Is a Miracle-less WIMP Ruled out?

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arXiv:2101.11031 with Tim M.P. Tait

Miracle-less WIMP

WIMPs: popular DM candidate for many years.

- Predicted by many BSM theories (e.g. SUSY)
- Freeze out of WIMPs $\longrightarrow$ correct relic abundance (WIMP Miracle)

However,

- Direct, indirect, and collider searches $\rightarrow$ constrain WIMP miracle regime
- No data before BBN $\rightarrow$ Early universe is unknown

> What are the constraints for WIMPs if we stay agnostic to the production mechanism?

Miracle-less WIMP

We make only the following assumptions:

1. WIMP is a real scalar $SU(2)_{EW}$ triplet, ϕ
2. Masses between 0.1 GeV $\lesssim m_\phi \lesssim$ 100 TeV.
3. DM abundance matches observed value

Outline:

1. General Model
2. Collider Constraints
3. Direct Detection
4. Indirect Detection

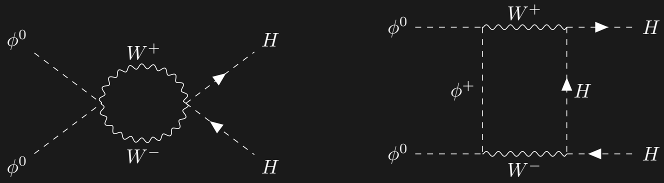
SU$(2)_{EW}$ Triplet Scalar DM

For a real SU$(2)_{EW}$ triplet scalar, ϕ, the most general, renormalizable Lagrangian is:

$$\mathcal{L} = \frac{1}{2}(D_\mu \phi)_i (D^\mu \phi)_i - \frac{\mu_\phi^2}{2}\phi^2 - \frac{\lambda_\phi}{4!}\phi^4 - \lambda H^\dagger \phi^2 H$$

SU(2)$_{EW}$ Triplet Scalar DM

Small Higgs coupling $\lambda \to$ fine tuning. λ is renormalized by the diagrams



with one-loop correction,

$$\lambda(\mu) \simeq \lambda(\mu_0) + \frac{g_2^4}{\pi^2} \ln\left(\frac{\mu^2}{\mu_0^2}\right)$$

Collider Searches

High energy colliders may be able to produce dark matter.
LHC $\to$ few search methods:

- Monojet searches
- Disappearing Charged Tracks (DCTs)
- Invisible Higgs decays

$m_\phi \lesssim 287$ GeV excluded[1] if: $\Delta m \equiv m_{\phi^\pm} - m_{\phi^0} \approx 166$ MeV (electroweak effects)

Can evade bounds by adding a dim. 6 operator $\to$ increases Δm:

$$\mathcal{L}_{\text{Mass}} = -\frac{1}{\Lambda^2}|\phi^a H^\dagger T^a H|^2 = -\frac{1}{16\Lambda^2}(\phi^0)^2(v+h)^4$$

[1] C.-W. Chiang, G. Cottin, Y. Du, K. Fuyuto, and M. J. Ramsey-Musolf, arXiv:2003.07867

Invisible Higgs Decays

If $m_\phi \leq M_h/2 \to h \to \phi^0\phi^0$

$$\Gamma_{h\to\phi^0\phi^0} = \frac{\sqrt{M_h^2 - 4m_{\phi^0}^2}}{16\pi M_h^2} v^2 \lambda_{\text{eff}}^2,$$

Branching ratio is bounded[2],

$$\mathcal{B}(h \to \text{inv}) = \frac{\Gamma_{\text{DM}}}{\Gamma_{\text{SM}} + \Gamma_{\text{DM}}} \leq 0.19$$

Requires $\lambda_{\text{eff}} \lesssim 10^{-2}$ for $m_{\phi^0} \ll M_h$.

