Searching for Dark Matter Annihilation in Dwarf Spheroidal Galaxies with Fermi

Tesla Jeltema
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on behalf of the Fermi LAT Collaboration
Outline

- The Fermi Gamma-Ray Space Telescope
- Gamma rays from dark matter annihilation
  - Fermi searches
- Dwarf spheroidal galaxies
  - targets and density profiles
- Fermi-LAT preliminary 9 month results
  - flux upper limits
  - DM annihilation cross-section upper limits
  - comparison to clusters of galaxies
Fermi Gamma-Ray Space Telescope

- Launched June 11, 2008

- Fermi-LAT began all-sky gamma-ray survey August 2008
  - 20 MeV to > 300 GeV
  - more 10x EGRET sensitivity

- Broad science:
  AGN, GRBs, Pulsars, SNRs, galactic and extragalactic diffuse emission, EBL, cosmic rays, indirect dark matter searches

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Fermi-LAT 3 Month Sky Map

206 bright sources (detected > 10 \(\sigma\)) in the 3 month catalog, 2/3 at |b| > 10 degrees
Gamma rays from WIMP annihilation

Secondary from $\pi_0$ decays

Prompt lepton pair production

\[ \Phi_{\text{WIMP}}(E, \Psi) = J(\Psi) \times \Phi^{PP}(E) \]

Astrophysical factor

\[ J(\Psi) = \int_{\text{l.o.s.}} dl(\Psi) \rho^2(l) \]

Particle physics factor

\[ \Phi^{PP}(E) = \frac{1}{2} \frac{\langle \sigma v \rangle}{m_{\text{WIMP}}^2} \sum_f \frac{dN_f}{dE} B_f \]
Gamma-ray Spectrum from WIMP annihilation

Gamma-ray yield for a 200 GeV WIMP
• cutoff at WIMP mass
• some final states give similar spectra

DM density distribution
annihilation cross-section

particle mass
final state

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### Fermi Dark Matter Searches

<table>
<thead>
<tr>
<th>Search Technique</th>
<th>advantages</th>
<th>challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactic center</td>
<td>Good Statistics</td>
<td>Source confusion/Diffuse background</td>
</tr>
<tr>
<td>Satellites, Subhalos</td>
<td>Low background, Good source id</td>
<td>Low statistics</td>
</tr>
<tr>
<td>Milky Way halo</td>
<td>Large statistics</td>
<td>Galactic diffuse background</td>
</tr>
<tr>
<td>Extragalactic</td>
<td>Large Statistics</td>
<td>Astrophysics, galactic diffuse background</td>
</tr>
<tr>
<td>Spectral lines</td>
<td>No astrophysical uncertainties, good source id</td>
<td>Low statistics</td>
</tr>
<tr>
<td>Clusters of Galaxies</td>
<td>Low background, Good source id</td>
<td>Low statistics</td>
</tr>
</tbody>
</table>

E.A. Baltz et al. JCAP07 (2008) 013

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Dwarf Spherodial Galaxies: Promising Targets for DM Signal

Milky Way dwarf spheroidals are:

- nearby
- very dark matter dominated (M/L ~ 10 – 2000)
- most are expected to be free of other astrophysical gamma-ray sources
- SDSS searches have doubled the number of known dwarfs
Choose ten best candidate, high latitude dSph galaxies
distance < 150 kpc
-30 > b > 30 degrees
Dark Matter Density Profiles

Astrophysical factor based on modeling of stellar kinematic data assuming NFW profile (e.g. Strigari et al. 2007, Geha et al. 2009)

<table>
<thead>
<tr>
<th>Name</th>
<th>$\rho_s$ $(M_\odot \text{pc}^{-3})$</th>
<th>$r_s$ (kpc)</th>
<th>$J^{NFW}$ $(10^{19} \text{GeV}^2 \text{cm}^{-5})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segue 1</td>
<td>1.65</td>
<td>0.05</td>
<td>0.97</td>
</tr>
<tr>
<td>Ursa Major II</td>
<td>0.17</td>
<td>0.25</td>
<td>0.57</td>
</tr>
<tr>
<td>Segue 2</td>
<td>0.61</td>
<td>0.06</td>
<td>0.1</td>
</tr>
<tr>
<td>Willman 1</td>
<td>0.417</td>
<td>0.17</td>
<td>0.84</td>
</tr>
<tr>
<td>Coma Berenices</td>
<td>0.232</td>
<td>0.22</td>
<td>0.42</td>
</tr>
<tr>
<td>Usra Minor</td>
<td>0.04</td>
<td>0.97</td>
<td>0.35</td>
</tr>
<tr>
<td>Sculptor</td>
<td>0.063</td>
<td>0.52</td>
<td>0.12</td>
</tr>
<tr>
<td>Draco</td>
<td>0.13</td>
<td>0.50</td>
<td>0.43</td>
</tr>
<tr>
<td>Sextans</td>
<td>0.079</td>
<td>0.36</td>
<td>0.05</td>
</tr>
<tr>
<td>Fornax</td>
<td>0.04</td>
<td>1.00</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Considering Fermi PSF, can approximate dwarfs as point sources (dwarf $r_s = 0.1$-0.8° compared to 68% PSF ~ 5° at 100 MeV and 0.75° at 1 GeV)

