HEAVY HIDDEN HOOPERON

A STATUS REPORT "AFTER THE HIGGS"

Submitted to PRD [arXiv:1404.6528]

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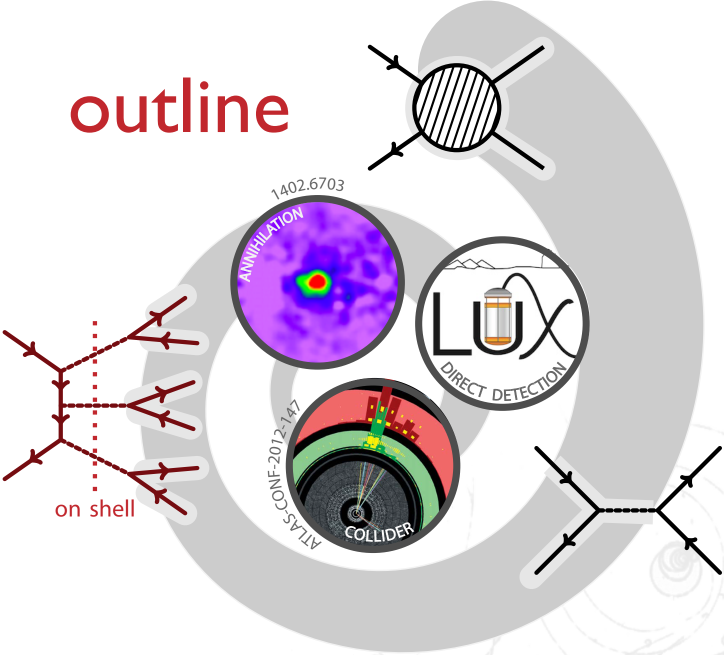
Santa Fe 2014 Workshop: LHC After The Higgs 4 July 2014

outline


1402.6703
ANNIHILATION
LUX
DIRECT DETECTION
ATLAS-CONF-2012-147
COLLIDER
on shell

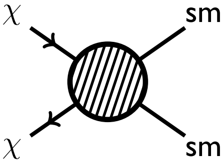
Dark Matter Exists

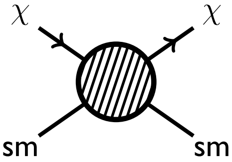
& couples to the Standard Model $\Omega_\chi h^2 \approx \frac{0.1 \text{ pb } c}{\langle \sigma_{\text{ann}} v \rangle}$

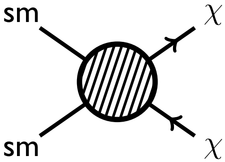
Assume: Dirac DM χ, thermal relic

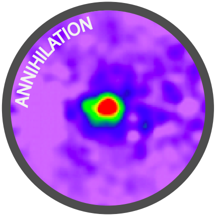
See, e.g. Fady Bishara's talk for non-thermal example

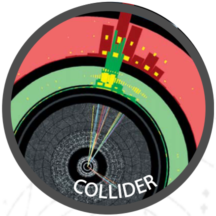
How Dark Matter talks to the Standard Model









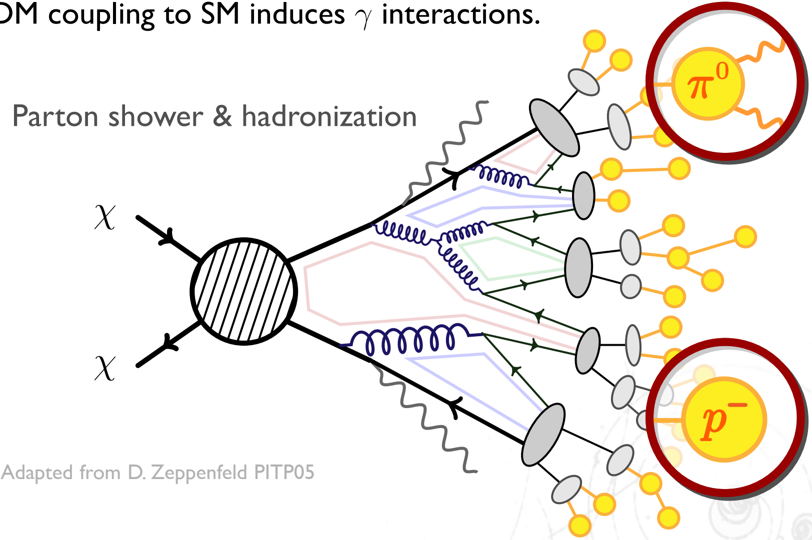


$$\Omega_\chi h^2$$

Exceptions: e.g. SIMP Miracle (1402.5143); DMdm (1312.2618); Agashe, Cui, et al. (1405.7370). See talk by Yanou Cui.

Light from Dark Matter

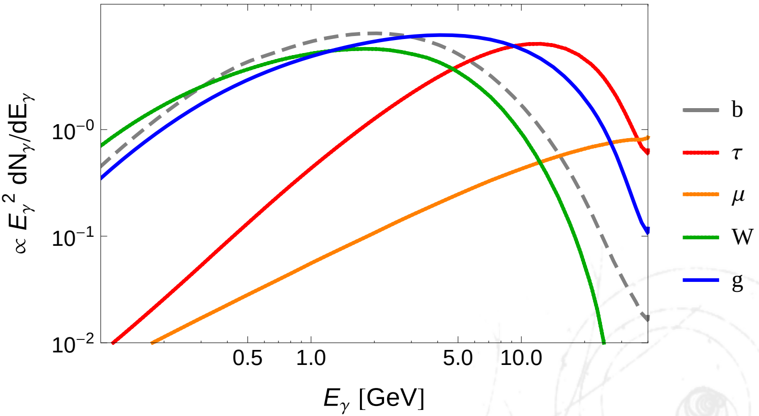
DM coupling to SM induces γ interactions.



Exceptions: e.g. RH neutrino portal, see Ian Shoemaker's talk.

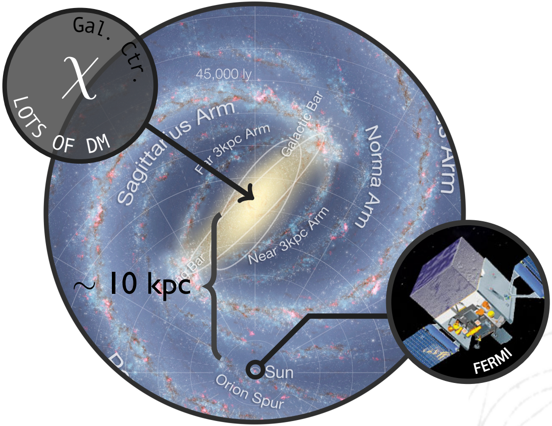
Light from Dark Matter: Shape Matters

40 GeV DM annihilating to SM pairs



Extracted from Pythia via PPPC4DMID, Cirelli et al. 1012.4515

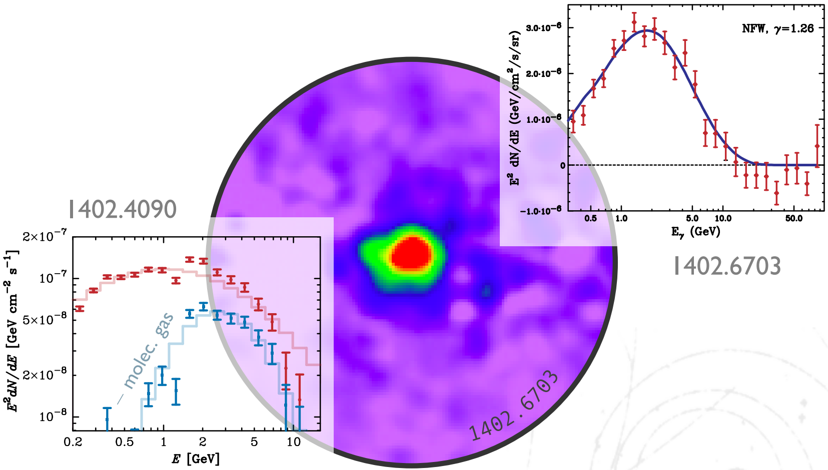
Where to look: Galactic Center



Also look at dwarf spheroidals: $m_\chi > 10$ GeV for $\chi\bar{\chi} \to b\bar{b}$ (1310.0828)

