Constraints on Light WIMPs from Isotropic Diffuse $\gamma$-Ray Emission

Michel H.G. Tytgat
Université Libre de Bruxelles
Belgium

Rencontres de Moriond: EW Interactions and Unified Theories
March 2011
There are some experimental indications of the existence of light dark matter, \( M \sim \text{few GeV} \).

Most likely to go away (see Steven Leman's talk), but the concordance is/was intriguing/stimulating.
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Here I discuss indirect constraints on light WIMPs based on the first-year Fermi-LAT data on the diffuse $\gamma$-ray background.

Based on work done in collaboration with Chiara Arina (RWTH Aachen).

ArXiv:1007.2765
JCAP 1101:011, 2011
WIMP?

1. DM + DM $\leftrightarrow$ SM + SM

2. Abundance from thermal freeze-out $\Omega \propto \langle \sigma v \rangle^{-1}$

If $\langle \sigma v \rangle \approx 3 \cdot 10^{-26} \text{cm}^2 \cdot \text{s}^{-1}$ WMAP OK!
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Indirect detection

DM + DM $\rightarrow$ $q/\bar{q}$, $\tau^+\tau^-$, ...

$\rightarrow$ $\pi^0$'s $\rightarrow$ $\gamma$'s
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\phi_\gamma \propto \langle \sigma v \rangle \times \frac{dN_\gamma}{dE} \times \int_{\text{los}} dl \frac{\rho_{dm}^2(l)}{m_{dm}^2}
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**Astrophysics uncertainties**

**Particle physics**
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particle physics

Light WIMPs

Astrophysics uncertainties
Where to look for DM in the Fermi-LAT gamma ray sky map?
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**Nearby dwarf galaxies**
- Dominated by DM (?)
- Low astrophysical background
- But low statistics

Abdo et al
arXiv:1001.4531

**Galactic centre?**
- Largest DM signal (?)
- But also largest astrophysical signal

**Galactic halo?**
- High statistics
- But modelling of galactic diffuse signal

**Isotropic diffuse emission**
- Contribution from Dark Matter halos for all redshifts (?)
- Large statistics
- But unresolved astrophysical sources

Abdo et al
JCAP 1004 (2010) 014
arXiv:1002.4415
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The Fermi-LAT spectrum (2010) is more constraining and has smaller error bars than the older analogous spectra from the EGRET experiment.

Pre-launch analysis has shown that the Isotropic Diffuse Emission is potentially very constraining for DM.

(Baltz et al; ...)

There are other analysis (2010). Give limits on « standard » WIMPs (neutralino, KK-dm,...), or Pamela-motivated models.

(Abdo et al; Hutsi et al; Abazajian et al)

Here I specifically focus on constraints on light WIMPs, with mass in the few GeV range (ie CoGeNT, DAMA).
Fermi-LAT data (& modelling) of Extragalactic diffuse emission

Actually the isotropic signal (galactic contribution expected)

Extragalactic diffuse emission from DM annihilation

Particle physics

$$\frac{d\Phi_\gamma}{dE} = \frac{c}{4\pi} \frac{\langle \sigma v \rangle}{2m_{dm}^2} \int_0^\infty \frac{dz'}{H(z')(1+z')^4} \frac{dN_\gamma}{dE'} \times B^2(z') \times e^{-\tau(E', z')}$$

B. Boost factor:

Halos of DM matter
(of all sizes @ all redshift $z$)

A. Optical depth:

Absorption of due to Compton scattering, pair production,...
A. Optical depth

Redshift @ emission

Gamma-ray energy @ z=0

Fermi-LAT range

Opaque

Transparent

(C. Arina, M.T.)
A. Optical depth

Redshift @ emission

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Absorption due to $\gamma + \gamma_{CMB} \rightarrow e^+e^-$

Transparent

Absorption due to $\gamma + \gamma_{IR} \rightarrow e^+e^-$

gamma-ray energy @ z=0

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A. Optical depth

Redshift @ emission

Gamma-ray energy @ z=0

Absorption due to 
\( \gamma + \gamma_{CMB} \rightarrow e^+e^- \)

Absorption due to 
\( \gamma + \gamma_{IR} \rightarrow e^+e^- \)

No absorption for \( M_{DM} < 20 \text{ GeV} \)

(Hutshi et al)

(C. Arina, M.T.)
B. Boost from DM halos @ all redshifts?

