Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS Science

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ISIS PI (SwRI)

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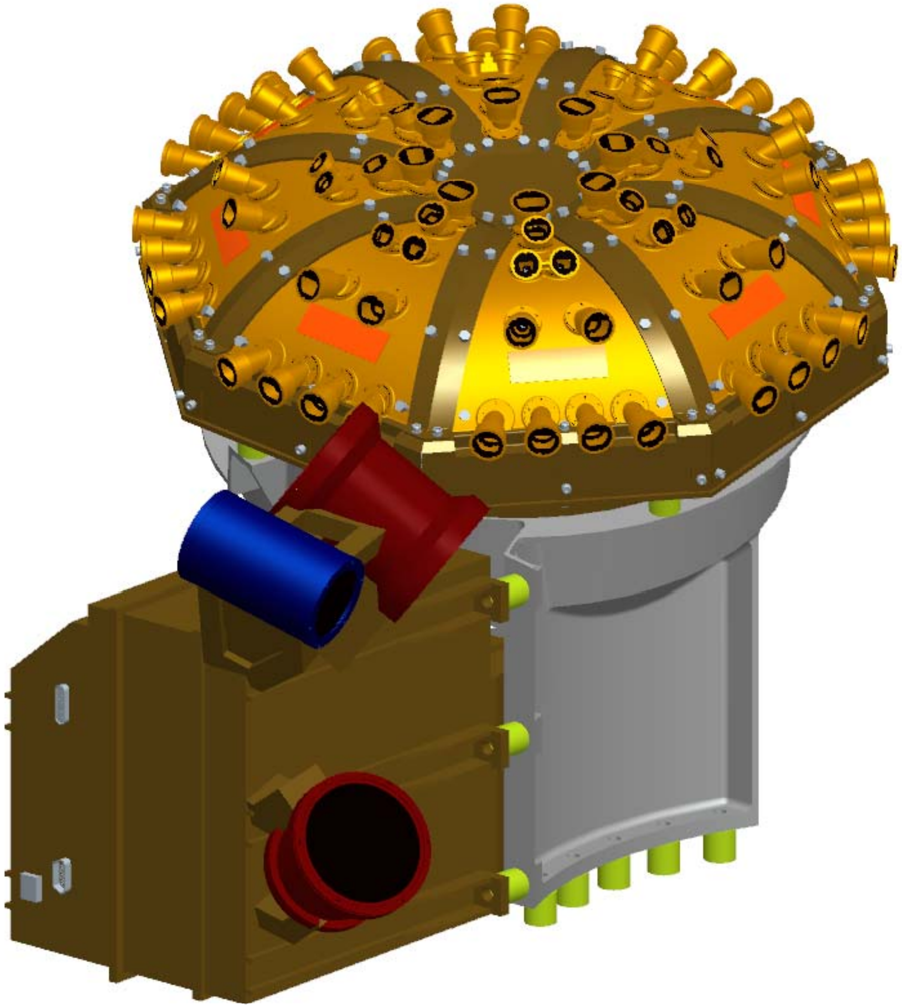

ISIS Science Team

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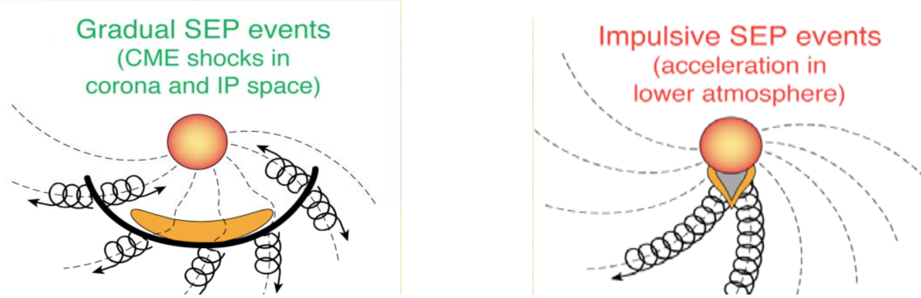
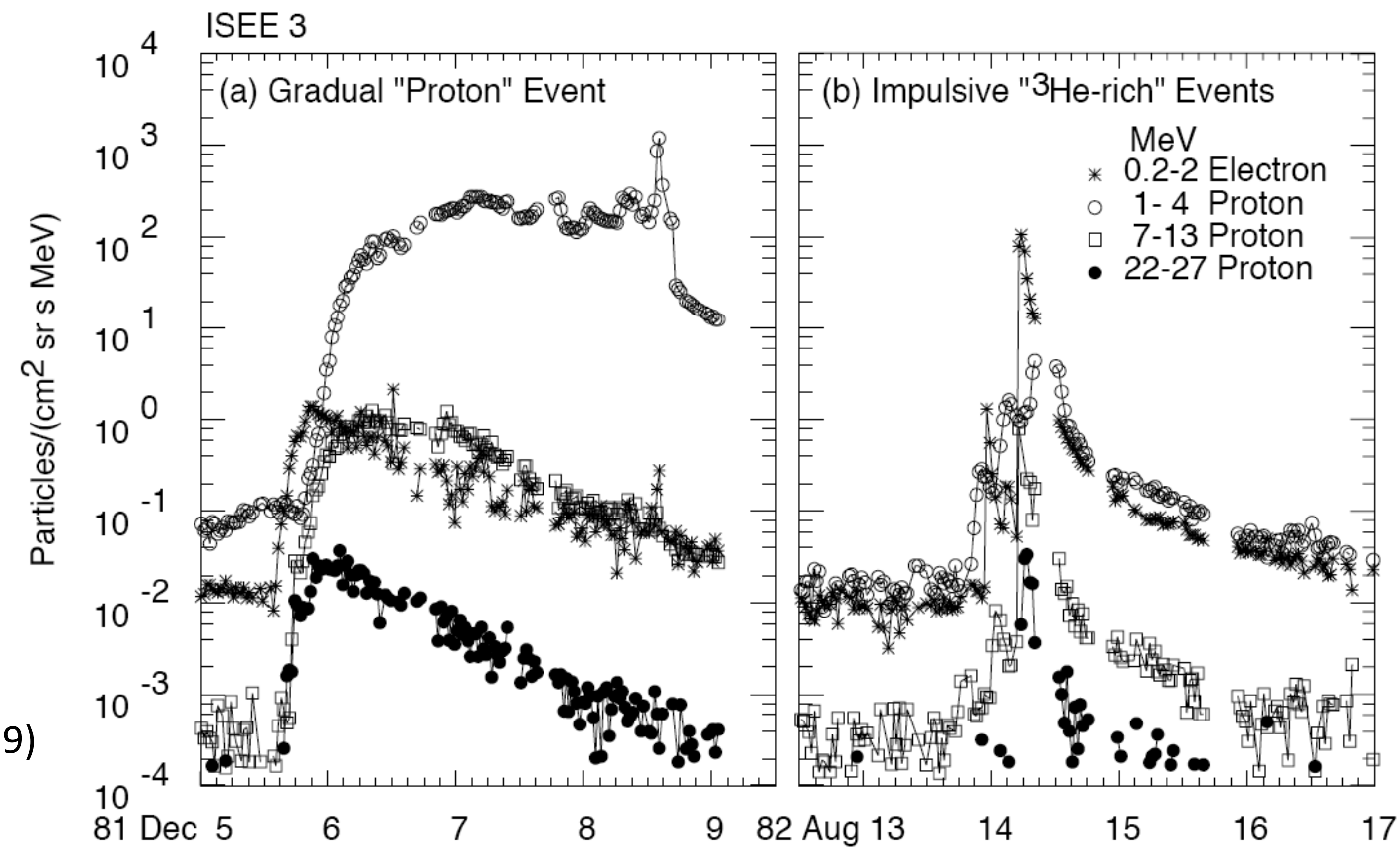
- PI: Dave McComas* (SwRI)
- Co-I: Eric Christian (GSFC), Deputy PI
- Co-I (Lo Lead): Ralph McNutt* (APL)
- Co-I (Hi Lead): Mark Wiedenbeck* (Caltech/JPL)
- Co-I (SOC Lead): Nathan Schwadron (UNH)
- Co-Is: Alan Cummings (Caltech), Mihir Desai (SwRI), Joe Giacalone (UArizona), Matt Hill (APL), Stefano Livi (SwRI), Bill Matthaeus (UDelaware), Dick Mewaldt (Caltech), Don Mitchell (APL), Tycho von Rosenvinge (GSFC)
- Senior Science Mentor (SSM) Team Members: Rob Gold (APL), Tom Krimigis (APL), Ed Roelof, (APL) and Ed Stone (Caltech)

