Fermi Large area telescope results: The sky at high energies and the Quest for Dark Matter signals

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Happy 3rd Birthday Fermi!!

11 June 2008
The Fermi LAT 1FGL Source Catalog

1451 sources
The Fermi LAT 2FGL Source Catalog

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range

1873 sources
1095 AGN’s
589 unidentified

Fermi Coll.
arXiv:1108.1435
What has Fermi found: The LAT two-year catalog

- Blazars: 1095 (57%)
- Unknown: 589 (31%)
- Non-blazar active galaxies: 1%
- Pulsars: 6%
- Supernova remnants: 4%
- Globular clusters, high-mass binaries, normal galaxies and more: 1%
- the Second Fermi LAT Catalog 2FGL:

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Galactic Nuclei</td>
<td>832</td>
<td>44%</td>
</tr>
<tr>
<td>Candidate Active Galactic Nuclei</td>
<td>268</td>
<td>14%</td>
</tr>
<tr>
<td>Unassociated</td>
<td>594</td>
<td>32%</td>
</tr>
<tr>
<td>Pulsars (pulsed emission)</td>
<td>86</td>
<td>5%</td>
</tr>
<tr>
<td>Pulsars (no pulsations yet)</td>
<td>26</td>
<td>1%</td>
</tr>
<tr>
<td>Supernova Remnants/ Pulsar Wind Nebulae</td>
<td>60</td>
<td>3%</td>
</tr>
<tr>
<td>Globular Clusters</td>
<td>11</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Other Galaxies</td>
<td>7</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Binary systems</td>
<td>4</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>1888</td>
<td>100%</td>
</tr>
</tbody>
</table>
Silicon Tracker tower
18 planes of X Y silicon detectors + converters
12 trays with 2.5% R.L. of Pb, 4 trays with 25%
2 trays without converters

Tracker

Grid

DAQ Electronics

Anticoincidence Shield

Thermal Blanket

Calorimeter (8.5 Rad.Length)
How Fermi LAT detects gamma rays

4 x 4 array of identical towers with:
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box

An anticoincidence detector around the telescope distinguishes gamma-rays from charged particles

Energy measurement with e.m. calorimeter

Conversion ($\gamma$ in $e^+/e^-$) in W foils

Incoming direction reconstruction by tracking the charged particles
Fermi IRF

Effective area P6_V3_DIFFUSE for normal incidence:
- front
- back
- total

Effective area P6_V3_DIFFUSE for energy=10000 MeV:
- front
- back
- total

Acceptance P6_V3_DIFFUSE:
- front
- back
- total

Energy (MeV):
- $10^2$
- $10^3$
- $10^4$
- $10^5$

Incidence angle (degrees):
- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80

Effective area integrated over the FOV (cm² sr):
- 0
- 5000
- 10000
- 15000
- 20000
- 25000
Fermi IRF

Energy resolution P6_V3_DIFFUSE for normal incidence

Energy resolution P6_V3_DIFFUSE for energy=10000 MeV

PSF P6_V3_DIFFUSE for normal incidence

PSF P6_V3_DIFFUSE for energy = 10000 MeV
How Fermi LAT detects electrons

Trigger and downlink
- LAT triggers on (almost) every particle that crosses the LAT
  - \(\sim 2.2 \text{ kHz} \) trigger rate
- On board processing removes many charged particles events
  - But keeps events with more that 20 GeV of deposited energy in the CAL
  - \(\sim 400 \text{ Hz} \) downlink rate
- Only \(\sim 1 \text{ Hz} \) are good \(\gamma\)-rays

Electron identification
- The challenge is identifying the good electrons among the proton background
  - Rejection power of \(10^3 - 10^4\) required
  - Can not separate electrons from positrons
Event topology

A candidate electron
(recon energy 844 GeV)

- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

A candidate hadron
(raw energy > 800 GeV)

