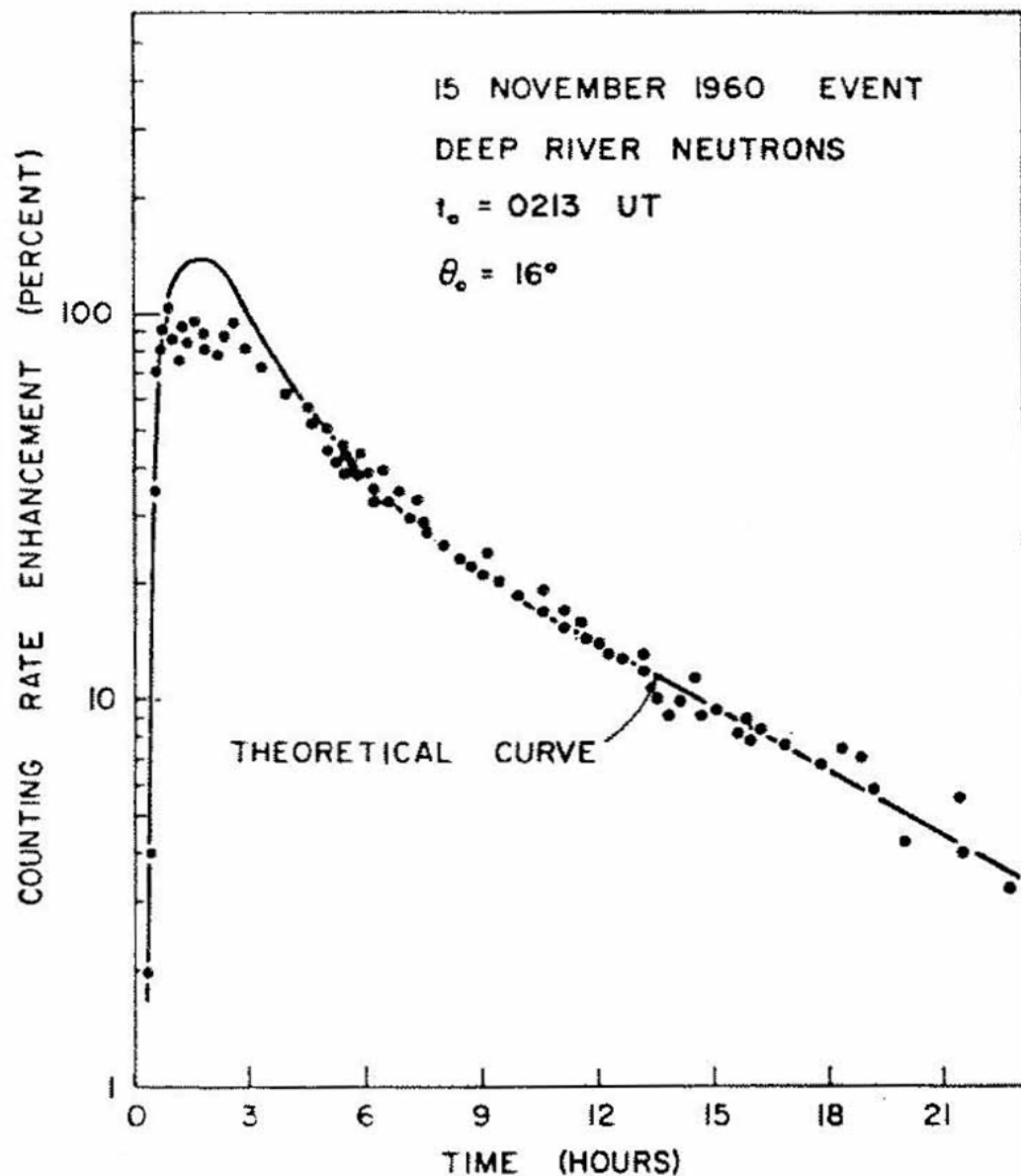
Heliosphere

Coma cluster of galaxies



Galactic supernovae





Theoretical fit, using equation 122, to the Deep River neutron monitor data for the November 15, 1960, event. θ_0 is the angle between the flare and the foot of the average magnetic field line passing through the point of observation [Burlaga, 1967].

