NESSC – 9 January 2007 (Remarks by Ed Chupp)

Energetic Solar Flare Ions and Electrons
(How are they accelerated?)

Several solar flares which have been studied with Gamma-Ray and Neutron spectrometers since 1980 to the present time show clear evidence for the acceleration of ions and electrons to relativistic energies in subsecond time scales.

The purpose of the present remarks is to present some examples of these observations and mention some theoretical efforts which attempt to explain the acceleration of the ions and electrons. Since electric fields in reconnection geometries have been proposed as the accelerator for both ions and electrons, we suggest that this aspect of solar flares should be included in the NESSC study of reconnection! Other mechanisms have also been proposed.

THE KEY POINT IS THAT:

when ions are accelerated to energies above ~ 300 MeV and interact with hydrogen nuclei in the solar atmosphere, pi meson production can occur, and neutral pions promptly decay into gamma-rays which have a broad energy spectrum with a peak at about 70 MEV. Charged energetic mesons decaying into positrons (or electrons) can also produce energetic bremsstrahlung photons.

Also, there are several flares in which bremsstrahlung from ultra-relativistic primary electrons ($\gamma > 100$) have been observed.

In addition, other nuclear reactions can produce energetic neutrons which can reach the earth before decay. These neutrons have been observed by spectrometers on several satellites and by ground based neutron monitors or neutron telescopes.

Several instruments on the attached list of space missions since the 1980's to the present have observed these high energy radiations. A new high energy gamma-ray telescope for studying celestial sources, GLAST, will be launched later this year and has a good chance of observing high energy solar flare gamma-ray spectra.

SOME EXAMPLES OF SOLAR FLARE PION AND NEUTRON OBSERVATIONS

R-1.) SMM/GRS 3 June, 1982 time history.
"Solar neutron emissivity during the large flare on 1982 June 3"
Chupp, E. L., Debrunner + 7 coauthors;
ApJ(1987), **318,** 913

R-2.) SMM/GRS Gamma-ray spectra.
"Neutral pion production in solar flares"
Forrest, D. J., + 5 coauthors; xxxxICRC(1985), **4,** 146

R-3.) Pion and Neutron production rate observed by SMM/GRS and Neutron Monitor on Jungfraujoch.
IBID Reference 1

R-4.) CGRO/EGRET 11 June, 1991 observation of
gamma-rays > 50 MeV (for 8 hours!!).
"Detection of a long duration gamma-ray flare on June 11, 1991 with EGRET on COMPTON-GRO"
Kanbach, G., + 9 coauthors, A&Asupp.(1993), **97,** 349

R-5.) CGRO/EGRET 11 June, 1991 Spectrum
IBID

R-6.) RHESSI OBSERVATIONS OF 2005 JANUARY 20 SOLAR FLARE
Share, G., + 5 coauthors – Presentation at 2006 Shine Workshop(Utah)- Available on line.

R-7.) SUMMARY OF 2005 JANUARY 20 FLARE
IBID

R-8.) RHESSI COUNT RATES
IBID

R-9.) CORONOS/SONG OBSERVATIONS OF 2005 JANUARY 20 FLARE
IBID

R-10.) CORONOS SPECTRUM OF 2005 JANUARY 20 FLARE
IBID

R-11.) COMPARISON OF FLARE AND SEPs FOR 2005 JANUARY 20 FLARE
IBID (Perpared by Dick Mewaldt)

For other events see;
"Long Duration Solar Gamma-Ray Flares"
J. M. Ryan, Space Sci. Rev. (2000) **93,** 581

SELECTED THEORETICAL EFFORTS

1.) "Particle Acceleration In Stressed Coronal Magnetic Fields"
Turkmani, R., Vlahos, L., Galsgaard, K., & Isliker, H., ApJ (2005) **620,** L59.

"Particle Acceleration in Stochastic Current" Sheets in Stressed Coronal Active Regions"
R. Turkmani, P. J. Cargill, K. Galsgaard, L. Vlahos, & H.Isliker, A & A (2006) **449,** 749.