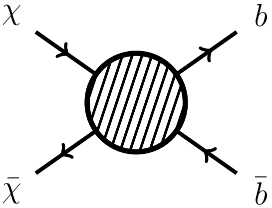
NASA/JPL-Caltech/ESO/R. Hurt

The γ-ray excess



Goodenough & Hooper (0910.2998, 1010.2752), Hooper & Linden (1110.0006), Abazajian et al. (1011.4275, 1207.6047, 1402.4090), Boyarsky et al. (1012.5839); Gordon & Macias (1306.5725); Daylan et al. (1402.6703). + more recent model building papers

The "Hooperon"



$m_\chi = 40$ GeV

$E_b = 40$ GeV
fits γ spectrum
10 GeV τ also fits

Overall normalization set by present annihilation rate

$$\langle \sigma_{b\bar{b}} v \rangle = 5 \quad (1.5) \quad \times 10^{-26}\ \text{cm}^3\ \text{s}^{-1}$$

$\gamma = 1.12$ (1402.4090)

$\gamma = 1.26$ (1402.6703)

$$\rho \sim r^{-\gamma}(1+r^\alpha)^{\frac{\gamma-\beta}{\alpha}}$$

Same ballpark as thermal relic σ (if s-wave)

Goodenough & Hooper (0910.2998, 1010.2752), Hooper & Linden (1110.0006), Abazajian et al. (1011.4275, 1207.6047, 1402.4090), Boyarskiy et al. (1012:5839); Gordon & Macias (1306.5725); Daylan et al. (1402.6703). + more recent model building papers

Some Recent Hooperon models

Higgs Portal: Okada & Seto 1310.5991, Ipek et al. 1404.3716

EFT: Huang et al. 1310.7609; Alves et al. 1403.5027

Coy DM: Dolan et al. 1401.6458

Simplified Models: Berlin et al. 1404.0022; Izaguirre et al. 1404.2018

Flavored: Agrawal, Lin, et al. 1404.1373; Agrawal, Gemmler, et al. 1405.6709.

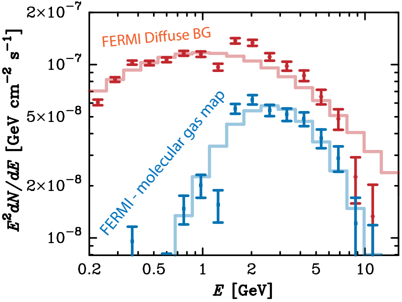
On-Shell Mediator: Dolan et al. 1404.4977; FT, Rajaraman, et al. 1404.4977; 1404.5257; Martin et al. 1405.0272

UV Models: Kyae & Park 1310.2284; Berlin et al. 1405.5204; Agashe, Cui, et al. 1405.7370; Cheung et al. 1406.6372; Huang et al. 1407.0038.

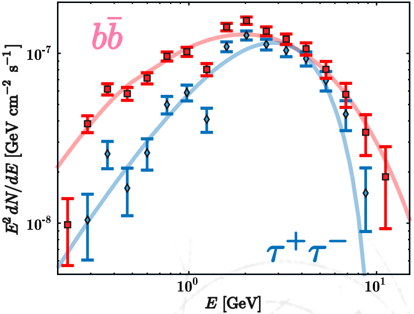
Also: see talks by Jong-Chul Park and Tongyan Lin.

Systematic Uncertainties

Background affects signal



Signal affects background

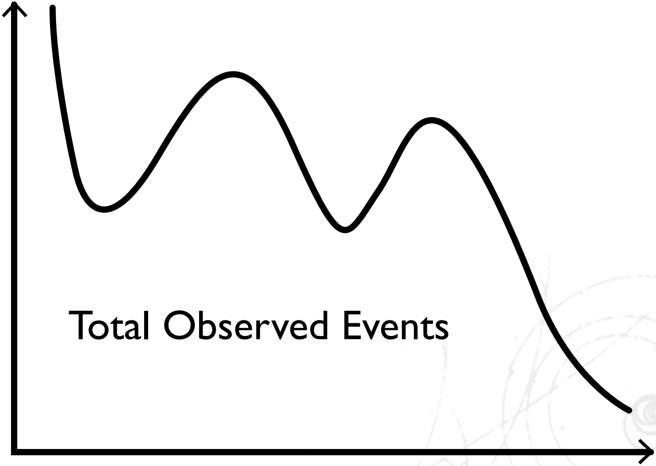


Multiple independent analyses, but all based on FERMI diffuse BG

Images adapted from Abazajian et al. 1402.4090

"Signal Affects Background"

A simple toy example:



"Signal Affects Background"

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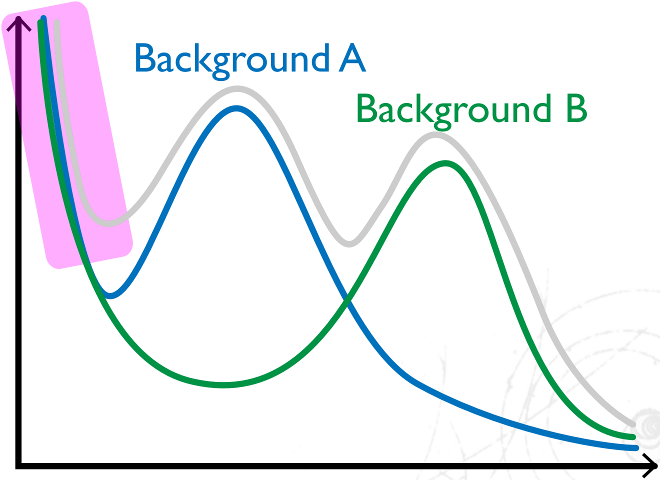

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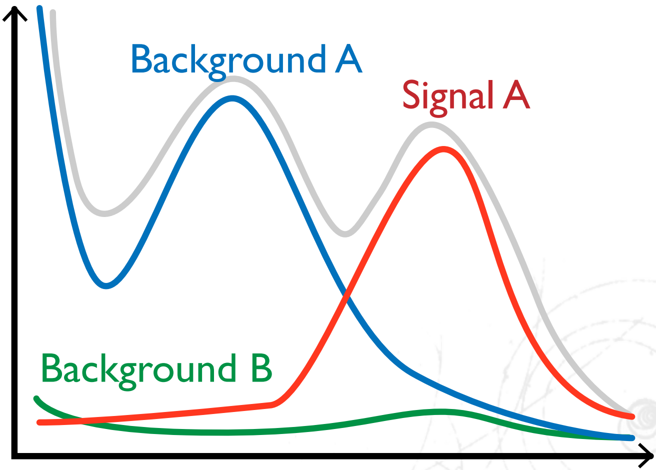
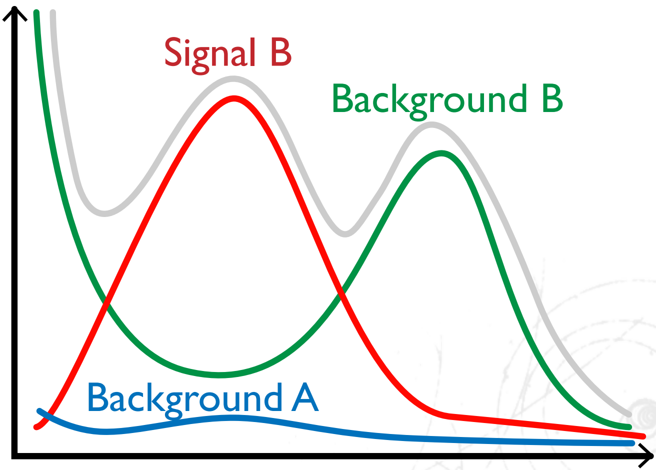


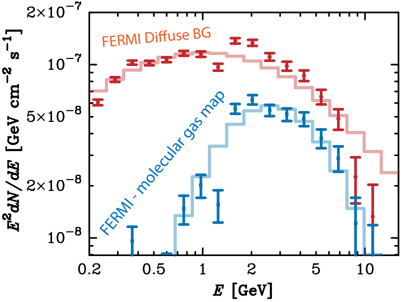
"Signal Affects Background"

A simple toy example:

