Fermi Solar Flare Observations

GI Program Progress Report, 28-January-2011

We present here a review of the current state of the various tasks we are undertaking for this GI program. The GBM solar flare catalog and quicklook products discussed below are available online through our Fermi Solar Flare Observations web site at http://hesperia.gsfc.nasa.gov/fermi_solar. The IDL software used to analyze Fermi solar data is available online in the SolarSoftWare (SSW) repository (http://www.lmsal.com/solarsoft/).

Task 1. Develop a solar flare identification strategy for GBM data

We have implemented a solar flare identification strategy. Using the daily CSPEC file provided at the GBM archive, we construct a measure of the net solar signal by 1) subtracting the summed rates in the anti-sunward detectors from the summed rates in the sunward detectors for two energy bands, 2) smoothing these two rates with a square wave to produce a value sensitive to solar flares and multiplying them together, and 3) multiplying that value by the short wavelength (0.5 – 4 Å) flux seen with the GOES soft X-ray sensor. Time intervals with this measure of the solar flux greater than the value typical for a C2 flare are identified as solar flares.

Task 2. Prepare a GBM solar flare catalog

We have generated a solar flare catalog using the flare identification strategy outlined above. There are currently 137 entries in the catalog covering the life of the mission. An automatic computer job runs every night to scan the previous day of data and add any new entries that are found. The flare identification number is constructed from the start time of the flare (YYMMDD_HHMM). The start, end time and duration of each flare are listed, as well as the peak time, peak count rate and total counts in the 12. to 25. keV energy band. The four most sunward GBM detectors, the associated GBM trigger number, if any, and the corresponding RHESSI flare number, if any, are also listed. A few representative lines from the catalog are shown in Figure 1.

Flare	Start time	Peak	End	Dur s	Peak c/s	Total Counts	Sunward Detectors	Trigger	RHESSI Flare #
091210_1056	10-Dec-2009 10:56:24	10:57:13	10:59:20	176	19291	1003601	n5 n1 n3 n4	bn091210456	
091216_0125	16-Dec-2009 01:25:13	01:25:29	01:55:43	1831	4177	600378	n5 n1 n3 n0		9121601
091216_0836	16-Dec-2009 08:36:20	08:36:50	08:37:29	69	6875	203286	n0 n3 n1 n5	bn091216359	9121619

Figure 1. Three entries from the GBM solar flare catalog showing flares on 2009 December 10 and 16.

This flare catalog is distributed in a binary FITS format as well as a text format in the SSW tree, and is also available online at http://hesperia.gsfc.nasa.gov/fermi/gbm/qlook/fermi_gbm_flare_list.txt.

Task 3. Quicklook Products

All GBM data are publicly available on http://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/, both as daily files and smaller files containing a short time interval for each triggered event. The daily and trigger files are available separately for each of the 14 detectors, and in high time resolution and high energy resolution formats. For each triggered event, a collection of quicklook plots showing light curves at various resolutions and energy bands is also available.

We have also created two quicklook plot archives. Daily plots showing a summary of GBM BGO and NaI data as well as the GOES time profiles, overlaid with indicators of GBM observing times are at http://hesperia.gsfc.nasa.gov/fermi/gbm/qlook/daily_plots/ organized in year and month directories. Orbital lightcurves (on RHESSI orbit times) of BGO and NaI data in several energy bands, also overlaid with indicators of GBM observing times are available at http://hesperia.gsfc.nasa.gov/fermi/gbm/qlook/orbit_plots/. These plots are

accessible directly or through the RHESSI quicklook browser tool at http://sprg.ssl.berkeley.edu/~tohban/browser/. A sample page is shown in Figure 2.

