Fermi-LAT constraints on diffuse Dark Matter annihilation from the Galactic Halo

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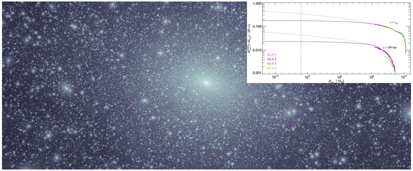
on behalf of the Fermi LAT collaboration

IDM 2010

Outline

1. Dark Matter Signal
2. Diffuse Backgrounds
3. Profile Likelihood
4. Preliminary Results

Instrument & Signal



Fermi Gammma-Ray Space Telescope

Using 16 months of Pass 6 'dataclean' (custom event class developed for the LAT EGB analysis) LAT data.

Separate front and back conversions.

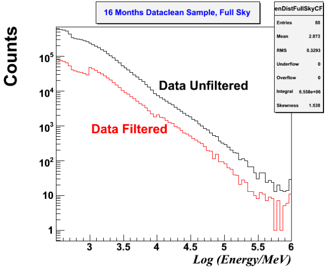
Galactic DM Halo

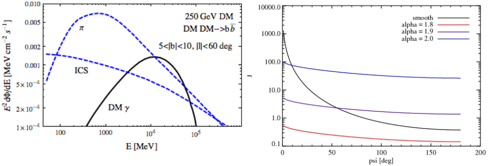
Source: WIMP annihilation and decay in the Milky Way host halo and galactic substructure.

Channel: $b\bar{b}$, $t\bar{t}$, $\tau^+\tau^-$, and $\mu^+\mu^-$.

Mass: 25 GeV increments (50 GeV for decay) from 25 GeV to 2 TeV.

Distribution: Einasto profile with extrapolated substructure content.





Zaharijas et al., 2010 Stockholm University

Background Model Parameter Space

GALPROP (Strong & Moskalenko 1998)

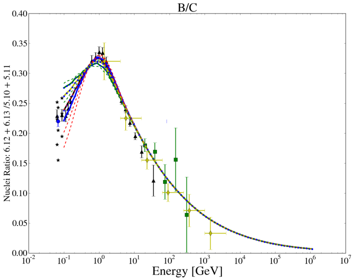
Cosmic-ray propagation code.

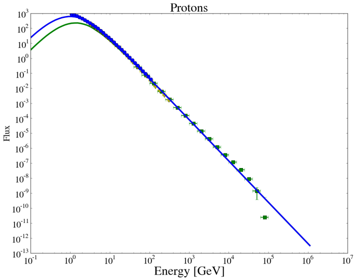
Pros: Physical model. Based on cosmic-ray measurements, instead of Fermi gamma-rays.

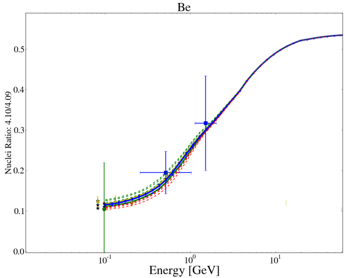
Cons: Considerable uncertainty in diffusion parameters. Fits the sky in a broad sense, but has large residuals on small scales.

Generate models to span this parameter space. Over 2k so far...

Parameter	Range
Diffusion Coefficient	$1\times10^{27} \rightarrow 4\times10^{29}$
Halo Height	$1 \rightarrow 11$ kpc
Diffusion Index	0.33, 0.50
Alfven Velocity	$0 \rightarrow 50$ km s^{-1}
Electron Injection Index	$1.8 \rightarrow 2.5$
Nucleon Injection Index (Low)	$1.7 \rightarrow 2.6$
Nucleon Injection Index (High)	2.26, 2.43
Source Distribution	Parameterized, SNR, Pulsars

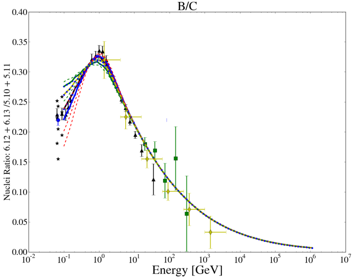


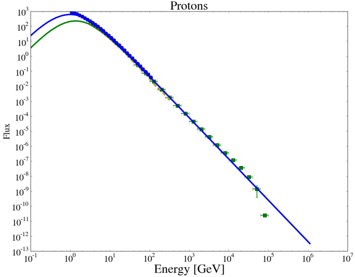




Reality Check

Version 54_z30FenpDT
For each diffusion setup, compare the CR at Earth's galactic radius (2-D Galprop) with local measurements.

