Phenomenology of CP-Violating Higgs Portal Dark Matter

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Revisiting the WIMP Solution to DM

For:

- Easily motivated
- Thermal Relic picture
- Experimental Anomalies
  - Fermi-LAT*
  - AMS-02 (?)

Against:

- Stringent direct detection constraints

Revisiting the WIMP Solution to DM

For:

- Easily motivated
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Annihilation Good

Against:

- Stringent direct detection constraints

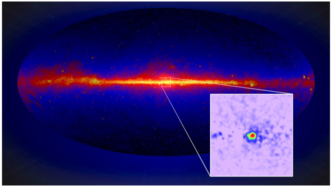
Scattering Bad

Fermi Galactic Center Excess

- Excess in gamma-rays in GC
- Possibly unresolved point sources (e.g. MSPs)

  [Abazajian et. al '14, many others]
- Possibly annihilating DM

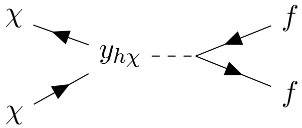
  [Goodenough & Hooper '09, many others]
  - $\mathcal{O}(60$ GeV$)$ DM
  - WIMP-like cross section ~ 3 pb
  - Favors Higgs-branching ratios

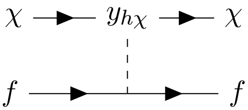


CP-Violating Higgs Portal Dark Matter

- Higgs Portal with complex coupling $y_{h\chi}$
- Majorana Fermion DM

$$\mathcal{L} \supset \frac{\Re[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\chi + \frac{i\Im[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\gamma^5\chi + g_{Z\chi} Z_\mu \bar{\chi}\gamma^\mu\gamma^5\chi$$





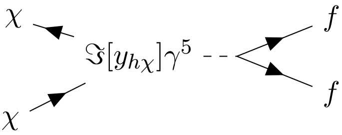
The Dark Matter EFT – Annihilation

$$\mathcal{L} \supset \frac{\Re[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\chi + \frac{i\Im[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\gamma^5\chi + g_{Z\chi} Z_\mu \bar{\chi}\gamma^\mu\gamma^5\chi$$

In the non-relativistic limit

$h\bar{\chi}\chi$ annihilation is suppressed

$$\langle \sigma v \rangle \propto \Im[y_{h\chi}]^2$$

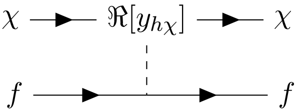


The Dark Matter EFT – Scattering

$$\mathcal{L} \supset \frac{\Re[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\chi + \frac{i\Im[y_{h\chi}]}{\sqrt{2}} h\bar{\chi}\gamma^5\chi + g_{Z\chi} Z_\mu \bar{\chi}\gamma^\mu\gamma^5\chi$$

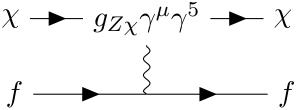
In the non-relativistic limit

$h\bar{\chi}\gamma^5\chi$ scattering is suppressed



$$\sigma_{SI} \propto \Re[y_{h\chi}]^2$$

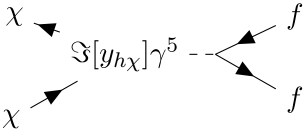
$Z_\mu\bar{\chi}\gamma^\mu\gamma^5\chi$ sets SD scattering



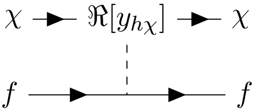
$$\sigma_{SD} \propto g_{Z\chi}^2$$

The Dark Matter EFT – Constraints

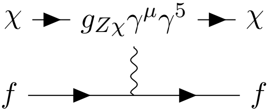
Annihilation



Spin- Independent

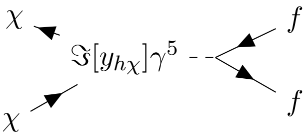


Spin- Dependent

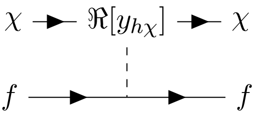


The Dark Matter EFT – Constraints

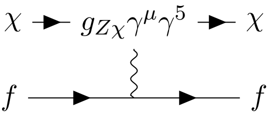
Annihilation



Spin- Independent

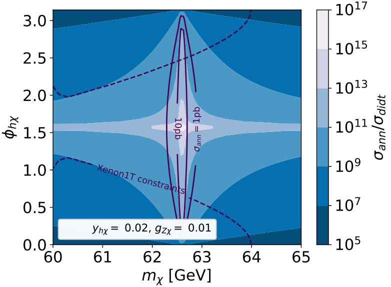


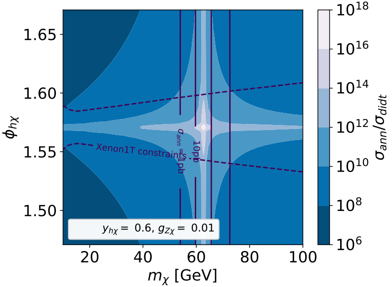
Spin- Dependent

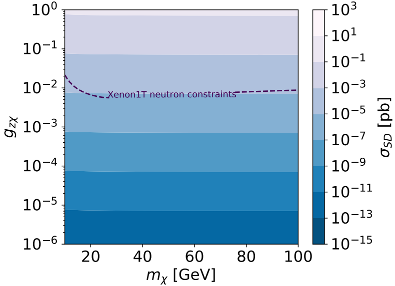


1. $\chi \sim m_h/2$, small $y_{h\chi}$
2. $\delta_{CP} \sim \pi/2$, large $y_{h\chi}$

