Diffuse γ Ray Constraints on Annihilating or Decaying DM after Fermi

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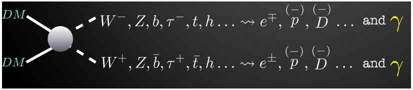
02^{nd} March 2010, Padova

Indirect Detection (γ Ray Constraints)



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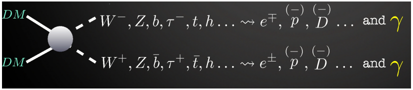

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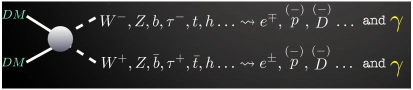

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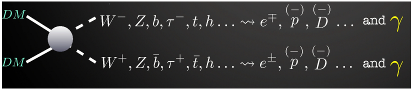

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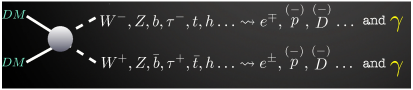

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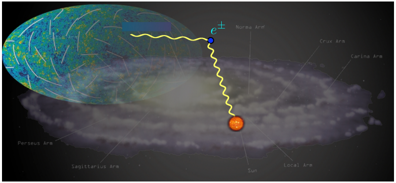

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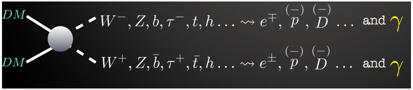

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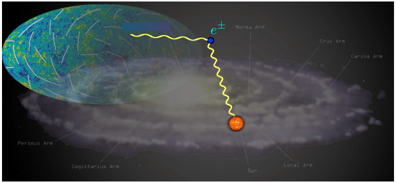
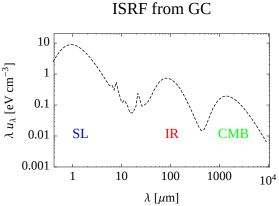
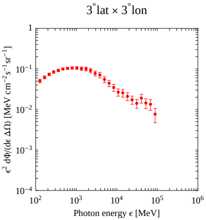
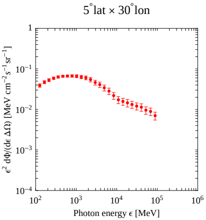




Diffuse γ Ray Emission (Fermi Data Points)





Talk by S. Digel

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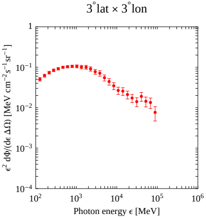
Fermi Data (FermiSymposium)

2 regions that surround the GC

- 3^o latitude $\times$ 3^o longitude
- 5^o latitude $\times$ 30^o longitude



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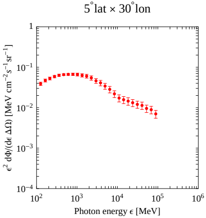

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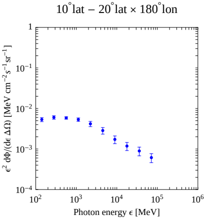
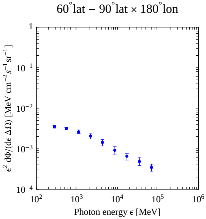


Talk by T. Porter



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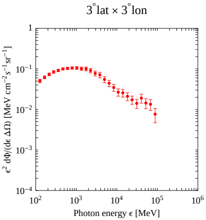

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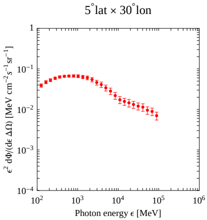

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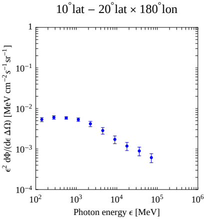

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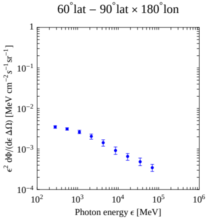

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The DM signals do not exceed more than 3σ the data

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ICS Fluxes at Earth from DM Ann/Dec

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Differential Power

The derivation is straightforward in terms of the well-known IC kinematics

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Electrons Number Density

The derivation can be done by solving the diffusion-loss equation

Derivation of the Electrons Number Density

$$\underbrace{-\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 D\frac{\partial f}{\partial r}\right]}_{\text{diffusion}} + \underbrace{v\frac{\partial f}{\partial r}}_{\text{advection}} \underbrace{- \frac{1}{3r^2}\frac{\partial}{\partial r}(r^2 v)p\frac{\partial f}{\partial p}}_{\text{convection}} + \underbrace{\frac{1}{p^2}\frac{\partial}{\partial p}\left[\dot{p}p^2 f\right]}_{\text{radiative losses}} = \underbrace{\frac{Q_e(E,r)}{4\pi p^2}}_{\text{source}}$$