*SPP Science Working Group (SWG) Members

SEP Events: Gradual vs. Impulsive

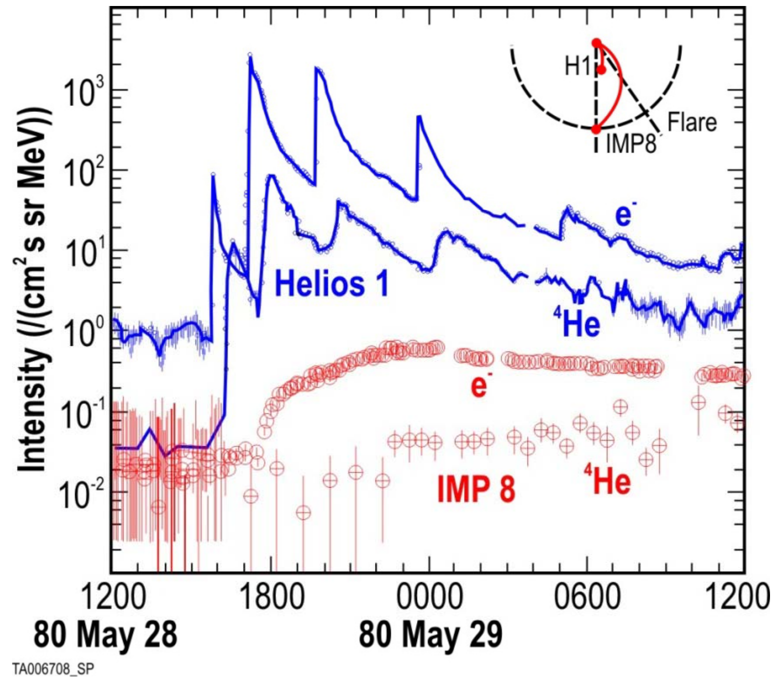




(Reames 1999)

Need to Measure Near the Sun

- Testing, discriminating, and refining SEP acceleration models is difficult at 1 AU due to distance from sources and mixing during transport
- Helios showed advantages of near-Sun observations of SEP processes near origin
- ISIS explores corona and inner heliosphere with state-of-the-art sensors; refines our understanding of acceleration, seed particles and transport; advances new models; and discovers new phenomena



Electron (e) and He (α) time profiles from Helios-1 (0.3 AU) and IMP-8 (1 AU) during five ISEP events in 1980 (from Wibberenz and Cane 2006). Magnetic connections to the flare site are indicated at upper right. Helios-1 observed five injections; IMP-8 only one. ISIS samples ~50-100 ISEP and ≳50 large SEP events inside 0.25 AU, where each event will be sharply peaked and 100-1000 times as intense, enabling detailed studies of (1) flare and CME-shock acceleration, (2) seed particle identities, and (3) the effects of particle transport in the interplanetary medium.