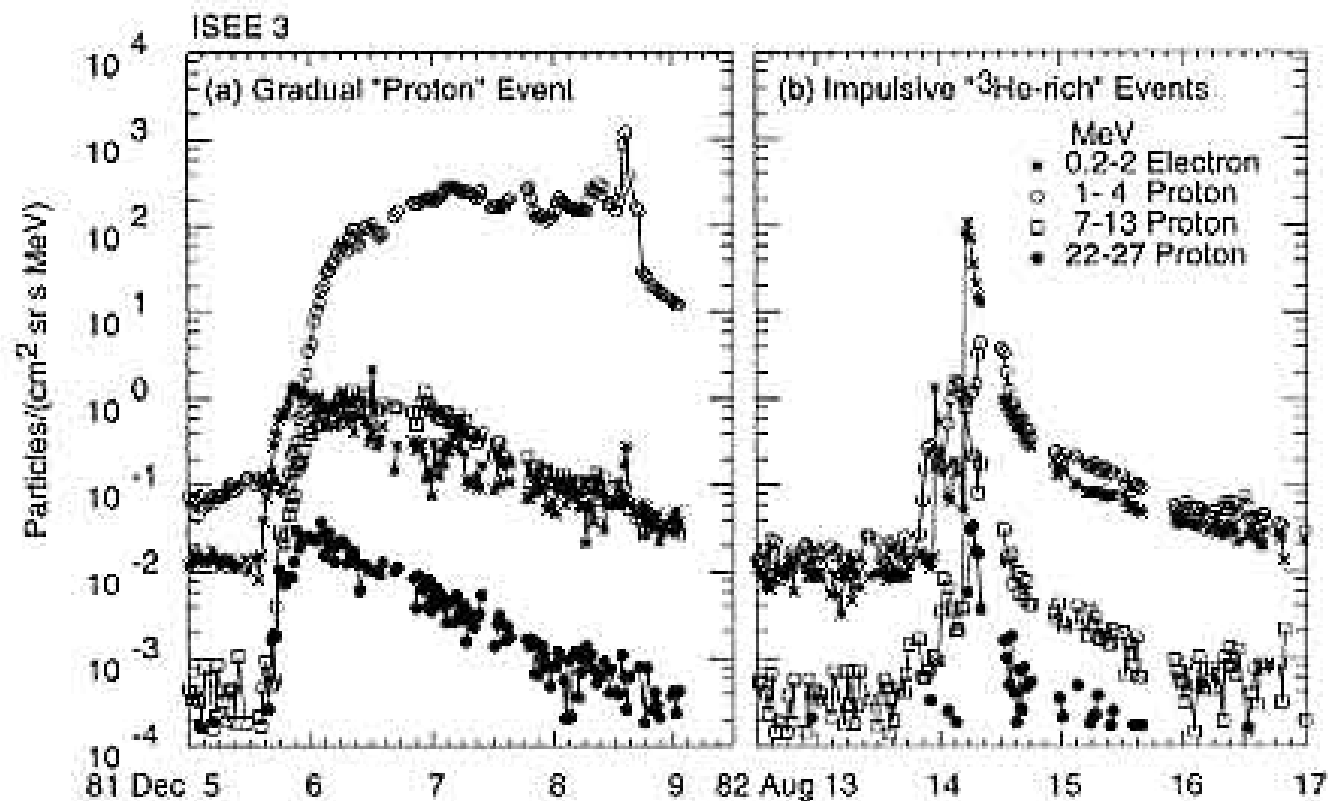


Figure 2.2. Intensity-time profiles of electrons and protons in 'pure' (a) gradual and (b) impulsive SEP events. The gradual event is a disappearing-filament event with a CME but no impulsive flare. The impulsive events come from a series of flares with no CMEs.

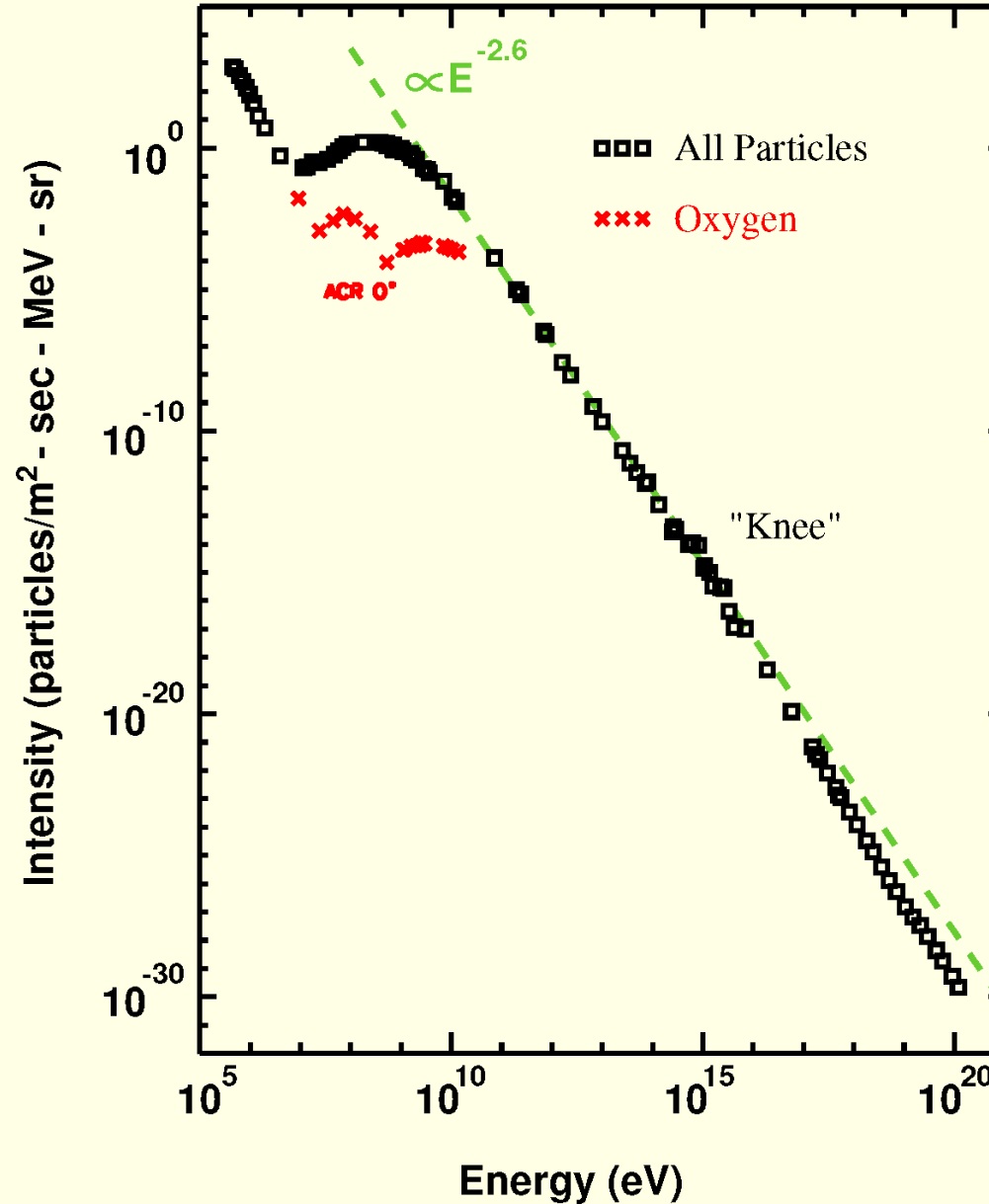
Galactic Cosmic Rays

- Galactic Cosmic Rays up to about 10^{15} eV kinetic energy are believed to originate from supernovae remnants, where they are accelerated by the expanding shock wave

