Dark Matter Constraints on Triangles with Indirect Searches

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Introduction

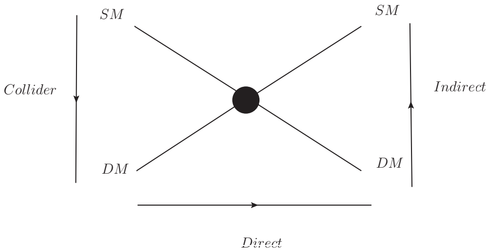
Generally limits on dark matter annihilation rates are stated in terms of a single annihilation channel, which would appear to be unrealistically simple.

We look at limits from dark matter annihilation in dwarf spheroidal galaxies to multiple SM final states from Fermi-LAT.

Looking at multiple channels at once can be seen in terms of a triangular visualization.

We will also discuss the case when channels are not completely independent of one another

Indirect Detection



Photon flux: $$\Phi_\gamma = \frac{1}{4\pi} \sum_f \frac{\langle \sigma v \rangle_f}{2m_\chi^2} \int_{E_{\min}}^{E_{\max}} B_f \left(\frac{dN_\gamma}{dE_\gamma} \right)_f dE_\gamma J$$

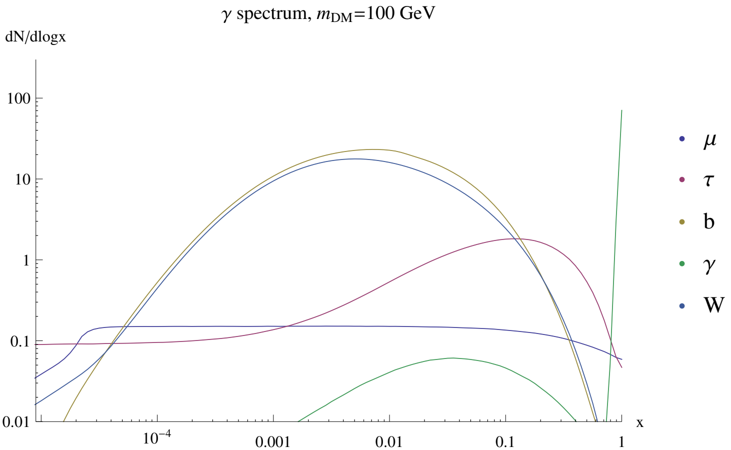
J-factor: $$J = \int_{\Delta\Omega} \int_{l.o.s} \rho^2(\mathbf{r}) dl d\Omega'$$

Fractional annihilation rate: $$B_f \equiv \frac{\langle \sigma v \rangle_f}{\langle \sigma v \rangle_{tot}}$$

Why dwarfs?

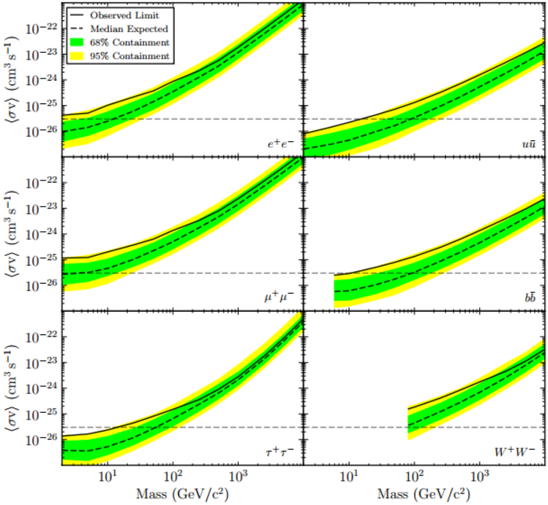
- High DM to light ratio
- Lack of astrophysical production of γ rays
- Low diffuse background

