Constraints on Dark Matter hypothesis with First Year of Fermi LAT Data

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on behalf of the Fermi-LAT Collaboration

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E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
ERMI observatory

LAT
Large Area Telescope
20 MeV to >300 GeV

All sky survey mode
Re-pointing Capabilities
  Autonomous
  Rapid slew speed
    (75° in < 10 minutes)
  25 µs deadtime

GBM
Gamma-ray Burst Monitor
Nal and BGO Detectors
8 keV - 30 MeV
correolative observations of transient events

KEY FEATURES
Huge field of view
  LAT: 20% of the sky (~2.4 sr) at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
Huge energy range
  Total of >7 energy decades including largely unexplored band 10 GeV - 100 GeV.
Currently no other telescope covering this energy range.
Great discovery potential

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**The LAT**

**Precision Si-strip tracker:**
- Si-strip detector, W converter foils,
  - 80 m² of Si active area,
  - 1.5 radiation lengths on-axis.

**Hodoscopic CsI calorimeter:**
- Array of 1536 CsI(Tl) crystals in 8 layers,
  - 8.6 radiation lengths on-axis.

**Segmented Anti-Coincidence Detector:**
- 89 plastic scintillator tiles and 8 ribbons, charged particles veto (0.9997 average detection efficiency).

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**Modular pair-conversion telescope**
- 4 x 4 array of identical towers

**Conversion**
- (γ in e⁺/e⁻) in W foils

**Incoming direction**
- Reconstruction by tracking the charged particles + γ identification

**Energy measurement**
- with e.m. Calorimeter + shower imaging

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Fermi LAT Collaboration, APJ 697, 1071 (2009)
Fermi is on its way since ~ 1.5 years

Fermi science: very broad and successful

- Systems with supermassive black holes (Active Galactic Nuclei)
- Gamma-ray bursts (GRBs)
- Pulsars
- Supernova remnants (SNRs), PWNe, Origin of Cosmic Rays
- Diffuse emissions
- Solar physics
- Probing the era of galaxy formation, optical-UV background light
- Solving the mystery of the high-energy unidentified sources

Discovery!
New source classes. Particle Dark Matter?
Other relics from the Big Bang?
Other fundamental physics checks.

Lifetime: 5 years (min)
Orbit: 565 km, circular, period 96'
Inclination: 25.6°
Indirect Detection of Dark Matter

Continuum signal:
\[
\chi \rightarrow W^+/Z/q \rightarrow \pi^0 \gamma \\bar{p}, \bar{d}
\]
\[
\chi \rightarrow W^-/Z/q \rightarrow \pi^- \mu \\bar{v}_\mu \mu
\]
\[
\gamma \rightarrow e^- \bar{v}_e
\]

Line signal:
\[
\gamma \rightarrow \gamma, Z, H, \ldots
\]

\[
\frac{d\bar{\Phi}_\gamma}{dE_\gamma} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_\chi^2} \sum_f \frac{dn_f}{dE_\gamma} B_f
\]
\[
\int_{\Delta \Omega} \int_{l.o.s} \rho^2(l) \ d\Omega(l) \ d\Omega
\]

Particle Physics

Astrophysics

DM distribution:
NFW, Moore, Isothermal, ...
How the FERMI-LAT telescope could help to disentangle the Dark Matter puzzle?

- **DM hunting targets**

<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, Point Sources</td>
<td>Low background, Good source id</td>
<td>Low statistics</td>
</tr>
<tr>
<td>Extra-galactic</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>Cosmic-ray electrons</td>
<td>Experimental hints, large stat. + DM models discrimin.</td>
<td>Astrophysical background Diffusion models</td>
</tr>
</tbody>
</table>

Pre-launch sensitivities published in E.A. Baltz et al. JCAP07 (2008) 013

- **Good understanding of galactic and extragalactic diffuse emission**
Galactic diffuse emission with Fermi

The data collected by the LAT from mid-August to end of December do not confirm the excess at intermediate latitudes.
Extra-Galactic diffuse emission with Fermi

spectrum compatible with a power law of index $= 2.41 \pm 0.05$ between 200 MeV and 102 GeV

