ANALYSIS OF SMM GRS HIGH-ENERGY (>10 MeV) DATA FROM THE SOLAR FLARE OF 1988 DECEMBER 16

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Abstract

The importance 1B flare, which began at 0830 UT on 1988 December 16, was one of the most intense above 10 MeV observed by the Gamma-Ray Spectrometer (GRS) on the SMM satellite. We use the data from this flare to test an alternative technique for analyzing the high-energy solar gamma-ray and neutron spectra incident on the GRS. The analysis shows gamma-ray emission > 10 MeV lasting at least 24 min., a large fraction of the entire observation. A power law of index -1.2 is used to model the high-energy gamma-ray spectrum, but a contribution from neutral pion decay cannot be ruled out. A clear response to solar flare neutrons is also present in the data. Using the simplifying approximation of a delta-function emission of the neutrons at the Sun, the neutron spectrum can be described by a power law of index -2.7 although the fit to the data is poor below 100 MeV. The GRS data imply a neutron emissivity of 2 x 10^{28}/sr above 50 MeV.

Gamma-Ray Spectrometer (GRS) on SMM The main objective of the GRS (Forrest et al. 1980) is to measure the solar flare gamma-ray flux in the energy range 0.3 to 9 MeV. However, the GRS has a high energy mode which uses both the seven 7.6-cm x 7.6-cm NaI (Tl) main channel detectors and a 25-cm x 7.6-cm CsI (Na) back section. These detectors are surrounded by 4π charged-particle shielding. Interactions resulting in energy loss between 10 and 100 MeV in either the NaI or CsI detectors or both, are recorded in two 4-channel pulse height analyzers - one for each detector. The data are accumulated in elements of a 5 x 5 matrix where the rows and columns correspond to energy losses in CsI and NaI, respectively. The time resolution for this high energy matrix (HEM) is 2.05 s.

Since launch of the instrument, the response of the CsI back section has changed, as indicated by changes in inflight calibration data and in background counting rates. One possible cause is a change in instrument thresholds. Another is a change in gain. If the latter is the cause, then the calibration data indicate an increase in gain of ~30% by December 1988, implying an effective energy loss range of 7 to 70 MeV in the CsI. Any change in gain of the NaI detectors, however, appears to be < 10%.

The response of the GRS to both gamma rays and neutrons has been calculated via Monte Carlo simulations as reported by Cooper et al. (1985). The simulations were done for the GRS in its nominal configuration, as well as for various gain offsets, particle shield thresholds, etc. The results are in the form of effective area for each HEM matrix element. For gamma-rays the calculations were done for an incident photon energy range of 10.5 to 200 MeV in 15 energy bins. For neutrons they cover the range 50 to 1000 MeV in 7 bins. We have shifted the CsI response to account for the apparent gain change in December 1988 compared to the nominal gain. However, the results depend only weakly on this modification.

Flare time history The large flare of December 16 was of GOES class X4.7 and importance 1B and was produced by Region 5278 at the location N26E37. In Figure 1, we show the time history for HEM "singles" events with energy loss > 25 MeV. By singles events, we mean those events which are seen either in the NaI or CsI, but not both. The simulations of Cooper et al. (1985) indicate that neutrons, in contrast to gamma rays, produce predominantly singles events. This is because gamma rays tend to shower, producing "multiple" events (see Chupp et al. 1985). Note that the emission continues, at a reduced level, until satellite nighttime. This extended emission is not seen in the "multiples" elements - a qualitative indication that it is due to solar flare neutrons. More quantitative is the ratio of multiple events to CsI singles events seen in the HEM during this flare. The variation in this ratio is consistent with emission dominated by gamma rays early in the flare, changing to neutrons late in the flare (cf. Chupp et al. 1985). This interpretation is supported by the results from applying the fitting techniques described below to the data.