ISIS Science Goals

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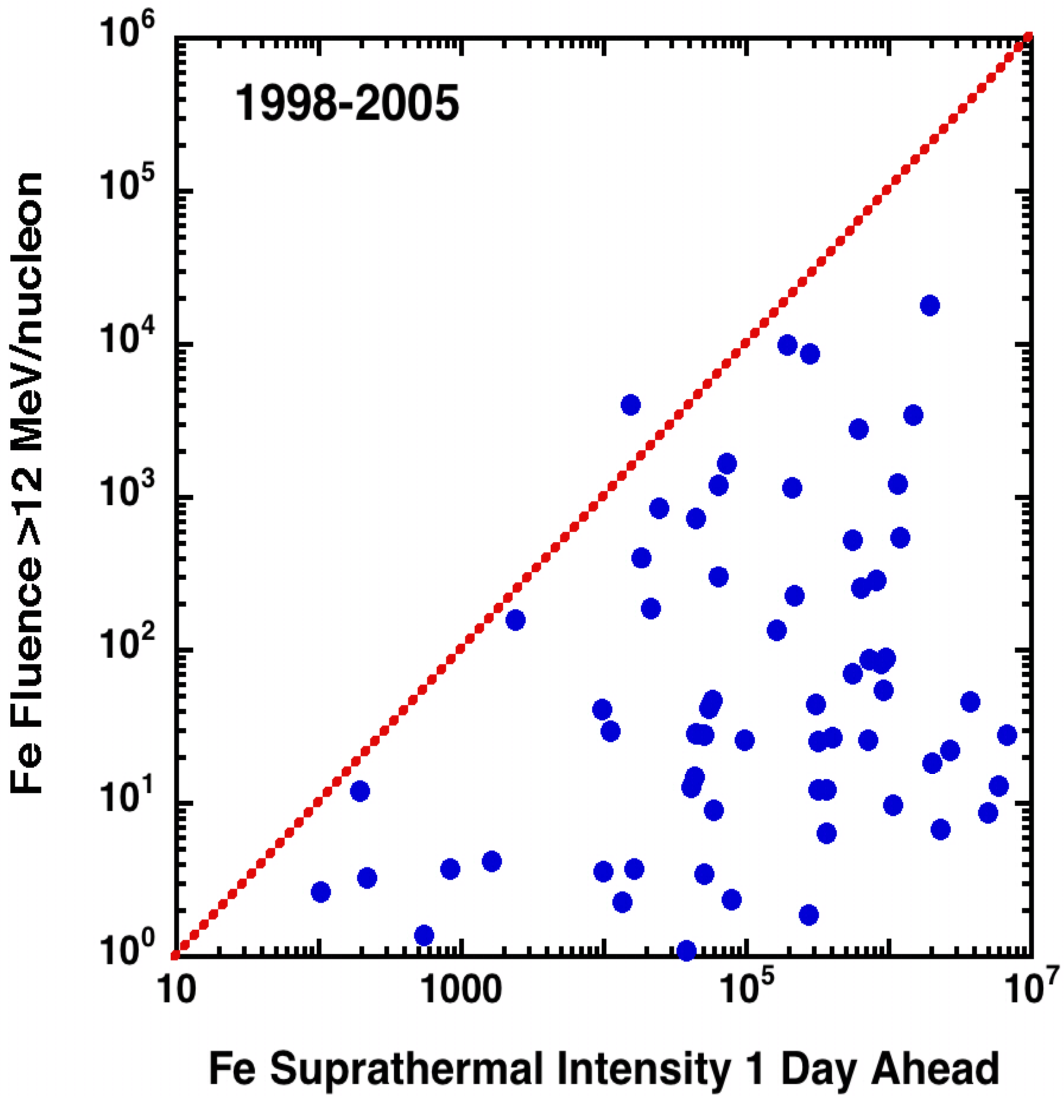
- Explore mechanisms that accelerate and transport energetic particles
  - Origin: Determine the seed populations and physical conditions necessary for energetic particle acceleration
  - Acceleration: Determine the roles of shocks, reconnection, waves, and turbulence in accelerating energetic particles
  - Transport: Determine how energetic particles propagate from the corona out into the heliosphere

Note: Includes coordinated analysis between ISIS and other SPP instruments of solar wind plasma, fields, and waves

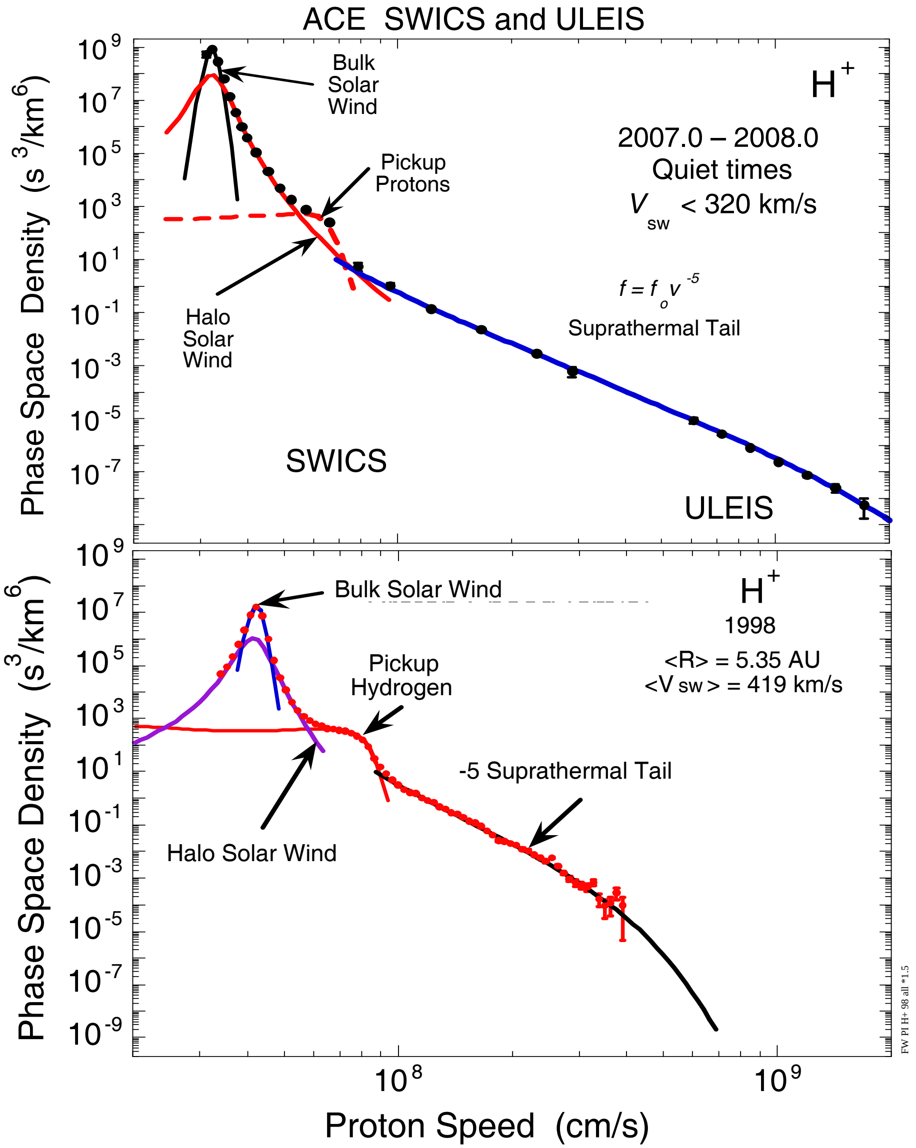
Origin: Suprathermal Seeds of SEPs



How does the suprathermal particle population through which a shock moves influence the resulting intensity of Energetic Particles that are accelerated?

