

Attempting to

Explaining the Acceleration and Transport of Solar Energetic Particles

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Caltech

And still trying....

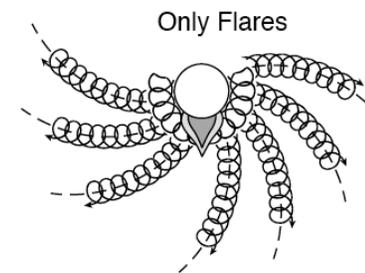
What are SEPs?

- First discovered - Forbush 1946 from ground based ion counters
- Assumed to be related to observed solar flares
- Kahler et al. (late 1970s and early 1980s) found strong correlation to CMEs
- Cane et al. (1986) made association with 2 types of X-ray events

Generation of Classes of SEPs

Two Groups =>	Impulsive Flare acceleration	Gradual Shock acceleration
$^3\text{He}/^4\text{He}$	~ 1	~ 0.0005
Fe/O	~ 1	~ 0.1
Q_{Fe}	~ 20	~ 14
Duration	Hours	Days
X-rays	Impulsive	Gradual
Coronagraph	--	CME (96%)

Old Picture:



New Picture:

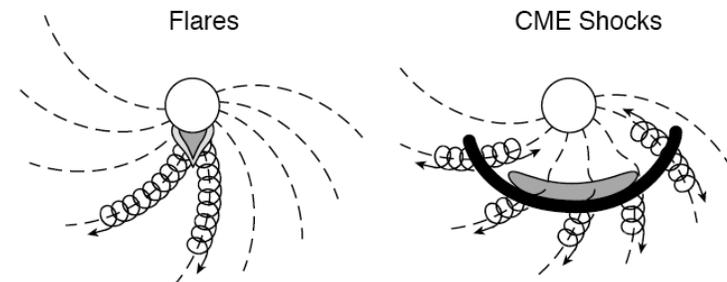


Figure 2.1. A paradigm shift.

Examples (Reames 1999)

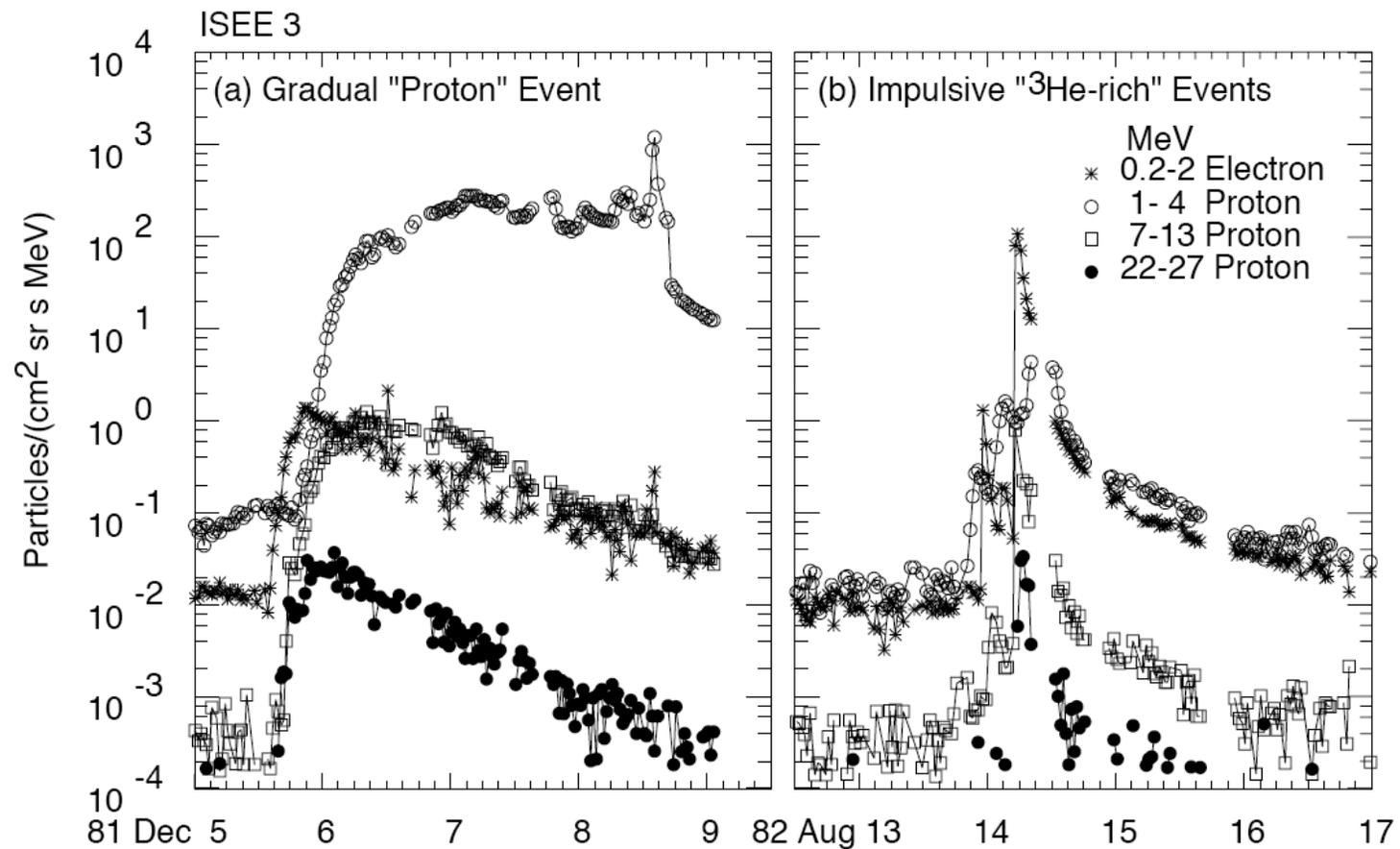
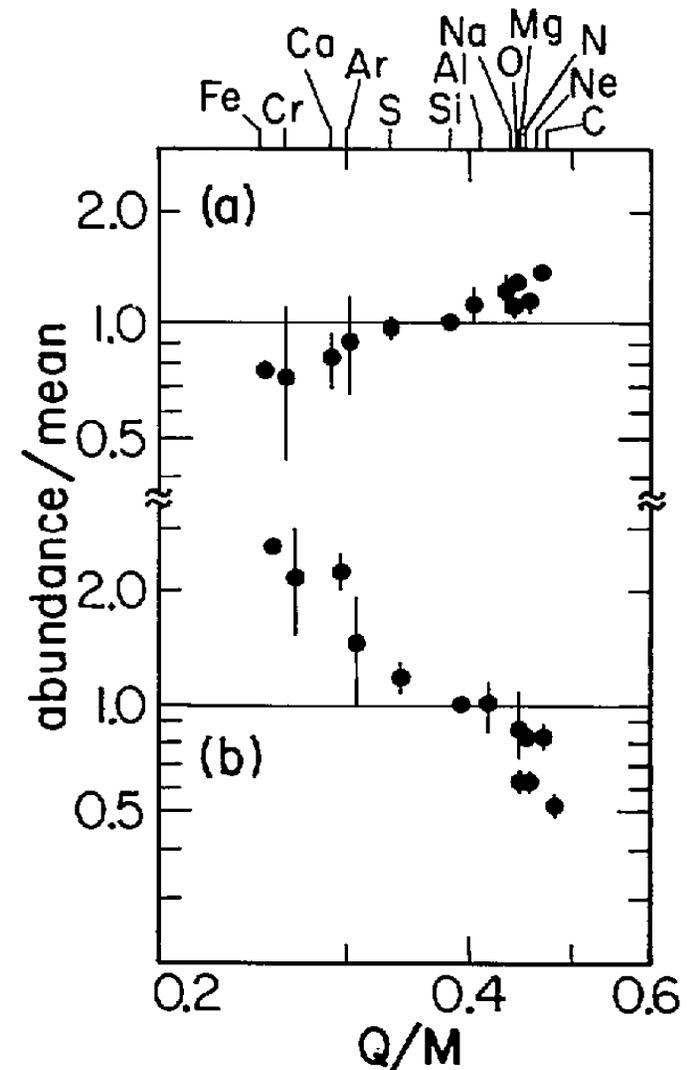


Figure 2.2. Intensity-time profiles of electrons and protons in 'pure' (a) gradual and (b) impulsive SEP events. The gradual event is a disappearing-filament event with a CME but no impulsive flare. The impulsive events come from a series of flares with no CMEs.

