Dark Matter in satellite galaxies: will future IACTs play a role?


Mattia Fornasa
University of Padova – INFN Padova
dSphs are satellite galaxies hosted in larger halos.

- Data on stellar content (velocity dispersion, colour, metallicity,...)

- “missing satellite problem” has been mitigated by the detection of a bunch of new objects in the last years

- total (stars+DM) mass is inferred, with similar value $M(r<300 \text{ pc})$ for all the dSphs

- largest known $M/L$ ratio
**Draco**

- Discovered in 1954 by Wilson et al.
- $d=(80\pm7)$ kpc
- ~200 stars
- $M/L\sim 200$
- Observation by many Air Cherenkov Telescopes (IACTs)
- No detection
- MAGIC observation in 2004 produced an upper limit of $\Phi_{u.l.}(E>140$ GeV$)=1.1\times10^{-11}$ cm$^{-2}$ s$^{-1}$

**Willman I**

- Discovered in 2004 by Willman, belong to the class of recently discovered objects with the SDSS
- $d=(38\pm7)$ kpc
- ~30 stars
- $M/L\sim O(10^3)$
- Larger uncertainties on the mass profile due to the small number of stars
- Possible effect of tidal disruption
- MAGIC observation in 2007 provided an upper limit of $\Phi_{u.l.}(E>100$ GeV$)\sim few\times10^{-12}$ cm$^{-2}$ s$^{-1}$
### Draco

From Albert et al., arXiv:astro-ph/0711.2574

### Willman I

<table>
<thead>
<tr>
<th>BM</th>
<th>$\Phi^\text{DM}(E&gt;100 \text{ GeV}) \ [\text{cm}^{-2}\text{s}^{-1}]$</th>
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</tr>
</thead>
<tbody>
<tr>
<td>I'</td>
<td>$2.64 \times 10^{-16}$</td>
<td>$9.87 \times 10^{-12}$</td>
</tr>
<tr>
<td>J'</td>
<td>$4.29 \times 10^{-17}$</td>
<td>$5.69 \times 10^{-12}$</td>
</tr>
<tr>
<td>K'</td>
<td>$2.32 \times 10^{-15}$</td>
<td>$6.83 \times 10^{-12}$</td>
</tr>
<tr>
<td>F*</td>
<td>$1.09 \times 10^{-16}$</td>
<td>$7.13 \times 10^{-12}$</td>
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<tr>
<th>BM</th>
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<tr>
<td>I'</td>
<td>$3.7 \times 10^4$</td>
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\[
\frac{d\Phi}{dE\,d\Omega} = \frac{\langle \sigma_{\text{ann}} v \rangle}{4\pi m^2_{\chi}} \frac{dN_{\gamma}(E)}{dE} \frac{1}{\Delta \Omega} \int_{l.o.s.} d\lambda \int_{\Delta \Omega} d\Omega \rho_{\chi}^2(\lambda, \theta, \varphi)
\]

**Particle Physics factor**

**Astrophysical factor**
Astrophysical factor

DM density profiles can be obtained from:
- stellar data (Jeans equation)
- $N$-body simulations

Different profiles can be distinguished comparing emission at small angles to large angles, but the total astrophysical factor ($\Phi_{\cosmo}$) within the central region is quite well determined.
Particle Physics factor

SUSY framework where the LSP is the neutralino $\chi$. In particular mSUGRA is defined by only 4 parameters ($m_0, m_{1/2}, \tan \beta, A_0$) and a sign ($\text{sign}(\mu)$).

4 interesting regions are usually defined.

From Battaglia et al., arXiv:hep-ph/0106204
Particle Physics factor

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From Battaglia et al., arXiv:hep-ph/0106204
Virtual Internal Bremsstrahlung (VIB)

Each mSUGRA point has its own energy spectrum. Differences from point to point are even larger if VIB is introduced: a new mechanism for $\chi\chi$ annihilation that

- increases the total number of photons produced above some energy
- creates bumps in the energy spectrum near $m_\chi$


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- increases the total number of photons produced above some energy
- creates bumps in the energy spectrum near $m_\chi$

Different upper limits are obtained for each mSUGRA point:

\[
\Phi_{u.l.}(E > E_0) = \frac{N_{exc,u.l.} \int_{E_0}^{E} \frac{dN_\gamma(E)}{dE} dE}{\int \frac{dN_\gamma(E)}{dE} A_{eff}(E) \Delta T dE}
\]

- Scan analysis on the upper-limit number of photons
- Distribution of boost factors
Next-generation IACTs

Features of a good IACT:
- low energy threshold to be sensitive to lower energy photons
- good energy resolution to detect features in the energy spectrum
- good angular resolution for source localization and possible identification of profile
- low sensitivity