Data fitting procedures To determine the gamma-ray and neutron fluxes reported here, we use a generalized non-linear regression fitting technique on the GRS HEM data. It is adapted from the routine CURFIT described by Bevington (1969). In the present implementation, the flare emissions can be modeled by any combination of gamma rays and neutrons. The gamma and neutron spectra are expressed in some functional form, which can be time varying.

To test the fitting procedure, we have re-analyzed the high energy data from the flare of 1980 June 21. Previous analysis (Chupp et al. 1985; Chupp 1988) showed that the high energy gamma rays were emitted impulsively (~ 1 min.), and that neutrons were most likely produced at the same time. The high energy events seen over the following 15 min. are therefore due to neutrons, detected over an extended period because of their velocity dispersion. For the present analysis of the June 21 flare, we assume a power-law gamma-ray spectrum during the impulsive period with no contribution from neutrons. The fitting procedure yields a best fit intensity and power-law index (-2.7±0.1) which, as expected, agrees with previous results (Forrest et al. 1985). For the extended phase of the emission, the data are divided into a number of time bins. For each bin, we use a model which consists of a power-law spectrum of gamma rays plus a neutron spectrum (at the Earth) that is gaussian in shape, with a center energy and width that is determined by the neutron time of flight and the velocity dispersion, respectively. Here, the fitting procedure gives only upper limits for gamma-ray emission, but a positive contribution from neutrons. The total neutron emissivity at the sun above 50 MeV is 3 x 10^28 neutrons/sr, again consistent with previous reports (Chupp 1988).

Results for the 1988 December 16 Flare For a preliminary analysis of this flare, we have assumed a delta-function injection of neutrons at the time of the maximum of peak 1 in Figure 1. A more realistic assumption would be a neutron production time history that follows the high-energy gamma ray emission (c.f. Chupp et al. 1987), but the delta-function model should give a first-order estimate of the solar neutron emissivity and spectral shape.

For simplicity, we also assume a power law-spectrum for the gamma rays. The addition of a neutral pion decay peak to the model gives a better fit to the data, but does not improve it enough to justify the added parameters. The extremely hard spectrum required for the fit (a power-law index of -1.2), however, may itself indicate the presence of a pion decay peak.

With the above simplifications, the analysis is identical to that used for the 1980 June 21 flare. The time history of the gamma ray flux (10 to 160 MeV) is shown in Figure 2. A significant emission is produced over a 24 min. period in a strong initial burst and a weaker second peak. The neutron flux (25 to 1000 MeV) detected at the earth is shown in Figure 3.

The time-integrated neutron spectrum at the sun, when fit with a power law spectrum, has a spectral index of -2.7. The delta-function production assumption, however, tends to steepen the neutron spectrum by mis-identifying higher energy neutrons produced later in the event as lower energy neutrons produced earlier at the assumed time of the injection. Therefore, a harder spectrum would be required for the GRS observation. In particular, a power law with an index of -2.4 is consistent with the December 16 data when data below 100 MeV are ignored. The present analysis implies a neutron emissivity at the sun of 2 x 10^{28} neutrons/sr, a result which is insensitive to the exact spectral shape.

Summary The flare of 1988 December 16 produced an observable flux of neutral radiation above 10 MeV. The gamma-ray emission was produced over an extended period of time, but application of a generalized non-linear regression technique permitted the separation of the gamma rays from neutrons in the GRS response. A first-order analysis modeled the gamma rays with a power law spectrum, the best-fit time-integrated spectrum being (25.3 ± 0.8) $E(MeV)^{(-1.2 \pm 0.1)}$ photons/cm^2. With the crude approximation of a delta-function injection of neutrons at the peak of the gamma-ray emission, we find a neutron emissivity at the sun of 2×10^{31} $E(MeV)^{-2.7}$ neutrons/MeV sr. An energy-integrated emissivity of 2 x 10^{28} neutrons/sr (>50 MeV) for this flare is insensitive to the spectral model used for fitting the data.

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