

***Introduction to the SHINE Campaign Events
2002 April 21 and 2002 August 24***

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SHINE 2004

Plenary Session on the SHINE Campaign Events

Big Sky, Montana

2004 June 28

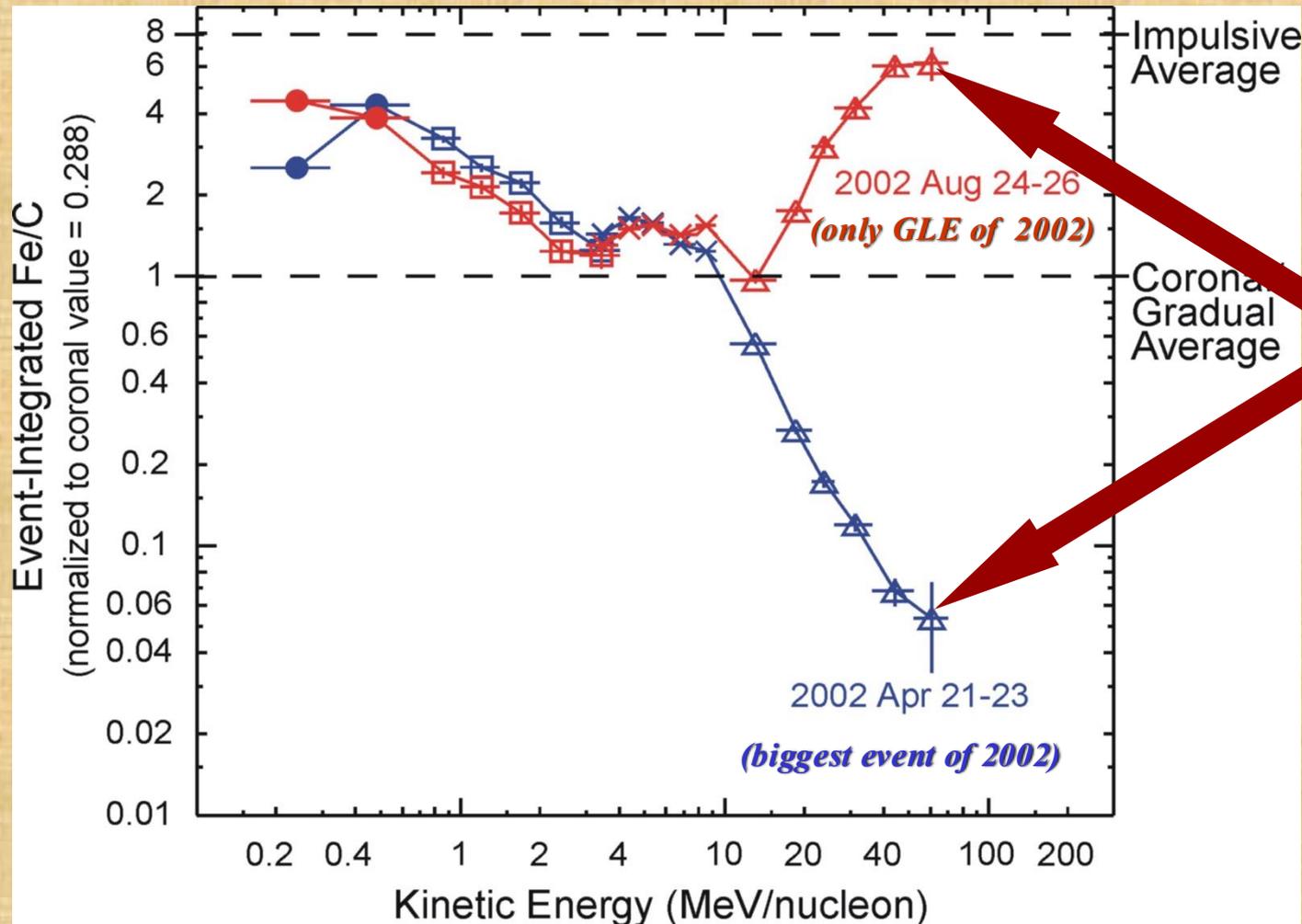
Outline

1. *Objective: What do we hope to learn by comparing these two events?*
2. *Review: Characteristics of these two events*
3. *Campaign Strategy*
 - Solar observations*
 - SEP Studies*
4. *Hypotheses about the SEP Physics*
5. *Additional Facts:*
 - Based on statistical study of the 44 largest SEP events of Cycle 23*
 - selected on the basis of >30 MeV proton fluence*
 - no heavy-ion biases*
 - Provide context for our deliberations.*
6. *Recent Modeling Efforts*
7. *Posters*

SEP Variability at High Energies

(above a few tens of MeV/nuc)

Fe/C (normalized to corona) vs. Energy



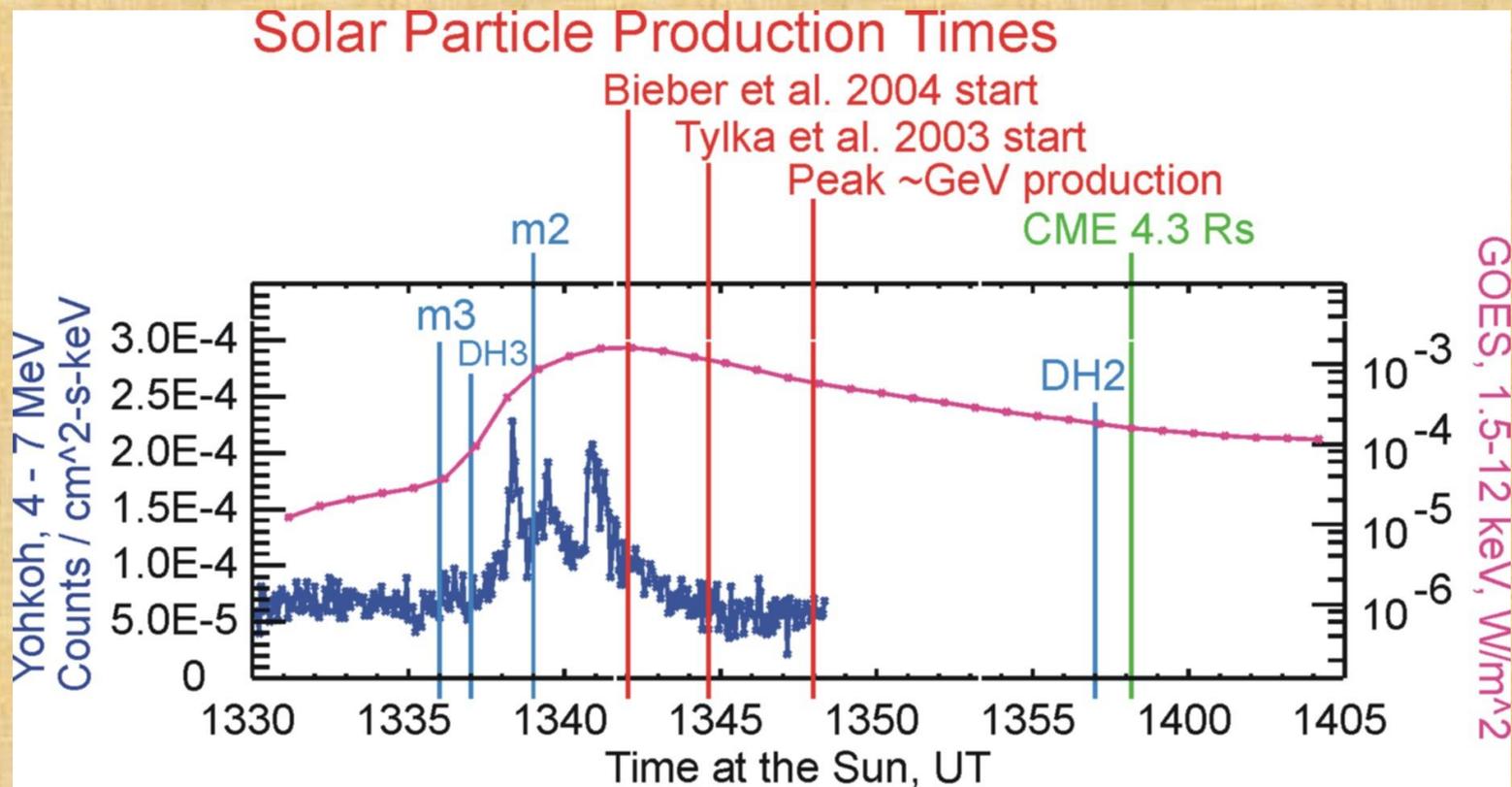
Our Objective:

Discover what makes these two events different at high energies!