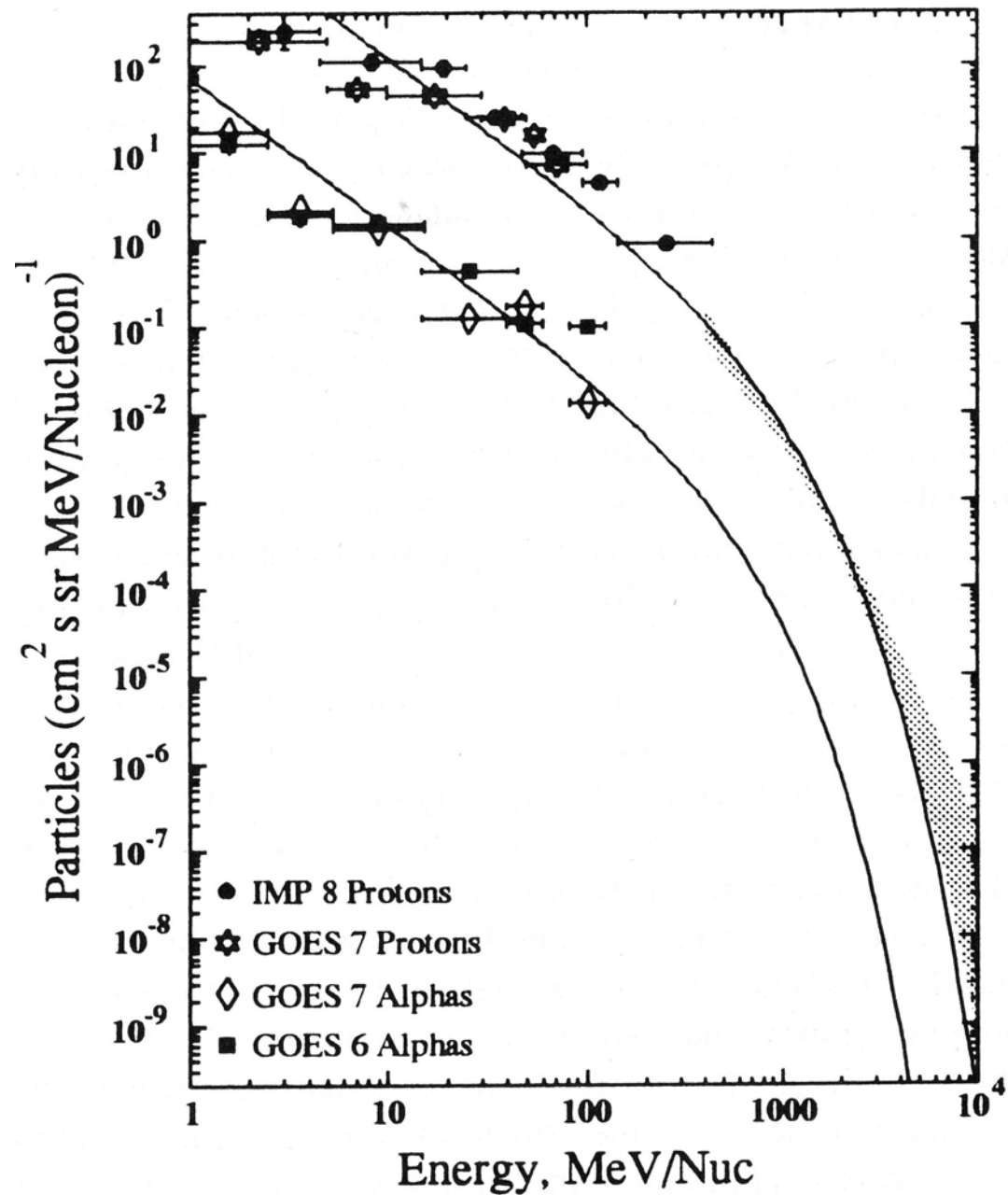


Supernova Remnant 1006 – Chandra image

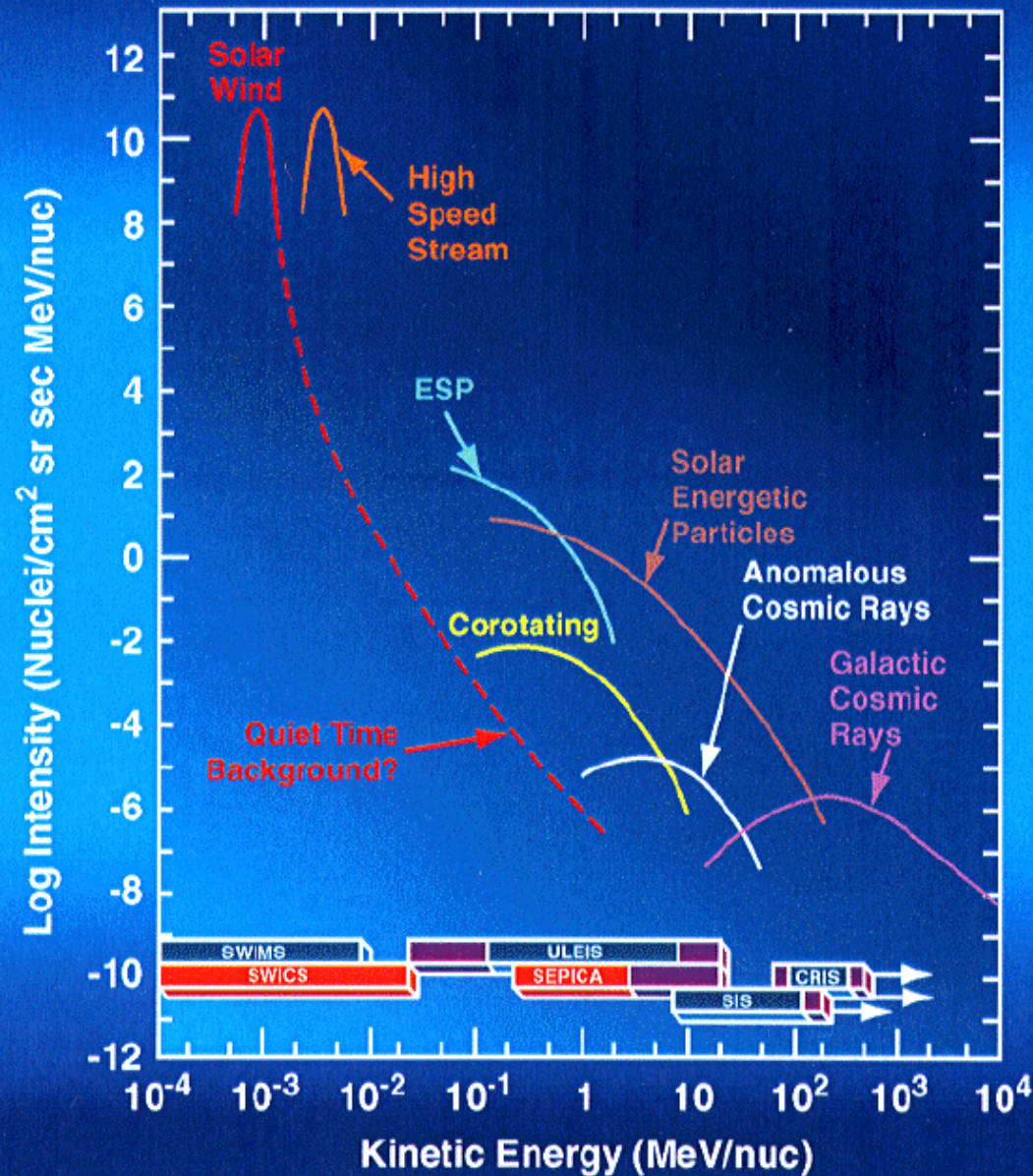
Cosmic-Ray Spectrum



Spectrum of SEP's



Spectra of Energetic Oxygen Nuclei



Isotopic Composition



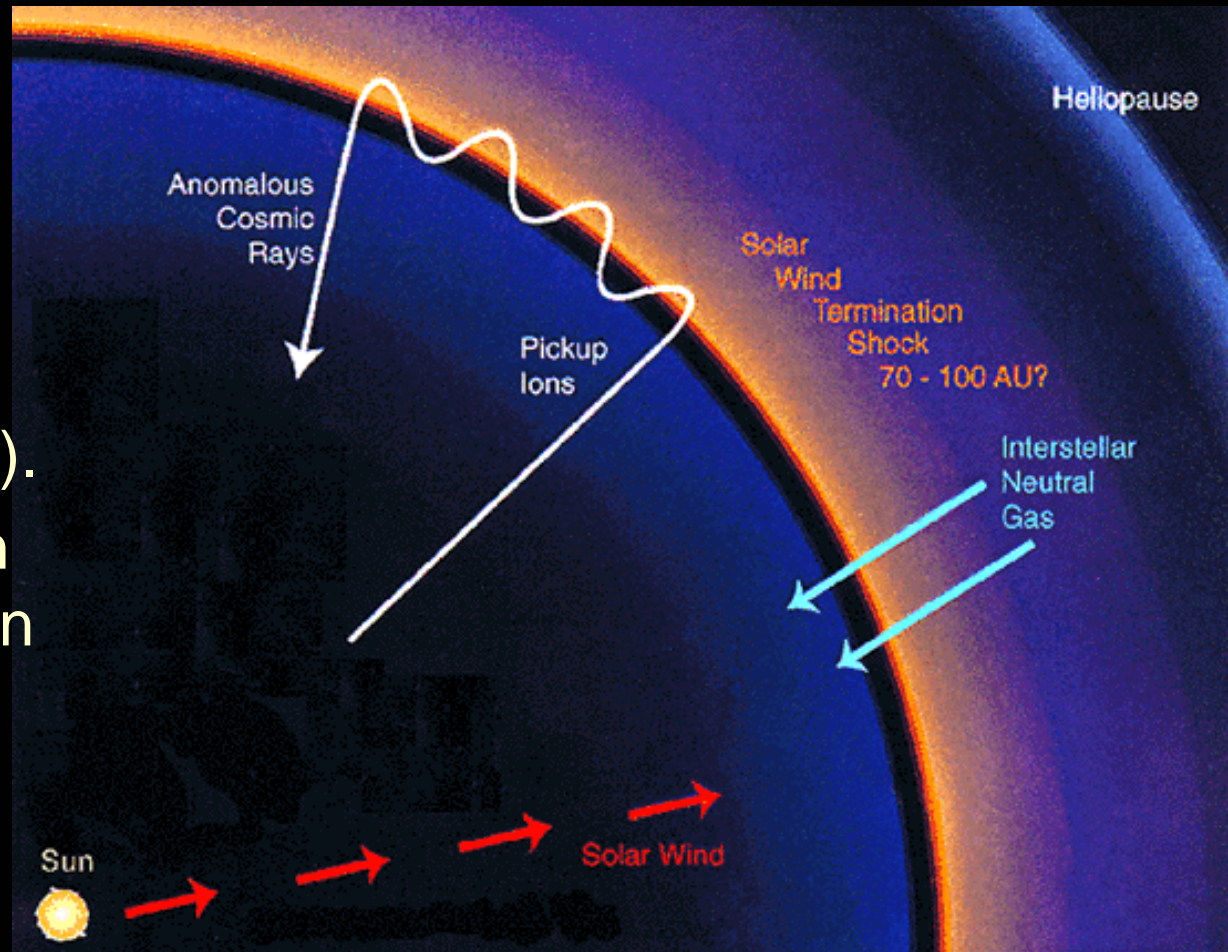
