A Search for Dark Matter Annihilation in Dwarf Spheroidal Galaxies with Pass 8 Data

Brandon Anderson
on behalf of the
Fermi-LAT Collaboration

5th Fermi Symposium
October 24, 2014
Introduction
**Dwarf Spheroidal Galaxies**

- **The Milky Way** is surrounded by satellite galaxies
- Close to Earth (25 kpc to 250 kpc)
- Luminosities range from $10^7 \, L_\odot$ to $10^3 \, L_\odot$
- Astrophysically inactive
- Most dark matter dominated objects known
- ~25 known

---

**Theoretical Yield**

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_\chi^2} \sum_f \frac{dN_f}{dE_\gamma} B_f \int_{\Delta \Omega} d\Omega \int_{\text{los}} \rho^2(l) \, dl(\psi) \, d\Omega$$

Brandon Anderson, Stockholm University | 5th Fermi Symposium
Pass 8

More data, more accuracy, and more information!

**Effective Area**  
+25%  
> 1 GeV

**Angular Resolution**  
+10-15%  
> 1 GeV

**Point-source Sensitivity**  
+40%  
@ 1-10 GeV

Containment in PSF classes

For more information see P. Bruel's talk from Wednesday.
### FOURTH GENERATION

<table>
<thead>
<tr>
<th>arXiv</th>
<th>irf</th>
<th>time</th>
<th>targets</th>
<th>joint?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001.4531</td>
<td>P6</td>
<td>11 mo.</td>
<td>10</td>
<td>no</td>
</tr>
</tbody>
</table>

### EFFECTIVE LIKELIHOOD

\[
L_2(\mathcal{D}|\mu, \theta_t) = L_{\text{LAT}}^{\text{LAT}}(\mathcal{D}_t|\mu, \theta_t)
\]
Data Set & Technique

<table>
<thead>
<tr>
<th>arXiv</th>
<th>irf</th>
<th>time</th>
<th>targets</th>
<th>joint?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001.4531</td>
<td>P6</td>
<td>11 mo.</td>
<td>10</td>
<td>no</td>
</tr>
<tr>
<td>1108.3546</td>
<td>P6</td>
<td>24 mo.</td>
<td>10</td>
<td>yes</td>
</tr>
<tr>
<td>1310.0828</td>
<td>P7</td>
<td>48 mo.</td>
<td>15</td>
<td>yes</td>
</tr>
</tbody>
</table>

**EFFECTIVE LIKELIHOOD**

\[
L_2(\mathcal{D}|\mu, \theta_t) = L_t^{\text{LAT}}(\mathcal{D}_t|\mu, \theta_t) \times \frac{1}{\ln(10)J_t \sqrt{2\pi\sigma_t}} e^{-\left(\log_{10}(J_t) - \log_{10}(J_t)\right)^2 / 2\sigma_t^2}
\]

\[
L_3(\mathcal{D}|\mu, \{\theta_t\}) = \prod_{\text{targets}} L_2(\mathcal{D}|\mu, \theta_t)
\]

*(term accounts for uncertainty in J-factor)*

*(combine information from all targets)*

*see talk from Alex on Wednesday, also poster 2.01*
**FOURTH GENERATION**

<table>
<thead>
<tr>
<th>arXiv</th>
<th>irf</th>
<th>time</th>
<th>targets</th>
<th>joint?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001.4531</td>
<td>P6</td>
<td>11 mo.</td>
<td>10</td>
<td>no</td>
</tr>
<tr>
<td>1108.3546</td>
<td>P6</td>
<td>24 mo.</td>
<td>10</td>
<td>yes</td>
</tr>
<tr>
<td>1310.0828</td>
<td>P7</td>
<td>48 mo.</td>
<td>15</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>P8</td>
<td>60 mo.</td>
<td>15</td>
<td>yes x2!</td>
</tr>
</tbody>
</table>


**EFFECTIVE LIKELIHOOD**

\[
L_2(D|\mu, \theta_t) = L_t^{\text{LAT}}(D_t|\mu, \theta_t) \times \frac{1}{\ln(10)J_t \sqrt{2\pi \sigma_t}} e^{-\frac{(\log_{10}(J_t) - \log_{10}(J))^2}{2\sigma_t^2}}
\]

\[
L_3(D|\mu, \{\theta_t\}) = \prod_{\text{targets}} L_2(D|\mu, \theta_t)
\]

\[
L_4(D|\mu, \{\theta_t\}) = \prod_{\text{classes}} L_3(D_c|\mu, \{\theta_t\})
\]

*(term accounts for uncertainty in J-factor)*

*(combine information from all targets)*

*(combine information from all psf classes)*

*see talk from Alex on Wednesday, also poster 2.01*
Pass 7 Status

The figure shows the cumulative density of different events as a function of mass and energy. The observed limit and the median expected values are compared, with 68% and 95% containment regions.