Spectra



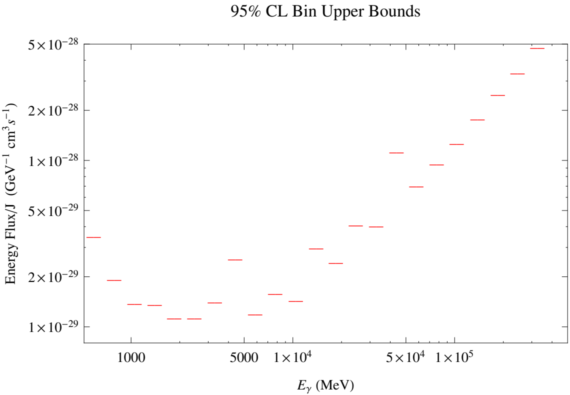
$x \equiv \frac{E_\gamma}{m_{DM}}$ arXiv: 1012.4515

Limits from Dwarfs



arXiv: 1310.0828

Limits from Dwarfs



Looking at Multiple Channels

If we want to look at three channels, we can look at a total annihilation rate:

$$\langle \sigma v \rangle_1 + \langle \sigma v \rangle_2 + \langle \sigma v \rangle_3 = \langle \sigma v \rangle_{tot}$$

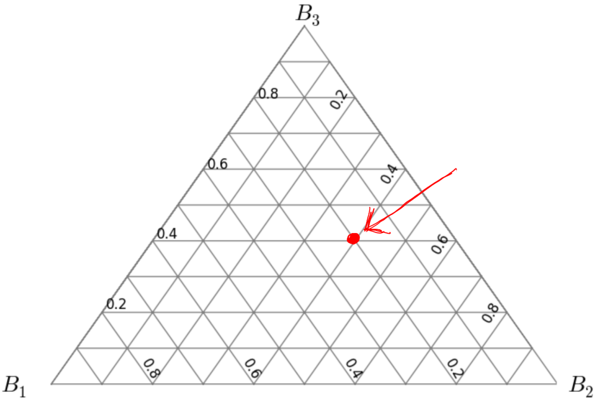
$$B_i \equiv \frac{\langle \sigma v \rangle_i}{\langle \sigma v \rangle_{tot}}$$

Normalizing to a total rate the sum of the fractional rates must sum to 1:

$$B_1 + B_2 + B_3 = 1$$

$\Rightarrow$ Can show constraints with a triangular visualization

Triangle!

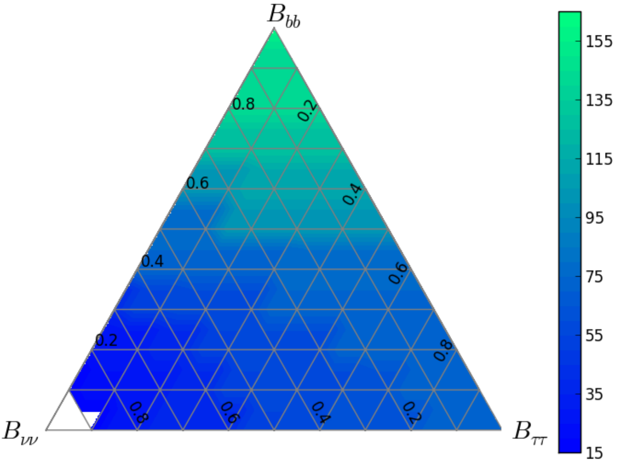


Vertices are the simplified models- 100% annihilation to single state

Constraint: $B_1 + B_2 + B_3 = 1$

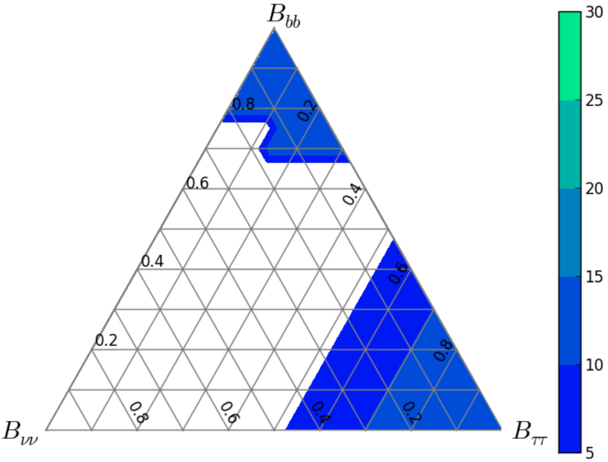
Red dot as an example is where: $(B_1, B_2, B_{3)} = (.2, .4, .4)$

$\langle \sigma v \rangle = 10 \langle \sigma v \rangle_{therm}$



Mass limits (GeV) for $\langle \sigma v \rangle = 10 \langle \sigma v \rangle_{\text{therm}}$ with annihilation into third family states.