(Mewaldt et al. 2006)

Origins: SW Ion Suprathermal Tail Observations

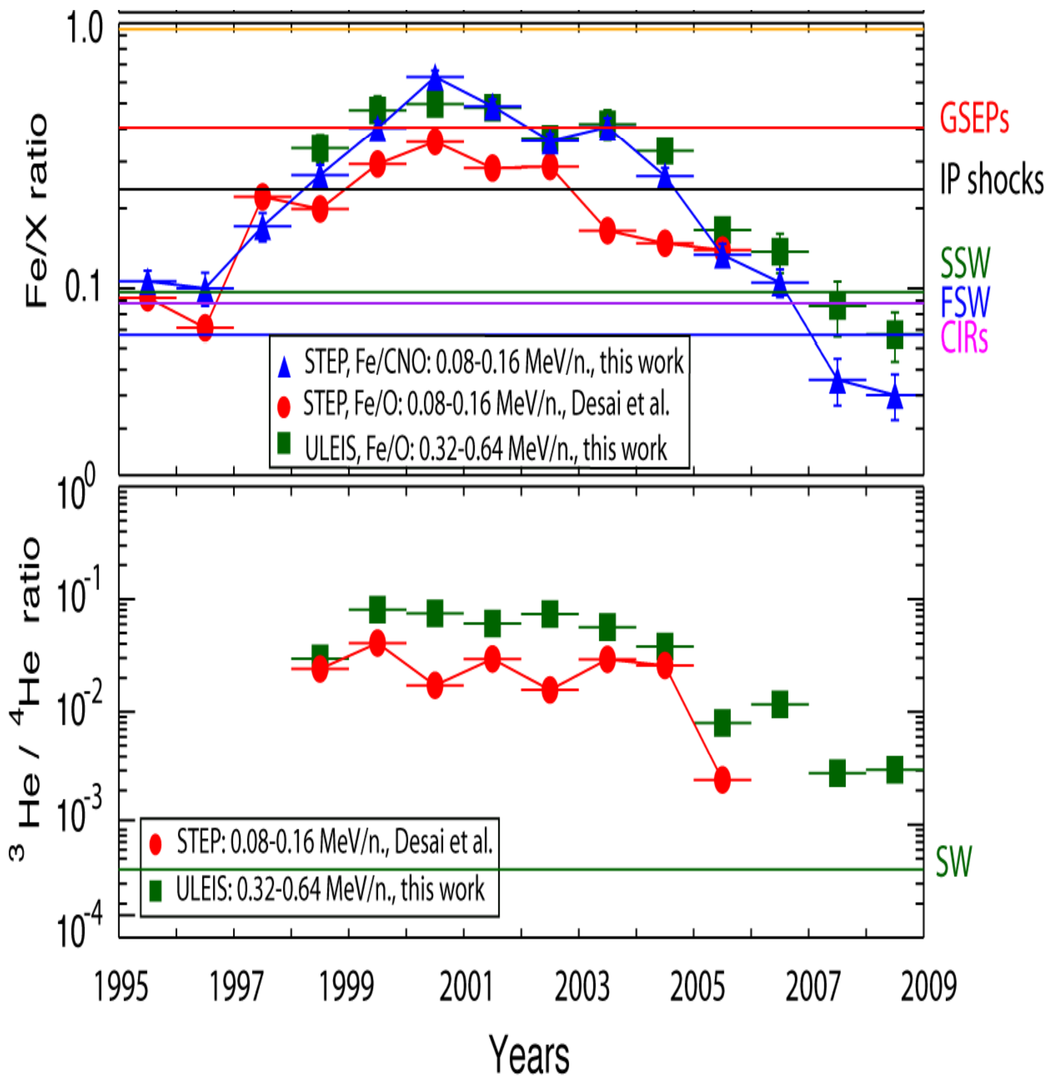


What mechanisms produce the widely observed suprathermal tails and how do they feed into SEP acceleration?

Are they produced in the corona by flares or are they produced in the heliosphere by stochastic acceleration?

(Fisk and Gloeckler 2007)

Origins: Temporal Variation of Composition



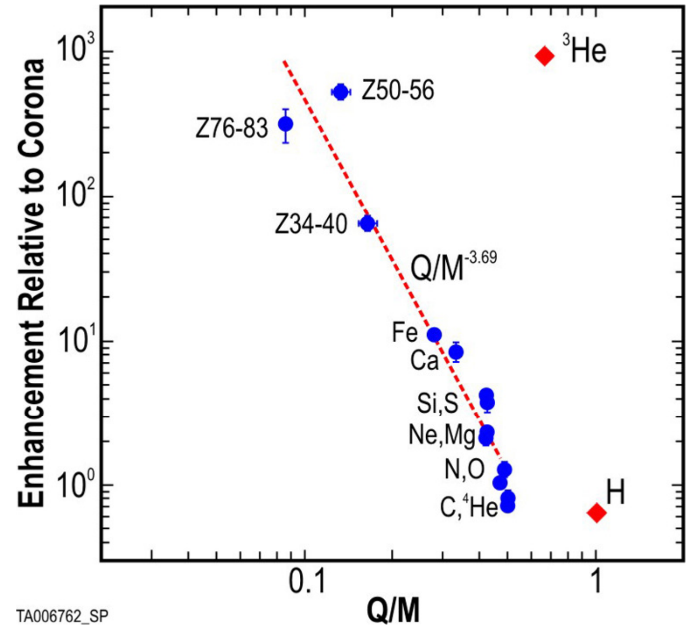
What causes the temporal variability in composition of the suprathermal tails?

Is the variation due to flare activity or changes in the physical conditions (turbulence, CMEs, compressions, prior shocks, etc.) in the inner heliosphere?

(Dayeh et al. 2009)

Acceleration: Impulsive Acceleration in Flares

- Explosive reconnection in X-class flares accelerates electrons to >10 MeV and ions to >100 MeV/nuc, but are not well understood
  - Fermi acceleration in collapsing magnetic islands
  - Possibly in conjunction with other mechanisms, e.g., stochastic acceleration by plasma waves, MHD turbulence, shocks, or direct electric field acceleration
- Impulsive SEPs at 1 AU reveal correlations between MeV ions and electrons and have large enrichments in 3He, heavy ions such as Fe and rare trans-Fe species (see Fig)
- Many large SEP events are "hybrids" with enrichments in 3He, heavy ions, and high-ionization states as well as shock-accelerated particles - Flare and shock contributions can only be separated near the Sun
- Acceleration of ever-present suprathermal tails in the solar wind is not well understood - understanding has broad implications for particle acceleration in nature



Multi-event average impulsive SEP abundance enhancements (relative to coronal composition) plotted vs Q/M for equilibrium charge states at 3 MK (from Reames & Ng 2004). A fit to all ions except H and 3He gives a slope of (Q/M)-3.69. Note that trans-Fe species are enriched by factors of ~50-500. ISIS measures the Q/M-fractionation in multiple ISEP events and provides constraints for reconnection-driven particle acceleration models.