Uses 3 D time dependent MHD model to describe acceleration in Coronal Magnetic Field stressed by footpoint motion which leads to stochastic reconnection electric fields. Electrons and ions reach relativistic energies in 10^{-2} s and 10^{-1} s, respectively.

2.) "Proton Acceleration in Analytic Reconnecting Current Sheets"
J. Heerikhuisen, Yuri E. Litvinenko, and I.J. D. Craig, ApJ(2002), **566:** 512.

Uses a self-consistent magnetic reconnection solution to investigate proton orbits, energy gains, and acceleration time scales for proton acceleration in solar flares. Protons up to $\sim$ 10 MeV can be accelerated in $\sim 10^{-2}$ s. Appropriate for a single loop.

3.) "Critical Issues for Understanding Particle Acceleration in Impulsive Solar Flares"
Miller, J. A., + 8 authors,
J. Geophys. Res, (1977), **102,** 14631

"Particle Accelaration in Impulsive Solar Flares"
Miller, J. A., Space Sci. Rev., (1998), **86,** 79

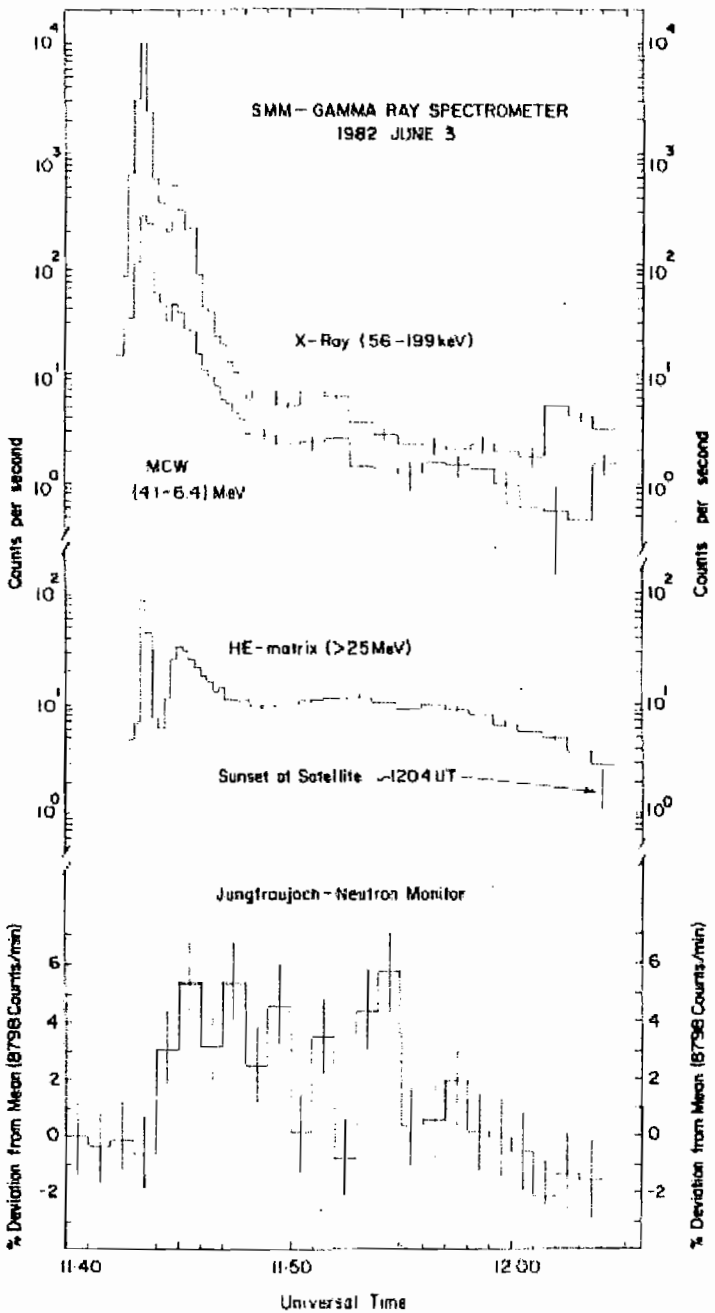
Hypothesizes stochastic acceleration of electrons and ions inside a loop filled with low frequency waves, (i.e., cascading MHD turbulence generated during the primary flare energy release). Acceleration of protons to an energy of ~ 100 MeV in time scales of seconds appears possible.

