Potential Impact of Alternative Observing Strategies on GBM Operations and Science

Executive Summary

The potential impact of new observing strategies is less significant for GBM than for the LAT. Nevertheless, strategies such as extended inertial pointing do have consequences for GBM science and operations. Temperature-dependent effects may exacerbate known instrument timing errors or may interrupt science operations. Sensitivity for measurements of GRBs or other short-term transients may be worse if the LAT boresight spends more time pointed away from the local zenith. All-sky monitoring of accreting pulsars and longer-term transients is less uniform during pointed observations. In this paper we summarize these effects for consideration in planning new Fermi observational strategies.

Introduction

The GBM was added to Fermi primarily to support LAT gamma-ray burst science by enabling real-time reorientation of the satellite and by providing context information on the burst characteristics at lower energies. GBM has produced important science results not only on GRBs but also on short-timescale transient emission from thunderstorms, solar flares, magnetars and x-ray bursters. GBM also plays a significant role as an all-sky monitor for longer-timescale variability of x-ray binaries, accreting x-ray pulsars, AGNs and even the Crab nebula, which prior to the GBM observations was considered an x-ray standard candle.

Given that the GBM is the secondary instrument on Fermi, one can hardly argue that it should dictate observing plans. However in deciding on whether, how and when to implement changes to the satellite observing strategy, the impact on GBM science and operations should be considered. Below we summarize several factors that may be relevant in making these decisions.

Instrument temperatures

New observing modes, especially those that involve extended inertial pointing, may result in temperature excursions that adversely affect the GBM performance. Two particular extremes are noteworthy:

1) Certain of the GBM detectors already operate close to their hot-end limits. The worst case is NaI 5 (counting from 0), which has reached a temperature of at least 42 C during a previous TOO. This is close enough to the red limit (50 C) to be a concern for new observing strategies. Exceeding the limit will result in some or all of the detectors being powered off temporarily. The duration of a power-off condition obviously depends on specific environmental conditions.

2) For extreme cold conditions the GBM detectors have heaters; thus their temperatures are not expected to be an issue. However, the temperature of the DPU is a significant concern for GBM even in moderate temperatures. In particular the frequency of the crystal oscillator that controls event timing varies with temperature and the GBM flight software relies on the more precise 1PPS signal from the spacecraft to correct for the oscillator drift. There is a region of temperature (well above any low-temperature limits) where an aliasing between the oscillator and the 1PPS causes a greatly increased number of errors (glitches) in the GBM time stamp. Most of the glitches are corrected in the ground software. However, in the region around 22 C, the number of glitches that the ground software is unable to correct becomes significantly larger. Manual correction of these glitches may be possible but would be an additional burden on the operations staff. Further study would be required to determine the extent to which these glitches can be corrected automatically.

In evaluating remediation strategies it would be useful to have predictions of the detector temperatures in advance of a non-standard pointing. In view of this, the GBM operations team recommends that the Fermi project investigate the feasibility of providing estimated temperatures for GBM components prior to the initiation of extended inertial pointings or other observing modes that differ significantly from the current survey mode.

Gamma-ray burst analysis

Not being in survey mode for GRB analyses may have several negative impacts. These include:

- Increased likelihood of unfavorable angles for localization as well as for spectral analysis at low energies where the detector response requires a small angle to the burst position.

- Increased likelihood of large angles between the triggered GRBs and the LAT boresight, making GRBs detected over the full Fermi energy range less likely.

- Increased difficulty in subtracting orbital background due to short exposures in pointed mode.

The direction to GRBs or other celestial events is determined from the relative rates of the NaI detectors. The orientation of the GBM NaI detectors was determined at a time when the expectation was that the *+z* axis (LAT boresight) would be pointed mostly near to the local zenith, so the detector orientations are optimized for the *+z* hemisphere. The actual survey mode, which spends most of the time with the +z axis offset from the local zenith, is therefore less than optimal. Changing the survey rock angle from 35° to 50° increased the likelihood for GRBs to be detected at large angles to the LAT boresight. Alternative observing modes could increase this even further.

