Indirect Searches of Dark Matter

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Based on
Le Zhang, Guenter Sigl; arXiv:0807.3429; JCAP09(2008)027

Le zhang, Javier Redondo, Guenter Sigl; arXiv:0905.4952; JCAP09(2009)012

Le Zhang, Christoph Weniger, Luca Maccione, Javier Redondo, Guenter Sigl; arXiv:0912.4504; JCAP06(2010)027

IDM2010, 27.07.2010

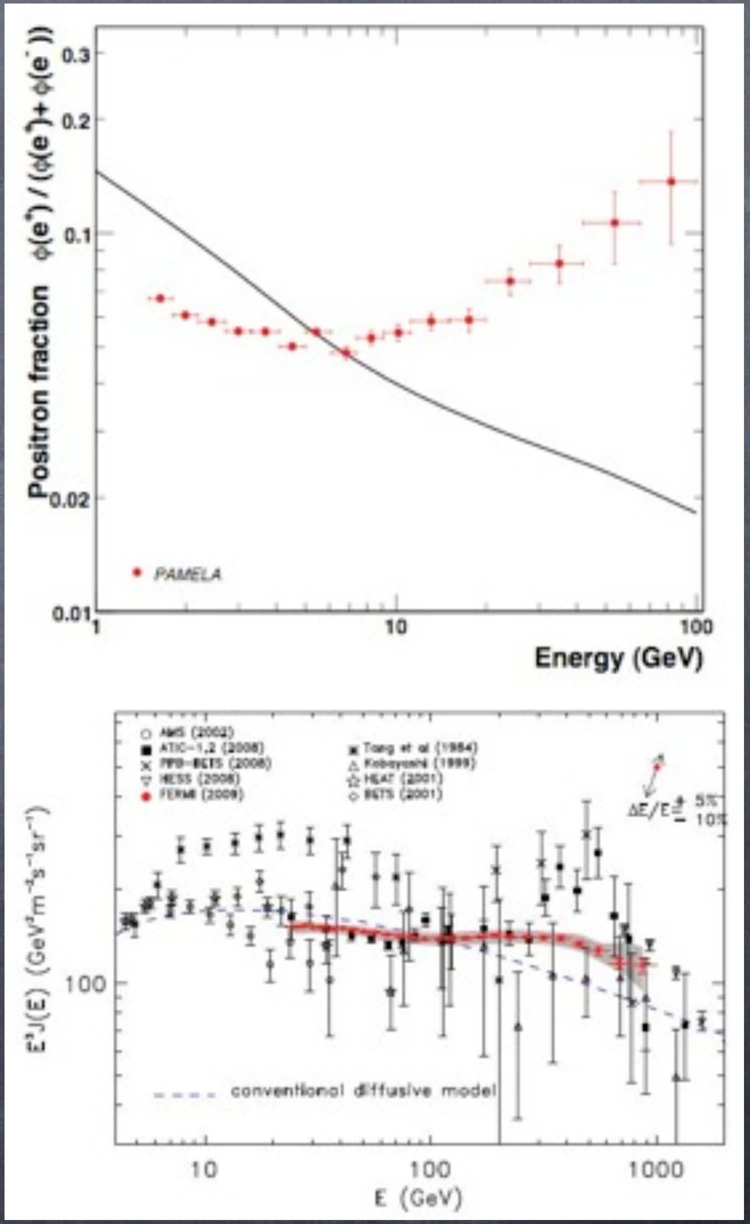
Outline

- What we have learned from astrophysics
  1. PAMELA (positron excess) 2. Fermi &ATIC (electron + positron excess)
- **Diffuse background** (Galactic decaying DM)
  - Construct response function (based on S/B; separate particle physics inputs & astrophysical inputs; fold with any decay spectrum to obtain constraints)
    1. gamma-rays 2. radio emissions 3. positron fluxes
  - Constraints on specific decay DM model
- **Anisotropic radio background** (extragalactic annihilating DM)
  - Constraining DM annihilation
- Summary

Latest Hints

from PAMELA, FERMI, ATIC

- Positron fraction excess
- Harder e+e- spectrum
- Antiprotons are well reproduced by astrophysical models



Excesses require ~TeV DM particles mostly annihilate/decay into leptons

Annihilation scenario , but need very large boost factor (~1000)

1) non-thermal production
2) Sommerfeld enhancement
3) Breit-Wigner enhancement
4) nearby clumps (within 1 kpc) and substructures

Decay scenario, naturally reproduced

Diffuse background

e+e- propagation in the MW

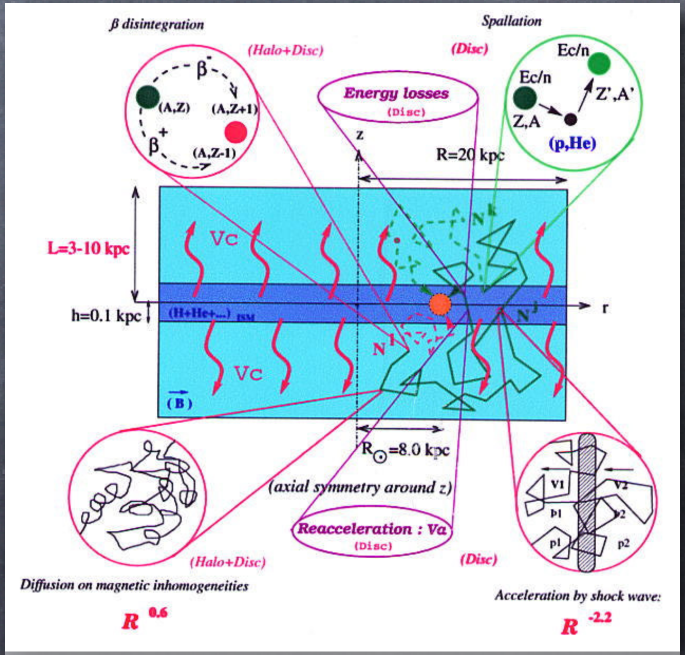
Galactic DM

$$\frac{\partial n}{\partial t} - \mathcal{D}n = Q(\mathbf{r},p) \qquad Q_\pm(\mathbf{r},E_0) = \frac{\rho_X(\mathbf{r})}{m_X\tau_X}\frac{dN_\pm}{dE_0}$$

