Dark Matter Theory Overview

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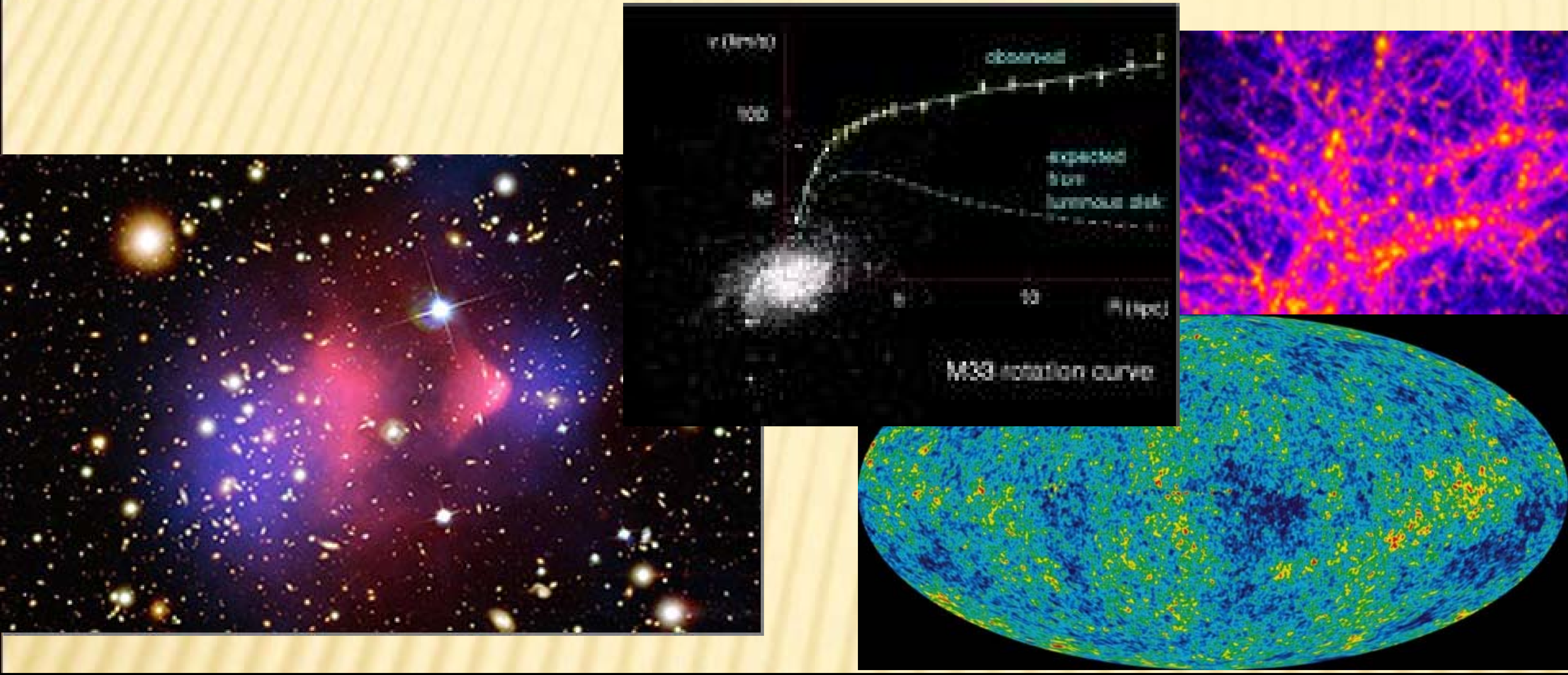
Outline

- ❖ Introduction
- ❖ Effective theories
- ❖ Collider phenomenology
- ❖ Annihilation and indirect detection
- ❖ Asymmetric dark matter
- ❖ Summary

Dark matter: the most concrete evidence there is new particle physics to be discovered.



Some DM candidates

- Thermal DM (i.e. a WIMP)
  →well motivated theoretically & good chance of detection
- Asymmetric Dark Matter
  → motivated by $\Omega_{DM} \approx 5\Omega_b$
- Axions
  → motivated by QCD strong CP
- Sterile neutrinos
  → new physics also needed in neutrino sector
- DM with only gravitational interactions
  →Nightmare scenario!

Thermal Relic Dark Matter

(1) Assume dark matter initially in thermal equilib.

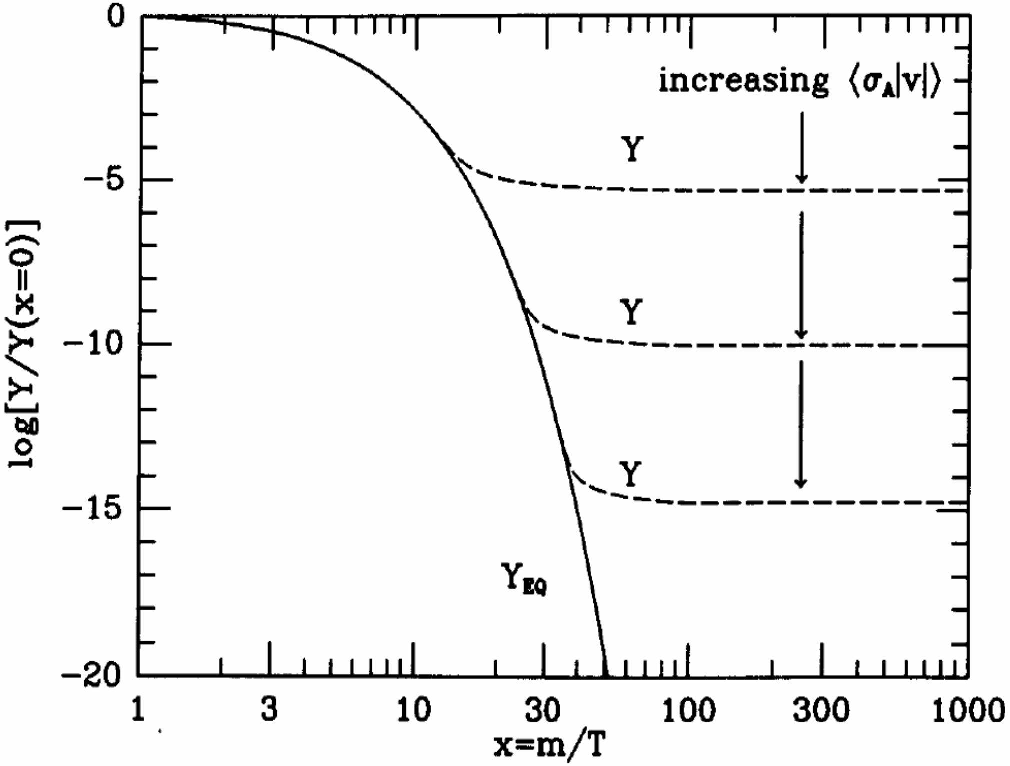
$$\chi\chi \leftrightarrow f\,\bar{f}$$

(2) Universe cools and the non-relativistic DM is Boltzmann suppressed:

$$N \sim (mT)^{3/2} e^{-m/T}$$

(3)"Freeze out" at m/T~20. Relic density fixed:

$$N = const. \propto \frac{1}{<\sigma v>}$$



→ Final dark matter abundance proportional to inverse of the annihilation cross section.

"WIMP Miracle"

- The thermal relic picture sets the "natural scale" for the dark matter annihilation cross section:

- $\Omega_{DM} \sim 0.2$ implies $\langle \sigma_A v \rangle \sim 2 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$

- Suggests electroweak-scale parameters since:

$$\langle \sigma v \rangle \sim \frac{\alpha^2}{(100\,\mathrm{GeV})^2} \sim 10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1}$$

→ 1)A compelling argument, given we have other reason to expect new physics at the GeV-TeV scale.

→ 2) Realistic prospects of detection:
  - annihilation signals (indirect detection)
  - nuclear recoils (direct detection)
  - monojets+missing ET (colliders)

“WIMPless Miracle” ?