Energization of Ions and Electrons in the Solar Atmosphere

- **The evidence from observations**
- **The Missions:**

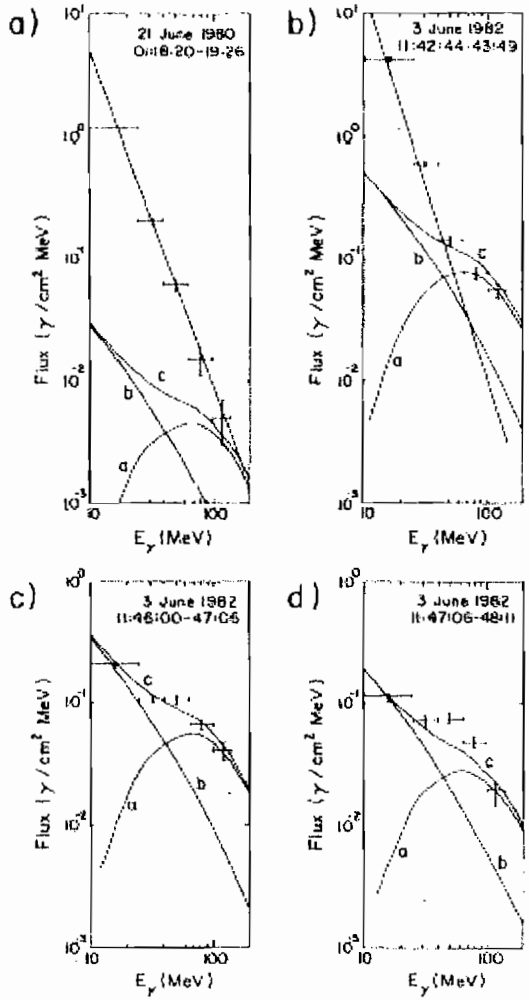
  SMM/GRS*, CGRO/EGRET/COMPTEL*,
  YOHKOH/GRS, GRANAT/PHEBUS*,
  RHESSI, CORONAS/SONG*,
  INTEGRAL/SPI*
  NEUTRON MONITORS*

  * Capable of observing emissions
    > 10 MeV


SMM–GAMMA RAY SPECTROMETER
1982 JUNE 3
X-Ray (56-199keV)
MCW
(4.1-6.4) MeV
HE-matrix (>25MeV)
Sunset at Satellite ~1204 UT
Jungfraujoch-Neutron Monitor
Counts per second
% Deviation from Mean (8798 Counts/min)
11·40
11·50
12·00
Universal Time