$$\mathcal{D}n = \nabla\cdot\left(D_{xx}\nabla n - \mathbf{V_c}n\right) + \frac{\partial}{\partial p}\left(p^2 D_{pp}\frac{\partial}{\partial p}\frac{n}{p^2}\right) - \frac{\partial}{\partial p}\left[\dot{p}\,n - \frac{p}{3}\left(\nabla\cdot\mathbf{V_c}n\right)\right]$$

Diffusion

Reacceleration



Energy loss

Convection

Relative abundance of elements (B/C, antiprotons, radiative nuclei C, O ...) determines propagation parameters

Response Function

Each injected electron energy evolves independently. With a finite numerical simulations at different injected energies we can construct a numerical response function of S/B.

for Monochromatic injection of e+e- at E_0

Solve the **transport equation**

$\chi \to e^+ + e^-$ Green's function satisfying

$$-\mathcal{D}\, n_{\pm}^{E_0}(\mathbf{r}, E) = \frac{\rho_X(\mathbf{r})}{m_X \tau_X}\delta(E - E_0)$$

Calculate the associated signals

$J^{E_0}(\Omega, E_\nu)$

1. Gamma-rays
2. radios
3. positron fluxes

maximize signal-to-background

RF as function of Ω, E_ν, E_0

$$F(\Omega, E_\nu; E_0) = \frac{J^{E_0}(\Omega, E_\nu)}{J^{obs}(\Omega, E_\nu)}\left(\frac{\tau_\chi}{10^{26}\ \mathrm{s}}\right)\left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)$$

Constraints by asking

✗ Specific decay spectrum

✔ Propagation model (affect e+e- <10 GeV)

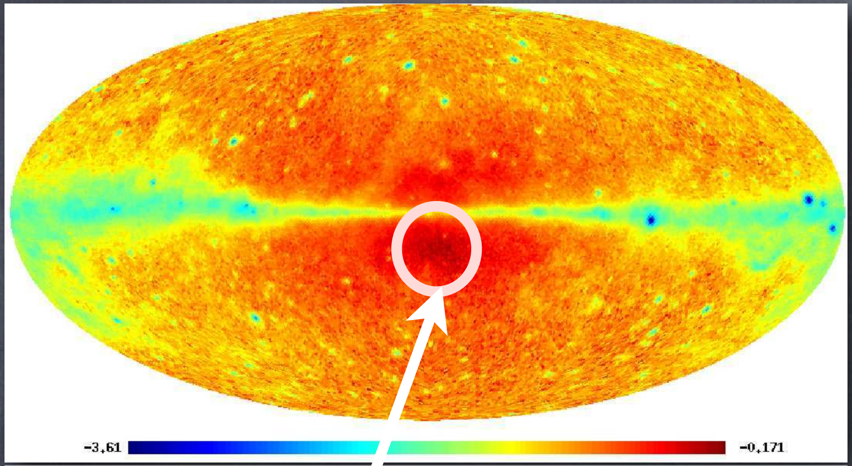
✔ Dark matter distribution (~10% influence)

Input from particle physics models

$$\int_{m_e}^{m_\chi} dE_0 F(\Omega, E_\nu; E_0)\frac{dN_e}{dE_0} \leq \left(\frac{\tau_\chi}{10^{26}\ \mathrm{s}}\right)\left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)$$

Response function: Part (I)

Based on gamma-ray observations by Fermi LAT

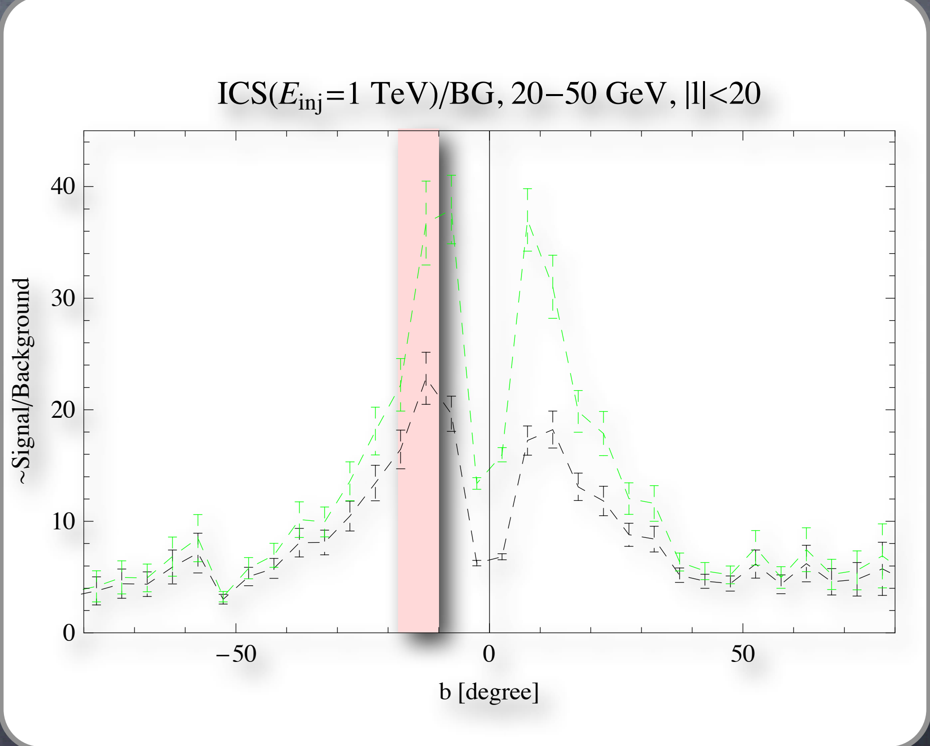


Warmer color indicates larger ratio

optimal patch (largest S/B) locates at intermediate latitude

$|l| \leq 20^\circ$ and $-18^\circ \leq b \leq -10^\circ$.