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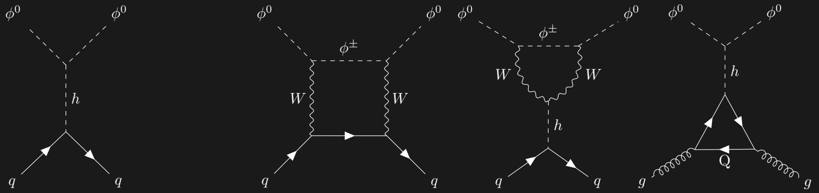
[2] A. M. Sirunyan et al. (CMS), Phys. Lett. B 793, 520 (2019), arXiv:1809.05937

Direct Detection

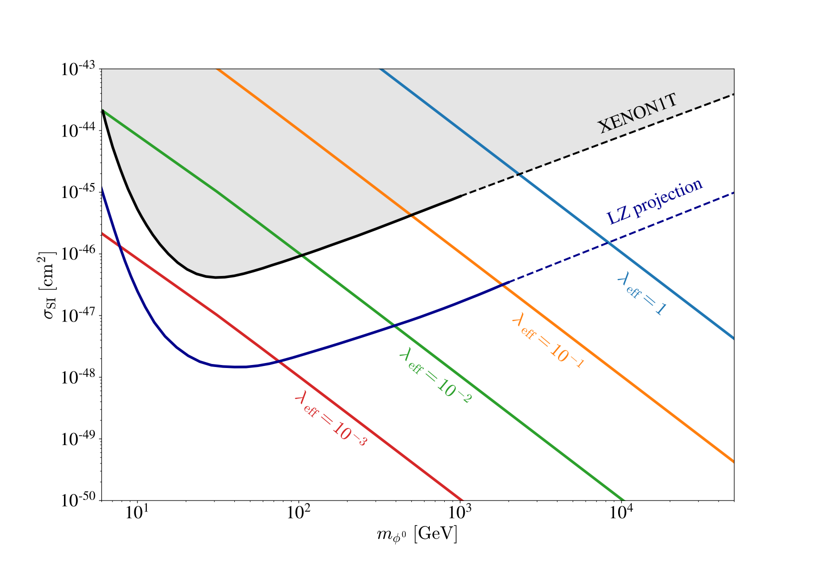
DM can scatter off nucleons in terrestrial experiments:



DM-nucleon cross section

$$\sigma_{\rm SI}(\phi\ n \to \phi\ n) = \frac{\lambda^2}{8\pi m_\phi^2}\frac{\mu_{\phi n}^2 m_n^2}{m_H^4}(f_{T,u}^n + f_{T,d}^n + f_{T,s}^n + \frac{2}{9}f_{T,g}^n)^2$$

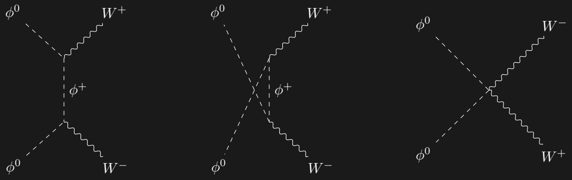
Direct Detection



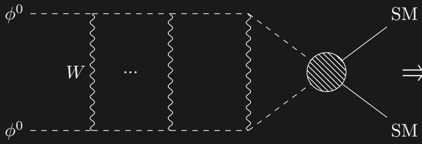
E. Aprile et al. (XENON), Phys. Rev. Lett. 121, 111302 (2018), arXiv:1805.12562
D. Akerib et al. (LUX-ZEPLIN), Phys. Rev. D 101, 052002 (2020), arXiv:1802.06039

Indirect Detection

- Most constraining annihilation final state, WW.