Acceleration: Diffusive Shock Acceleration (DSA)

- Thought to be the primary acceleration mechanism at CME-driven shocks, however unresolved issues continue to hamper the development of theoretical models of large gradual SEP events:
  - existence and effects of proton-amplified Alfvén waves near quasi-parallel shocks
  - conditions that affect acceleration efficiencies of CME shocks
  - roles played by shock geometry on the injection thresholds
- DSA models invoke proton-amplified Alfvén waves to trap ions near quasi-parallel shocks to increase acceleration efficiency
- Near-Sun observational evidence of the roles of diffusion and wave amplification in SEP events
- CME shock acceleration efficiencies are highly variable, likely due to different shock geometries, differing coronal conditions, and other poorly understood effects (e.g., seed particles) – can not be studied at 1 AU

Acceleration: SEP Energy Sources - CMEs

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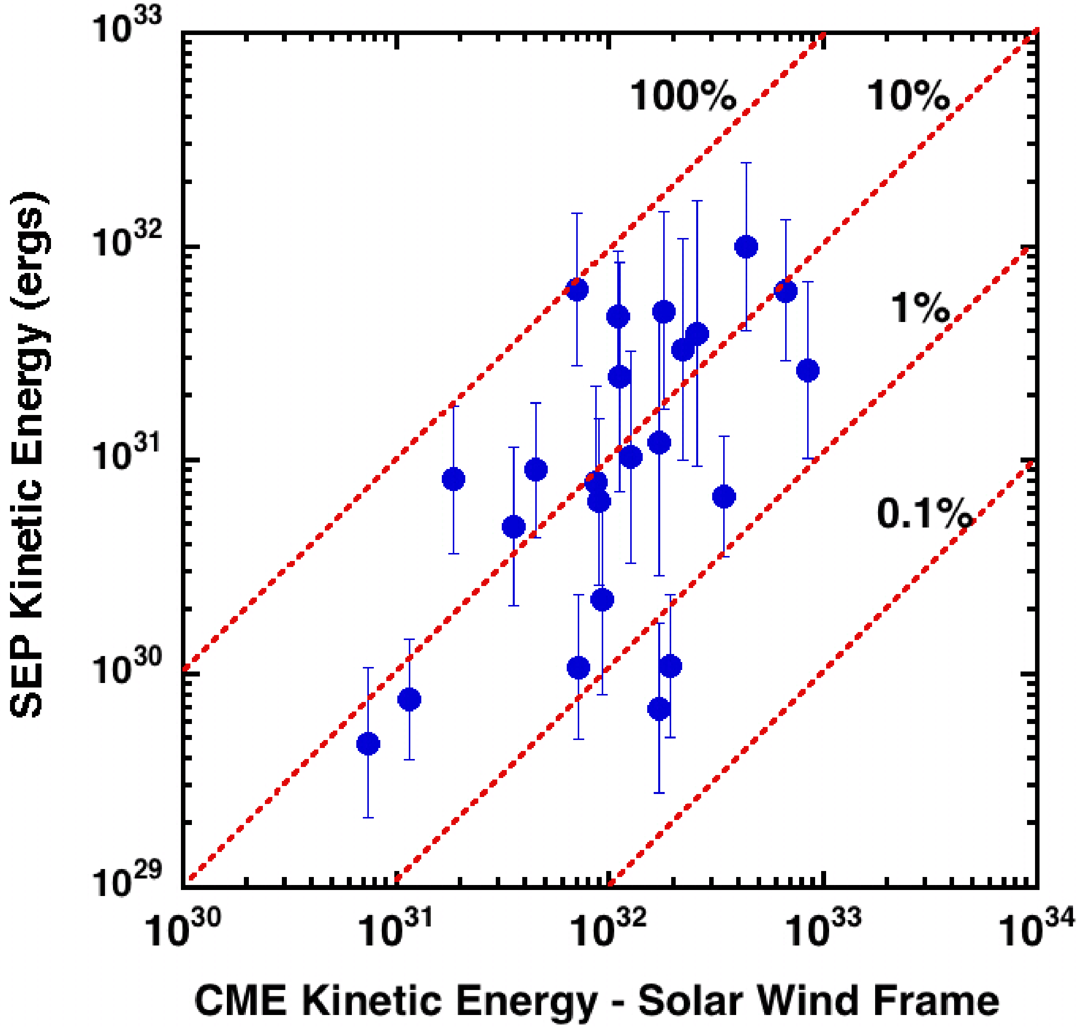
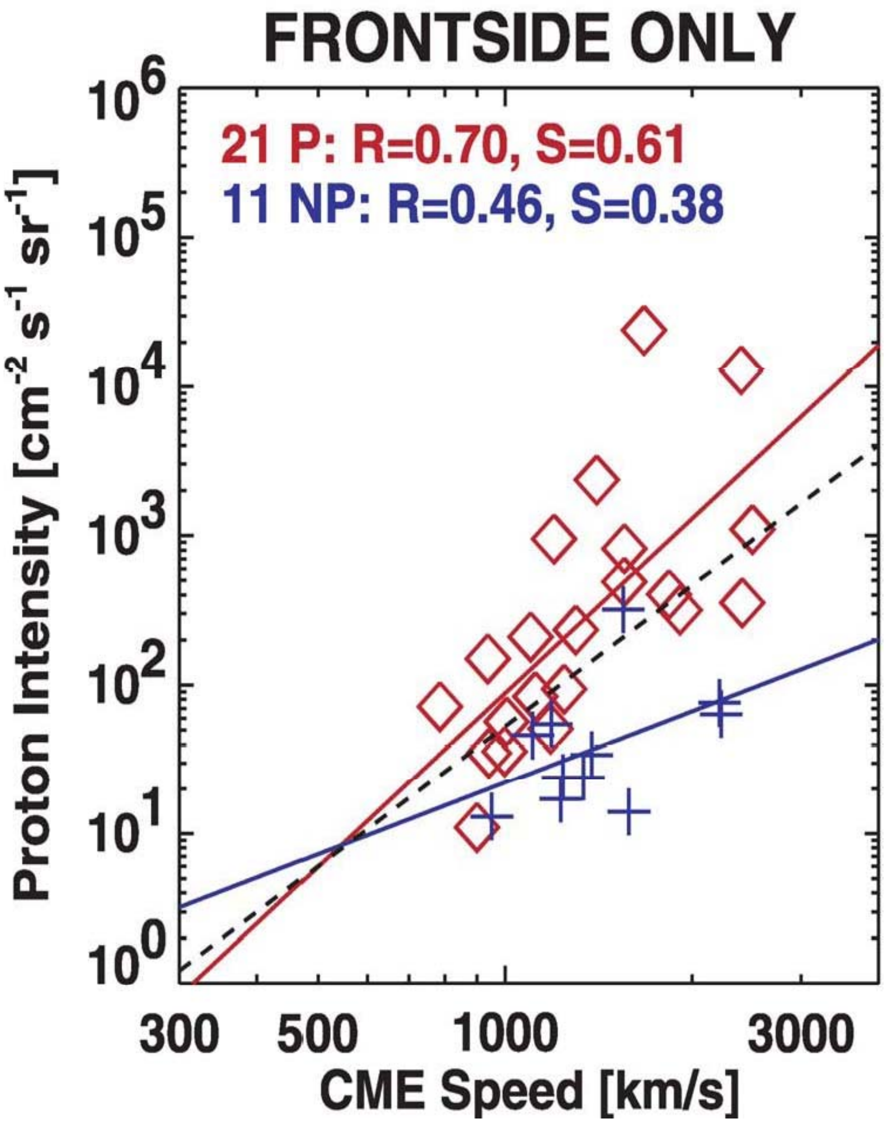


What fraction of the CME kinetic energy goes into accelerating energetic particles?

