RAPPORTEUR PAPER

Sun and Corona

+

Transient Phenomena in the Heliosphere

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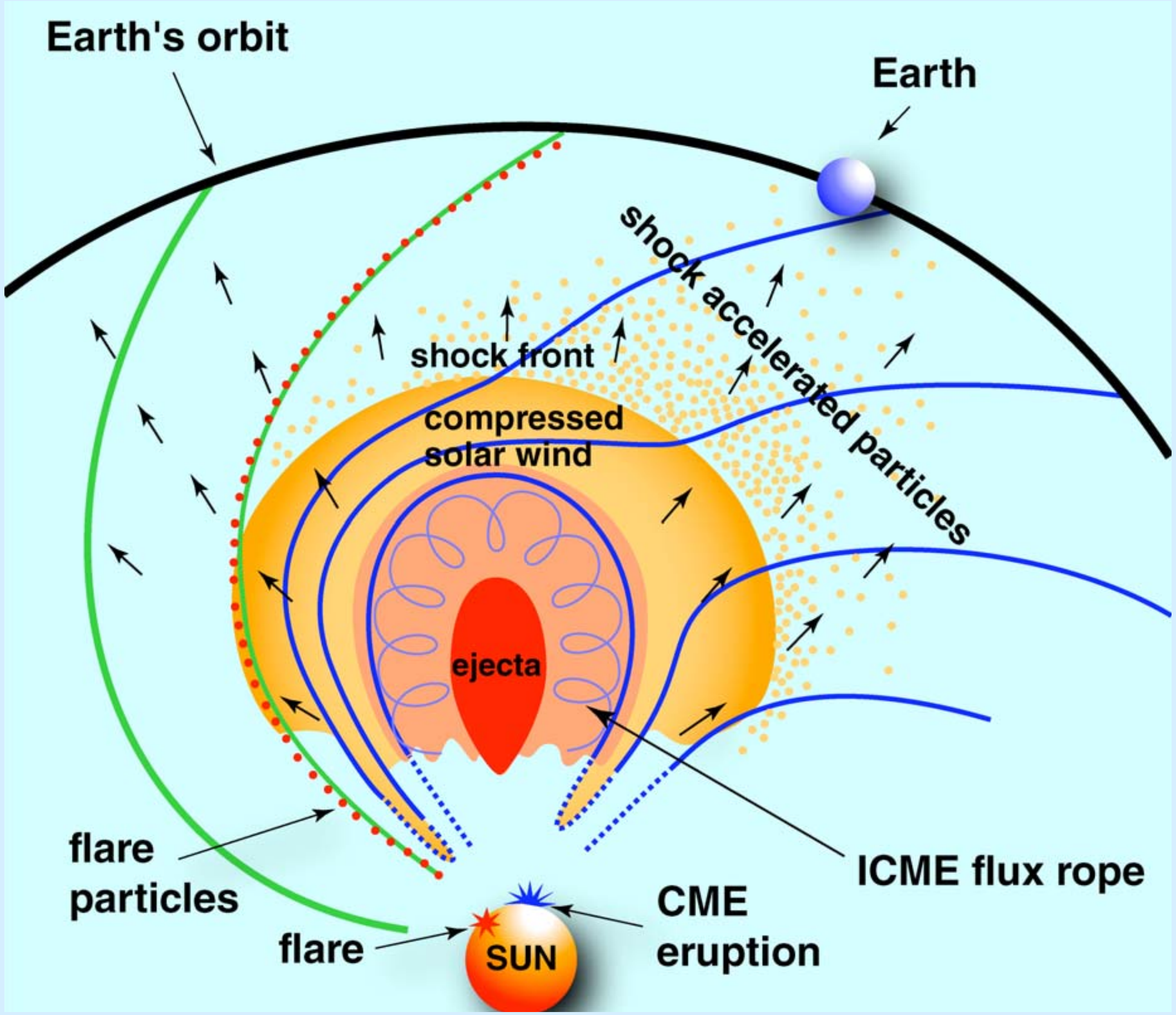
Sessions SH 1.2 - SH 1.7 + SH 2.1 - 2.4

SESSION SUMMARY

Session	Topics	Oral	Poster	Total
Sun and Corona				
SH 1.2	Energetic photons and electrons	4	2	6
SH 1.3	Solar neutrons	3	6	9
SH 1.4	Energetic charged particle spectra, composition and charge states	10	3	13
SH 1.5	Particle acceleration on / near the Sun	3	1	4
SH 1.6	Interplanetray Transport of SEPs	8	9	17
SH 1.7	Coronal Mass Ejections	2	6	8
Total		30	27	57
Transient Phenomena in the Heliosphere				
SH 2.1	Forbush decreases/Effects of coronal mass ejections	13	10	23
SH 2.2	Corotating regions/shocks	1	3	4
SH 2.3	Propagating interaction regions/shocks	2	5	7
SH 2.4	Merged interaction regions	0	1	1
Total		16	19	35

INTRODUCTION

SUN AND CORONA + TRANSIENT EFFECTS IN THE HELIOSPHERE



SUN AND CORONA

Flares: γ, n, e, ions

CMEs

IP Shocks

Particle Transport

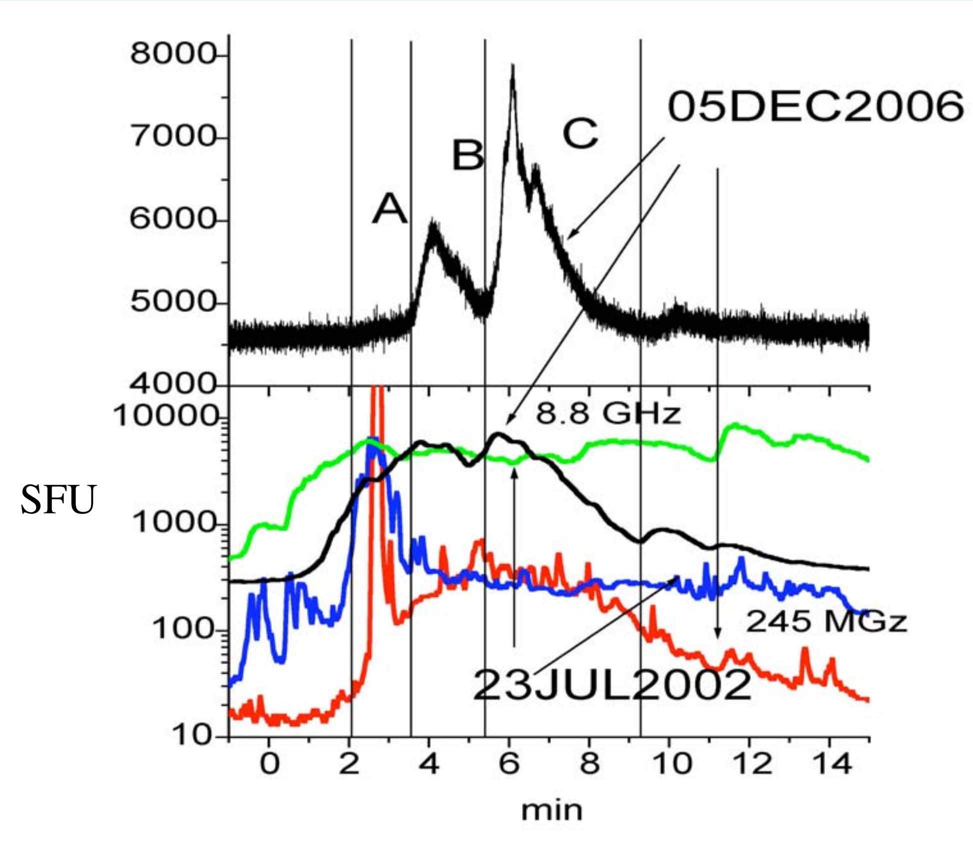
CIRs

Forbush Decrease

ENERGETIC PHOTONS AND ELECTRONS

ACS / SPI / Integral
Hard X-rays

SFU



Struminski & Zimovets, SH 1.2 - 188

SH 1.2

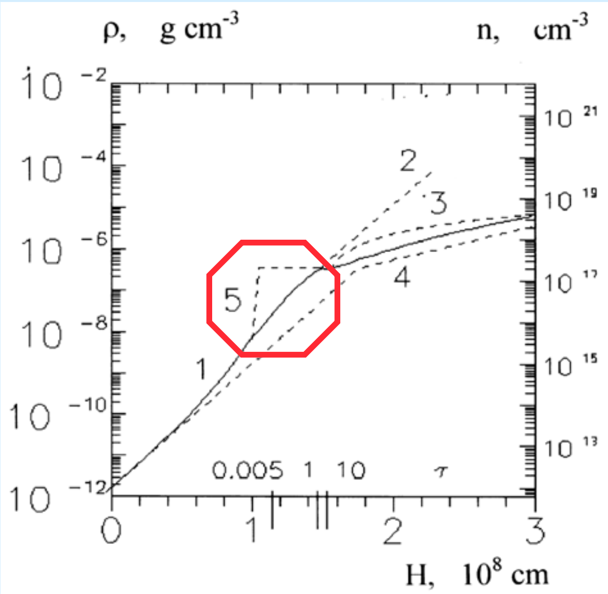
- **Hard x-ray (> 150 keV) from ACS/SPI Integral**
- **Coronas-F: γ-rays (0.1-20 MeV)**

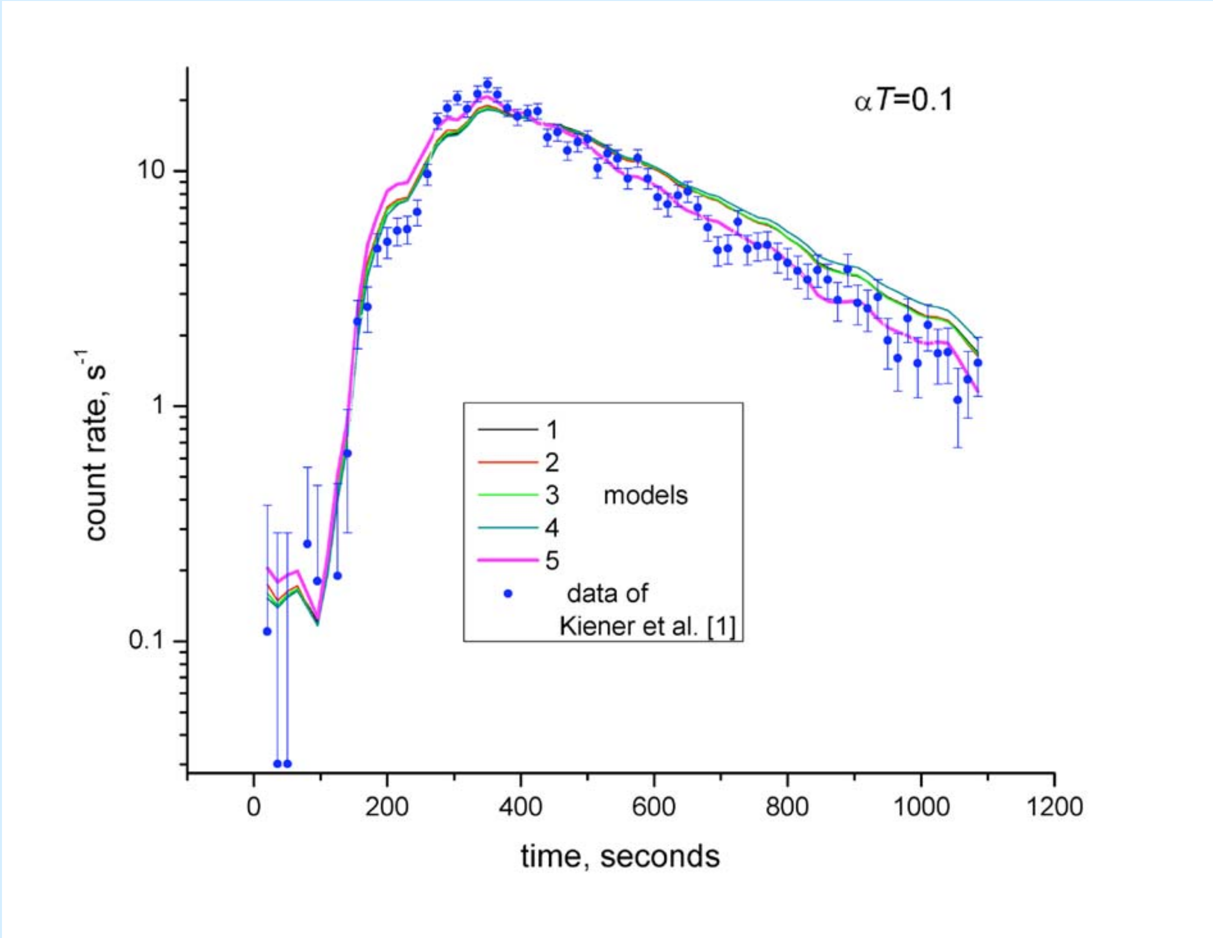
Study of several large flares

- **Zero Time - 8.8 GHz Radio Emission**
- **Hard X-ray emission in Phase B and C**
- **245 MHz shows peak in Phase A**
- **Effective p acceleration in Phase C**

(similar in other events, e.g. Sept 7, 2005)

ENERGETIC PHOTONS AND ELECTRONS

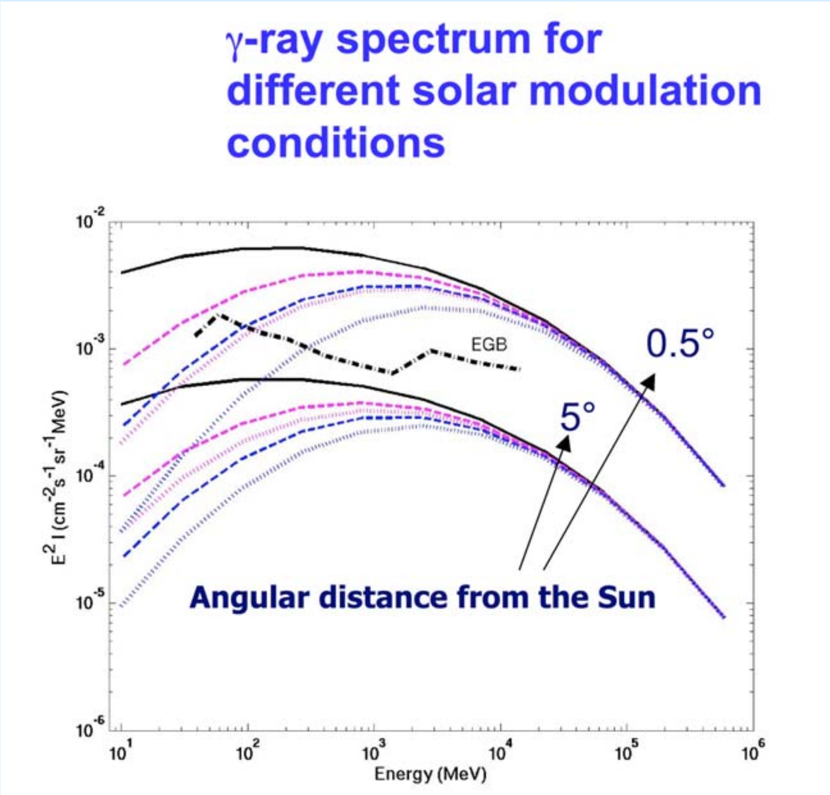




Modelling time profiles of
2.223 MeV γ-emission
Variables:
Density profile in photosphere
αT (Stochastic acceleration)
Best Fit: Model 5, i. e. enhanced density

SH 1.2 - 951 (Trottskaja & Miroshnichenko)

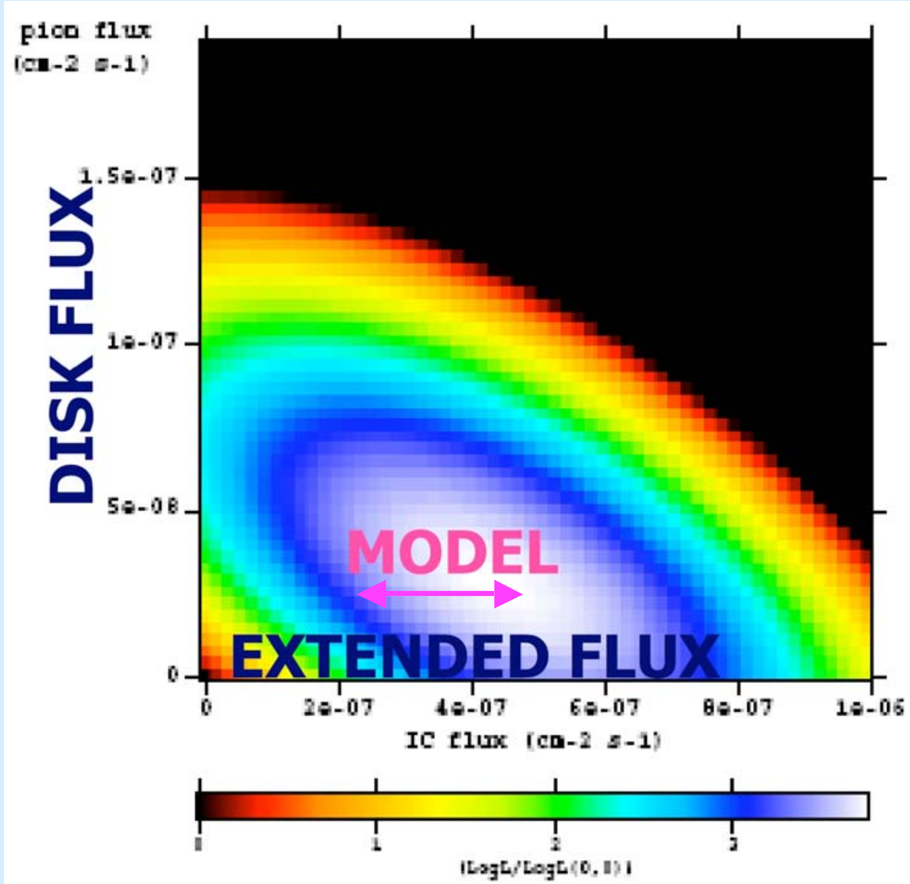
PHOTONS FROM INVERSE COMPTON EMISSION AT THE SUN



Modelling IC Flux with modulated GCR spectrum and the photon field of the Sun

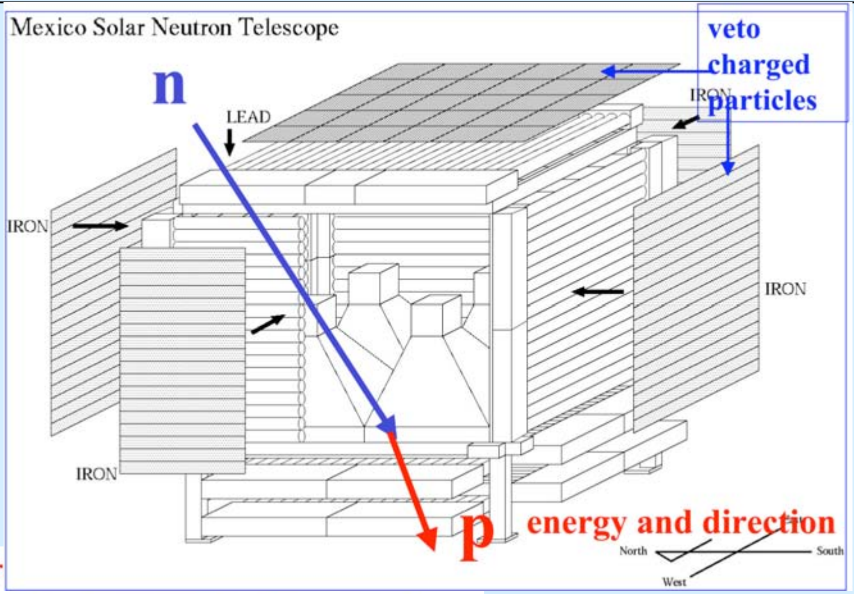
SH 1.2 - 600 (Orlando et al.)