To investigate the effect of zenith angle on geometry and localization, we looked at a sample of 163 GRBs with known location and their localization by GBM compared to the true location. The table below compares the quality of localizations for bursts incident within 90° of the *+z* axis with those incident at more than 90°:

True Zenith Angle from LAT Boresight	< 90°	> 90°
Number of GRBs	120	43
Location Median Statistical Error (1 sigma)	2.3°	4.9°
True Offset from Known Location (median)	3.8°	5.1°

This confirms that statistical errors and offsets from the true location are generally larger for bursts incident at more than 90° from the LAT boresight. When the survey mode rocking angle was changed from 35° to 50° the fraction of GRBs detected at angles more than 90° from the LAT boresight increased from ~17% to ~31%, leading to poorer localization accuracy on average. This fraction would likely increase further during inertial pointing or other modes in which the *+z* axis spends a greater fraction of time at large angles from the local zenith.

The effects of pointed observations on GRB background subtraction depend on the duration of the event and how long the pointed observations are. Polynomial functions fitted to adjacent background regions are adequate for prompt emission of most GRBs. If the spacecraft attitude changes too quickly or the source interval is too long (such as in searching for extended afterglow emission), another technique must be employed. An effective alternative technique for background modeling uses data from orbits with similar geographic footprints on adjacent days. For this technique we need 3 days of data in the same pointing to allow orbital subtraction for any event in the middle day. This is particularly important for studying long-lived emission at MeV energies in conjunction with LAT-detected extended emission, GRBs that are longer than a few hundred seconds, and solar flares.

Terrestrial Gamma-ray Flashes

We support occasional nadir pointings for LAT observations of TGFs, At least with the current detection criteria, GBM has reduced sensitivity to TGFs in nadir pointings because the LAT can be between the source and one of the BGO detectors. This does not occur when Fermi is oriented to view the sky, which is likely to be the case for any new observing strategy.

All-sky monitoring

GBM is an effective all-sky monitor for accreting pulsars. The impact of inertial pointing is simply to increase the effective area for exposure to some sources at the expense of others. The TOO observation of S3 0218+35 is an example. This TOO began in

September 2012 and lasted 7 days. Of the eight persistent sources we regularly detect, the sources 4U 1626−67, OAO1657−415, and GX 301−2 (4U 1223−62) were significantly impacted, with loss of detection or significantly increased errors in pulse frequency and pulse profile. For 4U 1626−67, detection was lost over the entire TOO. The effective exposure for 4U 1626−67 decreased by approximately a factor of 10. We also lost detection of the transient source GRO J1008−57, which was in outburst at that time. These sources are all at low declinations and at wide angles from S3 0218+35. As a result they had no useful exposure because the Fermi +z axis remained close to S3 0218+35 even when that source was Earth-occulted.

For the GBM Earth occultation technique, the effect is more complicated but the impact is similar. Pointed observations with Fermi appear to result in slightly better sensitivity for a few sources, but poorer sensitivity for most sources. For the occultation technique to work, the rate of change of the detector background rates must be slow compared to the time that it takes for a source to be occulted, which is determined by the atmospheric transmission at a given energy. In the energy range where the GBM occultation technique is most sensitive the spacecraft attitude changes can have a dominant effect on the rate of change of the background rates. If the attitude of the spacecraft changes too quickly, the occultation steps at that time cannot be decoupled from the background variations. Our experience in survey mode is that the spacecraft attitude changes are slow enough most of the time, except during the slew between rock angles. The latter is a relatively small fraction of the orbit and it is not correlated with occultations of specific sources, so the occultation sensitivity is relatively uniform over the sky. However, in our (admittedly limited) experience with TOO's, we find faster background variations during a large fraction of the orbit that prevent detection of many of the sources that GBM normally detects. Apparently this is due to the limb-following that the spacecraft does during the times that the TOO target is close to or behind the Earth's limb. The result is much worse sensitivity in the same region of the sky as the TOO target.

For example, during a pointed Fermi observation of the Crab Nebula, the overall sensitivity of the Earth occultation technique dropped considerably, going from approximately 19 sources detected at 5-sigma or better in the 300 ks interval prior to the TOO to only 6 sources detected at this level during the first 300 ks of the TOO. All 6 sources detected during the TOO were also detected in the previous 300 ks. However, GBM was unable to detect the Crab itself during the TOO.

In general the impact of inertial pointing GBM all-sky monitoring is less uniform sky coverage. This effect could be mitigated somewhat by an appropriate choice of alternative pointing during the times when the target source is Earth-occulted.