Fermi Solar Flare Observations

1. Summary

We propose to continue and expand our work over the last three years to make ***Fermi*** solar flare data readily available for analysis by the international solar physics community. The two-year time frame of the proposed effort is extremely important for solar physics since solar activity is expected to peak in 2012 or 2013. As of 11 January 2012, a total of 846 flares have been detected with GBM above 8 keV. We should record at least that number of additional GBM events above 8 keV in the next two years, and tens of events above 300 keV. Nine solar events have been detected to date with LAT above 30 MeV, and we anticipate tens more in the next two years. Thus, it is critical that we continue our work of providing the ***Fermi*** solar data and analysis tools that allow the solar community to achieve the full realization of the unique scientific potential of ***Fermi*** solar flare observations.

We propose the following four distinct tasks for the next two years of effort:

1. Continue to provide the scientific community with convenient access to GBM solar data and to our familiar temporal and spectral analysis tools available on Solar Software (SSW).
2. Augment this GBM service by making available the high time resolution CTIME and TTE data and by incorporating improvements in the spectral analysis techniques into our SSW analysis tools.
3. Make the solar LAT Standard and LLE data available to the scientific community for analysis with our SSW tools.
4. Work with the LAT team to optimize the selection of solar events and provide SSW tools for the spectral analysis of LAT data.

This proposal is relevant to NASA's Strategic Astrophysics Goals and to ***Fermi's*** GI objective to study transient sources.

2. Accomplishments to date

Under our currently funded GI program entitled "***Fermi*** Solar Flare Observations," we have developed software to make GBM data readily available and analyzable. Our ***Fermi*** solar data archive and the steps required for data analysis are fully documented on our web page at

http://hesperia.gsfc.nasa.gov/fermi_solar/

We promptly provide guidance and troubleshooting to ***Fermi*** solar data users on request.

As a result of our work, any user can now carry out detailed temporal and spectral analysis of GBM solar flare data with minimal instrument-specific knowledge. We have also started to add LAT display and analysis capabilities. Contemporaneous observations of the same flares, including those made with *RHESSI* and many other solar instruments, both space and ground-based, are also available for joint analysis using the same familiar software tools.

We have implemented an autonomous flare finder that identifies all GOES C-class and greater flares detected with GBM. Within 24 hours of observations, automatic procedures post the following GBM products online:

- The updated solar flare list at
  http://hesperia.gsfc.nasa.gov/fermi/gbm/qlook/fermi_gbm_flare_list.txt

- Daily and orbital quicklook light curve plots at http://sprg.ssl.berkeley.edu/~tohban/browser/?show=gbmo+gbmd&date=20100612&time=0055
- Time-dependent detector response matrix files for each GBM detector covering the duration of every flare found with our flare finder, both those that produced an onboard GBM trigger and those that did not.

For GBM analysis, we have made it especially easy for users to retrieve the data and response files. In OSPEX, our spectral analysis package, the user specifies a time interval of interest. The software then automatically locates and downloads the appropriate GBM data file from the ***Fermi*** archive, and the appropriate response file from our archive.

OSPEX was specifically designed for solar X-ray and gamma-ray data and already incorporates functions commonly used for solar flare X-ray and gamma-ray spectral analysis. Based on the work in Murphy et al. (2009), we are adding templates for the gamma-ray lines between ~300 keV and 10 MeV that depend on the spectrum, composition, and directionality of the accelerated ions, and the ambient solar abundance. In addition, other gamma-ray functions covering the full LAT energy range based on theoretical modeling of the pion-decay emission are now incorporated.

Other improvements include enhancing the detector response matrix file for BGO data analysis by increasing the photon energy resolution for better definition of solar line features, and implementing a rollover correction for high count-rate data.

Examples of the basic capabilities of our software tools are shown in Figures 1 and 2, where the quicklook time history and a fitted BGO spectrum are plotted for the GOES M2-class flare on 12 June 2010 that was the subject of the paper by Ackermann et al. (2012). This relatively weak X-ray flare was nevertheless detected with LAT up to energies of at least 400 MeV.