$I(> 100\text{MeV}) = (1.03\pm0.17) \times 10^{-5} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$
Search for cosmological DM

❖ Search for a DM annihilation signal from all halos at all redshifts

❖ Limits based on Fermi’s measurement of the isotropic diffuse gamma-ray emission

⇒ Limits can be very constraining for many DM interesting models, however the uncertainties on the evolution of the DM structure are large.
Search for cosmological DM

- Search for a DM annihilation signal from all halos at all redshifts
- Limits based on Fermi’s measurement of the isotropic diffuse gamma-ray emission

⇒ Limits can be very constraining for many DM interesting models, however the uncertainties on the evolution of the DM structure are large.
Fermi blind search for DM subhalos

Search criteria:
- More than 10° from the galactic plane
- No appreciable counterpart at other wavelengths
- Emission constant in time (1 week interval)
- Spatially extended: ~ 1° average radial extension for nearby, detectable clumps
- Spectrum determined by DM (both b-bbar and μ+μ- spectra are tested vs a (soft) power law hypothesis)

Blind analysis: finalize selection method with 3 months of data and apply to 10 months

Search for sources (>5σ significance) passing these criteria in the 200 MeV to 300 GeV energy range.

Background: point sources+diffuse Galactic and isotropic emission

No DM satellite candidates are found in 10 months of data

Consistent with result of sensitivity study based on Via Lactea II predictions for the DM distribution for a generic 100 GeV WIMP annihilating into b-bbar, \(<σv> = 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}\) (submitted to ApJ)

Work is ongoing to evaluate the sensitivity for other models
Search for DM in Dwarf spheroidal galaxies

- very large M/L ratios: ~10 to 1000 (M/L ~ 10 for Milky Way galaxy)
- most of them are expected to be free from any other astrophysical gamma source
- more promising targets could be discovered:
  SDSS [only ¼ of the sky covered] already double the number of dSphs these last years

Choose 14 best candidate, high latitude dSph galaxies
distance < 150 kpc
-30 > b > 30 degrees

Considering Fermi PSF, can approximate dwarfs as point sources
(dwarf $r_s = 0.1-0.8^\circ$ compared to 68% PSF ~ 5° at 100 MeV and 0.75° at 1 GeV)
Search for DM in Dwarf spheroidal galaxies

11 - months data analysis with 100 MeV $< E_\gamma < 50$ GeV
point sources from Fermi catalog + galactic and isotropic diffuse emission as bkg

No dwarf spheroidal galaxies detected so far

95% flux upper limits for several possible annihilation final states

constraints on annihilation cross sections versus WIMP mass derived for specific DM models assuming Dark Matter density profiles derived from modeling of stellar kinematic data (*) and NFW profile

(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

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Search for DM in Dwarf spheroidal galaxies

« Constrained » MSSM

Anomaly mediated SUSY breaking

Exclusion regions cutting into interesting parameter space for some WIMP models (NFW, no substructure).

WIMPs with large annihilation cross-sections into leptonic final states have been invoked to partially explain cosmic ray data as the by-product of dark matter annihilation.

- $\mu^+\mu^-$ final state, FSR only
- $\mu^+\mu^-$ final state, FSR + IC

Caveats:
- dSphs suffer from uncertainties in the diffusion coefficient
- Clusters of galaxies are better targets for this sort of constraints
Search for DM in Clusters of Galaxies

IC scattering of CMB photons is expected to dominate the DM signal from clusters

⇒ 6 selected clusters from HIGFLUCS catalog:

<table>
<thead>
<tr>
<th>Cluster</th>
<th>$z$</th>
<th>$J \left(10^{17} \text{ GeV}^2 \text{ cm}^{-5}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWM 7</td>
<td>0.0172</td>
<td>$1.4_{-0.1}^{+0.1}$</td>
</tr>
<tr>
<td>Fornax</td>
<td>0.0046</td>
<td>$6.8_{-0.9}^{+1.0}$</td>
</tr>
<tr>
<td>M49</td>
<td>0.0033</td>
<td>$4.4_{-0.1}^{+0.2}$</td>
</tr>
<tr>
<td>NGC 4636</td>
<td>0.0031</td>
<td>$4.1_{-0.3}^{+0.3}$</td>
</tr>
<tr>
<td>Centaurus (A3526)</td>
<td>0.0114</td>
<td>$2.7_{-0.1}^{+0.1}$</td>
</tr>
<tr>
<td>Coma</td>
<td>0.0231</td>
<td>$1.7_{-0.1}^{+0.1}$</td>
</tr>
</tbody>
</table>

No cluster of galaxies detected so far
(first 11 months of Fermi data)

Models fitting the Pamela positron excess with masses above 2 – 3 TeV are ruled out by the non-detection of the Fornax group.
The Galactic center as one of the most fascinating (and complex ...) region in the sky ...

- MWL source in the central parsecs of our Galaxy emitting from radio to TeV \(\gamma\)-rays. From radio to X-rays: originates from the SMBH Sgr A* but several possible counterparts for the hard X-rays / GeV / TeV \(\gamma\)-ray emissions

- Huge pp emissivity due to CRs streaming through very dense clouds (CMZ)
- SNRs and PWNs...
- Large Pulsar population! Deneva et al. 09: 3 pulsars detected near SgrA*. Inferred population of \(\sim\)2000 active radio pulsars!


- Search for DM in the GC:
  - Expect large DM annihilation/decay signal due to steep DM profiles
  - Caveats: good understanding of the astrophysical background is crucial to extract a potential DM signal from this complicated region of the sky: source confusion / diffuse emission modeling (very difficult!)

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Fermi Galactic Center Source

- Fermi’s year 1 catalog source closest to the GC: 1FGL J1745.6−2900
  - Location: l, b = 359.941°, -0.051°
  - (95% confinement radius: 1.1')
- 25 formal associations based on position (1 pulsar wind nebula, 1 supernova remnant, 2 TeV sources, 4 low mass Xray binaries, etc.)
- Future analyses based on spectral and timing information might narrow down the possibilities
- Marginal variability: 1 month interval over a period of 11 months, flux in 100 MeV-100 GeV energy range
Dark Matter constraints from GC FERMI data

- Preliminary analysis of a 7° x 7° region centered at the GC:
  - 11 months data analysis with $E_\gamma > 400$ MeV, front-converting events
  - Model: galactic diffuse (GALPROP) and isotropic emission. Point sources from Fermi 1 year catalog

- Model generally reproduces data well within uncertainties. The model somewhat underpredicts the data in the few GeV range (spatial residuals under investigation)

- Any attempt to disentangle a potential DM signal from the GC region requires a detailed understanding of the conventional astrophysics

- More prosaic explanations must be ruled out before invoking a contribution from DM if an excess is found (e.g. modeling of the diffuse emission, unresolved sources, ....)

- Analysis in progress to derive updated constraints on the annihilation cross section
Search for Spectral Lines

Smoking gun signal of dark matter!

- **Data set:**
  - 11 months data analysis with $30 < E_\gamma < 200$ GeV
  - Search region: $|b| > 10^\circ$ and $20^\circ \times 20^\circ$ around GC
  - Remove point sources (for $|b| > 1^\circ$)
  - The data selection includes additional cuts compared to standard LAT analyses to remove residual charged particle contamination

- **Spectral line search:**
  - The signal is the LAT line response function
  - The background is modeled by a power law function and determined by the fit
  \(\Rightarrow\) No astrophysical uncertainties
  - Optimal energy resolution and calibration very important for this analysis – resolution $\sim 10\%$ at 100 GeV

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Search for Spectral Lines

No line detection, 95% CL flux upper limits are evaluated

Assuming dark matter density distributions, we extracted constraints on the dark matter annihilation cross-section (or lifetime for decaying dark matter)