Elemental Composition



Charge State

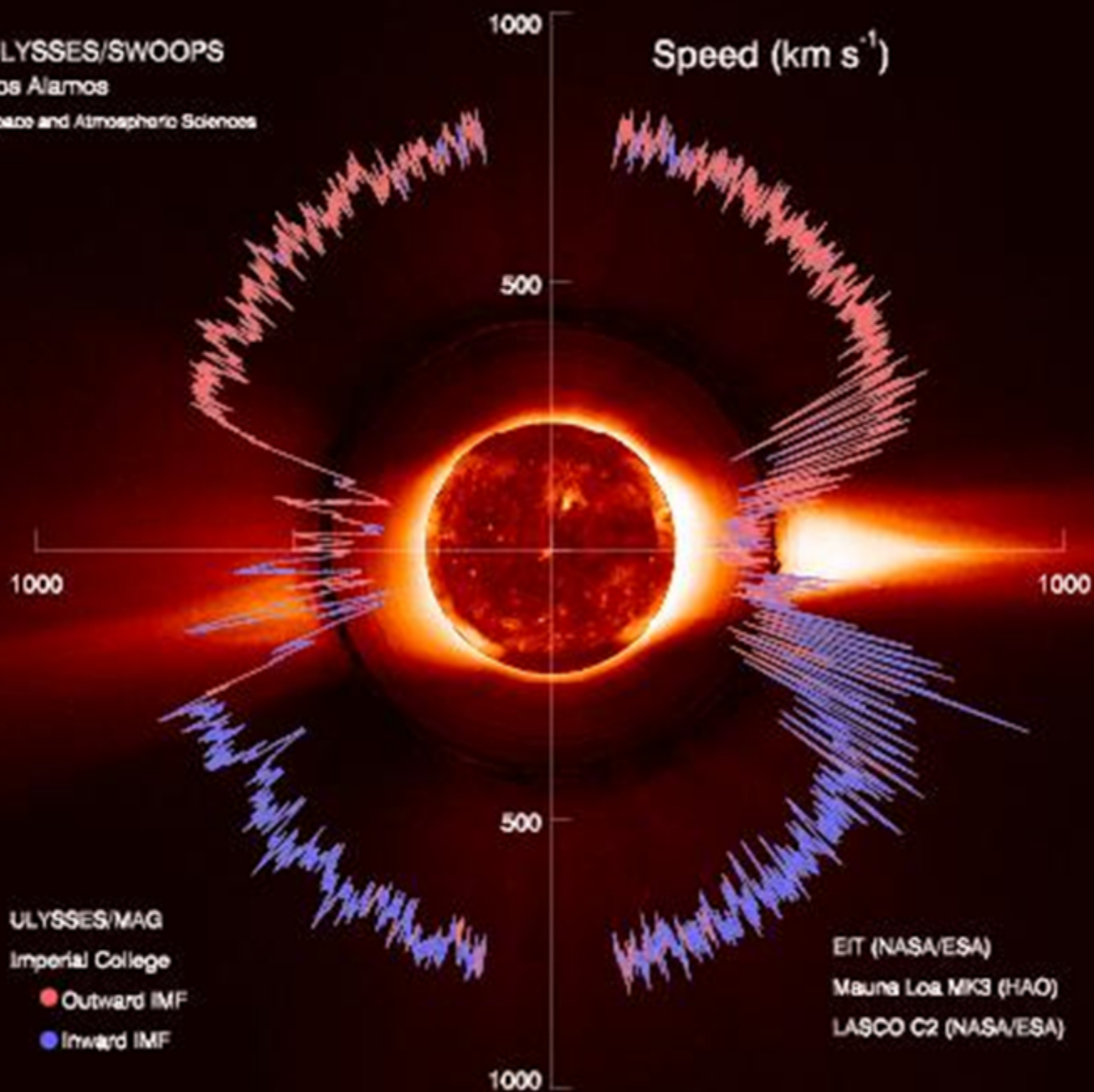
Anomalous Cosmic Rays

- Accelerated interstellar pickup ions
- Low charge states (+1) imply that they are accelerated rapidly (about 1 year).
- The best explanation for this is acceleration by a