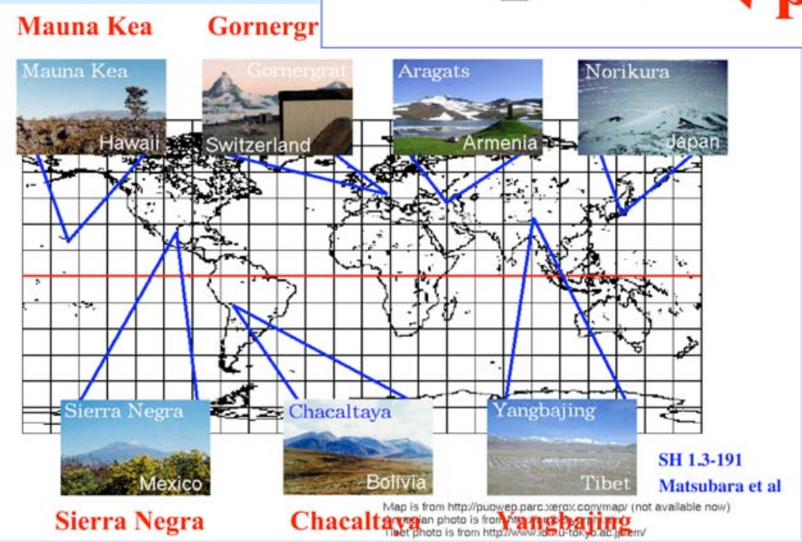
IC Flux from EGRET



With high sensitivity GLAST Measurements:
Infer electron spectrum in the inner heliosphere

SOLAR NEUTRONS -1





- High Energy Solar Neutrons provide information on the acceleration process at the Sun
- Time and duration of n production is directly related to the acceleration time of ions
- Energy of n is related to acceleration process
- Observation with NM, SNT and instruments on S/C
- SNTs provide energy and directional information
- Neutron propagation is not influenced by the magnetic field

SH 1.2 - 191 (Matsubara et al)

SOLR NEUTRON TELESCOPE STATIONS (SNT)

SOLAR NEUTRONS - 2

Neutron observations with NM and SNT and S/C observations:

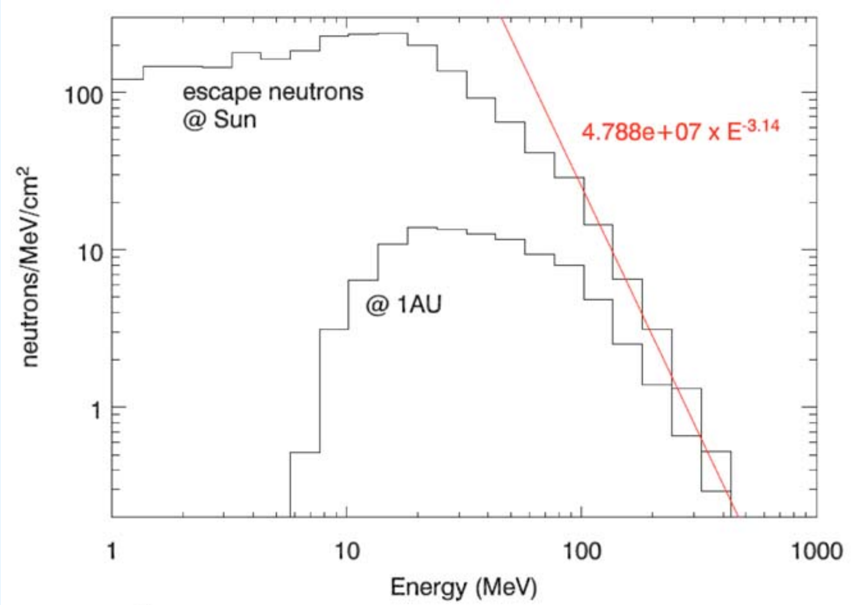
• Systematic search for solar neutrons in X-class flares during 2005 - 2006 SH 1.3-191; Matsubara et al.,

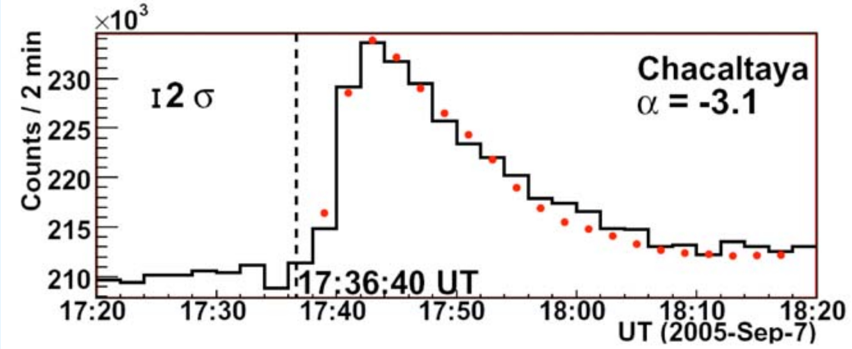
Result: Only September 7, 2005 event showed neutron signal

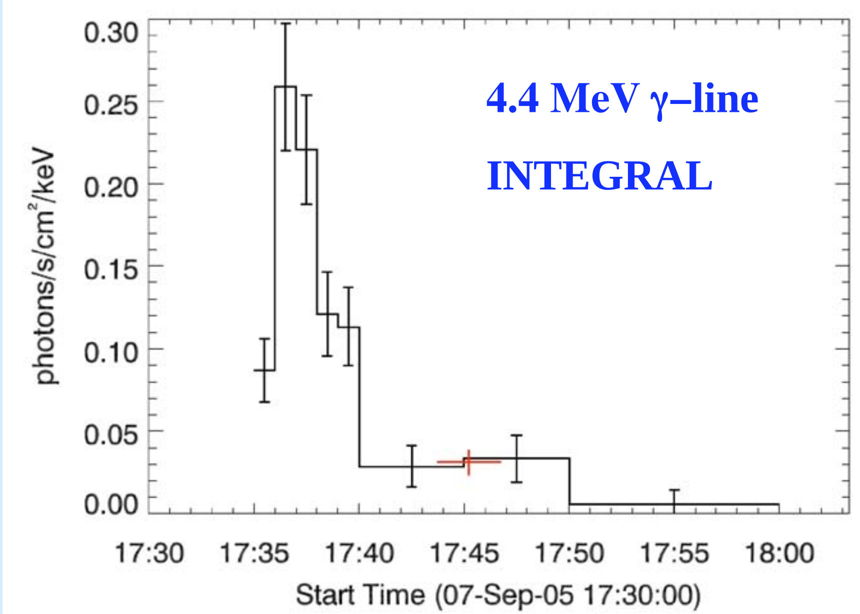
September 7, 2005 event investigated by several authors:

Neutron Time Profile and Spectra, September 7, 2005	SH 1.3-0374; Watanabe et al.
Neutron Spectrum derived from SNT(using SNT E-ch)	SH 1.3-0912; Sako et al.,
Neutron spectrum from SNT (using timing+response)	SH 1.3-1225; Gonzalez et al
October 28, 2003: Neutron Time Profile	SH 1.3-0371; Watanabe et al.
April 15, 2001: Neutrons and Protons in the event	SH 1.3-099; Muraki et al.

SOLAR NEUTRONS - 3
September 7, 2005 Flare







Fit of long lasting time profile using Hua's Loop Model, assuming injection time profile from 4.4 MeV γ-line

λ= 5000 (scattering parameter)

δ= 0.20 (convergence parameter)

s = -3.6 (p spectral index)

L = 38,600 km (from RHESSI and GOES/SXI)

SH 1.3-374 (Watanabe et al.)

SOLAR NEUTRONS - 4

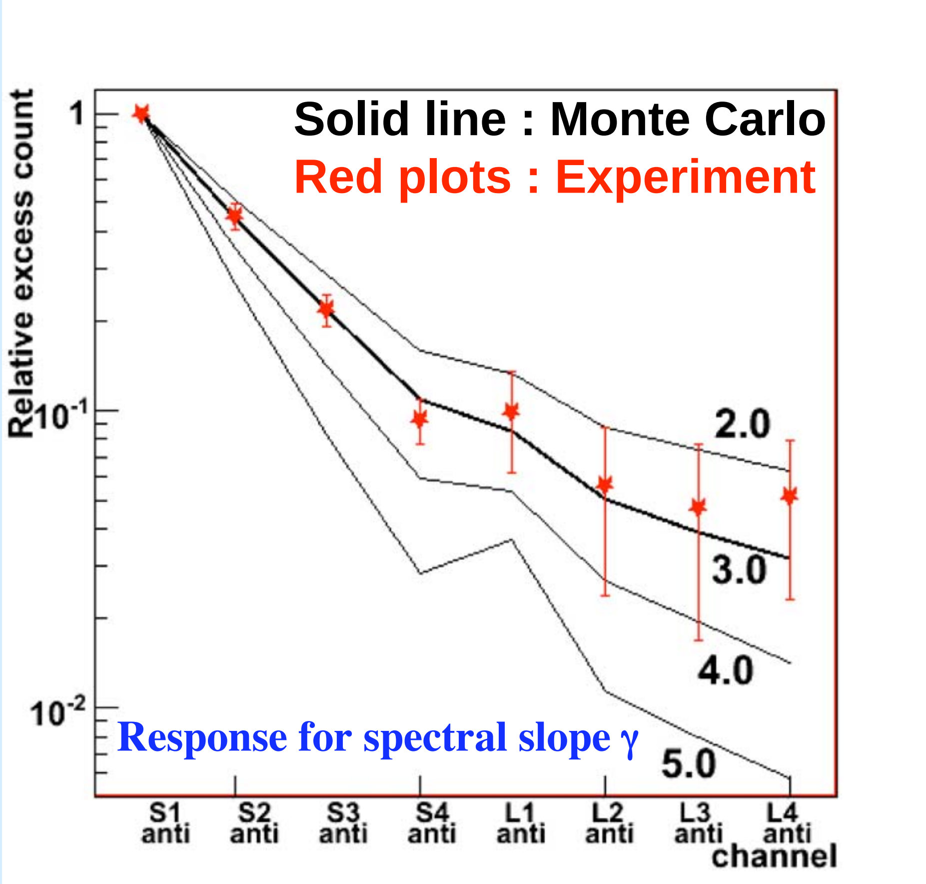
NEUTRON ENERGY SPECTRA

Independent approach to infer Energy Spectrum of Neutrons:

Monte Carlo Simulation, using:
- Decay during propagation to Earth
- Attenuation in atmosphere
- Energy response of several channels of the SNT

Neutron Injection Spectrum ~$E^{-3.0}$

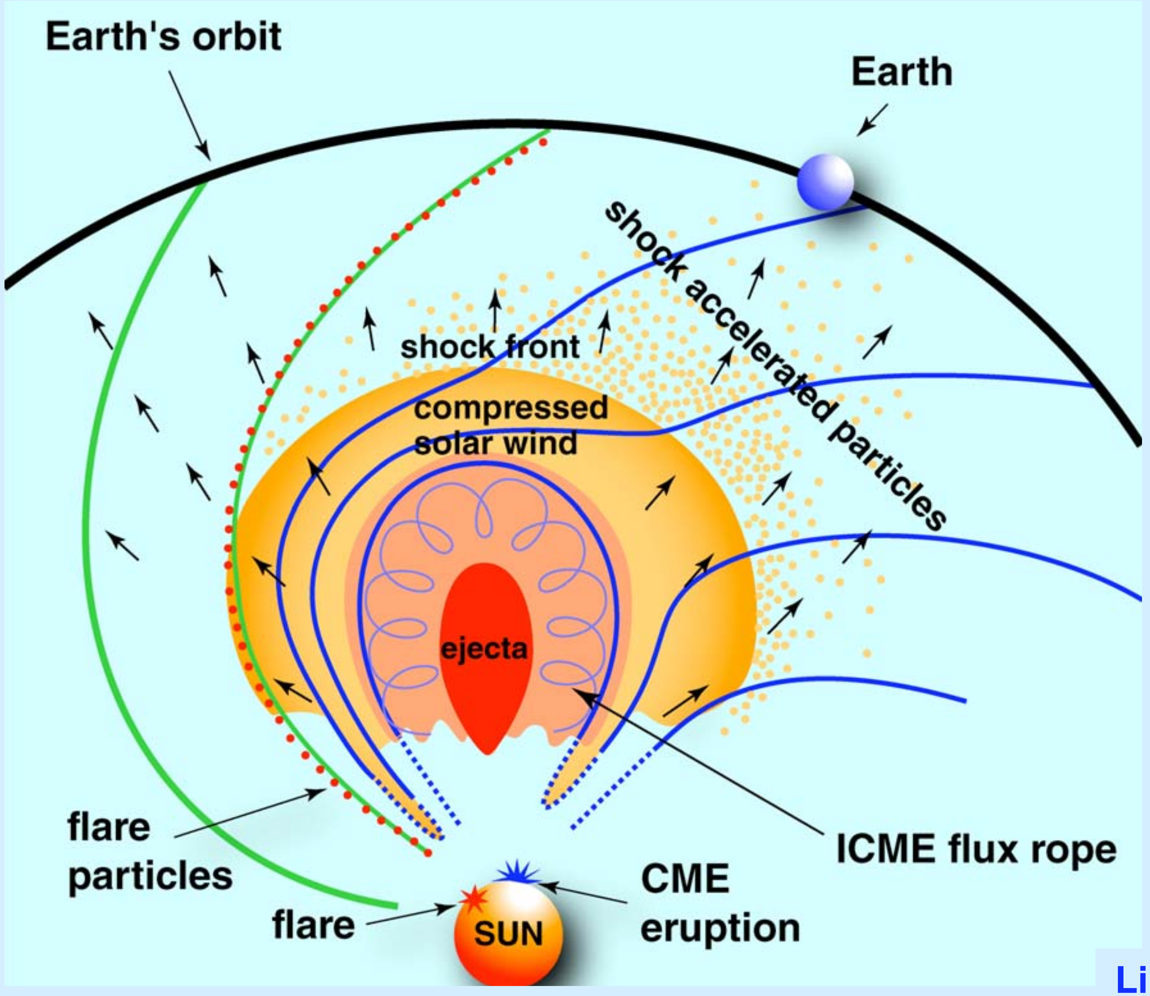
SH 1.3 - 912 (Sako et al.)