Signal-to-background



Response function: Results(I)

Based on Gamma-rays

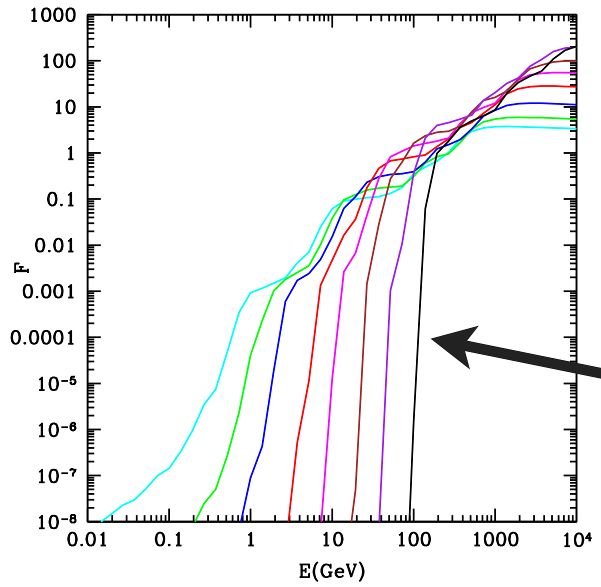


Figure 5. The $e^{\pm}$-response function F_γ based on γ-ray emission for the L1 model of Tab. 1. The $e^{\pm}$-response functions are derived from the eight $\gamma-$ray energy ranges $0.5-1$ GeV, $1-2$ GeV, $2-5$ GeV, $5-10$ GeV, $10-20$ GeV, $20-50$ GeV, $50-100$ GeV, and $100-300$ GeV from top to bottom at left side, respectively. The underlying sky patch $\mathcal{S}$ is defined by $|l| \le 20°$ and $-18° \le b \le -10°$.

- 8 energy bins from Fermi (0.5-300 GeV)
- Fix model L1 (best fit to cosmic ray data, e.g., B/C)
- Higher energy data provide stronger constraints, but have less statistics

arXiv:0912.4504; "Constraining Decaying Dark Matter with Fermi LAT Gamma-rays"
Le Zhang, Christoph Weniger, Luca Maccione, Javier Redondo, Guenter Sigl

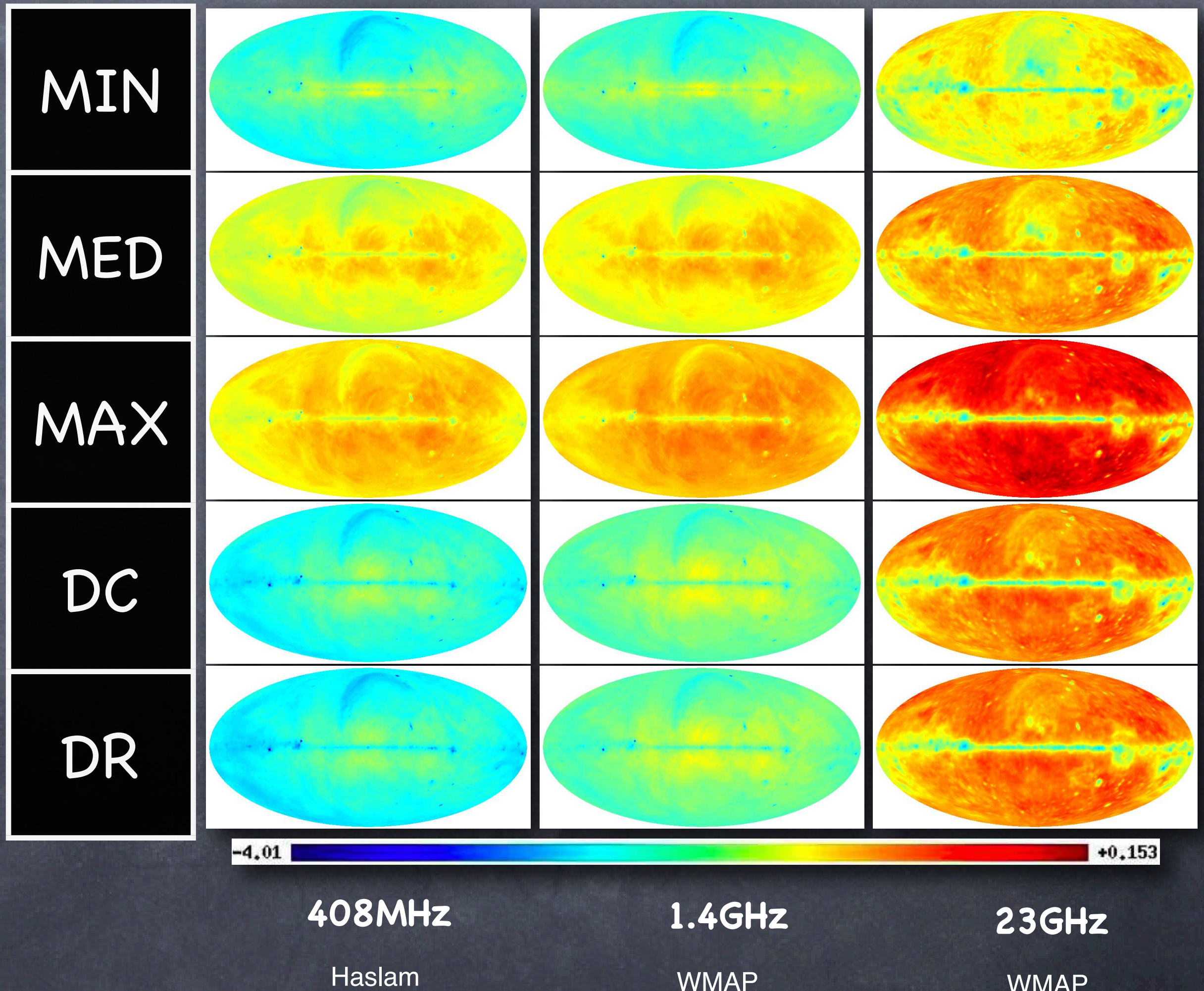
Response function: Part (II)