termination shock that is nearly perpendicular over most of its surface

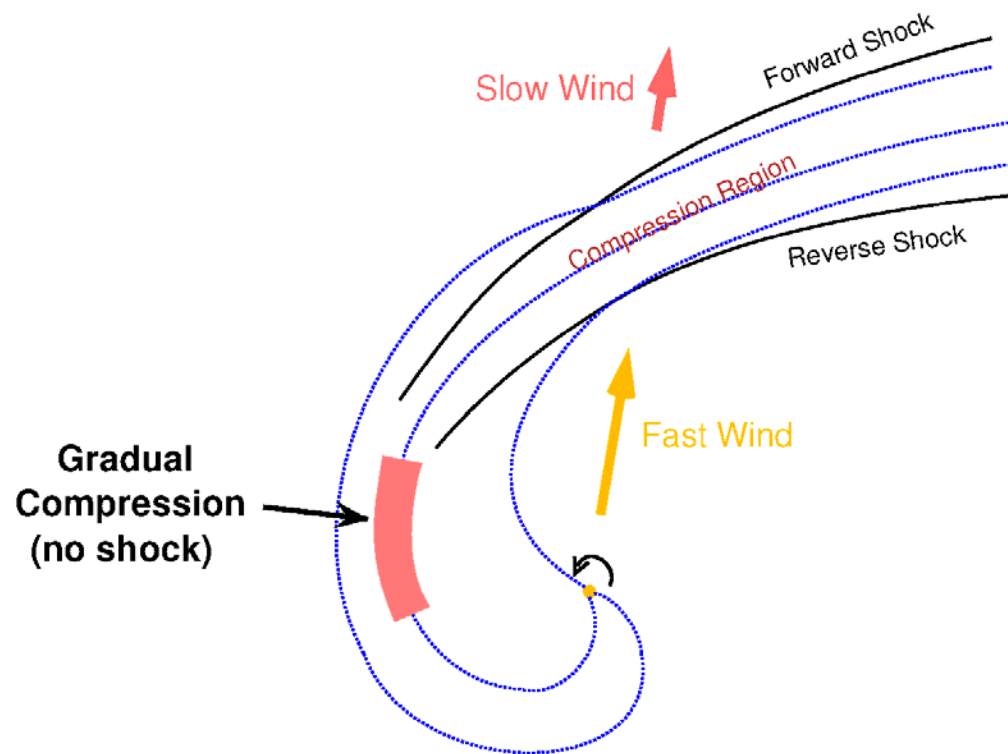
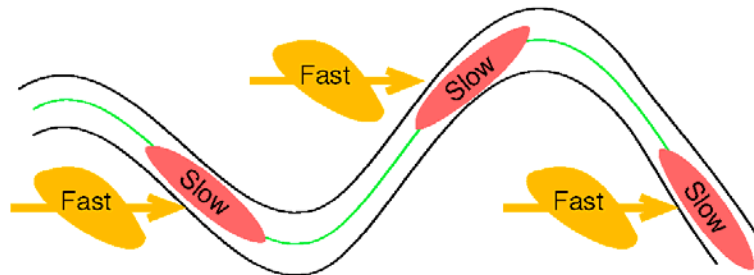
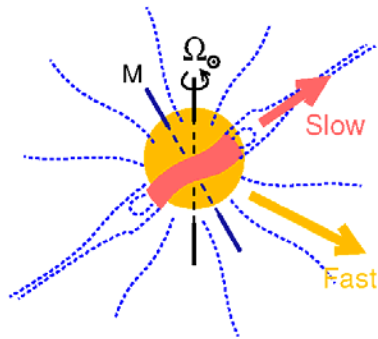


ULYSSES/SWOOPS
Los Alamos
Space and Atmospheric Sciences

Speed (km s^{-1})