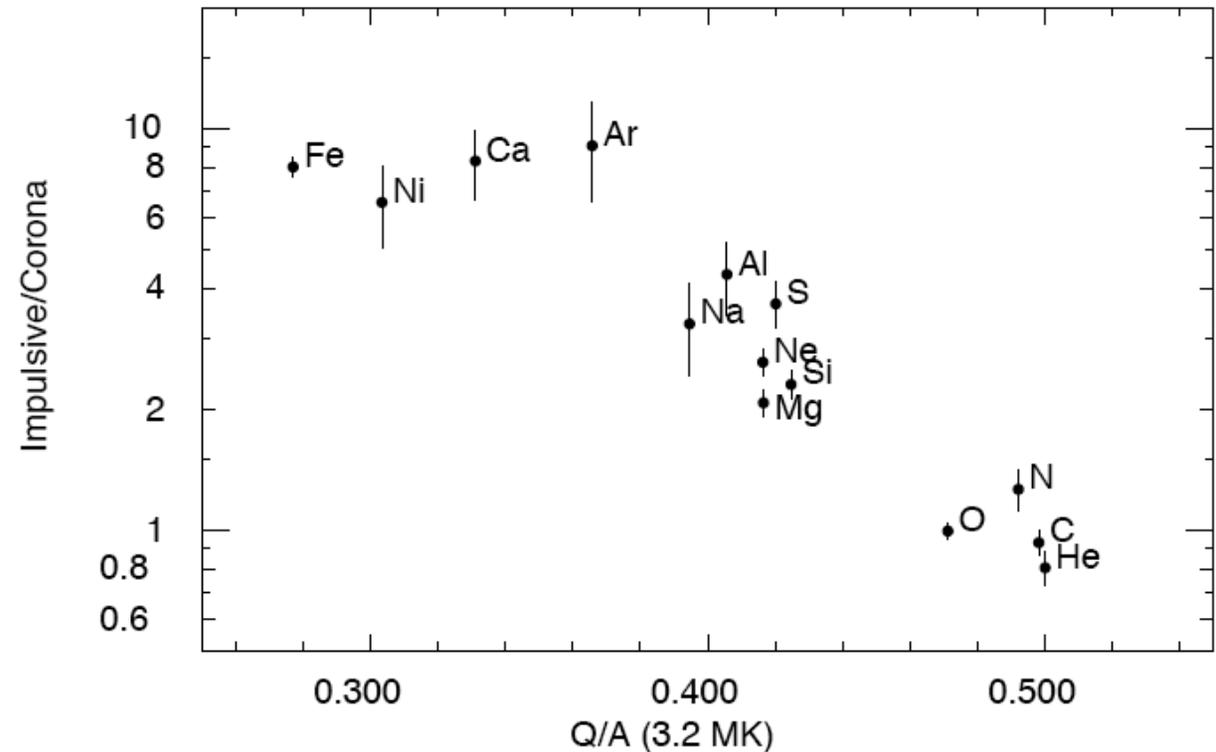
Composition

- Variability within large events
- Q/M organized, suggesting rigidity effects
- Reames believed that effect averaged out over many events (some doubts now)

Breneman and Stone 1985



Composition

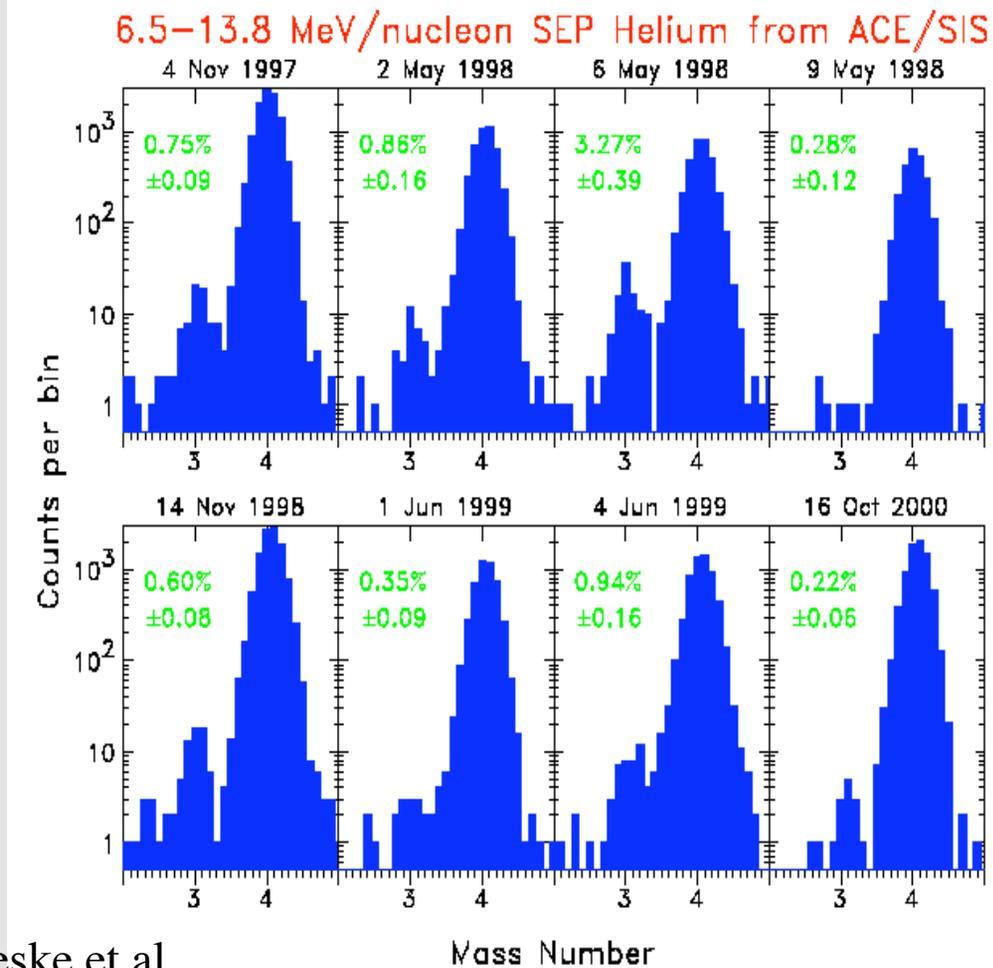


- Impulsive events showed a systematic fractionation
- Related to Q/M at Sun
- Q determined from models...assuming equilibrium

