The prolonged Fermi mission

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on behalf of the Fermi LAT collaboration

9th AGILE workshop
Frascati, April 16–17 2012
The Fermi observatory

**Large Area Telescope (LAT)**
- Pair conversion telescope.
- Energy range: 20 MeV–300 GeV
- Large field of view ($\approx 2.4$ sr): 20% of the sky at any time, all parts of the sky for 30 minutes every 3 hours.
- Long observation time: 5 years minimum lifetime, 10 years planned, 85% duty cycle.

**Gamma-ray Burst Monitor (GBM)**
- 12 NaI and 2 BGO detectors.
- Energy range: 8 keV–40 MeV.
Spacecraft/instrument status at $\sim L + 4$

Event statistics (as of yesterday):
- $\sim 230$ B triggers in orbit
- 45,769,690,466 events down-linked to ground
- 684,154,051 $\gamma$-ray candidates made public

All subsystem working properly, no performance degradation
- 0.06% of the TKR strips masked (out of 884,736)
- One readout on one CAL crystal (out of 1536) failed, using redundant

More than 99% up-time collecting science data (out of the SAA)
- Including detector calibrations/hardware issues
2012 NASA Senior Review

- Fermi planned as a 10-year mission with a 5-year prime phase
  - Prime phase ending in August 2013.
- NASA considers Mission extensions through Senior Review process every two years
  - All operating missions in (or about to begin) their extended phase participate.
  - SR committee evaluates the anticipated science productivity of each mission over the next four years, focusing on the next two years.
- The first Fermi SR just finished
  - http://science.nasa.gov/astrophysics/2012-senior-review/

“The SRC recommends funding at the desired level of augmentation to provide for full operations through FY14. We recommend an extension through 2016\(^1\) with a review in 2014.”

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\(^1\)2016 is the horizon as far as the 2012 SR, so this is not the same as recommending that the mission ends at that point.
(i) Continue doing what we’ve been doing:

- deeper exposure;
- more statistics;
- increasing fraction of pointed (target of opportunity and planned) observations.

(ii) Improve on what we’ve been doing in the prime phase and maximize the scientific reach of the observatory:

- better understanding of the instrument (reduce systematic uncertainties);
- better calibrations;
- event reconstruction improvements (better PSF, larger energy range);
- event selection improvements (larger effective area, less background);
- analysis improvements (e.g., LLE);
- operational improvements (new instrument configurations);
- external inputs (e.g., pulsar timing solutions, inputs to the DGE modeling...);

- This presentation mainly devoted to (ii)
  - (i.e., not a review of the Fermi science highlights).
Power law source detection threshold

--- Low energy
Bkg. dominated $\propto \sqrt{t}$

--- High energy
Photon counting nearly $\propto t$

- Envelope of the minimum detectable power-law spectra over the full band, varying the spectral index
  - (i.e, not a differential sensitivity plot)
- Accounts for uncertainties in the background and source density
  - P7SOURCE_V6 IRFs, bkg. and exposure weighted over $|b| > 10$
- High-energy limiting sensitivity comes from photon counting statistics (rather than the background)
  - Increase nearly linear with time, rather than $\sqrt{t}$
Beating the $\sqrt{t}$ for many classes already (e.g., transients)
Both for point source and diffuse studies

- (e.g., \(\sim 1\) EGB \(\gamma\)-ray per week above 100 GeV)
Fermi offers a unique opportunity for the measurement of possible CRE anisotropies

- Key factors: large exposure and large field of view
- Most stringent upper limits to date based on one year of data
  - More than 1.6 M CRE candidates above 60 GeV
- Limits are comparable to the level of anisotropy expected in realistic models
  - Can potentially expect to detect a signal in 8–10 years
Direct CR measurements: the LAT in context

Livetime (s)

Acceptance (m$^2$ sr$^{-2}$)

Space-based
Balloon
Calorimetric
Spectrometers

AMS02
AGILE
EGRET
Fermi LAT
LAT
AMS02 (CAL only)
CALET (planned)

T$_{obs}$ = 1 day
T$_{obs}$ = 1 month
T$_{obs}$ = 1 year
T$_{obs}$ = 10 years

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Improvements in the event selection

- Continuous effort by the LAT collaboration to make public the advances in the understanding of the detector
- First new event classification since launch (Pass 7) released in August 2011
  - Greater and more uniform acceptance
  - Significant enhancement at low energy (below \(\sim 100 \text{ MeV}\))
- End-to-end reworking of the event reconstruction, analysis and classification (Pass 8) ongoing
  - Larger effective area, better bkg rejection, extended energy range
Energy reconstruction extensively re-written

- Compensate for the saturation in the calorimeter above $\sim 70$ GeV per crystal

- Extend the measurement of the isotropic diffuse emission to the highest possible energies

- Extend the CRE spectrum into the multi-TeV band

- Extend the measurement of the spectrum of the Earth limb
**Two ideas under development**

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**TKR reconstruction**
(B. Wells, 219th AAS, Austin)

- Use event-by-event errors
  - as opposed to an *average* PSF parametrization
- Project covariant error ellipse into the sky
- Aim at improving the angular resolution by using all the available information

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**CAL reconstruction**
(L. Baldini et al., Fermi symposium 2011)

- The CAL has some imaging capability
  - at the level of $\sim 1^\circ$ above $\sim 10$ GeV
- Use the CAL as a *standalone* instrument
- Substantial increase of effective area at high energy
Applying the standard likelihood analysis below $\sim 100$ MeV proved to be more challenging than anticipated

- Steeply falling effective area and poor energy resolution

LLE can fill the gap between the GBM and the LAT (30–100 MeV) for short transients (e.g., GRBs, solar flares)

- Use a loose event selection and statistically subtract the background
  
  (i.e., not an event-by-event analysis)

- Release of LLE data/analysis tools coming soon
Near peak of TGF, LAT sees ~500 photons in ~5 µs integration time, assuming typical RREA spectrum. Total energy deposited in calorimeter = 2030 MeV, distributed among ~500 photons.

- Hard to reconstruct individual photons...
- ... but can address interesting questions:
  - Energy fluence in the ~ 5 µs elx integration time
  - Average rate of γ-rays between successive readouts
  - Energy endpoint of the spectrum
- dSph are the cleanest target for DM searches w/ Fermi
- Current limits on WIMP annihilation cross-section using dSph are the most constraining; they’ll improve with improved statistics
  - as $1/\sqrt{t}$ in the bkg-dominated region, as $\sim 1/t$ at high energy
- Optical surveys will discover more dSphs
  - Current dSphs come from SDSS covering about 1/4 of the sky
  - DES and PanSTARRS are ramping up
- Potential for stringent contraints on WIMP models
GBM continuous Time-Tagged Event (TTE) data
- One order of magnitude increase in TGF detection rate
- (16 ms trigger accumulation time sub-optimal for TGFs)

LAT engineering runs taking place to optimize the TKR readout configuration
- Improve high-energy direction reconstruction

“Compton trigger” configuration under discussion
- Increase low-energy (< 20 MeV) sensitivity
Conclusions

- Fermi prime phase (5 years) ending in August 2013
  - The observatory is performing extremely well, both from the operational and the scientific standpoint
- 2012 Senior Review committee recommends extending the mission through 2016 (pending review in 2014)
- Benefits of the extended mission well beyond the expectation from a deeper exposure
- Significant effort of the LAT collaboration to maximize the scientific reach of the observatory at all levels
- Fermi is really a scientific facility for the astrophysical community
  - Parallel effort to make the improvements available to the community at large as soon as practically possible