Data from ACE/ULEIS, ACE/EPAM, Wind/LEMT, & ACE/SIS

*Whatever makes these events different,
it probably happens very near the Sun...*

2001 April 15 Ground Level Event
(like 2002 August 24, but bigger)



***SEP onsets & peak of ~GeV production
occurred when the CME was at ~2 R_S.***

Why these two events?

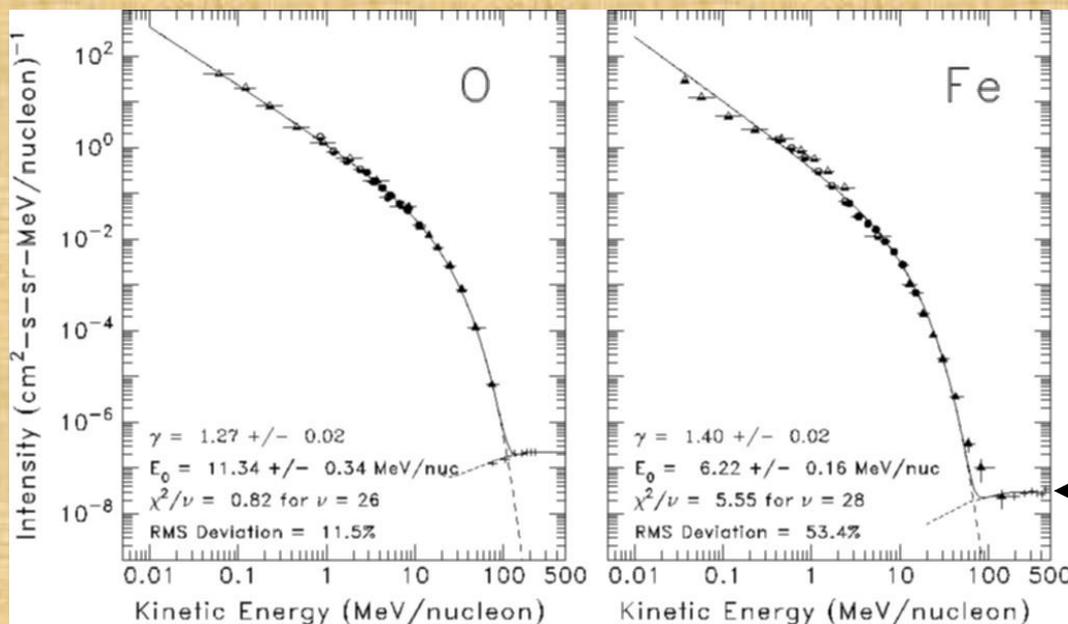
Similar solar sources -- a 'controlled' experiment!

	<i>21 Apr 2002</i>	<i>24 Aug 2002</i>
<i>CME (SOHO, S. Yashiro):</i>		
<i>Speed (km/s)</i>	<i>2409 km/s</i>	<i>1878 km/s</i>
<i>Flare (NOAA/SGD):</i>		
<i>Size</i>	<i>X1.5 / 1F</i>	<i>X3.1 / 1F</i>
<i>Location</i>	<i>S14° W84°</i>	<i>S02° W81°</i>
<i>SW Speed* at 1 AU (Wind, K. Ogilvie)</i>	<i>452-504 km/s</i>	<i>345-436 km/s</i>
<i>Nominal Magnetic Connection Longitude</i>	<i>W46°-W51°</i>	<i>W52°-W66°</i>
<i>Associated Shock at 1 AU (ACE, C.W. Smith):</i>		
<i>Transit Time to 1 AU</i>	<i>51 hours</i>	<i>58 hours</i>
<i>Velocity Jump (km/s)</i>	<i>~200 km/s</i>	<i>~100 km/s</i>
<i>ESP increase?</i>	<i>< 1 MeV only</i>	<i>< 0.5 MeV only</i>

** During the first 12 hours.*

Compare Spectra: 2002 April 21 & 2002 August 24

(Data from ACE/ULEIS, ACE/EPAM, Wind/LEMT, and ACE/SIS)

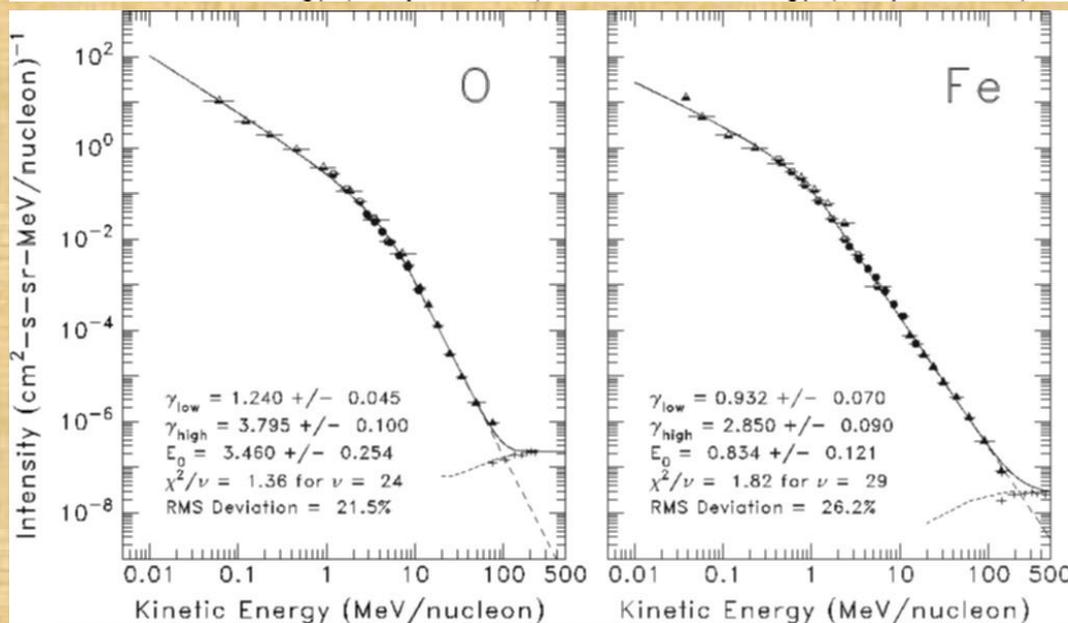


2002 April 21:

• Fits to $F(E) \sim E^{-\gamma} \exp(-E/E_0)$

• At high energies:

Fe softer than O (and C)



2002 August 24:

• Double power-laws:

Fits to Band et al. (1993) fcn

• At high energies:

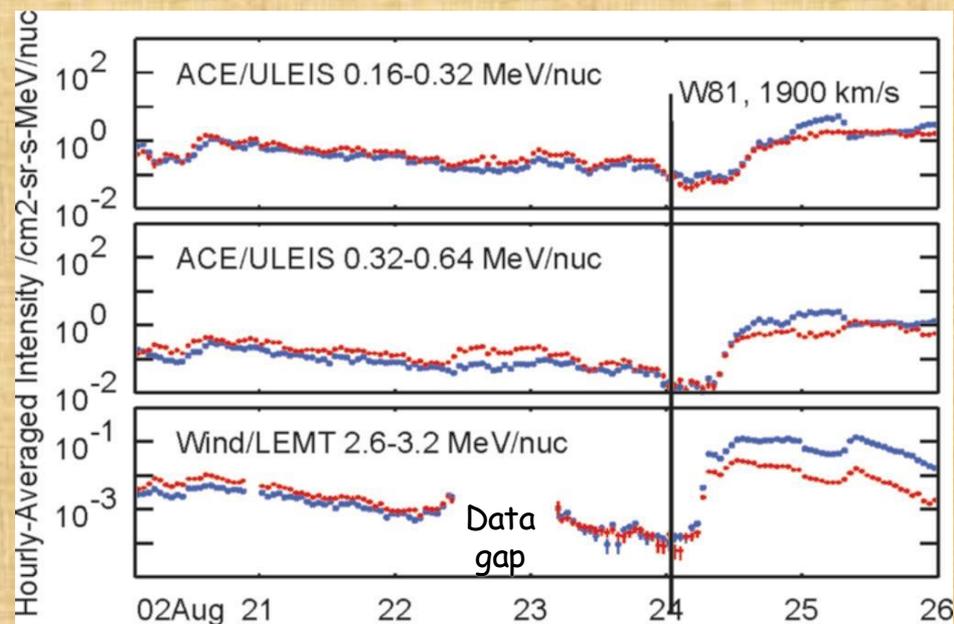
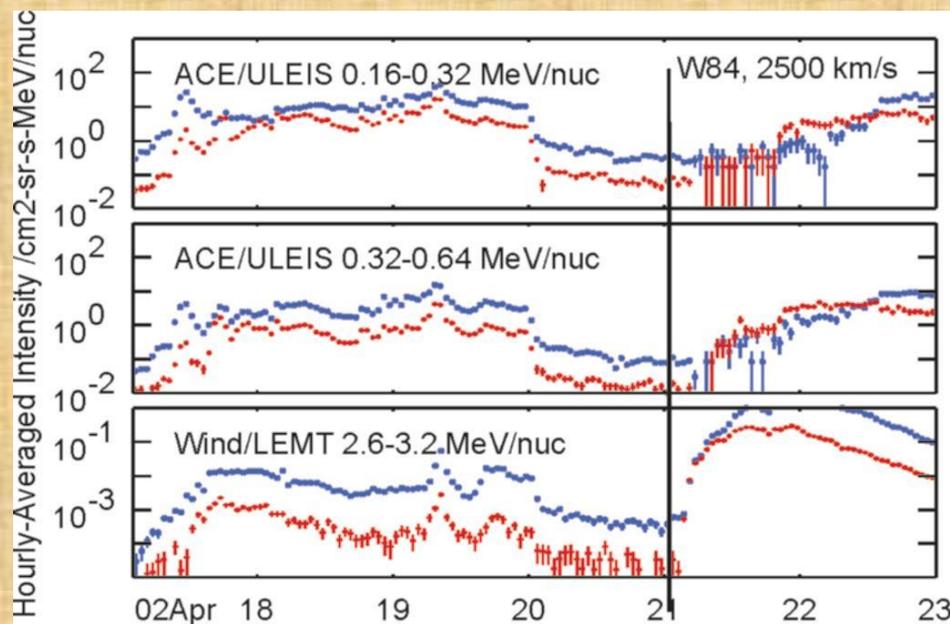
Fe harder than O (and C)

Pre-Event Particle Background

Blue: Oxygen **Red: Iron**

17-23 April 2002

20-26 August 2002



**Nominal Fe/O ~ 0.1 in the
4 days preceding the event**

**Enhanced Fe/O ~ 1 in the
4 days preceding the event**

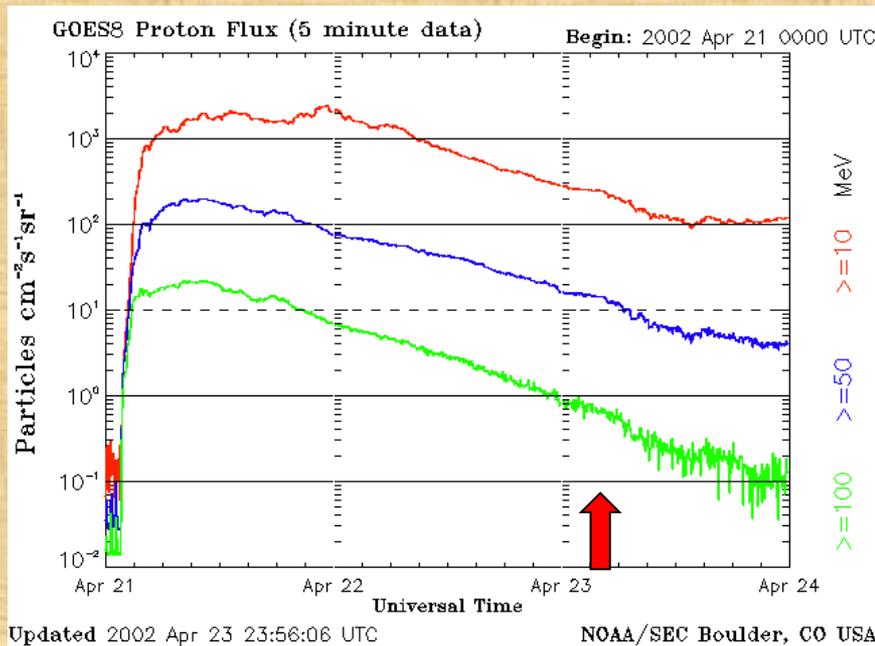
These two CMEs likely launched into very different seed populations.

GOES Protons

>10 MeV **>50 MeV** **>100 MeV**

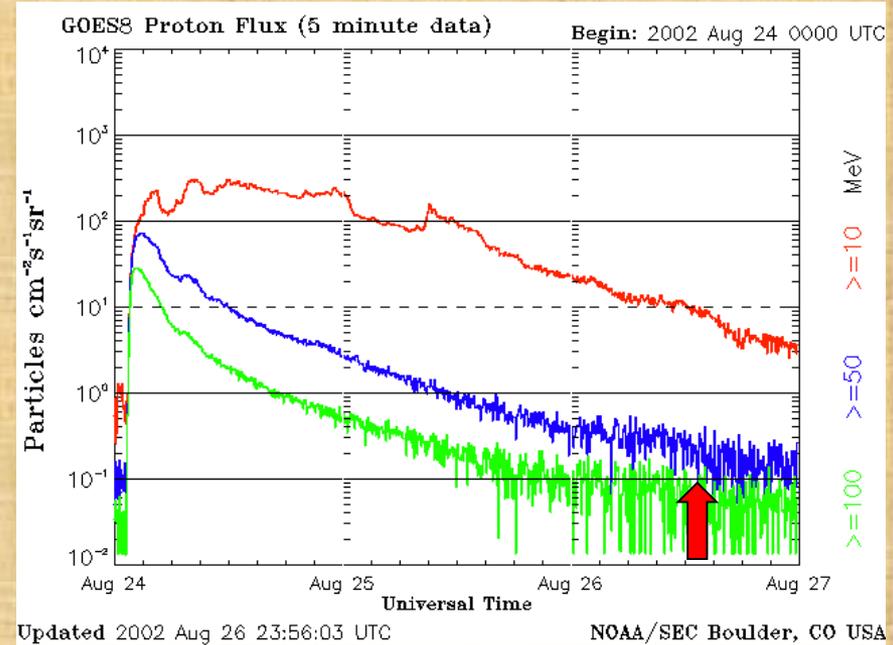
21 April 2002

(Fe-poor at high energies)



