Solar Cosmic Rays in Merida (30th ICRC): New Results and Ideas

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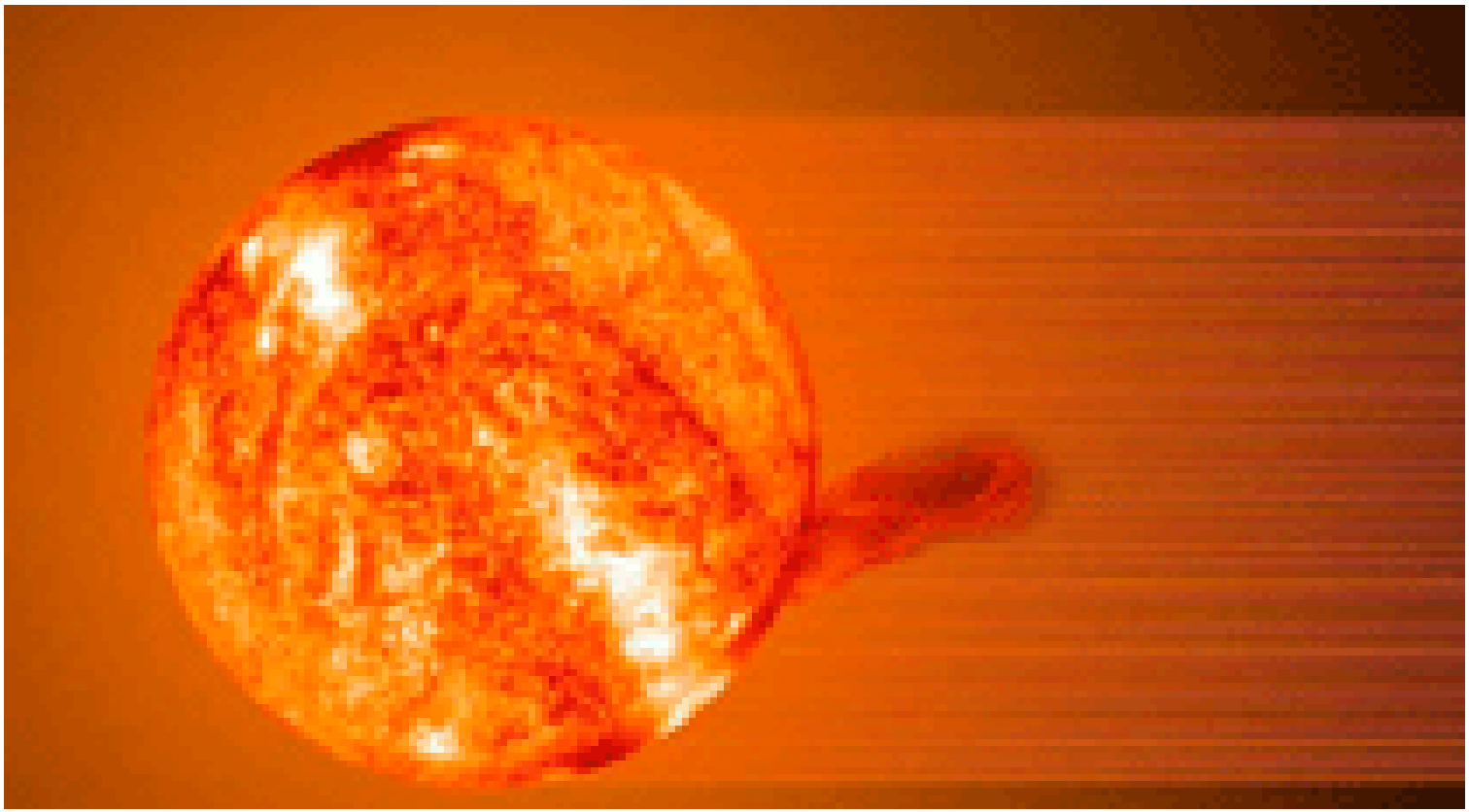
Gran Evento en Merida…

Abstract

- **Based on generous materials of the 30th International Cosmic Ray Conference (Merida, Yucatan, Mexico, 3-11 July 2007), we critically review the most keen, disputable questions of solar energetic particle (SEP) production at/near the Sun. The main of them are following:**
- **Two classes of SEP events: Impulsive vs. Gradual, or SEP event continuum?**
- **Multiple acceleration processes at/near the Sun**
- **High-energy cutoff of solar cosmic ray (SCR) spectrum**
- **Two mechanisms for particle acceleration at the Sun (on the data of the GLE of 20 January 2005)**
- **Two-source acceleration scenario for GLEs: Solar and interplanetary aspects**
- **New concept of Ground Level Enhancement**
- **Long-Standing Problems and Arising matters**

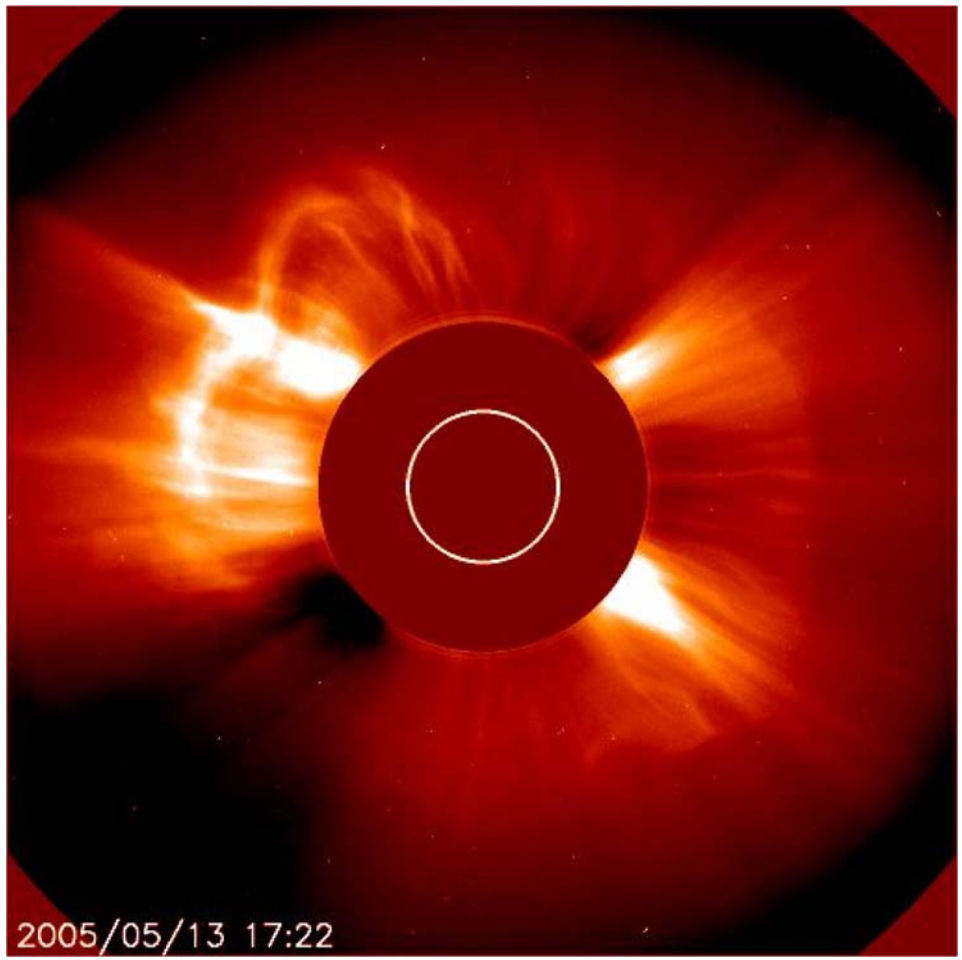
Reality: Our Dynamical and "Mysterious" Sun