\[ B^2(z) \propto \int dM \frac{dn}{dM}(z, M)(1 + z)^3 \int dr \, 4\pi r^2 \rho^2(r, M) \]

Number of halos of mass \( M \) @ redshift \( z \)
(here Press-Schechter)

Dark Matter profile
(here NFW, but dependence mild)
B. Boost from DM halos @ all redshifts?

\[ B^2(z) \propto \int dM \frac{dn}{dM}(z, M)(1 + z)^3 \int dr 4\pi r^2 \rho^2(r, M) \]

Number of halos of mass M @ redshift z (here Press-Schechter)

Dark Matter profile (here NFW, but dependence mild)

Depends on power spectrum of low mass halos (potentially down to \( M \sim 10^{-8} M_\odot \) ...)

extrapolations from WMAP measurements and/or numerical simu's
B. Boost from DM halos @ all redshifts?

Boost \( (1+z)^6 \)

No halo

Redshift

WMAP extrapolations
(Maccio et al)

Simulations extrapolations
(Bullock et al)
Results: model independent spectral energy density

\[ M = 10 \text{ GeV in } b\bar{b} \]
\[ \sigma = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1} \]
A simple model – scalar singlet DM

Two parameters model:

- $M_{\text{dm}}$
- Coupling to Brout–Englert–Higgs boson

$\lambda/M_h^2$

(Silveira & Zee; Mc Donald; Burgess et al;...)
A simple model – scalar singlet DM

Two parameters model:

\[ M_{dm} \text{ and coupling to Brout-Englert-Higgs boson} \]

\[
\begin{cases}
\lambda - M_{dm} \\
\Omega_{dm} - M_{dm} \\
\sigma_n - M_{dm}
\end{cases}
\]

(Silveira & Zee; Mc Donald; Burgess et al; ...
A simple model – scalar singlet DM

Spin-independent Cross-section (cm$^2$)

Scalar singlet mass

Andreas, Arina, Hambye, Ling & M.T.  arXiv:1003.2595
A simple model – scalar singlet DM

Spin-independent
Cross-section (cm$^2$)

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\[ \sigma v \text{ (cm}^2\text{)} \]

Xenon10 (2009)

Andreas, Arina, Hambye, Ling & M.T. arXiv:1003.2595
A simple model – scalar singlet DM

CoGeNT

CDMS-Si

WMAP

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A simple model – scalar singlet DM
Results: scalar singlet DM

95% CL exclusion limits from Diffuse Isotropic Emission

Spin-independent cross-section

Scalar singlet mass

Arina & M.T. arXiv:1007.2765
More results: scalar singlet DM

Forecast: Fermi-LAT resolving extra-galactic sources (AGN, Blazars,...)
BTW, this is an invisible Higgs scenario

For $M_{DM} = 7$ GeV:

- $m_{higgs} = 120$ GeV $\quad \text{BR}(h \rightarrow SS) = 99.5\%$
- $m_{higgs} = 200$ GeV $\quad \text{BR}(h \rightarrow SS) = 70\%$

LHC Discovery Potential

(14 TeV, $L = 30$ fb$^{-1}$)

(M.Warsinsky, ATLAS, ICHEP2007)

$$\sigma_n^0 \approx 5 \cdot 10^{-44} \text{ cm}^2$$

Fig. from Kanemura et al, 1005.5651
Recent Fermi-LAT data give interesting indirect constraints on Light Dark Matter candidates.

Not only Diffuse emission, also constraints from dwarf spheroidal galaxies (with different systematics, etc, not discussed here).

Nice interplay between direct and indirect detection.

See also important rôle of collider constraints (see the talk by Joachim Kopp)
Backup slides
In LXe experiments, mapping of signal (i.e., photoelectrons PE) to $E_{\text{recoil}}$ depends on the so-called Scintillation Efficiency ($\text{Leff}$).

Problem: $\text{Leff}$ poorly known at low recoil energies

See Collar & McKinsey vs Xenon100 debate

**Graphical Note:**
- **Cutoff @ 1 keV**
- **$\text{Leff}_\text{Med}$**
- **$\text{Leff}_\text{Min}$**
- **Light Dark Matter range**
- **$\text{Leff}_\text{Zep}$ (very conservative)**
Andreas, Arina, Hambye, Ling, M.T.  
(arXiv:1003.2595)
Prospect: 1 ton-days exposure (LeffMin)

Andreas, Arina, Hambye, Ling, M.T.
(arXiv:1003.2595)
(preliminary) dark matter exclusion limits

Notice: this S2-only exclusion limit curve is preliminary, and has not been fully reviewed by the XENON10 collaboration. Pending review it is subject to change.