24 August 2002

(Fe-rich at high energies)



- **>10 MeV profiles very similar, except for normalization.**
- **But >50, >100 MeV profiles have different shapes in the two events.**
- **No increase in high-energy particles at shock arrival at Earth (arrows).**

Campaign Strategy

1. Solar Observations

- *Identify differences in SOHO, TRACE, RHESSI, etc. observations*
- *Brainstorm about their possible relevance to SEPs*
 - suggest new hypotheses*
 - confirm or refute hypotheses motivated by SEP observations alone*
- *Two talks in this session:*
 - David Alexander: Pre-Event History of these Active Regions*
 - John Raymond: UVCS Observations*

2. SEP Studies

- *WG3 Session Tuesday Morning:*
 - “What causes energy-dependent Fe/O in large SEP events?”*
 - Invited talks by Desai, Giacalone, Kota, Li, and Tylka*

Hypotheses about These Events

The SEP differences between these two events are due to:

1. Shock Geometry and Seed Population

- August event involves a quasi-perp shock operating on a seed population containing both flare & solar-wind ions.*
- April event comes from a seed population dominated by the solar wind & accelerated by a shock, most likely quasi-parallel.*

2. Seed Population Only

- August event had a strong flare component in its seed particles; the April event did not.*
- Shock geometry effects are non-existent/irrelevant.*

3. A Direct Flare Component at High Energies

- Both shock geometry and seed population are irrelevant.*
- August event had a component directly accelerated to high energies by the flare.*
- The flare component was missing or overwhelmed in the April event.*

4. Other ideas??

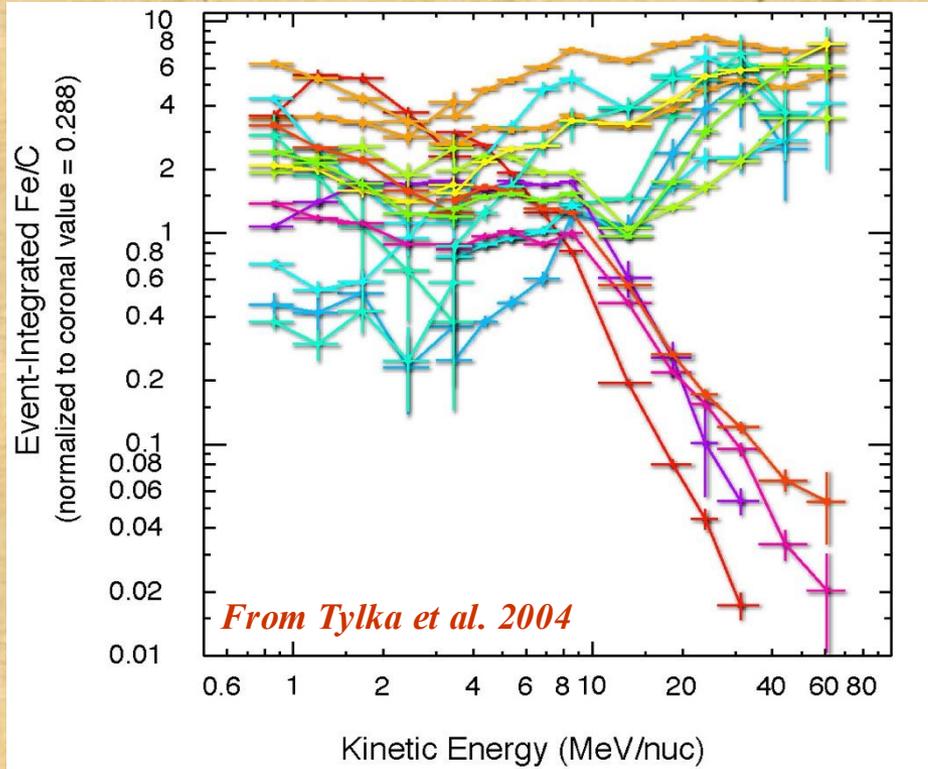
Additional “Facts”

- *based on the examination of large samples of events*
- *provide additional constraints & challenges for our hypotheses.*
 1. *SEPs vs. ESPs (traveling shocks at 1 AU)*
 2. *Longitude Distribution of Solar Source Regions*
 3. *Spectral Characteristics*
 4. *Average Fe/O Enhancement at High Energies*

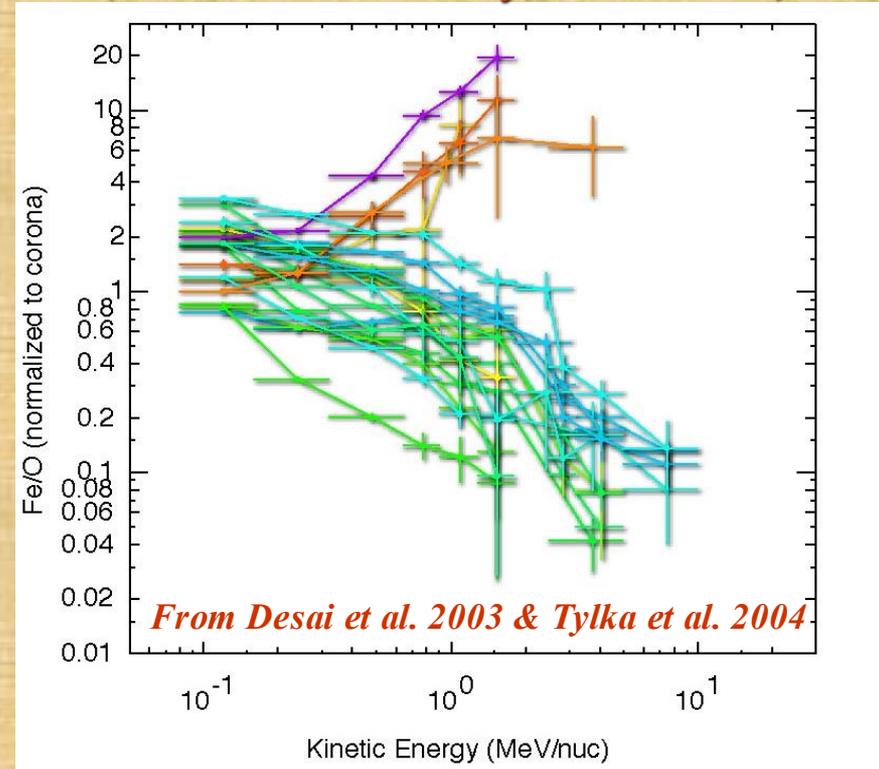
SEPs and ESPs

Strong Energy Dependence in Fe/C (and Fe/O)

Solar Energetic Particles (accelerated near the Sun)



Energetic Storm Particles (accelerated locally, near 1 AU)



Starting point: 44 SEP events 1997-2004 and 55 ESP events 1997-2002

In both cases, about 1/3 of the event sample showed strong energy dependence.