September 7, 2005 Event (Mexico SNT)

ENERGETIC CHARGED PARTICLES

Spectra, Composition, and Charge States



IMPULSIVE EVENTS

Acceleration related to Flare Process

"Flare Particles"

GRADUAL EVENTS

Acceleration related to Coronal / Interplanetary Shock

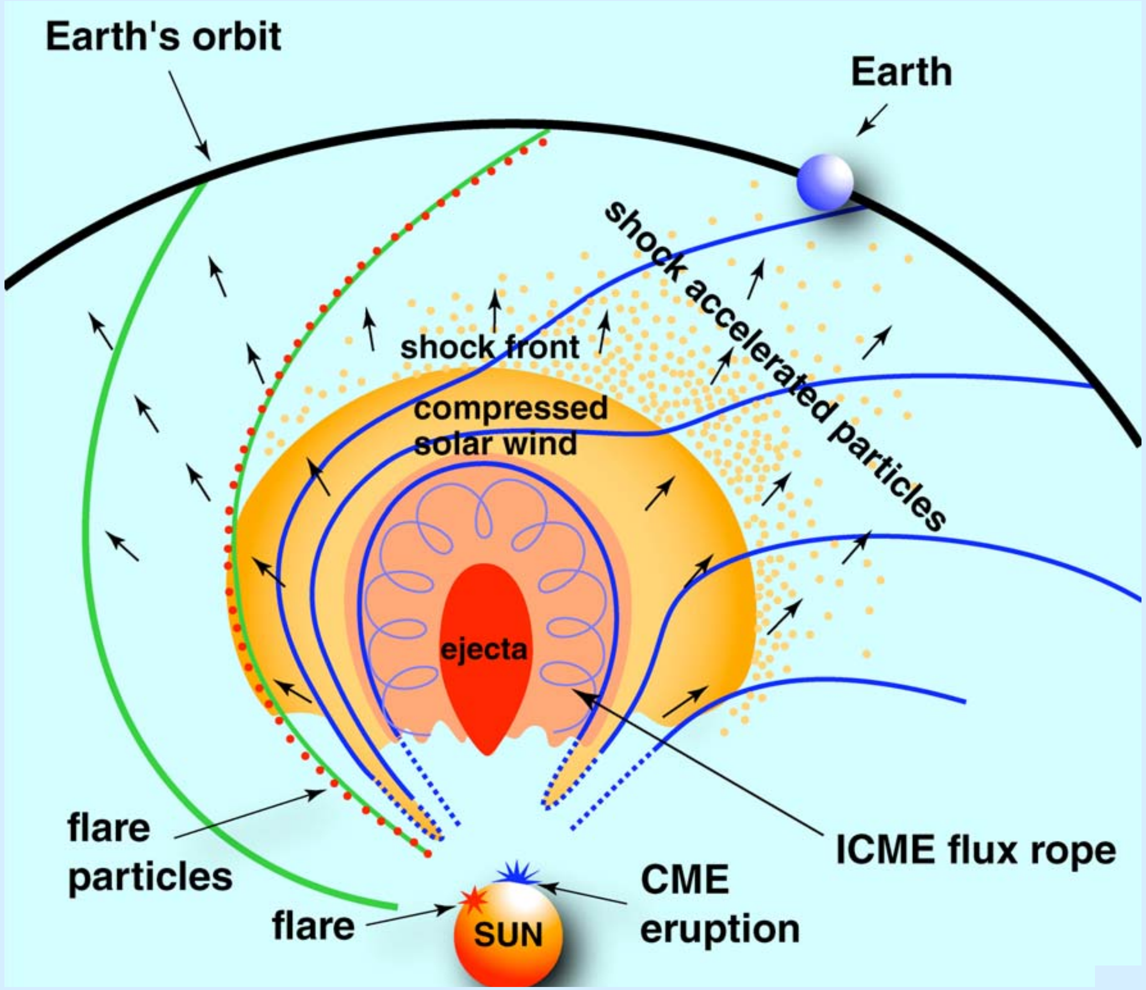
"Shock accelerated Particles"

	^{3}He-rich	gradual
particles	electron rich	proton rich
^{3}He/ ^{4}He	~ 1	~ 0.0005 (Solar Wind)
[Fe/O]/[Fe/O]$_{cor}$	~ 10	~ 1
H/He	~ 10	~ 100
Q_{Fe}	~ 20	~ 14
Duration	hours	Days
Long. Distrib	< 30°	~ 180°
Metric Radio	III, V	II,III,IV,V
Solar Wind	-	Ipl. shock
Event Rate	~ 1000/a	~ 10/a

Lin, 1970; Pallavicini et al., 1977, Reames 1999

ENERGETIC CHARGED PARTICLES

Spectra, Composition, and Charge States



IMPULSIVE EVENTS

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"Flare Particles"

GRADUAL EVENTS

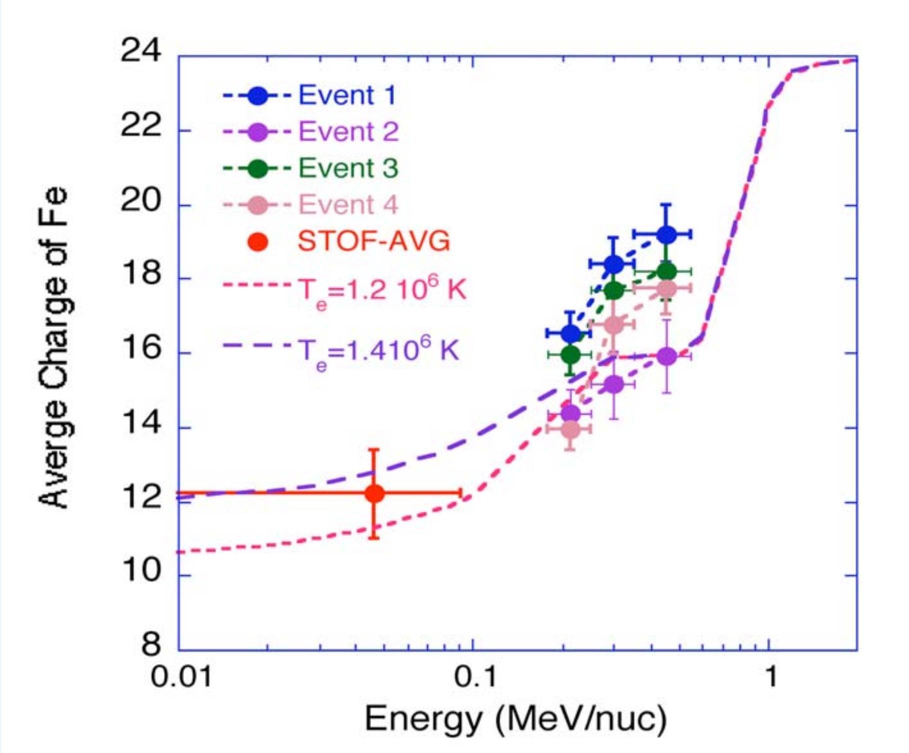
Acceleration related to Coronal / Interplanetary Shock

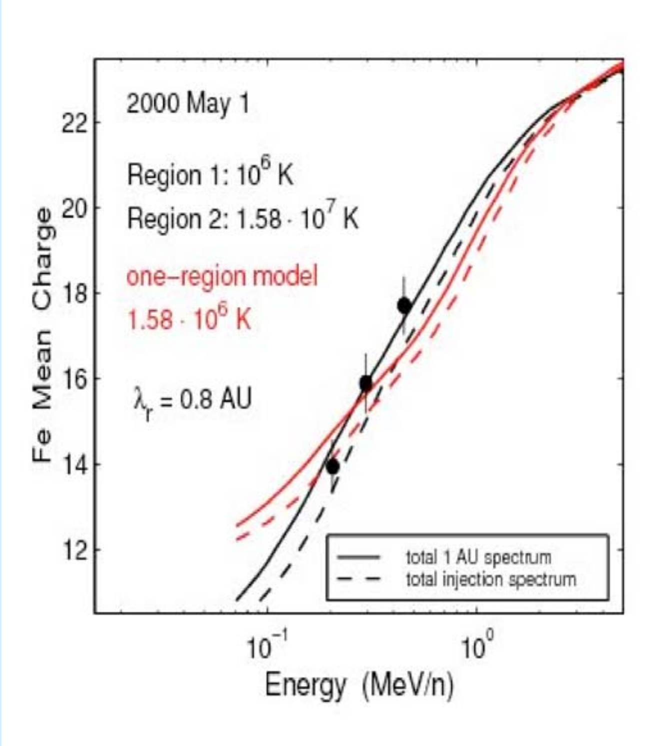
"Shock accelerated Particles"

	^{3}He-rich	gradual
particles	electron rich	proton rich
$^3He/^4He$	~ 1	~ 0.001 – 0.1
$[Fe/O]/[Fe/O]_{cor}$	~ 10	~ 1
[Mass 100-200]	> 100	
H/He	~ 10	~ 100
Q_{Fe}	~ 10-20 Q(E)	~ 10 at < 500 keV ~20 at > 10 MeV/n
Duration	hours	Days
Long. Distrib	< 30°	~ 180°
Metric Radio	III, V	II,III,IV,V
Solar Wind	-	Ipl. shock
CME	Y (narrow)	Y
Event Rate	~ 1000/a	~ 10/a

ENERGETIC CHARGED PARTICLES

³He-rich, Heavy Ion -rich Events





Result:
Acceleration Must be in the low corona Altitude < 0.2 R_S

Strong energy dependence of $Q_{Fe}(E)$ for ALL ³He-rich, Fe-rich events observed so far.

Möbius et al, ICRC 2003; Klecker et al., 2006

Kovaltsov et al., 2000; Kocharov et al., 200x

Numerical Model combining Stochastic Acceleration, Coulomb Loss, Ionization + Recombination with Interplanetary Propagation

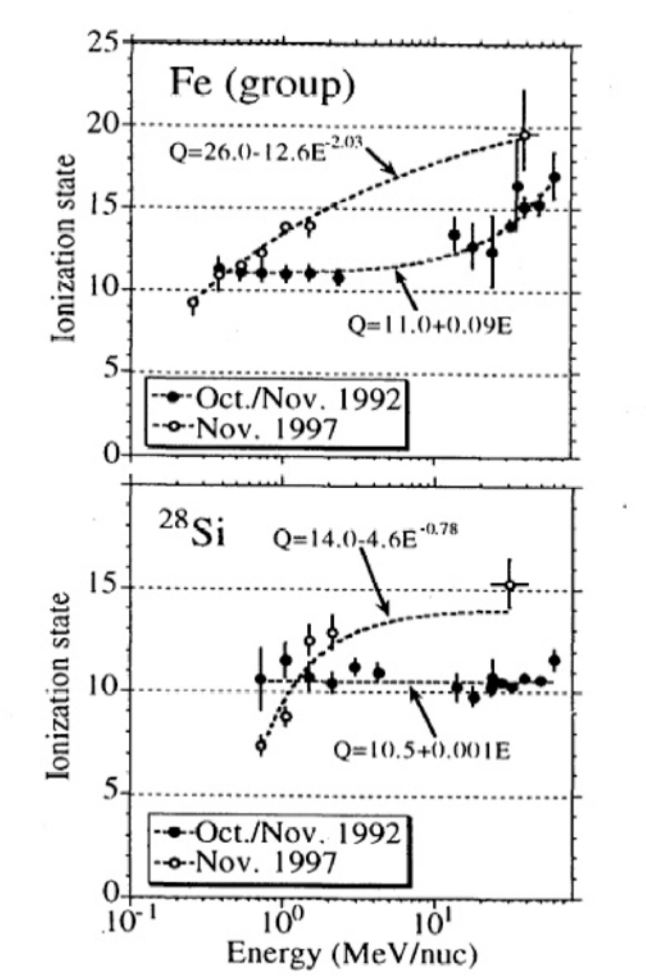
Kartavykh et al., SH 1.4 - 649

Ionic Charge States: Pérez-Peraza et al., SH 1.4-774

GRADUAL EVENTS

Energy Dependent Ionic Charge States

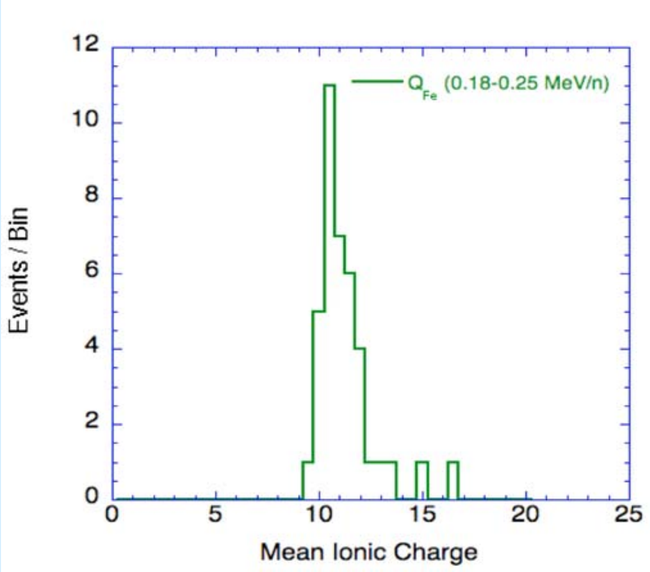
Large Variability of Q (E) for Heavy Ions, in particular for Fe



Mazur et al., 1999; Möbius et al., 1999

From SEP Event Averages:
At low energies of up to ~ 250 keV/amu:
Q_{Fe} ~ 10, similar to Solar Wind

At Interplanetary Shocks:



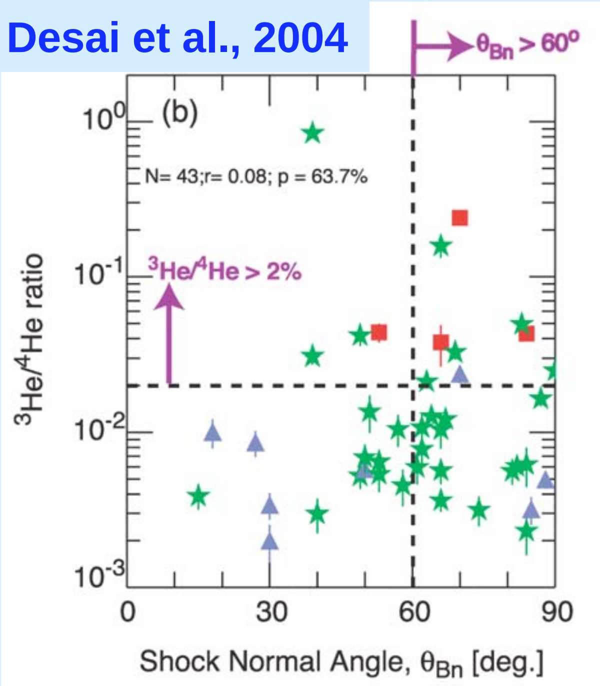
SH 1.4 - 667 (Klecker et al.)

Q_{Fe} (E) ~ 10.5 independent of energy in the energy range 0.18-0.43 MeV/n

NEW OBSERVTIONS : LARGE (*GRADUAL*) EVENTS

^{3}He at IP Shocks

Desai et al., 2004



^{3}He / ^{4}He ratio at ~1 MeV/nuc ions at interplanetary shocks.

He does not show Solar Wind Composition:

Scenario:

^{3}He from suprathermal ions from previous 3He-rich events

(Mason et al., 1999)

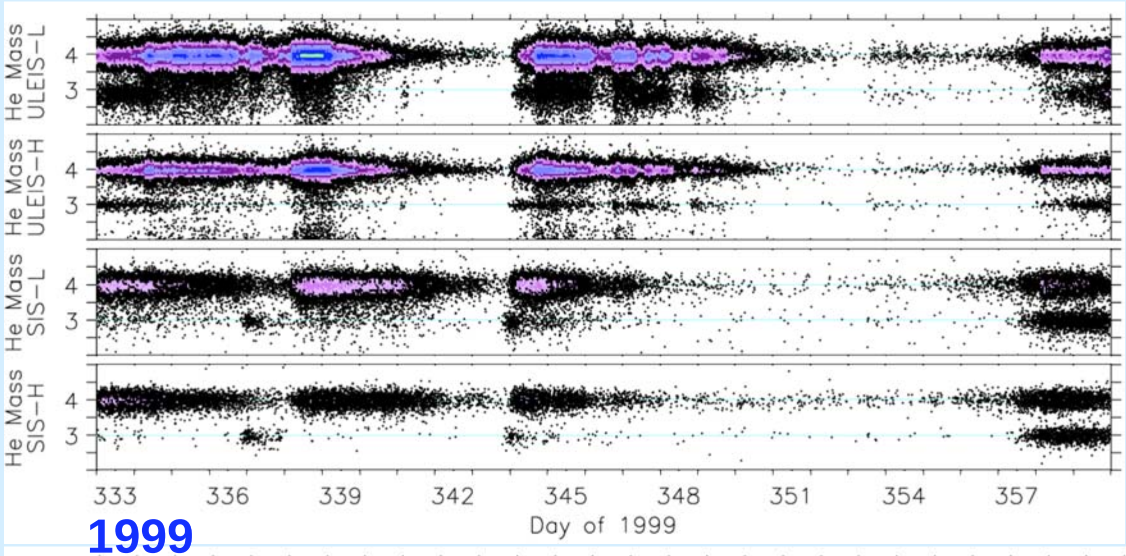
0.2-0.4

0.4-1.0

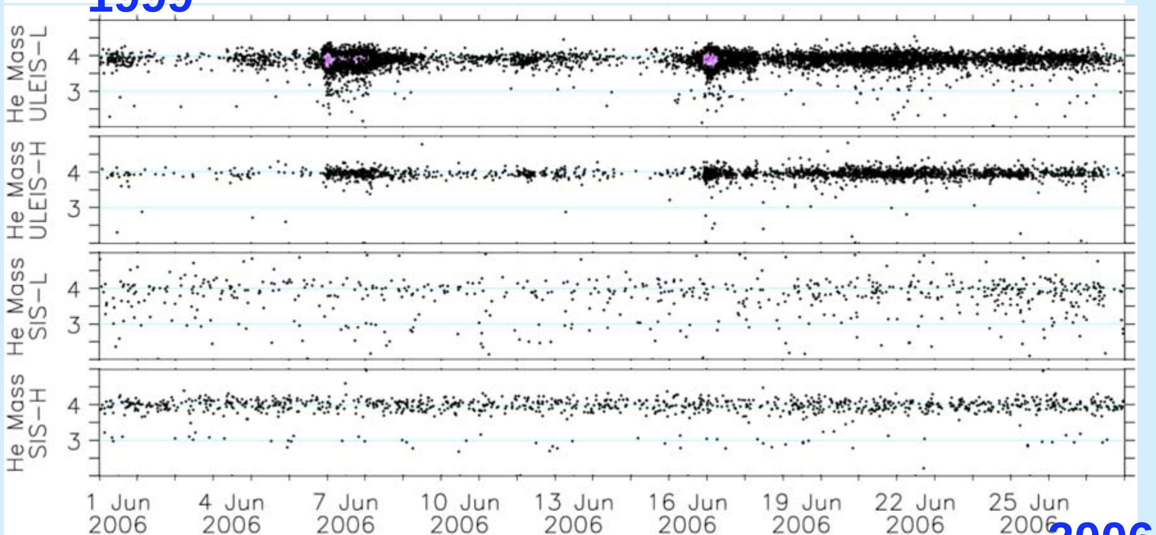
4.5-7.6

7.6-16.3

(MeV/n)