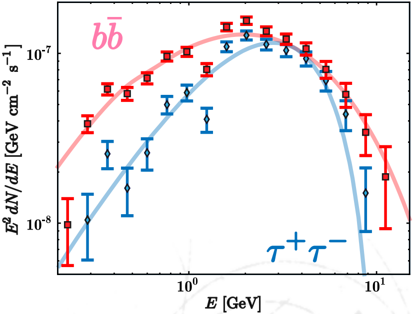


Systematic Uncertainties

Background affects signal



Signal affects background

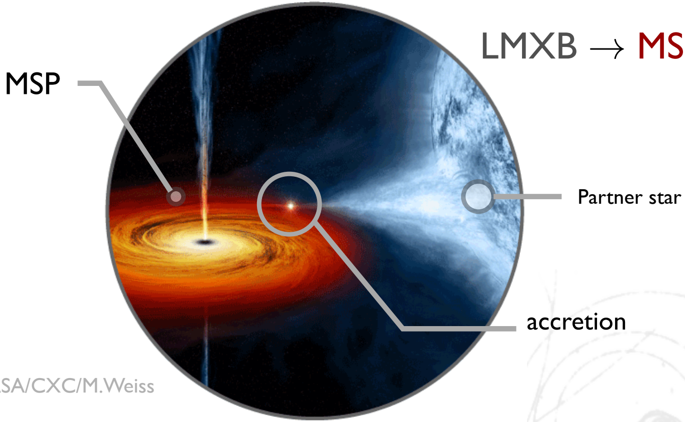


Multiple independent analyses, but all based on FERMI diffuse BG

Images adapted from Abazajian et al. 1402.4090

Millisecond Pulsar Alternative

Hooper et al. 1010.2752, 1110.0006; Abazajian et al. 1011.4275, 1207.6047 1402.4090
Wharton et al. 1111.4216, Yuan et al. 1404.2318, Mirabal 1309.3248 n.b.: Hooper et al. 1305.0830

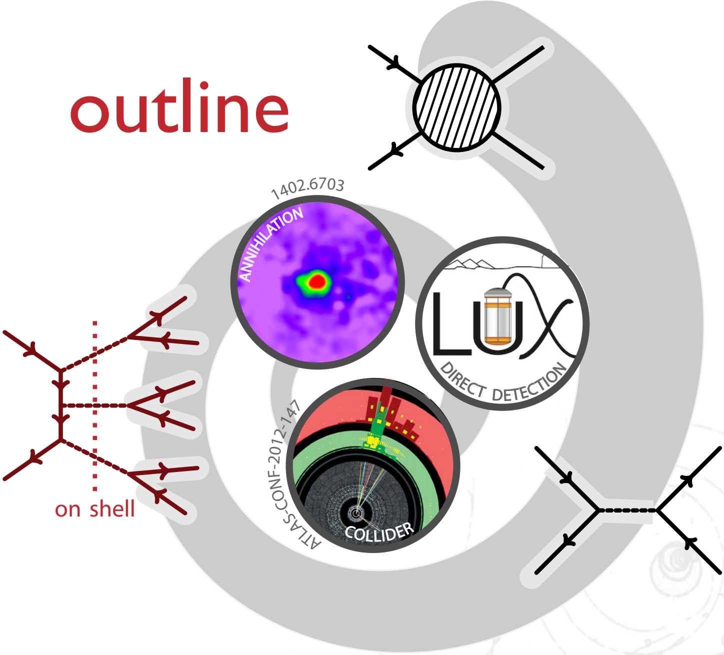


LMXB $\to$ MSP

NASA/CXC/M.Weiss

LMXB morphology is spot on degenerate with DM for γ-ray excess

outline


1402.6703
ANNIHILATION
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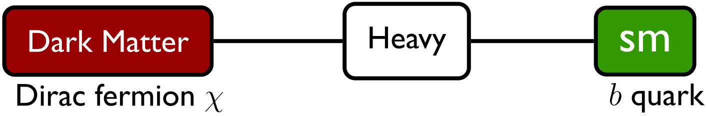
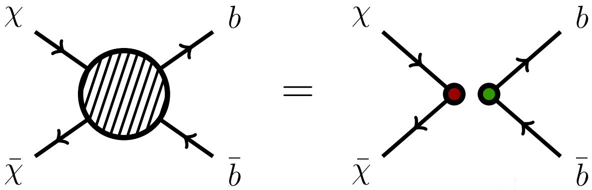
Contact Interactions





DM–SM interaction parameterized by a single coupling Λ^{-2}.

$$\mathcal{O} = \frac{1}{\Lambda^2} \left(\bar{\chi}\Gamma_\chi \chi\right) \left(\bar{b}\Gamma_b b\right)$$

Parameterization in Goodman et al. 1008.1783; see Alves et al. 1403.5027 for Hooperon fit

Contact Interactions are not preferred

Generically, contact interactions tightly constrained

Require: s-wave annihilation

D2	$(\bar{\chi}\gamma_5\chi)\,(\bar{q}q)$
D4	$(\bar{\chi}\gamma_5\chi)\,(\bar{q}\gamma_5 q)$
D5	$(\bar{\chi}\gamma^\mu\chi)\,(\bar{q}\gamma_\mu q)$
D6	$(\bar{\chi}\gamma^\mu\gamma_5\chi)\,(\bar{q}\gamma_\mu q)$
D7	$(\bar{\chi}\gamma^\mu\chi)\,(\bar{q}\gamma_\mu\gamma_5 q)$
D8	$(\bar{\chi}\gamma^\mu\gamma_5\chi)\,(\bar{q}\gamma_\mu\gamma_5 q)$
D9	$(\bar{\chi}\sigma^{\mu\nu}\chi)\,(\bar{q}\sigma_{\mu\nu} q)$
D10	$(\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi)\,(\bar{q}\sigma_{\mu\nu} q)$
D12	$(\bar{\chi}\gamma_5\chi)\,G_{\mu\nu}G^{\mu\nu}$
D14	$(\bar{\chi}\gamma_5\chi)\,G_{\mu\nu}\tilde{G}^{\mu\nu}$

See analysis in Alves et al. 1403.5027 for detailed analysis

Contact Interactions are not preferred

Generically, contact interactions tightly constrained

Require: s-wave annihilation

~~D2~~	$\cancel{(\bar{\chi}\gamma_5\chi)(\bar{q}q)}$	Mono-jet
~~D4~~	$\cancel{(\bar{\chi}\gamma_5\chi)(\bar{q}\gamma_5 q)}$	Mono-jet
~~D5~~	$\cancel{(\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q)}$	LUX (SI direct detection)
~~D6~~	$\cancel{(\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{q}\gamma_\mu q)}$	Related to D8
~~D7~~	$\cancel{(\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu\gamma_5 q)}$	Related to D5
~~D8~~	$\cancel{(\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{q}\gamma_\mu\gamma_5 q)}$	Mono-jet, XENON100 (SD)
~~D9~~	$\cancel{(\bar{\chi}\sigma^{\mu\nu}\chi)(\bar{q}\sigma_{\mu\nu} q)}$	UV completion?
~~D10~~	$\cancel{(\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi)(\bar{q}\sigma_{\mu\nu} q)}$	UV completion?
~~D12~~	$\cancel{(\bar{\chi}\gamma_5\chi)G_{\mu\nu}G^{\mu\nu}}$	Spectrum
~~D14~~	$\cancel{(\bar{\chi}\gamma_5\chi)G_{\mu\nu}\tilde{G}^{\mu\nu}}$	Spectrum

See analysis in Alves et al. 1403.5027 for detailed analysis

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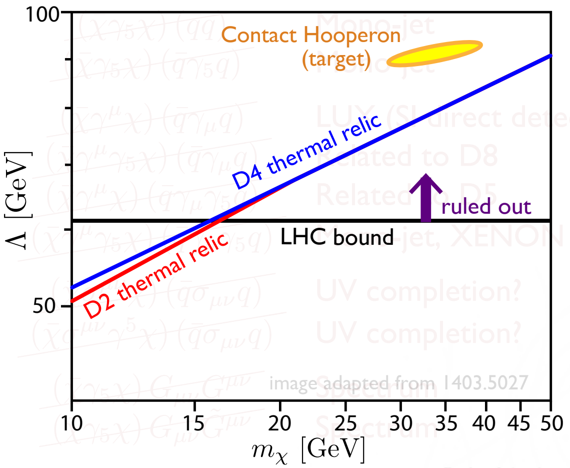
Require: s-wave annihilation