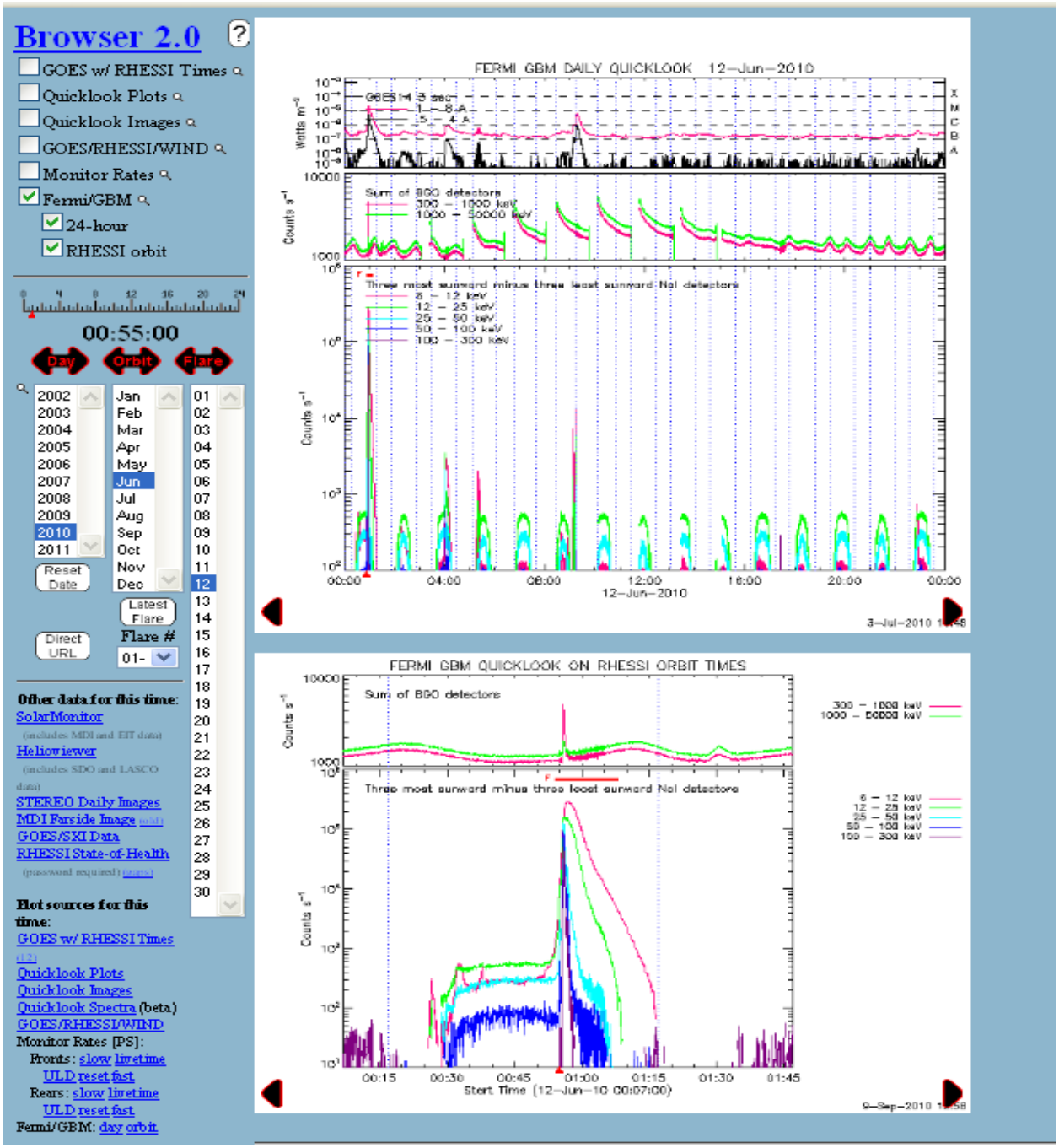

Figure 2. RHESSI quicklook browser page. The top plot shows the daily GOES, BGO, and NaI time profiles in several energy bands with GBM observing times overlaid. The bottom plot show the BGO and NaI time profiles in a single RHESSI orbit. The options on the left allow the user to select the time interval and the plots to display.