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Fermi Regions

Big Regions of the sky, well outside the GC

$$\theta = 1^{\rm o} \Rightarrow \lambda^{\rm o} = r_\odot \theta \simeq 0.15 \text{ kpc}$$

1. 0.45 kpc $\times$ 0.45 kpc
2. 0.74 kpc $\times$ 4.44 kpc
3. 1.48 kpc - 2.96 kpc $\times$ 26.65 kpc
4. 8.88 kpc - 13.33 kpc $\times$ 26.65 kpc

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- Turn out to be dominated by the ICS radiative process

Derivation of the Electrons Number Density

$$n_e(E_e, r) = \frac{1}{\dot{\mathcal{E}}(E_e, r)} \int_{E_e}^{m_\chi} d\tilde{E}_e \, Q_e(\tilde{E}_e, r)$$

- $\dot{\mathcal{E}}(E_e, r)$: Total power radiates into photon by an electron on energy E_e
- $Q_e(E_e, r)$: Source term in the diffusion-loss equation

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DM Annihilation

$$Q_e^{\rm ann}(E_e, r) = \frac{1}{2}\langle \sigma v \rangle \, n_\chi^2(r) \, \frac{dN_e^{\rm ann}}{dE_e}(E_e)$$

- $\langle \sigma v \rangle$: Annihilation cross section
- $n_\chi = \rho / m_\chi$: DM number density
- $dN_e^{\rm ann}/dE_e$: Electron spectrum produced by DM annihilation

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DM Decay

$$Q_e^{\rm dec}(E_e, r) = \Gamma_{\rm dec} \, n_\chi(r) \, \frac{dN_e^{\rm dec}}{dE_e}(E_e)$$

- $\Gamma_{\rm dec} = 1/\tau_{\rm dec}$: Decay rate
- $n_\chi = \rho / m_\chi$: DM number density
- $dN_e^{\rm dec}/dE_e$: Electron spectrum produced by DM decay

$$\frac{d\Phi_i^{\rm ann}}{d\epsilon} = \frac{1}{2}\frac{\langle\sigma v\rangle}{4\pi}\frac{\rho_\odot^2}{m_\chi^2} r_\odot \bar{J}_i^{\rm ann}\Delta\Omega\frac{dN^{\rm ann}}{d\epsilon}, \qquad \frac{dN^{\rm ann}}{d\epsilon} = 2\frac{1}{\epsilon}\int_{m_e}^{m_\chi} dE_e \frac{\mathcal{P}(E_e,\epsilon)}{\dot{\mathcal{E}}(E_e)} Y^{\rm ann}(E_e)$$

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ICS Fluxes at Earth from DM Ann/Dec

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Canonical Geometrical Factors

Annihilation Scenario

$$\bar{J}_i^{\rm ann}\Delta\Omega = \int_{\Delta\Omega} d\Omega(b,l)\int \frac{ds}{r_\odot}\frac{\rho^2[r(s,b,l)]}{\rho_\odot^2}$$

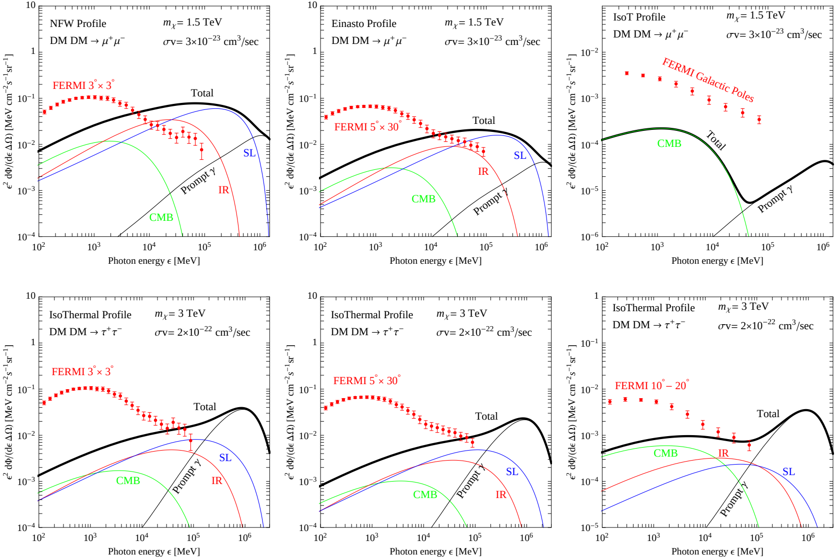
$b \longrightarrow$ Galactic latitude
$l \longrightarrow$ Galactic longitude