Is it controlled by turbulence levels, self excited waves, seed particles, shock properties, prior CMEs?

SEP-CME: Comparison of the kinetic energy of accelerated SEPs with the CME kinetic energy indicate that as much as ~10% of the CME energy goes into accelerated particles (Mewaldt et al. 2008).

Acceleration: CME-Driven Shock Efficiency

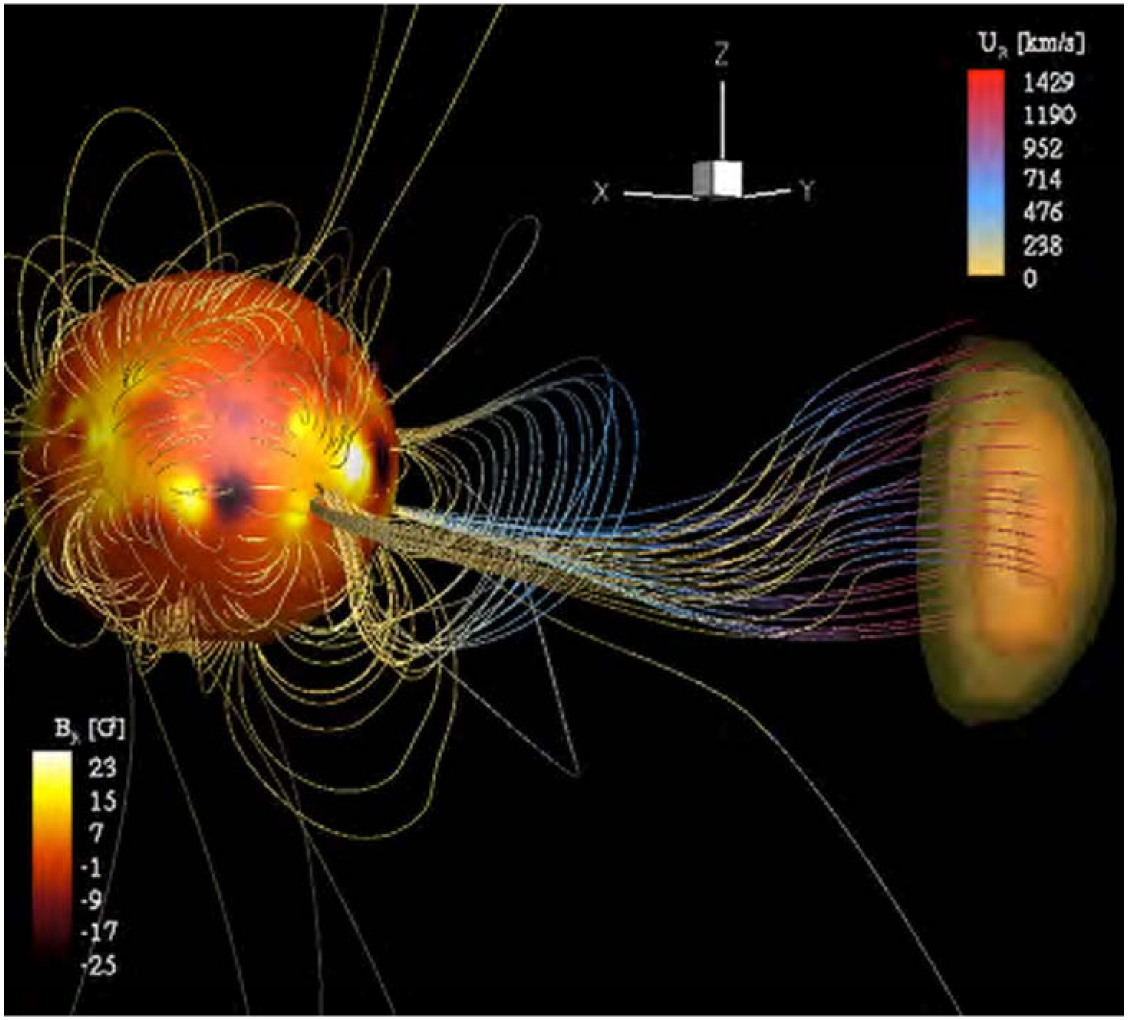


Why is the efficiency of CME-driven shock acceleration apparently greater when there has been a preceding CME?

Do prior CMEs modify the turbulence and other physical parameters or simply provide different seed particles?

(Gopalswamy et al. 2004)

Transport: How do SEPs Get to Earth?

