Collaboration with Gamma-ray Observations

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Gamma-Ray Observations in the 22nd Solar Maximum

Mission	Launch	Observations	Energy
GRANAT / GASOL	1989 Dec	Spectrum	0.075 - 120 MeV
GRO - BATSE	1991 Mar	Spectrum	0.05 - 20 MeV
OSSE		Spectrum	0.05 - 200 MeV
COMPTEL		Spectrum	1 - 30 MeV
EGRET		Spectrum	30 - 30000 MeV
SOLAR-A	1991 Aug	Spectrum	0.2 - 100 MeV
Max '91 HIREGS	1991 - 92	Spectrum (Ge)	0.015 - 10 MeV
HEIDI	1991 - 92	Image	0.02 - 0.7 MeV
CORONAS	1992 - 93	Spectrum	0.1 - 100 MeV
WIND	1992 - 93	Spectrum (Ge)	0.03 - 10 MeV
Mars Observer	1993	Spectrum (Ge)	0.03 - 10 MeV

Gamma-Ray Production Processes

1. Electron origin

   Bremsstrahlung (Continuum Spectrrum)

   Gamma-ray energy ---- Electron Energy

   Electrons --- primary, secondary (pion- muon- electron decay)

2. Proton / heavy nuclei origin

   Nuclear deexcitation lines --- C (4.44 MeV), O (6.13 MeV) etc.

   E_p = 10 - 30 MeV

   Positron annihilation line at 0.511 MeV

   Beta-unstable nuclei --- ^{11}C, ^{12}N, ^{15}O etc.

   E_p = 10 - 100 MeV

   Neutron capture line at 2.223 MeV --- $n + p \rightarrow d + 2.22$ MeV

   E_p = 50 - 200 MeV

   Neutral pion decay gamma-rays

   p + p → neutral pion → 2 gamma-rays peaked at 70 MeV

   E_p > 500 MeV

Improved Gamma-Ray Instruments

1. Time profile observations

   Large area detector -- Large counting rate ---- Good counting statistics

   High time resolution: << 0.1 s (broad band)

   1 s (full spectrum)

   Electrons and protons attain relativistic energies within 1 sec
   (rapid acceleration)

2. Spectrum observations

   High resolution Ge detector -- Powerful tool for nuclear line analysis

   Energy resolution (FWHM) : 1 keV at 1 MeV (cf. NaI: 60 keV at 1 MeV)

   Good separation of gamma-ray lines from electron bremsstrahlung continuum

   Wide range of gamma-ray energies -- 0.1 - 200 MeV

   Spectrum at > 10 MeV (electron bremsstrahlung or pion decay)

3. Imaging obserevations

   Direct --- Max '91 HEIDI (Rotational Modulation Collimator)

   E = 20 - 700 keV

   Spatial resolution 10 - 15 arc sec (1991)

   2 - 4 arc sec (1992)

   Gamma-ray imager identifies the sites of particle acceleration and interaction

   Electron interaction: bremsstrahlung

   Ion interaction: positron annihilation line at 511 keV

High Resolution Gamma-Ray Spectrometer (20 keV - 10 MeV)

High detection sensitivity to gamma-ray lines

Energy Resolution (FWHM)

HP-Ge detector cooled at 90 K --- 1 keV at 1 MeV

NaI scintillator --- 60 keV at 1 MeV

1. Nuclear line spectroscopy

Determine whether even small flares can accelerate protons to energies >10 MeV

Determine energy spectrum and angular distribution of accelerated proton

Poweful new method of obtainin g solar elemental abundances

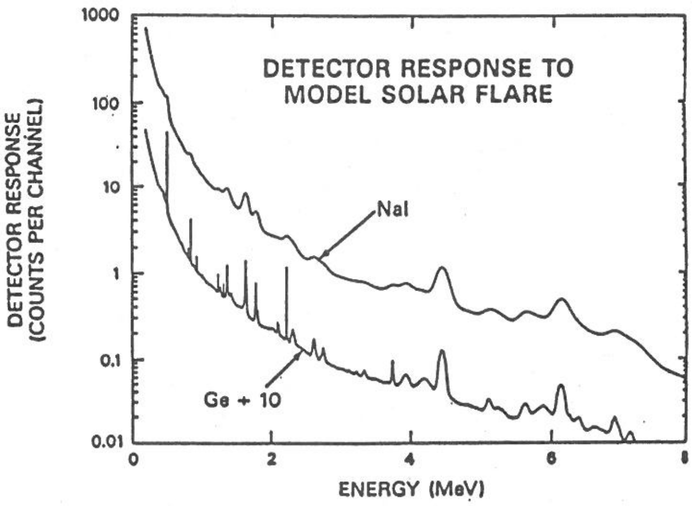
2. Hard X-ray continuum spectroscopy

Resolve between the steep thermal spectrum from high temperature superhot plasma and the power law spectrum from nonthermal ele' tron bremsstrahlung