R-1

Forrest et al. (1985) 19th ICRC **4**, 146

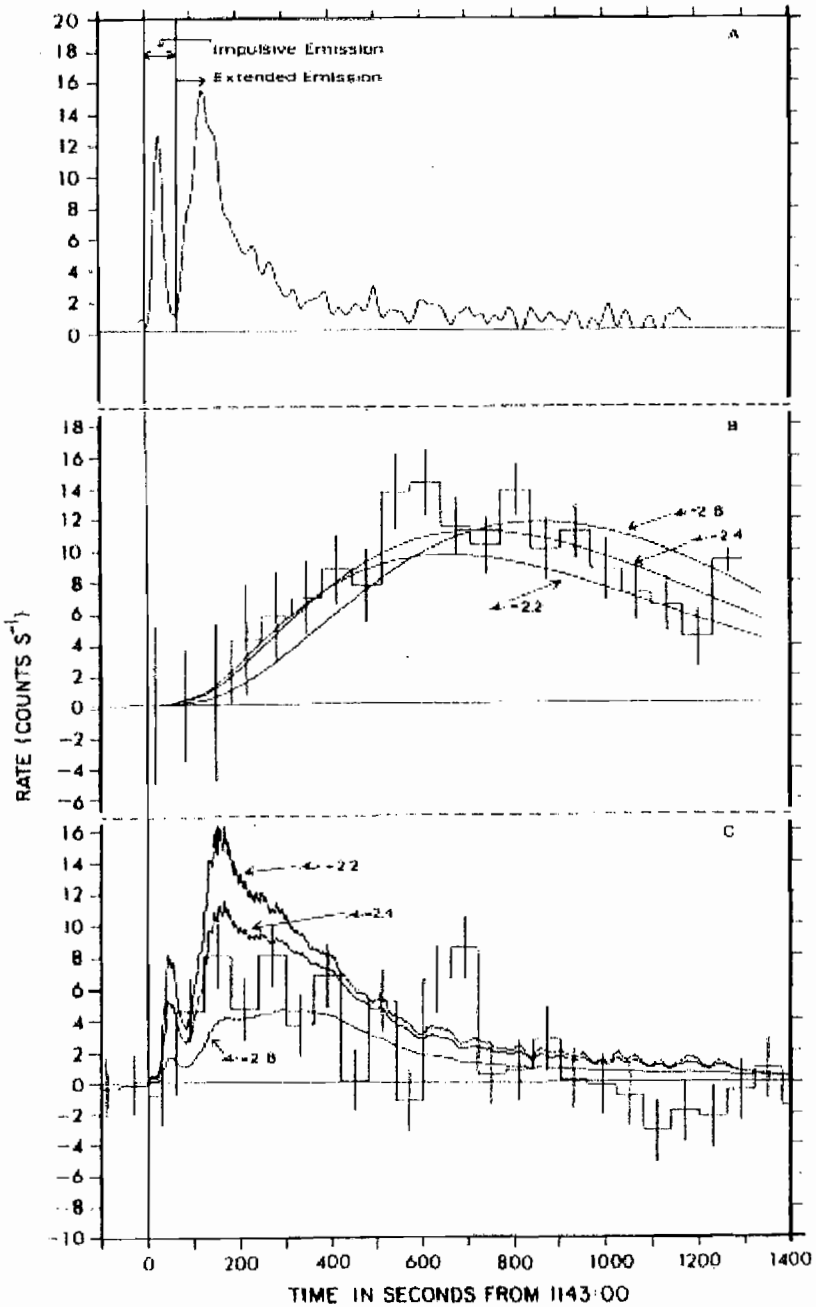


R-2

Pion Production Rate

SMM/GRS Neutron Rate

Jungfraujoch Neutron Rate



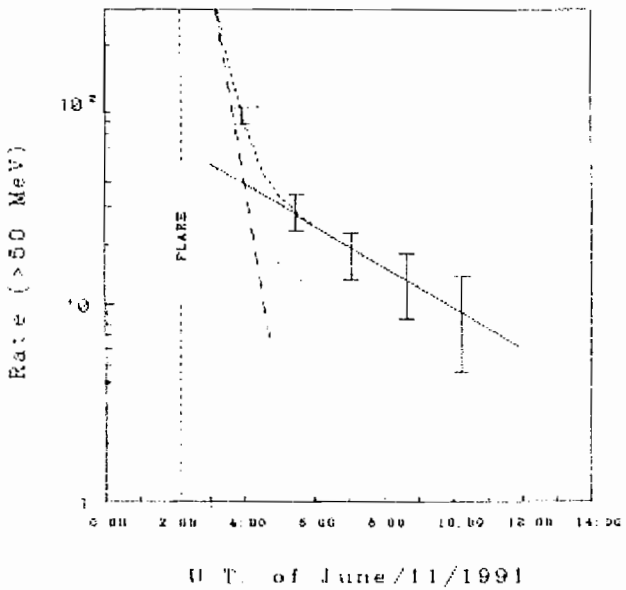


FIGURE 1. Time profile of the solar emission > 50 MeV on 1991, June 11, 1991. The two-component fit to the time profile is discussed in the text. The e-folding time constants derived are about 25 and 255 minutes.