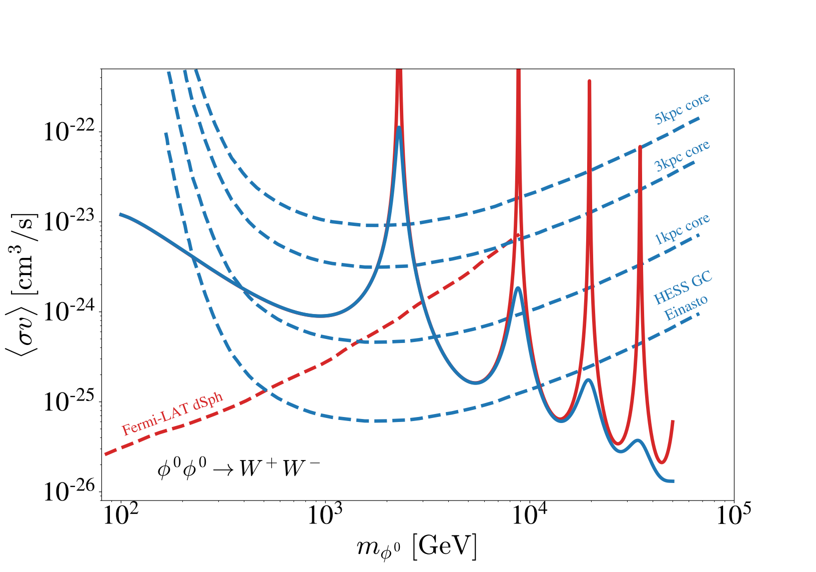


- Must include Sommerfeld, generated by ladder diagrams.



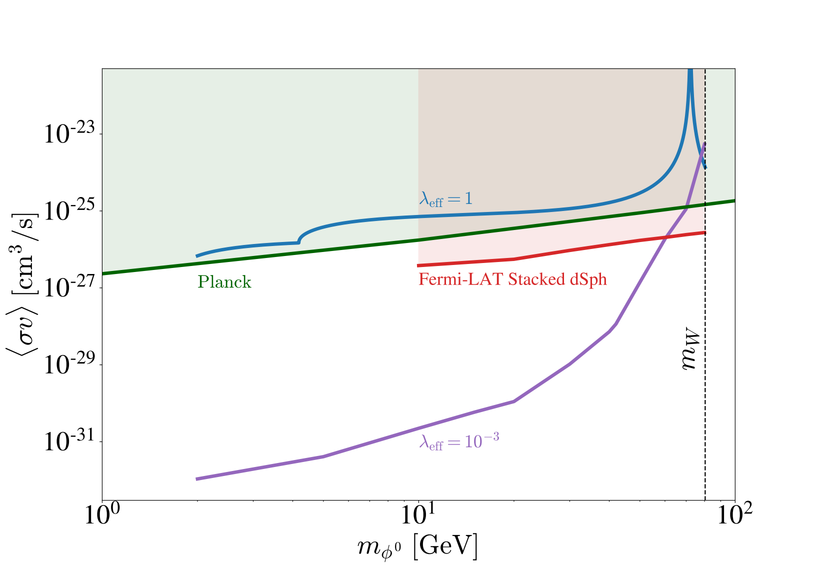
$\Longrightarrow$ Encodes effect of long range potential!

Indirect Detection

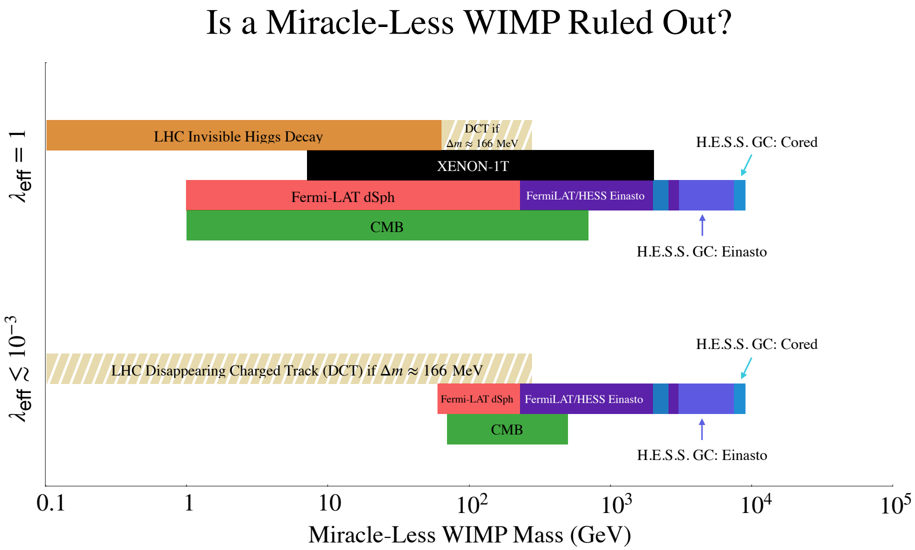


M. Ackermann et al. (Fermi-LAT), Phys. Rev. Lett. 115, 231301 (2015), arXiv:1503.02641
H. Abdallah et al. (H.E.S.S.), Phys. Rev. Lett. 117, 111301 (2016), arXiv:1607.08142

