Dark Matter Searches with the Fermi-LAT
The Large Area Telescope

Specifications

- all-sky coverage
- public data
- ~8 years observation (extended through 2018)
- 30 MeV to over 300 GeV

Acknowledgments

Ackerman+ [LAT Clb] 2012ApJS..203....4A44A

Via Lactea 2 Simulation
\[ \phi_s(\Delta \Omega) = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_{DM}^2} \int_{E_{\min}}^{E_{\max}} dN_{\gamma} \frac{dE_{\gamma}}{dE_{\gamma}} \times \int_{\Delta \Omega} \int_{l.o.s.} \rho_{DM}^2(r) dld\Omega' \]

\[ \text{particle physics} \]

*Weakly-Interacting Massive Particle

LAT-detectable products

\[ \pi_0 \rightarrow \gamma \gamma \]

or

\[ e^+ e^- \]
J-Factors

comparatively

10^{19}
dSph

10^{18-21}
clusters

10^{20}
dSphs

10^{22-23}
EGB

GC/Halo
Status

- extensive searches in standard targets

- dSph
  - Ackermann+ 2012ApJ...747..121A
  - GC
  - Ajello+ 2016ApJ...819...44A
  - Halo
  - Ajello+ 2016ApJ...819...44A

- clusters

- dSphs

- GC/Halo

- EGB

- Isotropic
  - Ackermann+ 2015JCAP...09..008T

- Lines
  - Ackermann+ 2012ApJ...747..121A
  - Unassociated Sources
  - Ackermann+ 2012ApJ...747..121A
Figure 2. Residual maps of the regions surrounding the subhalo candidate 3FGL J2212.5+0703 (left frame) and the known blazar 3FGL J2134.1-0152 (right frame). These maps display the photon flux per square degree (above 1 GeV) and have been smoothed with a 0.15 Gaussian. Whereas the source in the left frame shows significant evidence of spatial extension, the source in the right frame is consistent with point-like emission.

4 Systematic Uncertainties: Assessing the Robustness of 3FGL J2212.5+0703's Spatial Extension

In this section, we will describe tests that we have performed in order to establish the probability that the spatial extension observed from 3FGL J2212.5+0703 is authentic, as opposed to being the result of problems with the diffuse emission model or confusion between multiple nearby gamma-ray sources.

4.1 Using Associated 3FGL Sources as a Control Group

In addition to the unassociated sources discussed in the previous section, the 3FGL catalog contains many sources that have been associated with emission observed at other wavelengths. These sources, which are very unlikely to be dark matter subhalos, provide us with an opportunity to test our procedure for identifying spatial extension. In order to make a fair "apples-to-apples" comparison, we consider only those associated 3FGL sources that are located at high latitude (|b| > 20) and that emit a gamma-ray flux in the same range as our 12 subhalo candidates (10^9 cm^2s^-1 < F < 4.24 × 10^9 cm^2s^-1). Of the 251 sources that meet these criteria, 228 are associated with AGN, 16 with pulsars, six with galaxies, and one with a globular cluster.

Following the approach described in the previous section, we have tested each of these 251 sources for evidence of (spherically symmetric) spatial extension. While we found that none of these 251 sources exhibit as much evidence for extension as 3FGL J2212.5+0703, the flat-spectrum radio quasar 3FGL J1310.6+3222 does prefer extension at a slightly lower level, $2 \Delta \text{ln} L = 19.4$ (compared to 21.4 for 3FGL J2212.5+0703). Including this source, we found that five of these 251 sources prefer extension at the level of $2 \Delta \text{ln} L > 10$.

In Fig. 3, we present these results for a small sub-sample of these 251 sources. In the upper six frames:

- extensive searches in standard targets
- including a few others!
Figure 2: Residual maps of the regions surrounding the subhalo candidate 3FGL J2212.5+0703 (left frame) and the known blazar 3FGL J2134.1-0152 (right frame). These maps display the photon flux per square degree (above 1 GeV) and have been smoothed with a 0.15 Gaussian. Whereas the source in the left frame shows significant evidence of spatial extension, the source in the right frame is consistent with point-like emission.