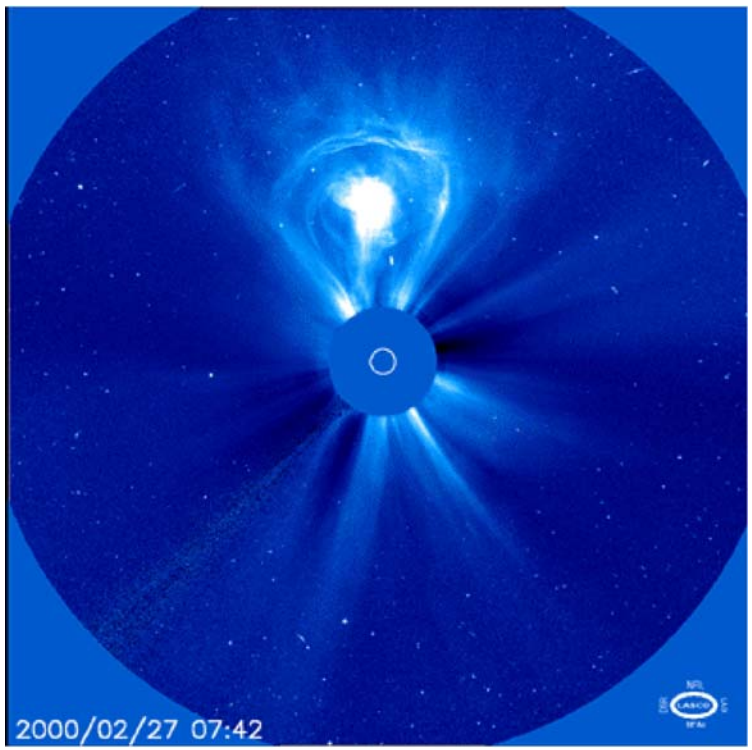
CME / SOHO May 13, 2005

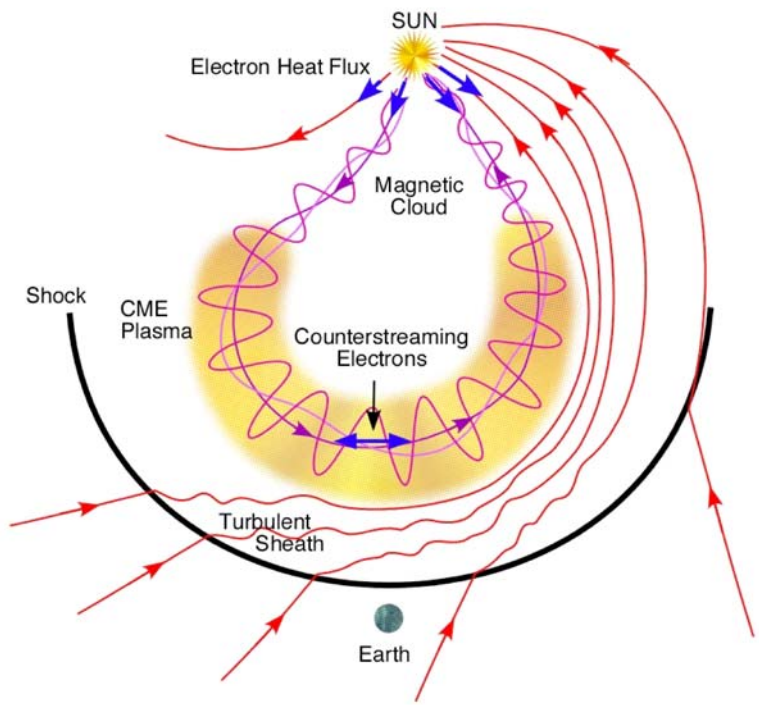
CME / SOHO May 13, 2005 17:22

M8 Flare 16:57

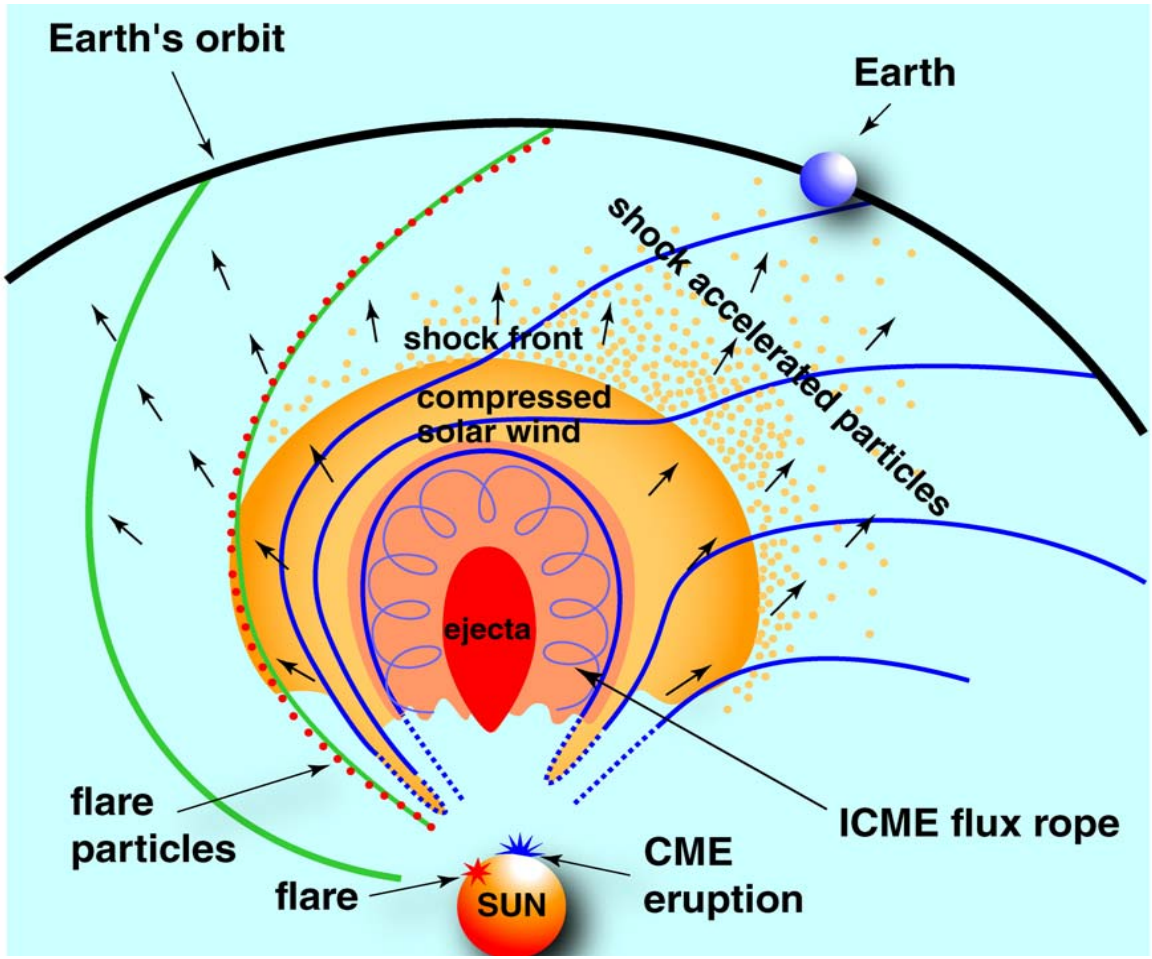


CME and ICME
Zurbuchen & Richardson, 2006





Images vs. Reality



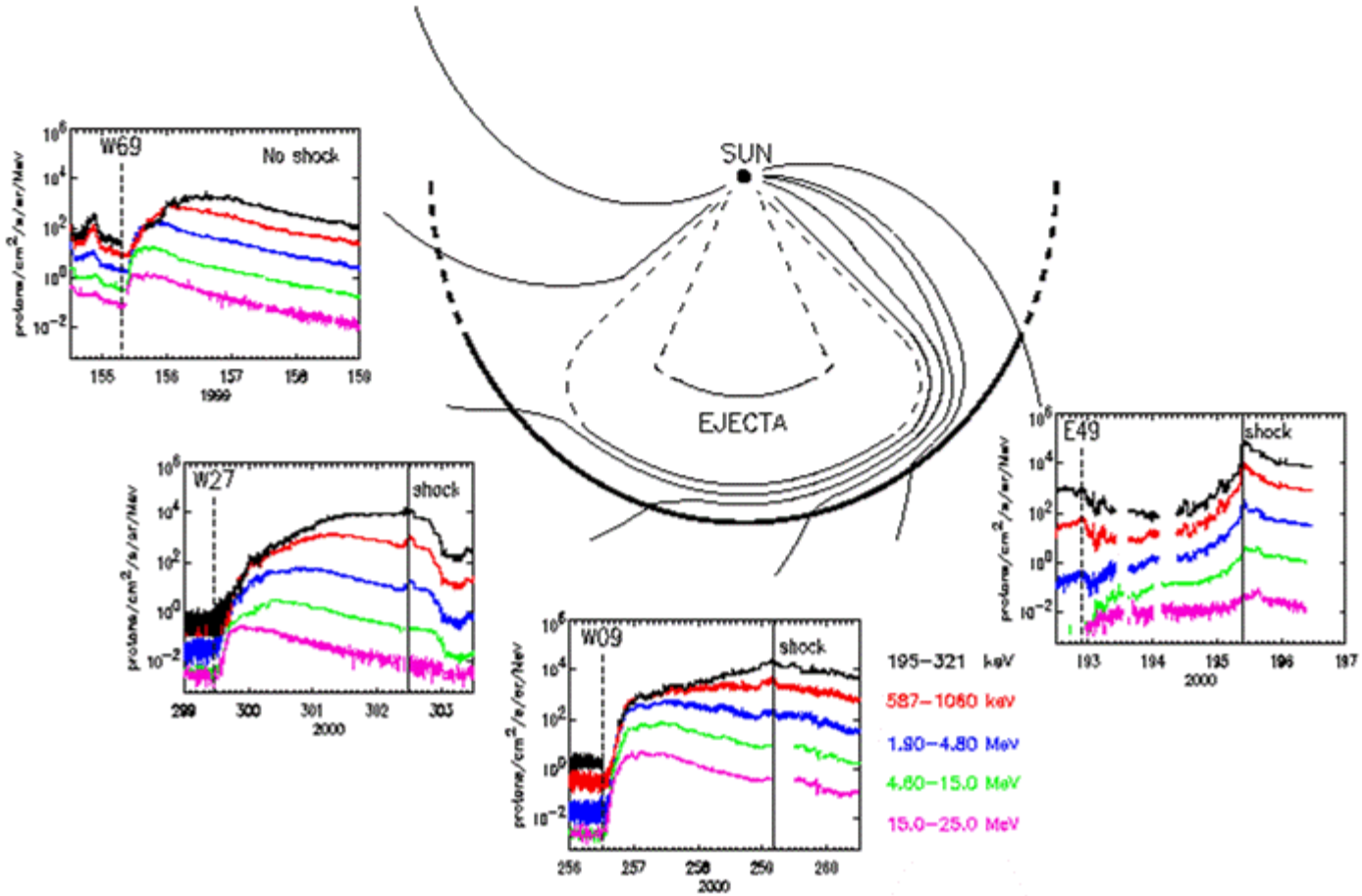
Two classes of SEP events

1. Observational Properties and Underlying Physical Mechanisms: Flare or CME?
2. Interpretation: Impulsive vs. Gradual or SEP Event Conrtinuum?
3. Open Questions in Current Paradigm of SEP acceleration.

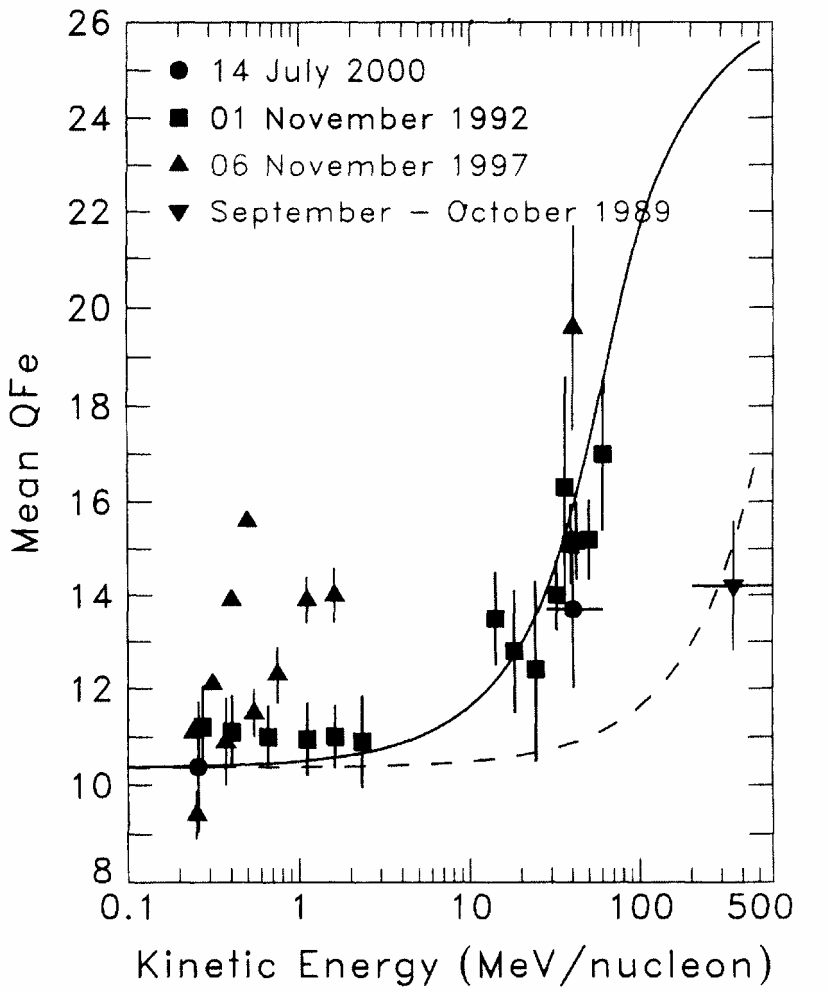
Two Classes of SEP Events (Reames, 1996)

Parameters of particles, observation method	Impulsive events	Gradual events
Particles: $^3He/^4He$ H/He Fe/O *Q*(Fe)	Electron-rich: ~ 1 ~ 1 ~ 10 ~ 20	Proton-rich: ~ 0.0005 ~ 0.1 ~ 100 ~ 14
Duration:	Hours	Days
Longitude cone	<30 degrees	~ 180 degrees
Radio type	III, V (II)	II, IV
X-rays	Impulsive	Gradual
Coronograph	-	CMEs (96%)
Solar Wind	-	IP Shock
Events/year	~ 1000	~ 10

Two Classes of SEP Events (Reames et al., 1996). Dependence of Particular Event, Particle Energy, and Observer's Locations (Cane et al., 2007)



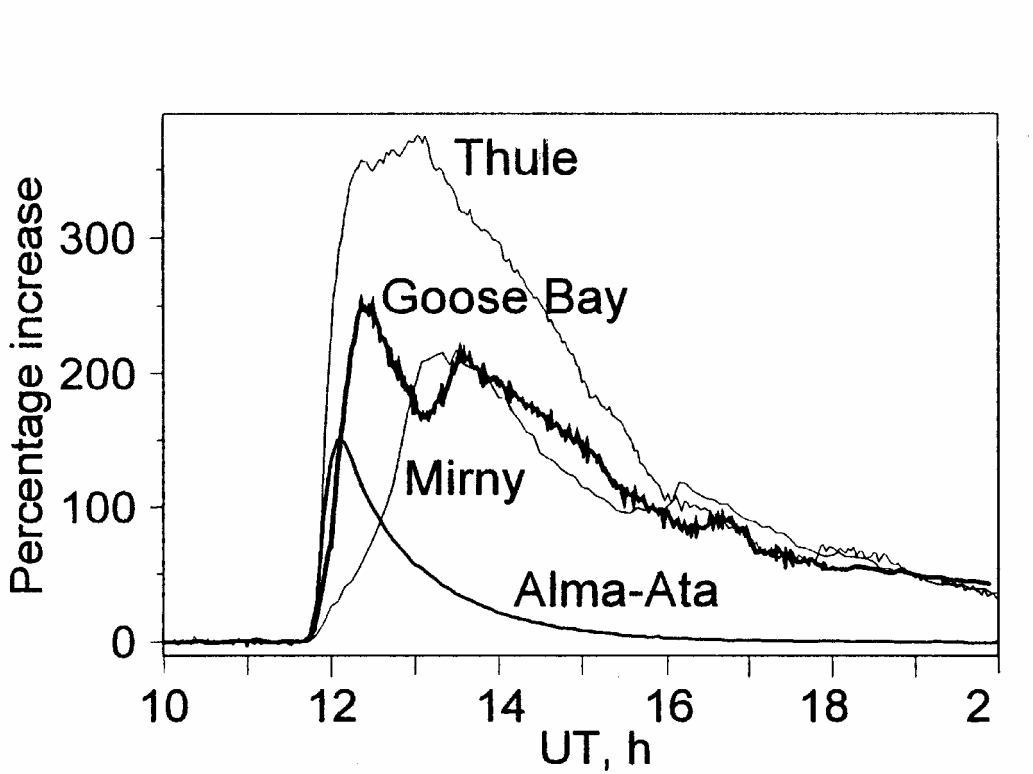
Energy Dependence of the Mean Ionic Charge State of Fe ions (Tylka *et al*., 2001).



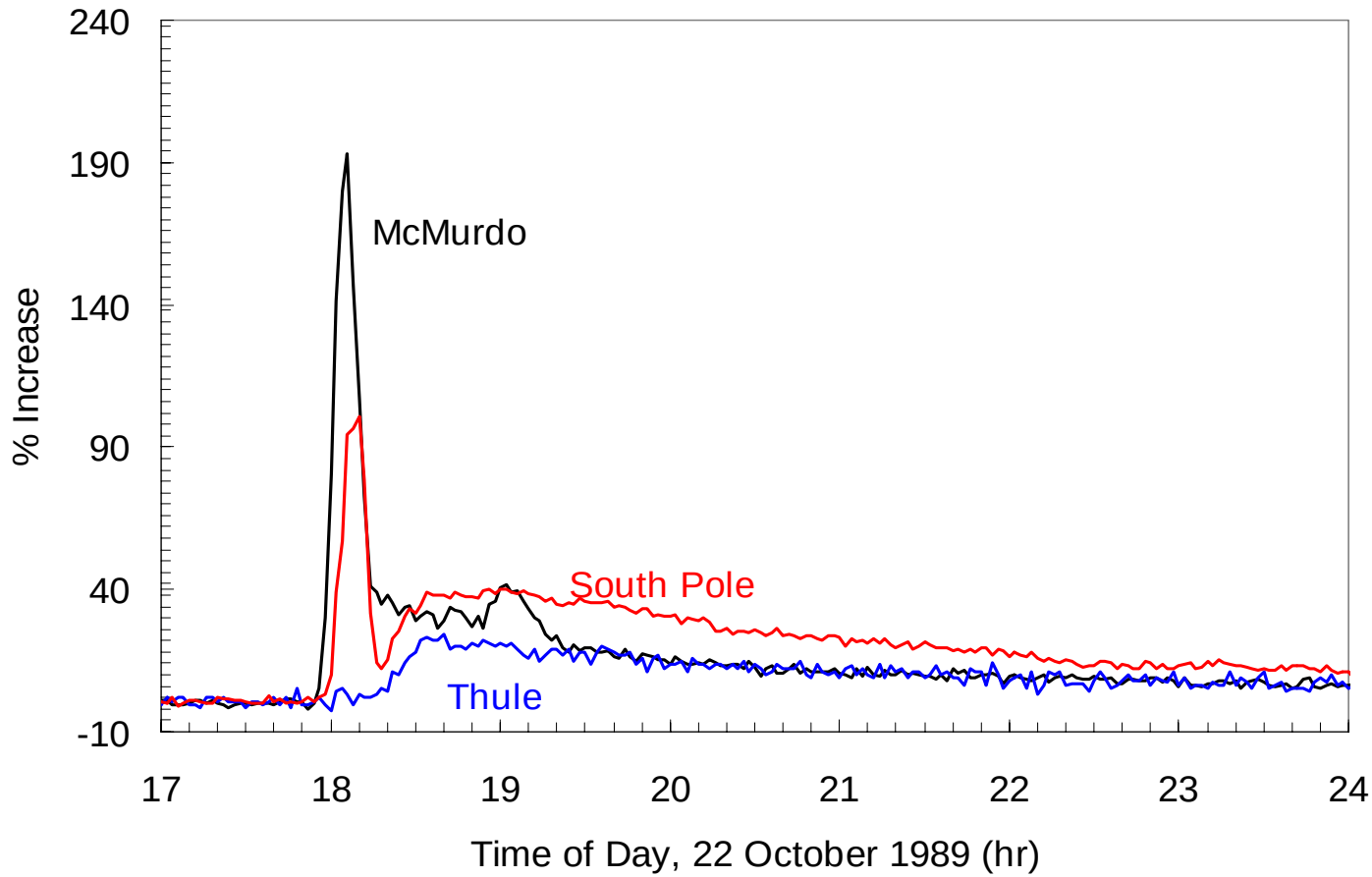
2. Multiple Acceleration Processes at/near the Sun

- Particle Intensity-Time Profiles
- Manifestations in X-Rays and Gamma-Radiation
- Escaping and Precipitating SEPs

