Fermi-Large Area Telescope: Present & Future

G. Tosti (1) on Behalf of the Fermi LAT Collaboration

(1) University & INFN Perugia
The \textit{Fermi} Observatory

International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

Launched on June 2008
Mission Lifetime: 5 year – Goal 10 year
• Fermi Large Area Telescope (LAT) and Gamma-Ray Burst Monitor (GBM)

• Performance of Fermi LAT
  – Large FOV (>2.4 sr)
    • 20% of the sky at any instant;
  – Large effective area
    • Up to a total value of 0.8 m²
  – Small dead time
    • Detailed light curve, time-resolved analysis
  – Every photon can be time-tagged
    • 1 ms accuracy
  – Wide energy coverage
    • From 20 MeV up to > 300 GeV

• Fermi GBM
  – Views entire unocculted sky
  – 12 NaI detectors [8 keV – 1 MeV]
  – 2 BGO detectors [200 keV – 40 MeV]
Instrument Response Functions:

Effective Area, PSF, Energy Dispersion

Also critical is the cosmic-ray rejection performance.

Residual cosmic rays are absorbed into “isotropic” signal.
Observation Modes

- Sky-survey mode
  - Normal operations mode
  - Full-sky every 2 orbits (~3 hrs)

- Target of Opportunity
  - Autonomous re-pointing for GRBs
  - Slew to keep target in FoV
  - Proposed pointed observations

Wide Field of View

LAT: ~2.4 sr, 20% of sky

GBM: Almost entire sky not occulted by Earth
• *Fermi* covers a huge interval of the EM spectrum
  – Crucial and unique spectral coverage
• Complement the large number of upcoming new survey instruments from VHE to radio wavebands
  – At the dawn of time domain astrophysics
The 2009 MW campaign on Mrk501

Mk501 was in low state during most of the campaign

3-day spectrum from TeV flaring activity

For first time, Fermi MAGIC/VERITAS spectra cover the complete high energy component over 5 orders of magnitude without gaps

Agreement in overlapping energies among instruments (with different time coverage) indicates that we managed to get the true average SED of Mrk501 during the 4.5 months campaign.

Most complete SED ever collected for Mrk501

(Abdo et al 2011)
Crab Nebula - “reference source” in High Energy Astrophysics

- Broad energy coverage of LAT enables overlap with TeV observations for bright sources.

Pulsar Subtracted Spectrum

GeV variability seen in Synchrotron spectrum only (highest energy electrons)
Fermi Highlights and Discoveries

**Extragalactic**
- GRBs
- Blazars (782)
- Radio Galaxies (12)
- Starburst Galaxies (4)
- LMC & SMC
- Globular Clusters (11)
- Nova (1)
- SNRs & PWN (68)
- Fermi Bubbles
- γ-ray binaries (6)
- Pulsars: isolated, binaries, & MSPs (122)
- Sun: flares & CR interactions
- TGFs
- Unidentified Sources (~600)

**Galactic**
- e⁺e⁻ spectrum
- e⁻
2FGL Catalog

[Diagram showing 1,873 sources categorized into AGN, AGN-Blazar, AGN-Non Blazar, Galaxy, Starburst Galaxy, Radio Galaxy, Seyfert Galaxy, nova, PSR, PWN, PSR w/PWN, SNR, Globular Cluster, HMB, Unassociated, Possible Association with SNR and PWN.

Based on integrated exposure (100 MeV to 100 GeV) from August 4, 2008, to July 31, 2010. TS > 25]

Credit: Fermi Large Area Telescope Collaboration
Fermi-LAT $\gamma$-ray Galaxies

3 months: LBAS

1 year: 1LAC

2 years: 2LAC
arXiv:1108.1420

More than 1000 AGN!

New Class of $\gamma$-ray emitters
Galactic sources of $\gamma$ and CR

Pulsars

Radio selected gamma pulsar
Gamma selected pulsar
Gamma millisecond pulsar

PWN grouped

SNRs grouped
Gamma-ray astrophysics is relatively young – many “basic” discoveries still being made.
Fermi: Dark Matter search strategy

**Satellites**
Low background and good source id, but low statistics
- *PRL 107, 241302 (2011)*
- *arXiv:1111.2604*
- *Paper submitted to PRD*

**Galactic center**
Good statistics but source confusion and diffuse background

**Milky Way halo**
Large statistics but diffuse background
- *Paper submitted to PRD*

**Sun**
- *PRD 84, 032007 (2011)*

**Spectral lines**
No astrophysical uncertainties, good source id but small branching ratio.
- *PRL 104, 091302 (2010)*

**e^+/-,complementary to γs**
- *PRL 102, 181101 (2009)*
- *PRD 82, 092004 (2010)*
- *PRD 82, 092003 (2010)*
- *PRL 108, 011103 (2012)*

**Extra-galactic radiation**
Large statistics, but astrophysics and galactic diffuse background
- *JCAP 04, 014 (2010)*

**Galaxy clusters**
Low background but low statistics
- *JCAP 05, 025 (2010)*

All-sky map of gamma-rays from DM annihilation from arXiv: 0908.0195 (based on Via Lactea II simulation)
The EGB spectrum is compatible with a feature-less power-law spectrum between 200 MeV -100 GeV
- Smooth spectrum for energies > 100 GeV
- Indications of spectral softening at high energies

Total contribution from FSRQ + BL Lac + Radio galaxies + Star-forming galaxies: ~ 50% - 80%
- ~ 25% foreground modeling uncertainty not included in EGB error bands.
- The remaining contribution could be due to more unresolved point sources populations or different diffuse process (as cosmological DM annihilation).
Fermi is starting to reveal large-scale regions of excess high-energy emission not predicted by interstellar emission models, including the “Fermi lobes” (Su, Slatyer, Finkbeiner, 2010) and other large scale hard-spectrum diffuse features. At this energies more than 500 sources have been revealed, and around 170 of those are still unassociated and are not observed at other energies.
In 2010, Fermi discovered huge lobes of high energy γ-rays above and below the galactic center. In 2012, Planck maps confirm the presence of these lobes at lower energy wavebands. Much work remains to refine the spectral and spatial properties of these bubbles in order to understand their origin.
What Fermi will do in next years:

- More exposure + technical and analysis improvements + New MW tools
- More sources (especially at $E > 10$ GeV)
- Extend the measurement of the IGRB to lower ($< 200$ MeV) and higher ($> 100$ GeV)
- Contribution of unresolved point sources to the EGB
- Improve limits on or measure the intergalactic magnetic field
- Improve limits on Dark matter components
- Etc.
Tracker (TKR):
18 Si bi-layers
Front- 12 layers (~60% $X_0$)
Back-  6 layers (~80% $X_0$)
PSF$_{\text{back}}$ ~ 2x PSF$_{\text{front}}$

Many EM showers start in TKR

Calorimeter (CAL):
8 layers (8.6 $X_0$ on axis)
30MeV to > 300 GeV

Hodoscopic, shower profile and direction reconstruction above ~200 MeV

CAL imaging allows to correct for energy leakage out of CAL

Anti-Coincidence Detector (ACD)
Segmented: less self-veto when good direction information is available

Trigger and Filter
Use fast (~0.1 $\mu$s) signals to trigger readout and reject cosmic ray (CR) backgrounds

Ground analysis uses slower (~10$\mu$s) shaped signals

CAL/ TKR aspect ratio trades field-of-view against collection volume