Based on radio observations

1. Pix-by-pix scanning over the whole sky with ~1 degree resolution until the largest excess is obtained

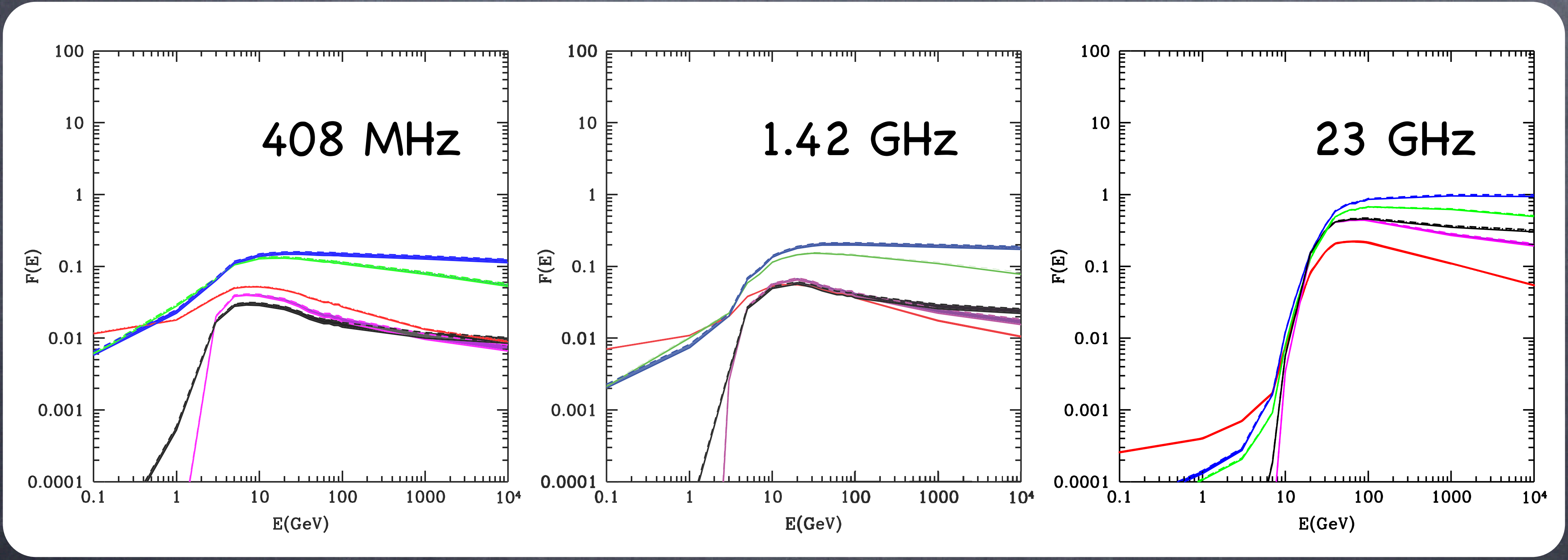
2. Large influence of propagation model on predicted DM signals

Signal-to-background (subtract CMB)



Response function: Results(II)