GLE of 29 September 1989: Two-Peak Structure

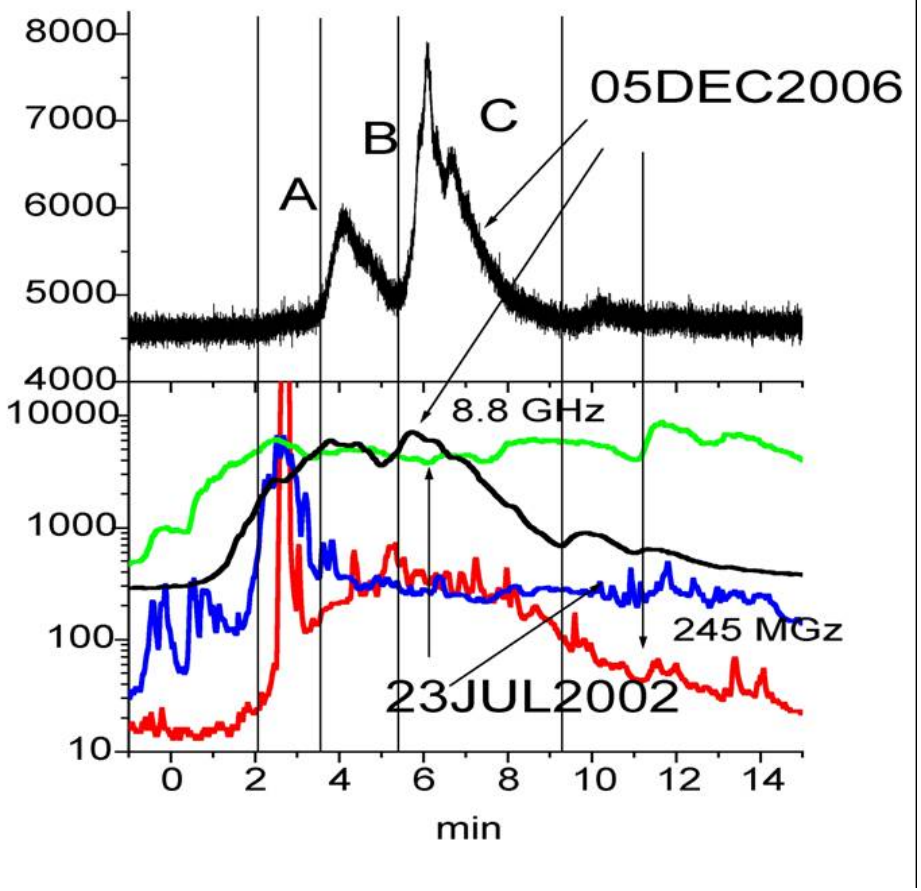


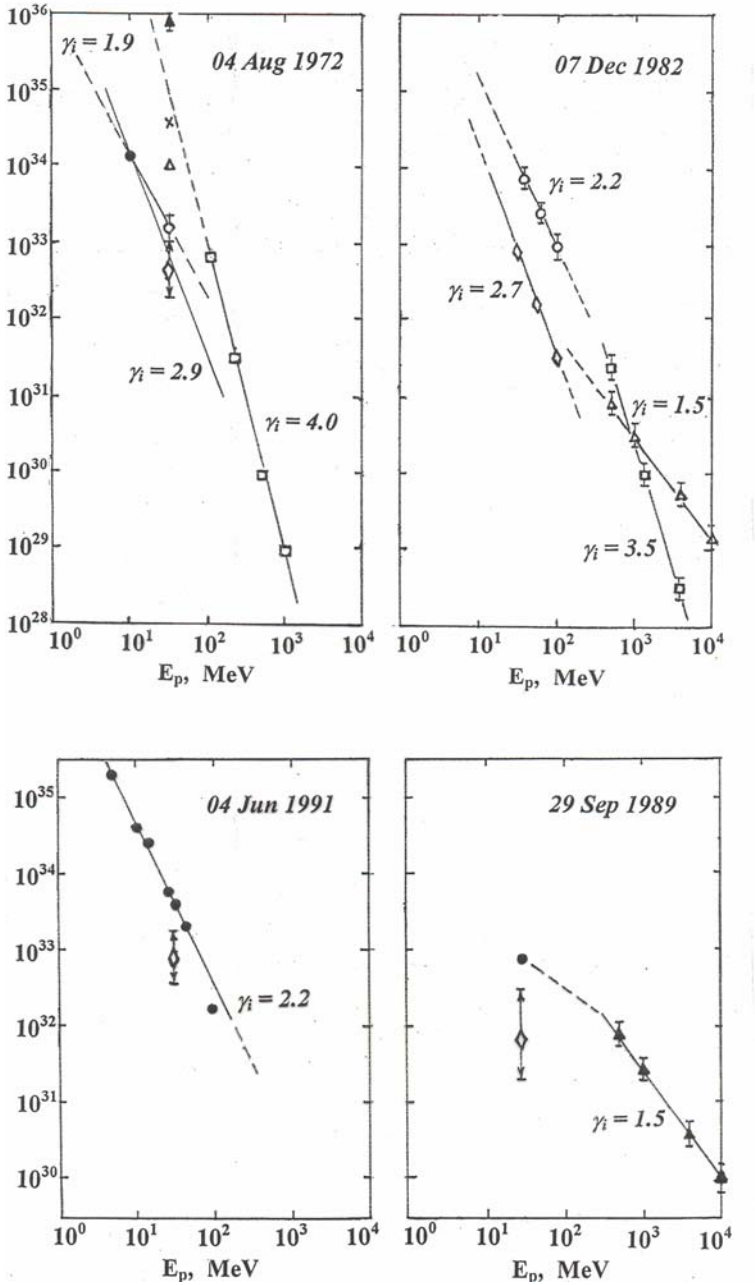
P1: A Common Occurrence
(After Shea and Smart, 1996)



Paper 897, McCracken & Moraal

Multiple Acceleration Processes at/near the Sun (Struminsky & Zimovets, 2007)





Source Spectrum by Different Data:

Integral energy spectra of accelerated solar protons in the sources by estimates for the four SEP events (Miroshnichenko, 2003).

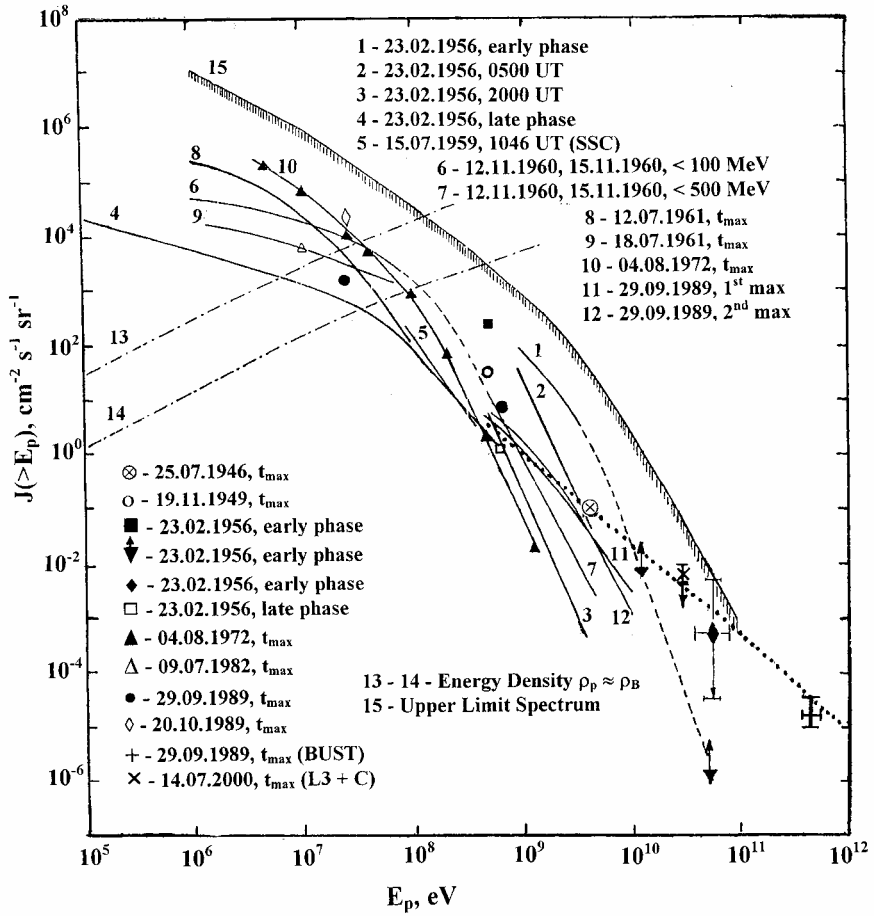
A number of escaping particles is methodically **higher** than a number of precipitating (interacting) ones.

3. High-Energy Cutoff of Solar Cosmic Rays

- Observational and Theoretical Aspects
- Ground-Based Observations for Protons
- Spectral Breaks in SEPs for Heavier Ions

Solar Cosmic Rays: Upper Limit Spectrum:

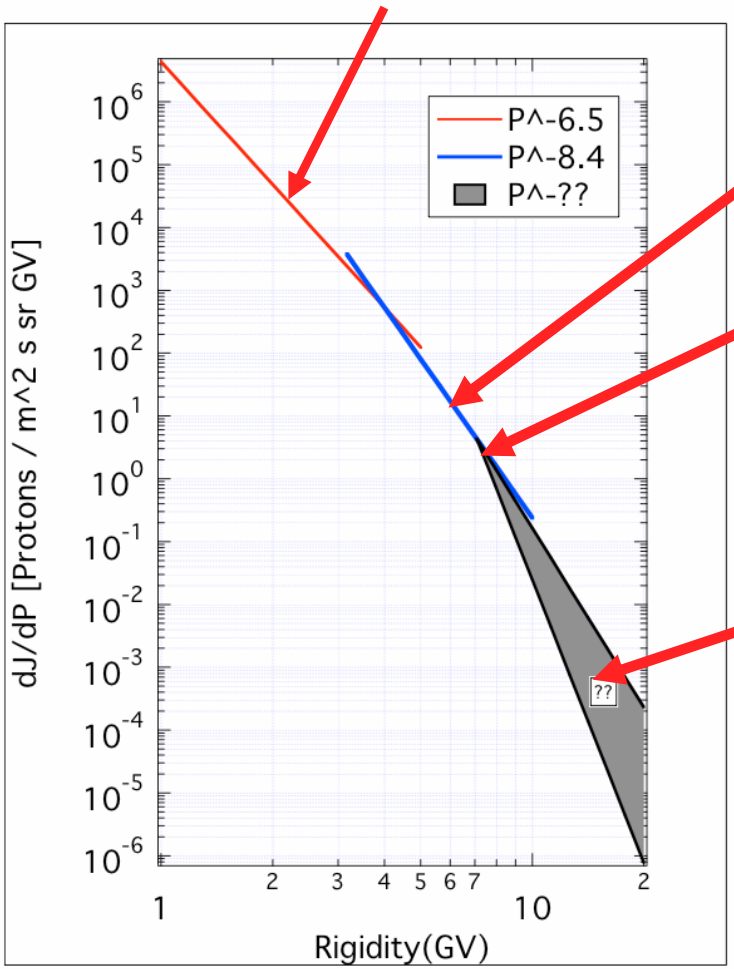
Miroshnichenko, 2003; also Muraki et al., 2007



The integral energy spectra for the largest proton events observed near the Earth in 1942-2000. The spectrum for galactic cosmic rays is also shown (dotted line).

The 20 January 2005 GLE: Rigidity Spectrum

Durham/Mt.Washington



Milagro/Climax

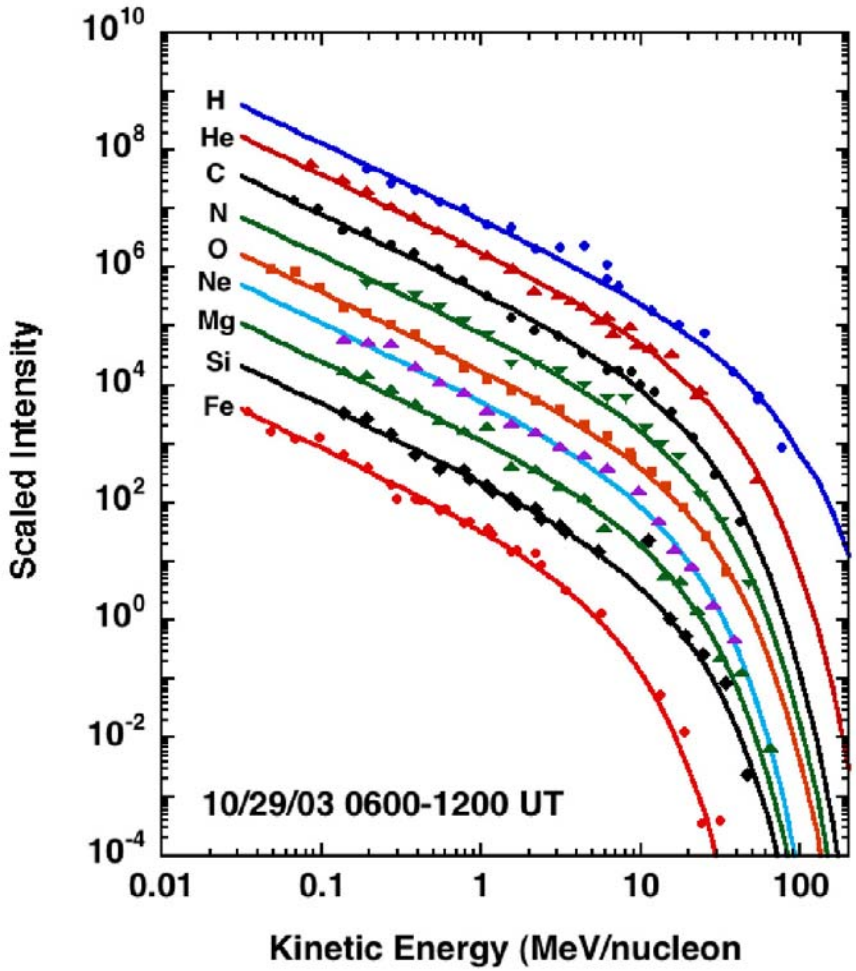
Milagro/Milagro

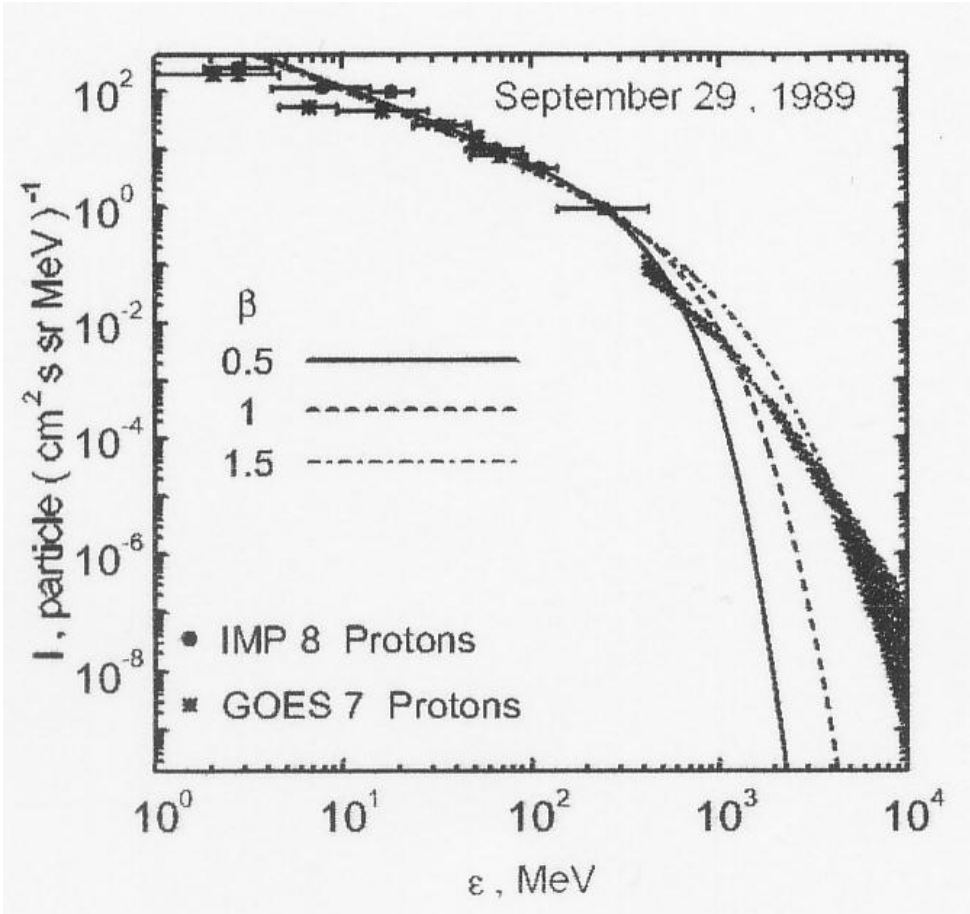
Higher, unanalyzed Milagro channels

Spectral index softens from 6.5 to ~8 at ~4GV

Paper 1152, Morgan et al.

Mewaldt et al., 2007: Spectral Breaks on 29 October 2003 (Shock Acceleration, Ellison-Ramaty, 1985)





GLE of 29 September 1989:

Proton energy spectrum by IMP 8, GOES 7, NM (Lovell *et al*. 1998, shaded) and calculated spectra (Berezhko and Taneev, 2003).

Diffusive Shock Acceleration;

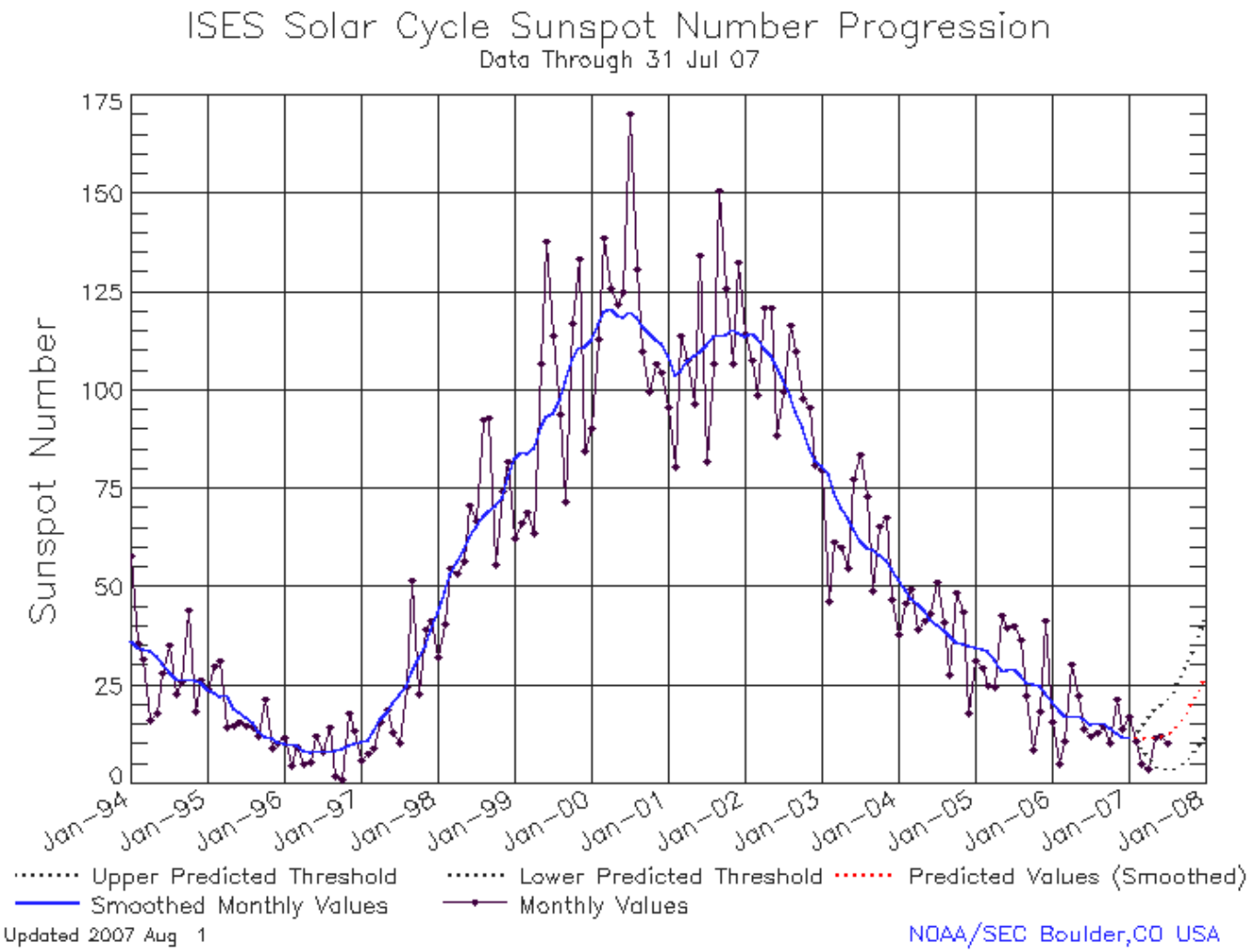
β - Alfvén wave spectral index.