- Actually, thermal freezeout does not single out the electroweak scale. The relic density simply sets

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

Feng & Kumar 2008

→ we can choose any m or g, provided we fix the ratio

Note: Partial wave unitarity bounds the cross section

$$(\sigma_J)_{\max} v_{\mathrm{rel}} \approx \frac{4\pi(2J+1)}{m_\chi^2 v_{\mathrm{rel}}}$$

→ rules out thermal relic DM for very large masses.

$$\langle \sigma v \rangle = \langle \sigma v \rangle_{thermal} \quad \Rightarrow \quad m_\chi < 300\,\mathrm{TeV}$$

Griest & Kamionkowski

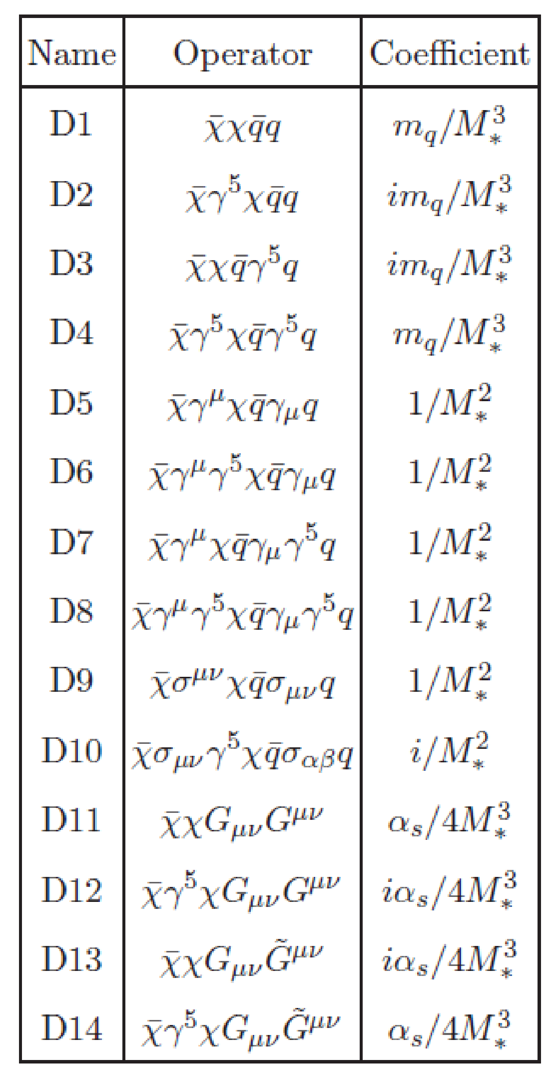
Effective operators

A model independent description of DM interactions with SM particles:

$$L_{Eff} = \frac{1}{\Lambda_{\rm eff}^2}\bar{\chi}\Gamma_\chi\chi\ \bar{q}\Gamma_q q$$

$$\Gamma_{\chi,q} \in \{1, \gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu}\}.$$

J.Goodman et al.



Name	Operator	Coefficient
D1	$\bar\chi\chi\bar q q$	m_q/M_*^3
D2	$\bar\chi\gamma^5\chi\bar q q$	im_q/M_*^3
D3	$\bar\chi\chi\bar q\gamma^5 q$	im_q/M_*^3
D4	$\bar\chi\gamma^5\chi\bar q\gamma^5 q$	m_q/M_*^3
D5	$\bar\chi\gamma^\mu\chi\bar q\gamma_\mu q$	$1/M_*^2$
D6	$\bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu q$	$1/M_*^2$
D7	$\bar\chi\gamma^\mu\chi\bar q\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar\chi\sigma^{\mu\nu}\chi\bar q\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar\chi\sigma_{\mu\nu}\gamma^5\chi\bar q\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar\chi\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar\chi\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar\chi\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar\chi\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

Advantages:
- Generic description
- Valid for direct detection where momentum transfer is very small

Disadvantages:
- EFT description can break down at colliders where q^2 is large.
- No good for light mediators

Bounds on EFT operators are becoming quite constraining!

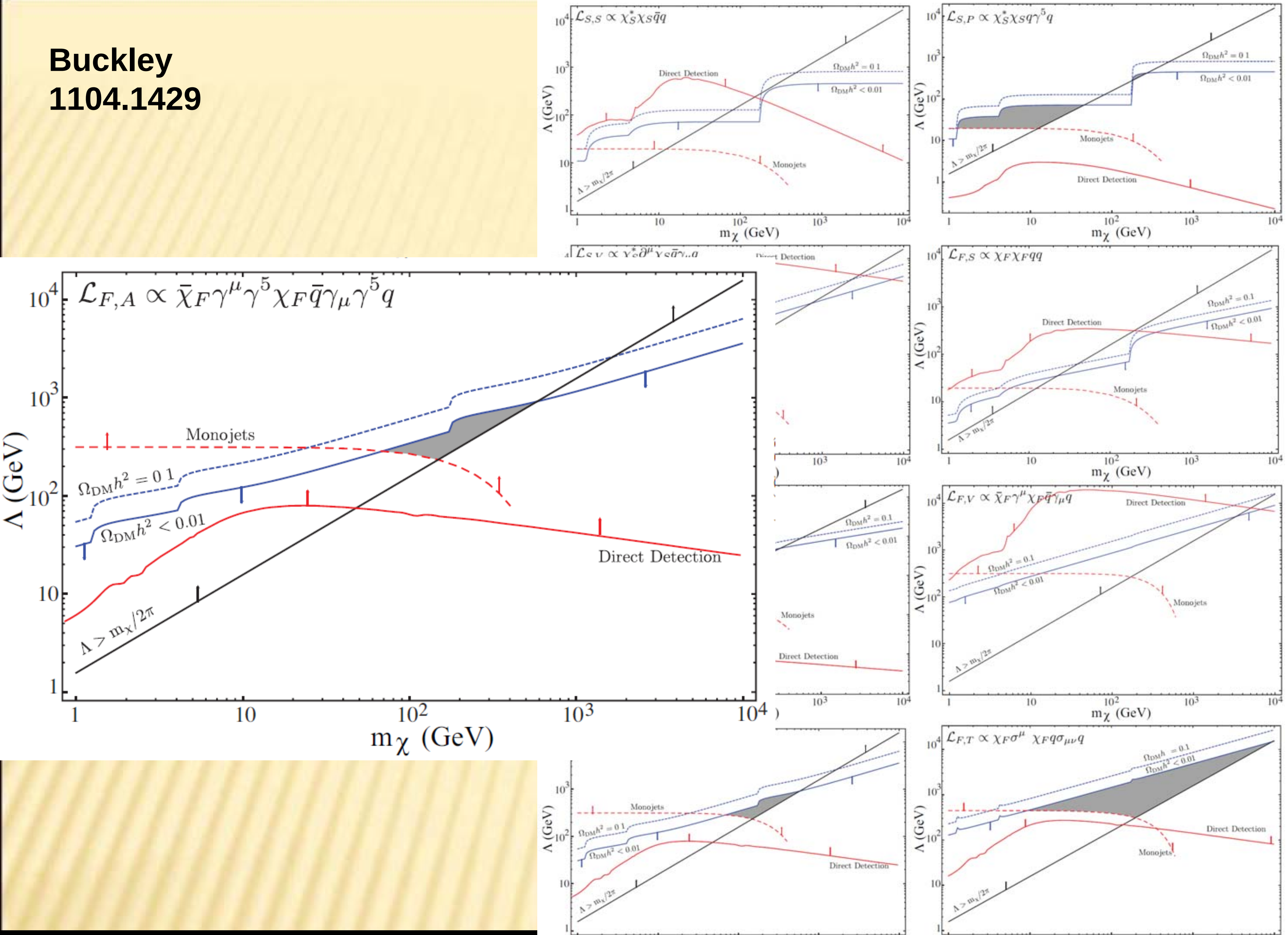
❖Relic density
→upper limit on Λ_{eff} (to prevent overclosure)

❖Direct detection, collider, and indirect detection
→ lower limits on Λ_{eff}

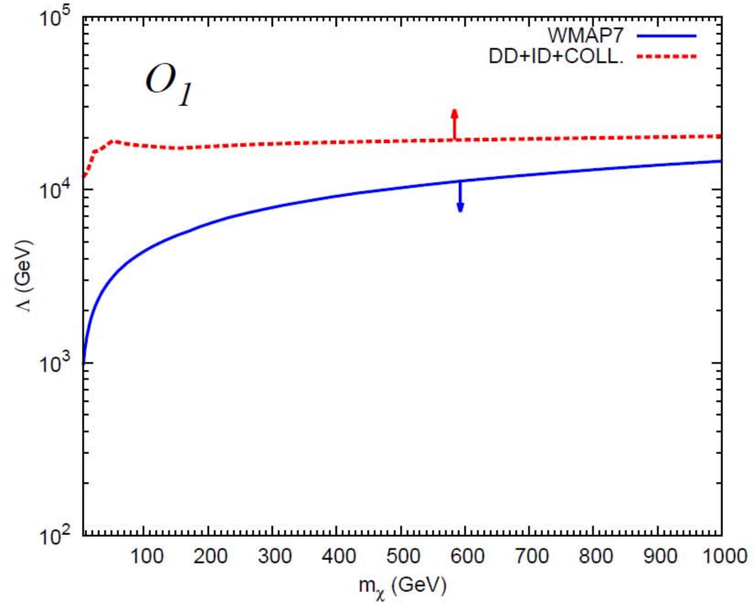
For many operators, these limits are in conflict!