1999

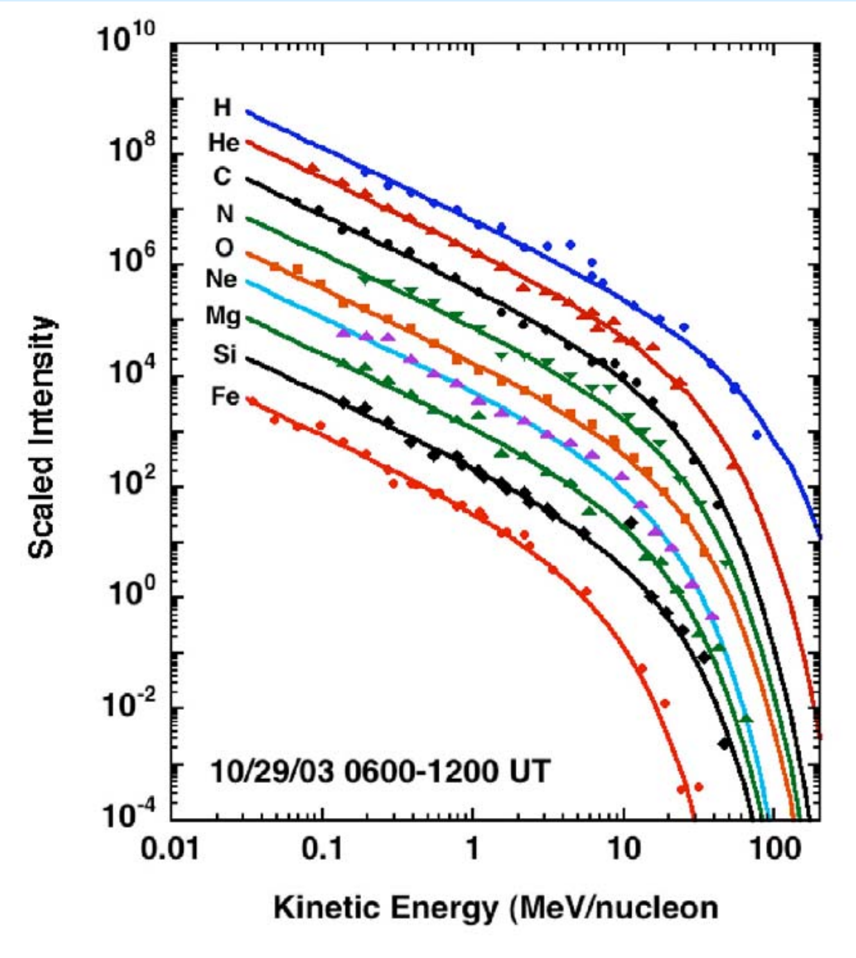


2006

SH 1.4 - 1121 (Wiedenbeck et al)

GRADUAL EVENTS

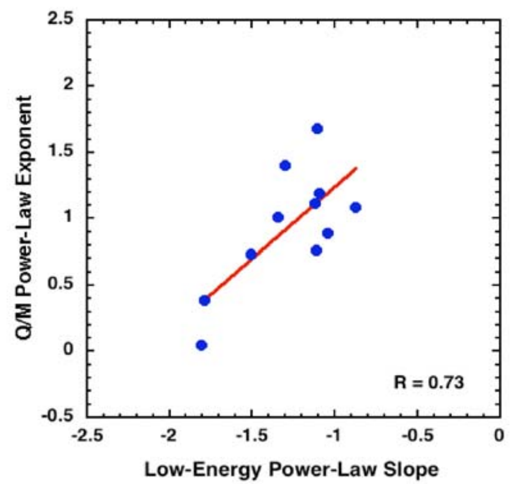
Spectra and Composition

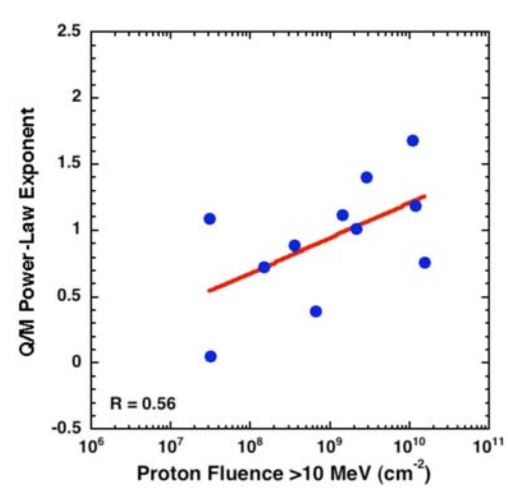


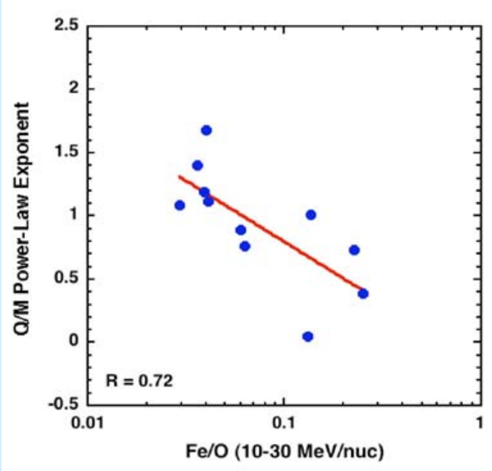
SH 1.4-1186 (Mewaldt et al.)

Spectral breaks scale wit Q/A:

Fit with j ~j$^{-\gamma}$ exp(-E/E$_0$); E$_0$~(Q/M)$^{\beta}$

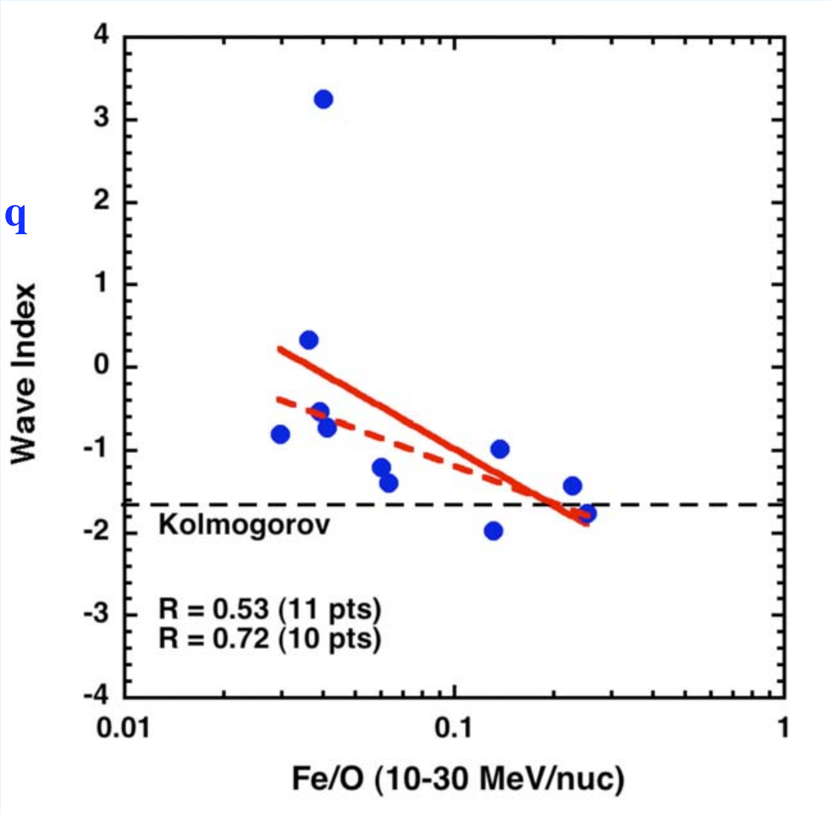






GRADUAL EVENTS

Spectra and Composition



- Relate Energy of spectral break to scattering mean free path (Cohen et al., 2005)

$\kappa = 1/3\, \lambda\, v$, $\kappa \sim (M/Q)^{\alpha}(E)^{(\alpha+1)/2}$

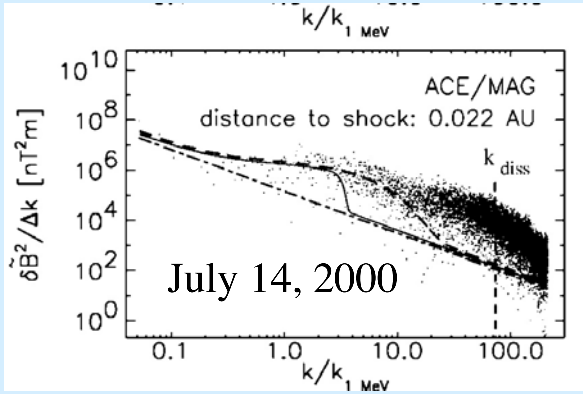
$E_1/E_2 = [(Q/M)_1 / (Q/M)_2\,]^{2\alpha/(\alpha+1)}$, i.e.

$\alpha = \beta / (2\text{-}\beta)$

$\alpha = 2 + q$

q: power law index of wave turbulence

q > - 2 … 0 additional wave power near shock



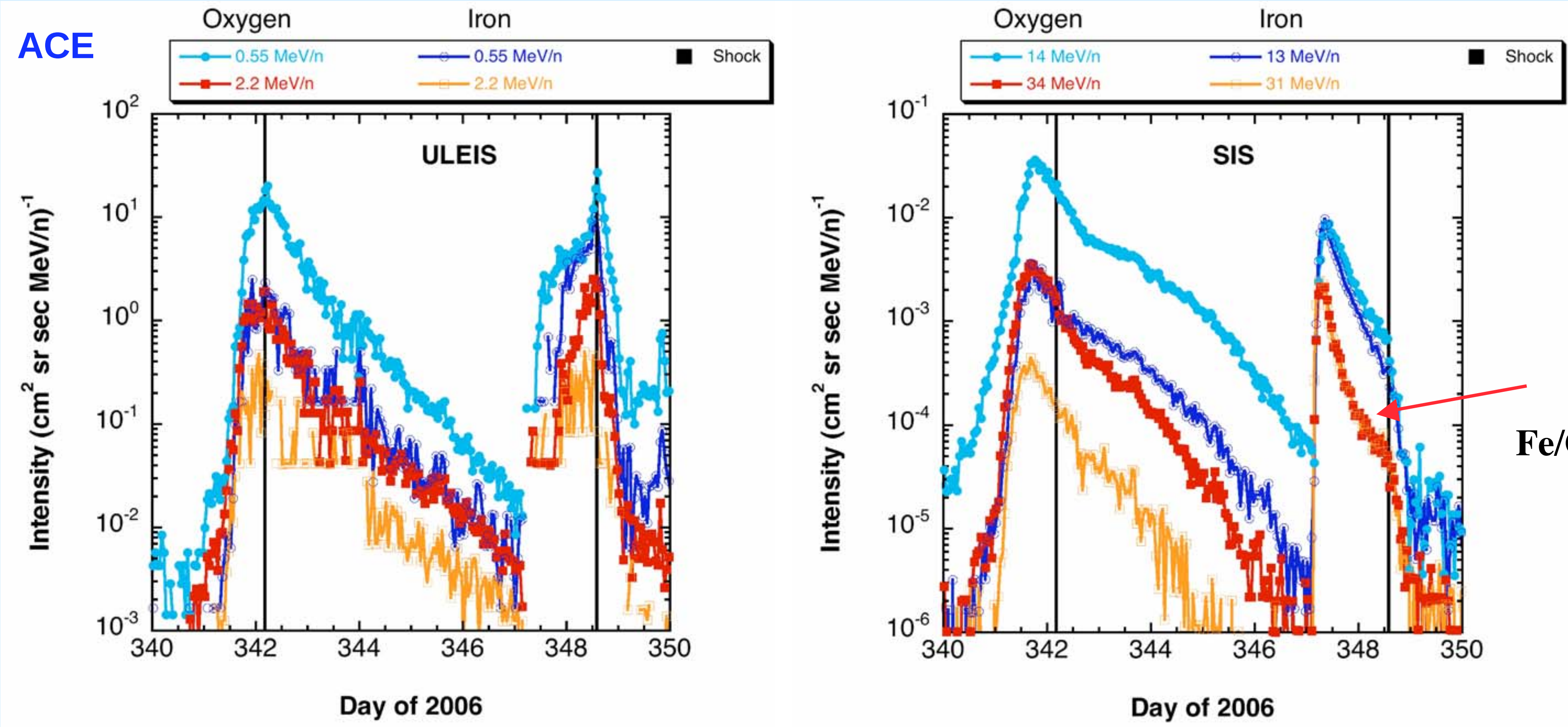
Bamert et al., 2004

Consistent with scenario of acceleration by quasi-parallel shock

SH 1.4 - 1186 (Mewaldt et al.)

GRADUAL EVENTS

Spectra and Composition



Fe/O~1

E70 **W25**

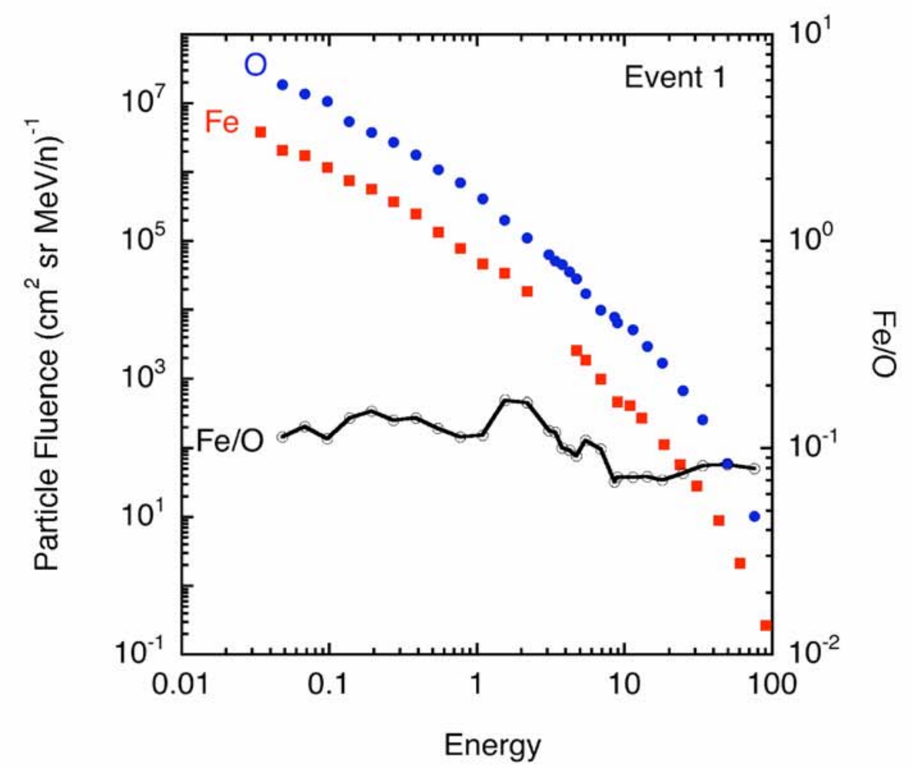
Shocks θ_{BN}=12±10° **θ_{BN}=36±19°**

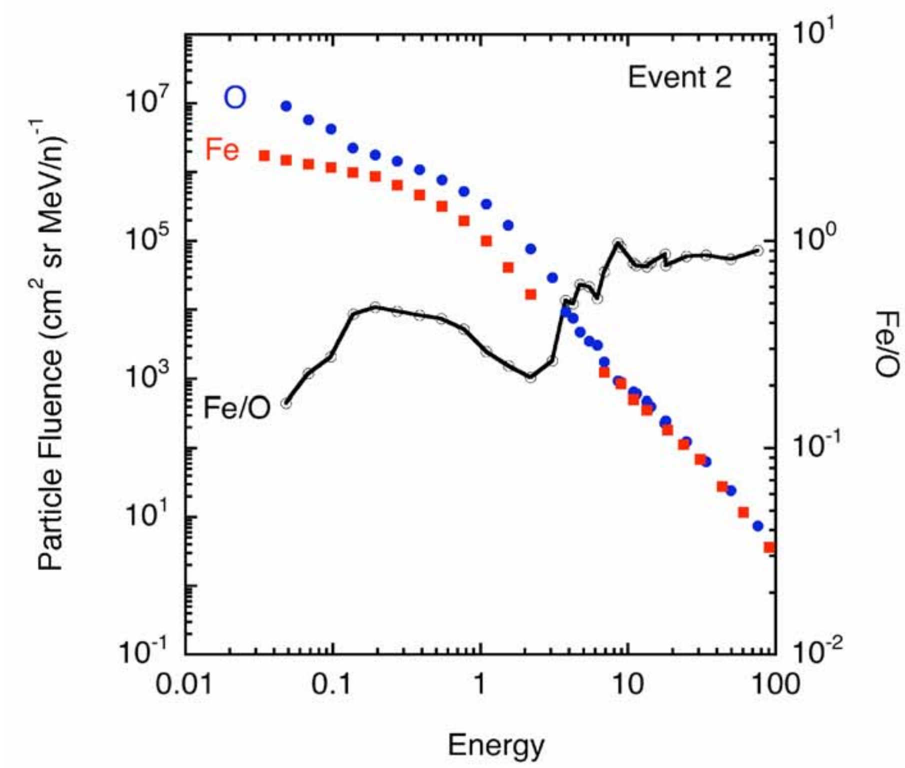
SH 1.4 - 1186 (Cohen et al.)