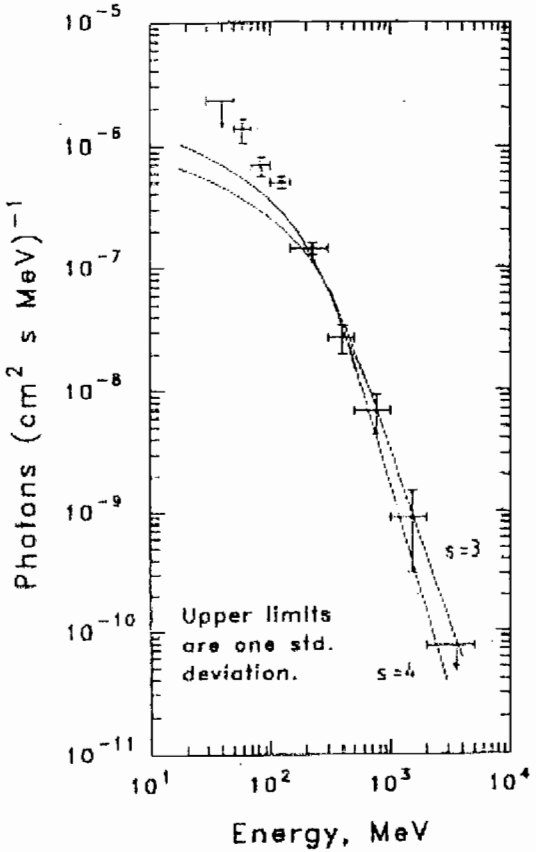


FIGURE 2. Spectrum of the solar flare on 1991, June 11 between 3:26 and 6:00 U.T. The theoretical spectra were calculated by Ramaty *et al.*, 1992.

RHESSI OBSERVATIONS OF THE 2005 JANUARY 20 SOLAR FLARE

Gerald Share[1,2], Ronald Murphy[2], David Smith[3],
Gordon Hurford[4],
Allan Tylka[2], and Robert Lin[4]

[1] UMD, [2]NRL, [3]UCSC, [4]UCB

Supported by NASA SEC-GI & SR&T

R-6

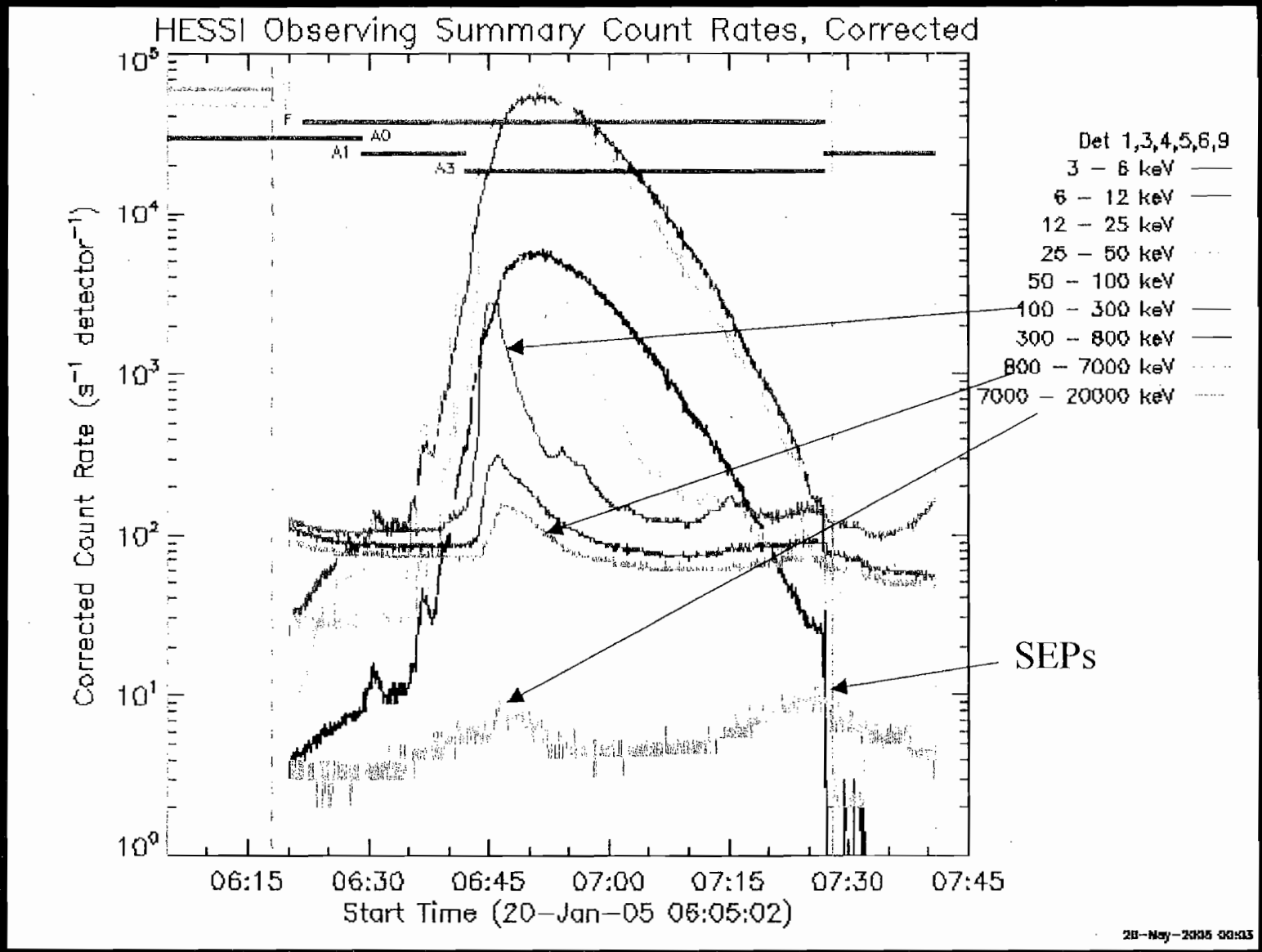
RHESSI has observed two distinct components of particle acceleration in the 2005 January 20th solar flare.