3. Physical parameters

Information on the temperature and density of the positron annihilation region

The temporal evolution of the accelerated electrons and ions can be closely followed with the high sensitivity measurements



Gamma-Ray Imaging of Solar Flares

Much of the current understanding of energetic particle phenomena in flares is based on timing and spectroscopic observations.

The gamma-ray imaging provides the data on the location, size, and number of the sites of particle acceleration.

Electrons:

The microwave emission can provide a magnetic field-weighted indication of the electron spatial distribution

At hard X-ray and gamma-ray energies, bremsstrahlung is the dominant emission mechanism for energetic electrons. Because bremsstrahlung emission is optically thin and independent of magnetic field, its interpretation is much more straightforward.

Protons and Ions:

There has been few direct measurements of the geometry of nonthermal ion acceleration and transport.

The nonthermal ion component is visible primary through emission produced by nuclear interactions with ambient solar material.

Because imaging at energies > 1 MeV is very difficult, the best prospect is provided by the 511 keV line, which is the strongest emission feature below 1 MeV produced by accelerated ion interaction. Moreover, because the positron annihilation radiation is delayed (mostly because of the finite lifetime of the positron emitting nuclei), imaging of the emission after the impulsive phase
will permit a much easier separation of the line emission from the underlying bremsstrahlung continuum.

Scientific return expected from the correlative studies of radio and gamma-ray observations

High spatial resolution radio imagers

Microwave: Nobeyama RH, VLA, WSRT, OVRO

Millimeter wave: BIMA

Gamma-ray instruments

Imager: HEIDI

Spectrometers: GRANAT, GRO, SOLAR-A, HIREGS

1. Collaboration of the radio imagers with the gamma-ray imager (HEIDI)

Radio imagers are sensitive to energetic electrons producing synchrotron radiation

HEIDI is sensitive to energetic electrons producing bremsstrahlung and to ions producing positron annihhilation radiation at 0.51 MeV

These radio imagers can provide the imaging data over a wide range of frequencies

In particular, BIMA is the only method of imaging the most energetic electrons in flares, because gamma-ray imaging at energies > MeV is presently difficult

The combination of radio and gamma-ray imaging observations provides critically needed information on the location of particle acceleration and interaction in relation to magnetic field structure and the nature of the energetic particle transport

2. Collaboration of radio imagers with the gamma-ray spectrometers

The gamma-ray spectrometers have high detection sensitivity and high time resolution to nonthermal electron bremsstrahlung radiation above a few MeV.

The energetic electrons in reasonable solar magnetic field will radiate at optically thin frequencies observable to all the radio telescopes.

The bremsstrahlung gamma-ray flux over a wide range of energies can be directly compared with the microwave and mm-wave images over a wide range of frequencies

Delay between gamma-ray and microwave / mm-wave peaks will be studied in relation to the location of the radiowave sources

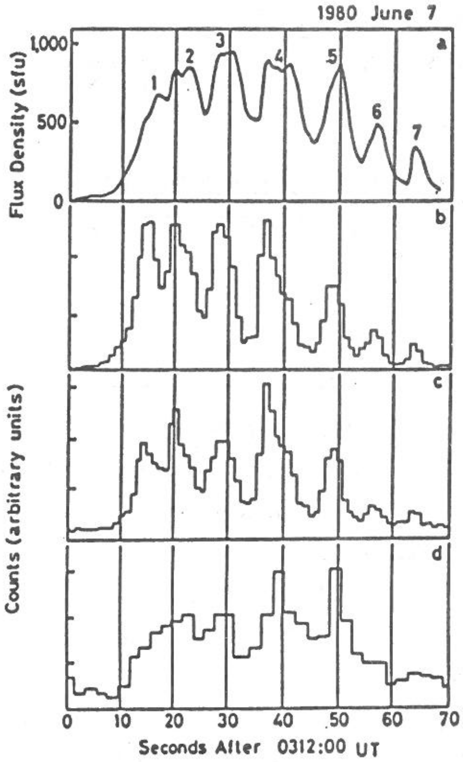
Rapid acceleration:
Electrons and ions are accelerated almost simultaneously to very high energies within 1 - 2 seconds of the flare onset