4 Systematic Uncertainties: Assessing the Robustness of 3FGL J2212.5+0703's Spatial Extension

In this section, we will describe tests that we have performed in order to establish the probability that the spatial extension observed from 3FGL J2212.5+0703 is authentic, as opposed to being the result of problems with the diffuse emission model or confusion between multiple nearby gamma-ray sources.

4.1 Using Associated 3FGL Sources as a Control Group

In addition to the unassociated sources discussed in the previous section, the 3FGL catalog contains many sources that have been associated with emission observed at other wavelengths. These sources, which are very unlikely to be dark matter subhalos, provide us with an opportunity to test our procedure for identifying spatial extension. In order to make a fair "apples-to-apples" comparison, we consider only those associated 3FGL sources that are located at high latitude (|b| > 20°) and that emit a gamma-ray flux in the same range as our 12 subhalo candidates (10^9 cm^2 s^-1 < F < 4.24 × 10^9 cm^2 s^-1). Of the 251 sources that meet these criteria, 228 are associated with AGN, 16 with pulsars, six with galaxies, and one with a globular cluster.

Following the approach described in the previous section, we have tested each of these 251 sources for evidence of (spherically symmetric) spatial extension. While we found that none of these 251 sources exhibit as much evidence for extension as 3FGL J2212.5+0703, the flat-spectrum radio quasar 3FGL J1310.6+3222 does prefer extension at a slightly lower level, 2 ln L' = 19.4 (compared to 21.4 for 3FGL J2212.5+0703). Including this source, we found that five of these 251 sources prefer extension at the level of 2 ln L' > 10. In Fig. 3, we present these results for a small sub-sample of these 251 sources. In the upper six frames...

---

Status

- extensive searches in standard targets
- including a few others!
- no clear detection
- results can be summarized by focusing on these two
first check for the unique signature
• early feature at 135 GeV, but
• present in off-regions
• significance has gone down

Galactic Center

highest potential flux

Weniger 2012

Ackermann+ [LAT Clb]
2012ApJ...747..2015arXiv150600013T
first check for the unique signature
- early feature at 135 GeV, but
- present in off-regions
- significance has gone down

Ackermann+ [LAT Clb]
2012ApJ...747..2015arXiv150600013T
Galactic Center

for continuum, we must model known sources

- cosmic rays + gas
- cosmic rays + light
- point sources
- “bubbles”

\{ multi-wavelength driven
\}

\{ gamma-driven

Preliminary

highest potential flux
Galactic Center

model known sources
- cosmic rays + gas
- cosmic rays + light
- point sources

examine what remains
- peaked at a few GeV
- extended (10 deg)
- spatially consistent spectrum?

highest potential flux

Preliminary
FIG. 10: The raw gamma-ray maps (left) and the residual maps after subtracting the best-fit Galactic diffuse model, 20 cm template, point sources, and isotropic template (right), in units of photons/cm$^2$/s/sr. The right frames clearly contain a significant central and spatially extended excess, peaking at $\sim 1-3$ GeV. Results are shown in galactic coordinates, and all maps have been smoothed by a 0.25 Gaussian.

We note that the Fermi tool gtlike determines the quality of the fit assuming a given spectral shape for the dark matter template, but does not generally provide a model-independent spectrum for this or other components. In Fig. 8, we show the spectrum of the dark-matter-like component, for values of $\alpha = 1.2$ (left frame) and $\alpha = 1.3$ (right frame). Shown for comparison is the spectrum predicted from a 35.25 GeV WIMP annihilating to $b\bar{b}$. The solid line represents the contribution from prompt emission, whereas the dot-dashed and dotted lines also include an estimate for the contribution from bremsstrahlung (for the $z = 0.15$ and 0.3 kpc cases, as shown in the right frame of Fig. 2, respectively). The normalizations of the Galactic Center and Inner Galaxy signals are compatible (see Figs. 6 and 8), although the details of this comparison depend on the precise morphology that is adopted.