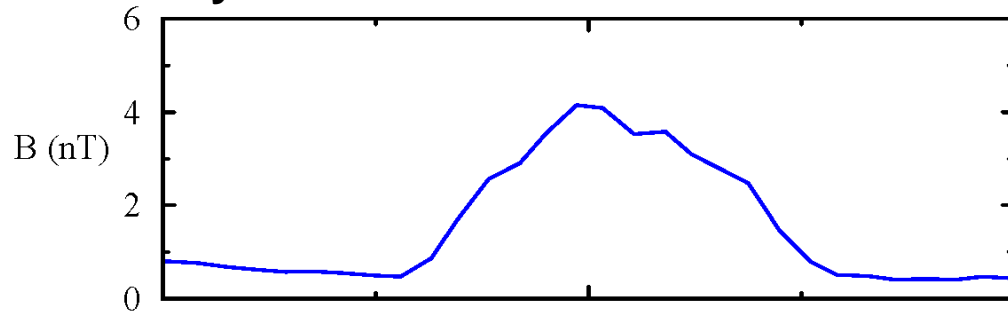


Co-rotating Interaction Regions

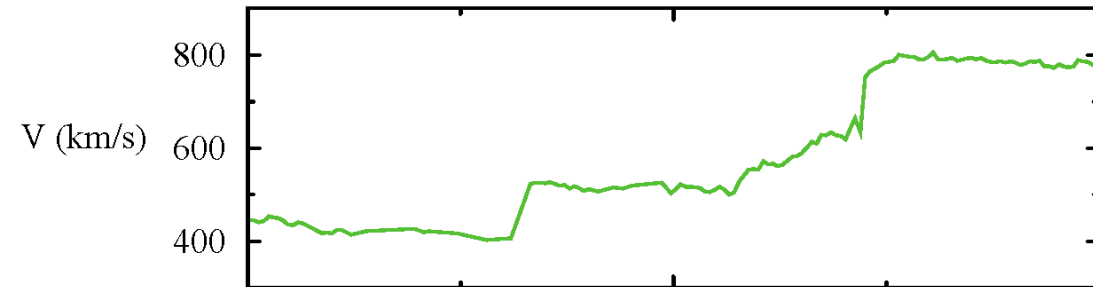


Corotating Interaction Regions

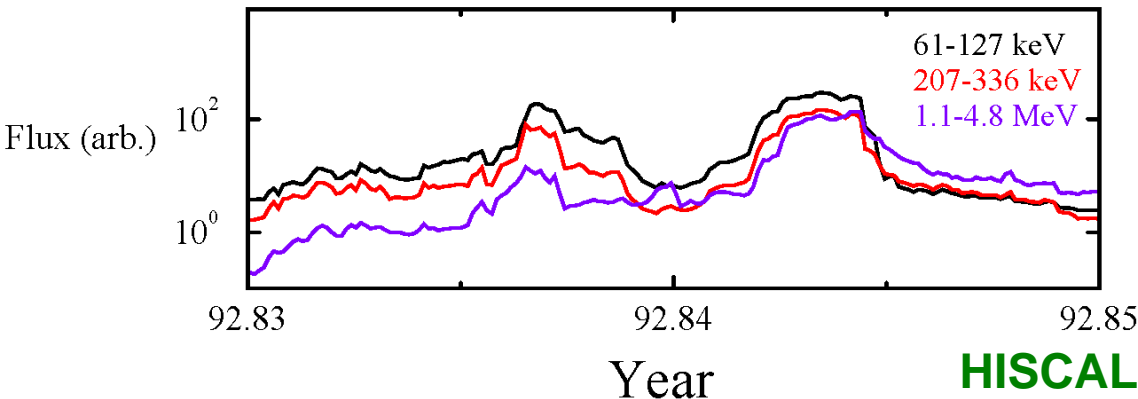
Ulysses data



Compression of the magnetic field within CIR.



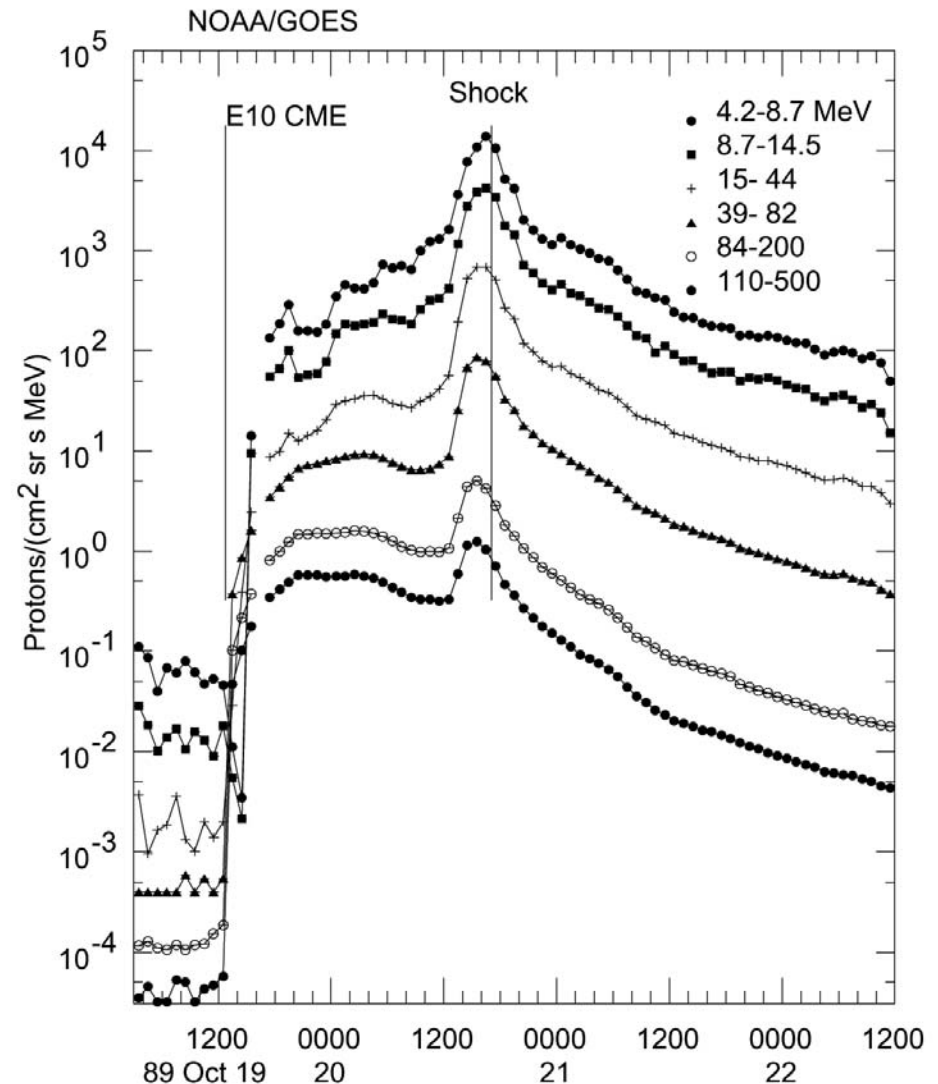
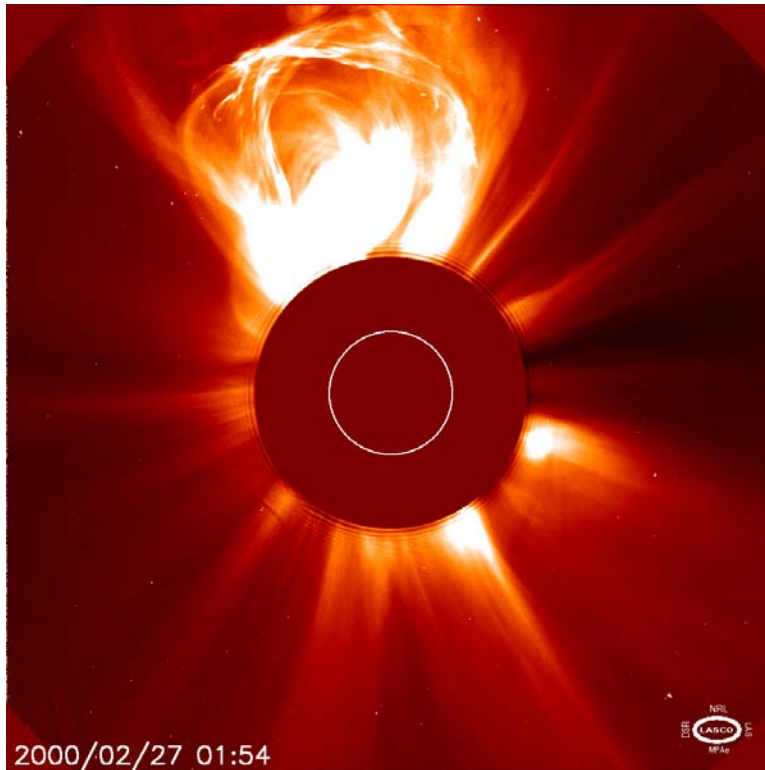
Slow, intermediate, and fast wind and both a Forward (F) and Reverse (R) shock.



