Indirect detection of the Wino dark matter

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Motivation

Dark matter (DM) can provide a very useful connection between the Early Universe and Beyond the SM physics. To take an advantage of growing precision of observations, we need to make theoretical predictions equally accurate. It needs detailed study of both particle physics and astrophysical phenomena. The aim of this work is to make such an analysis for a specific DM model to obtain robust and precise predictions and learn more about relative importance of different effects.

CR propagation

To obtain prediction for the CR fluxes at Earth location we solve using DRAGON the propagation equation:

$$\frac{\partial N^i}{\partial t} - \vec{\nabla}\cdot D_{xx}\vec{\nabla}N^i + \frac{\partial}{\partial p}\dot{p}N^i - \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{N^i}{p^2} =$$
$$Q^i(p,r,z) + \sum_{j>i} c\beta n_{\rm gas}(r,z)\sigma_{ij}N^j - c\beta n_{\rm gas}\sigma_{\rm in}(E_k)N^i$$

with the diffusion coefficient:

$$D_{xx} = D_0\beta^\eta\left(\frac{R}{R_0}\right)^\delta e^{\frac{|z|}{z_d}}\, e^{\frac{(r-r_\odot)}{r_d}} \text{ and } D_{pp}D_{xx} = \frac{p^2 v_A^2}{9}$$

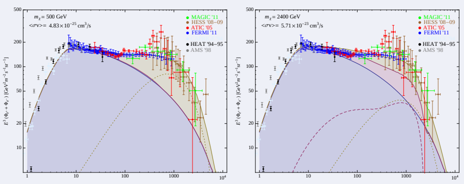
We assume Kraichnan turbulence $\delta = 0.5$ and scan diffusion zone thickness $z_d \in (0.5, 20)$kpc.

Other free parameters D_0, η, v_A and the primary injection spectra are fitted to the B/C, proton and electron data.

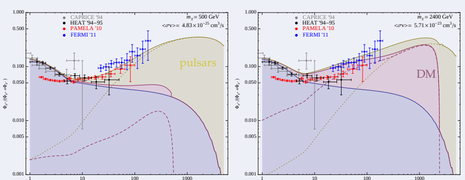
We identified **12 benchmark propagation models**, obtaining propagation uncertainty and its dependence on z_d.

Leptons

total $e^+ + e^-$



positron fraction

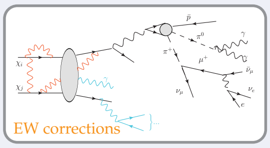


$\Rightarrow$ Wino DM **cannot** explain lepton CR puzzle without significant pulsar component

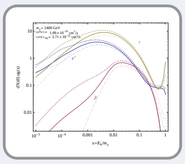
The Model

The MSSM serves as a strongly motivated framework for both BSM and DM physics. Among its natural realizations are scenarios where the DM candidate is the Wino:

- large $\langle\sigma v\rangle$ to W^+W^- $\Rightarrow$ thermal production at TeV scale $\Rightarrow$ **large EW corrections**

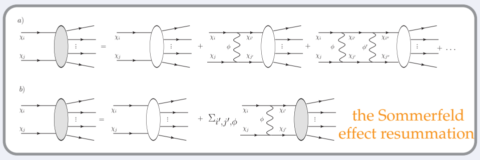


Even more than 20% change at one-loop and much softer spectra than at the tree level (important for $\bar{p}$'s and soft γ-rays)



- degenerate with $\chi^\pm$ $\Rightarrow$ **the Sommerfeld effect (SE)**

The $\langle\sigma v\rangle$ enhanced due to "long range force" between slow moving DM particles:
  - mediated by (mostly) $W^\pm$
  - needs $m_{\chi^\pm} - m_{\chi^0} \ll m_W$



Can change the $\langle\sigma v\rangle$ by $\mathcal{O}(1000)$ $\rightarrow$ resonance due to forming a loosely bound state between initial DM particles occurs

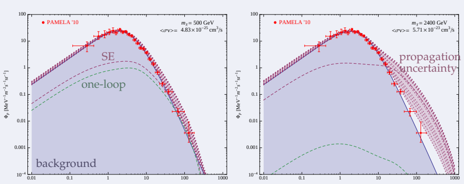
- suppressed coupling to Z^0, h $\Rightarrow$ **testable only in the indirect detection**