~~D2~~
~~D4~~
~~D5~~
~~D6~~
~~D7~~
~~D8~~
~~D9~~
~~D10~~
~~D12~~
~~D14~~



n)

(SD)

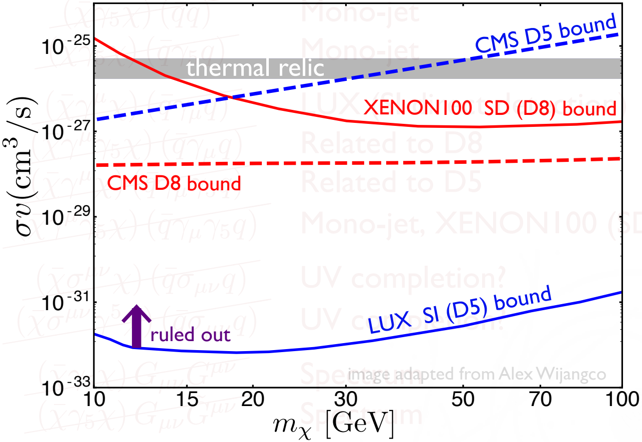
See analysis in Alves et al. 1403.5027 for detailed analysis

Contact Interactions are not preferred

Generically, contact interactions tightly constrained

Require: s-wave annihilation

~~D2~~
~~D4~~
~~D5~~
~~D6~~
~~D7~~
~~D8~~
~~D9~~
~~D10~~
~~D12~~
~~D14~~

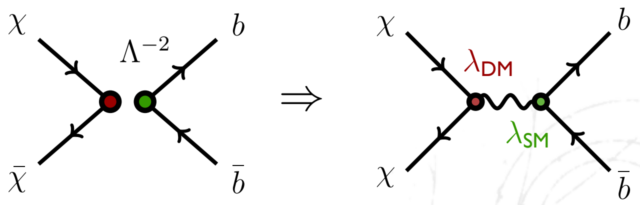


See analysis in Alves et al. 1403.5027 for detailed analysis

Exceptions

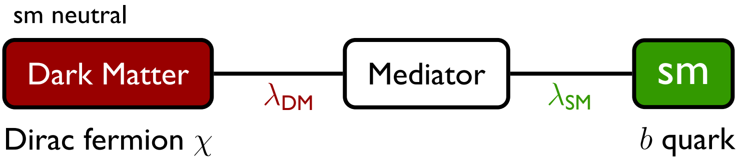
Contact $\mathcal{O}$ Exceptions:

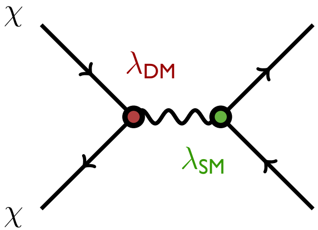
1. Majorana DM: $\bar{\chi}\gamma^\mu\chi = 0$
2. Tuning of chiral couplings (e.g. $Z\ell^+\ell^-$)
3. Non-decoupled mediator: $m_{\text{med}} <$ heavy



Simplified Models

Renormalizable, capture physics of mediator (1105.2838)





Simplest example: Coy Dark Matter
Dolan et al. 1401.6458

Systematic studies:
Chicago 1404.0022
Perimeter 1404.2018

Simplified Models

Simplified models describe the $m_{\text{med}} <$ decoupling regime

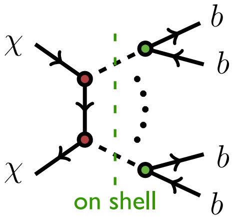
See **Berlin et al.** 1404.0022 and **Izaguirre et al.** 1404.2018 for a detailed survey of off-shell Simplified Hooperons. See Boehm et al. 1401.6458 for a prototype..

Model Number	*DM*	*Mediator*	*Interactions*	**Elastic Scattering**	**Near Future Reach?**	
					Direct	**LHC**
1	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{\rm SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
1	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}f$	$\sigma_{\rm SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
2	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
2	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
3	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{b}\gamma_\mu b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Maybe
4	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$ or $\sigma_{\rm SD} \sim (q/2m_\chi)^2$	Never	Maybe
5	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	Yes	Maybe
5	Majorana Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi,\ \bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	Yes	Maybe
6	Complex Scalar	Spin-0	$\phi^\dagger\phi,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Scalar	Spin-0	$\phi^2,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Complex Vector	Spin-0	$B^\dagger_\mu B^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Vector	Spin-0	$B_\mu B^\mu,\ \bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
7	Dirac Fermion	Spin-0 (t-ch.)	$\bar{\chi}(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
7	Dirac Fermion	Spin-1 (t-ch.)	$\bar{\chi}\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
8	Complex Vector	Spin-1/2 (t-ch.)	$X^\dagger_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
8	Real Vector	Spin-1/2 (t-ch.)	$X_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes

Table from 1404.0022

Simplified Hooperons + on-shell mediators

But: the $m_{\text{med}} <$ heavy regime also includes $m_{\text{med}} < m_\chi$
i.e. mediator is accessible as an on-shell annihilation mode

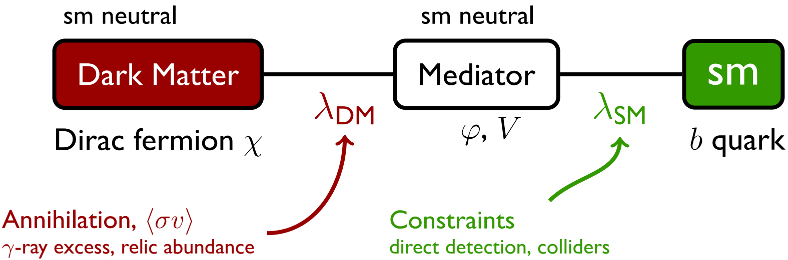


- Can be dominant mode
- Separates λ_{DM} from λ_{SM}
- Admits limit $\lambda_{\text{SM}} \ll \lambda_{\text{DM}}$
- Hides indirect detection signal from direct det. & collider bounds

Application to Hooperon: FT et al. 1404.6528 (this talk)
See also Dolan et al. 1404.4977 and Martin et al. 1405.0272

Previously: axion portal (Nomura & Thaler, 0810.5397),
cascade annihilation (+ Mardon, Stolarski 0901.2926)

On-Shell Simplified Models

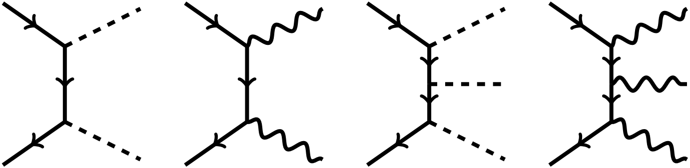


Requirements:

$$m_{V,\varphi} > 2m_b \qquad \lambda_{\text{DM}} \sim 1 \qquad \lambda_{\text{SM}} \ll 1$$

On-Shell Simplified Options

Require: s-wave annihilation:

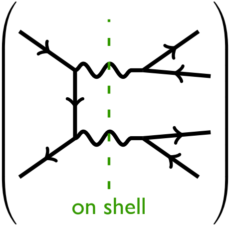


Med.	S (P)	V (A)	S (P)	V (A)
ℓ-Wave	p (p)	s (s)	p (s)	p (p)
m_χ	≈ 80 GeV	≈ 80 GeV	≈ 120 GeV	≈ 120 GeV

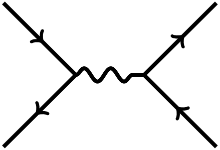
Further Requirements:

$$2m_\chi > \begin{cases} 2m_V & \text{for a spin-1 mediator} \\ 3m_\varphi & \text{for a spin-0 mediator} \end{cases}$$

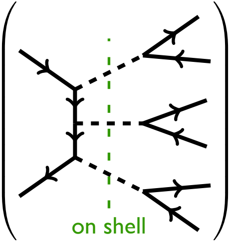
Dominance over off-shell



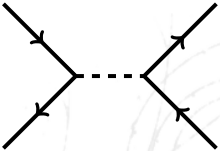
$\sim \lambda_{\text{dm}}{}^2 \gg$



$\sim \lambda_{\text{dm}} \lambda_{\text{sm}}$



$\sim \dfrac{\lambda_{\text{dm}}{}^3}{\sqrt{4\pi}} \gg$



$\sim \lambda_{\text{dm}} \lambda_{\text{sm}}$

Back-of-the-Envelope

Astrophysics

e.g. from Pythia

$$\frac{d\Phi(b,\ell)}{dE_\gamma} = n\frac{\langle\sigma v\rangle_{b\bar{b}}}{8\pi m_\chi^2}\,\frac{dN_\gamma}{dE_\gamma}\,\int_{\text{los}} dx\,\rho^2\left(r_{\text{gal}}\left(b,\ell,x\right)\right)$$