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Limits on $<\sigma v>$ are too weak (by O(1) or more) to constrain a typical thermal WIMP. However, Fermi’s constraints disfavor some models with non-thermally produced WIMPs. E.g. Wino LSP (Kane 2009) predicting a $\gamma Z$ line with $<\sigma_{\text{ann}} v> \sim 1.4 \times 10^{-26} \text{ cm}^3\text{s}^{-1}$ is disfavored by a factor of 2-5. Lifetime limits constrain some gravitino decay models with $\tau < 10^{29}$s (expected lifetimes: $10^{23}-10^{37}$s for $m_{3/2} \sim 100$ GeV). Constraints have also been placed on recently-proposed models that predict WIMPs annihilating into $\gamma + $Higgs.
The Fermi LAT is an excellent $e^- + e^+$ detector (but it can't discriminate charge). On board processing keeps all events with more than 20 GeV of deposited energy in the CAL.

It provides measurement of combined CR $e^- + e^+$ spectrum (up to energies of $\sim 1$ TeV) with very large statistics: $>200$ k events above 100 GeV (2.5k above 500 GeV) in 6 months.

It can achieve very low hadron contamination (rejection power $> 10^3$, and larger at higher energies) via separate series of trigger settings and cuts on detector variables.
Full spectrum combination of two separate analyses: Low-energy and high energy
- Errors dominated by systematic uncertainties (one year statistics ~ 8M evts)
- Our result is consistent with a flux fitted by a power law proportional to $E^{-3.08}$ ($E^{-3.3}$ for the conventional pre-Fermi model) which shows no prominent spectral feature but is consistent with a slight spectral hardening at around 80 GeV and with a slight spectral softening above 700 GeV.

Possible interpretations: revised diffusion model and/or extra component (astrophysical or DM)
- DM contribution is not required, however cannot be ruled out.

Extended Energy Range (7 GeV–1 TeV)
Fermi has been working very well and carrying out a wide variety of astrophysical measurements.

Fermi-LAT has opened a new window for indirect searches for DM and explores many complementary searches for DM signal. Even if no significant detections have been made, significant limits on the nature of DM have been placed. Best current Fermi limits: \( <\sigma v> \approx 10^{-25} \text{ cm}^3/\text{s} \) with < 1 year of data from dSph's, Clusters and Cosmological WIMP limits.

Our knowledge of the astrophysical background is uncertain and better understanding of the background is essential. In addition to accumulation of data, it will allow us to improve constrains on DM models.

Many improvements are forseen:
- improving the instrumental background rejection (charged particle contamination in the LAT data is larger than predicted from pre-launch estimates)
- improving the acceptance below 200 MeV will improve our ability to reliably extract a potential signal of new physics or set stronger constraints.
- inputs from multi-wavelength observations (for example GC, dSph's and DM satellites).

Fermi is a 5 to 10 year mission: we are just at the beginning!
IDM 2010
8th International Workshop on Identification of Dark Matter
http://www.lpta.univ-montp2.fr/idm2010
idm2010@lpta.univ-montp2.fr

26-30 July 2010
Montpellier 2 University
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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Institut de Physique Montpellier
More than 1000 sources in year one catalog

- About 250 sources show evidence of variability
- Half the sources are associated positionally, mostly blazars and PSRs
- Other classes of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)
- Uncertainties due to the diffuse model, particularly in the Galactic ridge
Searches for cosmological dark matter annihilations into $\gamma$-rays

The signal:

$$\frac{d\Phi_\gamma}{dE_0} = \frac{\sigma v}{8\pi} \frac{c}{H_0} \frac{\rho_0^2}{m^2_\chi} \times \int dz \left(1 + z\right)^3 \frac{\Delta^2(z)}{h(z)} \frac{dN_\gamma(E_0(1 + z))}{dE} e^{-\tau(z,E_0)}$$

Contributions from

> **Particle physics**
  > annihilation cross sections: $<\sigma v> \sim 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$ (WMAP)
  > WIMP mass: from $\sim 45 \text{ GeV}$ up to few TeV (Susy, KK, ...)
  > continuum plus line yield: $b\gamma\gamma \sim 3 \times b\gamma Z \sim 10^{-3}$ (loop suppression)