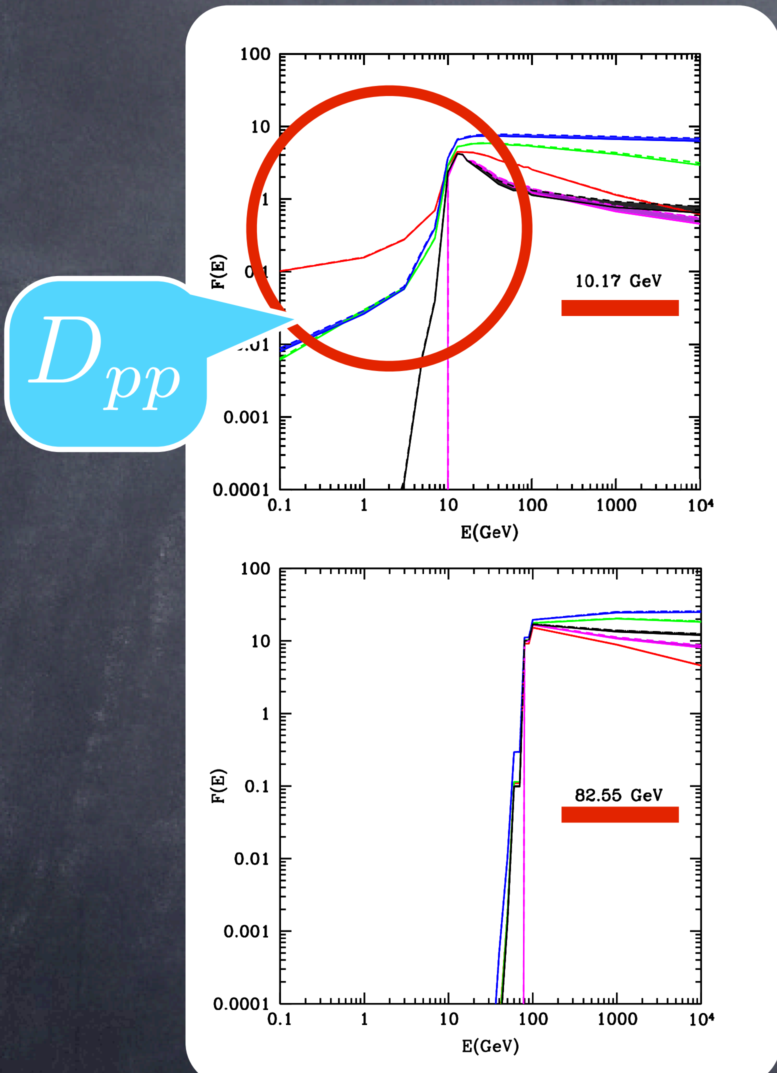
Based on radio emissions



arXiv:0905.4952; "Galactic Signatures of Decaying Dark Matter", JCAP 0909:012,2009
Le Zhang, Javier Redondo, Guenter Sigl

Response function: Results(III)

Based on Positron fluxes



In combination with PAMELA positron fraction (7 energy bins) and Fermi e+e- data

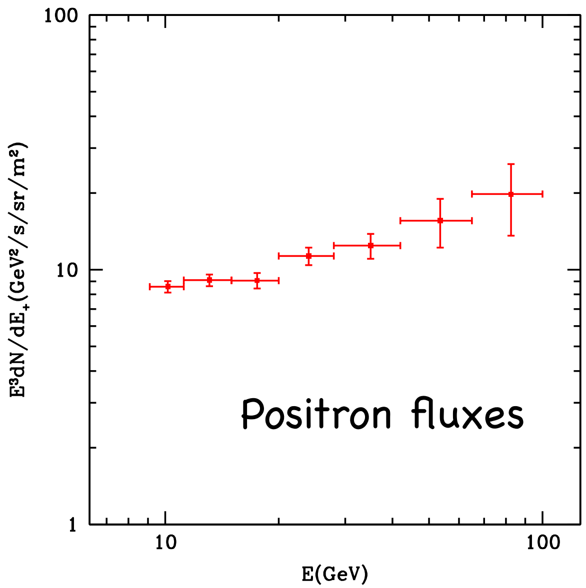


Figure 6. The positron flux observed at Earth as obtained by multiplying the $e^+ + e^-$ flux observed by FERMI [15] with the positron fraction measured by PAMELA [2, 3], see text.

arXiv:0905.4952, "Galactic Signatures of Decaying Dark Matter", JCAP 0909:012,2009
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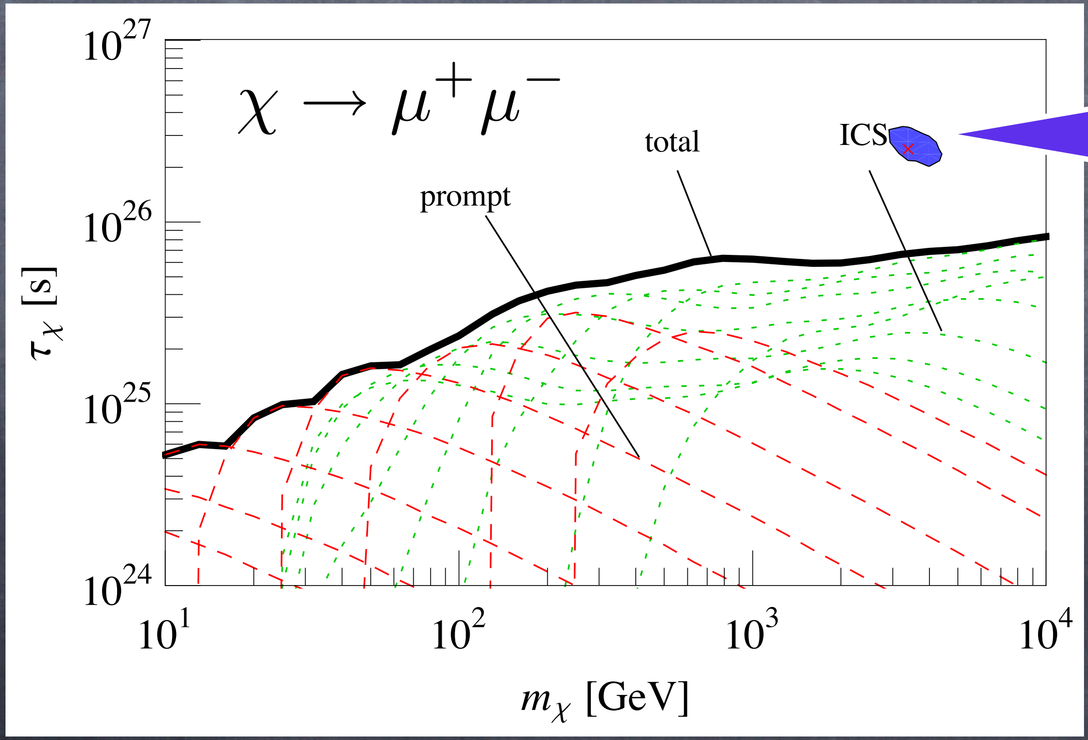
Constraints on DM models

Focus on the specific DM model:
bounds in mass vs. lifetime plane derived by response functions (ICS)



Allowed by PAMELA

Anisotropic Radio Background

Extragalactic DM Signatures

The cosmological background of synchrotron emissions from DM annihilations into e+e- which propagate in B field.

$$J(\nu,\Omega) \simeq \frac{Y_e[> E_c(\nu)]\,\langle\sigma v\rangle}{m_X^2}\,\frac{9\rho_m^2}{64\pi\sqrt{eB\nu}}\left(\frac{m_e^3}{0.29\pi}\right)^{1/2}\int dz\,\frac{(1+z)^{3/2}\delta^2(z,\Omega)}{H(z)\left[1+\frac{u_{\rm op}}{u_B}+\frac{u_0}{u_B}(1+z)^4\right]}$$