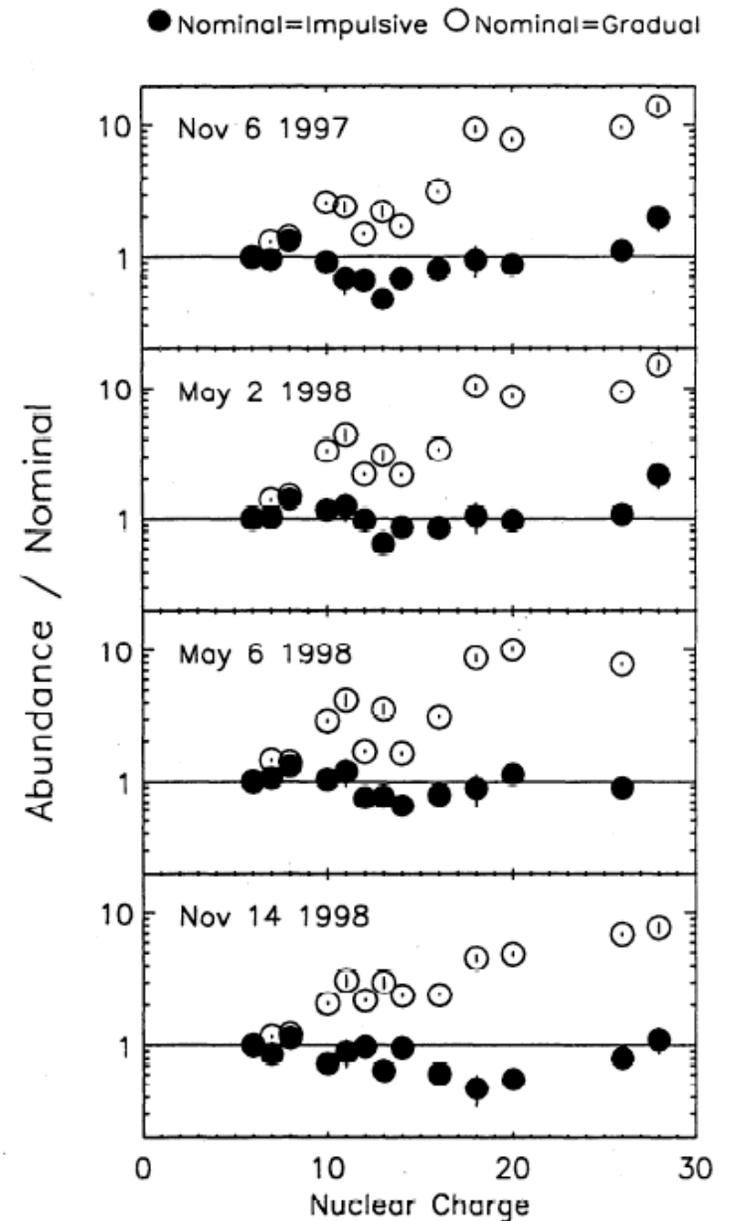
Now the Complications...

- ACE launched August 1997
- 2 new highly sensitive SEP (heavy ion) instruments => ULEIS + SIS
- November 1997 SEP events
 - mixture of impulsive and gradual characteristics
 - CME, days long, fairly large, gradual x-ray
 - impulsive heavy ion composition

SIS composition



Leske et al.

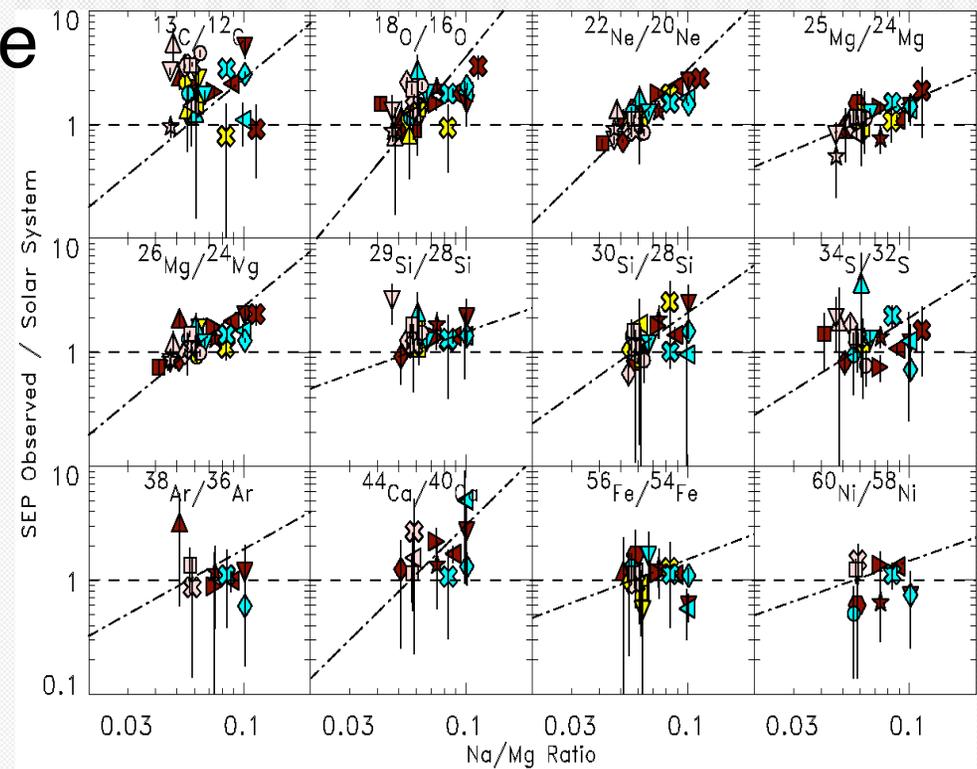


Cohen et al. 1999

Q/M Fractionation?

- Maybe this is the same effect B&S saw

Leske et al.

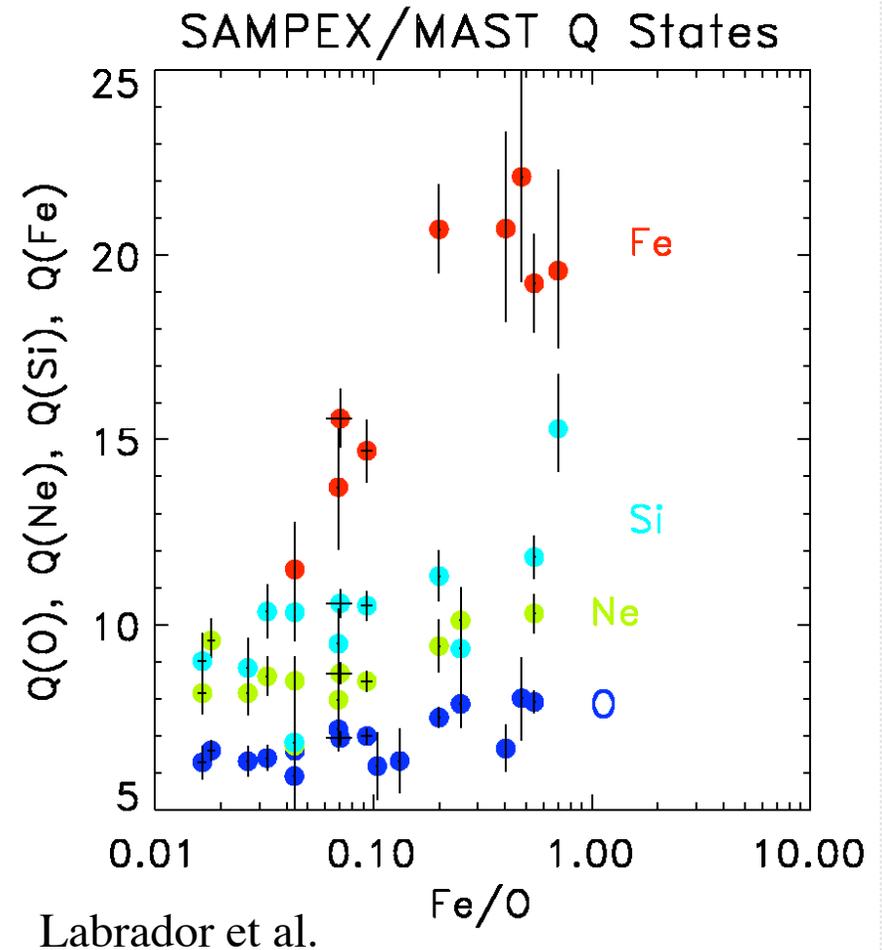


ACE/SIS SEP events starting (mm/dd/yy):