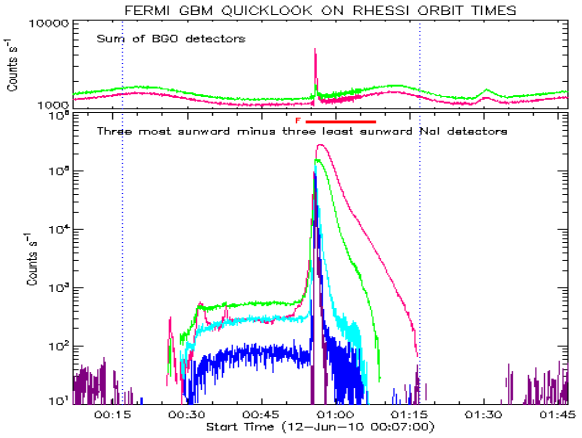

Fig. 1. GBM orbital quicklook plot of the 12 June 2010 M2 flare. The lower panel shows the count rate in a combination of the NaI detectors in five energy bands from 6 to 300 keV with a red bar marking the flare time interval. The upper panel shows the BGO data in two energy bands from 300 keV to 50 MeV.

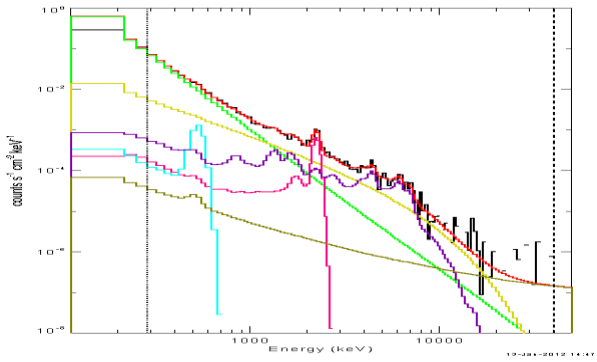

Fig. 2. Background-subtracted BGO count spectrum for 12 June 2010, 00:55:40 to 00:56:30 UT (black). The spectrum has been fit by the sum (red) of a power-law (green), a power-law with exponential cutoff (yellow), two lines at 511 keV and 2.223 MeV (cyan, magenta), a nuclear de-excitation component (purple), and a pion-decay component (olive).

3. Proposed Effort

3.1 Continuation and Augmentation of GBM Data Services

We will continue to provide the GBM data services described in Section 2 and augment them by making available the high time resolution CTIME and TTE data. We will also work with the GBM team to improve the spectral analysis, particularly in the areas of handling pulse pile-up and the spectral artifact around the iodine K-edge at 33 keV, and incorporate these improvements into our SSW tools.

Currently we provide access to the CSPEC data. In some cases, for example electron time-of-flight studies, users may be more interested in the CTIME data with 16 times higher time resolution (up to 64 msec) than the CSPEC data at the cost of 1/16 the energy resolution. We will provide the option to use the CTIME data as input to OSPEX, and will modify the software to allow use of the existing CSPEC detector response matrix data (stored on our online archive) by re-grouping the energy bins.

The TTE data are available for 300-s time intervals during GBM triggered events. We plan to generate an archive of pre-binned 128-channel, 32-msec spectra from the TTE data for every triggered event. The binning scheme is arbitrary so we can also build merged data sets with CTIME with 8 channel data at 32-msec, or finer, time resolution. When analyzing a flare, a user will have the option to merge these higher time-resolution data into the CSPEC or CTIME data. This will allow for detailed analysis during the flare while taking advantage of the extended data with lower time resolution to estimate pre- and/or post-flare background spectra.

3.2 LAT Data Availability

While the LAT standard data products are currently publicly available, further processing is necessary to analyze the data with the OSPEX tools familiar to the solar community. We plan to use the ***Fermi*** science tools on our server to autonomously generate an archive of LAT data with a 20° acceptance cone centered on the Sun for the entire ***Fermi*** mission. The archive will consist of a multi-channel spectrum covering the range 30 MeV to 10 GeV for every orbit with significant solar coverage. We will display these data (Figure 3) on our quicklook plots in the Browser interface, and will modify OSPEX to enable them to be read and analyzed.