- TKR: small number of extra clusters around main track
- CAL: large and asymmetric shower profile
- ACD: large energy deposit per tile
Fermi Electron + Positron spectrum

Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

AMS (Aguillar et al., 2002)
HEAT (Du Vernois et al., 2001)
Kobayashi, 1999
Fermi low-energy (PRELIMINARY)
Fermi high-energy (PRELIMINARY)
ATIC (Chang et al., 2008)
H.E.S.S. (Aharonian et al., 2009)
H.E.S.S. (Aharonian et al., 2008)
Pre-Fermi diffusive model
e\(^-\) from PAMELA and e\(^+\)e\(^-\) from FERMI
Principle: Use the Earth's Magnetic Field to Distinguish $e^+$ and $e^-$

- Pure $e^+$ region is in the west and same for $e^-$ in the east
- The regions vary with particle energy and the LAT position
- To locate these regions, we use a code written by Smart, D. F. and Shea, M. A.* which numerically calculates a particle's trajectory in the geomagnetic field

*Center for Space Plasmas and Aeronomic Research, The University of Alabama in Huntsville
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth’s magnetic field as a charge discriminator:

- The two independent methods of background subtraction, Fit-Based and MC-Based, produce consistent results.
- The observed positron fraction is consistent with the one measured by PAMELA.

Fermi Coll. arXiv:1109.0521
Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: $1/3$ into $e^+e^-$, $1/3$ into $\mu^+\mu^-$ and $1/3$ into $\tau^+\tau^-$. Here too antiprotons are not produced in dark matter pair annihilation.

[arXiv:0905.0636]
Lepto-philic Models

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[arXiv:0905.0636]
Cosmic Ray Electrons Anisotropy

the levels of anisotropy expected for Geminga-like and Monogem-like sources (i.e. sources with similar distances and ages) seem to be higher than the scale of anisotropies excluded by the results. However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters.

Distribution of significance, fitted by a Gaussian

Cosmic Ray Electrons Anisotropy

More than 1.6 million electron events with energy above 60 GeV have been analyzed on anisotropy

• Upper limit for the dipole anisotropy has been set to 0.5 – 5% depending on the energy
• Upper limit on fractional anisotropic excess ranges from a fraction to about one percent depending on the minimum energy and the anisotropy’s angular scale

Distribution of significance, fitted by a Gaussian

electron + positron expected anisotropy in the directions of Monogem and Geminga
SED of the isotropic diffuse emission (1 keV-100 GeV)


LAT error bars = statistical + instrumental systematic (added in quadrature)

uncertainties from galactic diffuse model not included
the Isotropic Gamma-ray Background (IGRB)

Preliminary
Update on the Isotropic Gamma-ray Background (IGRB)

200 MeV to 580 GeV

Also Consistent with a softening at high energy
extragalactic gamma-ray spectrum

others possible contributions to the extragalactic gamma-ray spectrum
The Fermi LAT 2FGL Source Catalog

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range
The Fermi LAT 15 * 15 degrees around the Galactic center from the 2FGL Source Catalog

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range

15 * 15 degrees

see German Vargas talk
Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios

The constraints due to the absences of charginos and the Higgs boson at LEP are also shown, as black dashed and red dot-dashed lines, respectively. Regions excluded by the requirements of electroweak symmetry breaking and a neutral LSP are shaded dark pink and brown, respectively. The green region is excluded by $b \rightarrow s\gamma$, and the pink region is favoured by the supersymmetric interpretation of the discrepancy between the Standard Model calculation and the experimental measurement of $g_\mu - 2$ within 1 and 2 standard deviations (dashed and solid lines, respectively).

Ellis et al., arXiv:1106.0768
Dwarf spheroidal galaxies (dSph): promising targets for DM detection
Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10^-2000).
➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
➢ SDSS [only \(\frac{1}{4}\) of the sky covered] already double the number of dSphs these last years
➢ Most of them are expected to be free from any other astrophysical gamma source.
✔ Low content of gas and dust.
Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

Flux upper limits are combined with the DM density inferred by the stellar data (*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on $\langle \alpha \rangle$ vs WIMP mass for specific DM models.