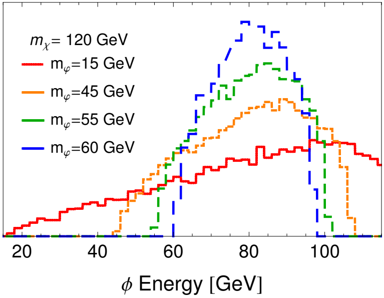
Particle Physics

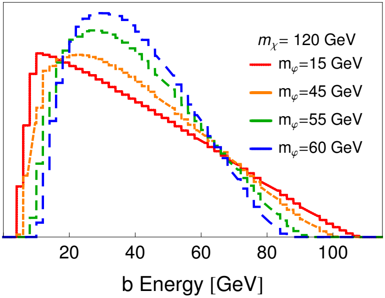
$m_{\text{DM}} \approx$ n $\times$ (40 GeV) n=2(3) for spin-1(0)

$\lambda_{\text{DM}} \approx$ 0.35 (1.25) for spin-1(0)

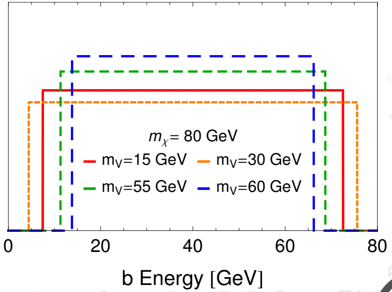
More final states requires smaller $\langle\sigma v\rangle_{\text{ann}}$ for signal flux
m_χ sets injection energy, larger for more final states

Boosted mediators





The boost of the on-shell mediator shifts the primary (and hence photon) spectrum.



Top: $\chi\bar{\chi} \to 3\varphi$

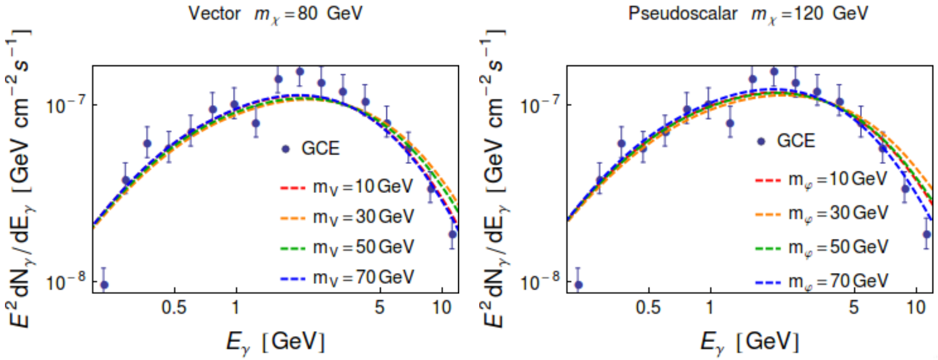
Bot: $\chi\bar{\chi} \to 2V$

n.b. similar to Kaustubh Agashe's talk

Range of spectra

For bin data D_i and model spectrum S_i:

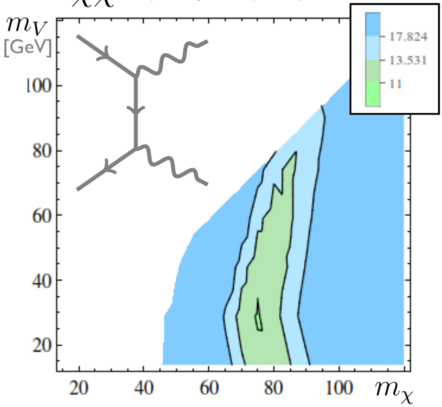
$$\text{goodness of fit} = \sum_i \left(\frac{\log D_i - \log\left(\lambda_{\text{dm}}{}^{2n} S_i\right)}{\log(0.2 D_i)} \right)^2$$



Warning: This is *not* a χ^2 fit & these are *not* 1σ errors.

Best fits

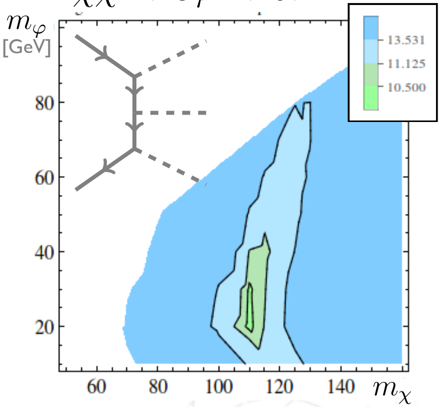
$\chi\chi \to 2V \to 4b$



$$m_\chi = 75 \text{ GeV}$$
$$m_V = 29 \text{ GeV}$$
$$\lambda_{\text{DM}} = 0.27$$

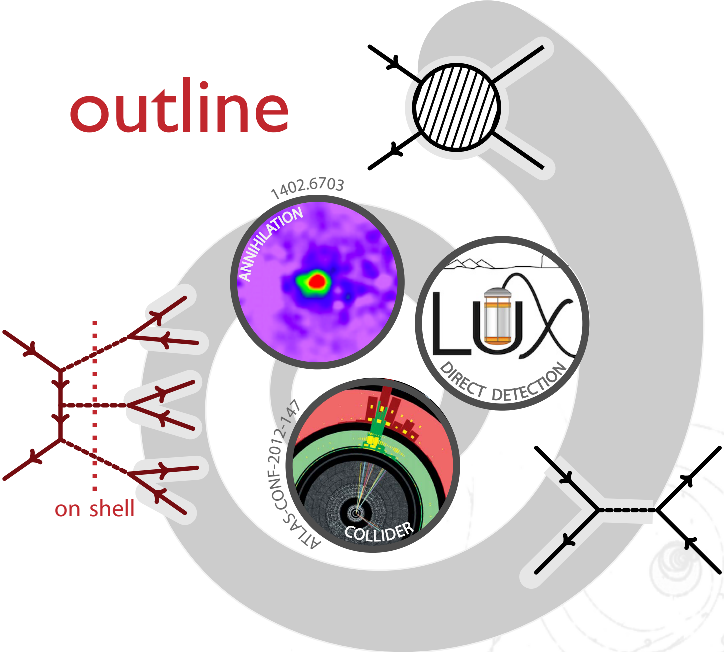
Br($V \to 2b$)=100%

$\chi\chi \to 3\varphi \to 6b$

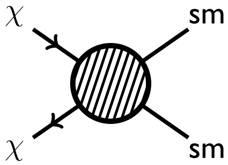


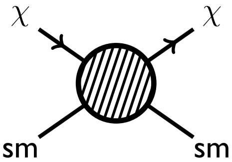
$$m_\chi = 110 \text{ GeV}$$
$$m_\varphi = 20 \text{ GeV}$$
$$\lambda_{\text{DM}} = 1.2$$