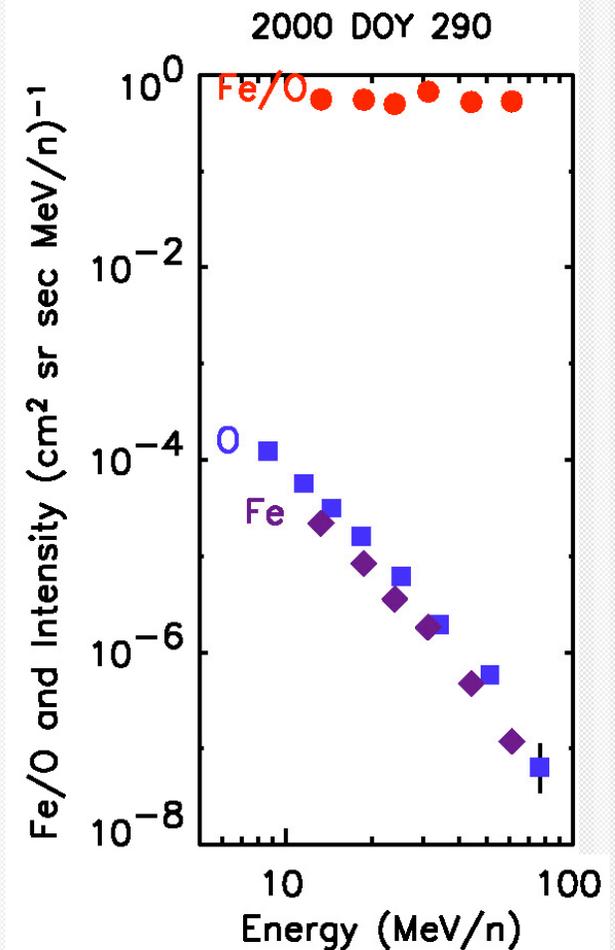
Q/M Fractionation?

- Maybe this is the same effect B&S saw
- But then Fe/O shouldn't be correlated with Q_{Fe}
- Plus ^3He enhancement is also unexpected



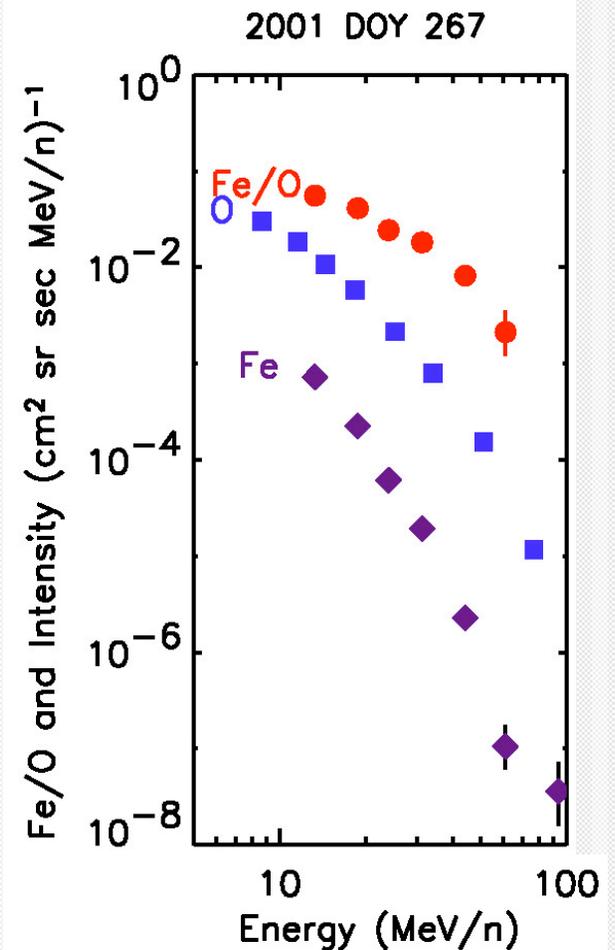
More Complications (acceleration)

- Shock theory says composition should be constant



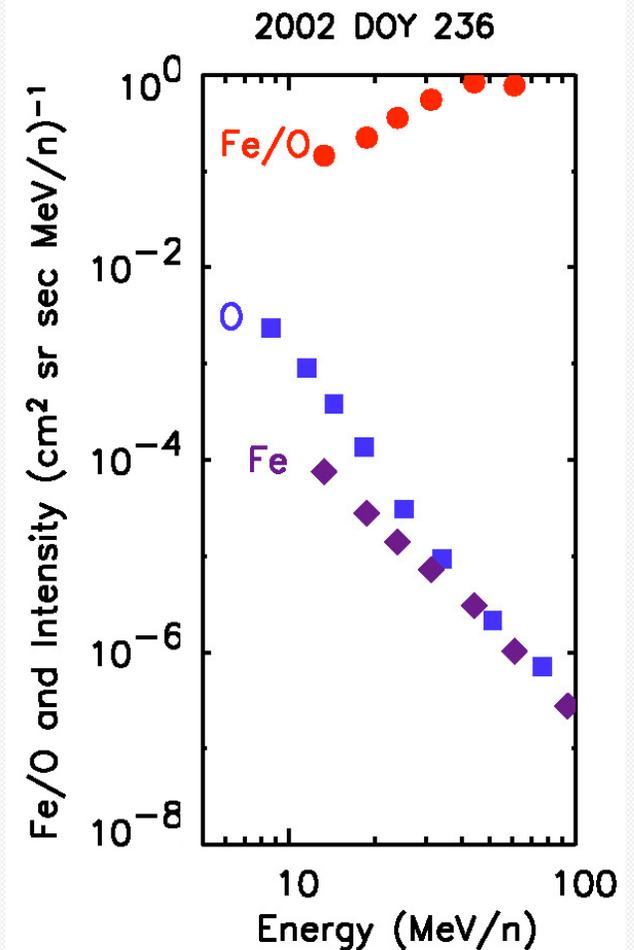
More Complications (acceleration)

- Shock theory says composition should be constant
- Composition is energy dependent
- No problem, Ellison and Ramaty (1985) suggested rigidity-based escape



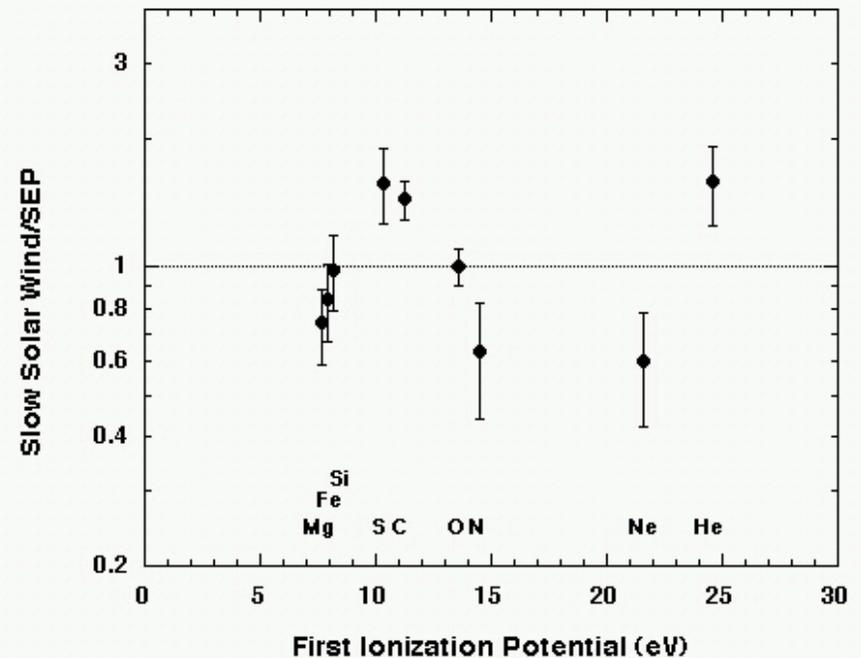
More Complications (acceleration)

- Shock theory says composition should be constant
- Composition is energy dependent
- No problem, Ellison and Ramaty (1985) suggested rigidity-based escape
- But, how to make Fe/O increase with E???