Galactic Center

model known sources
- cosmic rays + gas
- cosmic rays + light
- point sources
- “bubbles”

examine what remains
- peaked at a few GeV
- extended (10 deg)
- spatially consistent spectrum?
- sharp cutoff

highest potential flux

Preliminary

without / with bubbles

NASA/T. Linden, U. Chicago
Galactic Center

potential missing pieces

- dark matter signal

highest potential flux
Galactic Center

potential missing pieces

- dark matter signal
- millisecond pulsar population

both models fit both the spectrum and extension

highest potential flux

O'Leary+ (2015)  
arXiv:1504.02477
Aliu+ (2015)  
2015ApJ...800...61A
Galactic Center

potential missing pieces

- dark matter signal
- millisecond pulsar population

both models fit both the spectrum and extension but there is a fundamental difference

highest potential flux

Aliu+ (2015) 2015ApJ...800...61A

lumpy vs smooth

Bartels et al. 2015, arXiv:1506.05104
Dwarf Spheroidal Galaxies

the cleanest targets

dSph properties
- DM-dominated (1000:1)
- 10s to 1000s of stars trace the potential
- often high latitude (low diffuse background)
- nearby (<250 kpc)
- many! (50+) allows for joint analyses
Dwarf Spheroidal Galaxies

the clearest targets

joint dSph analysis
• 15 targets
• 4th generation
collaboration analysis
• 60 mo. Pass 8 data
• thermal exclusion to
100 GeV

Recent papers:
- LAT: Ackermann+ [LAT Clb] 2015PhRvL.115w1301A
- Drlica-Wagner+ [LAT + DES Clb] 2015ApJ...809L...4D
- Geringer-Sameth+ 2015PhRvL.115h1101G
what can the LAT say about WIMPs?

in context

- at the forefront in sensitivity for this mass range
- beginning to pressure thermal WIMPs
- still some potential for detection
the future

two big questions
• there are a few hints — can they be resolved?
• if we don’t see anything, what ultimate limits can we expect?
Projected Limits

beating $\sqrt{t}$

- ~20 new targets from the dark energy survey (DES)
- similar in character (southern hemisphere)
- waiting on spectroscopic follow-up for J-factors
Projected Limits

the dSph advantage

beating $\sqrt{t}$

- ~20 new targets from the dark energy survey (DES)
- similar in character (southern hemisphere)
- waiting on spectroscopic follow-up for J-factors
- even more with LSST

Charles+ [LAT Clb]
2015arXiv150600013T

Drlica-Wagner+ 2015ApJ...813..109D
Bechtol+ 2015ApJ...807...50B
Projected Limits

the dSph advantage

15 years, 60 dSphs
- should conclusively address GC models
- can reach thermal to 100s of GeV

Charles+ [LAT Clb]
2015arXiv150600013T
beyond WIMPs
Axion-Like Particles

\[ \mathcal{L}_{\alpha\gamma} = -\frac{1}{4} g_{\alpha\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} = g_{\alpha\gamma} E B a \]

by mixing with ALPs, gammas can
- survive propagation when they should not
- acquire spectral irregularities

Meyer 2016
Axion-Like Particles

in practice
Axion-Like Particles

in practice

analysis of NGC 1275

- no significant spectral irregularities
- strongly pressures models which fit EBL attenuation in IACT data
Axion-Like Particles

in practice

in case of a Milky Way supernova

- ALP conversion would allow photons to escape much earlier, becoming gamma rays again in the galactic magnetic field
- if it happens in the LAT lifetime, we can actually constrain ALP DM

Meyer+ 2016

NASA/ESA
summary

- the LAT has been an invaluable resource for indirect DM searches
- the field is driven by analyses of dSphs and the GC
- the potential of new targets (dSphs) and events (galactic supernovae) will keep things exciting