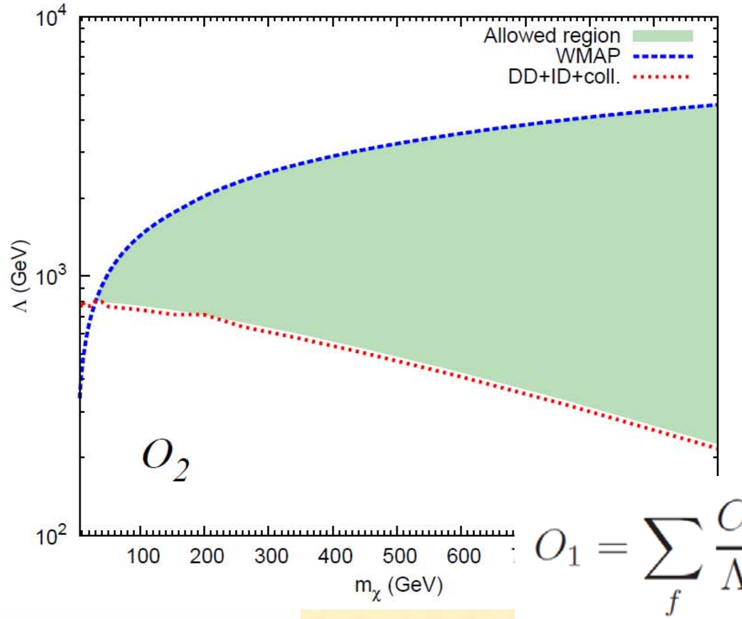
Possibilites:
-one of the remaining operators is correct
-non-trivial flavour structure in DM couplings
-EFT description inadequate

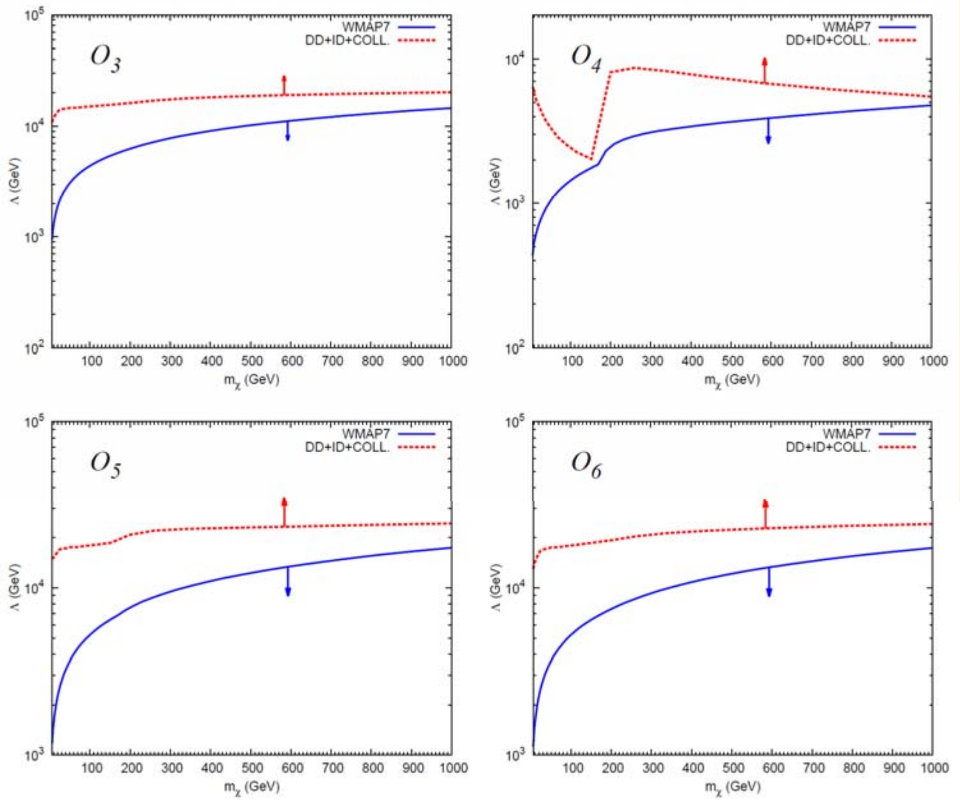
Buckley
1104.1429



K. Cheung et al, 1201.3402







$$O_1 = \sum_f \frac{C_1^f}{\Lambda_1^2} \left(\bar\chi\gamma^\mu\chi\right)\left(\bar f\gamma_\mu f\right) ,$$

$$O_2 = \sum_f \frac{C_2^f}{\Lambda_2^2} \left(\bar\chi\gamma^\mu\gamma^5\chi\right)\left(\bar f\gamma_\mu f\right) ,$$

$$O_3 = \sum_f \frac{C_3^f}{\Lambda_3^2} \left(\bar\chi\gamma^\mu\chi\right)\left(\bar f\gamma_\mu\gamma^5 f\right) ,$$

$$O_4 = \sum_f \frac{C_4^f}{\Lambda_4^2} \left(\bar\chi\gamma^\mu\gamma^5\chi\right)\left(\bar f\gamma_\mu\gamma^5 f\right)$$

$$O_5 = \sum_f \frac{C_5^f}{\Lambda_5^2} \left(\bar\chi\sigma^{\mu\nu}\chi\right)\left(\bar f\sigma_{\mu\nu} f\right) ,$$

$$O_6 = \sum_f \frac{C_6^f}{\Lambda_6^2} \left(\bar\chi\sigma^{\mu\nu}\gamma^5\chi\right)\left(\bar f\sigma_{\mu\nu} f\right)$$

Dark matter at the LHC

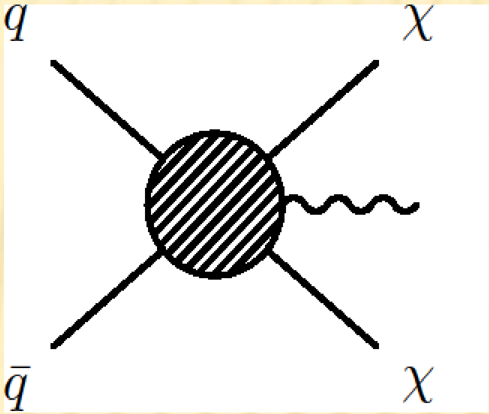
- The dominant DM production process at the LHC may be:

$$\bar{q}q \to \chi\chi$$

But this process is invisible to the detectors (DM stable, weakly interacting)

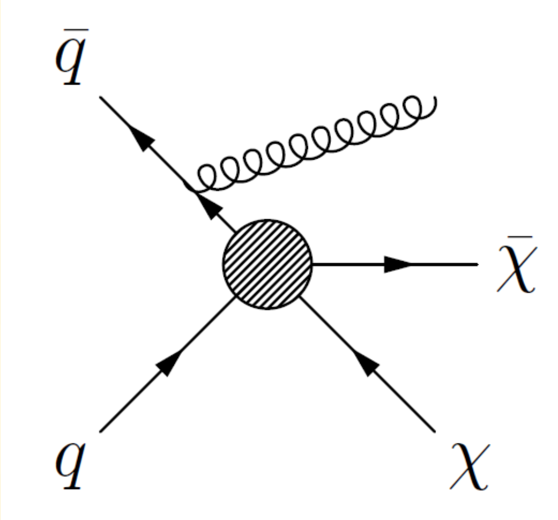
- We need visible particles in the final state, to recoil against some missing transverse energy,

e.g. $\bar{q}q \to \chi\chi + \text{single SM particle}$



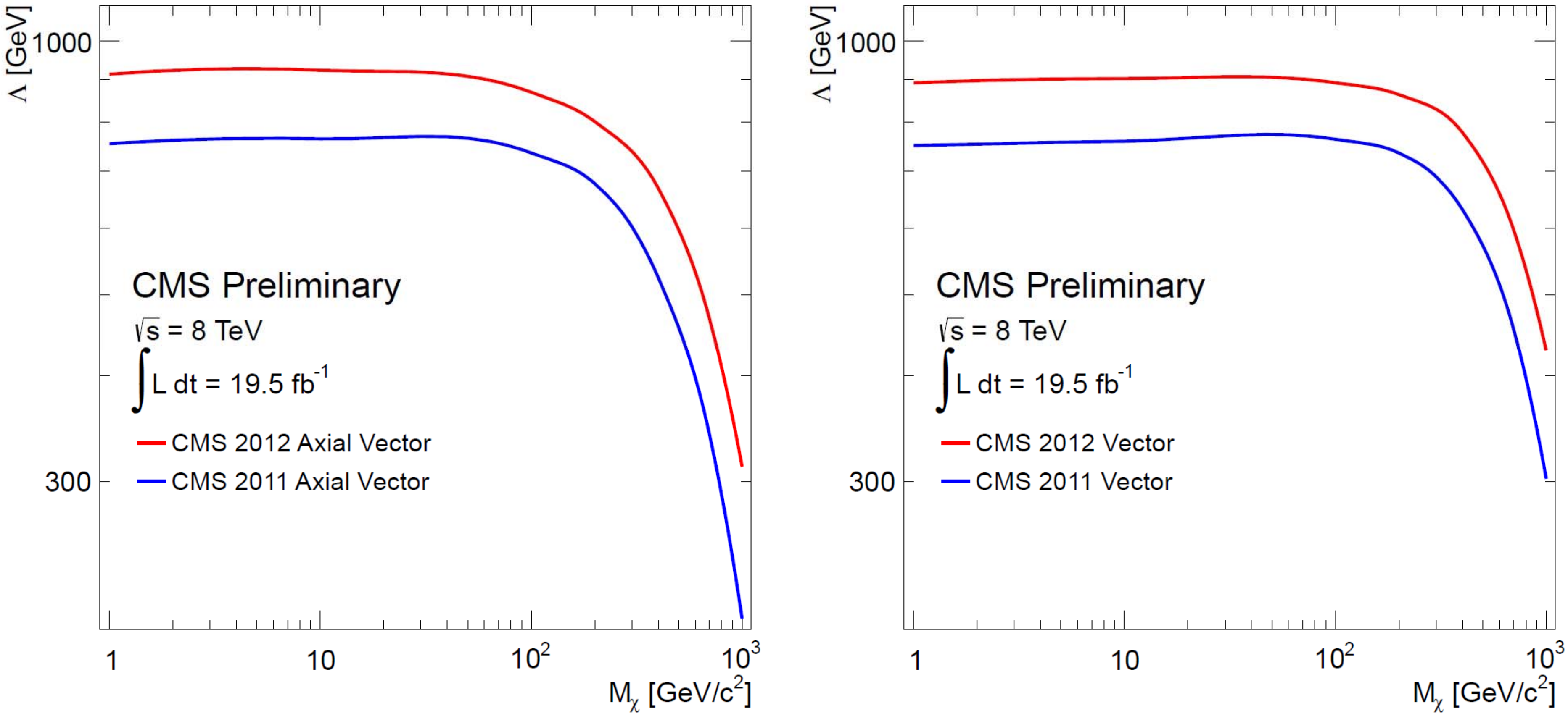
Dark matter visible as high pT state + missing ET