GRADUAL EVENTS

Spectra and Composition

Dec 6, 2006 **Dec 13, 2006**





E70 Shock θ_{BN}=12±10°

Type 1 Event: consistent with acceleration at quasi-parallel shock

SH 1.4 - 1186 (Cohen et al.)

W25 θ_{BN}=36±19°

Type 2 Event: ?

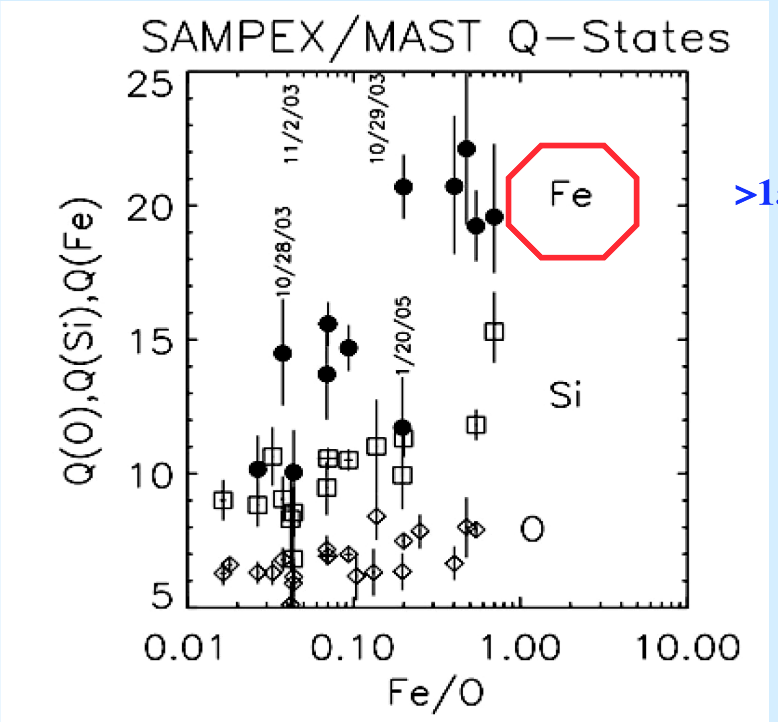
GRADUAL EVENTS

Correlation of Ionic Charge with Abundances

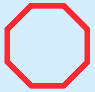
High Energy

At high energies:

- $Q_{Fe}(E)$ increasing at E > 10 Mev/nuc in many events
- Correlation of high Fe charge with high Fe/O abundance

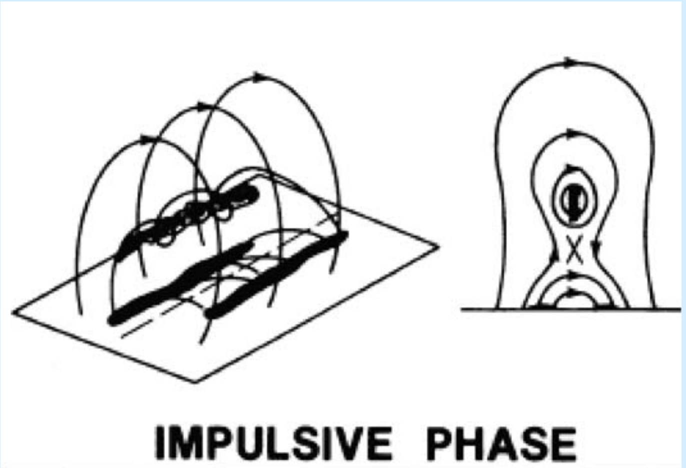


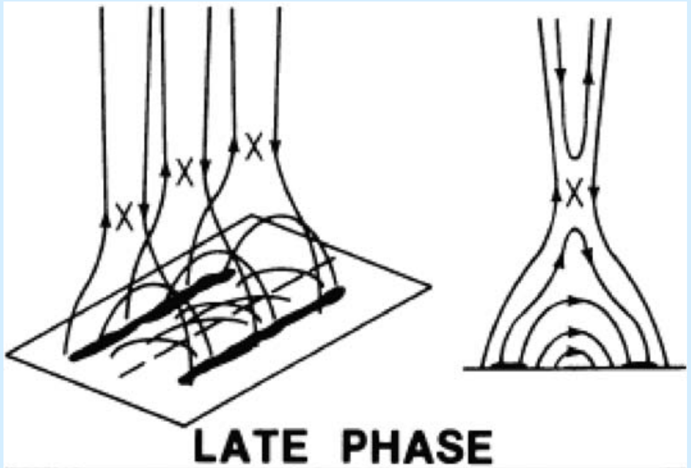
>15 MeV/n

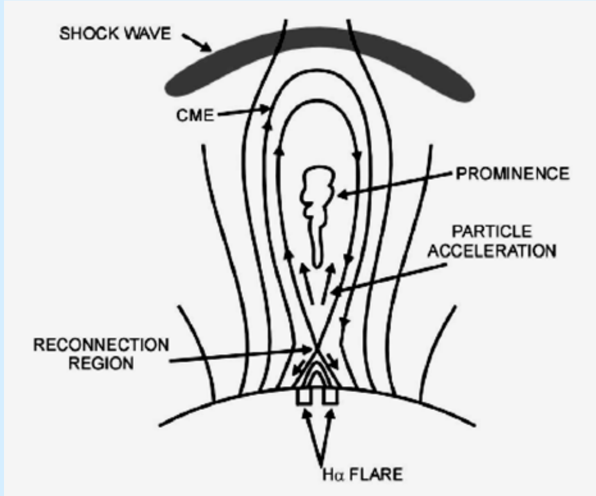
 Type 2 Events

Labrador et al., ICRC 2005

SCENARIO 1 FOR HEAVY ION ENRICHMENT AND HIGH CHARGE STATES AT HIGH ENERGIES







FIRST	SECOND	THIRD
FLARE IMPULSIVE PHASE	FLARE LATE PHASE	SHOCK ACCELERATION

THREE PHASES OF PARTICLE ACCELERATION

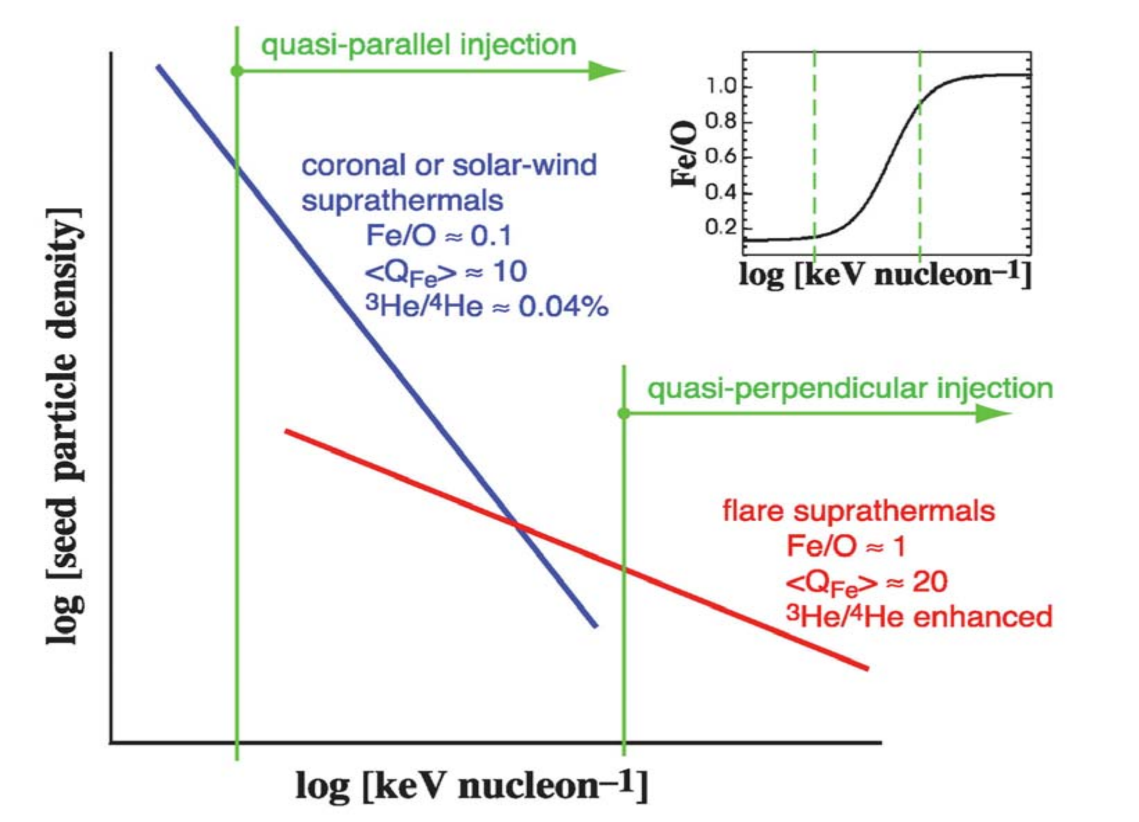
+

TWO CONDITIONS

(1) Open Field Lines; (2) Magnetic Connection

Cane et al.,2006; SH 1.4 - 405 (Cane et al.)

SCENARIO 2 FOR HEAVY ION ENRICHMENT AND HIGH CHARGE STATES AT HIGH ENERGIES



Tylka et al. 2001, 2005; Tylka & Lee, 2006

Further Investigation Needed

STEREO / ACE with 3 measurements separated in longitude may provide the clue

Model: Mixing of 2 Populations

1. Source with 2 components:

(1) Coronal Source

(2) Flare Source

2. Spectra with Q/M and θ_{BN} dependent roll-over E_0 at high energies:

$F_i = C_i\ E^{-\gamma} \exp(-E/E_{0i})$

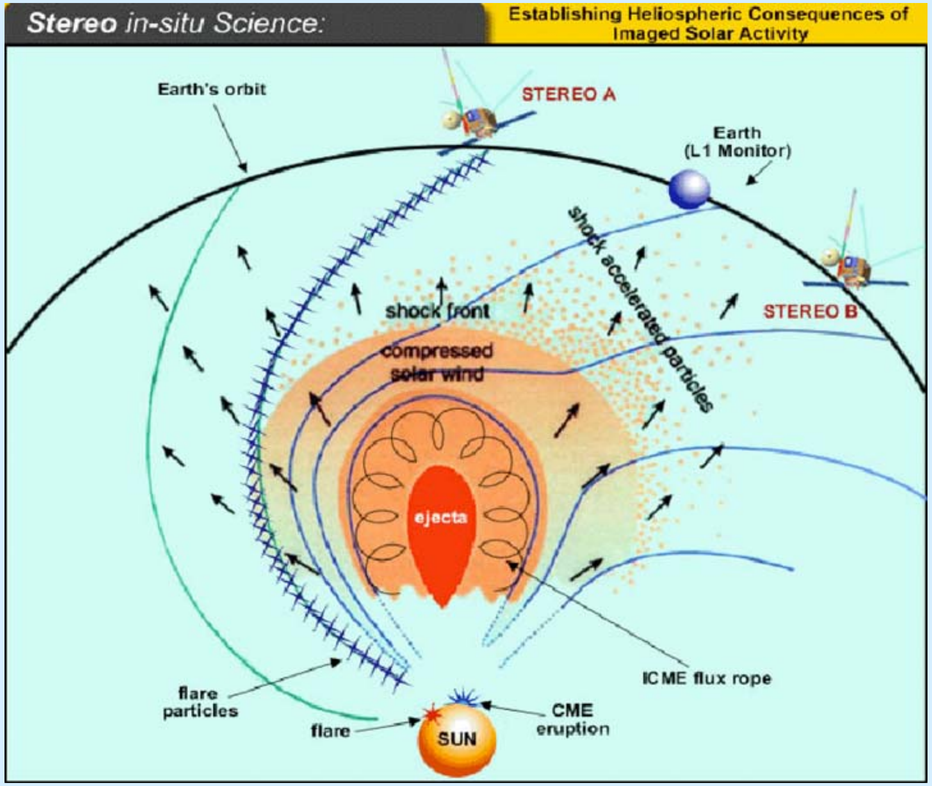
$E_{0i} = E_0\ (Q_i/A_i) * (\sec(\theta_{BN}))^{\alpha}$

$\alpha = 2\ /\ (2\gamma - 1)$

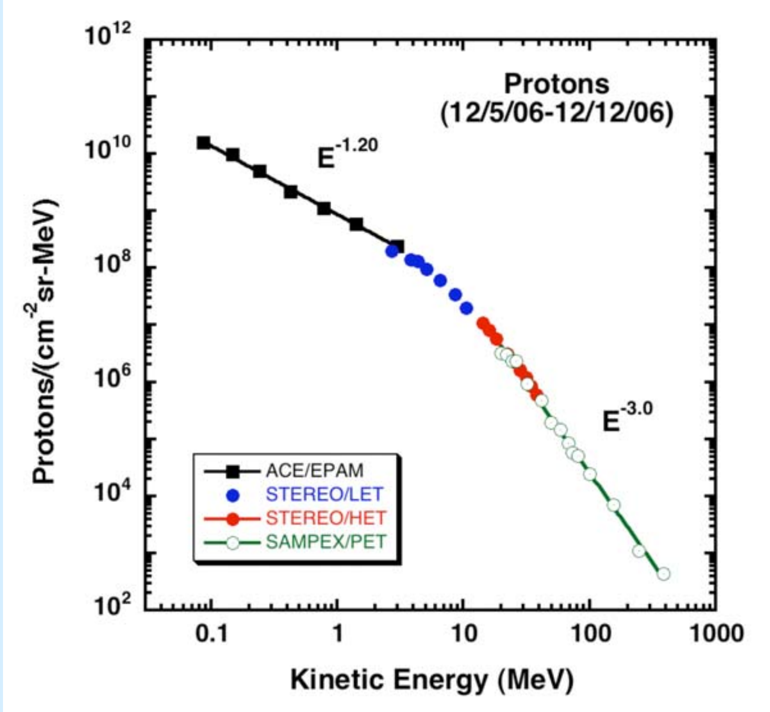
3. Higher injection threshold for large θ_{BN} (simulated by suppression of coronal component with increasing θ_{BN}).

4. Averaging spectra over $\theta_{BN,}$ i.e. assuming contributions from parallel and perpendicular shock

MULTI SPACECRAFT OBSERVATIONS



from STEREO / IMPACT Web Page



SH 1.4 - 1150 Cohen et al.

SH 1.4 - 1202 Von Rosenvinge et al.

SH 1.4 - 1218 Mewaldt et al.

Excellent agreement between instruments on STEREO and near Earth (ACE, SAMPEX, GOES)

Great potential for multi-spacecraft studies from different vantage points:

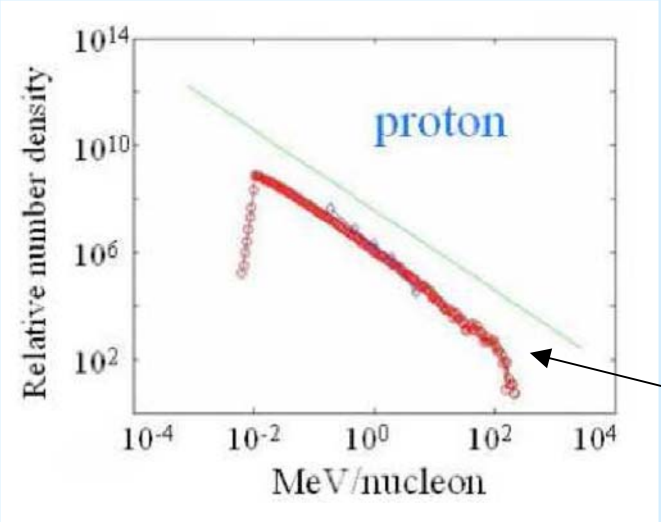
STEREO - ACE / SOHO

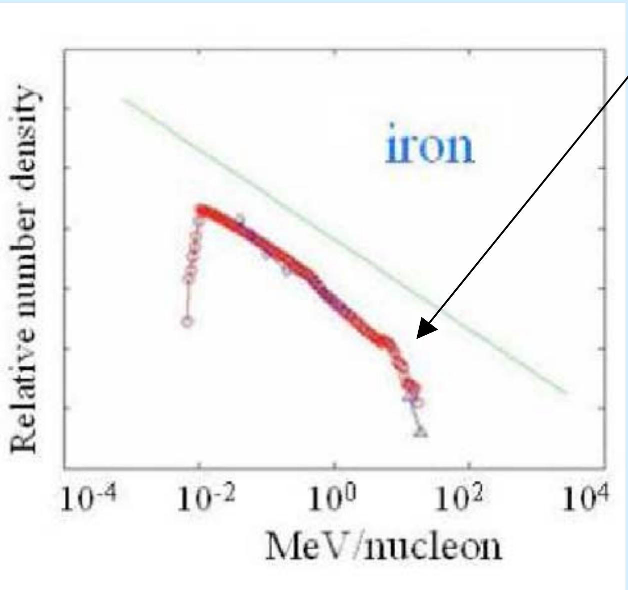
ACCELERATION AND TRANSPORT OF Solar Energetic Particles

Acceleration and Transport of SEPs

CME propagation + Transport	SH 1.7 - 0232, Kota
Shock Accel. Model (quasi-parallel)	SH 1.5 - 1273, Li, et al.,
Comparison of shock acc, stochastic acc,	SH 1.5 - 352, Perez-Peraza et al.
Acceleration in stochastic electric fields	SH 1.5 - 0140, Zimovets
Acceleration at perpendicular shock + recirculation	SH 2.3 - 1015, Nemeth
Propagation of e, p in impulsive events	SH 1.6 - 653 Dröge et al
Propagation of e in impulsive events	SH 1.6 - 1281 Li et al
SEP Event time scales and solar wind streams	SH 1.6 - 361, Kahler
Travel delays of impulsive SEPs	SH 1.6 - 366 Ragot & Kahler
Particle Propagation in the 3D Heliosphere	SH 1.6 - 455 Malandraki et al.