- Max Gap 90% C.L. upper limit between 1.6 keVr and 3.8 keVr
- 12.5 live days
- 1.2 kg target
- conservative -1σ Qv energy calibration
- no account of resolution (this would improve limits)

XENON10 S2-only (no discrimination)
Results from a Low-Energy Analysis of the CDMS II Germanium Data

CDMS collaboration arXiv:1011.2482
An 8 GeV candidate and the Fermi-LAT data from the Galactic Centre?

Hooper & Goodenough, arXiv:1010.2752
95% C.L. limits on annihilation cross sections from Milky Way dSphs

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<td>10 GeV</td>
<td>$\text{BR}(SS \to \tau^- \tau^+) \simeq 10%$ ( \text{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 90% )</td>
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<td>6 GeV</td>
<td>$\text{BR}(SS \to \tau^- \tau^+) \simeq 20%$ ( \text{BR}(SS \to b\bar{b} + c\bar{c}) \simeq 80% )</td>
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Table 1: 95 C.L. exclusion limits on the annihilation cross-section ($\sigma v$ in units of \(10^{26}\) cm\(^3\)·s\(^{-1}\)) based on the limits on the flux of gamma-rays set by Fermi-LAT for two representative dSphs (Ursa Minor and Draco), using the median value of the J-factors [26]. The last line is relevant for the 8 GeV candidate of Ref.[28]
95% C.L. limits on tau pairs annihilation from Extra-galactic gamma
This is consistent with other recent works.

Fitzpatrick, Hooper & Zurek

*ArXiv:1003.0014*

**Effective operators approach**

Barger, McCaskey, Shaughnessy

*ArXiv:1005.3328*

**Complex singlet scalar**

Effectively a **real** singlet scalar.
Dirac DM candidate, vector interaction?

Fitzpatrick, Hooper & Zurek

ArXiv:1003.0014

Effective operators approach

Mambrini ArXiv:1006.3318

Dirac fermion with a light $Z'$

OK if use the $Z'$ pole to enhance the annihilation cross section
95% C.L. limits on flux from dSphs between $100 \text{ MeV} < E < 50 \text{ GeV}$

- 100% in $b\bar{b}$
- 100% in $\tau^+ \tau^-$

But only published limits for $M > 30 \text{ GeV}$ neutralino and KK-dm candidates

Figures from Fermi-LAT; Abdo et al, arXiv:1001.4531
New limits on the gamma ray flux from dSphs from a light scalar singlet with WMAP cross section

Our (naive) extrapolations based on Fermi-LAT data

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<td>BR($SS \to \tau^+\tau^-$) $\simeq$ 10%</td>
<td>$8.5 \times 10^{-10}$</td>
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Our predicted fluxes but tentative (e.g. energy resolution, acceptance, ... not taken into account)

See also Fitzpatrick, Hooper & Zurek
95% C.L. limits on annihilation cross sections from Milky Way dSphs

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\[
\text{WMAP} \quad \rightarrow \quad \sigma v \quad 3 \times 10^{-26} \text{ cm}^3 \cdot \text{s}^{-1}
\]
Stacked analysis $\rightarrow$ stronger limits: light candidates in $b$-$b\bar{b}$ excluded @ 95% CL

From the talk by Maja LLENA GARDE (Fermi-LAT) @ IDM2010
95% C.L. limits on annihilation cross sections from Milky Way dSphs

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An 8 GeV candidate and the Fermi-LAT data from the Galactic Centre?

\[ E^2 \frac{dN}{dE} \text{ (GeV cm}^{-2} \text{s}^{-1}) \]

\[ m=30 \text{ GeV, } \bar{b}b \]

\[ m=30 \text{ GeV, } c\bar{c} \]

\[ m=8 \text{ GeV, } \tau^+\tau^- \]

\[ D<1^\circ \]

Hooper & Goodenough, arXiv:1010.2752
Could be (again, remember PAMELA?) pulsars...

Abazajian arXiv:1011.4275
Constraints on 8 GeV DM from synchrotron radiation (radio) @ GC !

8 GeV into e+/e−

Boehm, Silk and Enslin, arXiv:1008.5175
Stacked analysis → stronger limits: light candidates in b–b̅bar excluded @ 95% CL

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