Mono-"X"

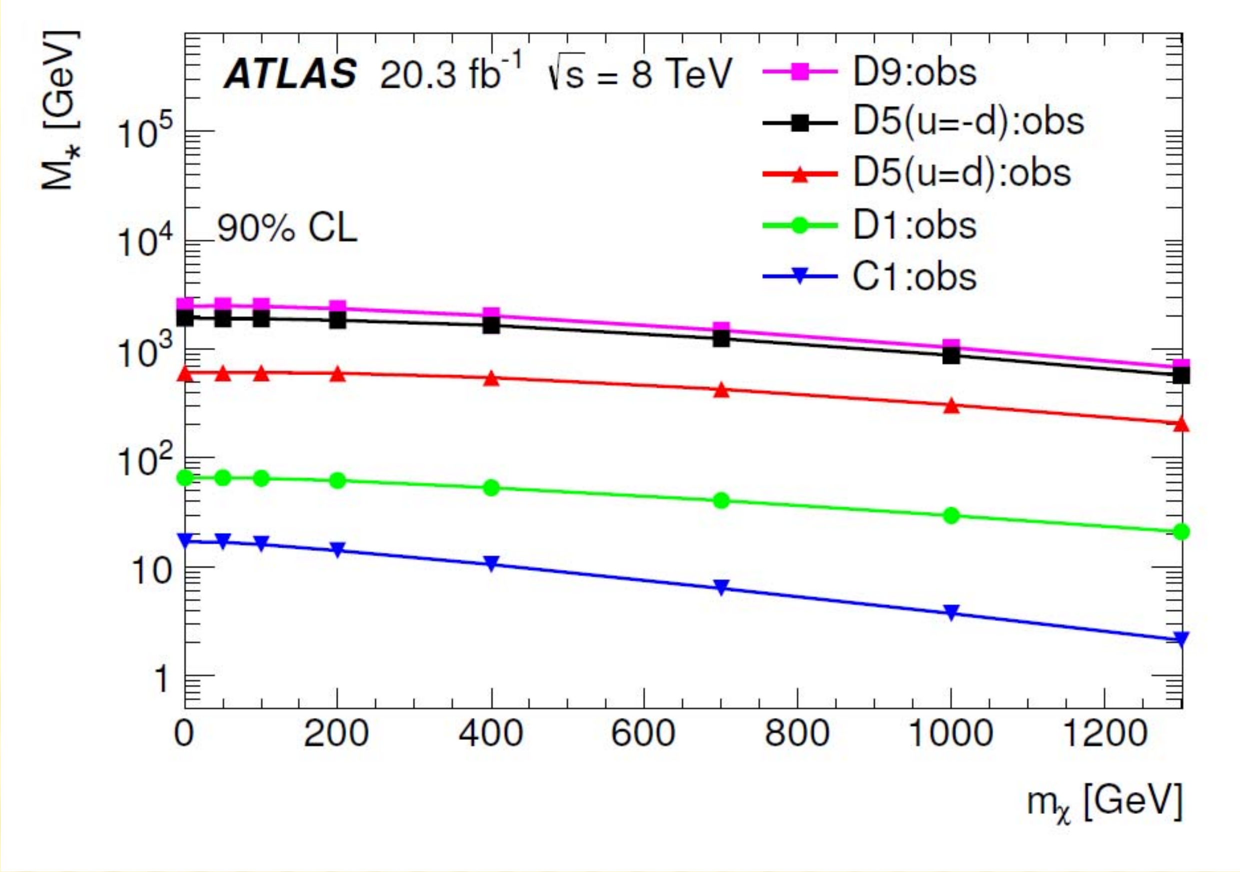


- mono-jet (gluon)
  - high cross section & large backgrounds
- mono-photon
  - complementary to (but less constraining than) monojets
- mono-Z (Bell et al., 1209.0231; Carpenter et al., 1212.3352)
  - complementary to monojets;
  - clean signal
- mono-W (Bai & Tait, 1208.4361)
  - can distinguish different couplings to u and d type quarks
- mono-Higgs (Petrov & Shepherd 1311.1511)