Emax = 300 MeV?

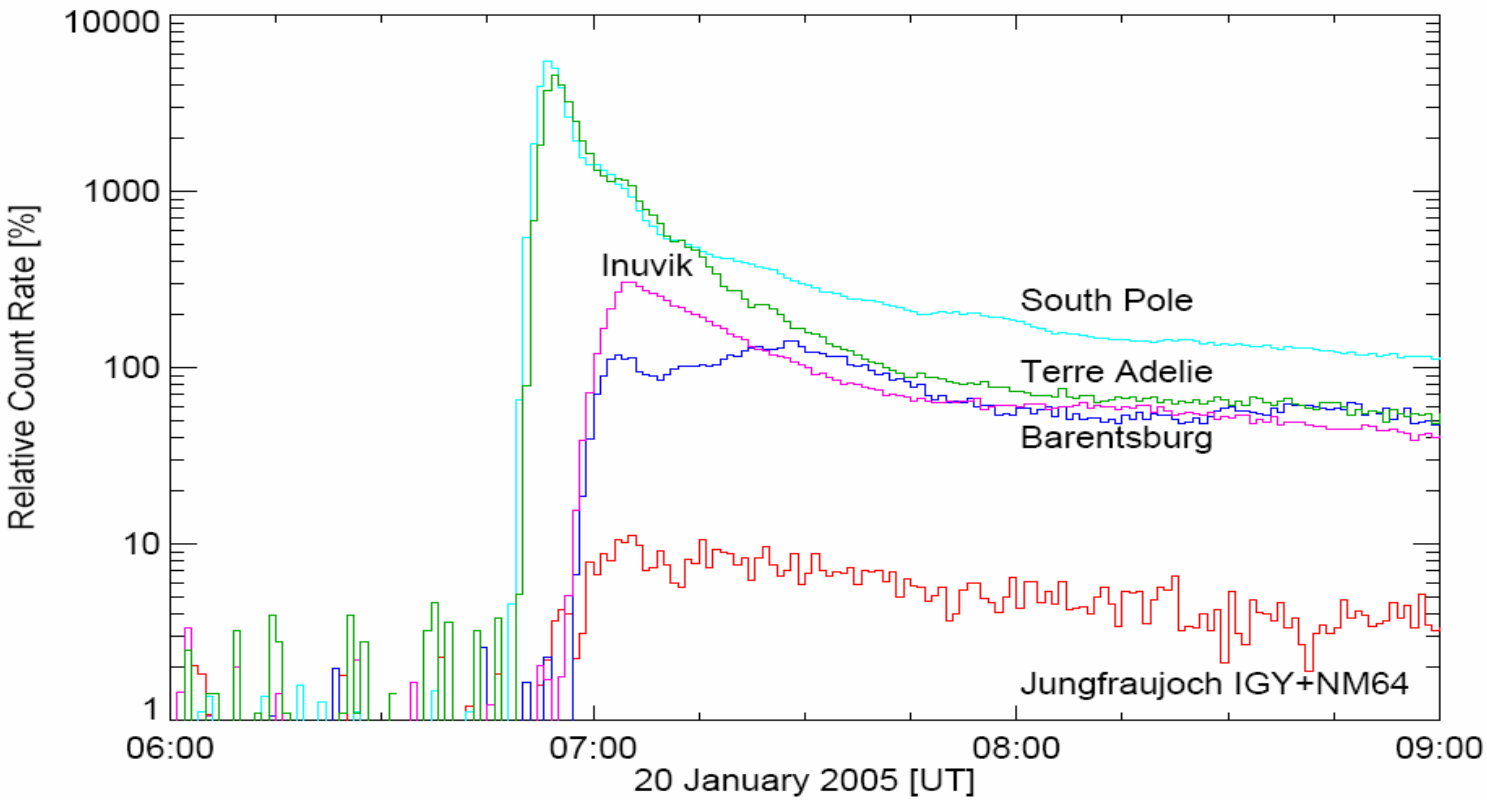
4. Two Mechanisms for Particle Acceleration at the Sun

- Two last GLEs of the 23rd of Solar Activity
- GLE69: 20 January 2005
- GLE70: 13 December 2006

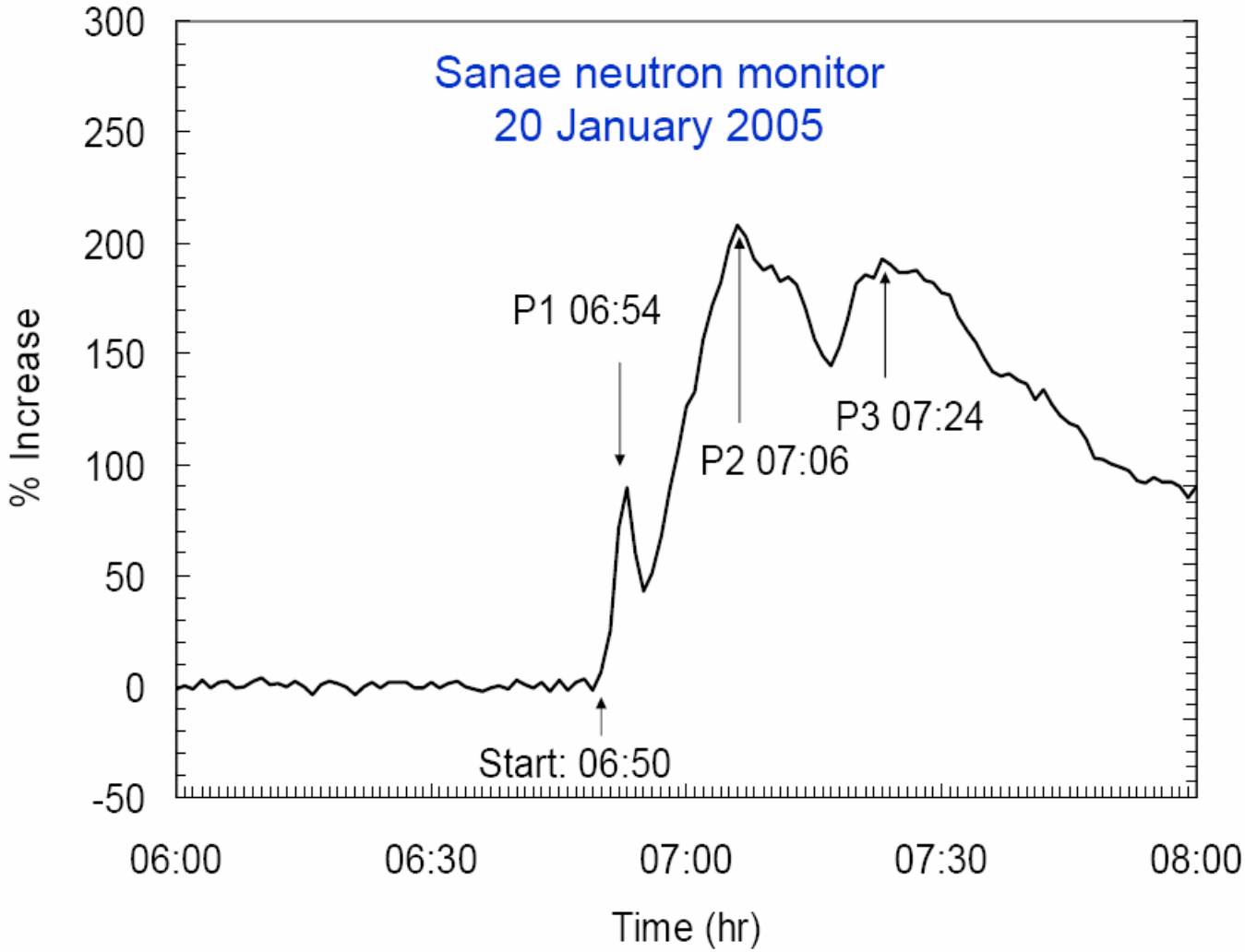
Solar Activity Cycle 23



The 20 January 2005 GLE69: Largest One after the GLE05 of 23 February 1956

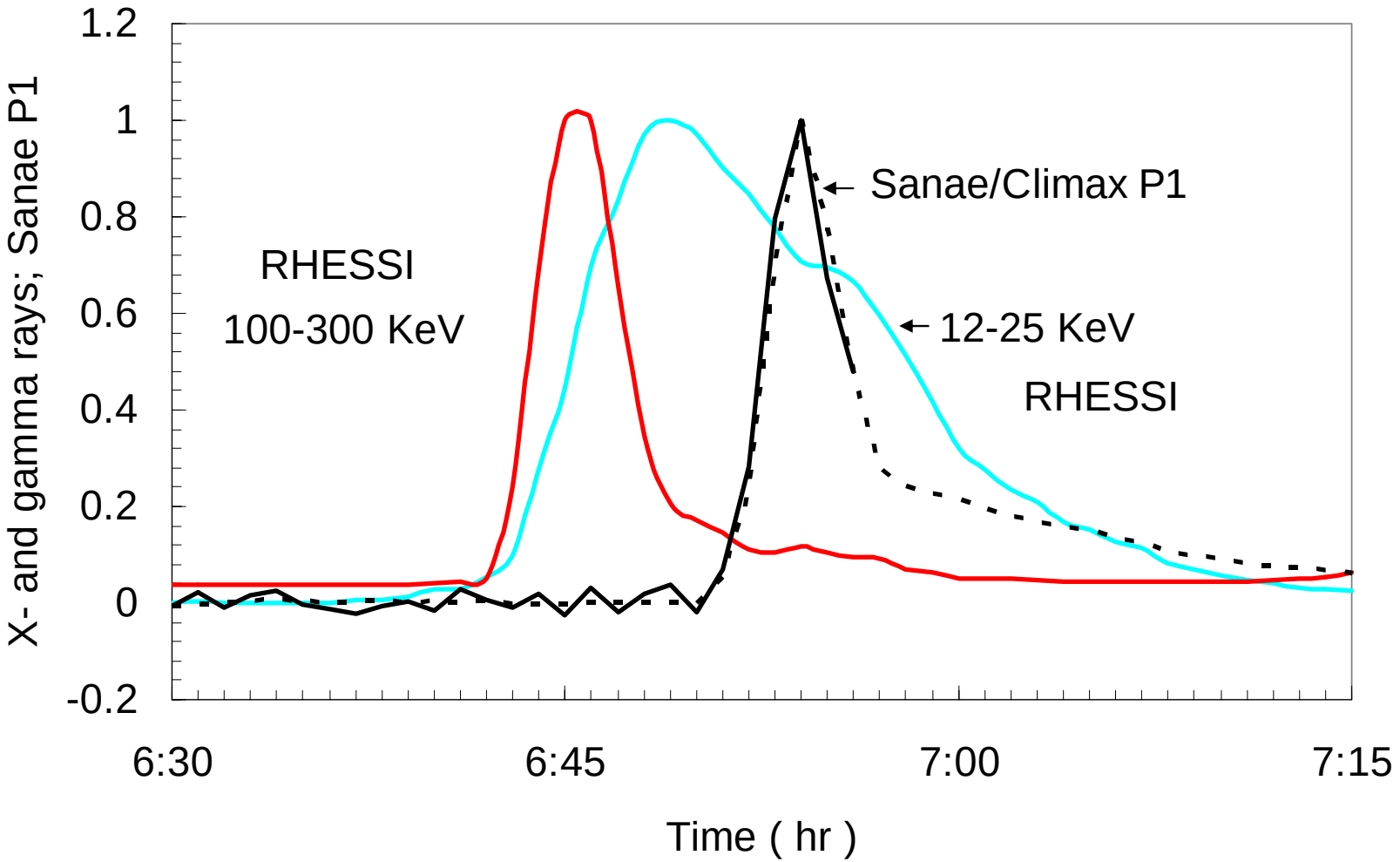


The 20 January 2005 GLE: Two Acceleration Mechanisms?



Paper 862, Moraal et al.

The 20 January 2005 GLE: Two Acceleration Mechanisms?