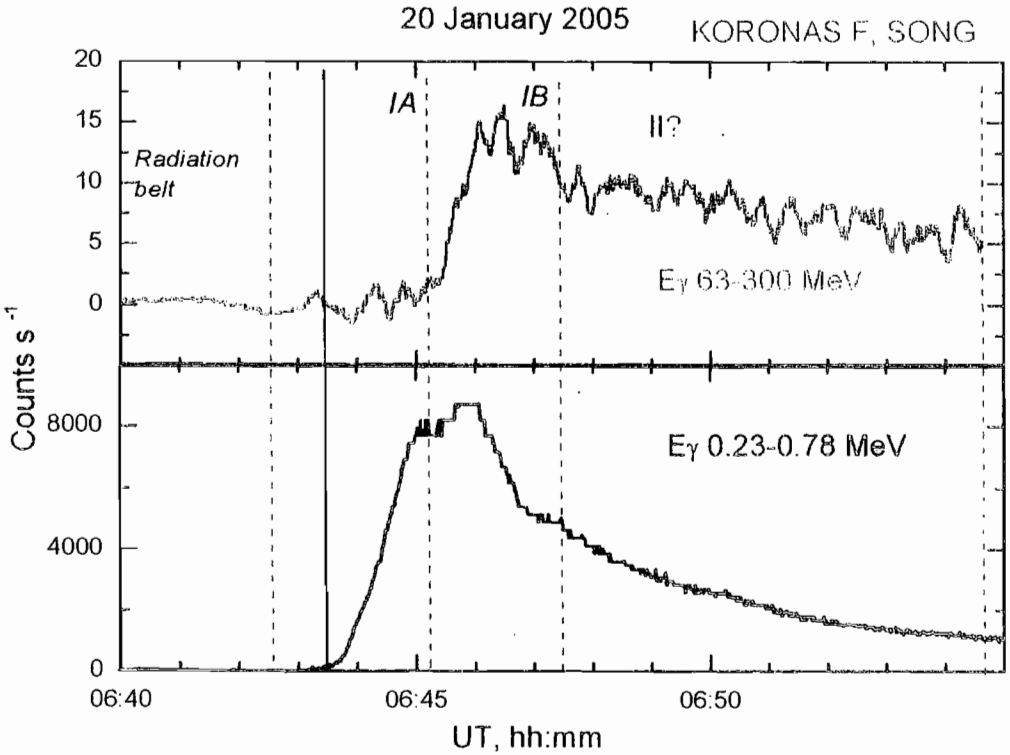
There is a 'normal' impulsive component beginning at ~06:42 UT, peaking at ~06:47 UT, lasting about 10 minutes, evidenced by bremsstrahlung and nuclear-line radiation interacting at a footpoint with an ion power-law index of ~-3.