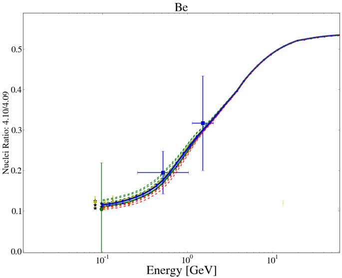




χ^2 Calculation

$$\chi^2 = \Sigma_j \Sigma_i^{Nj} \frac{(D_{ij} - T_{ij})^2}{\sigma_{ij}^2 + \Delta\phi_{ij}^2}$$

Solar Modulation Uncertainty



CR Data From:

HEAO-3, IMP, ATIC-2, CREAM, ACE, ISOMAX, AMS01, CAPRICE, & BESS

Assembling the Gamma-Ray Sky

Primary Electron IC

Secondary & Nuclei IC

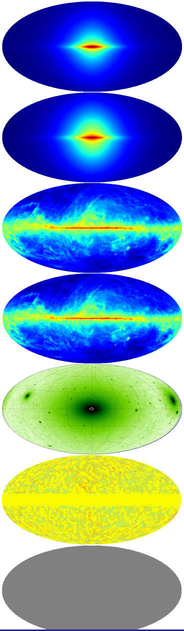
Bremss

Pion Decay

Dark Matter

Source Residuals

Isotropic:
EGB, Instrumental



Normalization

Free, Gaussian, Fixed

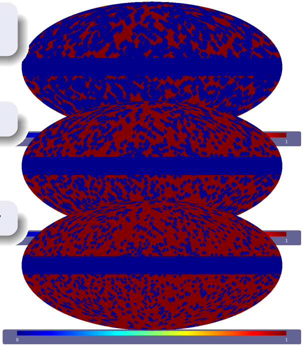
Masking

Galactic Plane
Sources

Source Mask
317MeV-1GeV

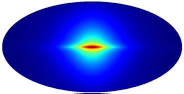
1GeV-10GeV

10GeV-100GeV

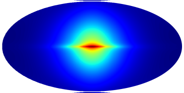


Assembling the Gamma-Ray Sky

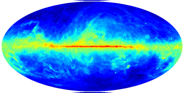
Primary Electron IC



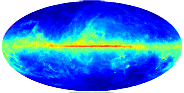
Secondary & Nuclei IC



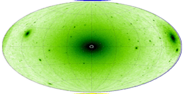
Bremss



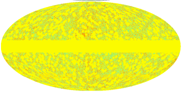
Pion Decay



Dark Matter



Source Residuals



Isotropic:
EGB, Instumental

Normalization

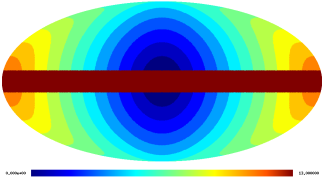
Free, Gaussian, Fixed

Masking

Galactic Plane
Sources

Binning

12 Annular Bins
80 Logarithmic Energy Bins



Upcoming Additions

IC Anisotropic
DM IC (lepto-phillic models)
Alternative ISRFs

Profile Likelihood

In Principle

Scanning the DM normalization, we smoothly transition between background models.

Step 1

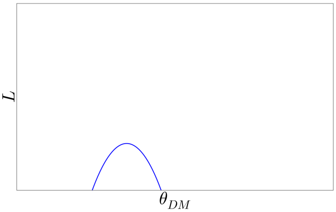
For each GALPROP model, maximize $\hat{L}$ w.r.t. linear parameters, $\vec{\alpha}$, for each value of θ_{DM} (Flux Normalization).

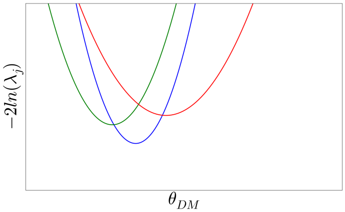
$\hat{L}_j(\theta_{DM}) = \prod_i P_{ij}(n_i; \vec{\alpha}_{max}, \theta_{DM})$

Step 2

Construct a test statistic for each diffuse model (different colors) using the best overall Likelihood and the CR fit probability.