> **Astrophysics**:
  > halo structures: choice of profile and concentration parameter
  > subhaloes contribution: 'clumpiness' boost factor, $10^4 < \Delta^2(z) < 10^6$
  > absorption (optical depth $\tau$): pair production on extragalactic light

> **Cosmology**:
  > cosmological parameters and expansion of the Universe

$$h(z) = \sqrt{\Omega_M (1 + z)^3 + \Omega_K (1 + z)^2 + \Omega_\Lambda}$$

E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
How Fermi LAT detects electrons

Trigger and downlink

- LAT triggers on (almost) every particle that crosses the LAT
  \(~ 2.2 \text{ kHz trigger rate}\)

- On board processing removes many charged particles events

But keeps all events with more that 20 GeV of deposited energy in the CAL

\(~ 400 \text{ Hz downlink rate}\)
Only \(~1 \text{ Hz are good } \gamma\text{-rays}\)
Hadron/electron discrimination

Main idea:

- Veto detectors (Anti-coincidence)
- Difference in shower shape for em/hadronic showers in calorimeter
- Background rejection gets harder with rising energy
- Full analyses apply combined information of several detectors in multivariate classification (Neural networks …)
Fermi LAT Energy resolution for electrons

*Energy resolution: ~ 20 %@ 1 TeV (cf. ATIC ~ 2 % @ 150 GeV and PAMELA ~ 6 % @ 200 GeV)*

E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
Energy resolution checks – High X0 events

- Critical for high energies
  - Shower leakage from CAL

- Select subsample of events with long path-length (HI-X0)
  - X0 > 13
    - 12 in CAL + minimum track length in TKR + events contained in a single CAL module

- Energy resolution X ~ 2 – 4
  - Down to 5% at 1 TeV (68% containment half-width)

- Instrument acceptance to ~ 5% of standard and limited to a specific portion of instrument phase space
  - Much higher systematics

E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
Comparison of standard and High-X0 spectra

- Consistent within their own systematics
- already demonstrated by simulation of LAT response to spectral features with artificially worsened resolution

⇒ the LAT energy resolution is adequate to detect prominent spectral features
⇒ the Fermi spectrum is NOT dependent on the energy resolution of the bulk of the events
Electromagnetic vs hadronic cascades
(events in the last energy bin 772 GeV - 1 TeV)

A candidate electron
(recon energy 844 GeV)

- few ACD tile hits in conjunction with the track
- clean main track with extra-clusters very close to the track - note backsplash from the calorimeter
- well defined symmetric shower in the calorimeter, not fully contained

A candidate hadron
(raw energy > 800 GeV)

- large energy deposit per ACD tile
- small number of extra clusters around main track, large number of clusters away from the track
- large and asymmetric shower profile in the calorimeter

E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
A simple interpretation of Fermi-LAT CRE spectrum

Numerical models of propagation of CR electrons can be tuned to fit Fermi data assuming a harder injection index:

- $\gamma_0 = 2.42$ ($\delta = 0.33$ - with reacceleration) : red line
- $\gamma_0 = 2.33$ ($\delta = 0.6$ - plain diffusion) : blue line

Problems: These tuned models are in tension with low-energy and HESS data (no big problems with gamma-ray data - work in progress)
The possibility to explain these data by invoking very steep electron spectrum is ruled out by Fermi-LAT

An extra source is needed !!

Unless some other mechanism enters to produce a large secondary e+ flux in standard sources (see Blasi 2009)

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Possible sources: Secondary production in pulsars

**Pulsars:** Most significant contribution to high-energy CRE:

Nearby \((d < 1 \text{ kpc})\) and Mature \((10^4 < T/\text{yr} < 10^6)\) Pulsars

NB: already invoked 20 years ago ... A. Boulares ApJ 342, 1989

Example of fit to both Fermi and Pamela data with known (ATNF catalog) nearby, mature pulsars and with a single, nominal choice for the \(e^+/e^-\) injection parameters
What if we randomly vary the pulsar parameters relevant for e+e- production? [injection spectrum, e+e- production efficiency, PWN “trapping” time]

Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.
Possible sources:
Electron production in primary CR sources

Positron excess can originate inside the primary CR sources (e.g. SNR), secondary being produced in the same site where CR’s are accelerated.