Propagation models

Benchmark			Fitted			Fitted		Goodness				
z_d [kpc]	δ	r_d [kpc]	$D_0\times10^{28}$ [cm^{2}s^{-1}]	v_A [km s^{-1}]	η	γ_1^p/γ_2^p	$R_{0,1}^p$ GV	$\chi^2_{B/C}$	χ^2_p	$\chi^2_{\bar{p}}$	χ^2_e $E_k > 5$ GeV	$\chi^2_{\rm tot}$
0.5	0.5	20	0.191	11.0	-0.60	2.11/2.36/2.18	16.9	0.69	0.67	0.37	0.68	0.65
1	0.5	20	0.53	16.3	-0.521	2.04/2.34/2.18	16.0	0.96	0.46	0.38	0.69	0.58
1.4	0.5	20	0.738	15.5	-0.499	2.11/2.36/2.18	16.1	0.51	0.62	0.36	0.71	0.60
1.7	0.5	20	0.932	16.2	-0.476	2.11/2.35/2.18	14.6	0.47	0.65	0.35	0.72	0.60
2	0.5	20	1.13	16.7	-0.458	2.11/2.35/2.18	14.6	0.48	0.59	0.35	0.72	0.58
3	0.5	20	1.75	18.5	-0.40	2.05/2.35/2.18	16.0	0.34	0.39	0.35	0.75	0.46
4	0.5	20	2.45	19.5	-0.363	2.05/2.35/2.18	16.0	0.79	0.33	0.36	0.75	0.49
6	0.5	20	3.17	19.2	-0.40	2.05/2.35/2.18	16.0	0.38	0.44	0.35	0.77	0.49
8	0.5	20	3.83	19.2	-0.370	2.05/2.35/2.18	15.2	0.39	0.53	0.35	0.77	0.54
10	0.5	20	4.36	19.1	-0.373	2.05/2.35/2.18	15.2	0.38	0.47	0.35	0.77	0.51
15	0.5	20	4.86	17.5	-0.448	2.11/2.36/2.18	14.8	0.46	0.89	0.34	0.77	0.74
20	0.5	20	5.19	17.1	-0.448	2.10/2.36/2.18	14.2	0.45	0.95	0.34	0.77	0.77

All models give a very good fit to the data. It is the main source of uncertainty. We can reduce it only if we add another input $\Rightarrow$ require agreement with the *Fermi* diffuse γ-ray data.

Antiprotons

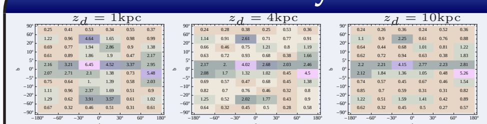


Sommerfeld effect, but also EW corrections have a **significant impact**

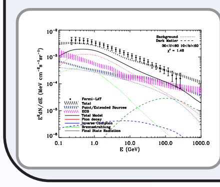
Thin propagation models give less $\bar{p}$'s and thus less stringent limits

$\bar{p}$'s alone constrain m_{χ^0}, but weakly

Gamma rays



Background gamma sky-maps for three propagation models (χ^2 values of the fit) $\Rightarrow$ **the thin diffusion zones are strongly disfavored**

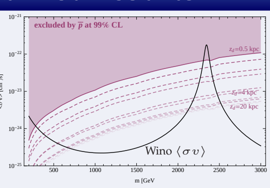


Spectrum at low energies underestimates the data $\rightarrow$ thicker z_d give more secondary (ICS) soft γ-rays

Combined results

From all these channels we can put limits on $\langle\sigma v\rangle$:
the strongest from **combined analysis** of $\bar{p}$'s and diffuse γ-rays

Additional channels studied:
leptons, ν's, $\bar{d}$'s, γ-rays from dSphs and Galactic Center



$\Rightarrow$ Combined: **Wino DM is ruled out** for $m_\chi \lesssim 450$ GeV and 2.2 TeV $\lesssim m_\chi \lesssim 2.5$ TeV

Resonance: excluded also by leptons, ν's and dSphs

Conclusion

We learnt that to obtain **robust** and **precise predictions** for dark matter indirect detection one indeed needs to look **beyond the tree level** and study **different detection channels simultaneously**.

References

[1] A. Hryczuk, R. Iengo and P. Ullio, JHEP **1103** (2011) 069 [arXiv:1010.2172 [hep-ph]].
[2] A. Hryczuk and R. Iengo, JHEP **1201** (2012) 163 [arXiv:1111.2916 [hep-ph]].
[3] I. Cholis, A. Hryczuk, R. Iengo, M. Tavakoli, P. Ullio, in prep.