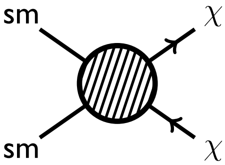
outline

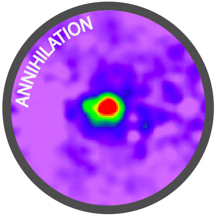

1402.6703
ANNIHILATION
LUX
DIRECT DETECTION
ATLAS-CONF-2012-147
COLLIDER
on shell

Bounds on SM interactions

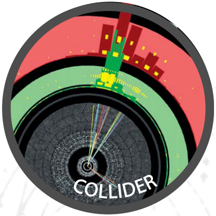




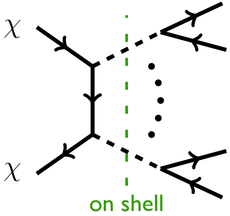


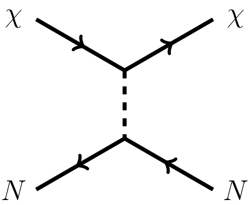


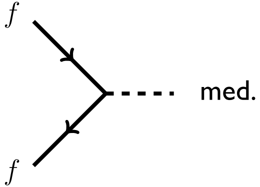
$\Omega_\chi h^2$

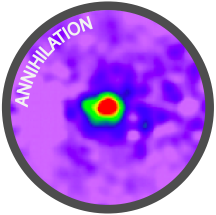


Bounds on SM interactions

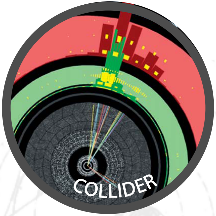




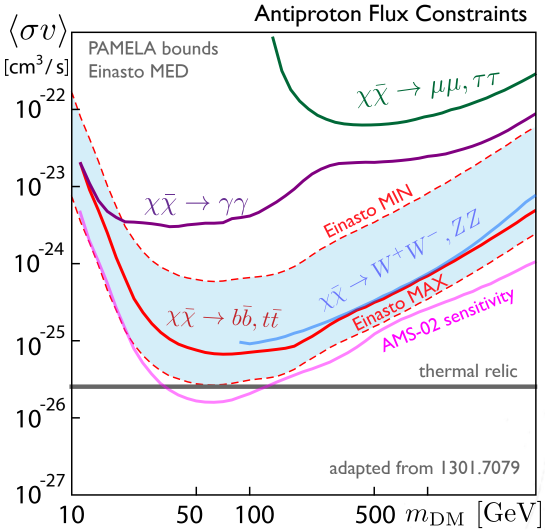




$$\Omega_\chi h^2$$



Indirect: Antiprotons?



PAMELA p^+ bounds: currently not constraining. Maybe AMS-02...

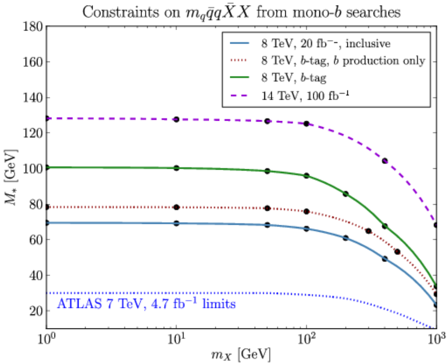
... but large propagation uncertainty, still lots of wiggle room.

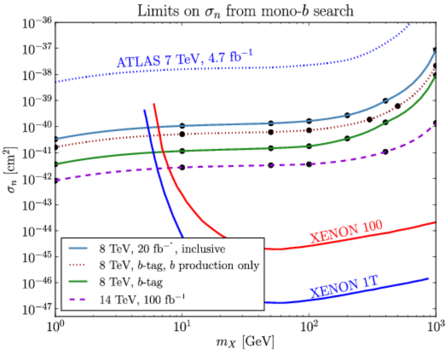
See talk by Jong-Chul Park (1404.3741).
Also: recently, 1406.6027 presents stronger bounds from p^+, e^+, radio

Collider: mono-b

See talk by Tongyan Lin, (1303.6638).

See Daylan et al. 1402.4090 (EFT), Izaguirre et al. 1404.1373 (simplified model). Mono-object analyses: UCI (1005.1286, 1008.1783, 1108.1196), Fermilab (1005.3757, 1103.0240), others.





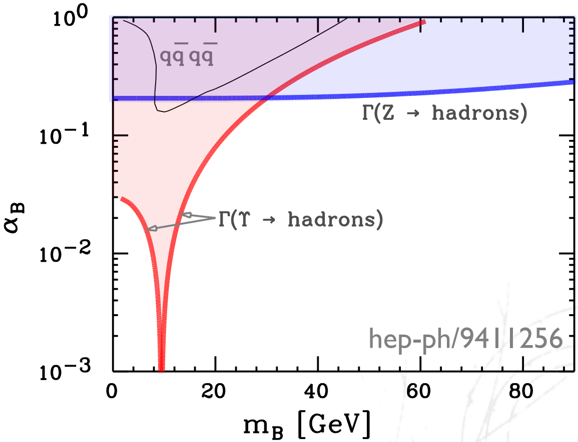
$\lambda_{\text{SM}}^{\varphi} \lesssim 0.2$ $\qquad$ $\lambda_{\text{SM}}^{V} \lesssim 0.6$

Conservative estimate: $m_q/M_*^3 \to \lambda_{\text{DM}}\lambda_{\text{SM}} s^{-1}$.

Simplified model > EFT: Graesser, Shoemaker, et al. (1107.2666, 1112.5457); UCI (1111.2359); Busoni et al. (1307.2253); Dolan, et al. (1308.6799).

Collider: search for the mediator

Prototype: gauged U(1)$_B$, bounds from LEP (Carone, Murayama)

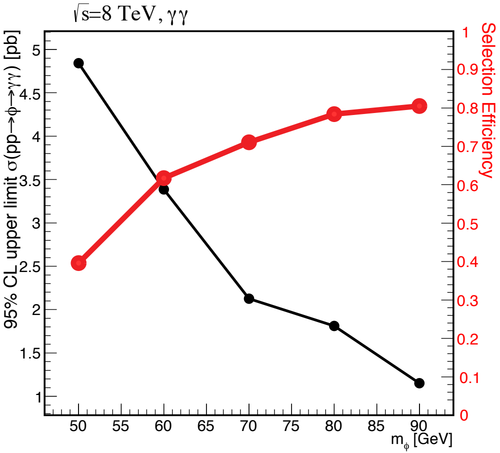


Bound $\lambda_{SM} \lesssim 1$. See also Dobrescu & Yu 1306.2629, Dobrescu & Frugiuele 1404.3947. See Queiroz & Shepherd 1403.2309, Burgess et al. 1103.4556 for mixing bounds.

Collider: search for the mediator

Open question: what about $\varphi \to \gamma\gamma$?

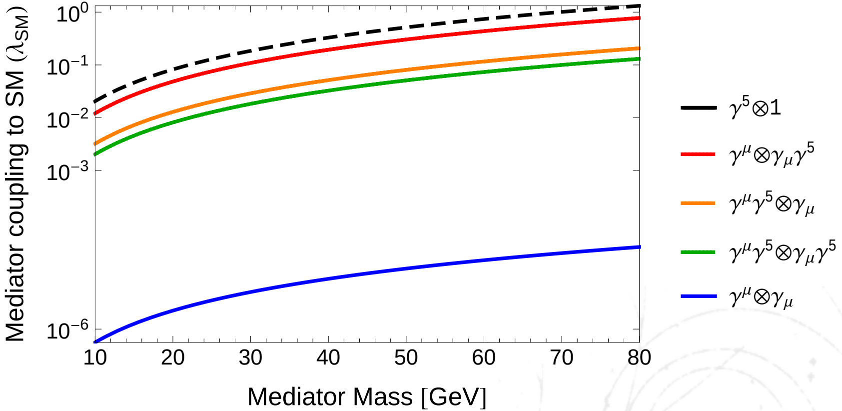
e.g. search for lepto-phobic, gauge-phobic "Higgs" at LHC?



Courtesy of D. Whiteson. 2γ with $p_T > 20$ GeV and $|\eta| < 2.4$.

Direct Detection

LUX SI 1310.8214, XENON100 SD 1207.5988



$\gamma^5 \otimes \gamma^5$ is q^4 suppressed, no bound below $\lambda_{SM} < \sqrt{4\pi}$.

Viability of a Thermal Relic

$2 \to 2$ Hooperon: $\langle \sigma v \rangle$ in right ballpark for thermal relic (s-wave)

$$\Omega_\chi h^2 \approx \frac{\mathbf{6} \times 10^{-26}\ \text{cm}^3/s}{\langle \sigma v \rangle_{\text{ann.}}} \qquad \left(\Omega_\chi h^2\right)_{\text{obs.}} = 0.12$$

$2 \to n$ SM particles has $n\times$ larger $\langle \sigma v \rangle$:

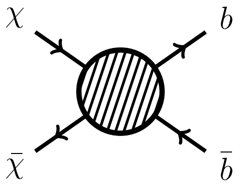
$$\frac{d\Phi(b,\ell)}{dE_\gamma} = n\frac{\langle \sigma v \rangle_{\text{ann}}}{8\pi m_\chi^2} \frac{dN_\gamma}{dE_\gamma} \int_{\text{los}} dx\, \rho^2\left(r_{\text{gal}}(b,\ell,x)\right)$$

$$m_\chi^2 \approx n^2 (\mathbf{40\ GeV})^2 \Rightarrow \langle \sigma v \rangle_{\text{ann}} \approx n \langle \sigma_{b\bar{b}} v \rangle$$

So: can we still get $\Omega_\chi h^2$ from freeze-out?