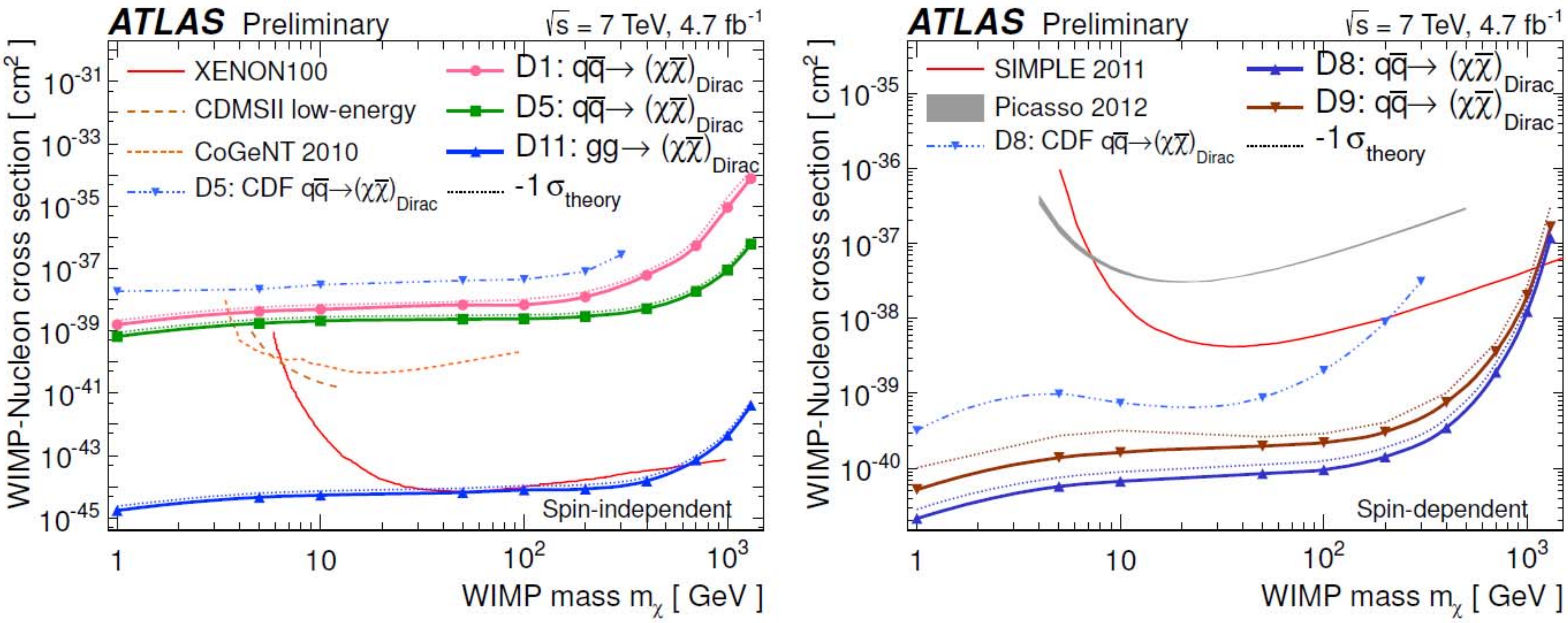
CMS mono-jet limits
CMS PAS EXO-12-048



ATLAS limits from hadronically decaying mono-W and mono-Z arXiv:1309.4017



ATLAS mono-jet limits



ATLAS-CONF-2012-084

EFTs are useful, but have limitations

❖EFT bounds can over-estimate constraints on a given model

e.g. Models with light mediators

❖EFT bounds can under-estimate constraints on a given model

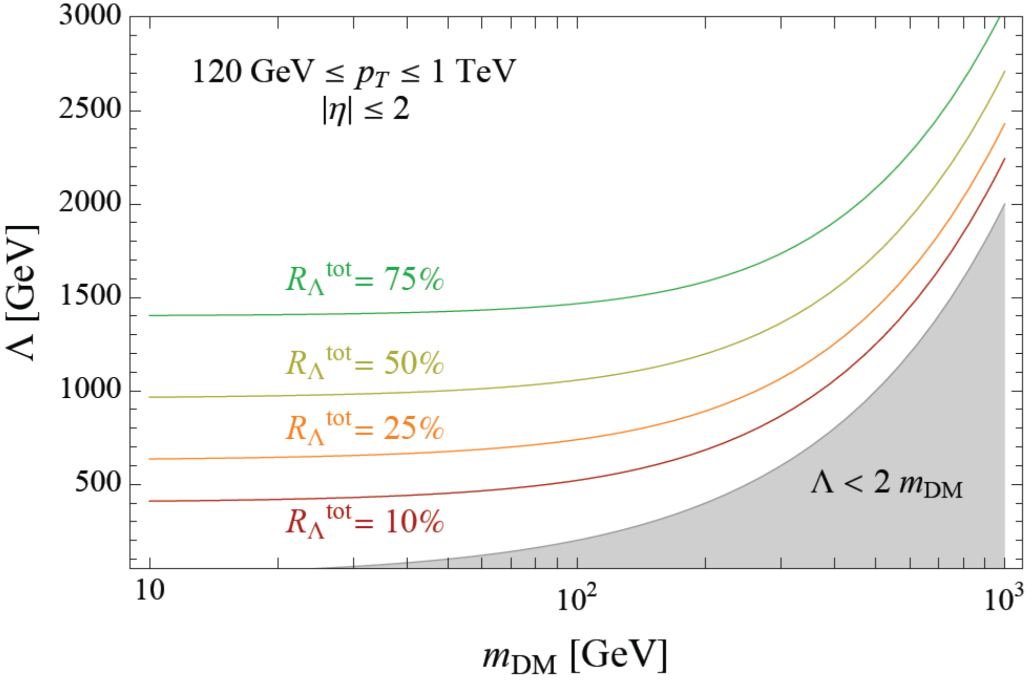
e.g. If DM-SM interaction mediated by a new coloured particle the EFT mono-jet bounds are often too conservative.

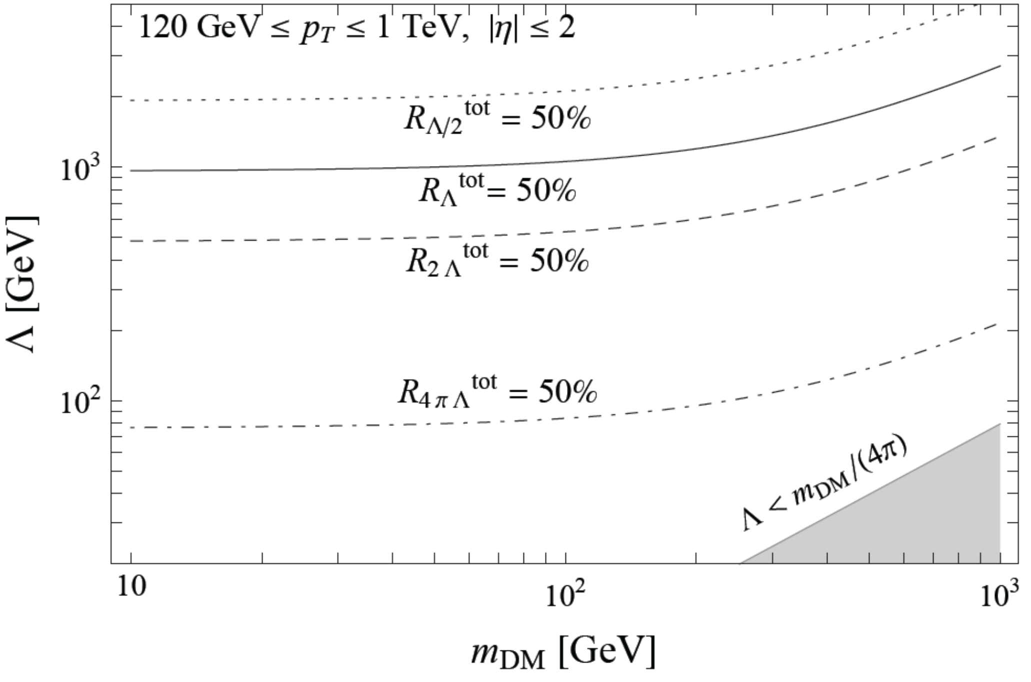
Importantly: in many UV complete theories, there exists other dark sector particles at energy scales accessible to the LHC. Either particles with SM quantum numbers, or a Z′ gauge boson, see arXiv:1003.1912

Breakdown of EFT description at colliders

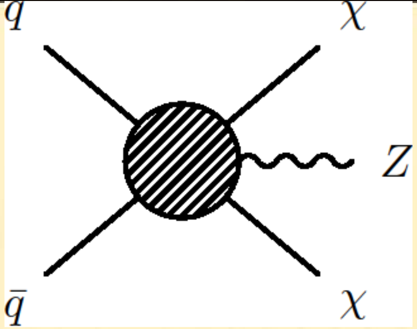
$$R_\Lambda^{\rm tot} \equiv \frac{\sigma_{\rm eff}\big|_{Q_{\rm tr}<\Lambda}}{\sigma_{\rm eff}}$$

G.Busoni et al, 1307.2253

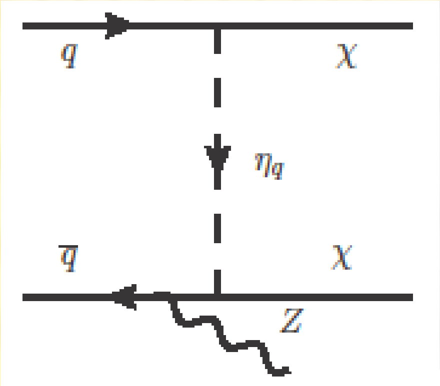


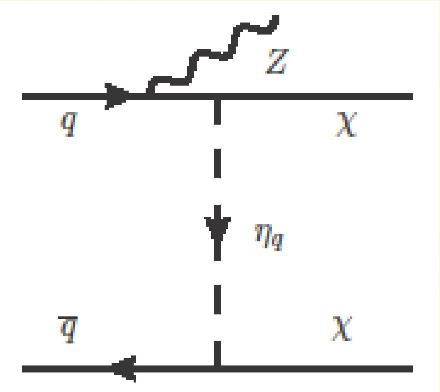


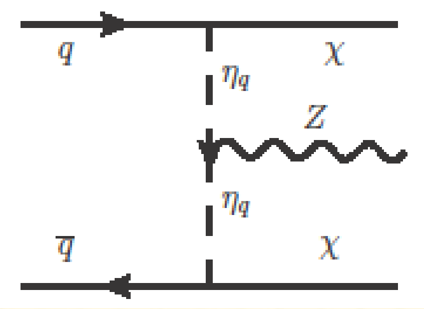
Example (Mono-Z)



Go beyond an EFT by introducing a mediator.
Radiation from mediator contributes to mono-X signals.







$$
\begin{aligned}
\mathcal{L}_{\text{int}} &= f_{ud}\bar{q}_{\mathrm{L}}\eta^{c}\chi_{\mathrm{R}} + h.c \\
&= f_{ud}\left(\eta_u \overline{u}_{\mathrm{L}} + \eta_d \overline{d}_{\mathrm{L}}\right)\chi_{\mathrm{R}} + h.c.
\end{aligned}
$$

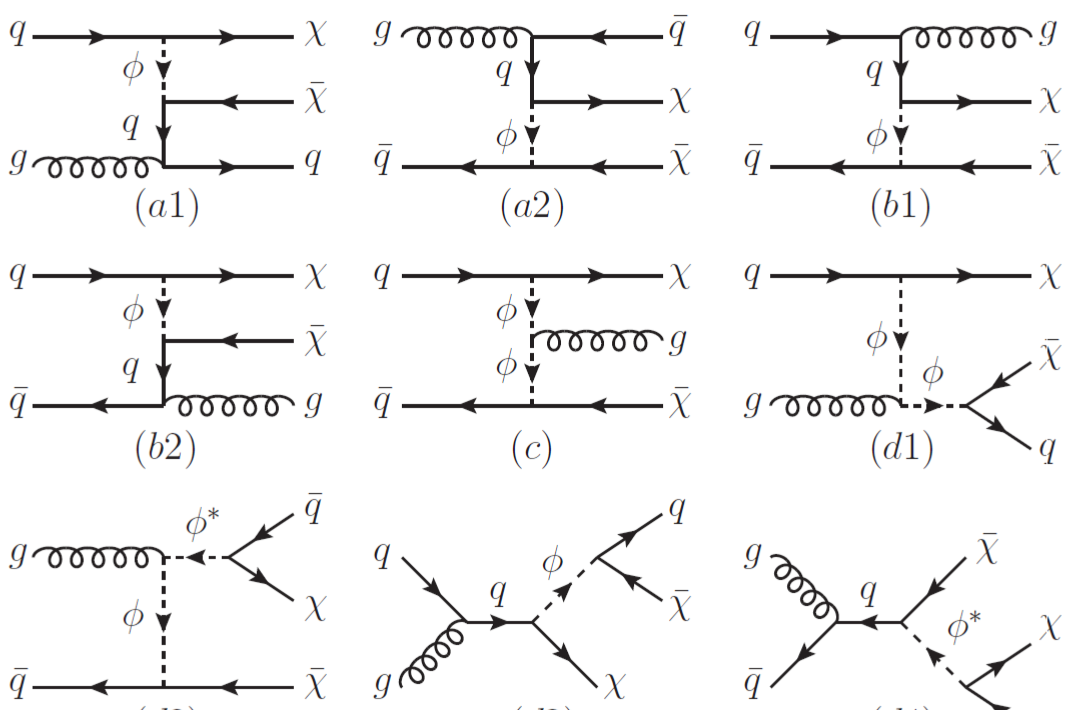
Bell et al
1209.0231

- Note: scalar charged under SM gauge groups, $\eta^c \sim (3,2,1/3)$,

(i.e. **χ and η are analogous to the neutralino and squark.**)

Go beyond an EFT by introducting a mediator

E.g. t-channel exchange of a scalar.