$\lambda_j(\theta_{DM}) = \frac{P_j^{CR} \hat{L}_j(\theta_{DM})}{(P_j^{CR} \hat{L}_j)_{best}}$





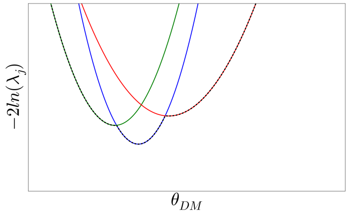
In Principle

Scanning the DM normalization, we smoothly transition between background models.

Step 3

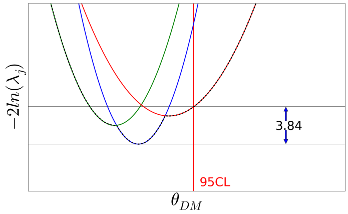
The profile likelihood is the curve that follows the minimum of all GALPROP models.

$$T_{chi^2}(\theta_{DM}) = -2ln\lambda_{j_{max}}(\theta_{DM})$$



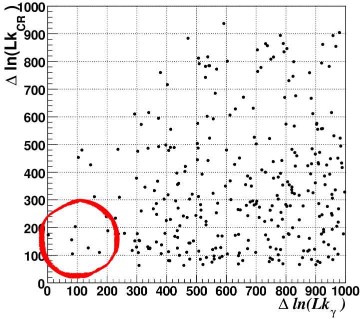
Step 4

Since $T_{chi^2}(\theta_{DM})$ behaves as a χ^2 with one d.o.f., we set the 95% confidence upper limit to where the profile likelihood rises by 3.84 above the absolute minimum.



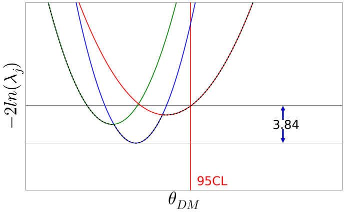
In Practice

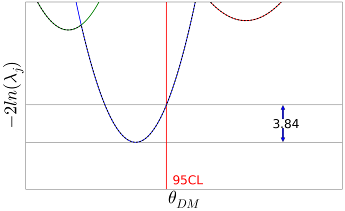
Sparse sampling means our limits all still come from a single model.



Sparse Sampling

Including χ^2 from the CR data in the Likelihood makes it difficult (naively sampling) to populate the region that satisfies both CR and gamma rays. This important region is currently dominated by a couple of models.





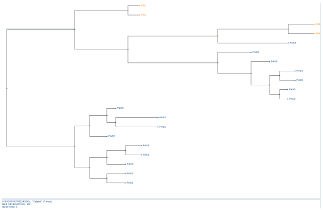
Classification Tree Refinement

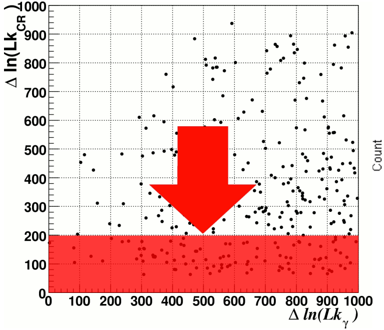
Intelligent Sampling

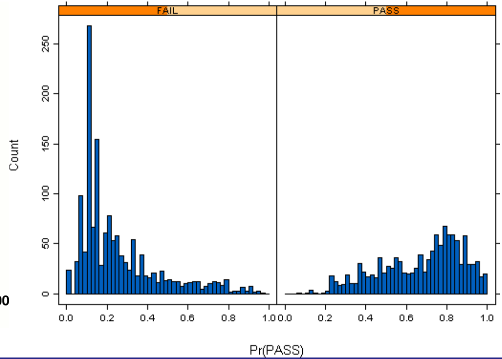
After some preliminary exploration, we can do better than blind sampling.

A classification tree 'learns' the complex relationship between a many parameter system and a conditional output - in our case, a χ^2 fit to CR data.

Predicting the CR-χ^2 before running GALPROP saves an immense amount of CPU-time, allowing us to focus on only the models which have some chance of affecting our limit.