Decay Scenario

$$\bar{J}_i^{\rm dec}\Delta\Omega = \int_{\Delta\Omega} d\Omega(b,l)\int \frac{ds}{r_\odot}\frac{\rho[r(s,b,l)]}{\rho_\odot}$$

$b \longrightarrow$ Galactic latitude
$l \longrightarrow$ Galactic longitude

Summary & Results (DM Annihilation)



Draw the Exclusion Lines $\langle\sigma_{\rm ann}v\rangle/m_\chi$ Plane

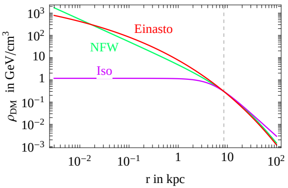
Recent Numerical Simulations (Einasto profile):

$$\rho_{\rm Ein}(r) = \rho_s \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^{\alpha} - 1\right)\right], \quad \alpha = 0.17.$$

Previously standard choices (NFW & IsoT):

$$\rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1 + \frac{r}{r_s}\right)^{-2}, \quad \rho_{\rm isoT}(r) = \frac{\rho_s}{1 + (r/r_s)^2}$$

DM halo model	r_s in kpc	ρ_s in GeV/cm^3
NFW	20.0	0.26
Einasto	21.8	0.05
Isothermal	3.20	2.31

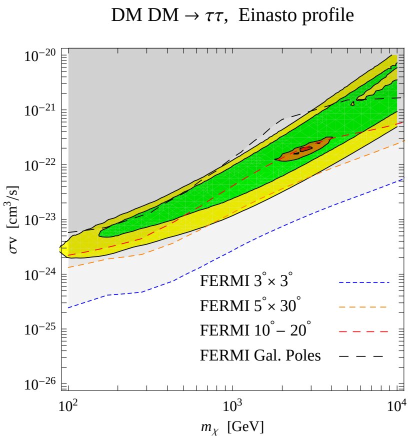


- Consider a Benchmark DM Halo profile

- Calculate the ICS signal and the prompt signal in each given primary annihilation channel spanning the DM mass in a range between 100 GeV up to 10 TeV

Draw the Exclusion Lines $\langle \sigma_{\rm ann} v \rangle / m_\chi$ Plane

- Consider a Benchmark DM Halo profile
- Calculate the ICS signal and the prompt signal in each given primary annihilation channel spanning the DM mass in a range between 100 GeV up to 10 TeV
- Require that the DM signals do not exceed more than 3σ the FERMI experimental data



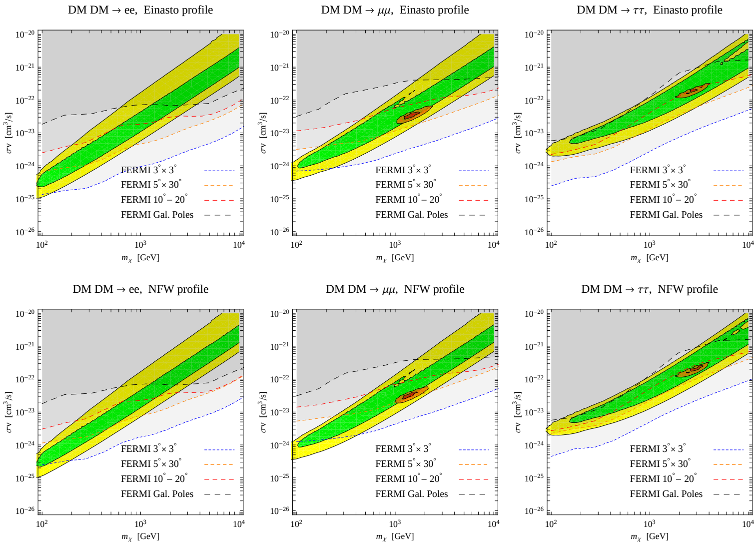
P.P., M. Cirelli, P.D. Serpico

The PAMELA allowed region (green 95% C.L. and yellow 99.999% C.L.)

FERMI + HESS + PAMELA allowed region (red 95% C.L. and orange 99.999% C.L.)

are completely excluded by the IC + Prompt γ constraints !!!