The Dark Matter EFT – Constraints







A Singlet-Doublet Realization

- $SU(2)_L$ Singlet ψ_1, $Y = 0$
- $SU(2)_L$ Doublet $\psi_2 = \begin{pmatrix} \psi_{2c} \\ \psi_{2n} \end{pmatrix}$, $Y = 1/2$
- $SU(2)_L$ Doublet $\tilde{\psi}_2 = \begin{pmatrix} \tilde{\psi}_{2n} \\ \tilde{\psi}_{2c} \end{pmatrix}$, $Y = -1/2$

$\implies$ 3 Majorana degrees of freedom

$$\psi_1,\ \frac{1}{\sqrt{2}}\left(\psi_{2n} + \tilde{\psi}_{2n}\right),\ \frac{1}{\sqrt{2}}\left(\psi_{2n} - \tilde{\psi}_{2n}\right)$$

+ 1 Dirac (Charged) degree of freedom $\{\psi_{2c}, \tilde{\psi}_{2c}\}$

A Singlet-Doublet Realization

$$\mathcal{L} \supset Y \bar{\psi}_1 \left(\frac{v+h}{\sqrt{2}} \right) \psi_{2n} + \tilde{Y} \bar{\psi}_1 \left(\frac{v+h}{\sqrt{2}} \right) \tilde{\psi}_{2n} - m_2 \bar{\psi}_{2n} \tilde{\psi}_{2n} - m_2 \bar{\tilde{\psi}}_{2c} \psi_{2c} - \frac{m_1}{2} \bar{\psi}_1 \psi_1 + \text{h.c.}$$

- 4 couplings, 3 fields $\implies$ 1 free phase. Choose

$$Y \equiv y e^{i\delta_{CP}/2}, \;\; \tilde{Y} \equiv \tilde{y} e^{i\delta_{CP}/2}$$

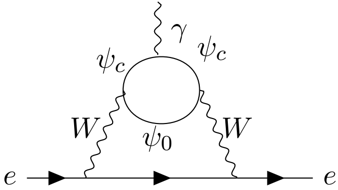
- χ is lightest mass eigenstate.
- Model Parameters $\{m_1, m_2, y, \tilde{y}, \delta_{CP}\}$

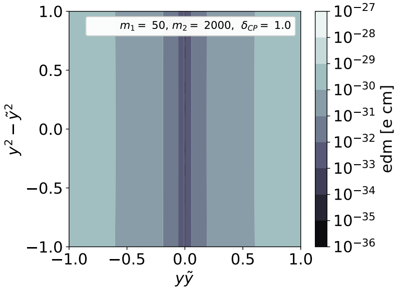
Singlet-Doublet - Constraints

- Electron Electric Dipole Moment

$$\frac{|d_e|}{e} \sim \frac{y\tilde{y}\sin[\delta_{CP}]}{m_2^2} \lesssim 1.1 \times 10^{-29} \text{ cm}$$

[ACME Collaboration '18]

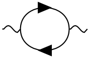




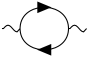
Singlet-Doublet - Constraints

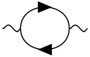
- Oblique Corrections

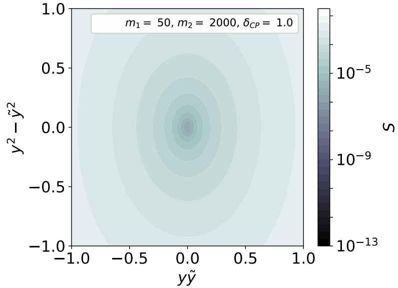
$$S, W \sim \frac{y^2 + \tilde{y}^2}{m_2^2}$$

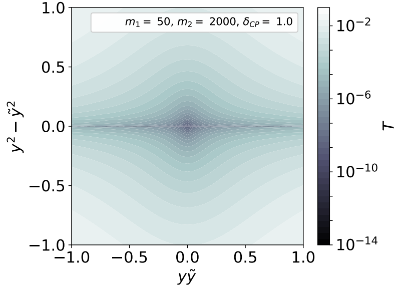
$$\sim \frac{\partial}{\partial p^2}\; W_3$$  $$W_3$$

$$T, U \sim \frac{y^2 - \tilde{y}^2}{m_2^2}$$

$$\sim\; W_1$$  $$W_1$$

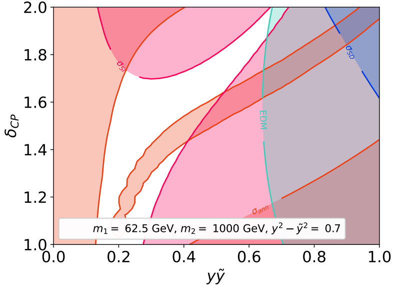
$$-\; W_3$$  $$W_3$$



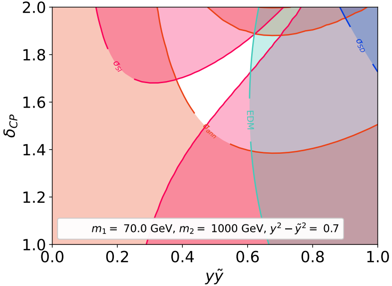


Putting it all together

m_χ on-resonance



$\delta_{CP} \sim \pi/2$



Conclusions

- CP-Violating Higgs Portal Dark Matter provides an alternative to mass resonance, if phase is close to $\pi/2$
  - Candidate solution to GCE that respects scattering constraints
- Singlet-Doublet mixing provides a non-anomalous way to realize this.
- Viable parameter space for

$$m_2 \gtrsim 1000 \text{ GeV}, \; m_1 \sim 60 - 80 \text{ GeV}, \; \delta_{CP} \sim \pi/2$$

Thank you!