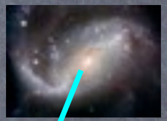
Conservative Model Estimation

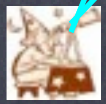
$$E_c(\nu) = 5.9\left(\frac{\nu}{1\,\mathrm{GHz}}\right)^{1/2}\left(\frac{B}{6\,\mu\mathrm{G}}\right)^{-1/2}\ \mathrm{GeV}$$

$Y_e[> E_c(\nu)]$ Multiplicity per annihilation of electrons and positrons with energies larger than the critical energy which corresponds to radio emission of the frequency ν (typical value is 10)

$\delta^2(z,\Omega)$ Clumping factor depend on

1. Halo profile (NFW)
2. Halo evolution (PS)
3. Lower mass cut-off (~ dwarf galaxy)





Limber approximation

$$C_l \simeq \int dr\,\frac{w^2(r)}{r^2}P_f(l/r,z)$$

$$P_f = P_f^{1h} + P_f^{2h}$$

Signatures in Anisotropic Radio Sky

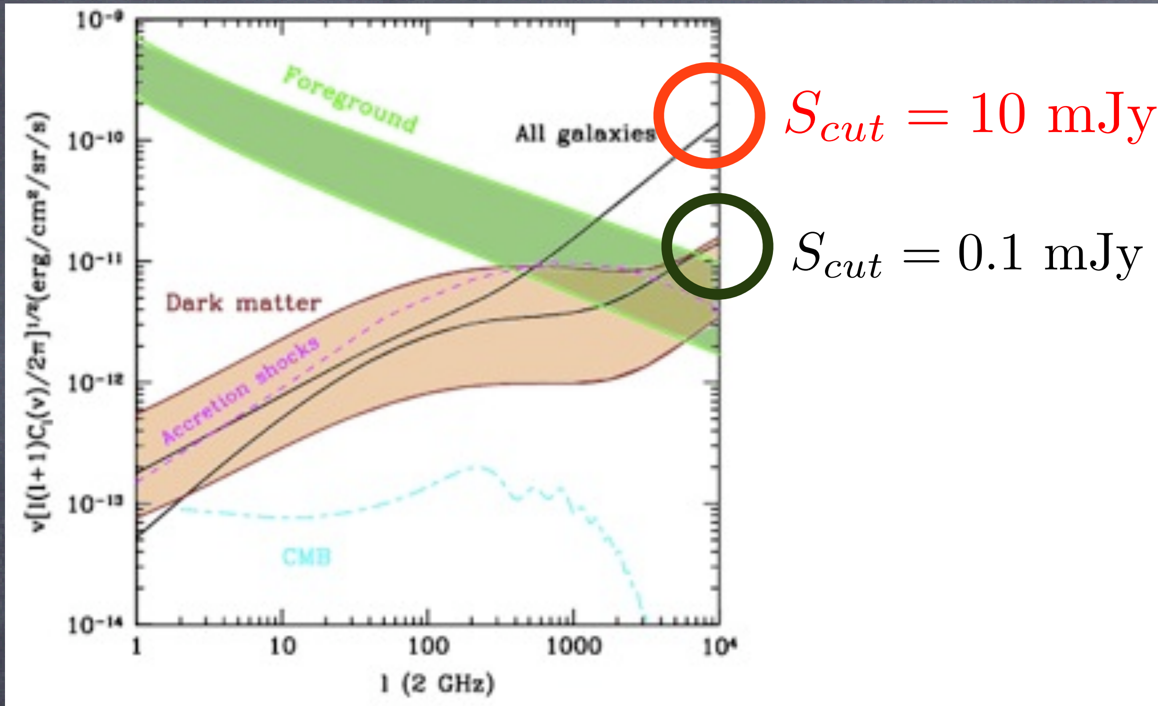


Figure 7. Angular power spectra of the radio sky at 2 GHz compared with various estimates of the Galactic foreground at Galactic latitude $b > 20°$ (green shaded region) and the CMB (cyan curve). The brown band represents the annihilation spectrum, where the upper and lower ends correspond to $F_{dm} = 10$ and $F_{dm} = 1$, respectively (see equation (39)), and from which halos brighter than 0.1 mJy were removed. The black dotted and black solid curves represent the total signal from normal and radio galaxies, for luminosity cuts $S_{cut} = 10$ mJy and $S_{cut} = 0.1$ mJy, respectively. Also shown is a possible contribution from intergalactic shocks [56], normalized such that its angular power spectrum is comparable to the Galactic foreground.

DM annihilation signal tends to be **flatter** than astrophysical contributions.

Why?

For DM, more power at

1. large scales due to many faint sources have more power at large scales.

2. small scales due to Fourier transform of $\rho^2(r)$ have more power at small scales than for $\rho(r)$.

Reduce contaminations by removing bright sources.

Summary

- **Analysis of diffuse background: Galactic DM signatures**
  Response functions constructed by signal-to-background (gamma-rays, radio emissions and positron fluxes)
  - Independent of particle physics model
  - Easily applied to any decay model (analytical fits are available) once folded with e+e- spectrum
  - Powerful Constraints, but DM models fitting PAMELA data are still not in conflict with gamma-ray observations