More Complications (seed pop.)

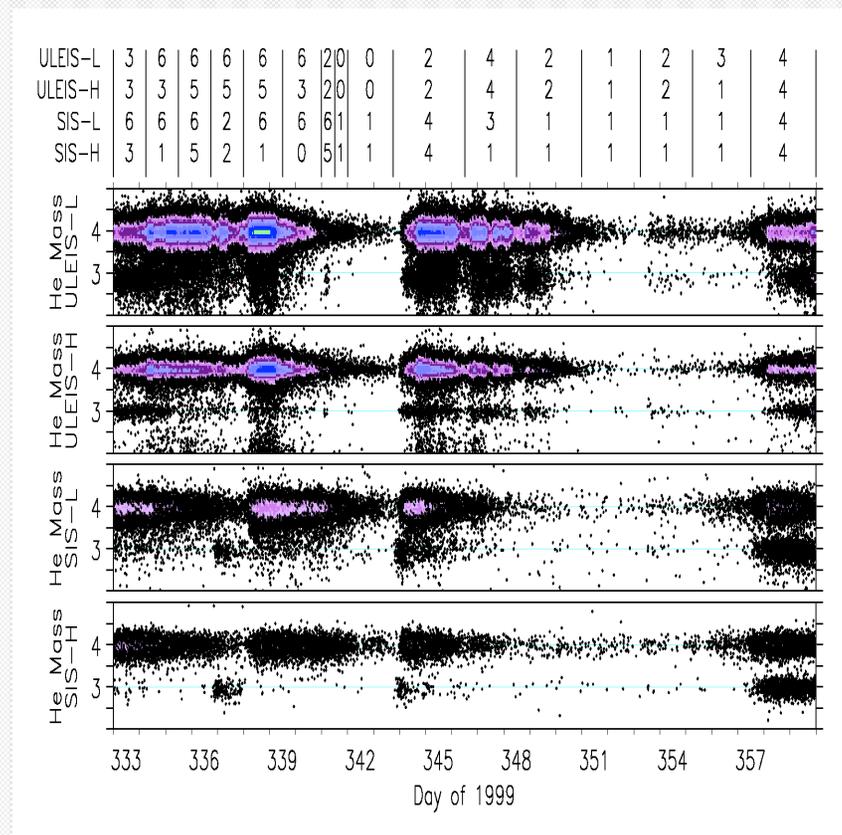
- SEP composition always taken to be same as solar wind (coronal)
- But is it?



Mewaldt et al. 2000

More Complications (seed pop.)

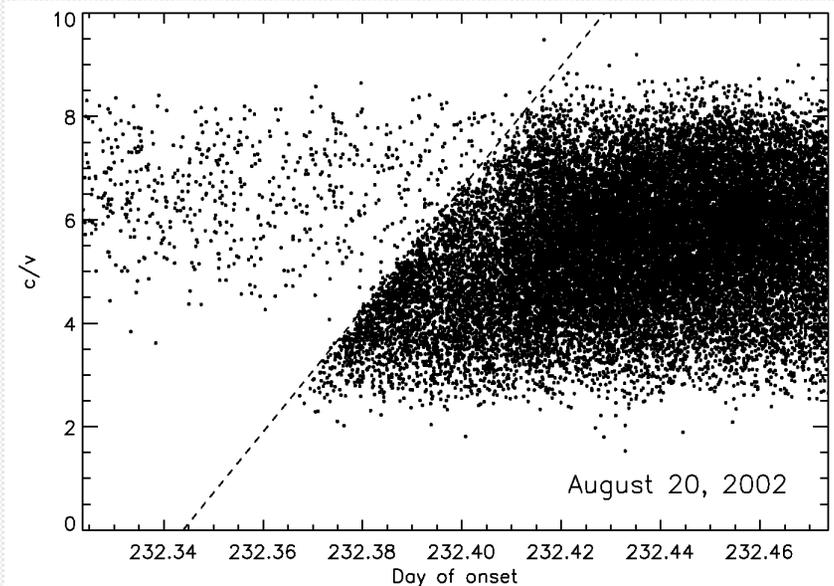
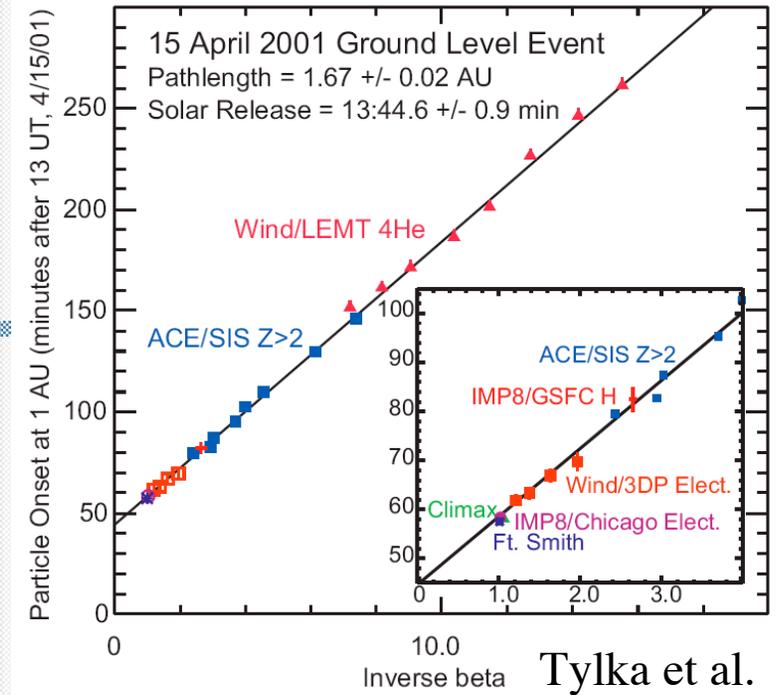
- SEP composition always taken to be same as solar wind (coronal)
- But is it?
- And what about all that ^3He ?



Wiedenbeck et al.