Energetic Particles peaking at The F/R shocks, with a larger intensity at the reverse shock.

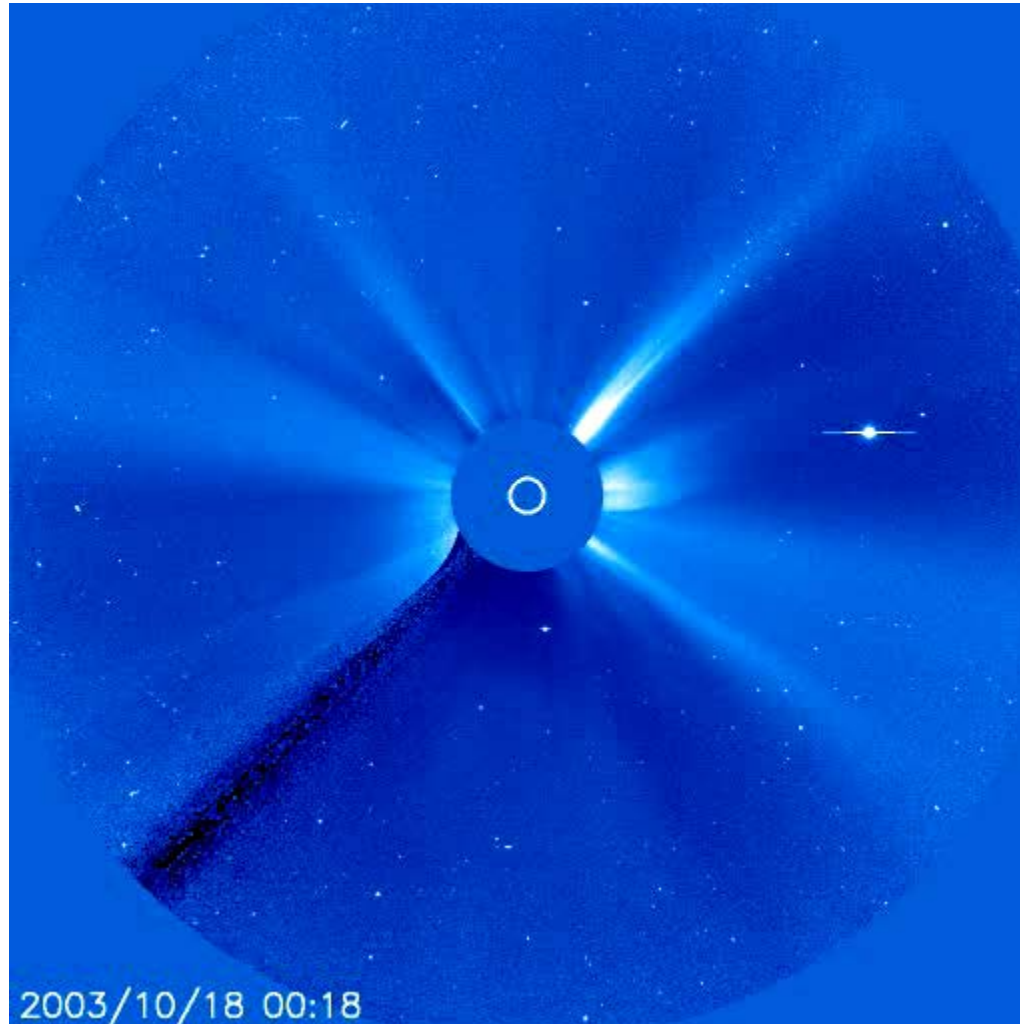
HISCALE data courtesy Tom Armstrong

Large CME-related SEP events

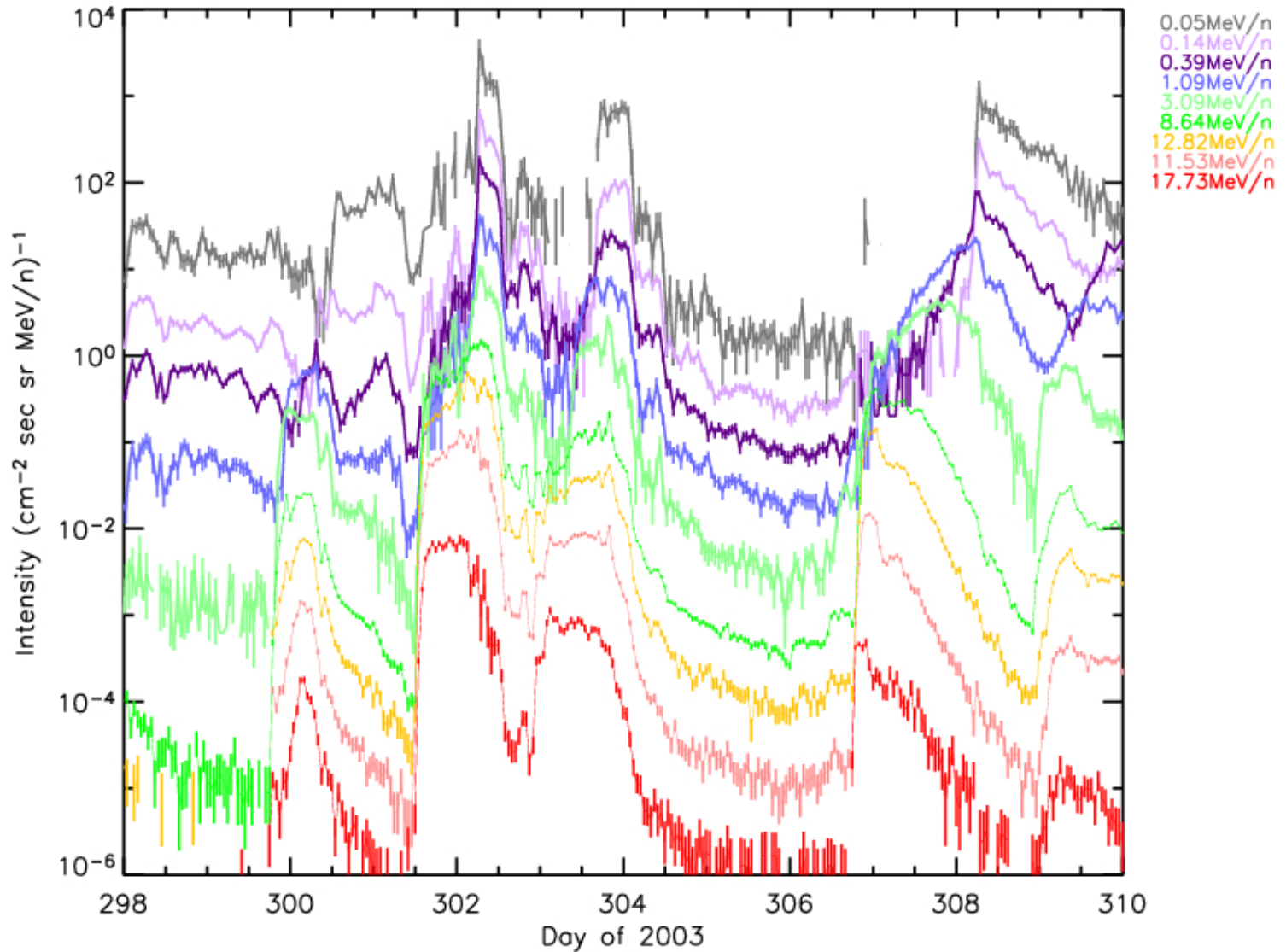


SOHO/LASCO (C3) Coronagraph

“Halloween” solar storms of 2003



ACE Observations (1AU)

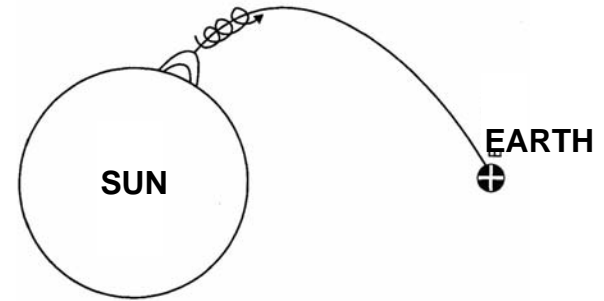


Solar-Energetic Particle (SEP) Paradigms

The initial view was that ALL SEPs originated from flares

In the early-mid 1990's, the two-class paradigm was suggested

Impulsive
Events



Gradual
Events

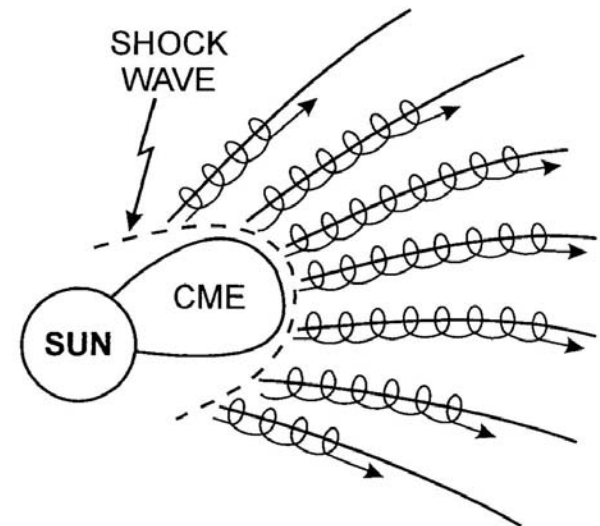
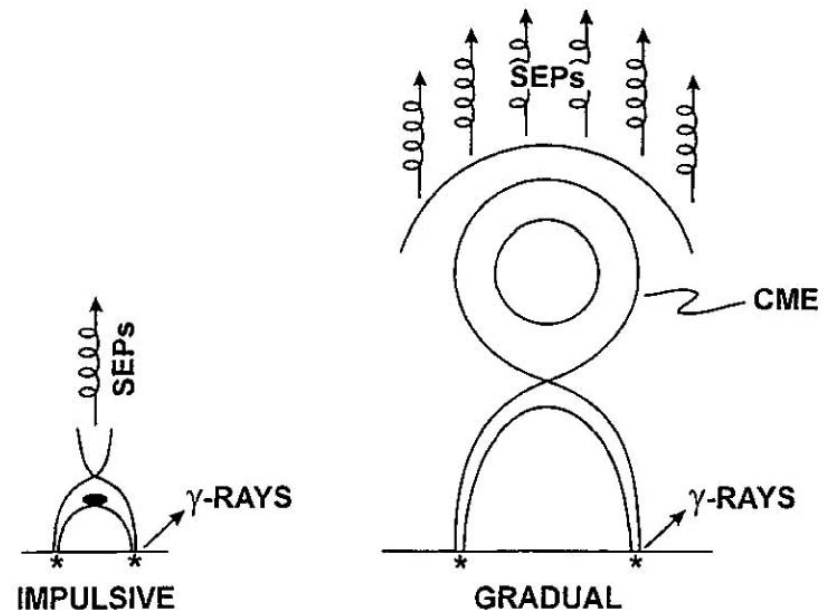


TABLE 1. PROPERTIES OF IMPULSIVE AND GRADUAL EVENTS (45)

- In the two-class paradigm, SEP events are associated with impulsive solar flares, or gradual solar flares
- More-sensitive instrumentation (ACE, WIND, SOHO, TRACE, etc.) has clearly demonstrated that the distinction is NOT CLEAR

| | IMPULSIVE | GRADUAL |
|---------------------------|---------------|-------------|
| PARTICLES: | ELECTRON-RICH | PROTON-RICH |
| $^3\text{He}/^4\text{He}$ | ~1 | ~0.0005 |
| Fe/O | ~1 | ~0.1 |
| H/He | ~10 | ~100 |
| Q_{Fe} | ~20 | ~14 |
| DURATION | HOURS | DAYS |
| LONGITUDE CONE | <30° | ~180° |
| RADIO TYPE | III, V(II) | II, IV |
| X-RAYS | IMPULSIVE | GRADUAL |
| CORONAGRAPH | --- | CME |
| SOLAR WIND | --- | IP SHOCK |
| EVENTS/YEAR | ~1000 | ~10 |



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