Same range of behavior in both SEP and ESP events (but at different energies).

Longitude Distribution of SEP Events

• These large Fe-rich events are observed from sources all across the Sun

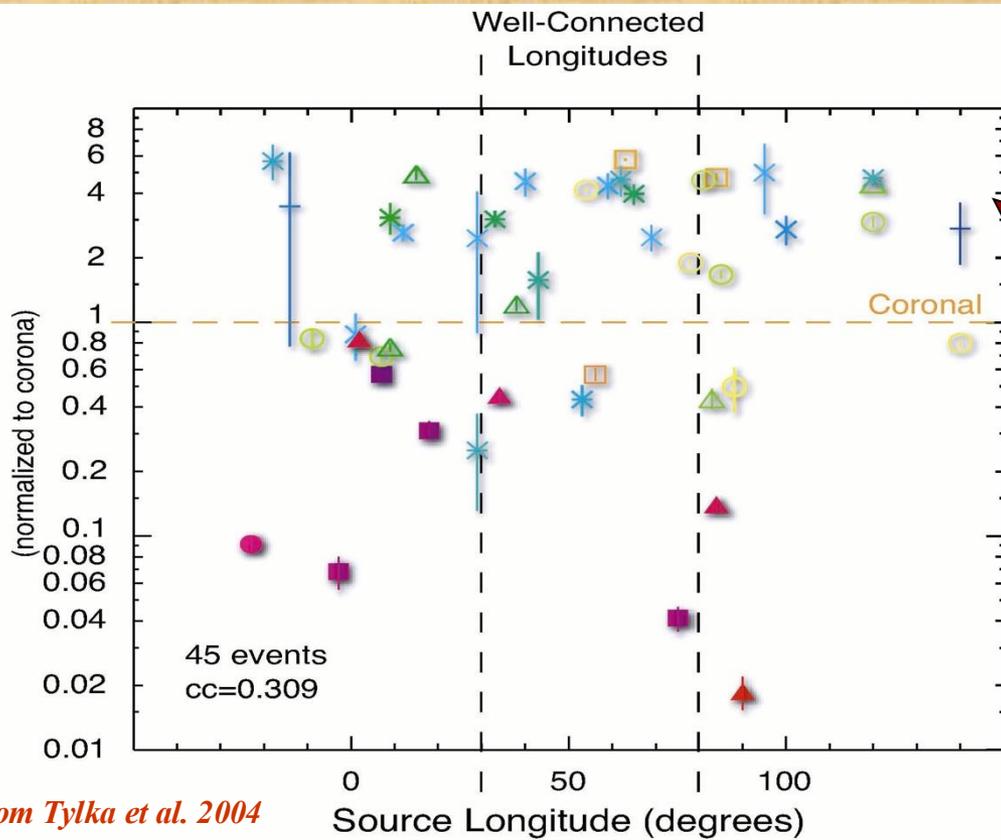
• Unlike classic ^3He -rich "impulsive" events:

• observable only at magnetically-connected solar longitudes:

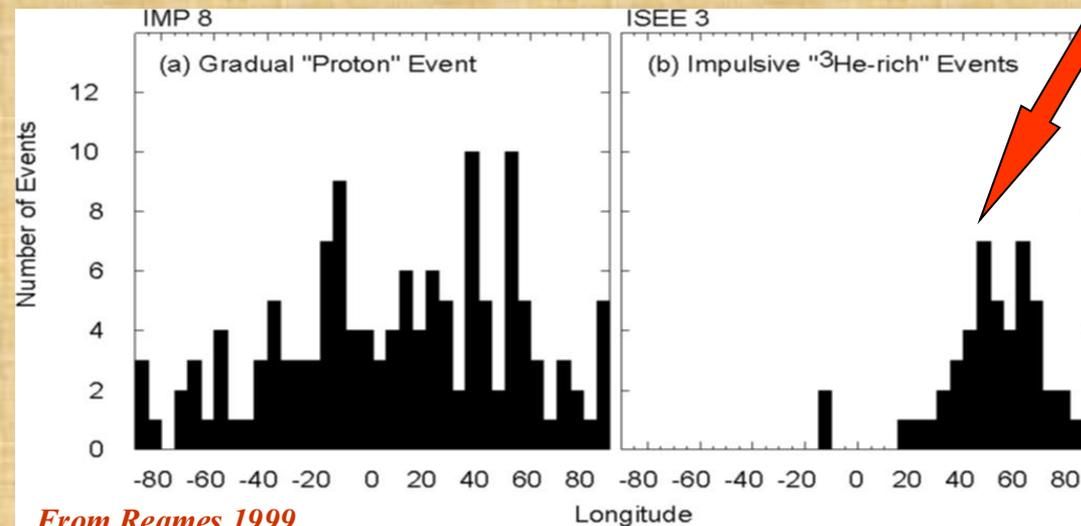
• 85% between W30 and W80.

• Spread primarily due to variation in solar wind speed.

ACE/SIS Fe/O at 30-40 MeV/nucleon
(normalized to corona)