More Complications

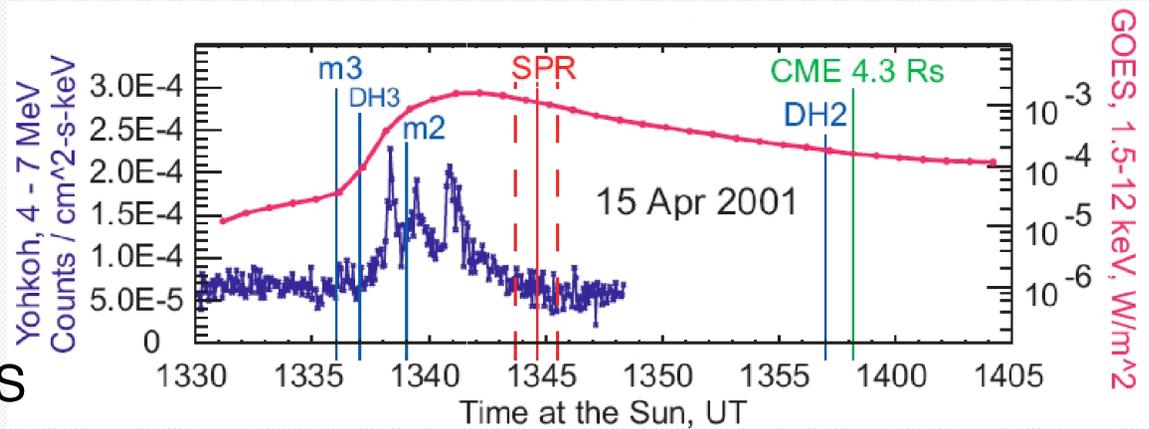
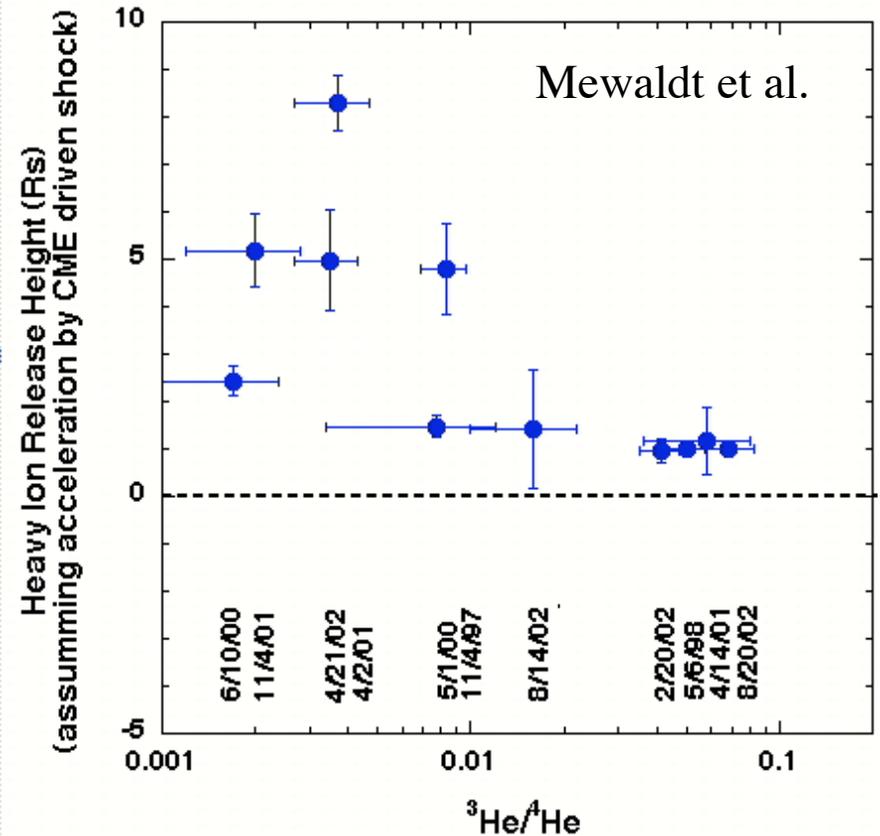
- Timing studies
 - velocity of particles
 - observed time
 - path length (assumed)
=> Injection Time
- Compared to
 - Radio emission
 - CME position



More Complications

- Timing studies
 - velocity of particles
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- Compared to
 - Radio emission
 - CME position
- Shocks at $<10 R_S$
- Maybe flares?

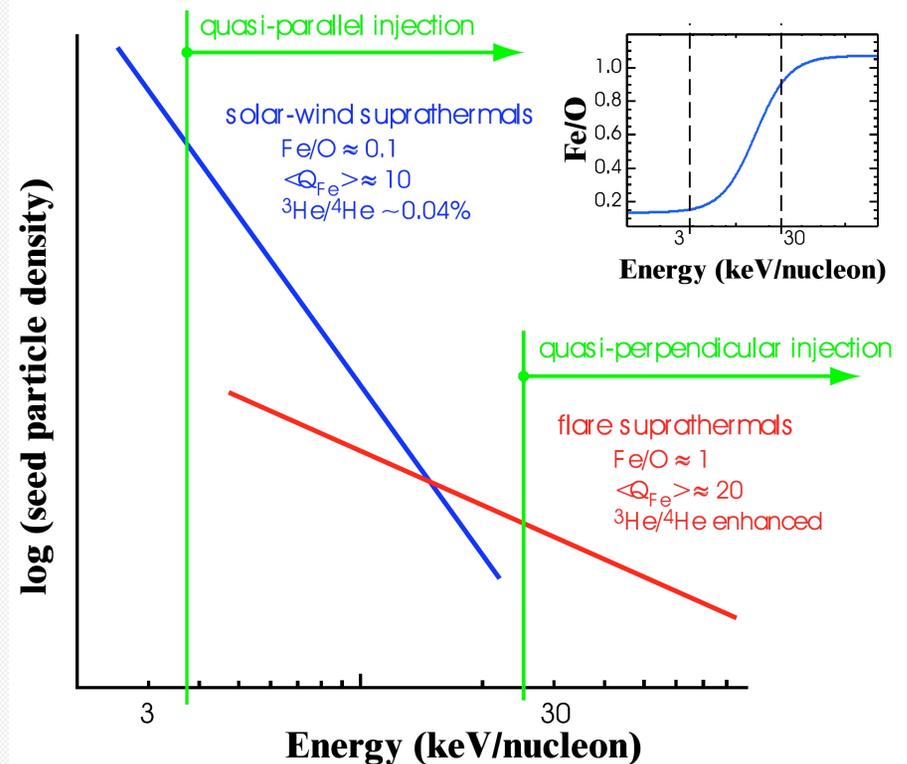


(back to) The Big Questions

- What is (are) the acceleration mechanism(s)?
 - Shocks?
 - Flares?
- What is being accelerated?
 - Coronal / Solar Wind material?
 - Flare material?
- How does transport affect the composition / spectra?

Don't Give Up on Shocks!

- Remnant flare seed population
- Perpendicular shocks vs parallel shocks



Tylka et al. 2005

Shock Acceleration interlude

Decker 1988

- Parallel shocks - Fermi acceleration
 - bouncing back and forth across shock
 - takes many passes
- Perpendicular shocks - drift acceleration
 - local E field accelerates along shock front
 - very fast, not many passes required

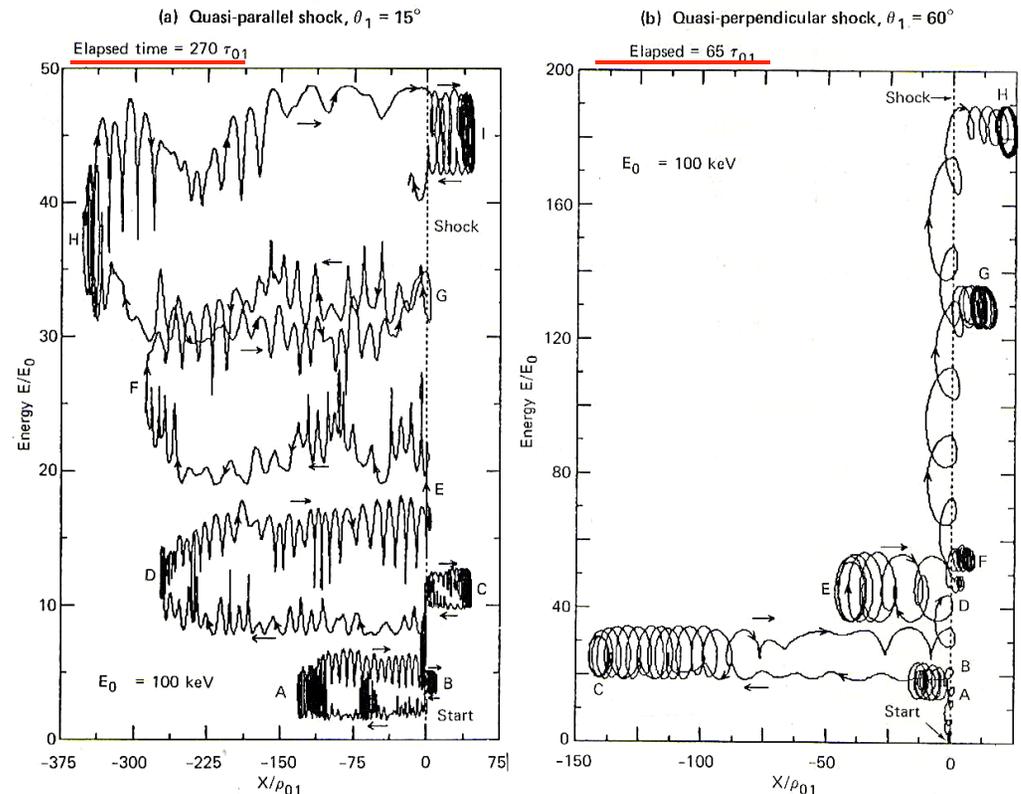


Fig. 19. (a) Sample particle orbit showing multiple shock encounters at a quasi-parallel ($\theta_1 = 15^\circ$) shock. Shown in the energy E/E_0 ($E_0 = 100$ keV) versus particle's x -coordinate in shock frame K (ρ_{01} = upstream gyroradius at injection). Elapsed time is 270 upstream gyroperiods, τ_{01} . (b) Sample particle orbit at a quasi-perpendicular ($\theta_1 = 60^\circ$) shock. Elapsed time is $65\tau_{01}$ (adapted from Decker and Vlahos, 1986a).