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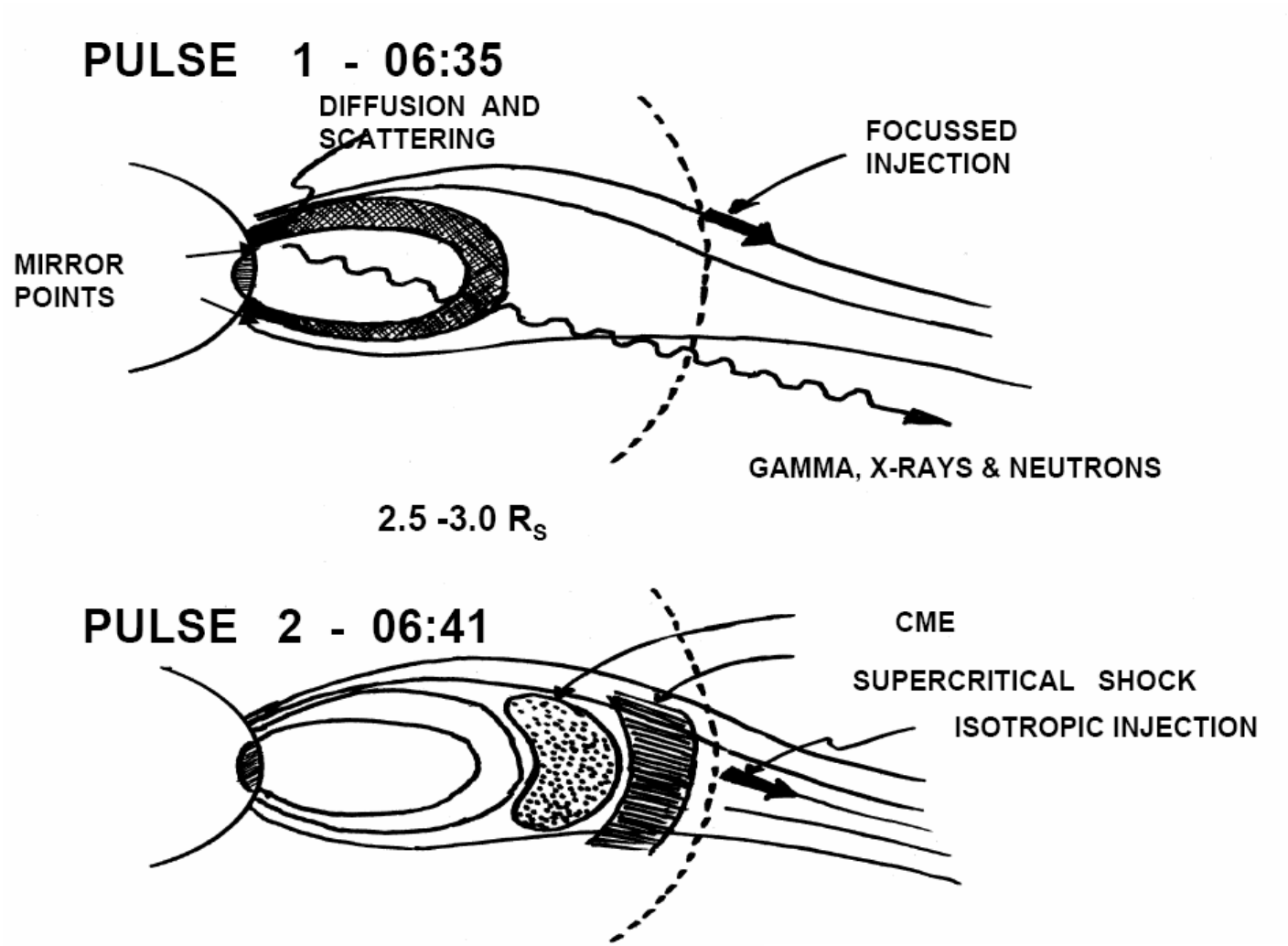
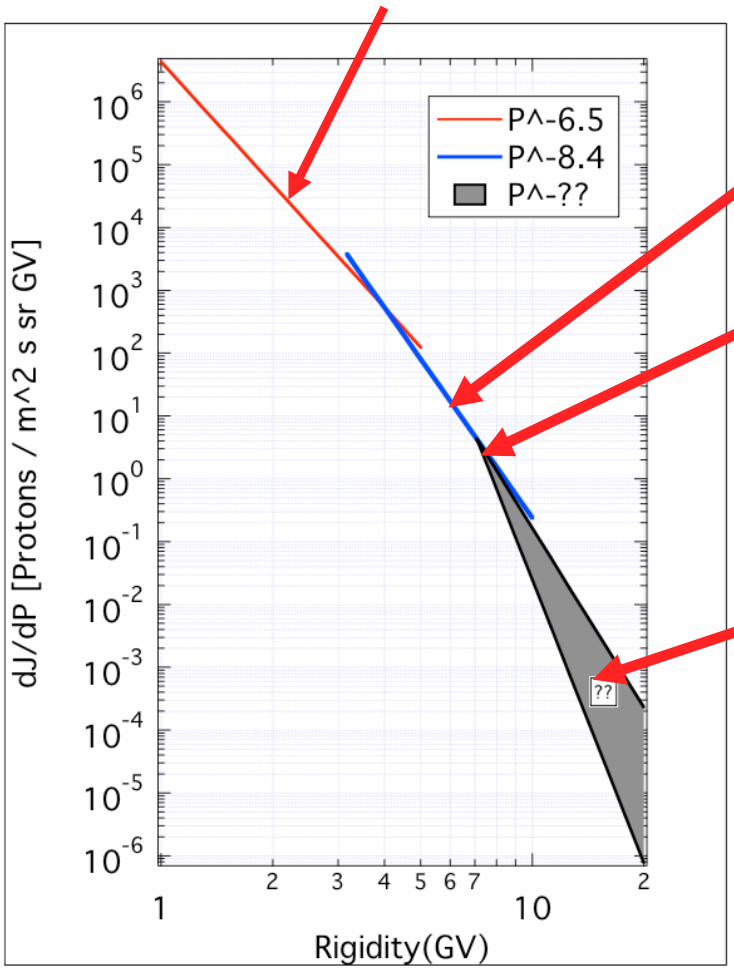
The 20 January 2005 GLE: Two Acceleration Mechanisms?



Paper 897, McCracken & Moraal

The 20 January 2005 GLE: Rigidity Spectrum

Durham/Mt.Washington



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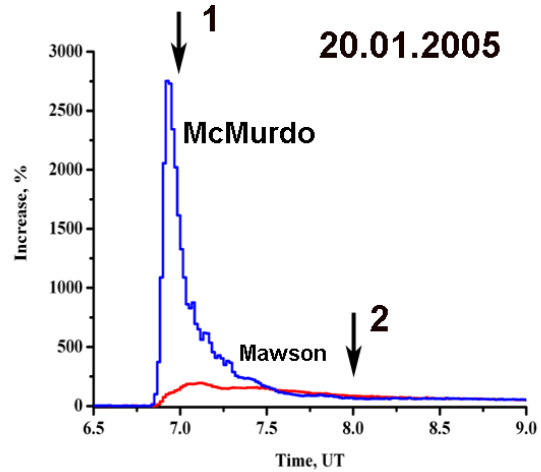
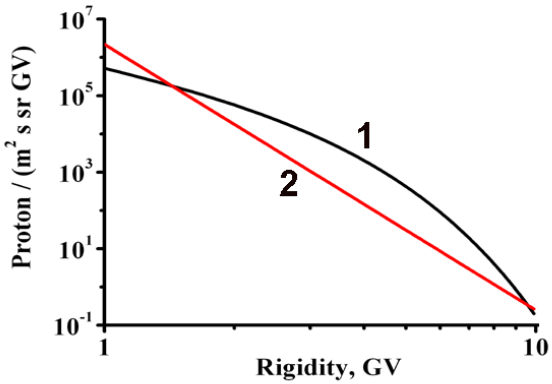
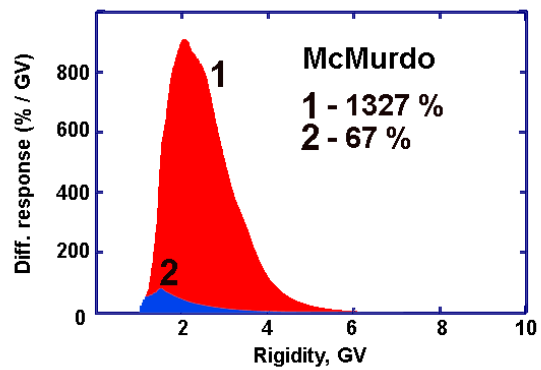






Two-component GLE of 20 January 2005

(Vasheyuk et al., 2005, 2007): Intensity-Time Profiles, Rigidity Spectra, and NM Response Functions

THE GENERIC SOLAR ENERGETIC PARTICLE EVENT (GLE and Lower Energies)

THE IMPULSIVE PHASE

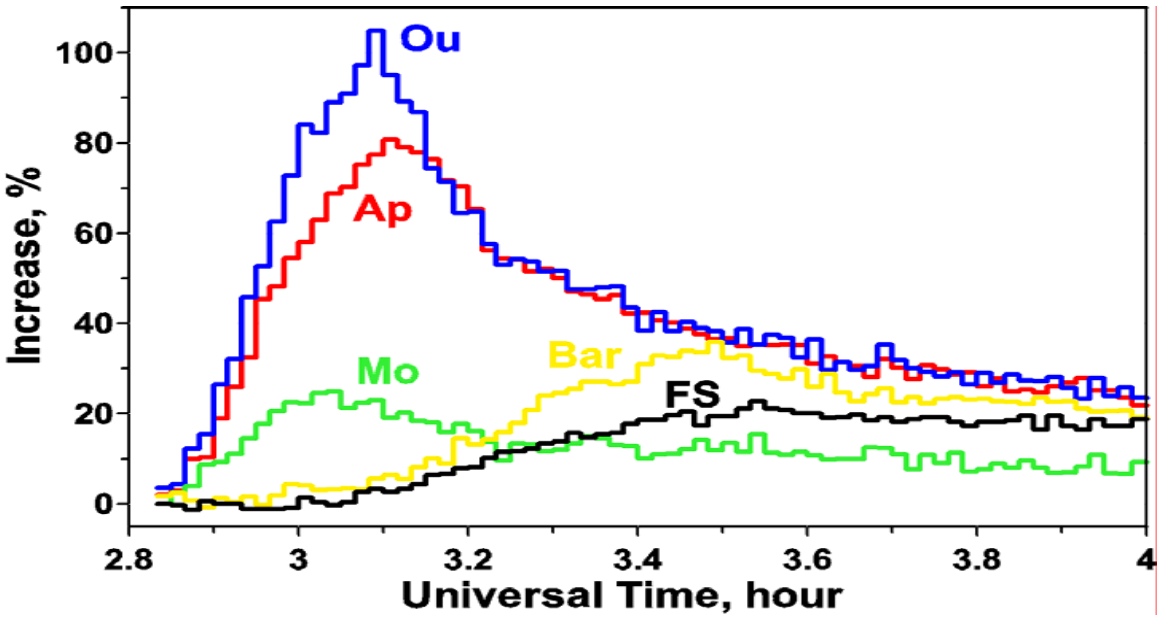
- A highly anisotropic pulse of cosmic rays at Earth
- Coincident release of high energy gamma and neutron pulses
- Hard cosmic ray spectrum
- Acceleration low in corona
- Scatter free propagation due to focusing close to the Sun.
- High He/He ratio; high ionization state.
- From western third of solar disk

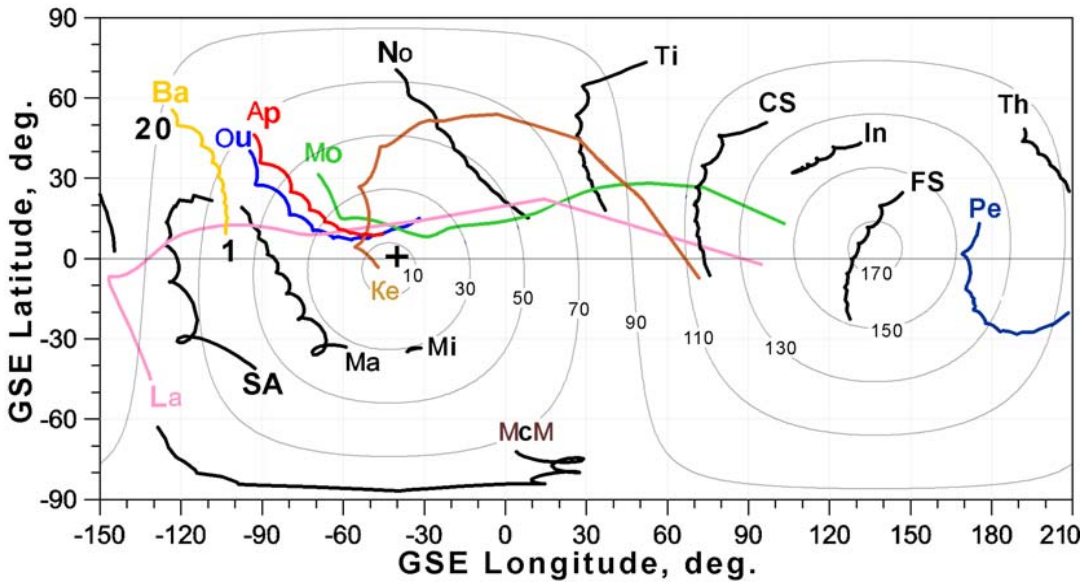
THE GRADUAL PHASE

- Mildly anisotropic pulse of cosmic radiation at Earth
- Soft cosmic ray spectrum
- Acceleration high in the corona, >2.5-3.0 R_s
- Diffusive propagation to Earth
- From central regions of solar disk

Similar conclusion by Vashenyuk et al., Paper 643 Paper 897, McCracken & Moraal

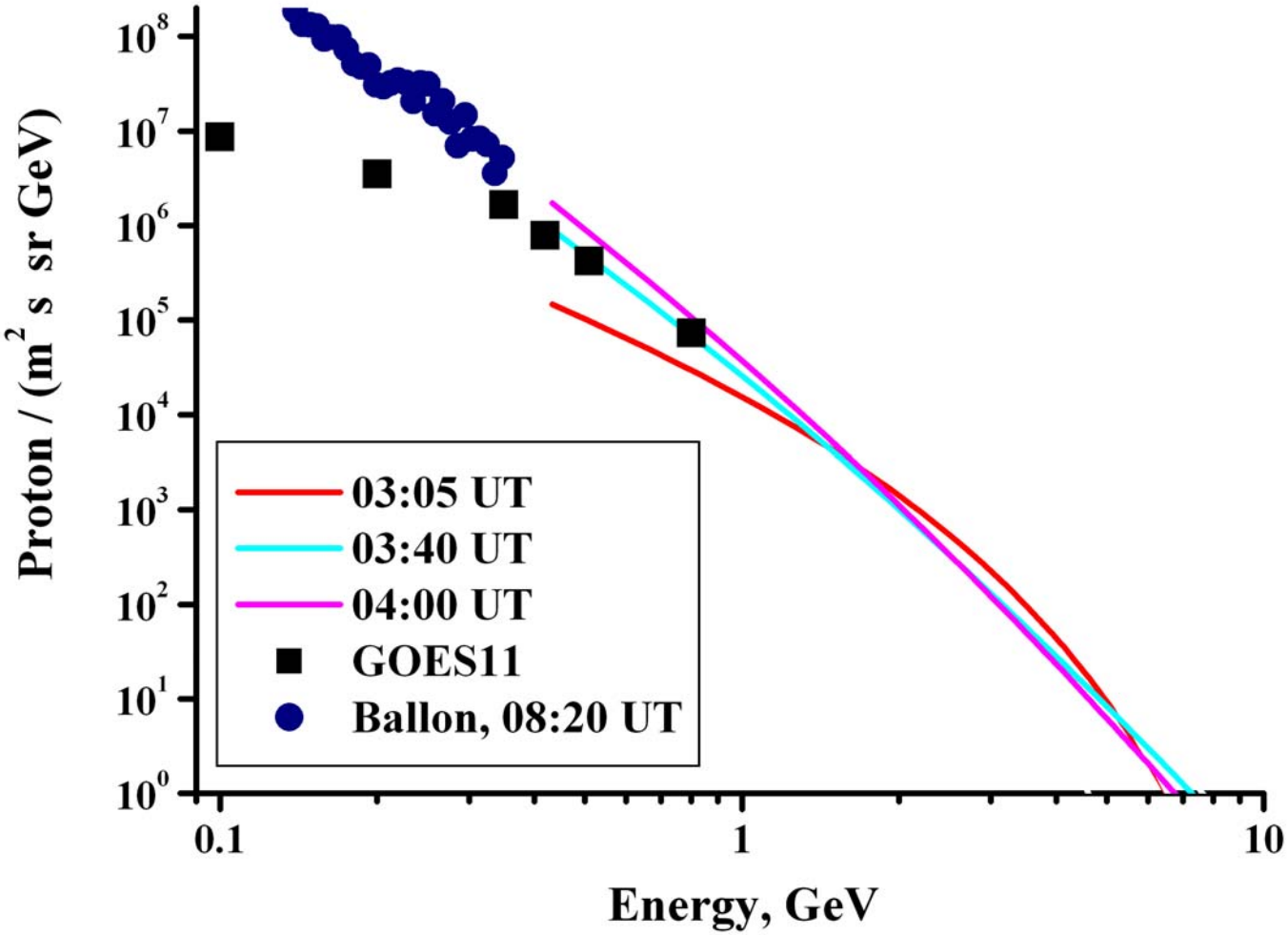
The 13 December 2006 GLE70





Paper 643, Vashenyuk et al.

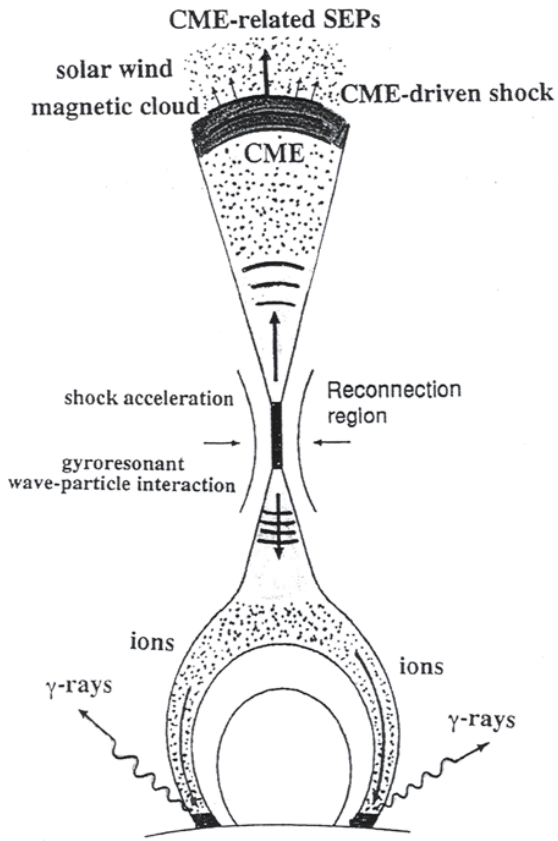
13 December 2006 GLE70: Energy Spectrum



Paper 643, Vashenyuk et al.