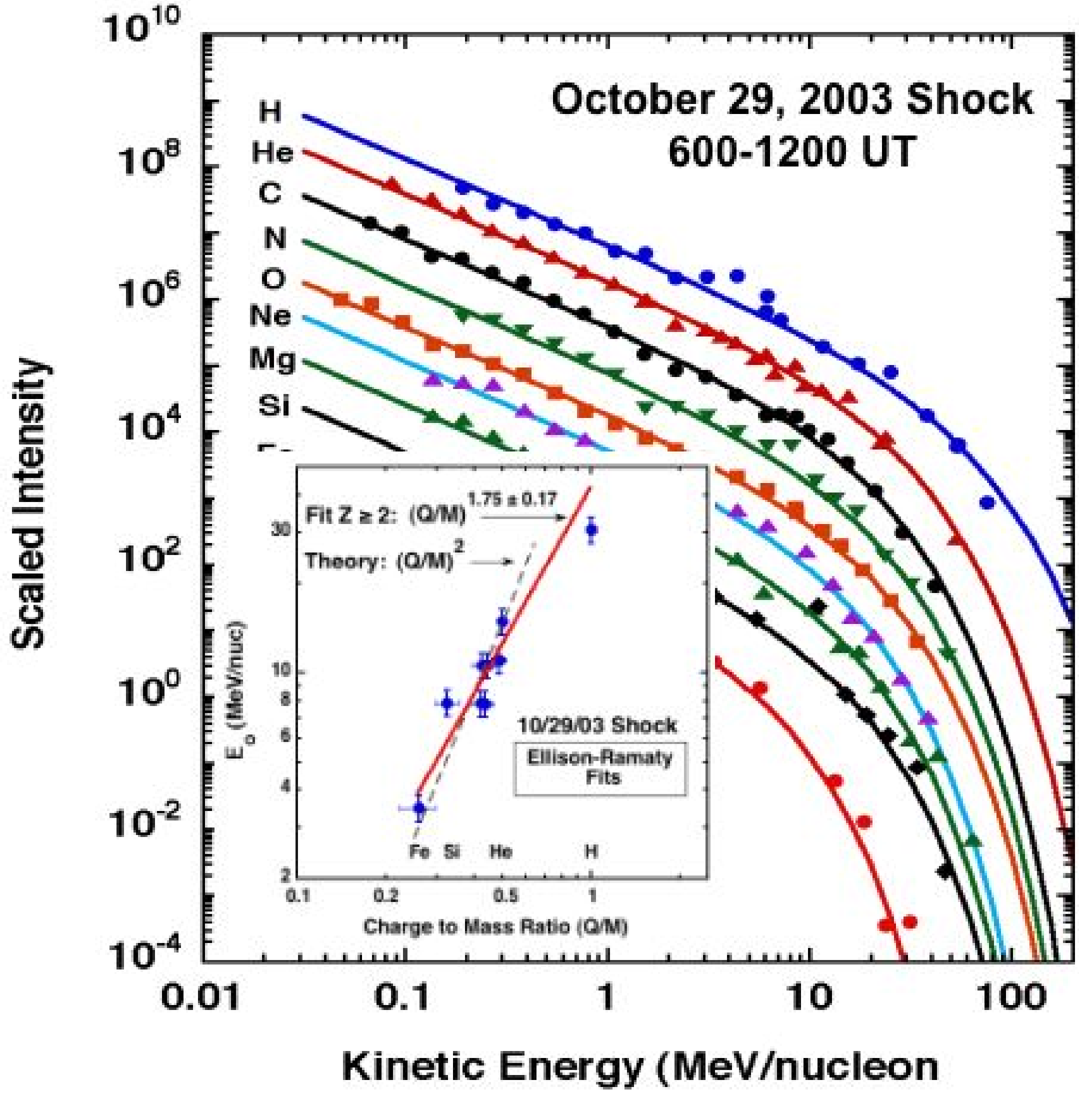


How are SEP properties affected by transport through the heliosphere?

What are the roles of diffusion, adiabatic deceleration, magnetic structure, self excited waves, shock properties, etc.?

(Roussev et al. 2007)

Transport: Energy Spectral Breaks



Why does shock acceleration suddenly become less efficient at high energy?

Is it because of M/q dependant escape or shock shape, or lack of waves…?

…Or, what else causes spectral breaks?

(Mewaldt et al., 2006)

Energetic Neutral Atoms (ENAs)