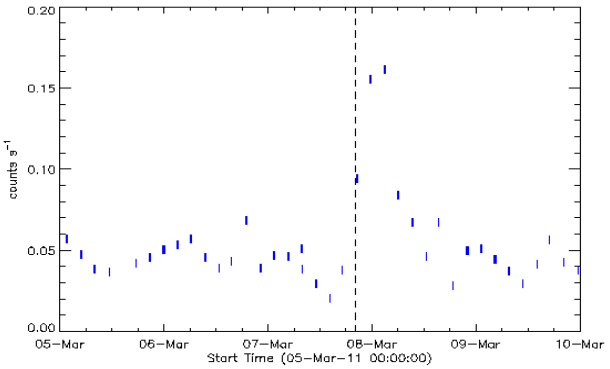

Fig. 3. Average LAT count rate integrated above 30 MeV for each high solar-exposure rock angle for a transient source centered on the Sun over the 5-day period 5 March to 10 March 2011. A marked rise in the count rate is seen after an M-class flare that peaked at ~20:00 UT on 7 March (dashed vertical line).

The ***Fermi*** team plans to make LAT LLE data for triggered flares publicly available. We will add the LLE time profile to our quicklook plots in the Browser interface to enable identification of impulsive solar emission detected with LAT. (Typically such flare emission will not appear in the highly screened LAT standard products.) We will also modify our analysis software to retrieve LLE data from the ***Fermi*** archive in order to display and analyze them in OSPEX.

3.3 LAT Data Analysis

We will provide SSW tools for the spectral analysis of LAT data that are fully integrated with the analysis of GBM and RHESSI observations. An example of the capability that will be available is the combined GBM and LAT spectrum in Figure 4 of Ackermann et al. (2012). Currently, we analyze flare data sets by treating the different instruments independently, but we will develop the capability of fitting the combined data sets with a single model spanning the full energy range and with the relative sensitivities of the different instruments as free parameters within the expected uncertainties.

4. Schedule and Management

Year 1 of proposed effort

- Continue to provide user support and the GBM and LAT data products detailed in Section 2.
- Add CTIME and TTE data analysis capabilities.
- Provide access to LAT standard and LLE flare data and add the measured flux above 30 MeV from the solar direction to the quicklook browser plots.
- Verify the LAT analysis tools and modify OSPEX to accommodate the new data sets.

Year 2

- Continue to provide user support and the GBM and LAT solar data products.
- Continue to refine software incorporating advances in spectral analysis techniques as they are developed in conjunction with the GBM and LAT teams.
- Develop the capability of fitting combined data sets.

5. Personnel

PI Brian Dennis (0.05 FTE) will act as the liaison with the solar physics community to promote awareness of these capabilities and encourage collaboration with other missions.

Funded CoIs

Richard Schwartz (0.1 FTE) will provide the scientific and software expertise to integrate the analysis of GBM and LAT data into our SSW tools. He will also work with the GBM and LAT teams to improve spectral analysis techniques and incorporate them into SSW.

Kim Tolbert (0.1 FTE) will maintain the software to produce the GBM products detailed in Section 2, and add software to handle CTIME, TTE, and LAT standard and LLE data.

Gerald Share (0.05 FTE) will provide scientific oversight to ensure that all data analysis tools are available to fully optimize the scientific return from the ***Fermi*** solar observations.

Rob Preece (0.05 FTE) will act as liaison with the GBM team.

Unfunded Collaborators

Nicola Omodei will provide the expertise to incorporate the LAT data products into OSPEX.

6. References

Ackermann et al., 2012, "***Fermi*** Detection of gamma-ray emission from the M2 Soft X-ray Flare on 2010 June 12," ApJ, 745, 144.

Murphy et al. 2009, "Nuclear Gamma-Ray De-Excitation Lines and Continuum from Accelerated-Particle Interactions in Solar Flares," ApJS, 183, 142.