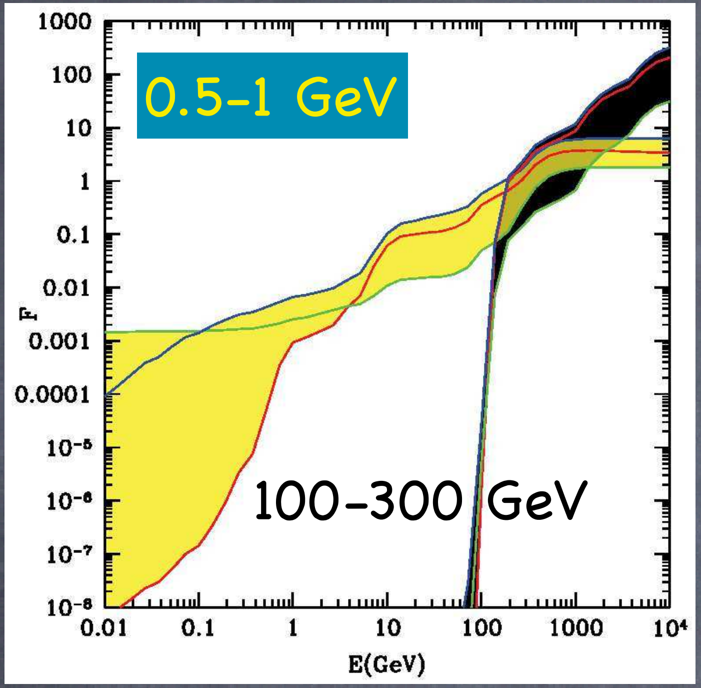
- **Analysis of anisotropic background: extragalactic DM signature**

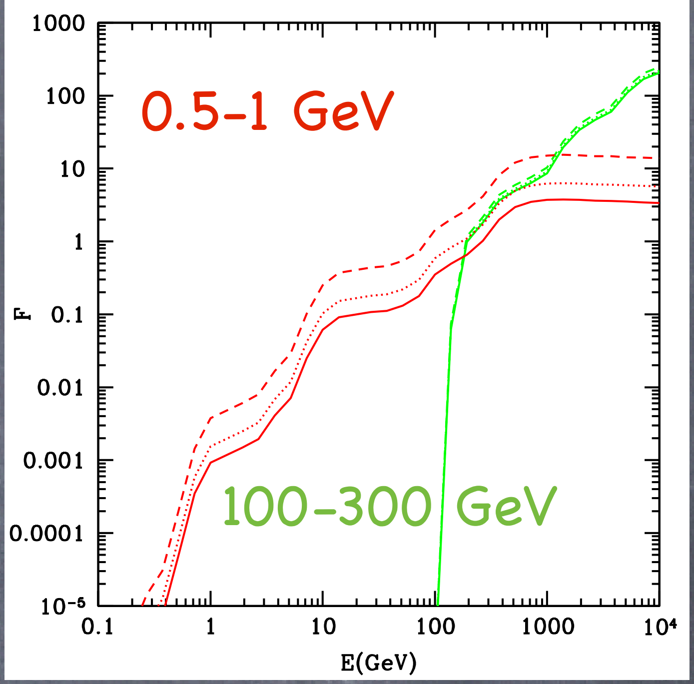
$$F_{\rm dm} \equiv \left(\frac{A_b}{10}\right)\left(\frac{Y_e}{10}\right)\left(\frac{\langle\sigma v\rangle}{3\times10^{-26}{\rm cm^3 s^{-1}}}\right)\left(\frac{100{\rm GeV}}{m_X}\right)^2\left(\frac{10\,\mu{\rm G}}{B}\right)^{1/2}$$

  - Current radio observations are sensitive to $F_{dm} \geq 10$
  - Foreground cleaning and source removal strongly improve constraints

Thanks for your attention

Response function: Uncertainties





Uncertainties of propagation model

1. Lager uncertainties on Low energy data (<10 GeV) (e.g. reacceleration, height of zone,convection, ...)
2. Better knowledge of background can improve the constraints by factor ~10
3. Variation from halo density profile is subdominant (Kra -10%, Iso -10%, Ein +30%)