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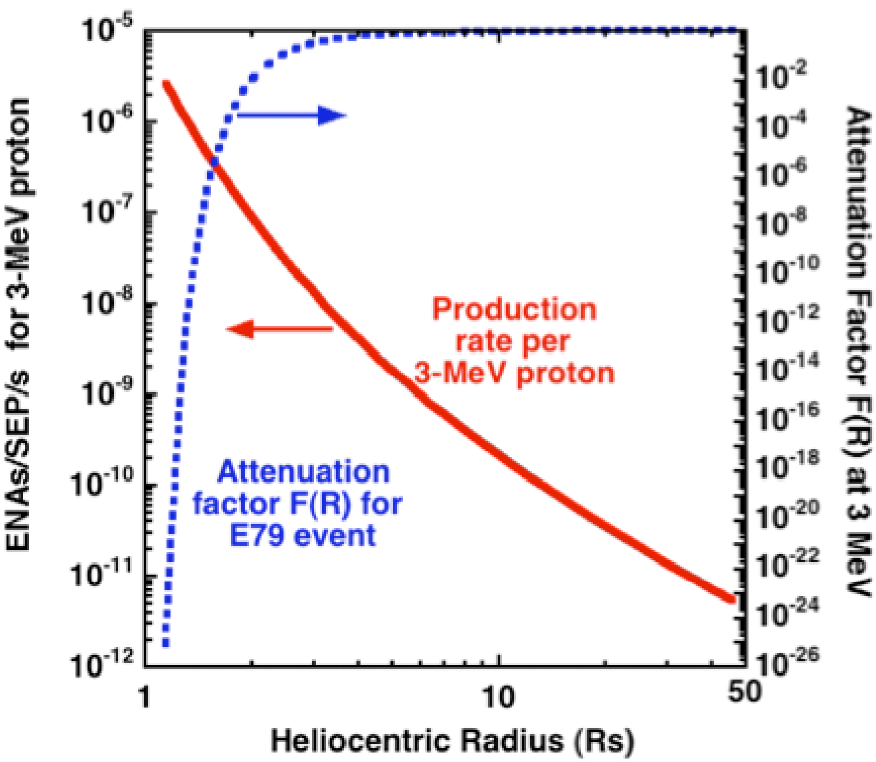
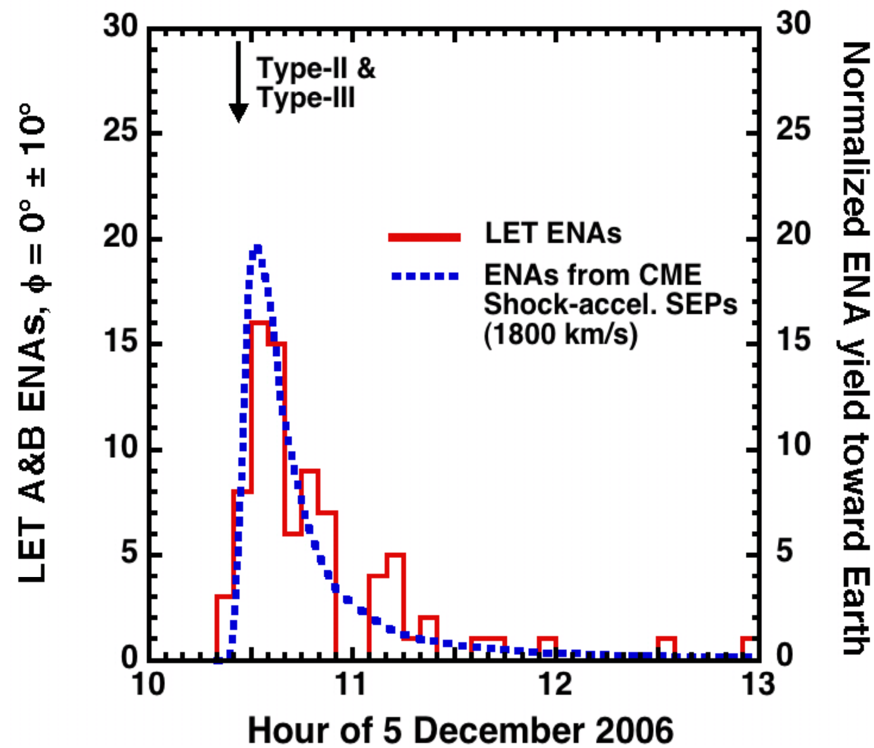
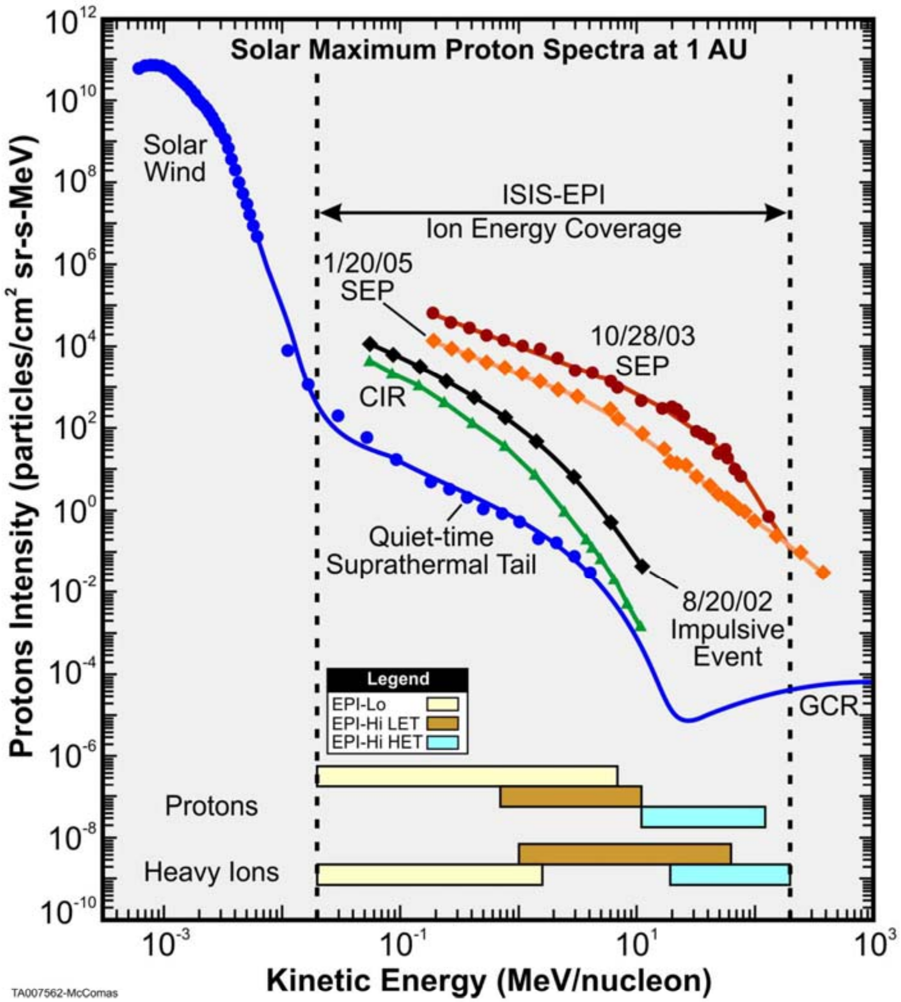
What can ENAs from solar eruptions tell us about how SEPs are accelerated and escape the Sun?





Calculated ENA emission profiles versus time as a shock moves from 2 to 20 Rs. (Mewaldt et al., 2009)

Measurement Summary



ISIS-EPI also provides electron measurements from ~0.025 to 6 MeV

- Determine in both gradual & impulsive Solar EP events:
  - Energy spectra
  - Composition (electrons, protons, major heavy elements)
  - Timing
  - Pitch angle distributions
- Measure ^{3}He as a key indicator of impulsive events
- Measurements of other populations (CIRs, ACRs, and GCRs) provide important new information on the radial dependences of these particles

Driving Requirements

- Energetic electron energy range: ≤0.05 to ≥3 MeV
- Energetic protons and heavy ions: ≤0.05 to ≥50 MeV/nuc
- Field of View: ≥π/2 sr in both sunward and anti-sunward hemispheres including coverage within 10° of the nominal Parker spiral field direction at perihelion
- Composition: at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe
- Maximum intensity <1MeV: ≥10^6 particles/cm^2sr-s
- Maximum intensity >1MeV: ≥$5x10^5$ particles/cm^2sr-s

Primary Measurement Requirements

MRD Req't	Parameter	Required	Comment/Heritage
MRD-96a MRD-97a	Energy range	e^-: ≤ 0.05 to ≥ 3 MeV p^+/i: ≤ 0.05 to ≥ 50 MeV	Combined energy range of all sensors; small gaps in energy coverage are acceptable
MRD-96b MRD-97b	Energy binning	≥ 6 bins/decade	ΔE/E≤16%
MRD-96c MRD-97c	Highest cadence	e^-: ≤ 1s for selected high-statistics electron rates p^+/i: ≤ 5s for selected high-statistics ion rates	Additional rates at lower cadences, as appropriate for expected statistics and bit rate allocation
MRD-96d MRD-97d	Field of view	≥ π/2 ster coverage in both sunward and anti-sunward hemispheres, including coverage within 10 degrees of the nominal Parker spiral field direction at perihelion	Combined sky coverage of all sensors, some regions densely sampled rather than 100% covered
MRD-96e MRD-97e	Angular sectoring	e^-: ≤ 45 degree sectors p^+/i: ≤ 30 degree sectors	
MRD-97e	Composition	at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe	Measured species; not all measured under all conditions
MRD-98a	Max. intensity <1 MeV	≥ 10^6 particles/cm^2-sr-s	
MRD-98b	Max. intensity >1 MeV	≥ 5x10^5 particles/cm^2-sr-s	Highest intensities measured over restricted fields of view

Summary

- ISIS energetic particle measurements play key role in understanding origins, acceleration, and transport mechanisms
- Science goals have been mapped to measurement requirements
- These key requirements have been flowed down into the instrument design through the systems engineering process