5. Two-source acceleration scenario for GLEs

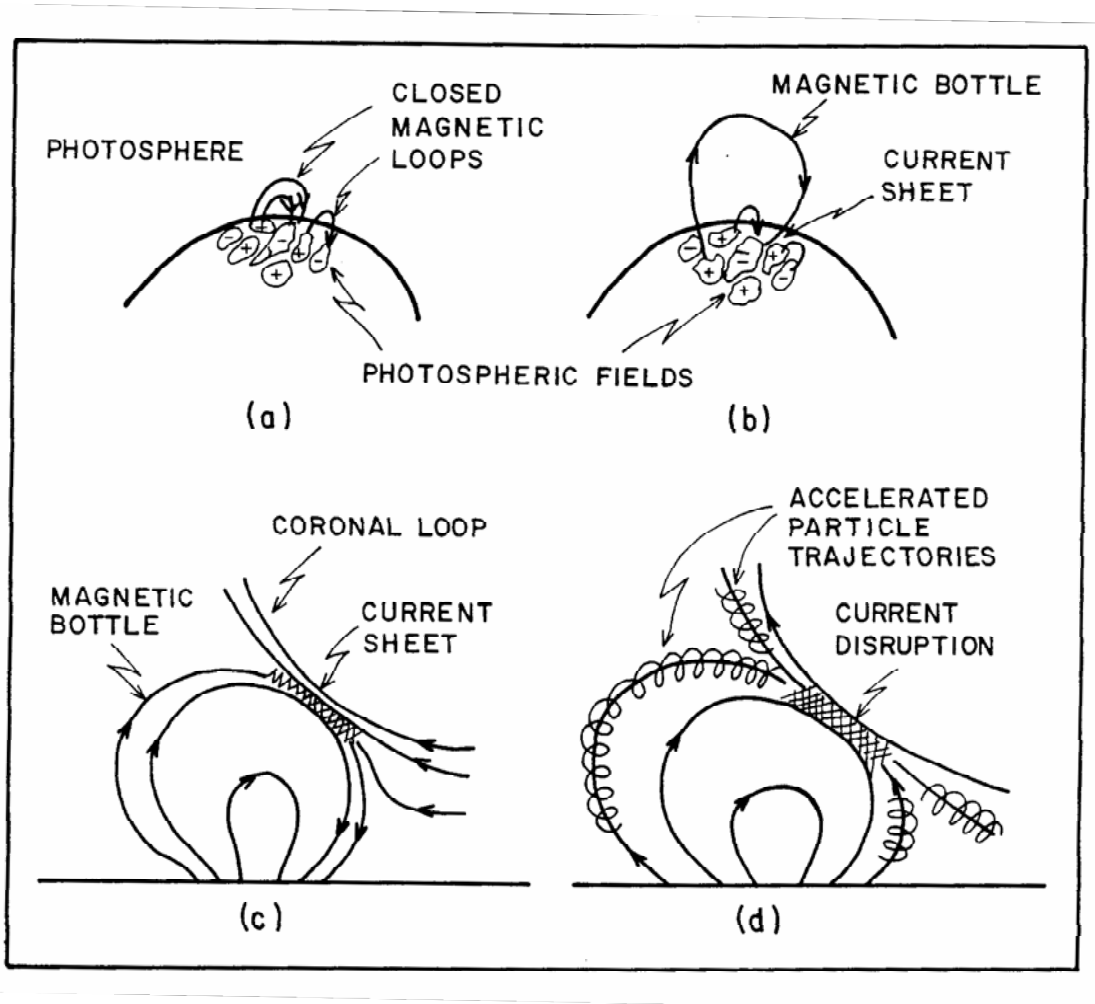
- Two-source model for GLEs
- Magnetic Reconnection in Acceleration Scenarios
- Extended Coronal Structures
- Propmt and Delayed Components
- Statistics of Two-Component GLEs

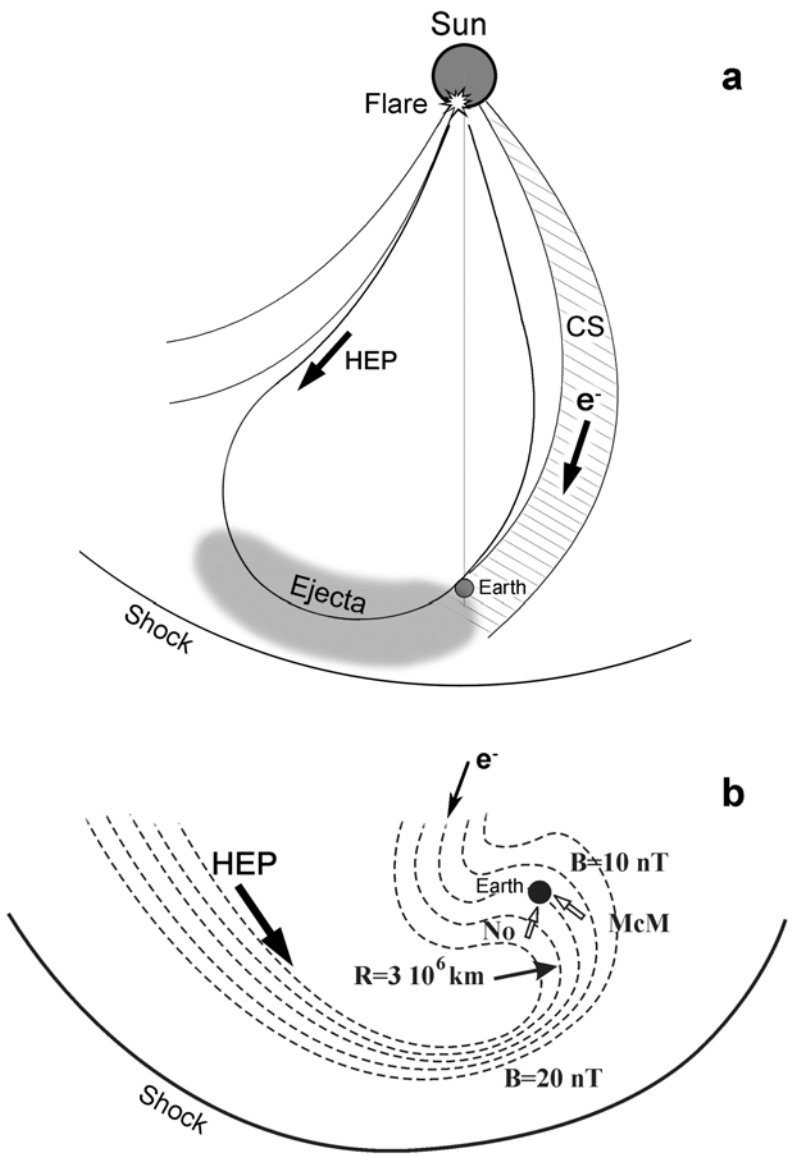


High energy particle production processes

Production of SEPs in the Solar Atmosphere: Separation of Two Classes of SEP Events – Impulsive and Gradual Ones (Yoshimori et al., 2000)

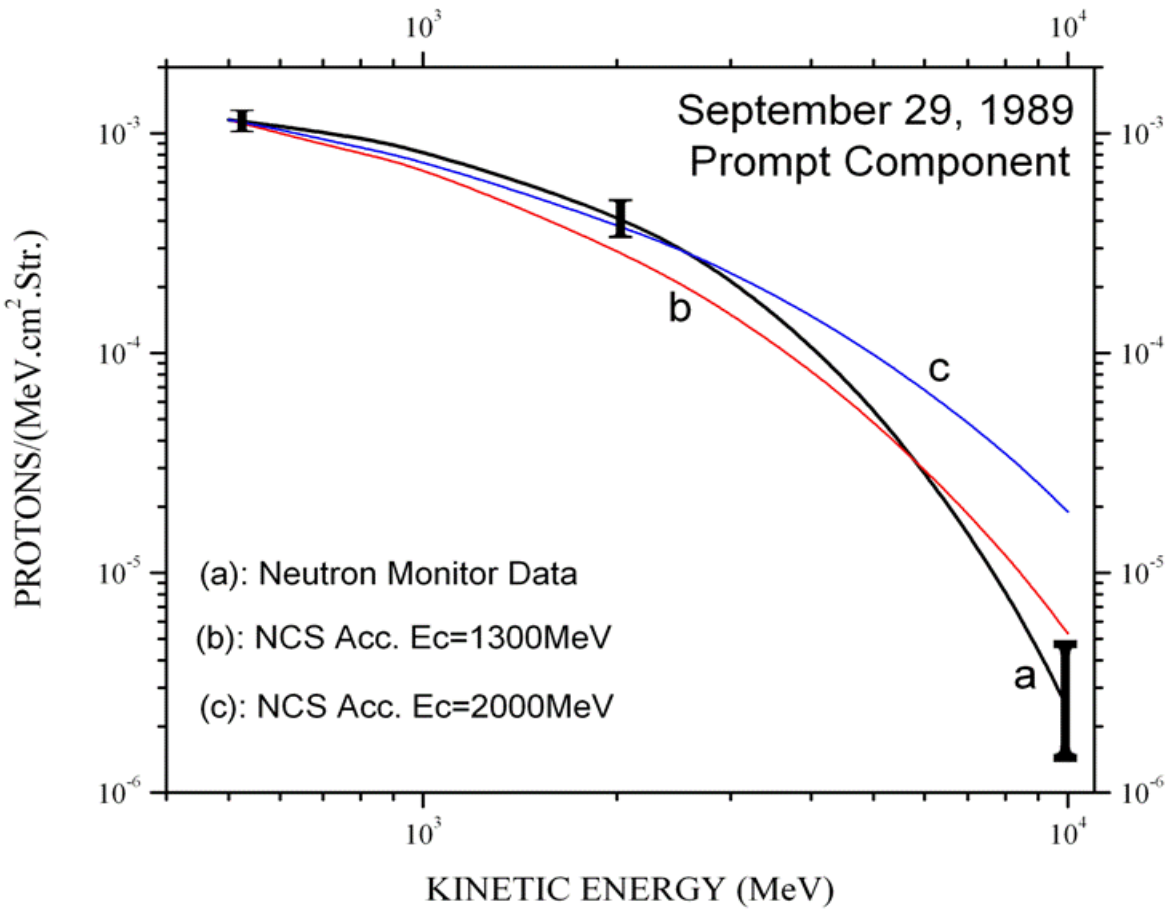
Two-Source Model (Perez-Peraza et al., 1992)





a. Proposed model for the IMF structure during the GLE of 28 October, 2003; b. Spatial structure of the IMF near the Earth, reconstructed with use of IMF and solar wind data (Miroshnichenko et al., JGR, 2005)

Direct Field Acceleration in a Magnetic Neutral Current Sheet (Perez-Peraza et al., 2007)



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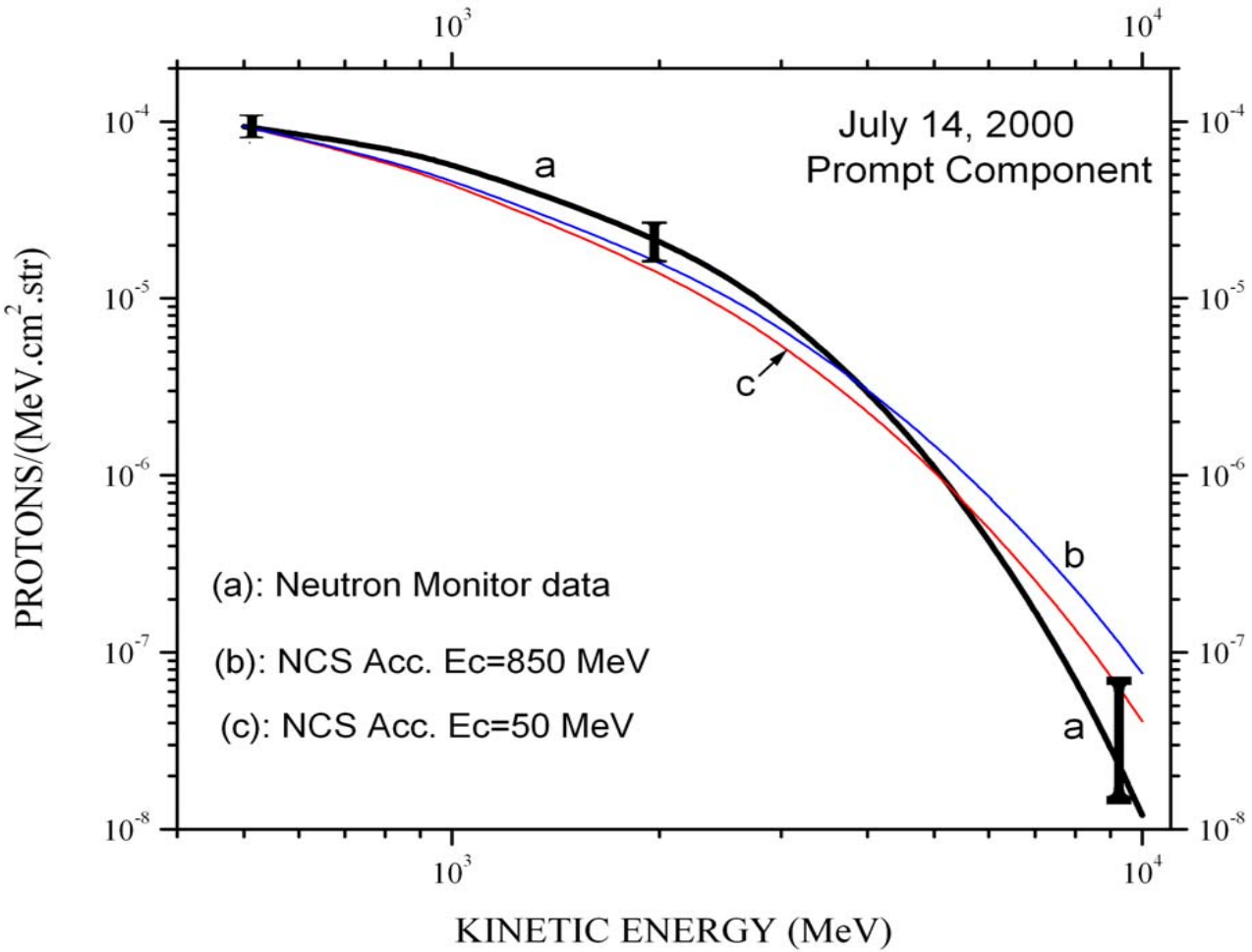
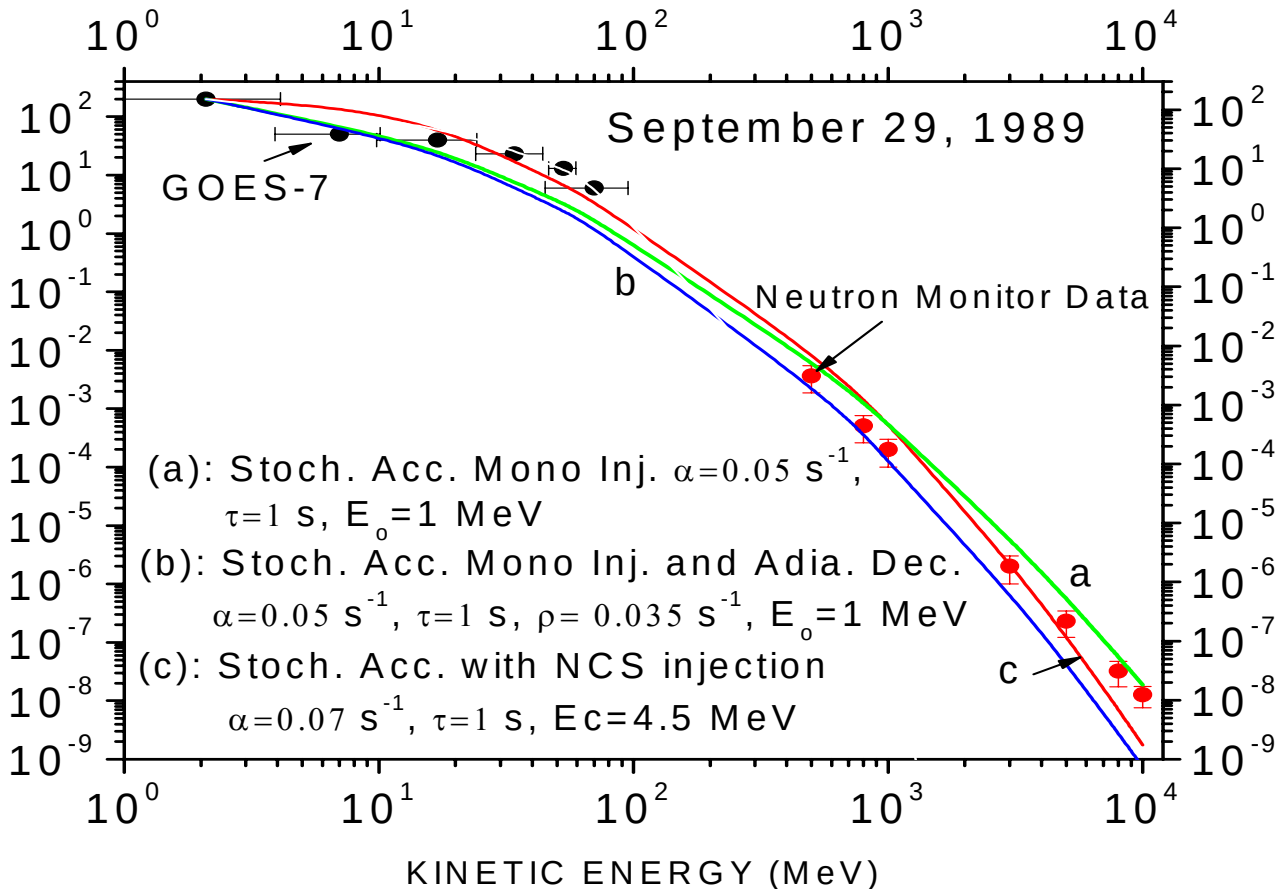