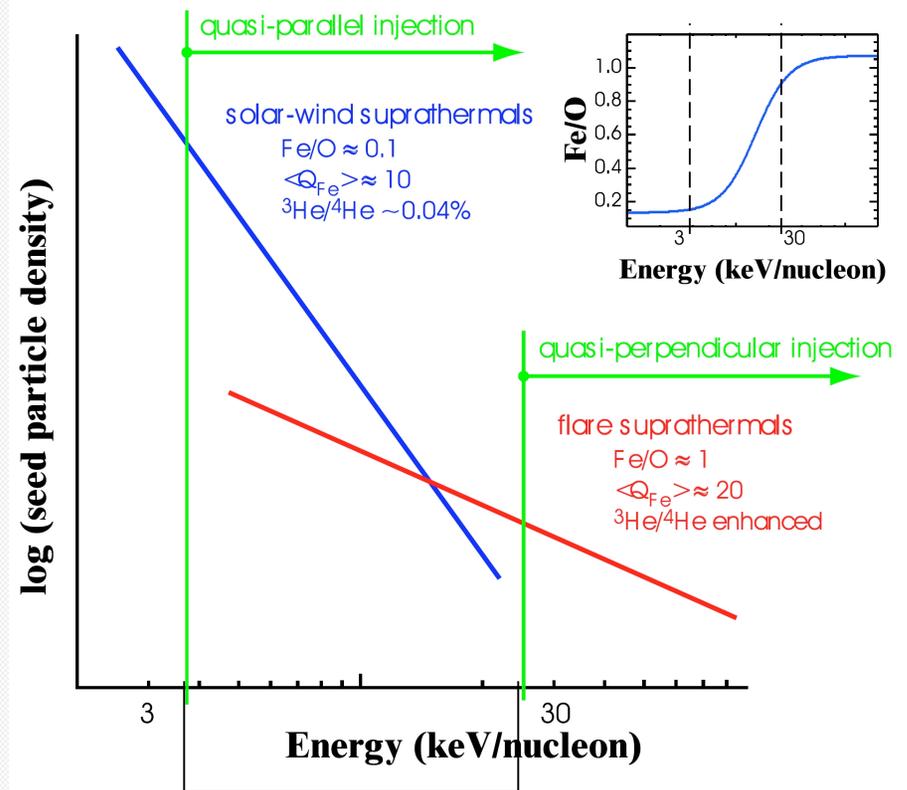
parallel

perpendicular

Don't Give Up on Shocks!

Tylka et al. 2005

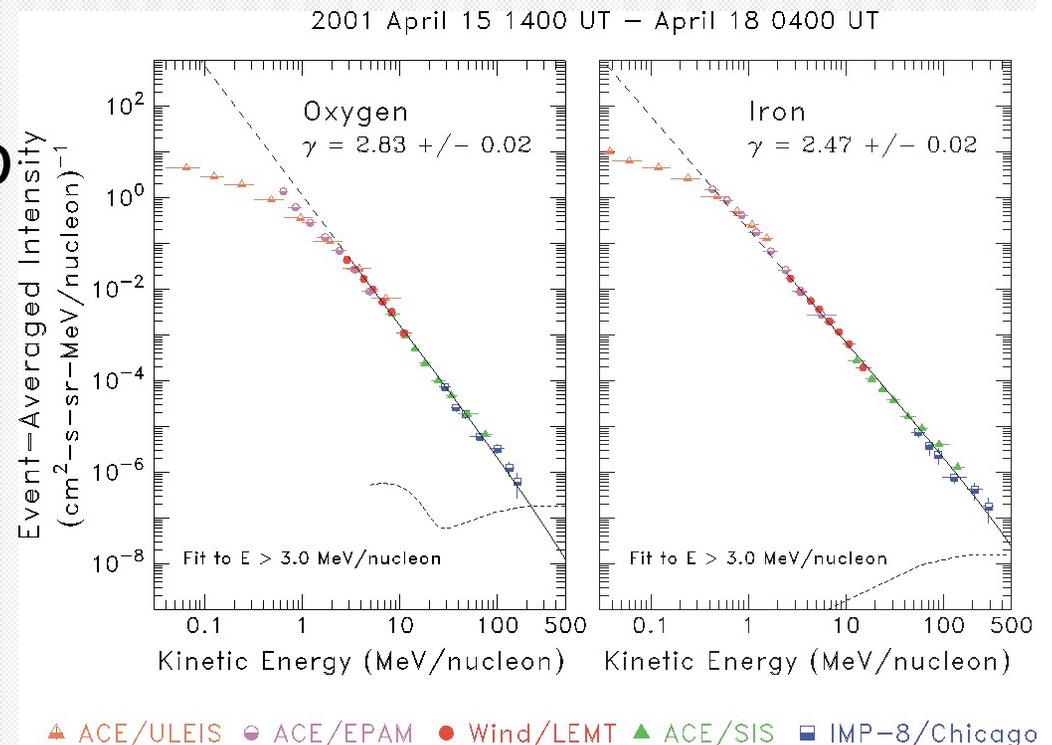
- Remnant flare seed population
- Perpendicular shocks vs parallel shocks



but is this true??

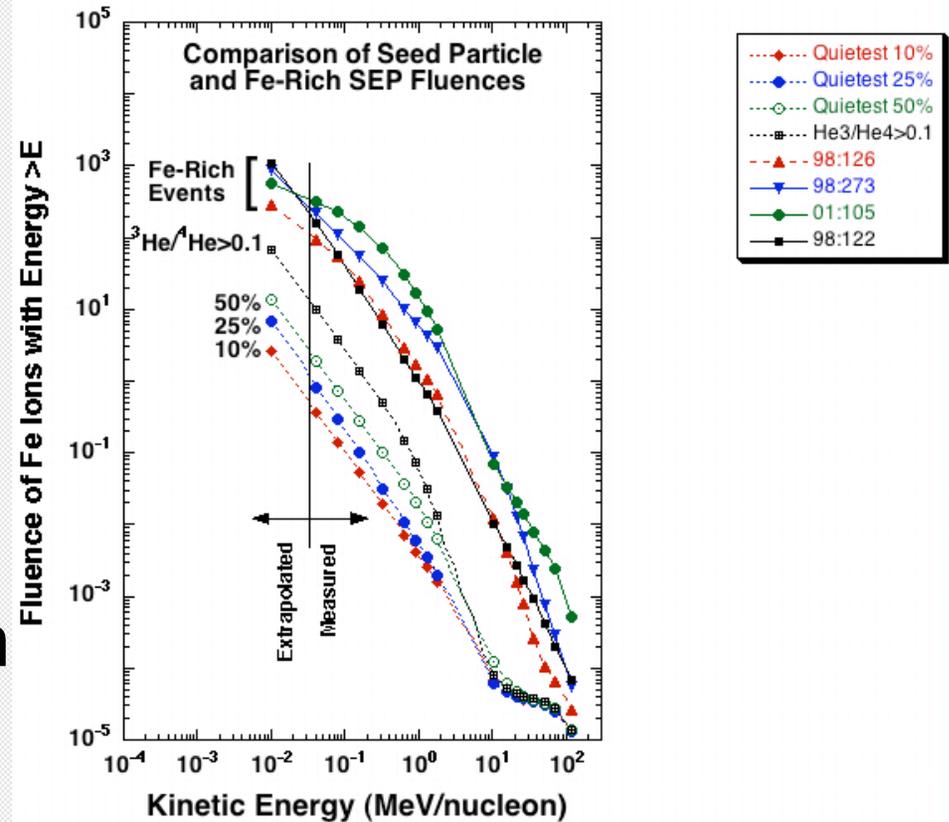
Don't Give Up on Shocks!