$\langle \sigma v \rangle = \langle \sigma v \rangle_{therm}$



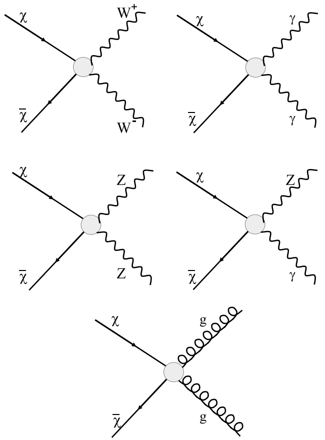
Mass limits (GeV) for $\langle \sigma v \rangle = \langle \sigma v \rangle_{\text{therm}}$ with annihilation into third family states.

Extending to Interfering Channels

In the case where channels are completely independent of each other, we can vary each channel separately.

This is not necessarily the case however, there can be channels which interfere with each other.

Extending to EFTs which interfere



$$\mathcal{L}_7 = \frac{1}{\Lambda_7^3}\bar{\chi}\gamma^5\chi\sum_i k_i F^i_{\mu\nu}F_i^{\mu\nu}$$

$$\langle\sigma v_{rel}\rangle_{WW} = \frac{k_2^2}{4\pi\Lambda_7^6}\sqrt{1-\frac{m_W^2}{m_\chi^2}}(16m_\chi^4 - 16m_W^2 m_\chi^2 + 6m_W^4)$$

$$\langle\sigma v_{rel}\rangle_{ZZ} = \frac{(k_1 s_w^2 + k_2 c_w^2)^2}{4\pi\Lambda_7^6}\sqrt{1-\frac{m_Z^2}{m_\chi^2}}(16m_\chi^4 - 16m_Z^2 m_\chi^2 + 6m_Z^4)$$

$$\langle\sigma v_{rel}\rangle_{Z\gamma} = \frac{s_w^2 c_w^2(k_2 - k_1)^2}{16\pi m_\chi^2\Lambda_7^6}(4m_\chi^2 - m_Z^2)^3$$

$$\langle\sigma v_{rel}\rangle_{\gamma\gamma} = \frac{4(k_1 c_w^2 + k_2 s_w^2)^2}{\pi\Lambda_7^6}m_\chi^4$$

$$\langle\sigma v_{rel}\rangle_{gg} = \frac{4k_3^2}{\pi\Lambda_7^6}m_\chi^4.$$

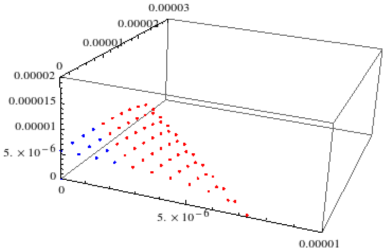
For channels which can be turned on independently of each other, it is sufficient to look at a total rate:

$$\langle \sigma v \rangle_1 + \langle \sigma v \rangle_2 + \langle \sigma v \rangle_3 = \langle \sigma v \rangle_{tot}$$

If we extend to looking at EFTs, a constraint to a total rate will yield:

$$(ak_1 + bk_2)^2 + ck_3^2 = \langle \sigma v \rangle_{tot}$$

Allowed regions in coupling space for $m_{DM} = 10\text{GeV}$, $\langle \sigma v \rangle = \frac{1}{10} \langle \sigma v \rangle_{therm}$:
Red not allowed
Blue allowed



Summary

- Dwarf galaxies provide an excellent region to look for DM annihilations
- Constraining annihilation rates for a mix of multiple channels provide more robust bounds on models
- Some types of operators will interfere with each other allowing multiple channels to open with the same operator