IC + Prompt γ Constraints (DM Annihilation)



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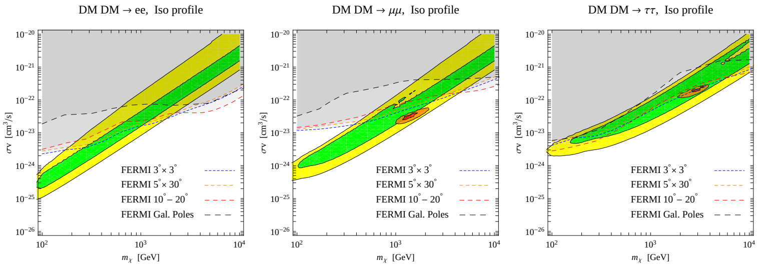

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For the smooth isothermal profile, regions of the parameters space seem to be reopened.

The FERMI + HESS + PAMELA allowed region in the case of annihilation into muons is not excluded yet

DRAW THE EXCLUSION LINES $\tau_{\rm dec}/m_\chi$ PLANE

- IC + Prompt γ Constraints from our Galaxy
- IC + Prompt γ Constraints from the residual "Isotropic radiation"

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$$\frac{d\Phi^{\rm dec}_{\rm cosm}}{d\epsilon} = \Gamma_{\rm dec}\frac{\Omega_\chi \rho_{c,0}}{m_\chi}\frac{1}{H_0}\int_0^\infty dz \frac{e^{-\tau(\epsilon,z)}}{\sqrt{\Omega_{\rm M}(1+z)^3+\Omega_\Lambda}}\frac{dN}{d\epsilon}(\epsilon(1+z))$$

Draw the Exclusion Lines $\tau_{\rm dec}/m_\chi$ Plane

- IC + Prompt γ Constraints from our Galaxy
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$$\frac{d\Phi^{\rm dec}_{\rm isotropic}}{d\epsilon} = \frac{d\Phi^{\rm dec}_{\rm cosm}}{d\epsilon} + 4\pi \frac{d\Phi^{\rm dec}_{\rm halo}}{d\epsilon\, d\Omega}\bigg|_{\rm Anti-GC}$$

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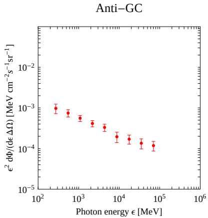

Talk by M. Ackerman, FermiSymposium

The "Isotropic Signal" does not exceed more than 3σ the FERMI data

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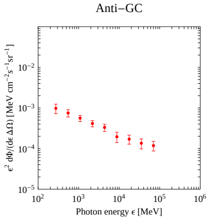


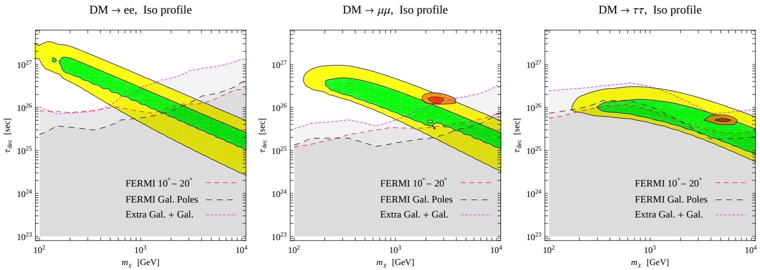
Talk by M. Ackerman, FermiSymposium

The "Isotropic Signal" does not exceed more than 3σ the FERMI data in the Anti-GC

Annihilation Scenario

- Stronger dependence on the angular distance from the GC is introduced in the galactic flux (no longer "Isotropic signal")
- Dependence on the DM profiles and the clumpiness of DM halos is introduced in the cosmological flux (not well understand)

IC + Prompt γ Constraints (DM Decay)



P.P., M. Cirelli, P.D. Serpico

The residual "Isotropic radiation" measured by FERMI imposes the strongest contraints

It excludes the decay explanation of the FERMI+HESS+PAMELA anomalies for the $\tau\tau$ channel and starts to exclude the decay explanation for the $\mu\mu$ channel

Conclusions

Leptonic Annihilation modes:

- For the NFW or Einasto profiles, the current data exclude not only DM scenarios explaining the FERMI+HESS+PAMELA allowed regions, but also PAMELA regions alone to hight confidence level
- For "cored" profiles, regions of the parameters space seem to be reopened (The annihilation into muons is not excluded yet)

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Leptonic Decay modes:

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Tensions with other Constraints:

- Constraints from Synchrotron radiation (Bertone et al. arXiv:0811.3744)
- Constraints from Ionization and Heating of the InterGalactic Medium

(Cirelli, Iocco, Panci arXiv:0907.0719), (Huetsi et al. arXiv:0906.4550), (Galli et al. arXiv:0905.0003)