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<tr>
<td>$E_0$</td>
<td>100 GeV</td>
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<td>30 GeV</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>30-20%</td>
<td>20-10%</td>
<td>10%</td>
</tr>
<tr>
<td>$\Theta_r$</td>
<td>0.10°</td>
<td>0.05°</td>
<td>0.02°</td>
</tr>
<tr>
<td>$S(E&gt;E_0)$</td>
<td>$5 \times 10^{-11} \text{cm}^{-2}\text{s}^{-1}$</td>
<td>$1.4 \times 10^{-11} \text{cm}^{-2}\text{s}^{-1}$</td>
<td>$1.5 \times 10^{-11} \text{cm}^{-2}\text{s}^{-1}$</td>
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- Started in April 2009. Stereoscopic observation allows much better discrimination of background.
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Array of 30-100 telescopes of different size. The goal is to cover the energy range $10 \, \text{GeV}-100 \, \text{TeV}$. Final layout is not defined yet. Operation after 2013.
### Future boost factors

#### Draco (NFW)

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<tr>
<td>I'</td>
<td>(7.5 \times 10^{-16})</td>
<td>(19000, 14000, <strong>2900</strong>)</td>
<td>4.7 \times 10^{-15}</td>
<td>(3100, 2100, <strong>490</strong>)</td>
</tr>
<tr>
<td>J'</td>
<td>(1.0 \times 10^{-16})</td>
<td>(140000, 32000, <strong>7600</strong>)</td>
<td>5.2 \times 10^{-16}</td>
<td>(28000, 4900, <strong>1200</strong>)</td>
</tr>
<tr>
<td>K'</td>
<td>(7.0 \times 10^{-15})</td>
<td>(2000, 2000, <strong>470</strong>)</td>
<td>3.5 \times 10^{-14}</td>
<td>(410, 260, <strong>61</strong>)</td>
</tr>
<tr>
<td>F*</td>
<td>(4.5 \times 10^{-16})</td>
<td>(31000, 16000, <strong>3800</strong>)</td>
<td>1.1 \times 10^{-15}</td>
<td>(13000, 2800, <strong>670</strong>)</td>
</tr>
<tr>
<td>J*</td>
<td>(3.7 \times 10^{-16})</td>
<td>(38000, 7400, <strong>1700</strong>)</td>
<td>4.2 \times 10^{-16}</td>
<td>(34000, 1200, <strong>290</strong>)</td>
</tr>
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#### Willman 1 (NFW)

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<tr>
<td>I'</td>
<td>(1.5 \times 10^{-15})</td>
<td>(9200, 6200, <strong>150</strong>)</td>
<td>9.4 \times 10^{-15}</td>
<td>(1500, 1000, <strong>25</strong>)</td>
</tr>
<tr>
<td>J'</td>
<td>(2.1 \times 10^{-16})</td>
<td>(69000, 16000, <strong>380</strong>)</td>
<td>1.1 \times 10^{-15}</td>
<td>(14000, 2400, <strong>58</strong>)</td>
</tr>
<tr>
<td>K'</td>
<td>(1.4 \times 10^{-14})</td>
<td>(990, 990, <strong>24</strong>)</td>
<td>7.1 \times 10^{-14}</td>
<td>(200, 130, <strong>3</strong>)</td>
</tr>
<tr>
<td>F*</td>
<td>(9.2 \times 10^{-16})</td>
<td>(15000, 8100, <strong>190</strong>)</td>
<td>2.2 \times 10^{-15}</td>
<td>(6500, 1400, <strong>34</strong>)</td>
</tr>
<tr>
<td>J*</td>
<td>(7.6 \times 10^{-16})</td>
<td>(19000, 3700, <strong>88</strong>)</td>
<td>8.5 \times 10^{-16}</td>
<td>(17000, 610, <strong>15</strong>)</td>
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Substructures and Sommerfeld enhancement

Boost factor can be provided by:
- (sub-)substructures in the halo of the dSph, depending on the concentration of the (sub-)substructures. Estimated from 2 to 20.

- Sommerfeld enhancement, depending on the velocity of the DM and largest effects are achieved at particular resonances. It can reach $10^5$.

From Pieri et al., arXiv:astro-ph.HE/0902.4330
20% (13%) probability that Fermi will detect gamma-rays from DM annihilating in Draco (Segue I) halo.

From Martinez et al., arXiv:astro-ph.HE/0902.4715
Conclusions

• Observation of dSphs with IACTs (Draco and Willman 1) but none detection

• Upper limits depend on the energy spectrum and boost factors also depend on the halo model

• Distribution of boost factors can span orders of magnitude

• Next generation of IACTs is considered with improved performances

• Boost factor are, in some cases, reduced to a reasonable level. Future IACTs may be able to probe interesting regions for detection, also in the case that Fermi LAT will skip detection.