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Fermi-LAT Data Analysis

- 9 months of data
  - cuts to remove particle background and Earth’s albedo
  - energy range 100 MeV to 50 GeV
  - 10 degree radius
  - binned analysis

- Backgrounds:
  - model galactic and isotropic diffuse
  - include point sources from 9 month catalog

first-year paper coming soon
Unfortunately, no dwarf spheroidal galaxies detected so far.

Example raw count map > 1 GeV

Example smoothed count map > 1 GeV

5°x5° centered on Segue 1

5°x5° centered on Willman 1

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Fermi-LAT Flux Upper Limits

Flux upper limits assuming a point-like source at the dwarf location

Using DMFIT package, Jeltema & Profumo 2008

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Annihilation Cross-Section Limits

- Use 95% confidence upper limits on > 100 MeV flux
- Assume a $\bar{b}b$ final state

Beginning to constrain some thermally produced WIMP models with the right relic density (NFW, no substructure).

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Annihilation Cross-Section Limits

- Same for $\mu^+\mu^-$ final state
- Limits considering only final state radiation

![Graph showing annihilation cross-section limits vs. WIMP mass](image-url)
We expect significant IC gamma-ray emission for high mass WIMP models annihilating to leptonic final states.

The IC flux depends strongly on the uncertain/unknown diffusion of cosmic rays in dwarfs.

We assume a simple diffusion model similar to what is found for the Milky Way

\[ D(E) = D_0 E^{1/3} \text{ with } D_0 = 10^{28} \text{ cm}^2/\text{s} \]

(only galaxy with measurements, scaling to dwarfs??)
Inverse Compton Contribution

IC emission can dominate for leptonic final states at $m > 300$ GeV.

Draco: variation in diffusion coeff. $10^{28}$ vs. $10^{29}$

Segue 1: diffusion more significant in small dwarfs
Constraints Including IC Emission

Combined constraints for FSR plus IC with reference diffusion model ($D_0 = 10^{28}$ cm$^2$/s).

![Graph showing constraints for FSR plus IC with reference diffusion model. The graph includes lines for different regions such as Segue I, U Major II, Segue II, Willman I, Coma B., U Minor, Sculptor, Sextans, and Fornax. Notably, the Draco region is highlighted with $D=10^{28}$ cm$^2$/s and $D=10^{29}$ cm$^2$/s. The graph also shows the Fermi best-fit region and a preliminary prediction for the $\mu^+\mu^-$ final state, with IC.]

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Comparison to Cluster of Galaxies

- Large DM densities and low backgrounds, similar to dwarfs
  (see Jeltema et al. 2009, Pinzke et al. 2009)

- Not detected in 9 months of data
  (see Keith Bechtol’s talk at TeV PA)

- Diffusion of $e^+e^-$ is not expected to be significant,
  reducing the model dependence of the predicted IC emission.
Comparison to Cluster of Galaxies

Constraints for combined FSR + IC

Muon-Antimuon final state

Ruled out by Fermi-LAT Gamma-Ray Limit

Preliminary

Fornax and Coma clusters: NFW, no substructure

50% of mass in substructure

Beginning to constrain some models for Pamela $e^+$ excess.

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Conclusions

- Fermi-LAT provides a new window for indirect searches for dark matter.

- No dSph galaxies detected in 9 months of data.

- Flux upper limits are beginning to constrain some thermally produced WIMP models with the right relic density (NFW, no substructure).

- Fermi observations of clusters and dwarfs (diffusion dependent) are beginning to probe DM models fitting the Fermi and Pamela e⁺e⁻ data.
IDM 2010
8th International Workshop on Identification of Dark Matter
http://www.lpta.univ-montp2.fr/idm2010

26-30 July 2010
Université Montpellier 2
Montpellier, France

Dark matter candidates
Dark matter direct searches
Dark matter indirect searches
Connections with accelerator searches
Halo models and structure formation
Gravitational lensing
Neutrino physics
Cosmology and dark energy

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