(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

Dwarf Spheroidal Galaxies upper-limits Update

Upper limits, Combined Likelihood limits of 10 dSphs

- Thermal WIMP cross-section
- $\mu^+\mu^-$ Channel
- $b\bar{b}$ Channel
- $\tau^+\tau^-$ Channel
- $W^+W^-$ Channel

PRELIMINARY

WIMP cross-section [cm$^3$/s]

- $10^{-21}$
- $10^{-22}$
- $10^{-23}$
- $10^{-24}$
- $10^{-25}$
- $10^{-26}$

WIMP mass [GeV]

- $5\text{GeV}$
- $10^1$
- $10^2$
- $10^3$
- $1000\text{GeV}$

robust constraints including J-factor uncertainties
Dwarf Spheroidal Galaxies upper-limits Update

Upper limits, Joint Likelihood of 10 dSphs

- $3 \times 10^{-26}$
- $\mu^+ \mu^-$ Channel
- $b\bar{b}$ Channel
- $W^+ W^-$ Channel
- $\tau^+ \tau^-$ Channel

Robust constraints including J-factor uncertainties

Fermi Lat Coll.
arXiv:1108.3546
CREs from DM annihilation

Schuster et al. (2010) discuss 2 scenarios in which dark matter annihilation leads to cosmic-ray electron and positron (CRE) fluxes from the Sun:

- **intermediate state scenario**: Dark matter annihilates in the center of the Sun into an intermediate state $\Phi$ which then decays to CREs outside the surface of the Sun

- **iDM scenario**: Inelastic dark matter (iDM) captured by the Sun remains on large orbits, then annihilates directly to CREs outside the surface of the Sun
There is a class of models that has garnered interest recently in light of claims that iDM could naturally explain such observations as the 511 keV line observed by INTEGRAL/SPI and the apparently inconsistent results of DAMA/LIBRA and CDMS if the DM scattered inelastically and thereby transitioned to an excited state with a slightly heavier mass. The bounds we derive exclude the relevant cross sections by 1–2 orders of magnitude -> the parameter space of models preferred by DAMA/LIBRA can be ruled out for \( m > 70 \) GeV for annihilation to \( e^+e^- \).
Wimp lines search
Fermi LAT 23 Month Line search results
Flux Upper Limits, 7 GeV – 200 GeV

- ± 20 % overall scale systematic error (+20 % systematic for UL).
  Additional systematic on spectral structures with LAT resolution for E < 13.2 GeV of s/bg ~ 1%.
- 7 and 10 GeV bins use a modified event selection to reduce the systematic uncertainty associated with public IRFs.
- For E > 12 GeV no indication of a spectral structure systematic effect is seen.
Fermi LAT 23 Month $\gamma Z$-Cross-section limits
7 GeV – 200 GeV

• ± 20 % overall scale systematic error (+20 % systematic for UL).

Additional systematic on spectral structures with LAT resolution for $E<13.2$ GeV of $s/bg \sim 1\%$. 
Decay lifetime lower limits

- Limits similar for all 3 DM density profiles due to linear dependence of flux on $\rho$
- Disfavors lifetimes smaller than $10^{29}$ s
Looking Ahead

http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

Many further improvements in instrument performance in progress

- Event reconstruction and choices of event selection “knobs” all determine instrument performance. For stability, standard event class definitions established with IRFs.
- Data were released with Pass6.
- Some known issues, described in Caveats on FSSC site and in LAT papers, addressed with patch to IRFs.
- Longer-term: Pass7 and Pass8 to address the remaining issues.
- Pass7 release imminent

Improved standard photon classes
- Event analysis taking into account “ghost” events
- Working closely with FSSC on ease of use for user community.
- Exciting progress on Pass8, expected to be the ultimate version.