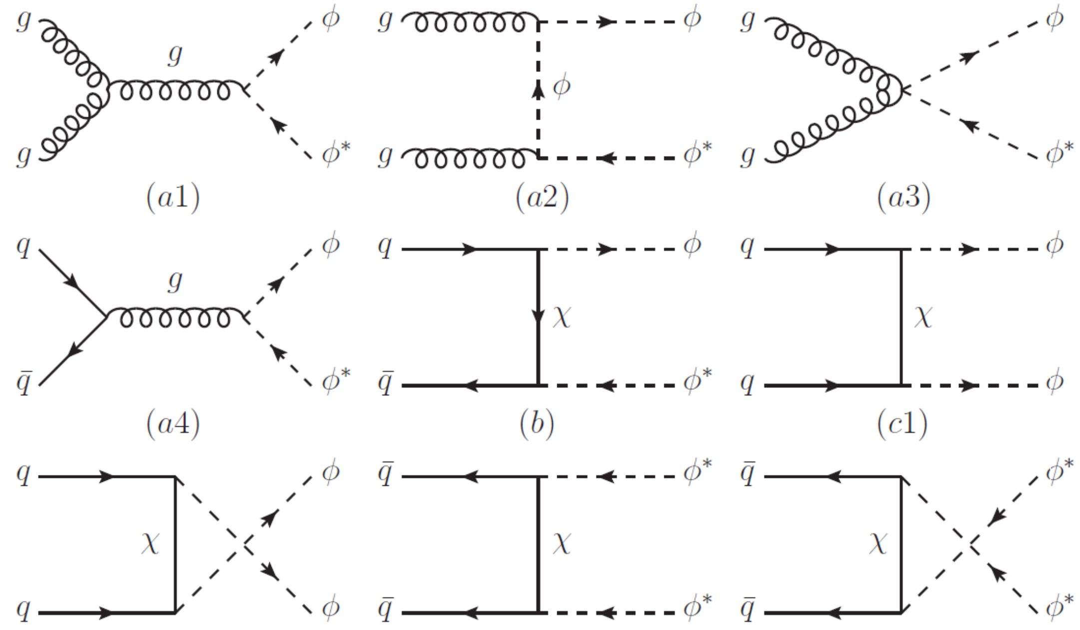
(a1) (a2) (b1)

(b2) (c) (d1)

(d2) (d3) (d4)

Mono-jets

Mediator pair production



(a1) (a2) (a3)

(a4) (b) (c1)

(c2) (c3) (c4)

H.An et al, 1308.0592

See also:
Chang et al. , 1307.8120
Bai & Berger, 1308.0612
DiFranzo et al., 1308.2679

Co-Annihilation

EFTs assume a separation of scales → enables all dark sector particles (other than the DM itself) to be integrated out. May not be valid.

Consider models in which there are 2 (or more) dark sector particles of similar mass, $\{\chi_1, \chi_2\}$, with $m_1 \approx m_2$.

- Relic density controlled by co-annihilation of χ_1 and χ_2
- χ_2 decays to χ_1 with lifetime << age of universe

Generalise the EFT description:

$$\frac{1}{\Lambda_{11}^2}\bar{f}\Gamma_1 f\bar{\chi}_1\Gamma_2\chi_1 \ ,$$

$$\frac{1}{\Lambda_{12}^2}\bar{f}\Gamma_1 f(\bar{\chi}_1\Gamma_2\chi_2 + h.c.)$$

$$\frac{1}{\Lambda_{22}^2}\bar{f}\Gamma_1 f\bar{\chi}_2\Gamma_2\chi_2 \ .$$

Bell, Cai & Medina, in preparation

If $\Lambda_{11} \gg \Lambda_{12}\,\Lambda_{22}$ → Self annihilation of χ_1 is suppressed

Relic density

- Co-annihilation of χ_1 and χ_2 controls the relic density

$$\sigma_{eff} = \sigma_{11} + e^{-\Delta m/T}(1+\Delta m/m)^{3/2}\sigma_{12} + e^{-2\Delta m/T}(1+\Delta m/m)^{3}\sigma_{22}$$

Indirect detection

Suppressed by large Λ_{11}

Direct detection

$\chi_1 + N \rightarrow \chi_2 + N$ cannot happen unless mass gap is tiny

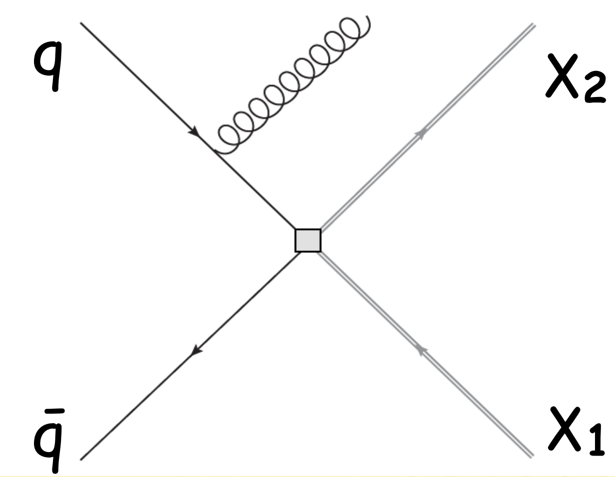
Colliders

-Monojets: $pp \rightarrow \chi_1\,\chi_2 + \text{jet}$

-New signals: $pp \rightarrow \chi_1\,\chi_2 \rightarrow \chi_1\,\chi_1 + \text{SM}$

A monojet signal may be seen in a region of parameter space for which self-annihilating dark matter has already been ruled out by direct detection.

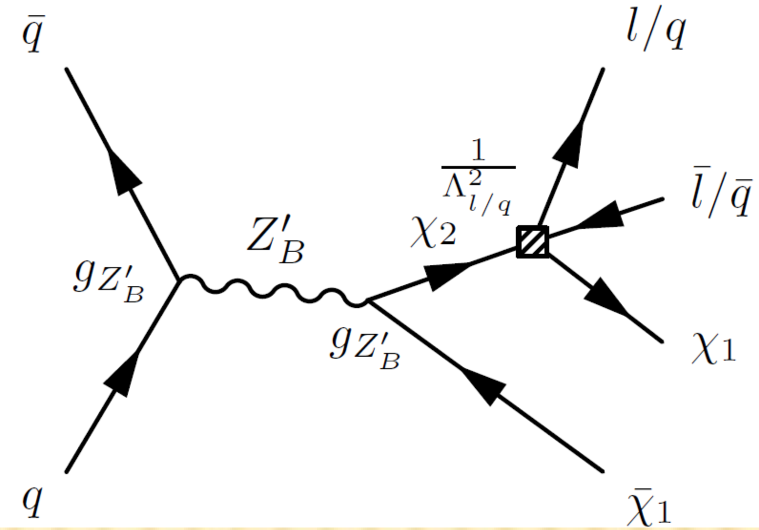
Collider signals of co-annhilation



Monojets:

$pp \to \chi_1 \chi_2 + \text{jet}$

This will look identical to a standard monojet if the SM particles produced by χ_2 decay are very soft.



χ_2 decay signal:

$pp \to \chi_1 \chi_2 \to \chi_1 \chi_1 + \text{SM}$

$\chi_2 \to \chi_1 + l^+l^-$

or $\chi_2 \to \chi_1 + q\text{qbar}$

Both could be observed with forthcoming LHC data!

Bell, Cai & Medina, in preparation

DM and missing E_T at colliders

If we see a MET signal that can be attributed to a new weakly interacting particle, we won't know if it is really the dark matter without other information.

- Is is stable?

→DM must be stable on a timescale of order 10 Gyr. Colliders will tell us about stability on only nanosecond timescales (long enough to escape the detector).

- Does it contribute all the relic density?

→ Need to measuring its couplings to all SM particles.