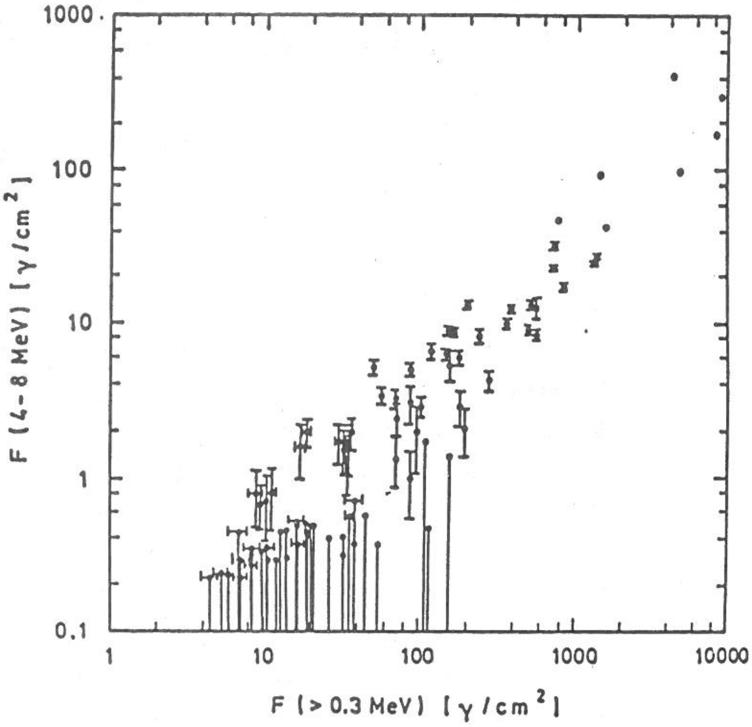
The emission of nuclear gamma-rays is well correlated to the emissiopn of electron bremsstrahlung > 300 keV. We can use this fact with the spatial information provided by the radio imagers to locate the sites of electron activity in a flare, and thus the sites of energetic proton activity

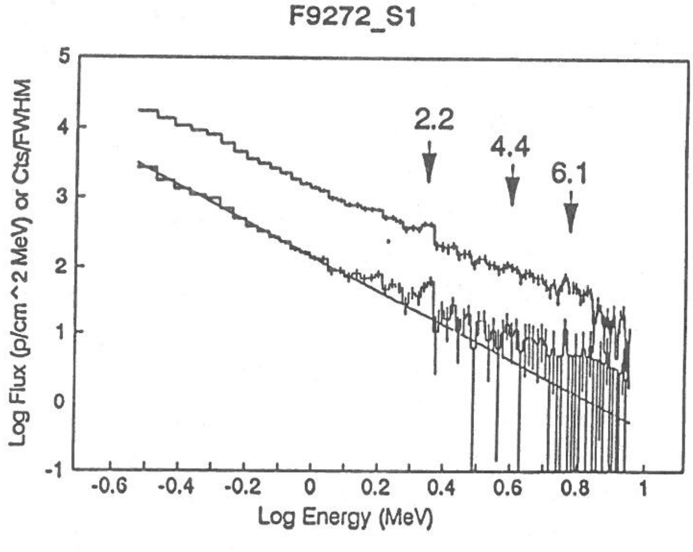
The neutron capture line at 2.22 MeV and nuclear deexcitation lines at 4.44 and 6.13 MeV were detected from the behind the limb flare of 1989 Sept. 29. This indicates the organized tranport of energetic particles or acceleration at remote and/or extended site.

Whether gamma-rays and mm-waves come from identical region will be established by studying the anisotropy of mm-wave flares on the disk

Advance of understanding of particle acceleration will require the study of time-dependent spatial evolution of high energy flare emission simultaneously with the time-dependent spectral evolution of the flare







F = (141 ± 1) E(MeV) ^ (-2.54 ± 0.06)

F(2.2) = 6.7 cm ^ -2

F(4.1-6.3) = 14.0 cm ^ -2