Results of continuum and line WIMP searches in dwarf galaxies with Fermi

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Based on
Joint analysis of targets
Gamma-rays from dark matter annihilations

Source flux

\[
F = \frac{\langle \sigma v \rangle}{8\pi M^2_\chi} N_\gamma J
\]

astrophysics

Observed counts

\[
= F \ast (\text{PSF} \times \epsilon)
\]

LAT exposure
Joint analysis of dwarfs

Weight dwarfs according to expected signal and expected background

Test statistic

\[ T = \sum_{i \in \text{dwarfs}} w_i N_i \]

\[ w_i \propto \frac{\text{exposure} \times J}{\text{background}} \]

Compute exact probability distributions for \( T \) for any choice of \( \Phi_{PP} \)

Coverage is automatic
Background found by sampling in region around each dwarf
Joint analysis of dwarfs

Weight dwarfs according to expected signal and expected background

Test statistic

\[ T = \sum_{i \in \text{dwarfs}} w_i N_i \]

where:

- \( w_i \) is the weight for dwarf \( i \)
- \( N_i \) is the observed count for dwarf \( i \)
- \( w_i \propto \frac{\text{exposure} \times J}{\text{background}} \)

Compute exact probability distributions for \( T \) for any choice of \( \Phi_{PP} \)

Coverage is automatic
Result (continuum)

95\% upper limit on $\Phi_{PP}$

$$\Phi_{PP} < 5.0 \times 10^{-30} \text{ cm}^3 \text{s}^{-1} \text{ GeV}^{-2}$$

PRL 107, 241303 (2011)

$\Phi_{PP} = \frac{\langle \sigma v \rangle}{8\pi M_{\chi}^2} N_\gamma$ place limits on any dark matter model
Relic abundance

see also Ackermann et al. PRL 107, 241302 (2011), Mazziotta, Loparco, de Palma & Giglietto arXiv:1203.6731
Statistical vs. systematic uncertainty

\[ \langle \sigma_A V \rangle [\times 10^{-8} \text{cm}^3\text{s}^{-1}] \]

- \( \bar{b}b: M > 40 \text{ GeV} \) (19 - 240)
- \( \tau^+\tau^-: M > 19 \text{ GeV} \) (13 - 80)

\[ M_x [\text{GeV}] \]

\[ \Omega_{\text{WIMP}} h^2 < 0.1 \]

\[ \Omega_{\text{WIMP}} h^2 > 0.1 \]

mass lower limit (GeV)

PRL 107, 241303 (2011)
Squeeze more information out of photons

e.g. line emission search from combined dwarfs
Squeeze more information out of photons
e.g. line emission search from combined dwarfs

![Graph](image)

- **Boötes I**
- **Draco**
- **Fornax**
- **Sculptor**
- **Segue 1**
- **Sextans**
- **Ursa Minor**

- **Angular separation [deg]**
- **Photon energy [GeV]**
- **130 GeV ± 15%**
- **3.7 years**
- **Pass 7**
- **Source class**

Geringer-Sameth and Koushiappas, arxiv:1206.0796,
Rapid Communication in PRD (in press)
Use more info than $N_i$

Which dwarf
Energy
Angular separation from dwarf

$$T = \sum_{i=1}^{N} w_i$$

Each photon gets a weight

Sum over all photons from all dwarfs

$$w = \begin{cases} 
\frac{s}{b} & \text{search} \\
\frac{s}{s+b} & \text{upper limit}
\end{cases}$$

Find background distribution by sampling
Photon weights

Line search at $M_\chi = 130$ GeV

Seg1, $M_\chi = 40$ GeV, $\langle \sigma v \rangle = 3 \times 10^{-26}$ cm$^3$ s$^{-1}$, $\chi \chi \to b\bar{b}$
Results

Line search

Cross section limits