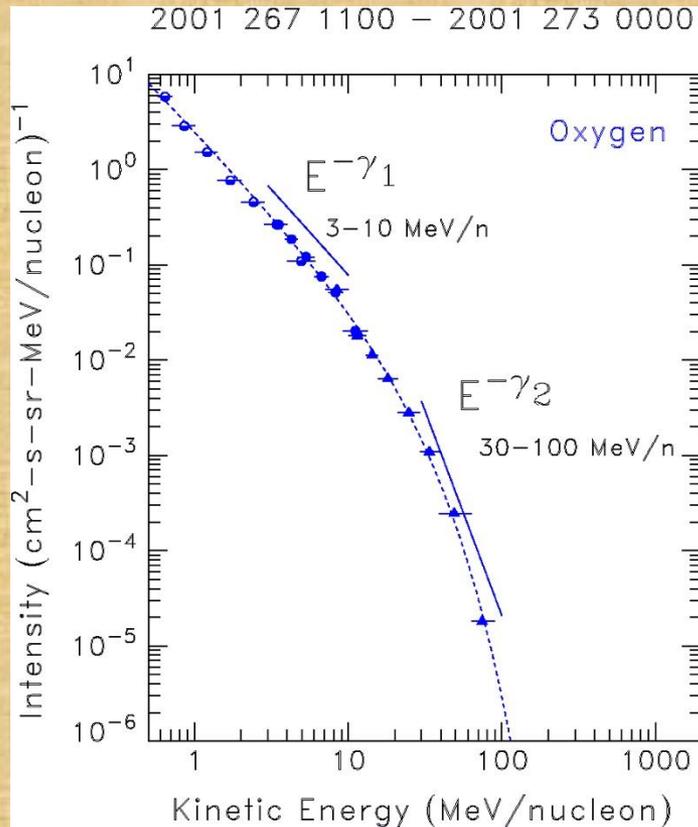
From Tylka et al. 2004



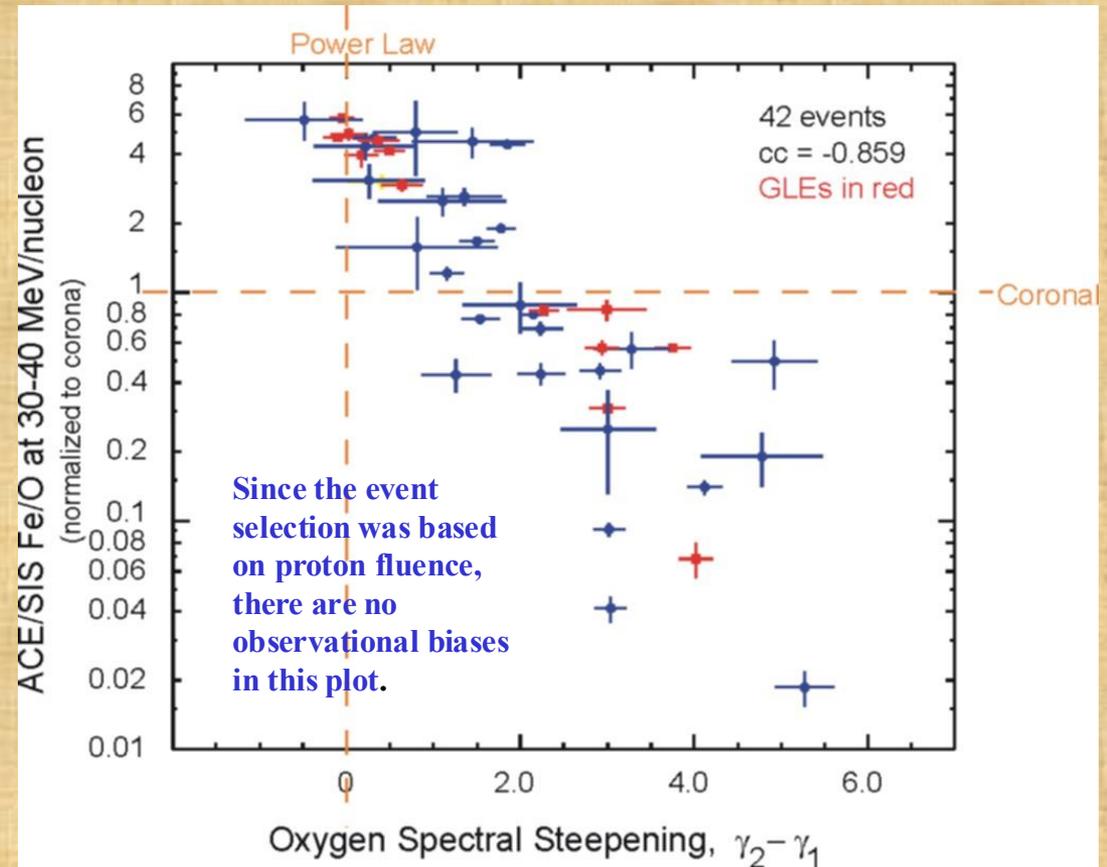
From Reames 1999

Fe/O vs. Spectral Steepening

Event-Integrated Oxygen Spectrum



Fe/O at 30-40 MeV/nuc v. $\gamma_2 - \gamma_1$

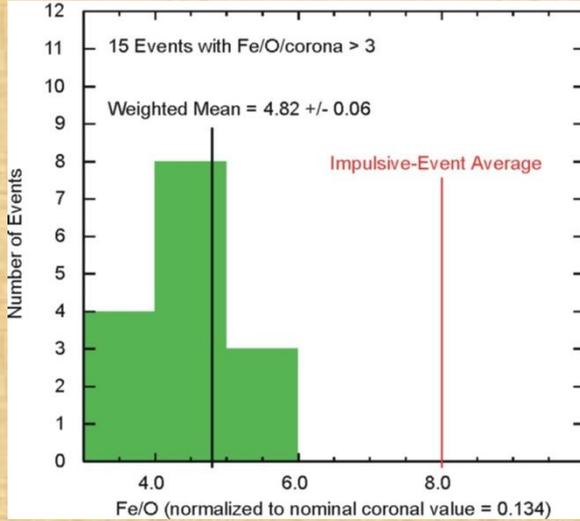


Events with enhanced high-energy Fe/O tend to have spectra more like power laws.

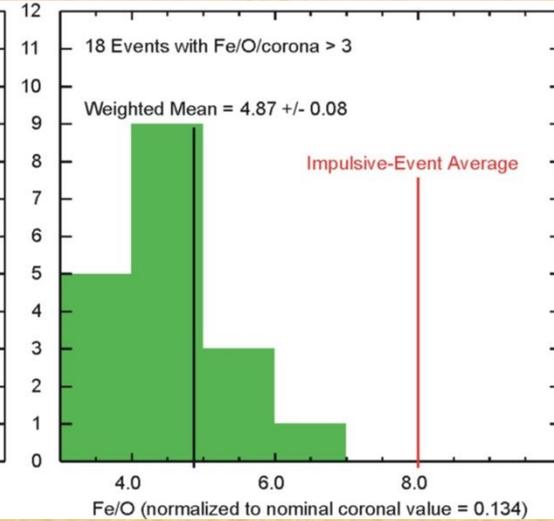
Events with suppressed high-energy Fe/O tend to have spectra that steepen at high energies.

Average Fe/O Enhancement at High Energies

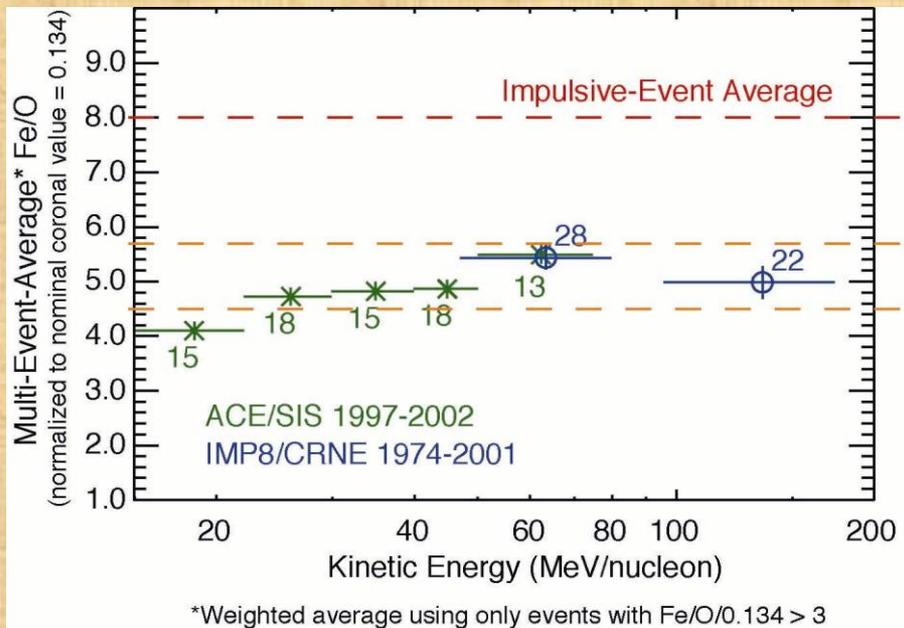
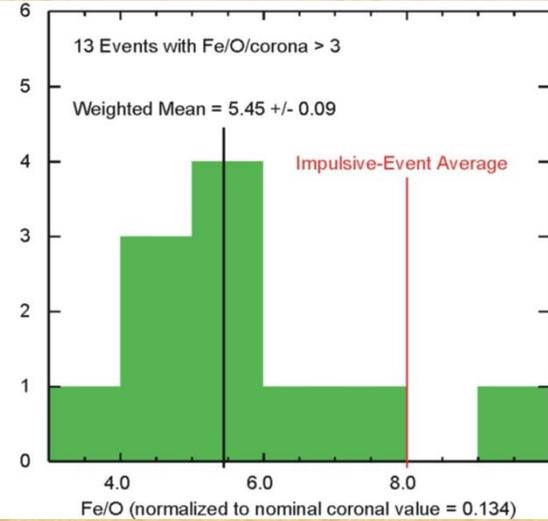
30-40 MeV/nuc



40-50 MeV/nuc



50-75 MeV/nuc



For events with enhanced Fe/O at high energies, the average Fe/O value “plateaus” at ~5x coronal.