Vector Mediator as Thermal Relic

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{\gamma} \left(1 + \frac{r^{\alpha}}{r_0^{\alpha}}\right)^{\frac{\gamma-\beta}{\alpha}}$$



$$\langle \sigma_{b\bar{b}} v \rangle = \ (1.5) \quad 5 \ \times 10^{-26}\ \text{cm}^3\ \text{s}^{-1}$$

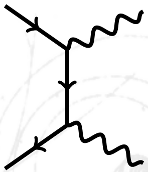
$\gamma = 1.26$ (1402.6703)

$\gamma = 1.12$ (1402.4090)

Ballpark of thermal relic σ

$\langle \sigma v \rangle_{\text{ann.}}$ between 3 – 10 $\times 10^{-26}$ cm^3 s^{-1}

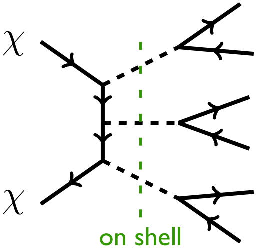
Vector mediator works for Dirac χ



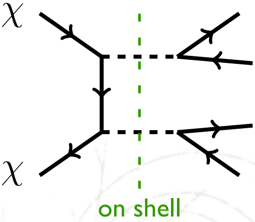
Spin-0 Mediator as Thermal Relic

Scalar mediator is more difficult,

1. $\langle \sigma v \rangle_{\text{ann}} = 3 \times \langle \sigma v \rangle_{b\bar{b}}$
2. p-wave irreducible contributions



$$\sim \frac{\lambda_{\text{dm}}}{\sqrt{4\pi}}\sqrt{\frac{x_f}{3}}$$

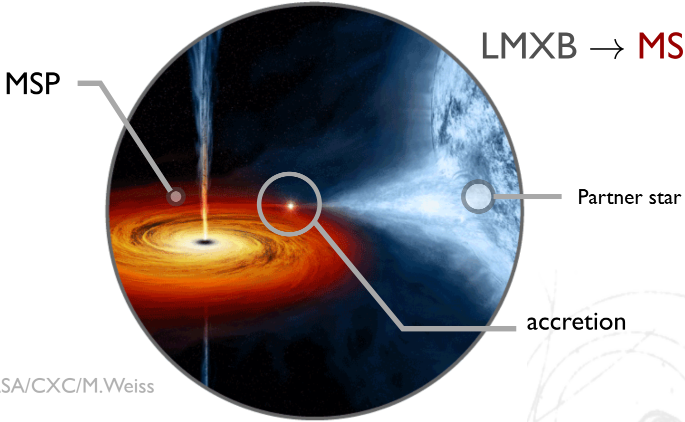


Is there any way to same thermal freeze out?

Millisecond Pulsar *Partial* Alternative?

Hooper et al. 1010.2752, 1110.0006; Abazajian et al. 1011.4275, 1207.6047 1402.4090
Wharton et al. 1111.4216, Yuan et al. 1404.2318, Mirabal 1309.3248 n.b.: Hooper et al. 1305.0830

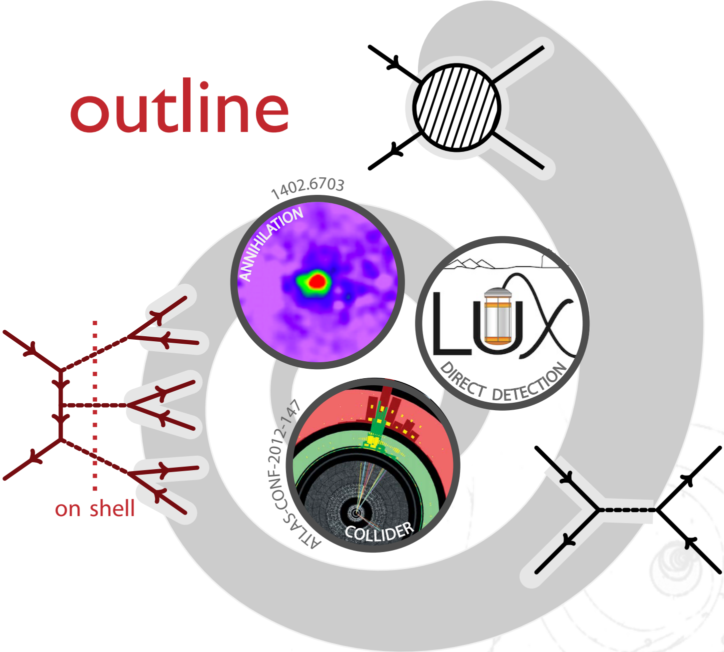
LMXB → MSP



NASA/CXC/M.Weiss

LMXB morphology is spot on degenerate with DM for γ-ray excess

outline


1402.6703
ANNIHILATION
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Model Building

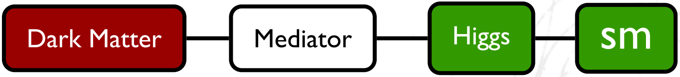
Spin-1 Mediator

Prototype is gauged $U(1)_B$, expect universal coupling to quarks.
Exception? ρ-like states in composite Higgs? (Contino et al. 1109.1570)

Spin-0 Mediator

$$\mathcal{L}_{\varphi\text{-sm}} = \frac{\lambda_u y^u_{ij}}{\Lambda}\varphi H \cdot \bar{Q} u_R + \frac{\lambda_d y^d_{ij}}{\Lambda}\varphi \tilde{H} \cdot \bar{Q} d_R + \frac{\lambda_\ell y^\ell_{ij}}{\Lambda}\varphi \tilde{H} \cdot \bar{L} \ell_R$$

Recent UV completion through 'Higgs-portal'-portal: Ipek et al. 1404.3716



Exception? $\chi\bar{\chi} \to \varphi_1\varphi_2$ is s-wave on-shell (Nomura & Thaler 0810.5397)
See also Agrawal et al. 1404.1373 for flavored DM.

Pre-conclusion: on-shell mediators

med.	Mass [gev]		Interaction		Coupling		
spin	m_χ	$m_{\text{mes.}}$	DM	SM	λ_{dm}	λ_{sm}	Relic?
spin-0	110	20	γ^5	$\mathbb{1}$	1.2	< 0.08	MSP?
"	"	"	γ^5	γ^5	"	$< 0.02^*$	"
spin-1	45	14	γ^μ	γ_μ	0.18	$< 10^{-6}$	$\gamma = 1.3$
"	"	"	$\gamma^\mu\gamma^5$	$\gamma_\mu\gamma^5$	"	< 0.004	"
"	"	"	$\gamma^\mu\gamma^5$	γ_μ	"	< 0.006	"
"	"	"	γ^μ	$\gamma_\mu\gamma^5$	"	< 0.02	"

spin-1 assumes universal coupling to quarks, spin-0 is b-philic
* est. mono-b projected, all other bounds from direct detection

- Combined with on-shell mediators, there is a range of Hooperon masses (both lighter and heavier than usual)
- Framework to parametrically separate indirect signal from direct/collider bounds

Moving forward: Now what?

FERMI analysis in progress! What to think about now?

I Bounds

- See Jong-Chul's talk
- e.g. last week, Bringmann et al. 1406.6027

II Morphology

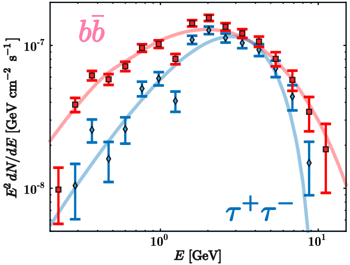
e.g. black hole distortion of DM profile in dwarfs (1406.2424) and the galactic center (1406.4856)

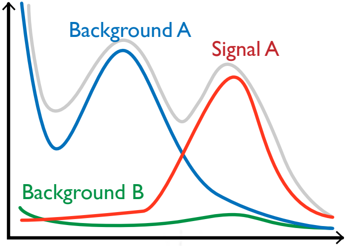
III Spectrum

Generalize DM templates; feeds into fit

Spectrum

Recall: 'signal' spectrum matters for fit.