NB: A smoking-gun signature of the in-source positron production mechanism is a rise in the antiproton fraction.

Besides antiprotons, other smoking guns: Ti/Fe, B/C all should have a spectral upturn!
Three classes of models can be invoqued: (non exaustive list!)

→ "leptophilic" models annihilating directly to leptons and predominantly to $\mu+\mu-$
  (e+e- channels gives too many hard electrons and $\tau+\tau-$ channels gives too soft electrons)
  (see e.g. Fox & Popptiz, Hamik&Kribs 2008, L.Bergstrom et al., ...)

→ e+ - e- models with monocromatic $e^{\pm}$ pairs from DM annihilations
  (see e.g. Arkani-Hamed et al. 2009)

→ super-heavy DM models: annihilation into gauge bosons (see e.g. Cirelli et al. 2009)

Data prefers models with large masses (> 1 TeV)

This is hard to accomodate within MSSM considering the anti-proton (gamma) constraint.

Assuming a "standard" diffusion model and a "standard" dark matter halo, the annihilation cross-section (set by DM abundance in Big bang freeze out) is not sufficient to explain the data. Large boost factors are needed (~1000) or enhancement of annihilation cross-section.

Most models make predictions which are testable with soon existing data (gamma-rays).

E.Nuss for the Fermi-LAT Collaboration, Moriond, 2010
Dark matter interpretation(s)

PRELIMINARY

<table>
<thead>
<tr>
<th>Model</th>
<th>Ann. Final State</th>
<th>Mass (GeV)</th>
<th>$\langle \sigma v \rangle$ (cm$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+e^-$</td>
<td>$e^+e^-$</td>
<td>500</td>
<td>$9 \times 10^{-25}$</td>
</tr>
<tr>
<td>Leptophilic</td>
<td>$33%(e^+e^-)+33%(\mu^+\mu^-)+33%(\tau^+\tau^-)$</td>
<td>900</td>
<td>$4.3 \times 10^{-24}$</td>
</tr>
</tbody>
</table>
Comments on boost factors

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Important loss of energy for e+’s (magnetic field, interstellar radiation field) → large survey volumes for low detected energies

p’s do not lose energy, but convective wind and spallation processes very efficient at low energy for p's (no loss of energy) → larger volume survey at high energies

Probability for a close and massive clump is very small! (O(10^{-3}-4) clumps /MW volumes)

Lavalle et al., 06

Lavalle et al., 08

Parameter diffusion length (for L = 4 kpc)
- anti-proton [E_{max} = 1 TeV]
- positron [E_{S} = 1 TeV]
- positron [E_{S} = 0.5 TeV]
- positron [E_{S} = 0.25 TeV]

\[ \frac{E}{E_{max}} \text{ for } p \]

Lavalle et al., 08
Inverse Compton Emission and Diffusion in Dwarfs

> 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

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

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

IC gamma-ray emission can dominate for leptonic final states by a factor of 10-100 at \( m > 300 \) GeV.

Preliminary

Draco: diffusion model uncertainty \( 10^{29} \text{ vs } 10^{29} \)

Segue 1: diffusion more important in small dwarfs
GLAST/LAT performance

- $A_{\text{eff}} \sim 9000 \text{ cm}^2$ (energy dependent)
- Angular resolution: $3.5^\circ$ at 100 MeV, $0.8^\circ$ at 1 GeV
Expected cross sections

Continuum, $\gamma\gamma$ and $\gamma Z$ lines annihilating cross sections

\[ \langle \sigma v \rangle \approx 3 \times 10^{-26} \text{ cm}^{-3} \text{ s}^{-1} \]

\[ \approx 2 \times 10^{-29} \text{ cm}^{-3} \text{ s}^{-1} \]