Task 4. Response Matrix Generation

We have installed the GBM response matrix software developed at UAH on our server. As part of the automatic daily processing task, we generate a response matrix for each of the 14 GBM detectors covering the time period of every solar flare identified. The archive of response matrix files is at http://hesperia.gsfc.nasa.gov/fermi/gbm/rsp/. These response files are needed for detailed spectral analysis and cross-calibration with RHESSI and other solar instruments.

Task 5. Spectral Analysis

We have enhanced OSPEX, our spectral analysis package, so that it is now possible to analyze both GBM and LAT data. For GBM, we have made it especially easy for users to retrieve the data and response files. In OSPEX, the user specifies the time interval directly or by selecting a GBM or RHESSI flare, and the software automatically locates and downloads the appropriate GBM data file from the Fermi archive, and locates and downloads the appropriate response file from our response file archive to the local computer. LAT data and response files are provided by the LAT team only upon request. OSPEX was also modified to handle GBM's multiple response matrices covering a flare as the instrument slews across the Sun. The matrices for time intervals overlapping the analysis time interval are combined by a weighted average. Once the data and response files are selected in OSPEX, the analyst proceeds to subtract background, and fit the data to any (or combinations) of the more than 25 parameterized functions of theoretical models.

Task 6. Joint analysis of GBM and LAT spectra

The 2010 June 12 solar flare was the first gamma-ray flare of Cycle 24. Data from the GBM NaI and BGO detectors have been analyzed using the OSPEX software. The resulting fits of the BGO data using OSPEX agree well with fits using recently revised GBM-team software. The NaI hard X-ray time profiles have been compared with 80 GHz microwave emission from Nobeyama. The correlation is excellent and the lag in the radio profile supports a trap model for accelerated electrons. We have compared the background-subtracted spectra obtained in the NaI and BGO detectors during the 50 s impulsive phase of the flare and found excellent agreement. The BGO spectrum reveals the presence of nuclear line gamma-ray emission as shown in Figure 3. It has been fit by bremsstrahlung and nuclear line and continuum components that provide information on both the accelerated electron and ion spectra.

We can obtain information on the spectrum of accelerated ions by comparing the time profiles of the nuclear de-excitation and neutron capture lines. This comparison is shown in Figure 4. We use the nuclear de-excitation line time profile for the acceleration time profile of ions and then compute the expected 2.223 MeV line time profile. We find good agreement with data for an accelerated ion spectrum having an index of ~3.6.

We are currently preparing a paper on this flare for publication in ApJ. It will also contain information on the high-energy emission observed by LAT that we will obtain in collaboration with LAT science team members.

Task 7. Improve pion-decay model

Public-domain LAT data do not show evidence for emission >30 MeV from this flare. This is due to the highly restrictive selection criteria applied for celestial gamma-ray studies. There is another technique developed by LAT team members to enable the analysis of the data during flares. This is known as the LLE technique. LAT data in this format can be analyzed both by LAT and GBM team members ,and can also be studied using OSPEX. Results from this analysis are currently under study.

In doing the necessary fits, several pion-decay gamma-ray emission templates were developed and are being used to fit the LAT spectra.