ACCELERATION AND TRANSPORT OF Solar Energetic Particles





Acceleration at quasi-parallel shock

Fit of Sept 27, 2001 SEP Event

Q/A dependent spectral breaks can be reproduced

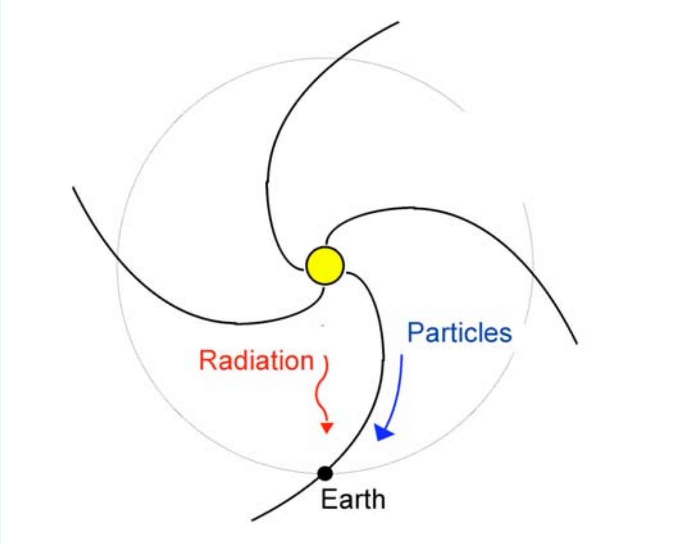
Numerical Code for particle acceleration and transport at quasi-parallel shock, including

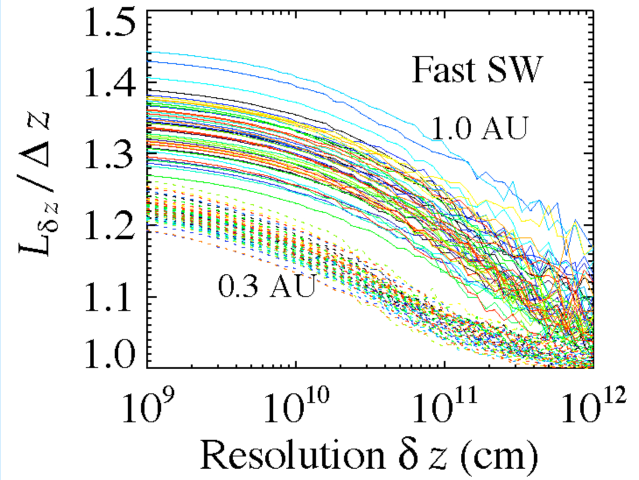
- **local injection**
- **Fermi acceleration at the shock**
- **self-consistent excitation of waves at the shock**
- **particle scattering and escape**

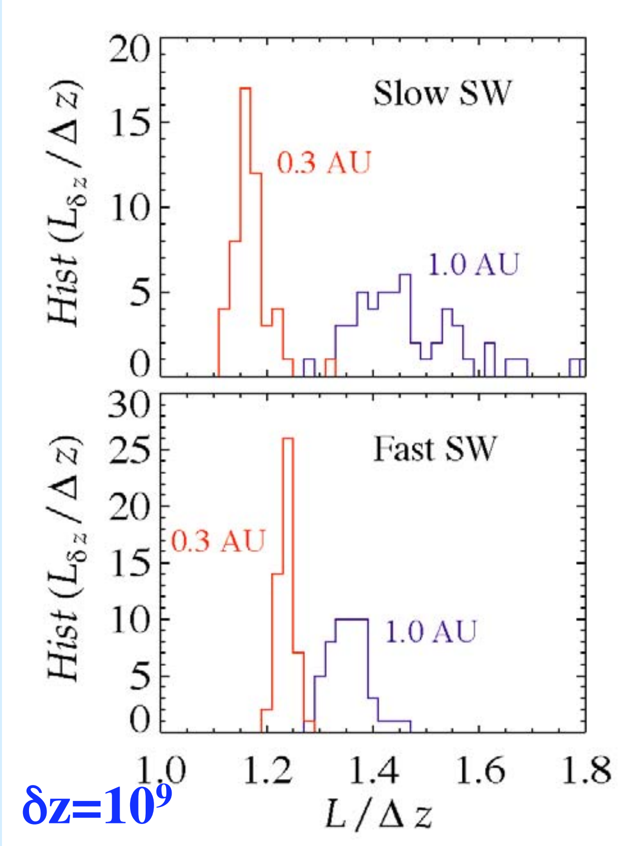
SH 1.5 - 1273 G. Li, et al

ACCELERATION AND TRANSPORT

Time Delay between Injection at the Sun and 1AU







Solar release time (t_{SRT}) is often computed from the particle arrival time t_{arr} and assuming propagation along the Parker Spiral field line of length L

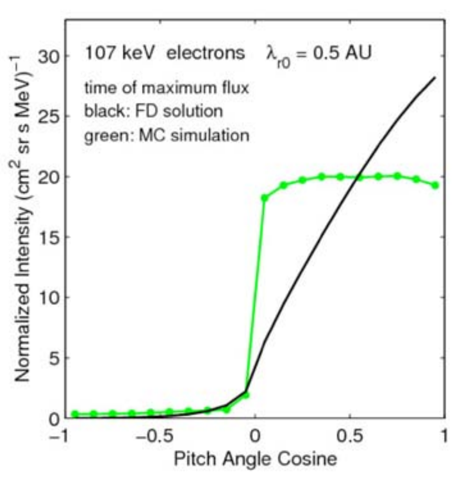
- Lengthening of field lines due to turbulence
- use measured turbulence to simulate lengthening for various length scales δz

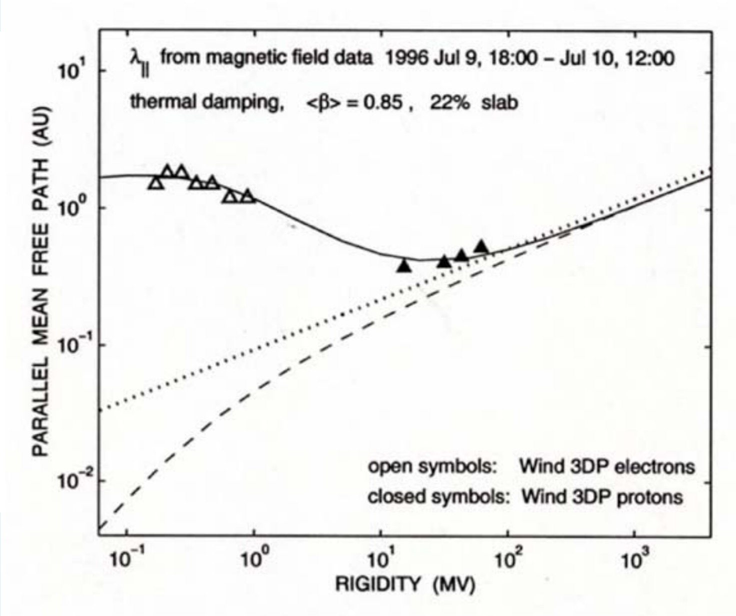
$$t_{arr} = t_{SRT} + L / v$$

SH 1.6 - 366 (Ragot & Kahler)

ACCELERATION AND TRANSPORT

Propagation in Impulsive Events





Solar Particle Propagation
Combination of:
Azimuthal Transport Close to the Sun (Coronal Diffusion)
Transport Parallel To *B*
Pitch Angle Scattering, Focusing, Adiabatic Losses
Possible Diffusion Across The Average Magnetic Field

MC Simulation using $D_{\mu\mu}$ from DQLT

FD: finite difference solution

Transport using focused diffusion model

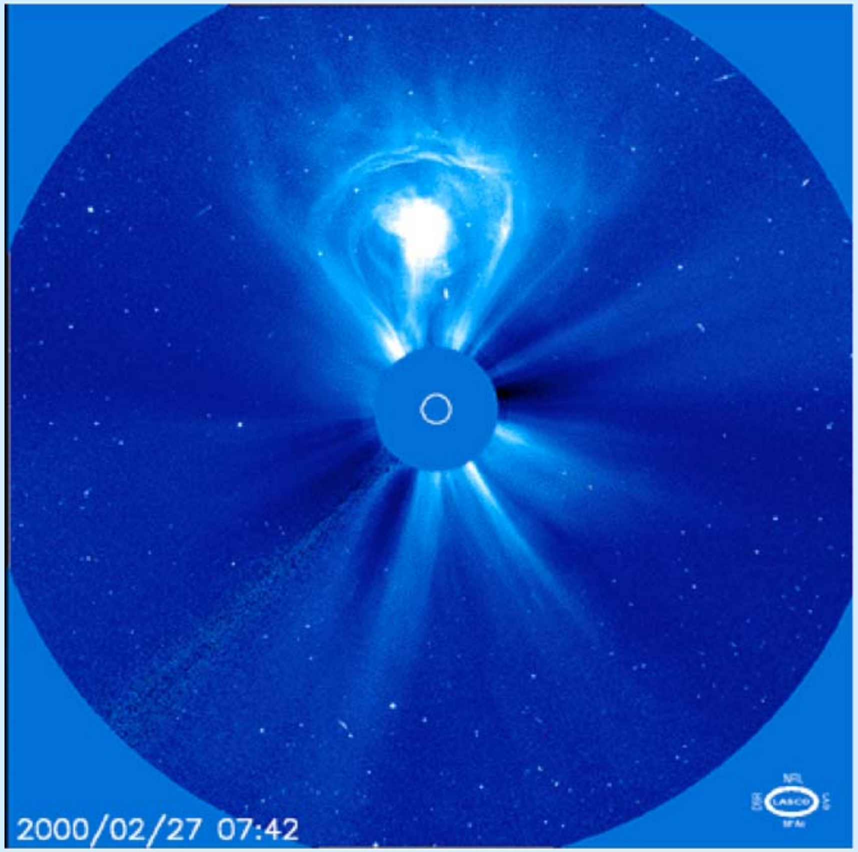
$$\frac{\partial f}{\partial t} + \mu v \frac{\partial f}{\partial z} + \frac{1-\mu^2}{2L} v \frac{\partial f}{\partial \mu} - \frac{\partial}{\partial \mu}\left(D_{\mu\mu}(\mu)\frac{\partial f}{\partial \mu}\right) = q(z,\mu,t)$$

λ_{II} computed with 10-20% slab and 80-90% 2D turbulence, DQLT

SH 1.6 - 653 (Dröge et al.)

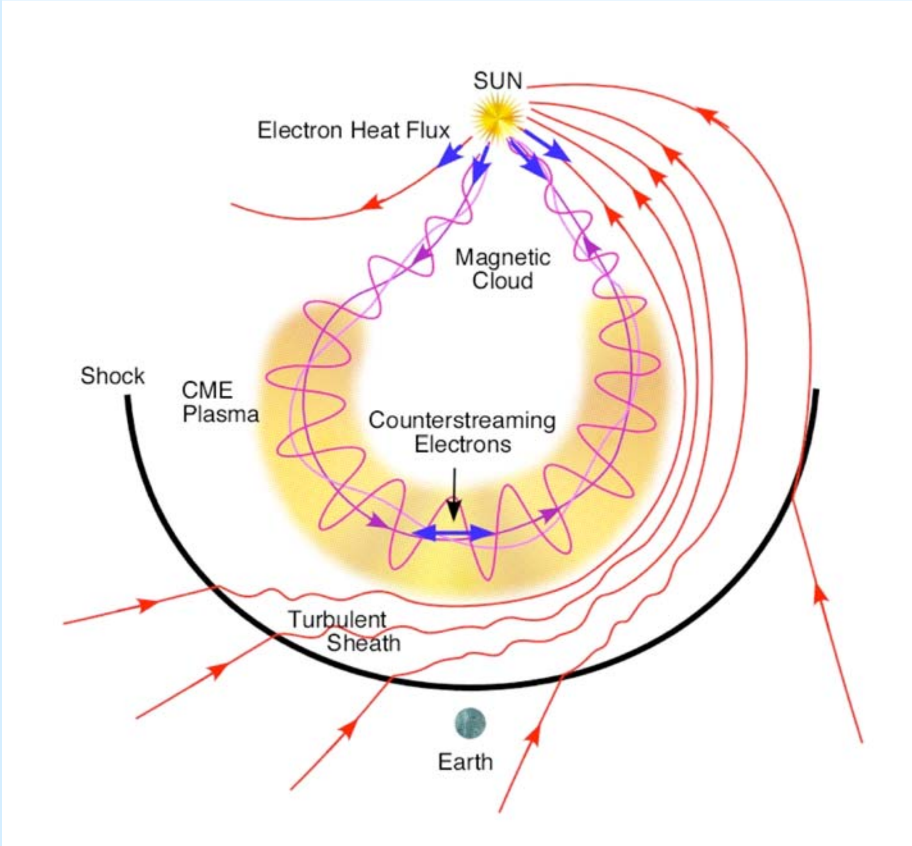
CORONAL MASS EJECTIONS - SH 1.7

CME



SOHO / LASCO

ICME



Zurbuchen & Richardson, 2006

CORONAL MASS EJECTIONS

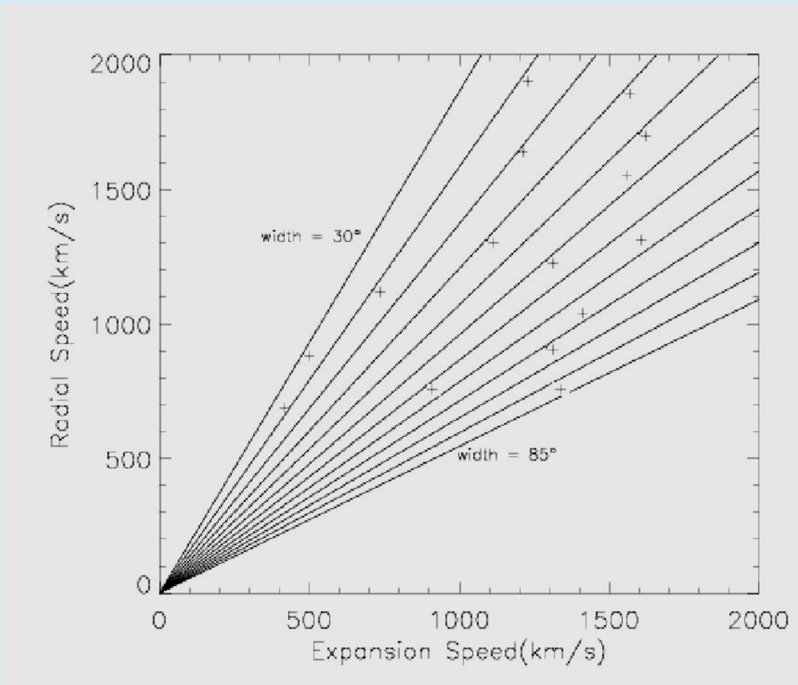
SH 1.7

232	SEP Acceleration at evolving CMEs with changing shock-geometry; Kota
330	Relationship of Coronal Mass Ejections and high speed Solar wind Streams with Geomagnetic activity Pankaj; Kumar Shrivastava
107	Characteristics of CMEs with respect to their source region during 23rd sunspot cycle; M. Pratap
108	Study of Halo, Partial Halo CMEs in association of intense geomagnetic storms. M. Pratap
153	Waiting time distribution of emissions in complex Coronal Mass Ejections; Adolfo Mendez Berhondo, et al.
796	Variations in cosmic ray intensity and interplanetary parameters on the onset of coronal mass ejection; Kumar, et al.
1245	Analytical model for expansion speed for Limb CMEs, Muñoz et al.
1309	Magnetic Clouds: The cylindrical elliptic approach; Vandas, et al.