➤ Significantly below the flare average of ~8x coronal.

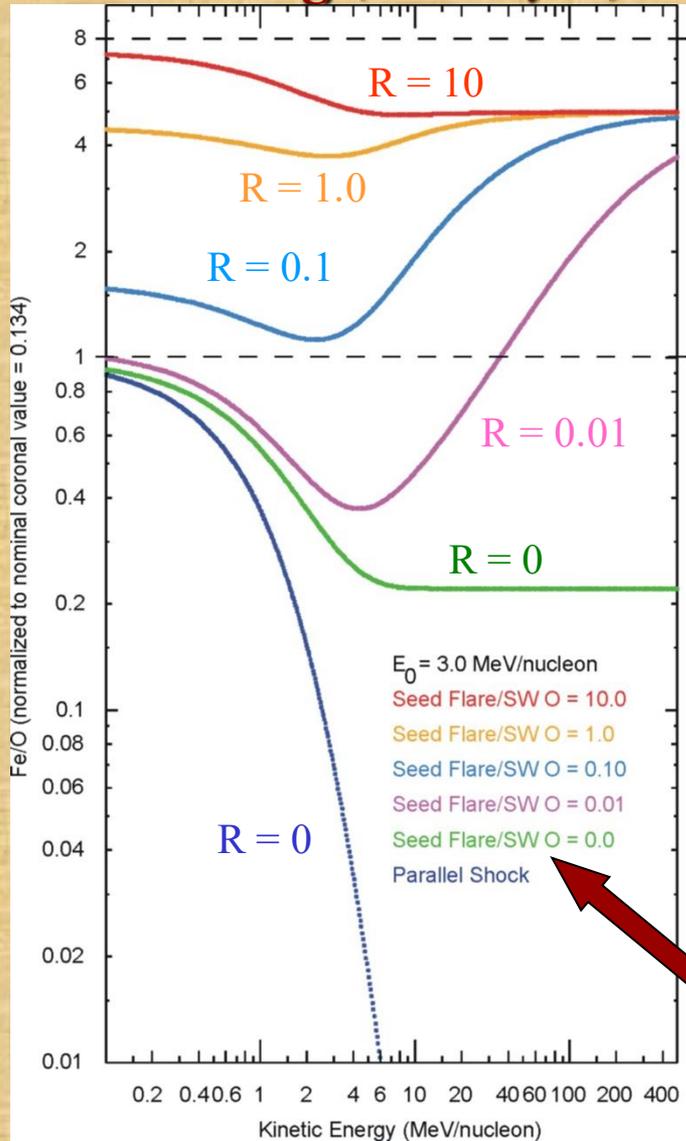
Numbers on the datapoints tell how many events were used in the average.

Summary of Additional Facts

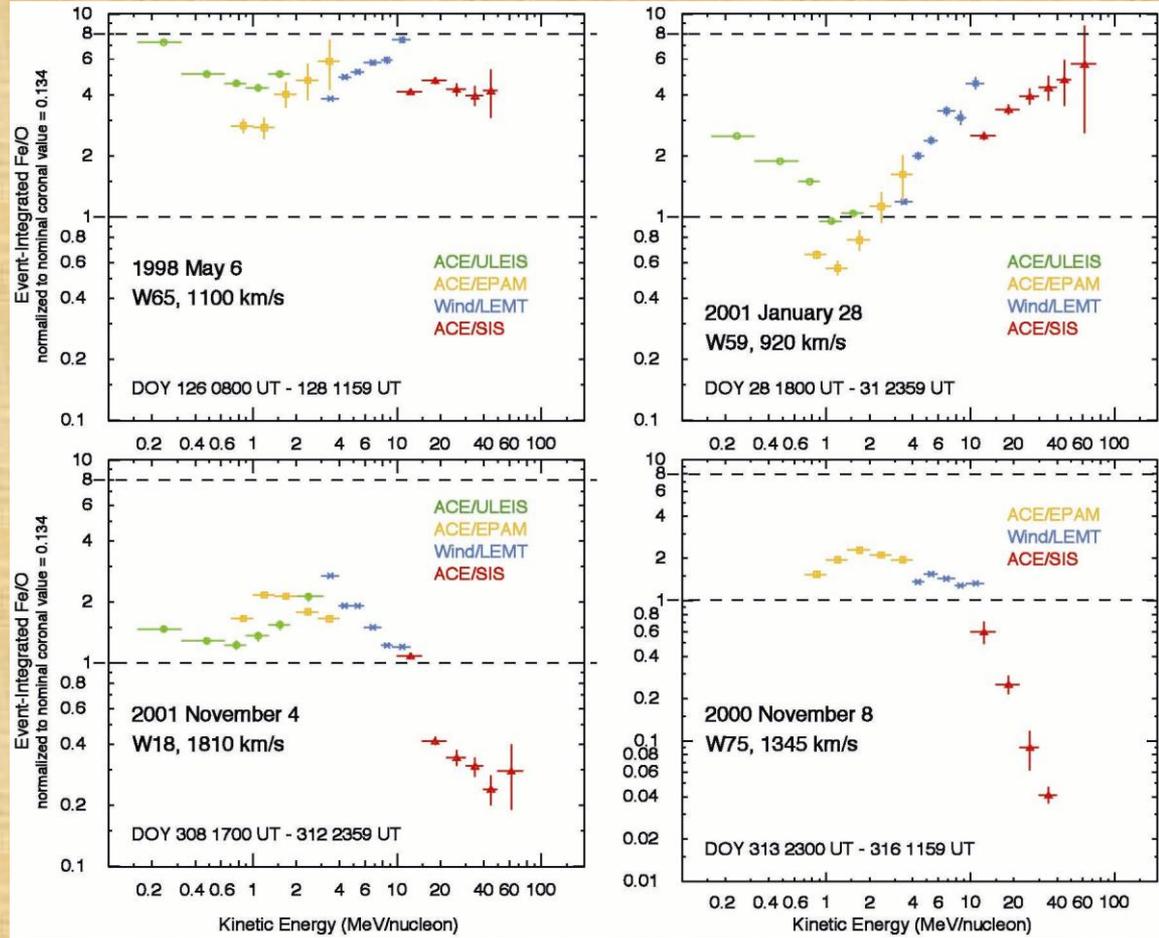
1. *The same types of extreme energy dependence in Fe/O are seen in both high-energy SEPs (accelerated near the Sun) and ESP events (accelerated by shocks near 1 AU, but at lower energies.)*
 - *Suggests (but does not prove) a common origin in shock physics.*
2. *SEP events with enhanced high-energy Fe/O are seen from a broad range of source longitudes.*
 - *Not like “classic” flare-associated impulsive events, with $^3\text{He}/^4\text{He} > 10\%$ at ~ 1 MeV/nuc*
3. *Enhanced Fe/O is anti-correlated with spectral steepening at high energies.*
 - *There are spectral as well as compositional differences to be explained.*
4. *For events with enhanced Fe/O at high energies, the average Fe/O value “plateaus” at $\sim 5x$ coronal.*
 - *This average is significantly below the impulsive average of $\sim 8x$ coronal.*

The "Zoo" of Fe/O vs. Energy

Modeling (Lee & Tylka)



Data



Modeling based on:

Variable shock geometry (quasi-perp & quasi-parallel)