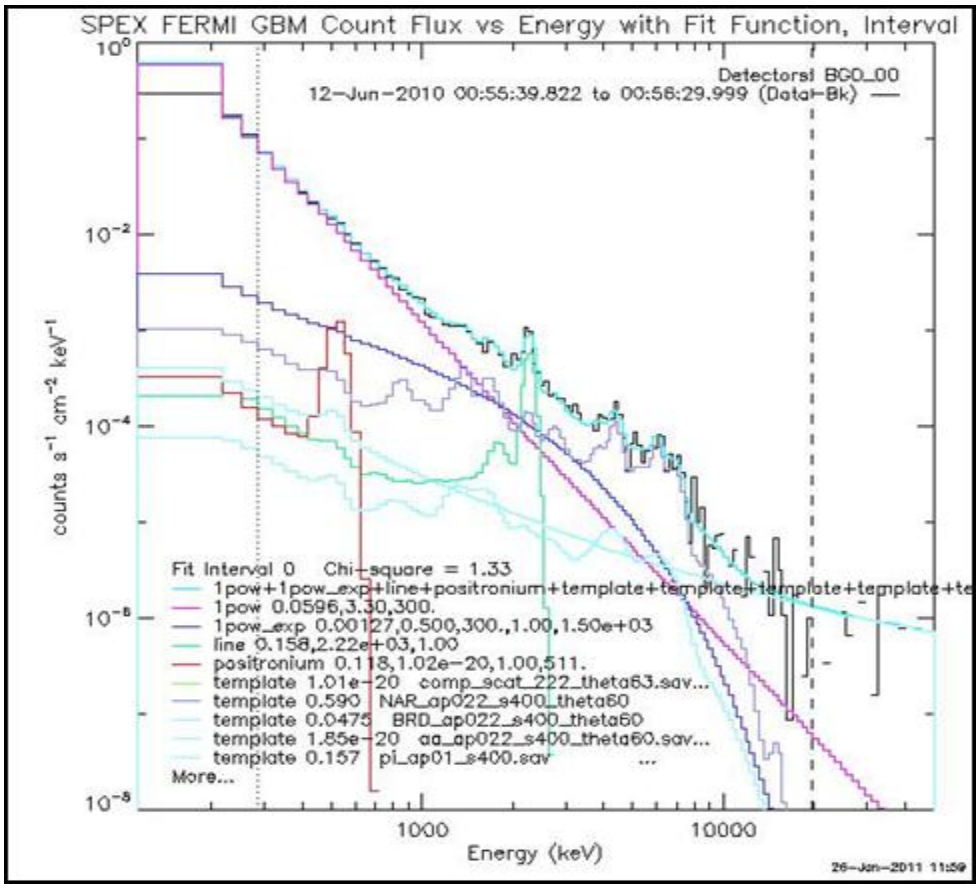

Figure 3. Background-corrected gamma-ray spectrum from the BGO detector fit by the sum of several bremsstrahlung and nuclear functions.

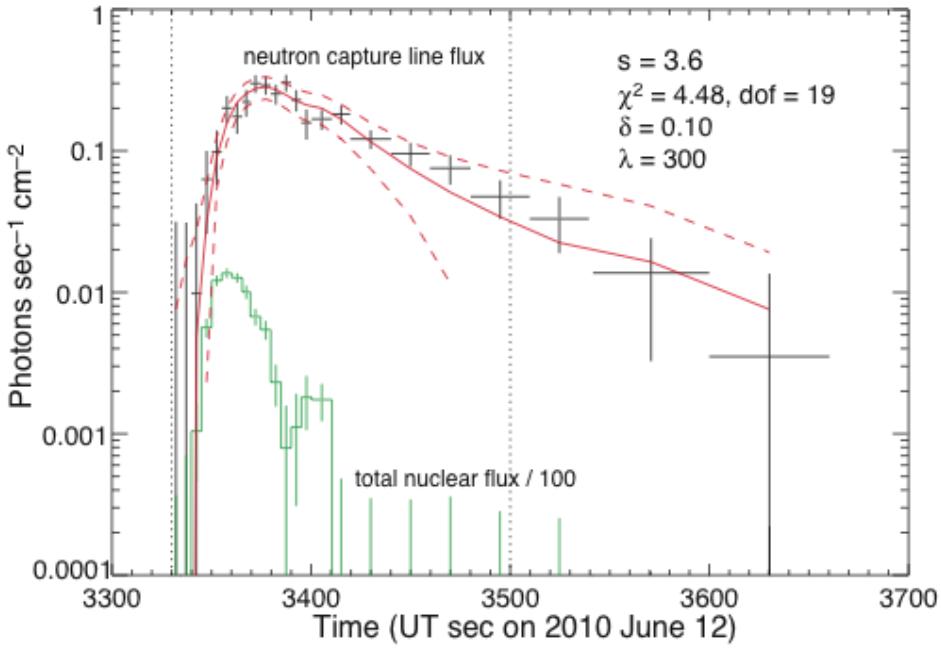

Figure 4. Time history of the total nuclear flux and the neutron capture line flux for the 2010 June 12 event.