Stochastic Process in a Fast Magnetosonic Wave Environment (Perez-Peraza et al., 2007)



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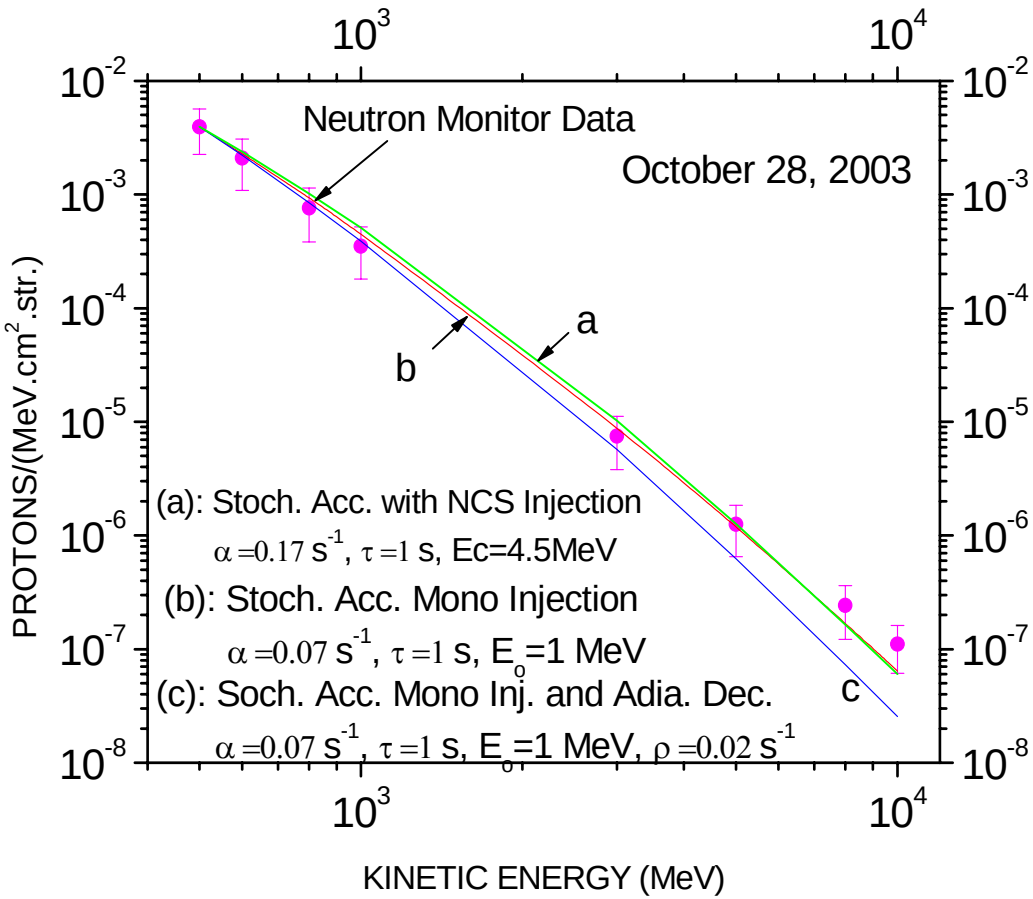


Large GLEs of 1956-2006 with Two Components (Vashenyuk et al., 2007)

GLE No.	Date of GLE	Type II onset	Flare importance	Helio-coordinates	PC spectrum (exponential) J_0	PC spectrum (exponential) E_0	DC spectrum (power-law) J_1	DC spectrum (power-law) γ
1/05	230256	0331*	3B	N25W85	1.4×10^6	1.30	4.2×10^6	5.2
2/31	070578	0327	1B/X2	N23W82	5.6×10^4	0.71	1.2×10^4	4.1
3/38	071282	2344	1B/X2.8	S19W86	5.7×10^3	0.65	7.2×10^3	4.5
4/39	160284	0858	-/-	S??W132	-	-	5.2×10^4	5.9
5/42	290989	1133	??/X9.8	S24W105	1.9×10^4	1.54	3.5×10^4	4.1
6/44	221089	1805	2B/X2.9	S27W31	7.5×10^4	0.87	1.5×10^4	6.1
7/47	210590	2219	2B/X5.5	N35W36	6.3×10^3	0.83	2.7×10^3	4.1
8/55	061197	1155	2B/X9.4	S18W63	7.3×10^3	1.20	5.0×10^3	4.3
9/59	140700	1020	3B/X5.7	N22W07	3.3×10^5	0.35	2.0×10^4	6.4
10/60	150401	1319	2B/X14.4	S20W85	1.3×10^5	0.53	3.5×10^4	5.3
11/65	281003	1102	4B/X17.2	S16E08	1.4×10^4	0.59	1.5×10^4	4.4
12/67	021103	1703	2B/X8.3	S14W56	5.6×10^4	0.33	2.7×10^3	6.6
13/69	200105	0644	2B/X7.1	N14W61	2.5×10^6	0.49	7.2×10^4	5.6
14/70	131206	0226	2B/X3.4	S06W24	1.1×10^6	0.33	4.4×10^4	5.5

6. New Concept of GLE: Solar and Interplanetary Aspects

- Concept of Multiple Acceleration Processes at/near the Sun
- Extended Coronal Structures
- Two Separate Sources of Acceleration
- CME-Driven Shocks
- Scattering Conditions
- Two Different Paths for PC & DC Particles in the IMF

Two Components: Interplanetary vs. Solar Origin?

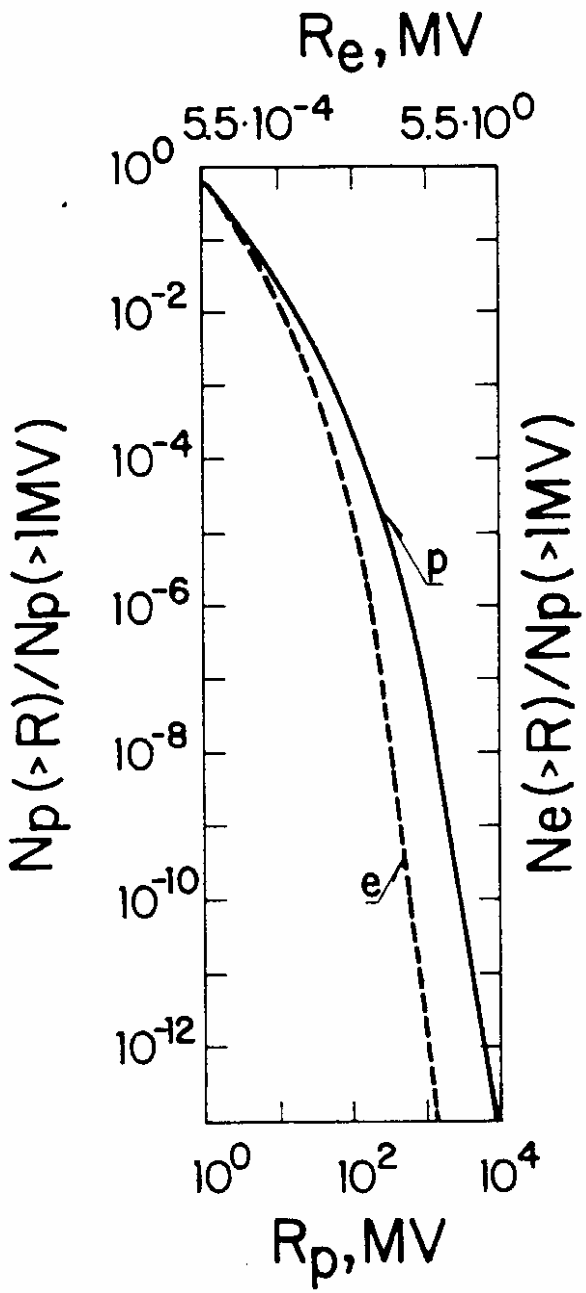
- **Scattering conditions as a cause of “spike” in the SCR intensity (Fedorov & Shakhov, 1993; Earl, 1995; Fedorov et al., 1995; Ruffolo & Khumlumlert, 1995, and others).**
- **Two different paths for PC & DC particles in the IMF (Cramp et al., 1997)**
- **Two individual injections (Torsti et al., 1991, 1992)**
- **Dual acceleration/release processes (Shea & Smart, 1997; Cramp et al., 1997)**
- **Two separate sources in extended coronal structures (Miroshnichenko et al., 1995, 1996, 2000)**
- **GLEs as a separate class of SEP events (Shea & Smart, 1996, 1997; Miroshnichenko et al., 2000, Miroshnichenko, 1997, 2001; Vashenyuk et al., 2005, 2006).**

Special Workshop on GLE Concept and NM Status (SEE2007, Greece)?

- **Taking into account our modeling results, we do not believe that the hypothesis of "an interplanetary origin" of the features mentioned can resolve alone the problem of relativistic proton events.**
- **There are some grounds to accept a two-source model of SCR generation itself at/near the Sun, in the frame of the concept of multiple acceleration processes in the solar atmosphere.**

7. Long-Standing Problems and Arising Matters

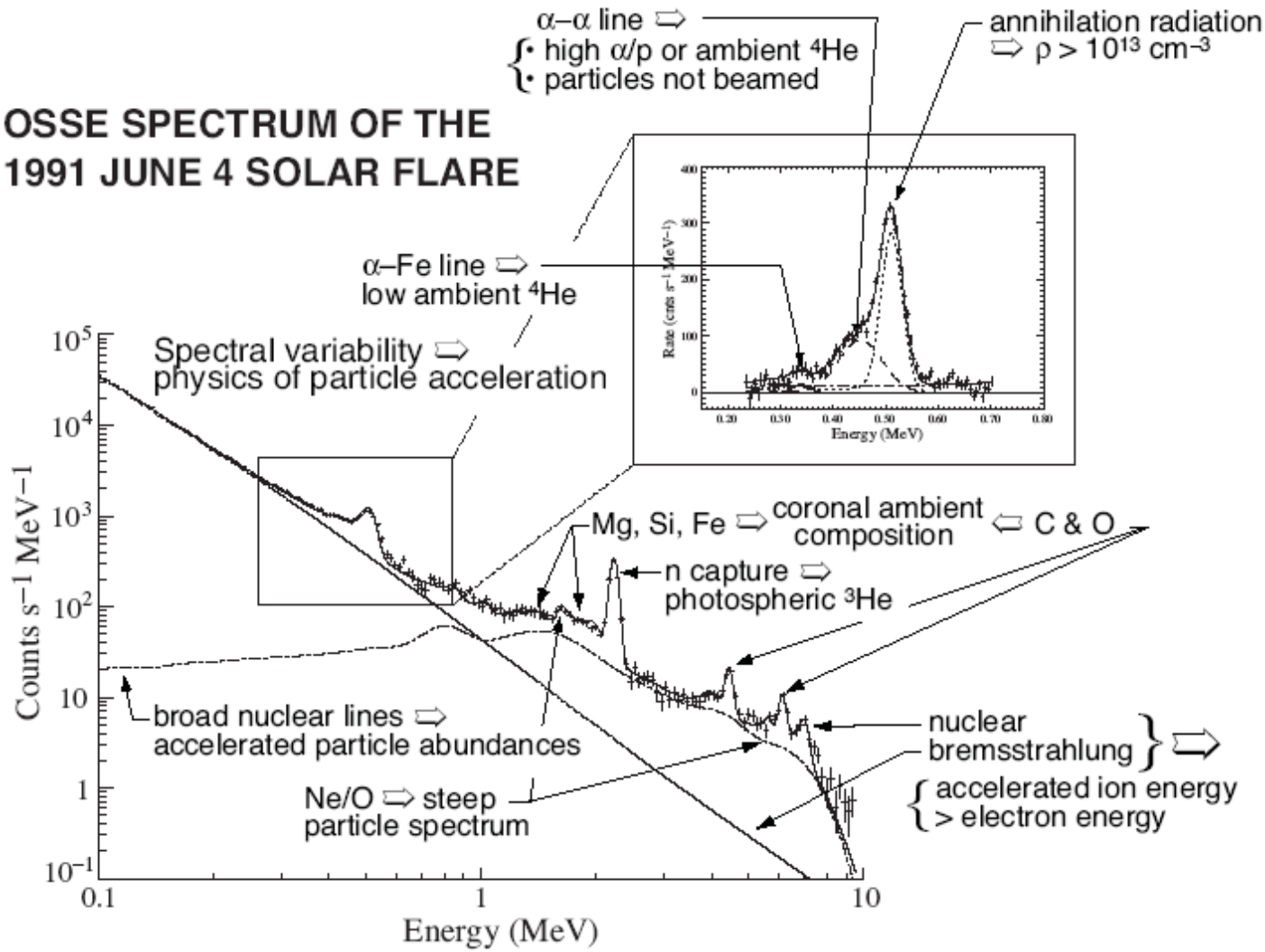
- Observations, Methods, and Theory
- Initial Stage of Acceleration
- Physical Implications of Gamma-Emission and Neutron Data
- Modeling Techniques
- Method of Additional Fluctuations
- Non-Standard Detectors



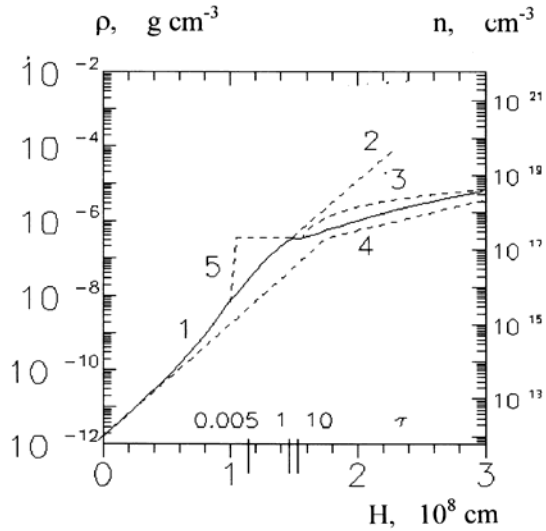
Spectrum Splitting for Protons and Electrons in the Source

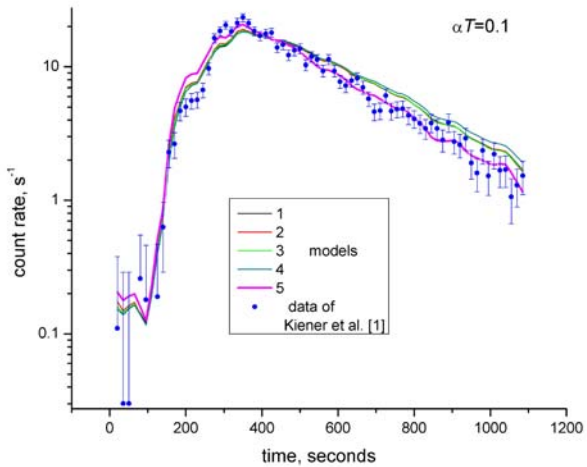
(Miroshnichenko, 1995): Expected differentiation of the normalized rigidity spectra of accelerated particles due to different efficiency of acceleration mechanisms and different pattern of energy losses of electrons and protons (dashed and solid lines, respectively).