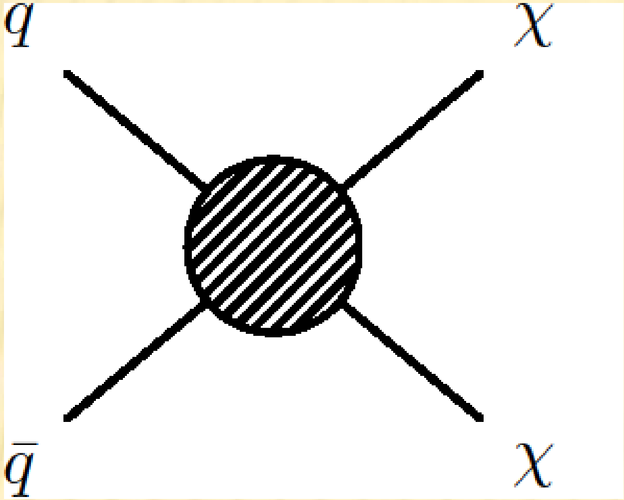
- Consistent with direct and/or indirect detection?

→ E.g. Do we see a gamma ray line at the same energy as the DM mass inferred at the collider?

Detecting Dark Matter

production (collider searches)

→



↓

scattering
(direct
detection)

←

annihilation (indirect detection)

Dark matter annihilation

Expand annihilation cross section in velocity, v:

$$\langle\sigma v\rangle = a + bv^2 + O(v^4)$$

a -- from s-wave (L=0) annihilation
b -- both s-wave and p-wave (L=1) contributions

In galactic halos, v~ 10^{-3}c, so only the s-wave contribution is significant.

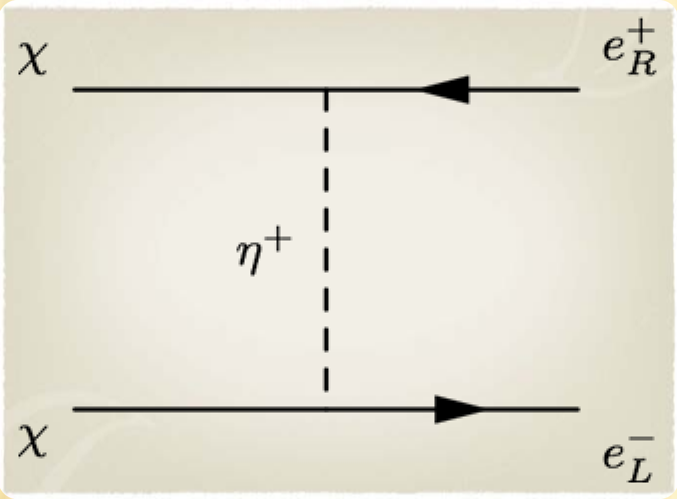
Typically assume annihilation cross section dominated by 2-body final states.

But if 2-body final states are suppressed (e.g. helicity suppression of s-wave) → 3-body final states important.

Example of suppressed annihilation

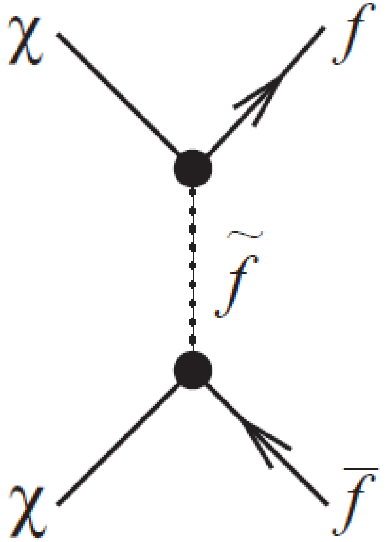
Dark matter = gauge-singlet Majorana fermion = χ

$$\mathcal{L} = f(\nu_L \eta^0 - \ell_L \eta^+)\chi + h.c.$$



s-wave is helicity suppressed due to mismatch of fermion chirality and allowed spin state.

SUSY analogue

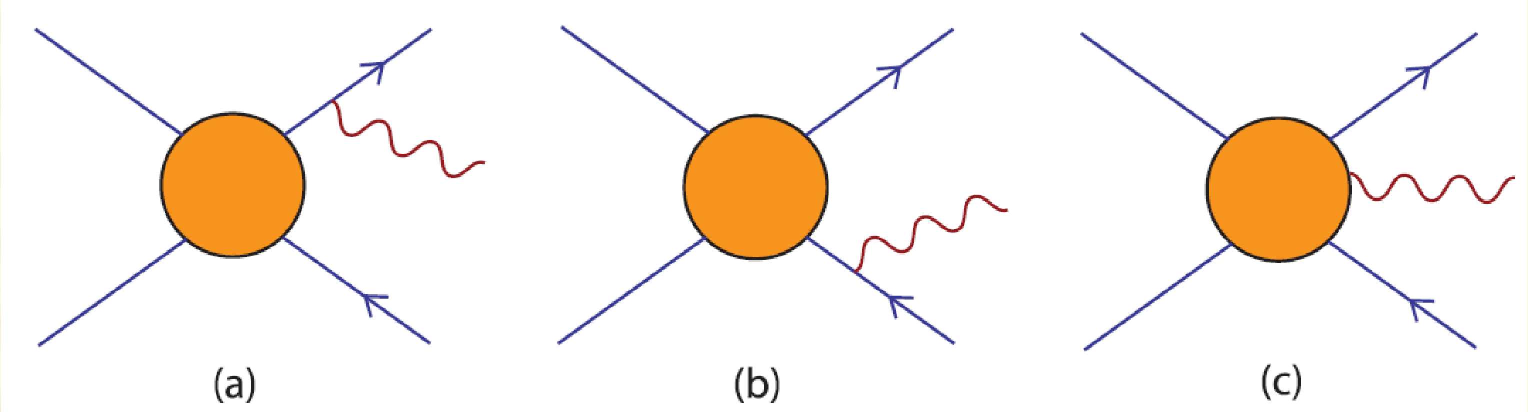


Annihilation of bino dark matter to fermions via exchange of sfermions

Lifting the suppression (photons)

Emission of a photon can lift the suppression

Bergstrom, PLB 225, 372, 1989; Flores, Olive, Rudaz, PLB 232, 377, 1989; Bringmann, Bergstrom, Edsjo, 2008; Barger, Gao, Keung, Marfatia, 2009,



Final state radiation (FSR)

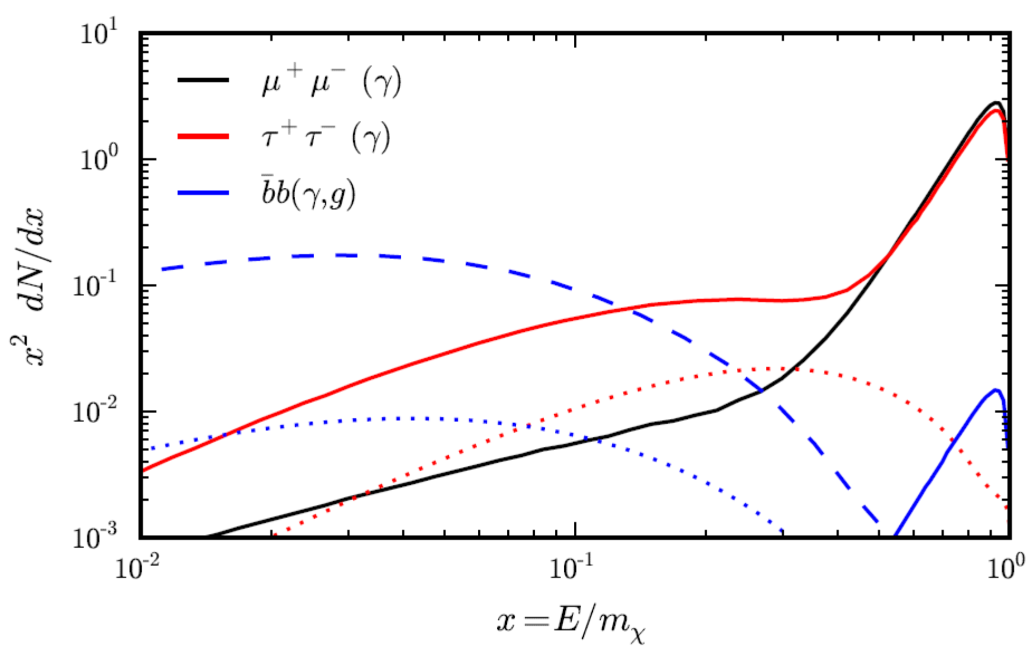
Virtual internal bremsstrahlung (VIB)

3 final states particles → fermions no longer required to be in disallowed spin state → helicity suppression removed

Effect most pronounced for near-mass χ (DM) and η (propagator) (i.e. coincides with the co-annihilation region)