SH 2.1

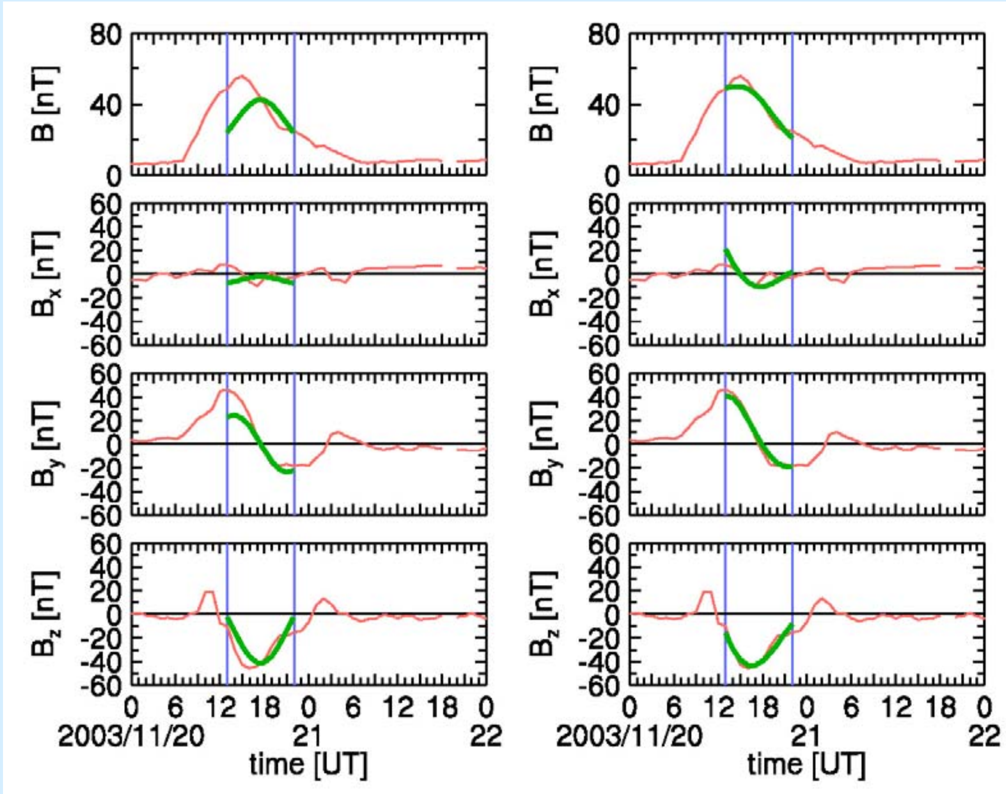
54	Coronal Mass Ejections and Cosmic Ray Long Term Modulation; Lara & Caballero-Lopez
381	A Survey of Interplanetary Coronal Mass Ejections During 1996 – 2007 Richardson & Cane

INFERRING ICME PROPERTIES



Relating expansion speed to radial speed (SOHO / LASCO C2 + C3), assuming constant opening angle of the CME cone

SH 1.7- 1245 (Muñoz et al)



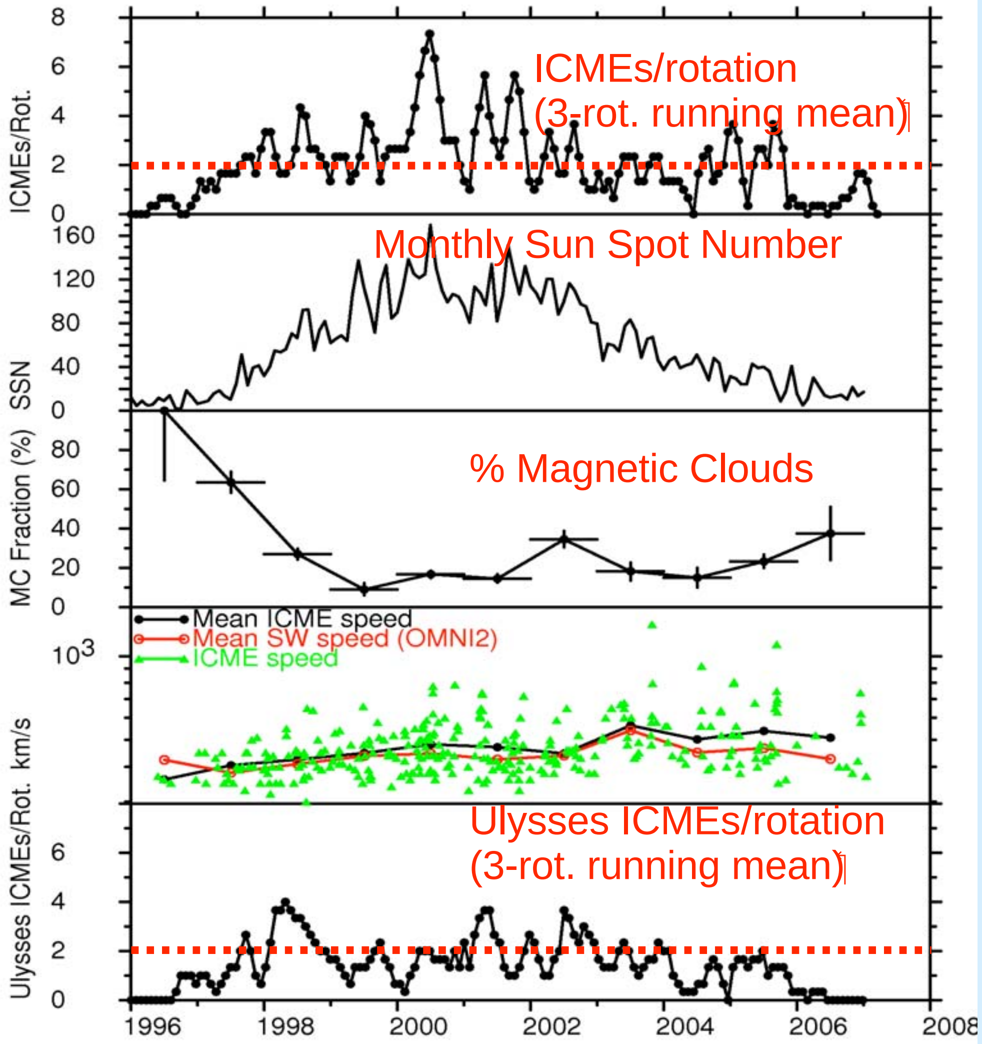
Radial CME Flux Tube

Elliptical CME Flux Tube

Fit of Magnetic Field Profiles assuming elliptical cross section of flux tube

SH 1.7- 1309 (Vandas et al)

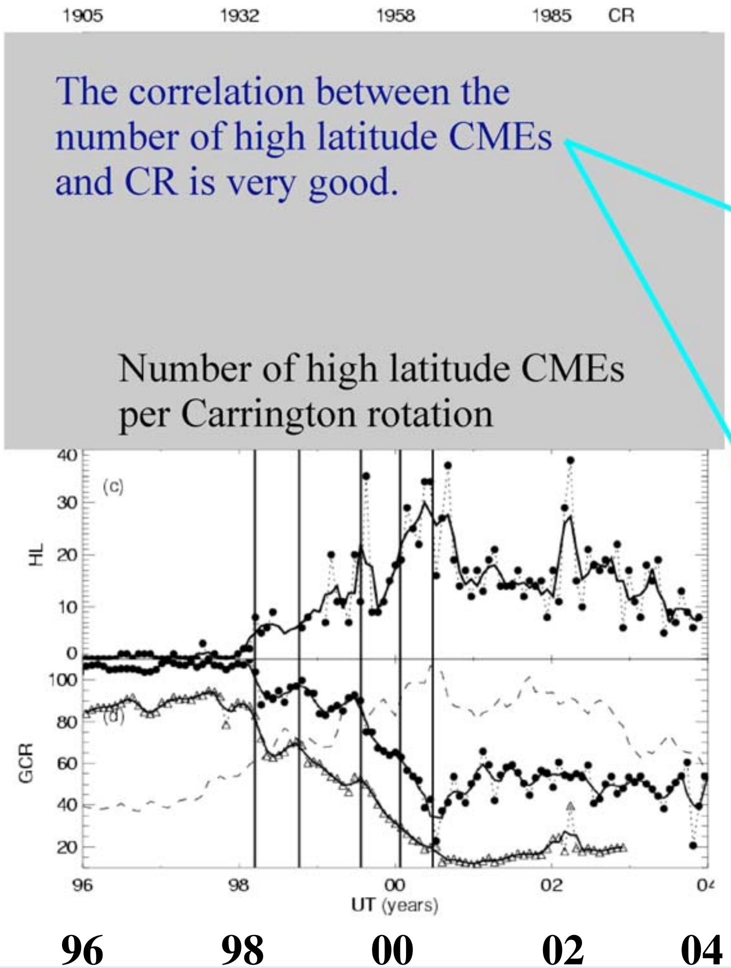
ICME PROPERTIES, 1996-2007



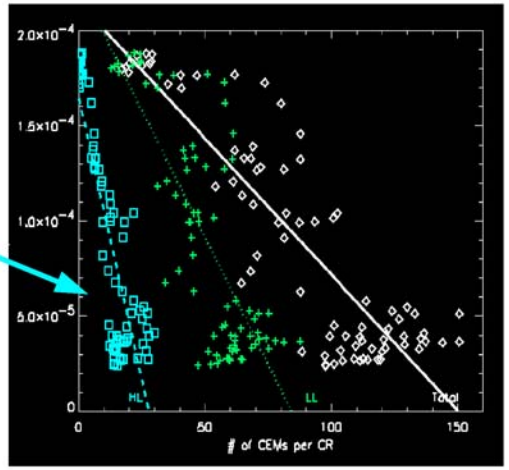
- **ICME rate has nearly returned to that during the previous solar minimum;**
- **ICME rate does not strictly follow the sunspot number;**
- **Increasing trend in fraction of magnetic clouds?**
- **Mean ICME speeds are highest during declining phase of this solar cycle.**
- **ICME rate at Ulysses is comparable to that at Earth (~2/rotation), despite the variations in s/c latitude.**

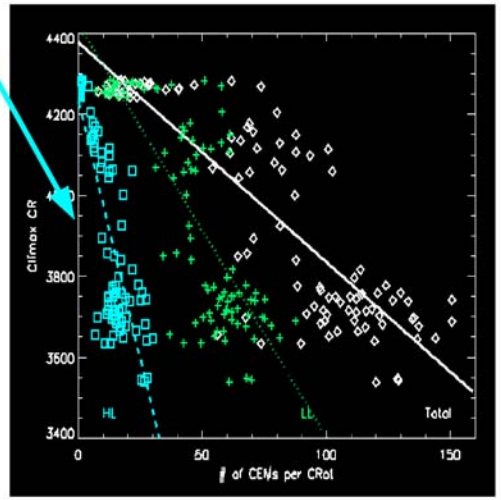
SH 2.1- 0381 (Richardson & Cane)

CMEs AND MODULATION

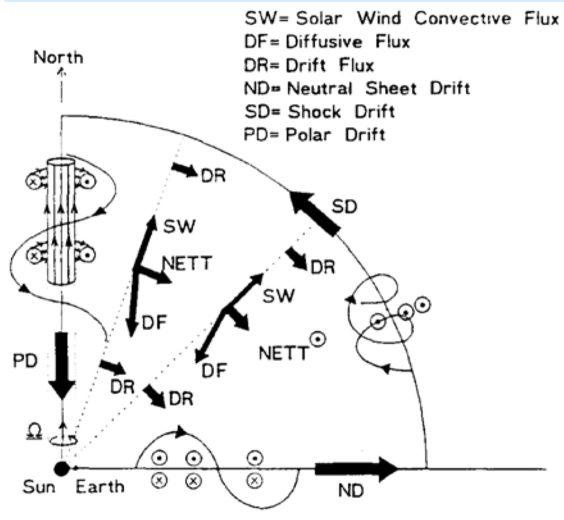


CLIMAX NM





CMEs per CRT



During A>0 Cycle

Drift from poles to ecliptic

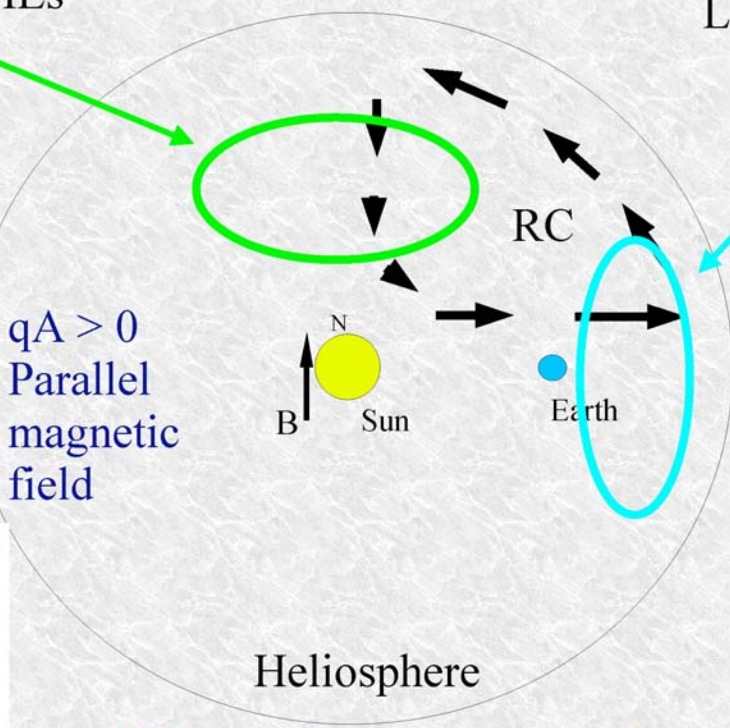
Efficient modulation by

High Latitude CMEs

SH 2.1-054 (Lara & Caballero-Lopez)

CMEs AND MODULATION

This cartoon represents the proposed scenario for the CME -CR latitudinal interaction.



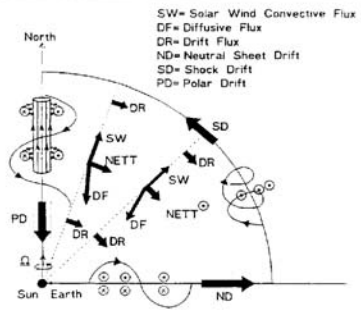
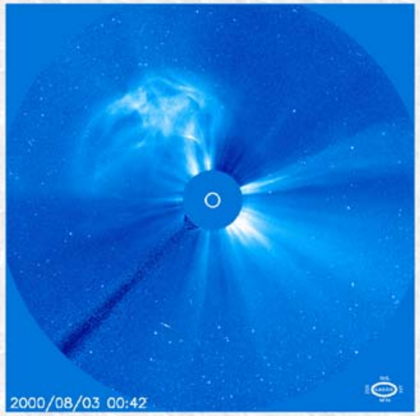


Figure 2. Meridional projection of a quarter heliosphere showing the major cosmic ray transport processes.

The CR flux starts decreasing when the high latitude CME activity increases.



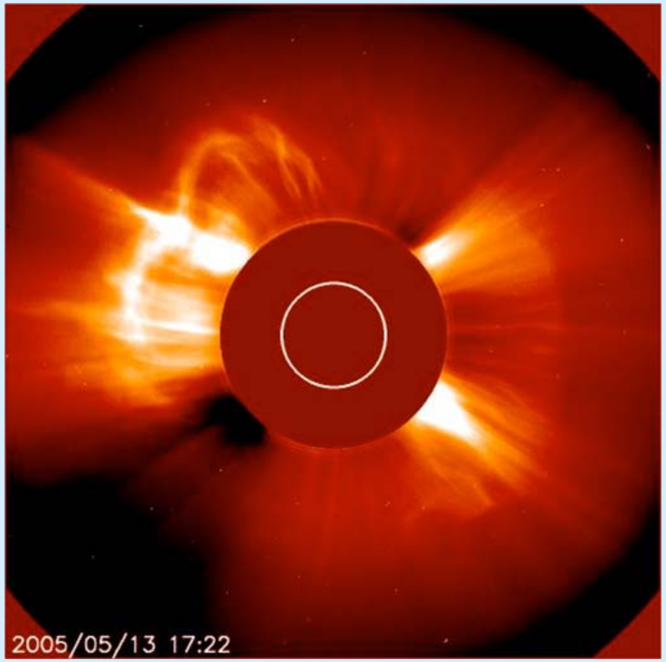
SH 2.1-054

(Lara & Caballero-Lopez)