Energy spectrum of the 4 June 1991 flare (Share and Murphy, 2000)



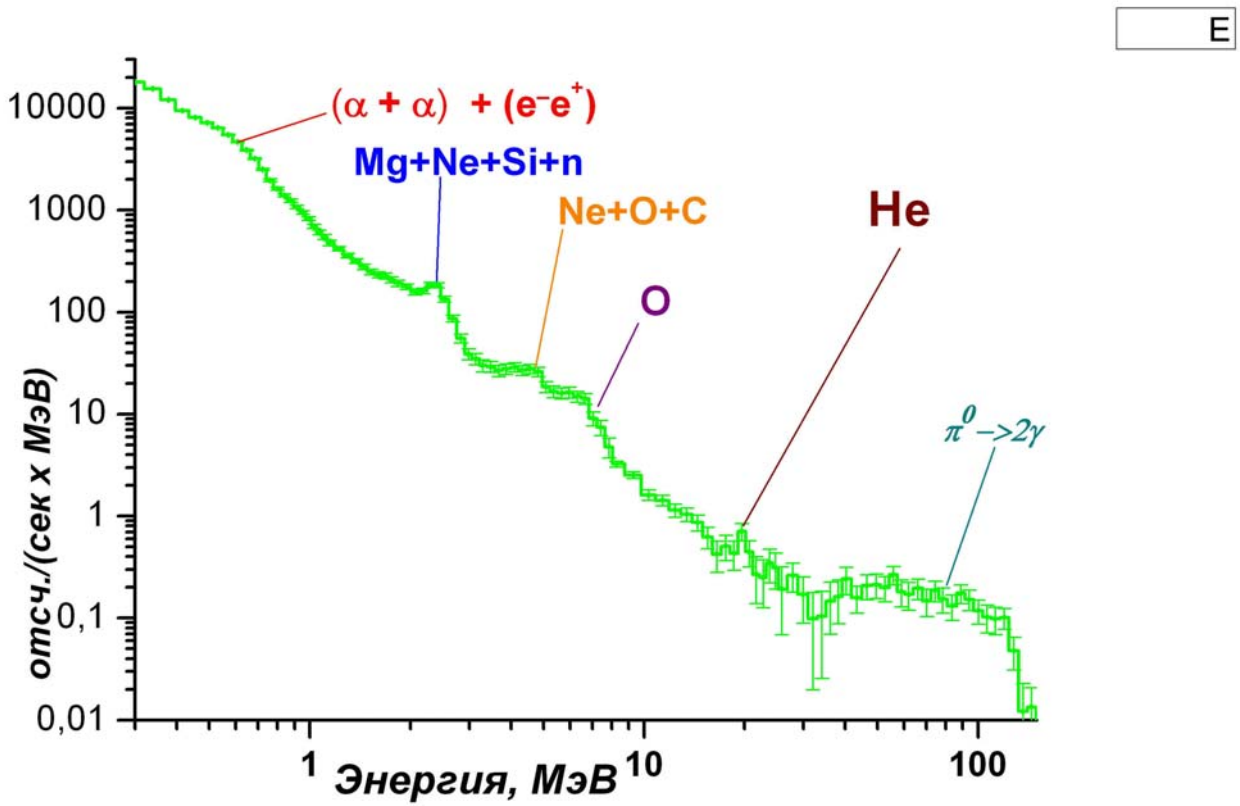
Effect of Density Enhacement (EDE) in the Solar Atmosphere on 28 October 2003 (2.223 MeV line)



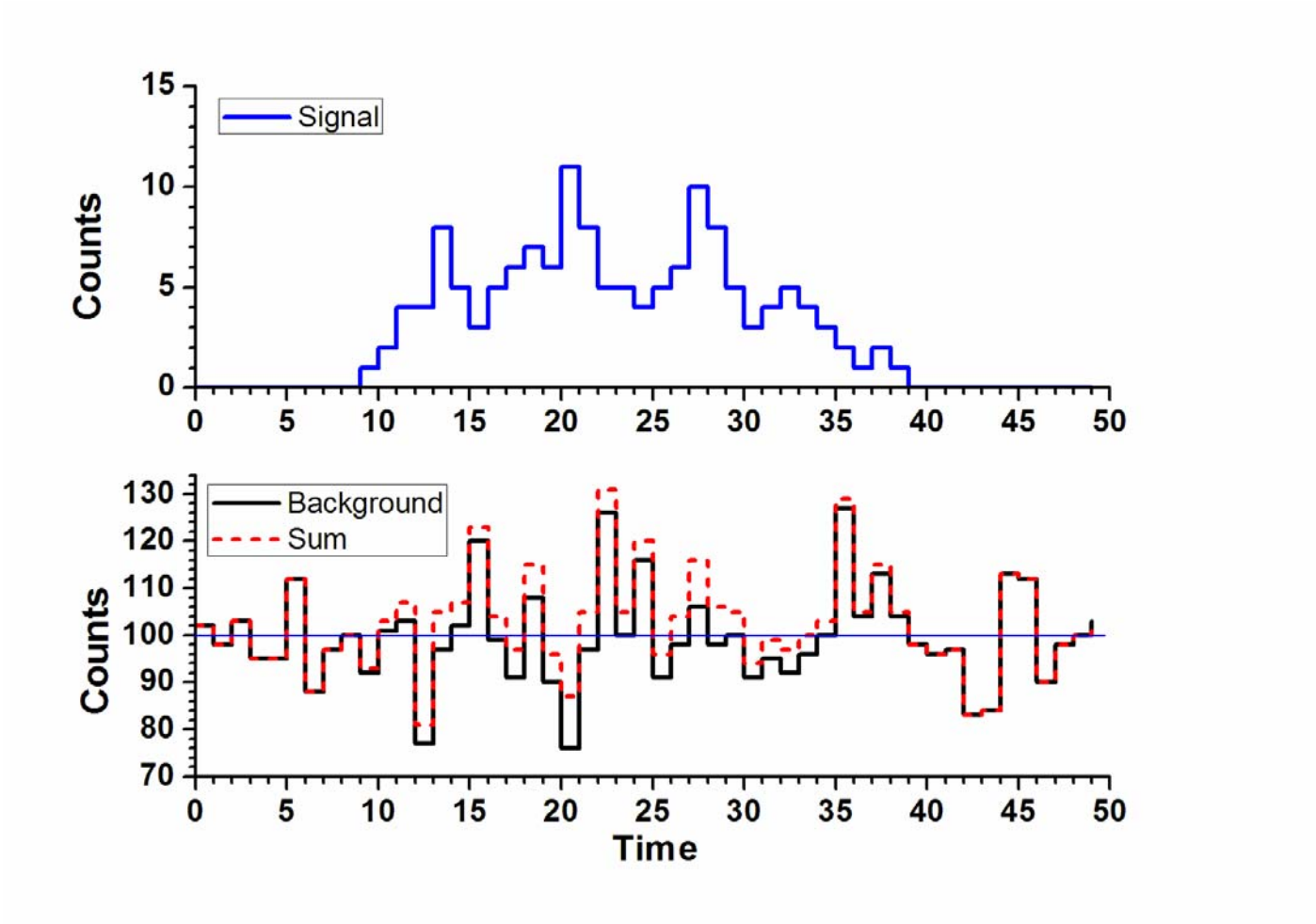


Models of the Solar Atmosphere Density (left)
Modelling time profiles of 2.223 MeV g-emission (right)
Variables: Density profile in photosphere; aT (Stochastic acceleration). Best Fit: Model 5, i. e. enhanced density (Troitskaja & Miroshnichenko, 2007)

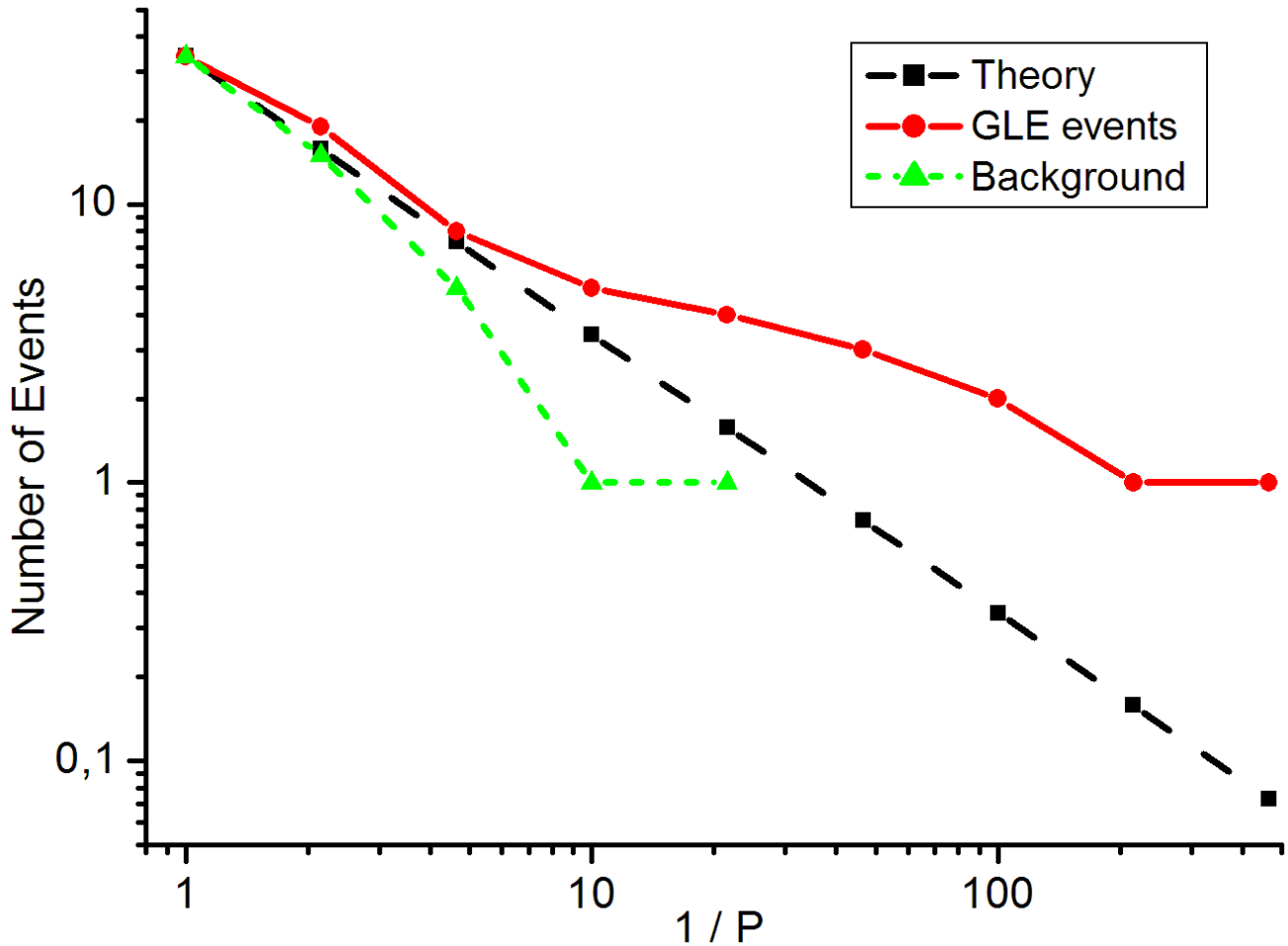
CORONAS-F, Event of 20 January 2005, Neutron Capture Line 20.58 MeV (He-3)



Counting rate of the background distributed under Poisson law with $\lambda = 100$, weak signal, and their sum (Karpov & Miroshnchenko, 2007)



Muon Bursts at the Baksan Underground Scintillation Telescope (Karpov & Miroshnichenko, 2007)



Muon Diagnostics of the Earth's Atmosphere, Near-Terrestrial Space and Heliosphere: First Results and Prospects

- GLE69 of 20 January 2005: The muon counting rate increases at GRAND Array above 10-sigma level in the 6-minute interval (e.g., D'Andrea & Poirier, 2005)
- GLE70 of 13 December 2006: In 10-minute counting rate summarized over URAGAH super-modules, maximum enhancement value equals to 0.61(+/-0.09)% and is above 6-sigma level (e.g., Timashkov et al., 2007, papers 296, 298, 305)

Saludos de Chichen Itza!

30th ICRC + VIII COLAGE + SEE2007 + … = CONTINUAMOS…

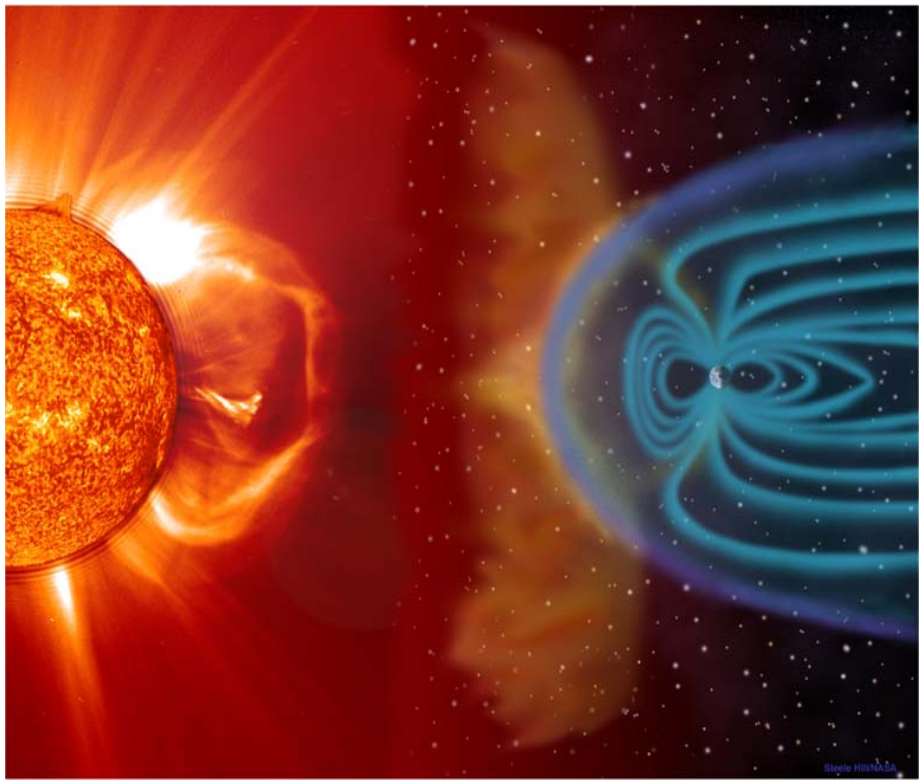
E. Flueckiger: Take home messages

- New large GLE on December 13, 2006
- Ongoing discussion about two mechnisms for particle acceleration at the Sun (on the basis of the January 20, 2005 GLE)
- Cosmogenic Radionuclides (^{7}Be,^{10}Be,^{14}C)

  New type of Neutron Monitor with time range of up to 100’000 years
- Nitrate technique for GLE archive established
- New probing techniques for space weather applications: muon diagnostics

B. Klecker: 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