- Remnant flare seed population
- Perpendicular shocks vs parallel shocks
- But how do they do this??



Don't Give Up on Shocks!

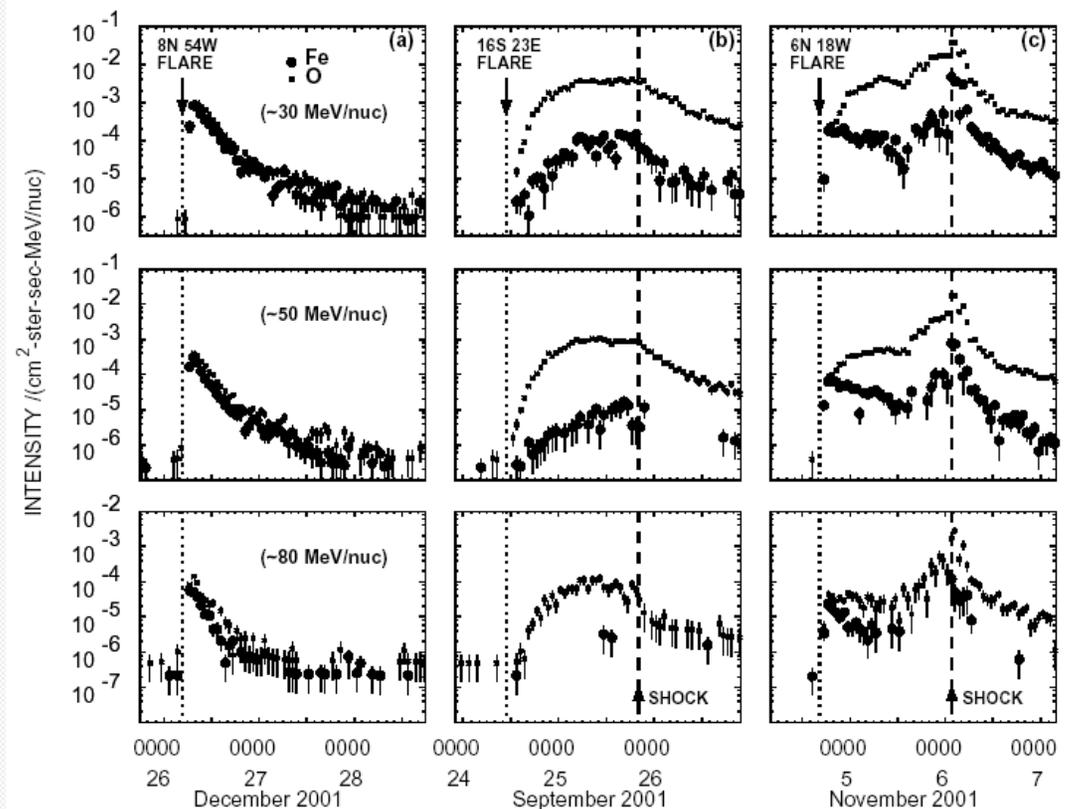
- Remnant flare seed population
- Perpendicular shocks vs parallel shocks
- But how do they do this??
- And are there enough flare remnants?



Mewaldt et al.

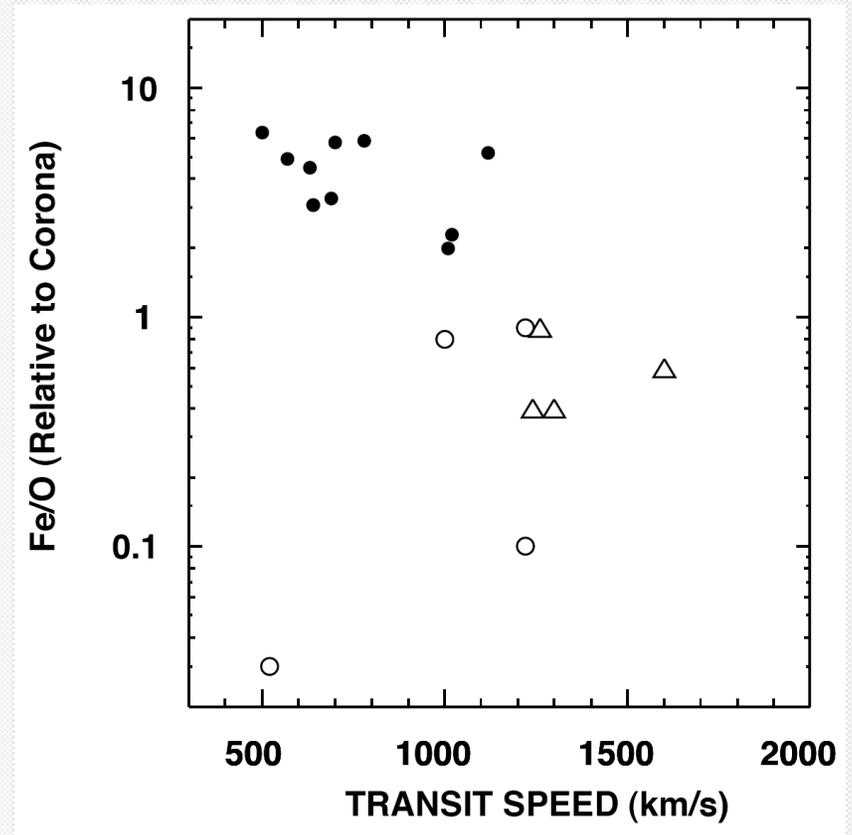
What About Flares?

- Know flares accelerate particles
- Maybe seeing the flare contribution directly



What About Flares?

- Know flares accelerate particles
- Maybe seeing the flare contribution directly
- For strong shocks the flare component gets overwhelmed



What is the flare acceleration mechanism??

Cane et al. 2003

The Big Debate

How to get 'flare' material in big SEP events?

Shock acceleration of flare suprathermals

- Pros
 - Shocks will accelerate anything
 - Shock theory is advanced
- Cons
 - Don't know characteristics of shocks close to Sun
 - Don't know characteristics of suprathermals
 - Don't know if shocks can form that close to Sun

Direct flare contribution

- Pros
 - Know flares accelerate particles
 - Simple
- Cons
 - Flare acceleration mechanism is not well known - hard to test with observations
 - Don't know how variability created

What is SHINE doing?

- Acceleration
 - IP shock modeling and observations
 - WG2+3 Tues AM
 - WG2+3 Tues PM
 - End to end modeling (CMEs to shocks to SEPs = the whole enchilada)
 - WG1+2+3 Thur AM (mostly status)
 - WG1+2+3 Thur PM

What is SHINE doing?

- Acceleration (more)
 - Near the Sun (flares mostly)  most open field
 - WG3 Wed AM
 - Radio signatures
 - WG1+3 Thur AM (conflicts with end-to-end modeling part 1)
- Seed population
 - Suprathermal sources
 - WG3 Mon PM

What is SHINE doing?

- Transport

- Outer Heliosphere observations

- WG3 Thur PM (conflicts with end-to-end modeling part 2)

(not just SEPs, but also solar wind and magnetic structures)

Last Advice

- Listen to the Plenary Talks
 - most are given by excellent speakers
 - most are given as a overview/introduction to one of the working groups
- Don't be shy
 - most speakers are happy to discuss things afterwards (SHINE is better than most)
 - you won't be the only one 'lost' is a detailed question-answer exchange