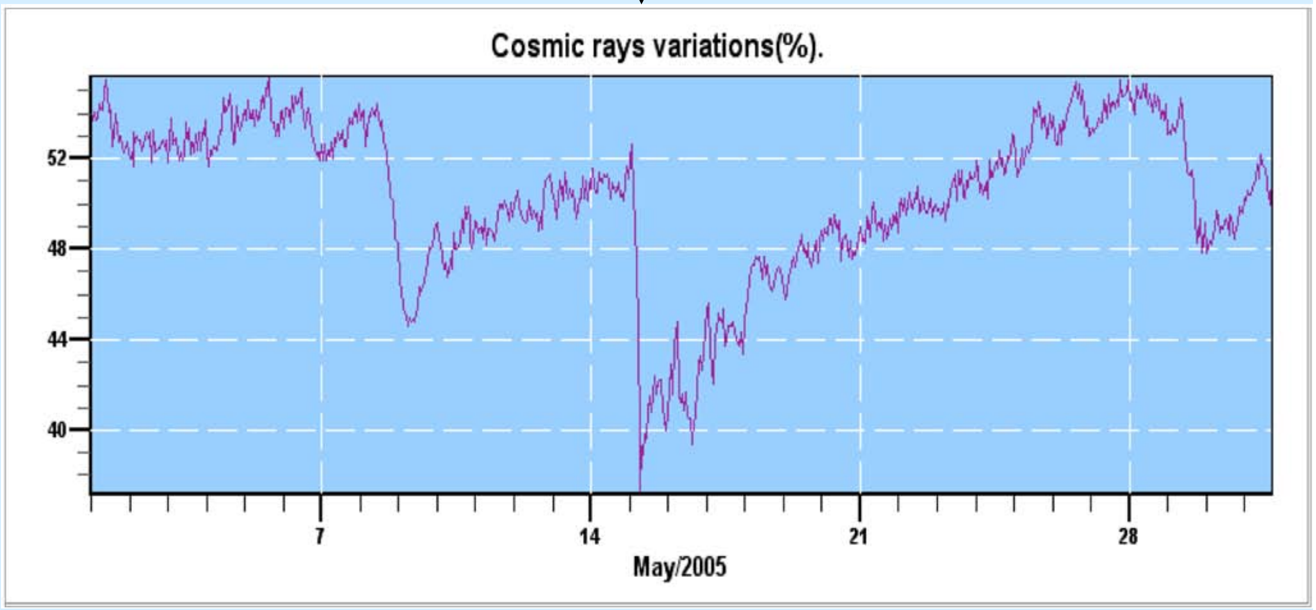
FORBUSH DECREASE / EFFECTS OF CMEs

Typical Time Profile of Forbush Decrease

Interplanetary Shock arrival: May 15 02:19
(SOHO) Average Speed: 1240 km/s



NM

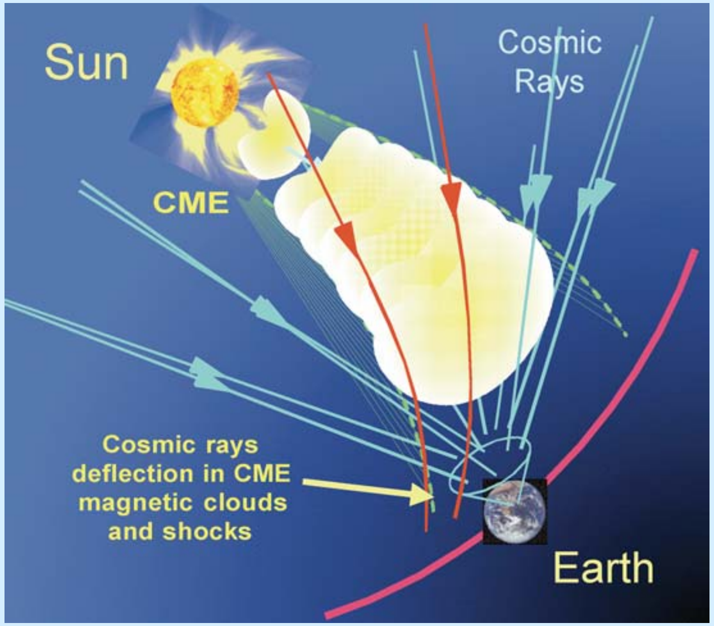


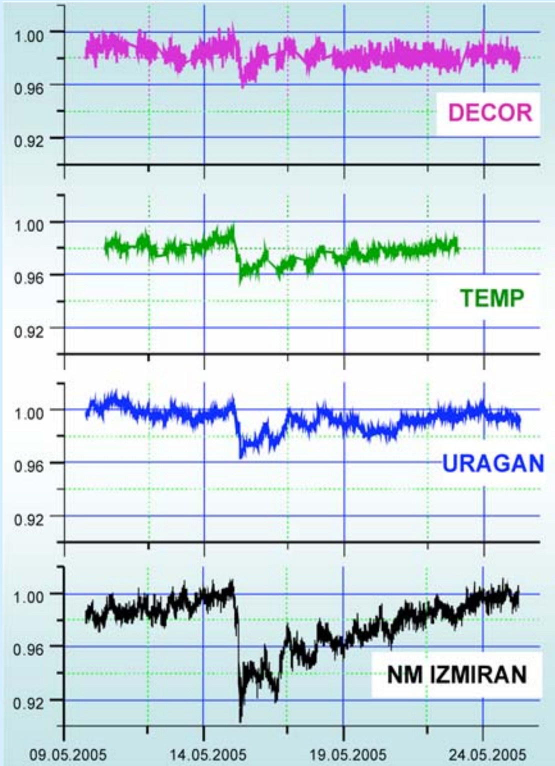
CME / SOHO May 13, 2005 17:22

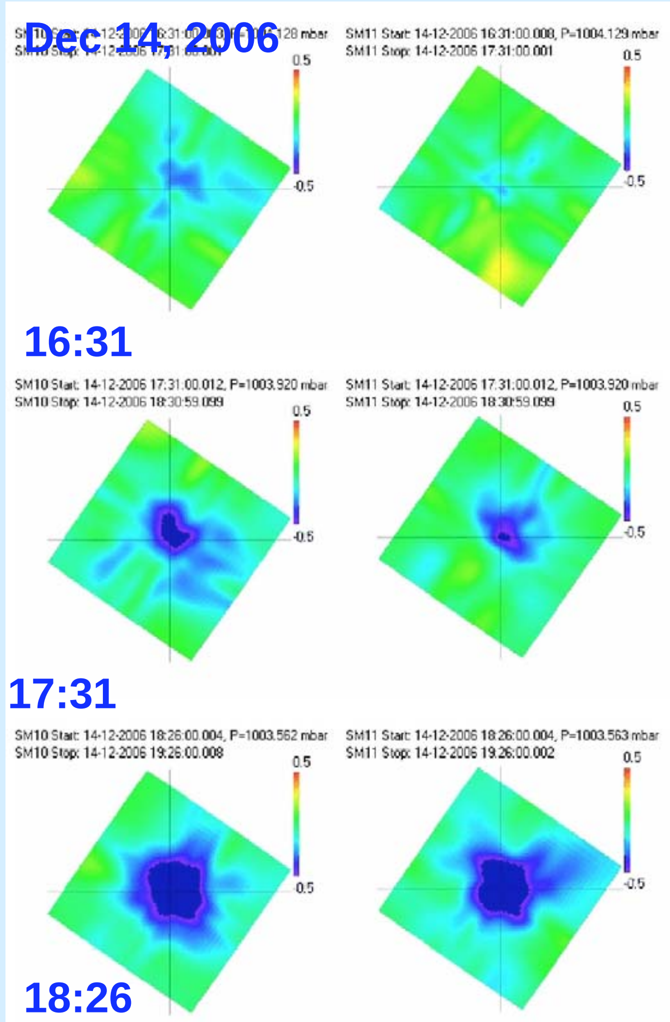
M8 Flare 16:57

SH 2.1 - 48 (Jain et al.)

FORBUSH DECREASE / EFFECTS OF CMEs





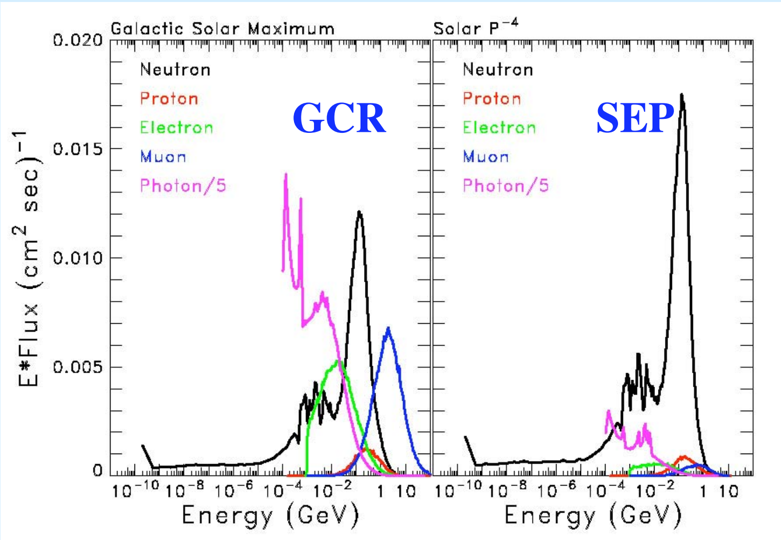


Muon Hodoscope

- Three detectors with thresholds of 2.6, 2.7 and 5.6 GeV
- Using 3 detectors and variation of response with zenith angle allows to reconstruct 2 D - dynamics of the Forbush decrease

SH 2.1 - 305 (Timashkov et al.)

FORBUSH DECREASE EFFECTS



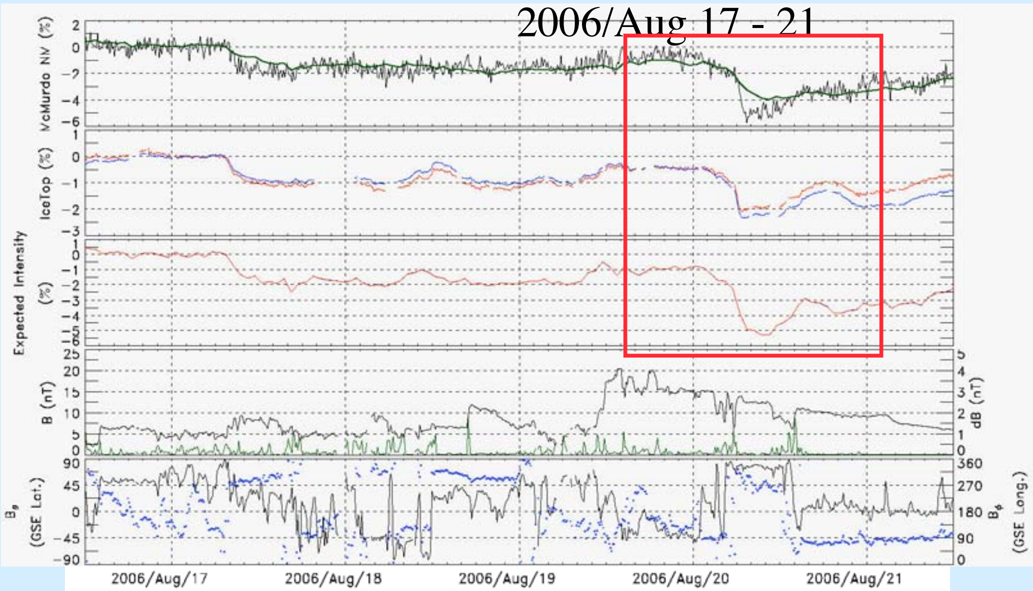
IceTop: Air Shower Array at the South Pole

Ice Cherenkov Counters

Response of IceTop to

GCR and SEP

2006/Aug 17 - 21



NM McMurdo

IceTop - measurement

IceTop- simulation

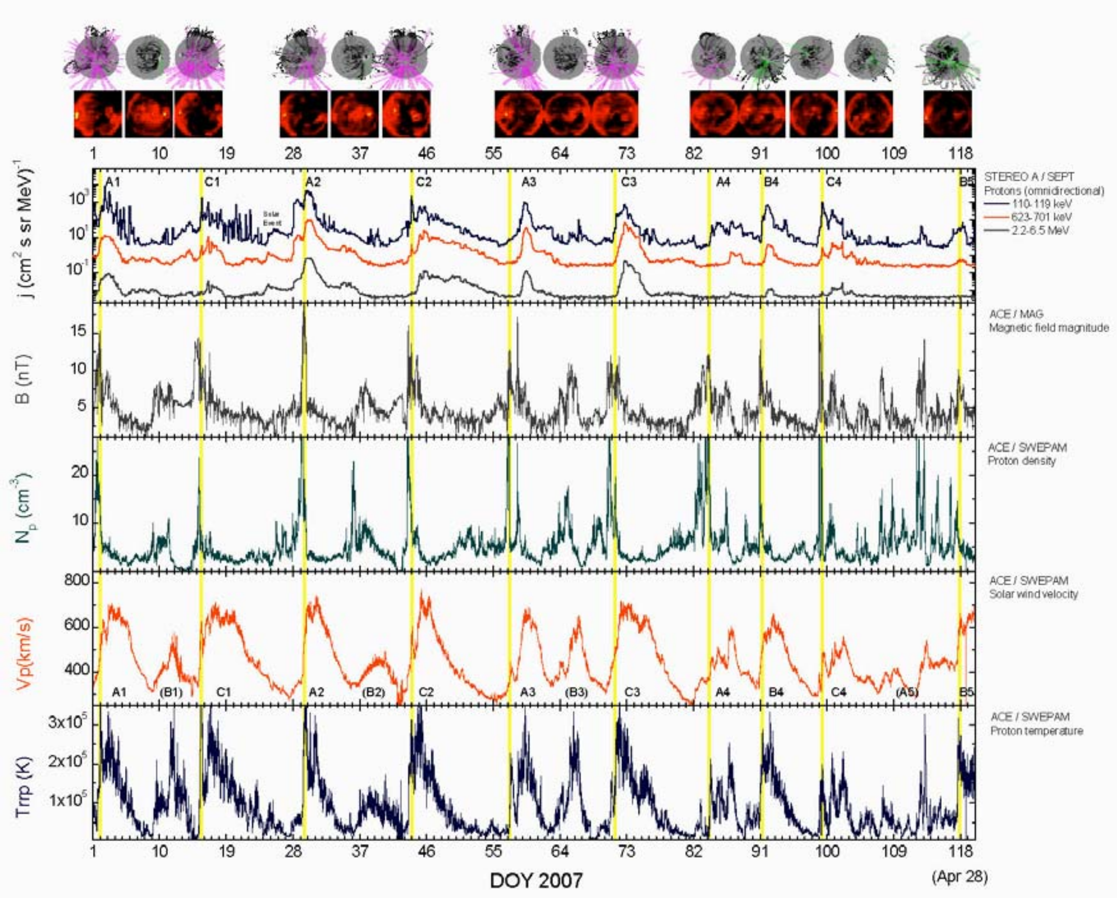
IMF

High sensitivity (~500 m²) measurements at Antarctica

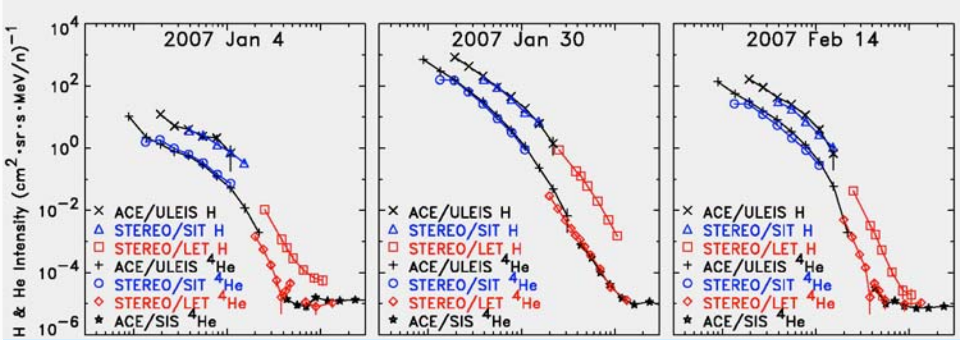
SH 2.1 - 729 (Kuwabara et al.)

COROTATING INTERACTION REGIONS - SHOCKS

CIRs observed by STEREO and ACE in early 2007



SH 2.2-924 (Müller-Mellin et al.)



SH 2.2 - 1224 (Leske et al.)

Unsolved Questions, e.g.

Composition (C/O ~1, different from SEP)

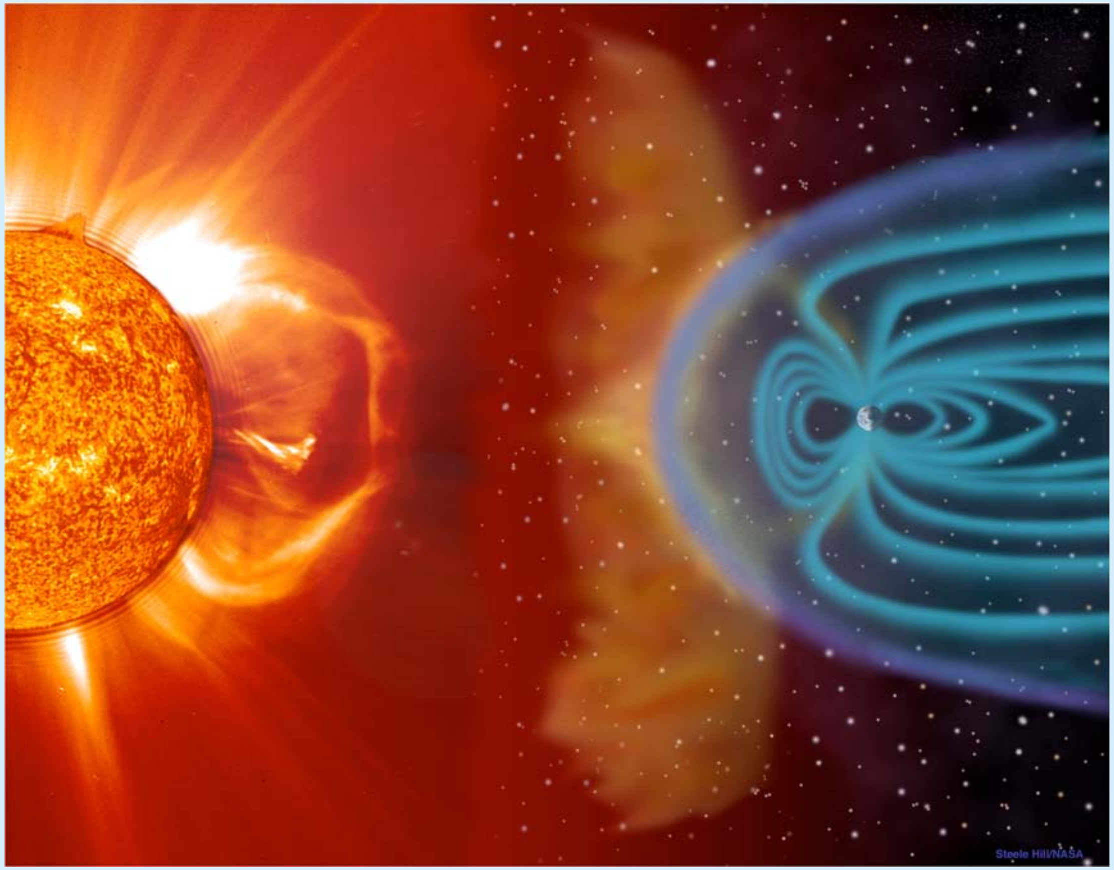
Anisotropies

Large perp. Diffusion?

Questions can be tackled with increasing separation of STEREO A and B

THINGS TO HAPPEN BETWEEN NOW AND THE NEXT ICRC

… a Wish List …



- **Looking forward for solar activity to pick up**
- **Many Flares, CMEs, GLEs …**
- **Multispacecraft Measurements with STEREO, ACE, RHESSI, TRACE, …**
- **Modelling Effort on Acceleration in Impulsive Events, including charge stripping, 3He and Heavy Ion enrichment, and interplanetary propagation**
- **Modelling of CME Propagation, and particle acceleration at the evolving parallel and perpendicular Shock …**

SEE YOU AT THE 31th ICRC