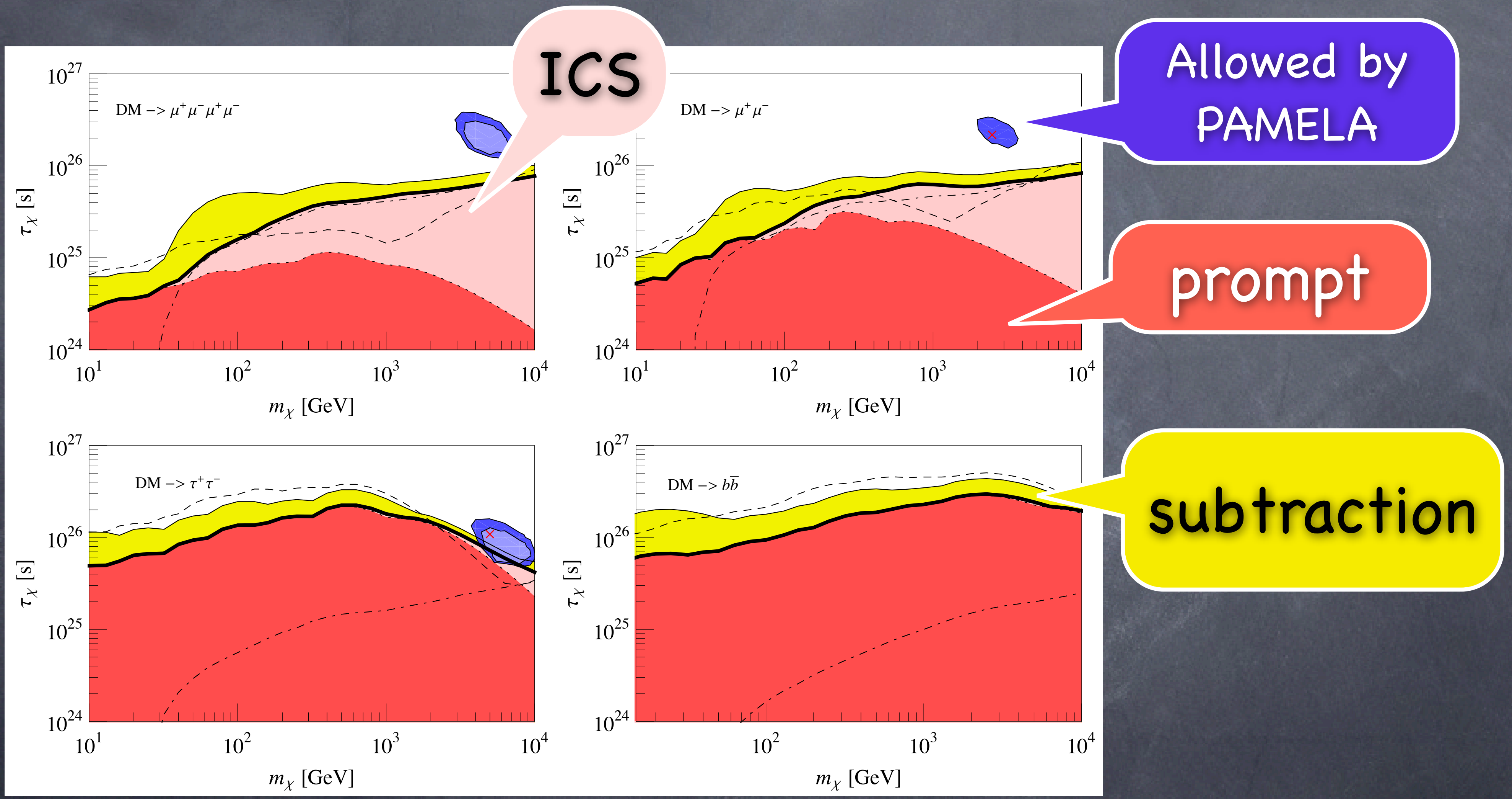
Uncertainties of background subtraction

Solid : raw data

Dotted: PP gamma-rays

Dashed: all astrophysical background

Constraints on DM models



Dashed: Based on extragalactic ICS + prompt and prompt from Galactic anti-center

Diffusion models

Model	δ^1	D_0 $[10^{28}\text{cm}^2/\text{s}]$	R [kpc]	L [kpc]	V_c [km/s]	dV_c/dz km/s/kpc	V_a [km/s]	h_{reac} [kpc]
MIN	0.85/0.85	0.048	20	1	13.5	0	22.4	0.1
L1	0.50/0.50	4.6	20	4	0	0	10	4
MAX	0.46/0.46	2.31	20	15	5	0	117.6	0.1

Model	δ§	D_0 $[\text{kpc}^2/\text{Myr}]$	R [kpc]	L [kpc]	V_c [km/s]	dV_c/dz km/s/kpc	V_a [km/s]	h_{reac} [kpc]
MIN	0.85/0.85	0.0016	20	1	13.5	0	22.4	0.1
MED	0.70/0.70	0.0112	20	4	12	0	52.9	0.1
MAX	0.46/0.46	0.0765	20	15	5	0	117.6	0.1
DC	0/0.55	0.0829	30	4	0	6	0	4
DR	0.34/0.34	0.1823	30	4	0	0	32	4

Table A1. Typical combinations of diffusion parameters that are consistent with the B/C analysis. The first three propagation models correspond respectively to minimal, medium and maximal primary antiproton fluxes, abbreviated by MIN, MED, and MAX, respectively. In the DC model, the secondary $e^{\pm}$, p and $\bar{p}$ fluxes fit the data well, and the DR model can easily reproduce the energy dependence of the B/C data.

The Average Diffuse Background

An optimal windows at frequencies $\nu \sim$ 2 GHz

Constraints can be improved ?

If foreground is more isotropic, then less contamination in anisotropic radio sky !

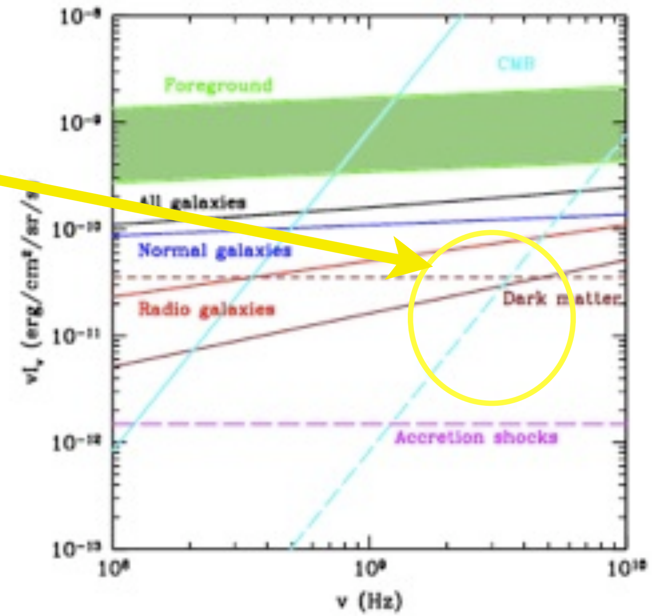


Figure 1. The average diffuse background flux intensity with no point source removal. Contributions from normal galaxies (blue curve), radio galaxies (red curve), from radio and normal galaxies combined (black curve), and from a scenario for radio emission from galaxy cluster shocks (magenta curve) [56] (see the text for the normalization) are compared to our fiducial dark matter annihilation scenario with $m_\chi = 100$ GeV, $\langle \sigma v \rangle \sim 3 \times 10^{-26}$ cm^3 s^{-1}, $A_b = 10$, $B = 10\ \mu$G, $M_{\rm min} = 10^6 M_\odot$ (brown curves). Here, the solid brown curve is for $Y_e = 10$, while the dashed brown curve is for $Y_e(E) \simeq m_\chi/E$. Also shown is the CMB background (cyan solid curve) as well as its part that can be subtracted, determined by uncertainties of the absolute CMB temperature (dotted cyan curve). The Galactic foreground at Galactic latitude $b > 20°$ is shown as the green band within uncertainties.