Key points:
- Observed Limit
- Median Expected
- 68% Containment
- 95% Containment

The results are compared to simulations and random positions, with significance adjusted to match blank-field sensitivity.

**Outstanding Questions**

- What causes the non-asymptotic TS distribution?
- Is the excess dark matter?
**Primary Cause?**

- Using a more extensive point-source catalog relieves some of the MC-data discrepancy.
- Could be further relieved by adding multi-wavelength sources (e.g. BZCAT, see 1409.1572)

![Graph showing cumulative fraction vs. TS](image)

- $b\bar{b}$, $M = 25$ GeV
- **2FGL**: 2 years, 1873 sources
- **3FGL**: 4 years, 3033 sources
- Preliminary
Results
Results (expected limits)

(bands derived from 300 random blank-sky sets)
Results
(no significant emission detected)

(bands derived from 300 random blank-sky sets)
Comparative Limits

![Graph showing limits on different processes with mass on the x-axis and cross-section on the y-axis.]

- **Fermi-LAT Pass 8 Dwarfs (95% C.L.)**
- **Ackermann+ 2014 Dwarfs (95% C.L.)**
- **Aleksic+ 2014 MAGIC Segue 1 (95% C.L.)**
- **Abramowski+ 2011 H.E.S.S. GC Halo (95% C.L.)**

**Thermal Relic Cross Section**

**Preliminary**
Galactic Center Excess (GCE) Compatibility

Preliminary

Fermi-LAT Pass 8 Dwarfs (95% C.L.)
- Ackermann+ 2012 MW Halo (3 $\sigma$)
- Ackermann+ 2014 Dwarfs (95% C.L.)
- Calore+ 2014 (2 $\sigma$)
- Daylan+ 2014 (2 $\sigma$)
- Abazajian+ 2014 (1 $\sigma$)
- Gordon & Macias 2013 (2 $\sigma$)

$\langle \sigma v \rangle$ (cm$^3$ s$^{-1}$)

$b\bar{b}$

$bb$

Mass (GeV)

$10^{-27}$

$10^{-26}$

$10^{-25}$

$10^{-24}$

Brandon Anderson, Stockholm University | 5th Fermi Symposium
GCE Compatibility

Preliminary

\[
\langle \sigma v \rangle \text{ (cm}^3 \text{s}^{-1})
\]

- Fermi-LAT Pass 8 Dwarfs (95% C.L.)
- Ackermann+ 2012 MW Halo (3 \( \sigma \))
- Ackermann+ 2014 Dwarfs (95% C.L.)
- Calore+ 2014 (2 \( \sigma \))
- Daylan+ 2014 (2 \( \sigma \))
- Abazajian+ 2014 (1 \( \sigma \))
- Gordon & Macias 2013 (2 \( \sigma \))

Rescaled to \( \rho_{\text{local}} = 0.4 \text{ GeV cm}^{-3} \)

Mass (GeV)
# Systematics

<table>
<thead>
<tr>
<th>NFW vs. Burkert</th>
<th>7 alternative models</th>
<th>bracketing values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22%</td>
<td>10%</td>
<td>8%</td>
</tr>
</tbody>
</table>

@ 100 GeV WIMP Mass

*depending on CDM trust
The Future

Preliminary

Brandon Anderson, Stockholm University | 5th Fermi Symposium
Conclusion

- Dwarf spheroidals continue to provide extremely robust constraints due to their low astrophysical uncertainty.
- Pass 8 dwarf WIMP limits are now the most stringent below 1 TeV (exclude thermal b-bbar < 100 GeV)
- There is mild tension between the new limits and the galactic center excess WIMP.
- Within the next few years, additional data coupled with new targets should conclusively address the tension, and exclude thermal for some channels up to a few hundreds of GeV.