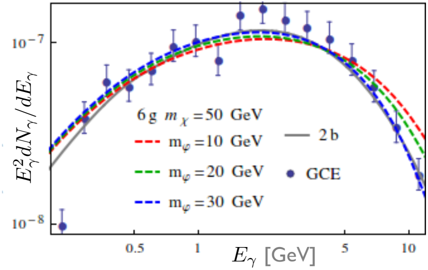
Full astrophysical fit for non-standard DM decays
($\chi\chi \to$ 4, 6 SM, $\chi\chi \to tc$). In progress, FT with Nic Canac.

Left image adapted from Abazajian et al. 1402.4090

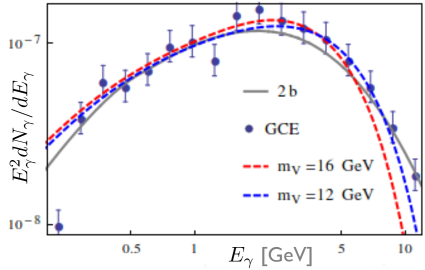
Playing with the Spectrum

See FT et al. 404.6528, Martin et al. 1405.0272, and FT work in progress.

$\chi\bar{\chi} \to 6g$



$\chi\bar{\chi} \to 2 \times \left[\tau\bar{\tau}\text{ (85\%) or } b\bar{b} \text{ (15\%)}\right]$

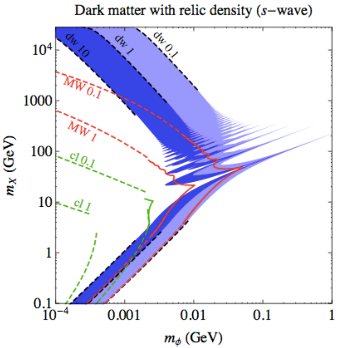


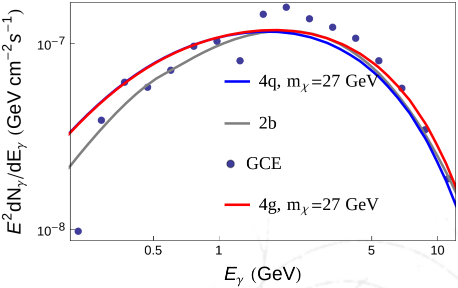
- Data: $b\bar{b}$ residual, for comparison only. Need to re-fit!
- Can bend spectra (e.g. interpolate between τ and b spectra)
- Mixture with hard spectra (leptons) can access DM masses below conventional Hooperon

Self-Interacting Dark Matter?

This framework contains all the pieces for SIDM

See talk by Ian Shoemaker.





$m_V = 1$ GeV, preliminary only

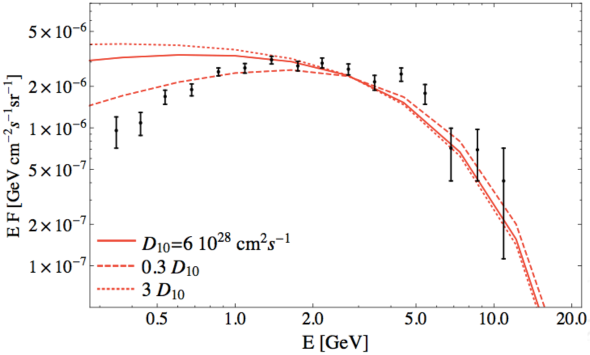
Non-trivial fit: small scale structure sets m_V light and $m_\chi(m_V)$

dN_γ/dE_γ is more subtle near $m_V \sim \Lambda_{\text{QCD}}$. Work in progress with Hai-Bo Yu.

Figure from Tulin et al. 1302.3898

Electron spectrum?

γ spectrum from electrons is usually too hard. But (1405.7928):



Inverse Compton spectrum from electrons injected 1 Myr ago from a source of $E = 4 \times 10^{52}$ erg for different diffusion indices.

Conclusion

Diffuse γ-Ray Excess: maybe DM, maybe pulsars.

Comprehensive simplified model analyses for $\chi\bar{\chi} \to 2$ SM.

On-shell mediators separate indirect from direct/collider searches.

Think about morphology and spectrum.

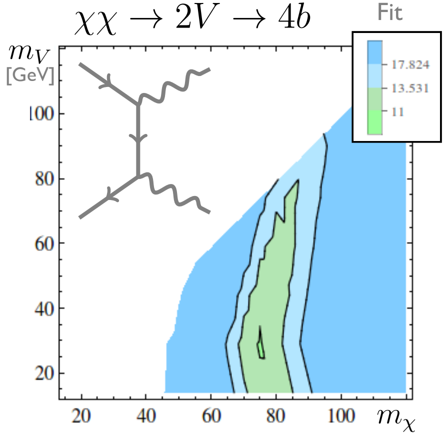
Official FERMI analysis soon!

Independent of 'Pass 7 FERMI diffuse background' used by other groups.
Look for: spectrum, systematic errors.

Back-up Slides

(for posting to the web)

Spin-1: b-philic vs. universal q



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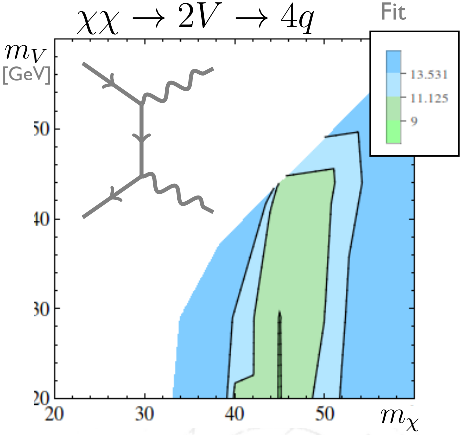
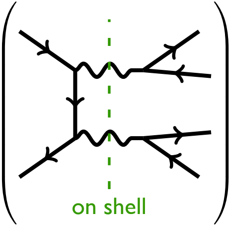
$m_V = 29$ GeV
$\lambda_{\text{DM}} = 0.27$
Br($V \to 2b$)=100%

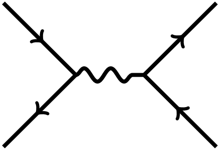


$m_\chi = 45$ GeV
$m_\varphi = 14$ GeV
$\lambda_{\text{DM}} = .18$
Cascade smears spectrum

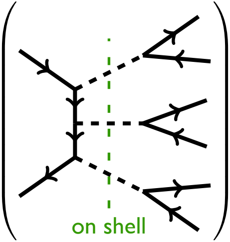
Dominance over off-shell



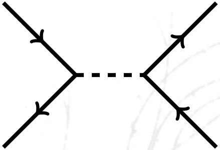
$\sim {\lambda_{\text{dm}}}^2 \quad \gg$



$\sim \lambda_{\text{dm}} \lambda_{\text{sm}}$

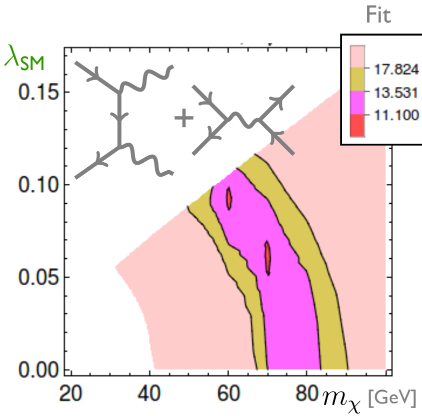


$\sim \dfrac{{\lambda_{\text{dm}}}^3}{\sqrt{4\pi}} \quad \gg$

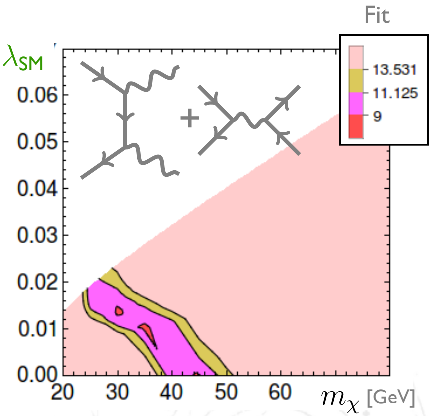


$\sim \lambda_{\text{dm}} \lambda_{\text{sm}}$

Indirect: on-shell contamination



b-philic vector



universal vector

Indirect: on-shell contamination