Indirect Detection: Below the W mass



N. Aghanim et al. (Planck), Astron. Astrophys. 641, A6 (2020), arXiv:1807.06209



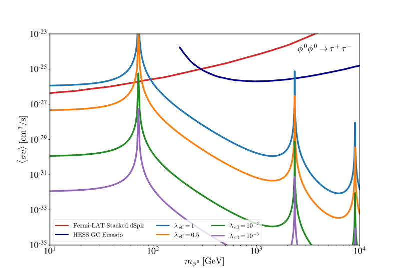
Is a Miracle-Less WIMP Ruled Out?
$\lambda_{\rm eff} = 1$
LHC Invisible Higgs Decay
DCT if
$\Delta m \approx 166$ MeV
XENON-1T
Fermi-LAT dSph
FermiLAT/HESS Einasto
CMB
H.E.S.S. GC: Cored
H.E.S.S. GC: Einasto
$\lambda_{\rm eff} \lesssim 10^{-3}$
LHC Disappearing Charged Track (DCT) if $\Delta m \approx 166$ MeV
Fermi-LAT dSph
FermiLAT/HESS Einasto
CMB
H.E.S.S. GC: Cored
H.E.S.S. GC: Einasto
0.1
1
10
10^2
10^3
10^4
10^5
Miracle-Less WIMP Mass (GeV)

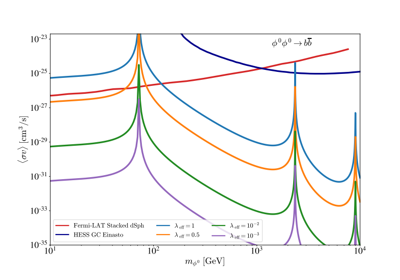
Questions?

Back-up Slides

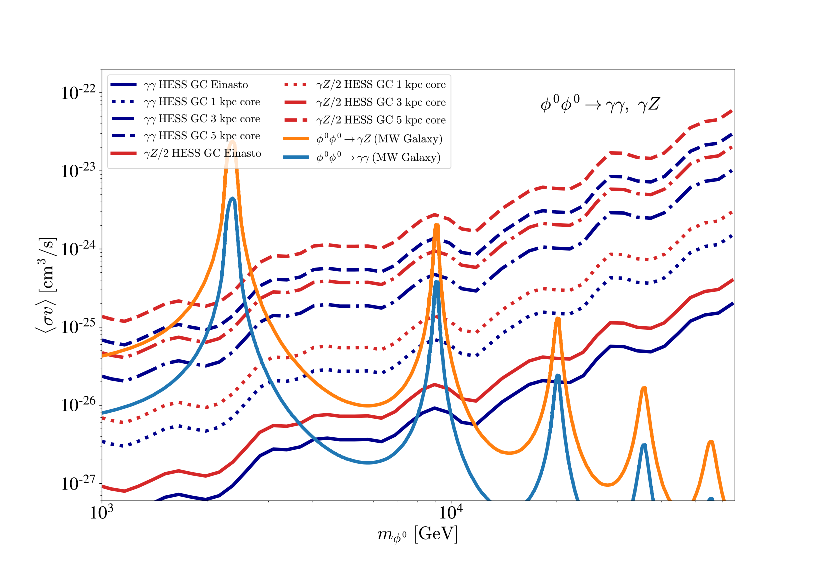
Indirect Detection

We can have annihilation into SM fermions through the Higgs portal.





Indirect Detection



L. Rinchiuso, N. L. Rodd, I. Moult, E. Moulin, M. Baumgart, T. Cohen, T. R. Slatyer, I. W. Stewart, and V. Vaidya, Phys. Rev. D 98, 123014 (2018), arXiv:1808.04388