Variable seed population (SW & flare suprathermals)

Posters on the 2002 Campaign Events

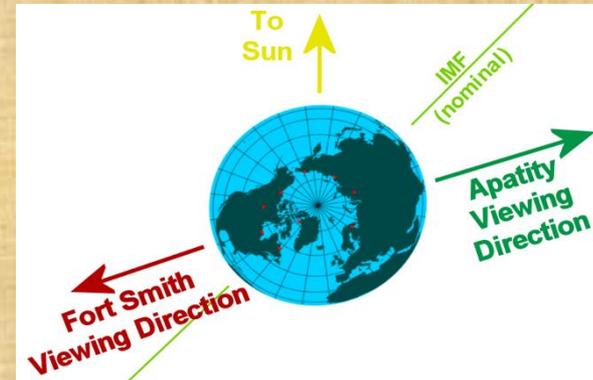
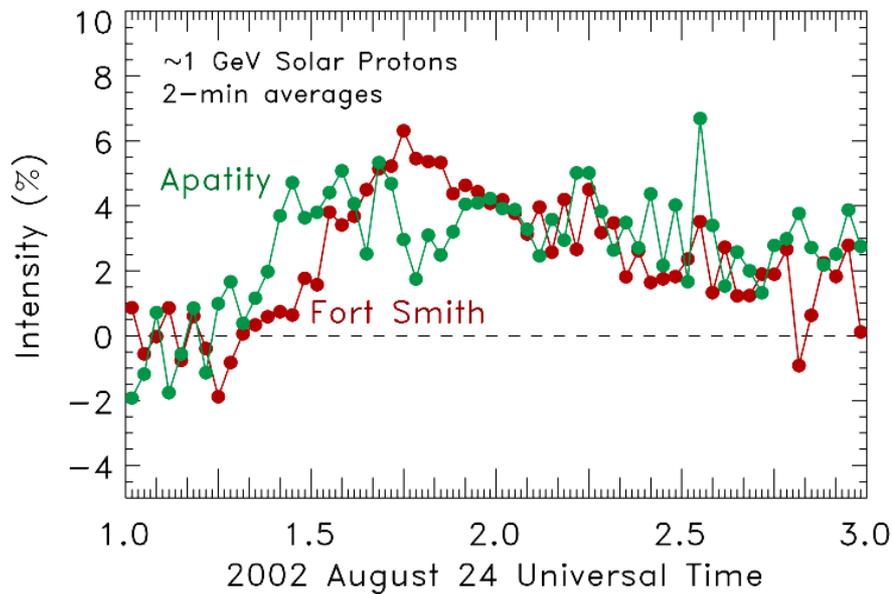
8. Alexander, David - SHINE SEP Campaign Events: Detailed Comparison of active regions AR9906 and AR0069 in the build-up to the SEP events of 21 Apr 2002 and 24 Aug 2002
9. Daou, Antoun G. - Transient activity in regions AR9906 and AR0069 in the build-up to the SEP events of 21 Apr 2002 and 24 AUG 2002
10. Liu, Rui - SHINE SEP Campaign Events: Global and Local Magnetic Field Evolution in Build-up to the SEP events of 21 Apr 2002 and 24 Aug 2002
11. Coyner, Aaron - SHINE SEP Campaign Events: Long-term development of solar corona in build-up to the SEP events of 21 Apr 2002 and 24 Aug 2002
12. Gopalswamy, Nat - Coronal and Interplanetary Shocks of 2002 April 21 and their Implication to the CME Onset Time
13. Cane, Hilary - The role of CMEs and their shocks in determining SEP abundances
14. Tylka, Allan et al. - Shock Geometry, Seed Populations, and the Origin of Variable Elemental Composition at High Energies in Large Gradual Solar Particle Events
15. Keller, Kristi - Validation of Heliosphere Models
16. Evenson, Paul - Spaceship Earth Observations of the 24 August 2002 Event

SPACESHIP EARTH *OBSERVATIONS OF THE 24 AUGUST 2002 EVENT (a SHINE campaign event)*

J. W. Bieber, P. Evenson, R. Pyle, D. Ruffolo, and T. Khumlumlert

Earliest onset is observed by Sunward viewing stations (e.g., Apatity) ...

... but at event maximum, the highest intensities are from the anti-Sunward hemisphere (e.g., Fort Smith).



We analyze data collected by the 11-station Space-ship Earth neutron monitor network to derive and model the evolution of the particle density and anisotropy in this event.

Timing Results (at Sun): Start of Production of GeV-protons: 01:08 \pm 2 min

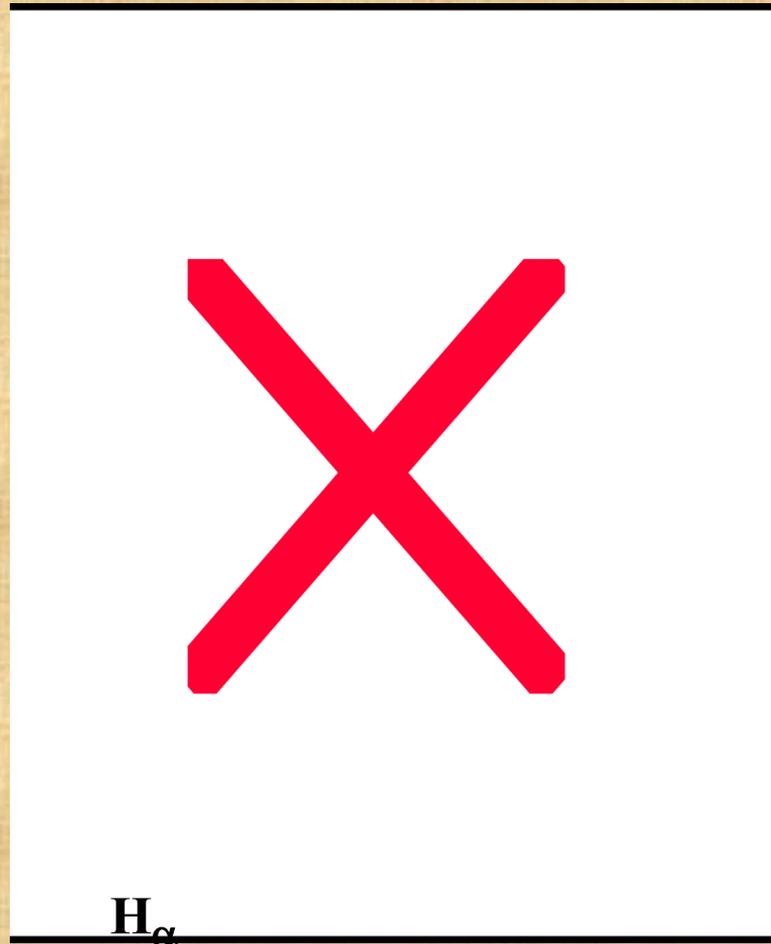
Estimated CME Location: 3.8 \pm 0.4 R_S

For comparison: H α : Start 00:47; Peak 00:55; End 01:15

SEP COMPOSITION INDICATES TWO COMPONENTS²⁰

FLARE (Fe/O>1) AND **CME-SHOCK** (Fe/O<1)

Event-averaged Fe/O (relative to corona)



Contributions of the two components vary with energy from event to event and observing location. Plot shows >10 MeV/nuc values for 45 events.

- No in situ shock at 1 AU
- Shock – no particle effect at 1 AU
- Particle effect at shock passage

..... **April 21 2002:**
strong shock component

..... **August 24 2002:**
impulsive flare component dominant