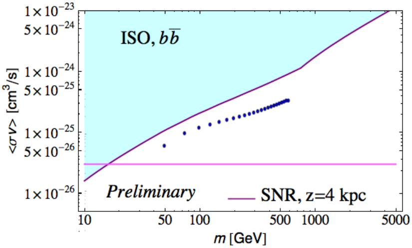






Preliminary Limits

Zaharijas et al. 2010



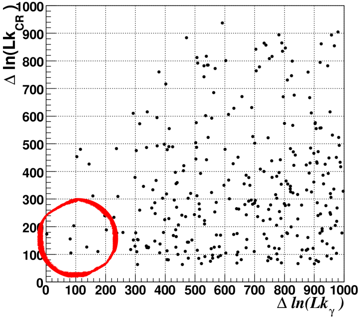
Note: Dots → 95% CL (this analysis, w/ DM subst.)
Line → 3σ

Remedies

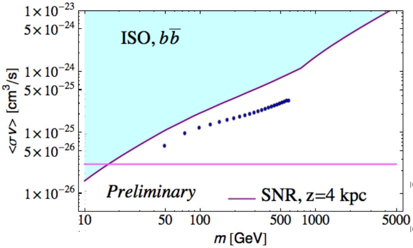
1. Classification Tree.
   Small Variations around best fit.

Caveats

1. Incomplete sampling of parameter space near best fit.



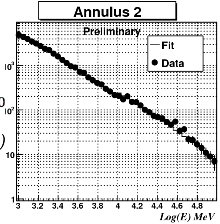
Zaharijas et al. 2010

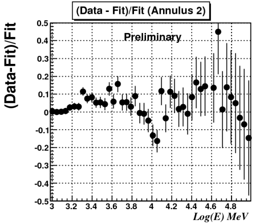


Note: Dots $\longrightarrow$ 95% CL (this analysis, w/ DM subst.)
Line $\longrightarrow$ 3σ

Caveats

1. Incomplete sampling of parameter space near best fit.
2. Poor Residuals

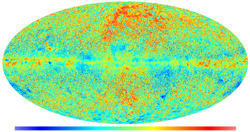




Remedies

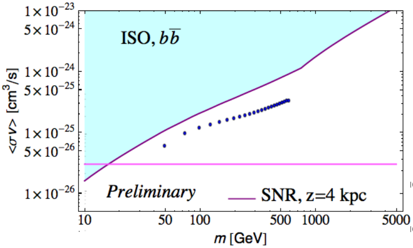
1. Classification Tree.
   Small Variations around best fit.
2. Energy Smearing

T. Porter, TeVPA 2010



Preliminary Limits

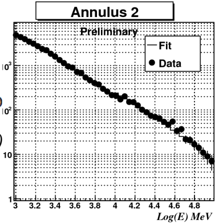
Zaharijas et al. 2010

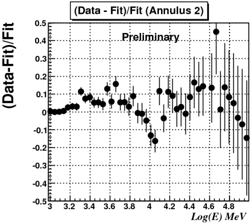


Note: Dots $\longrightarrow$ 95% CL (this analysis, w/ DM subst.)
Line $\longrightarrow$ 3σ

Caveats

1. Incomplete sampling of parameter space near best fit.
2. Poor Residuals
3. Incomplete Modelling

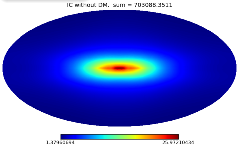




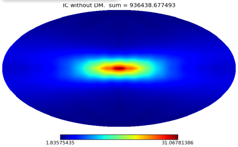
Remedies

1. Classification Tree.
   Small Variations around best fit.
2. Energy Smearing
3. ISRFs/Anisotropic IC

Isotropic IC



Anisotropic IC



Summary & Outlook

- There is no significant detection of DM given the statistical errors and the systematic uncertainties in modeling the diffuse background.
- Making progress on a thorough treatment of the physical background uncertainties.
- Still need better model population around the best fit.
- Sizeable residuals persist even in our best models. Working on several ideas to reduce them.
- Working with another Fermi-LAT group at Stockholm University, who are performing a parallel analysis that uses a multi-component float fit based on a single conservative galactic diffuse model.