A separate component began with a sharp 1-2 min peak at ~06:46 UT, with a spectrum dominated by pion-decay radiation; emission lasted for ~2 hours. No information as yet on how compact this source is.

The GLE event commenced at 06:48 UT and was observed at energies >4 GeV. An ~5 min-wide peak was observed at ~06:53 UT.

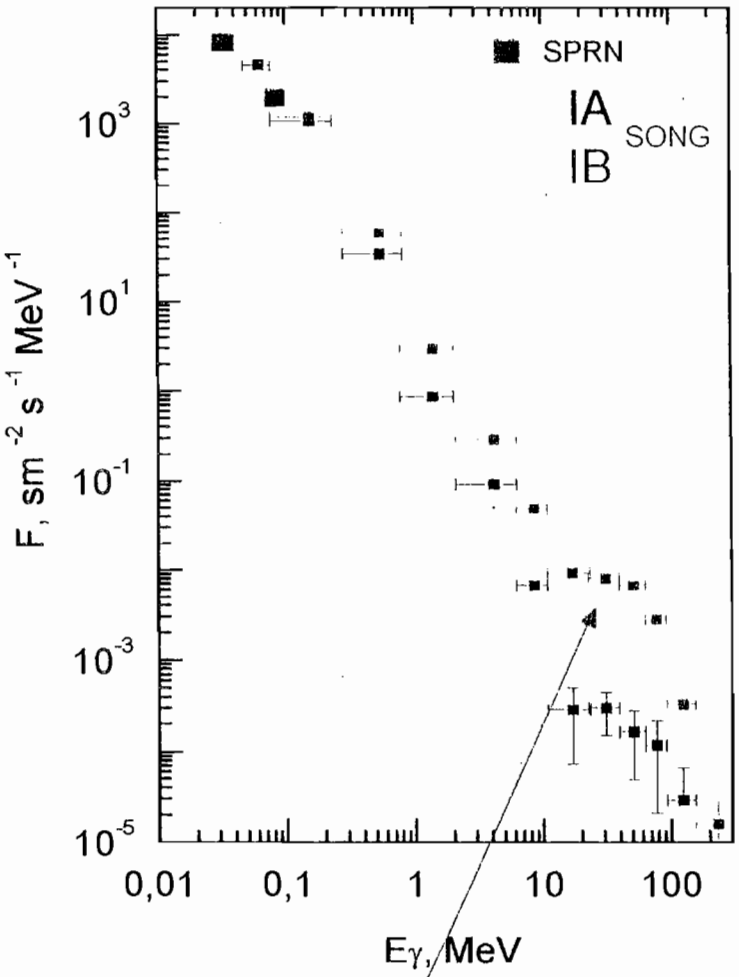
RHESSI observation of the 2005 January 20





CORONAS (Kuznetsov et al. 2005/6) also observed this high-energy component with a time profile similar to that observed by RHESSI.

20 January, 2005



06:43:30 – 06:45:10 UT

06:45:10 – 06:47:25 UT

The CORONAS spectra at the peak in the decay phase are consistent with a pion-decay origin.

R-10

Comparison of accelerated particles interacting at the Sun and observed in space (Mewaldt, priv. comm. 2005)

Total number of protons >30 MeV:

- Solar flare impulsive component: $(2.8 \pm 0.8) \times 10^{32}$
- Solar flare high-energy component: $\leq 0.7 \times 10^{32}$
- Event integrated SEPs: 210×10^{32}

Power-law spectral index:

- Solar flare impulsive component: 3.0 ± 0.05
- Solar flare high-energy component: <2.3
- Event integrated SEPs: 2.15