Bremsstrahlung signals

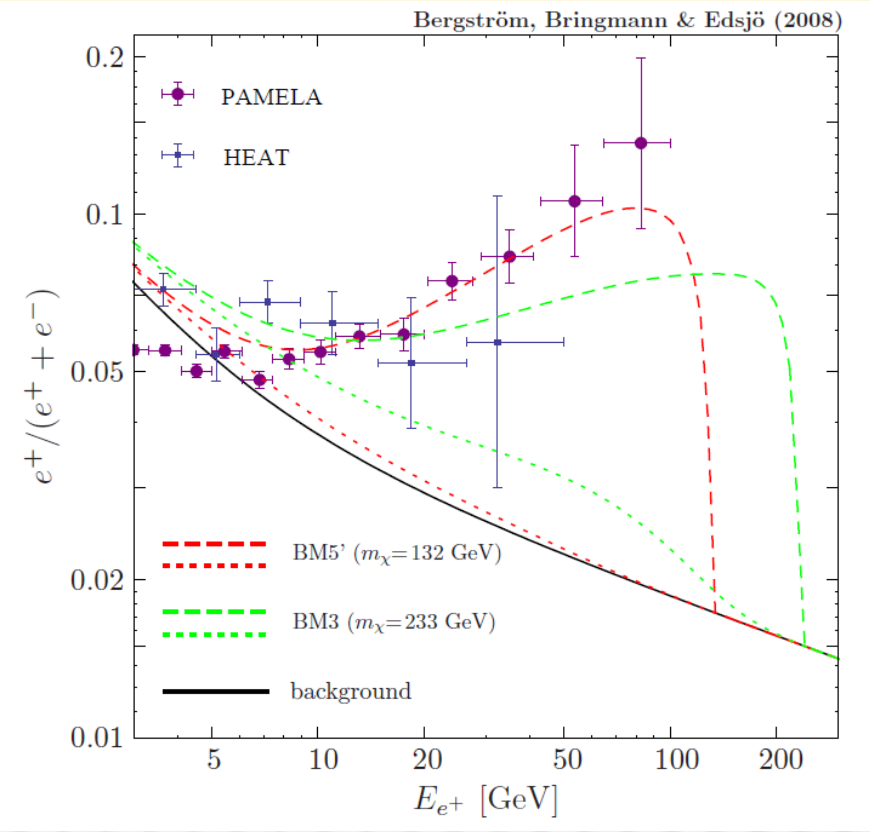
Gamma rays



Bringmann, Huang, Ibarra, Weniger, arXiv:1203.1312

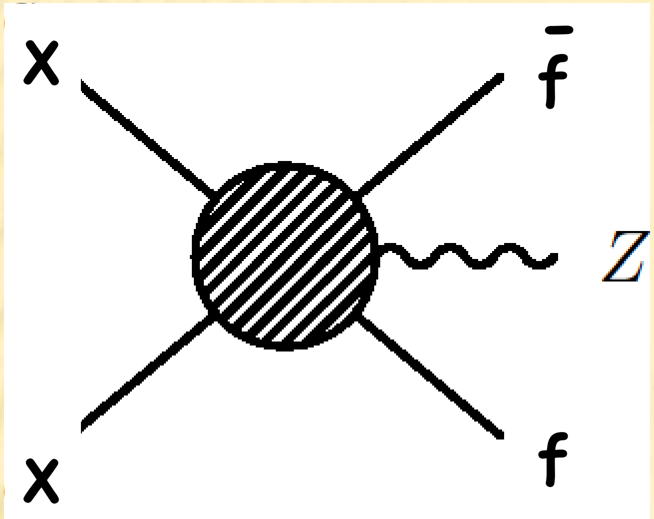
FERMI gamma ray line at ~130GeV fit by bremsstrahlung signal with m~150GeV, arXiv:1203.1312

Positrons



Bergstrom, Bringmann, Edsjo, PRD 2008

Lifting the suppression: electroweak (W,Z) bremsstrahlung



Bell, Dent, Jacques & Weiler, PRD 2010.

Bell, Dent, Galea, Jacques, Krauss & Weiler, PLB 2011, arXiv:1104.3823

Ciafaloni, Cirelli, Comelli, De Simone, Riotto & Urbano, JCAP 2011

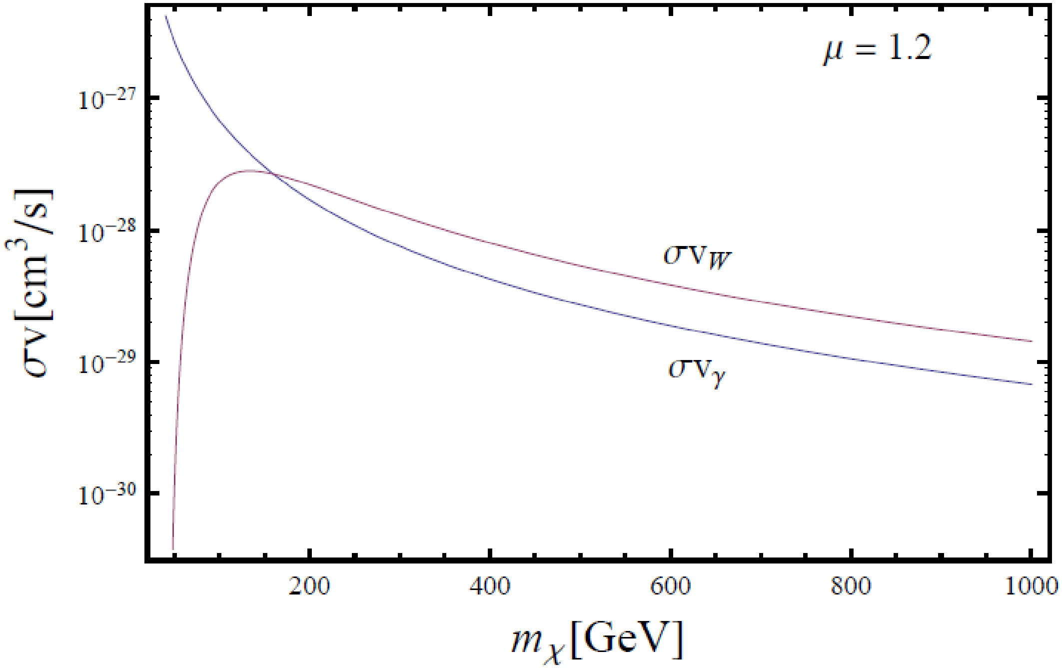
- Radiating a W or Z boson can also lift the suppression

- distinct phenomenology: W and Z bosons decay to charged leptons, neutrinos, gammas, and hadrons

  → significant hadron production even for "leptophillic" models

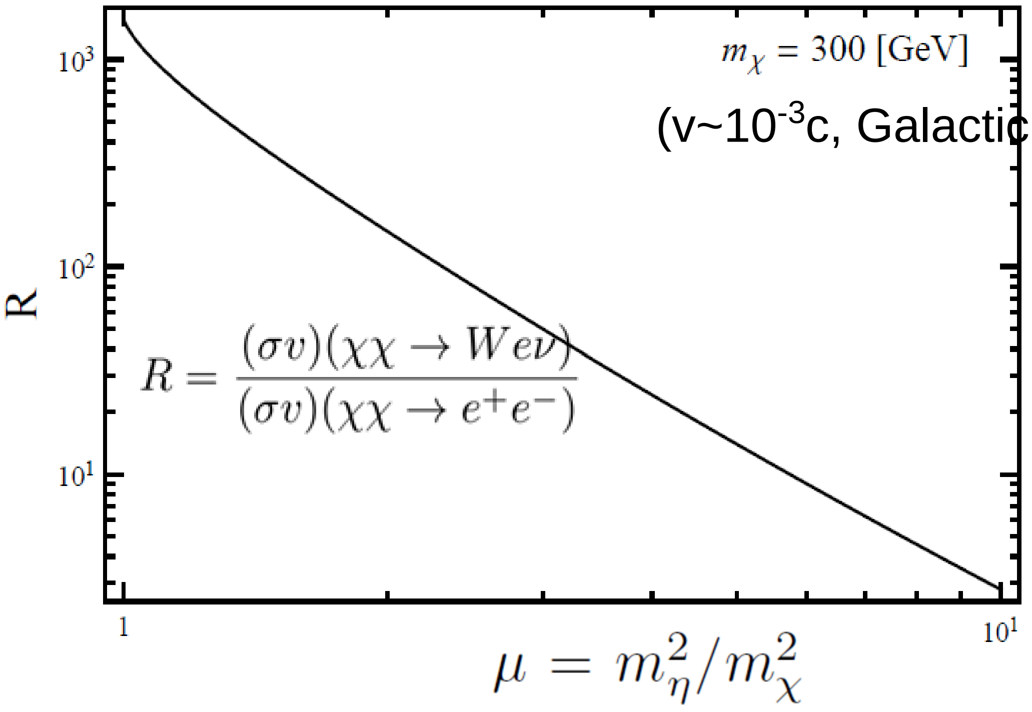
Rate W-brem > γ-brem (except near m_W threshold)

$$\sigma_{\text{brem, total}} = \sigma_{e^+\nu W^-} + \sigma_{\bar{\nu} e^- W^+} + \sigma_{\bar{\nu}\nu Z} + \sigma_{e^+e^-Z} + \sigma_{e^+e^-\gamma} = 7.16\,\sigma_{e^+e^-\gamma}.$$



Cross-section ratio of 3-body:2-body final states

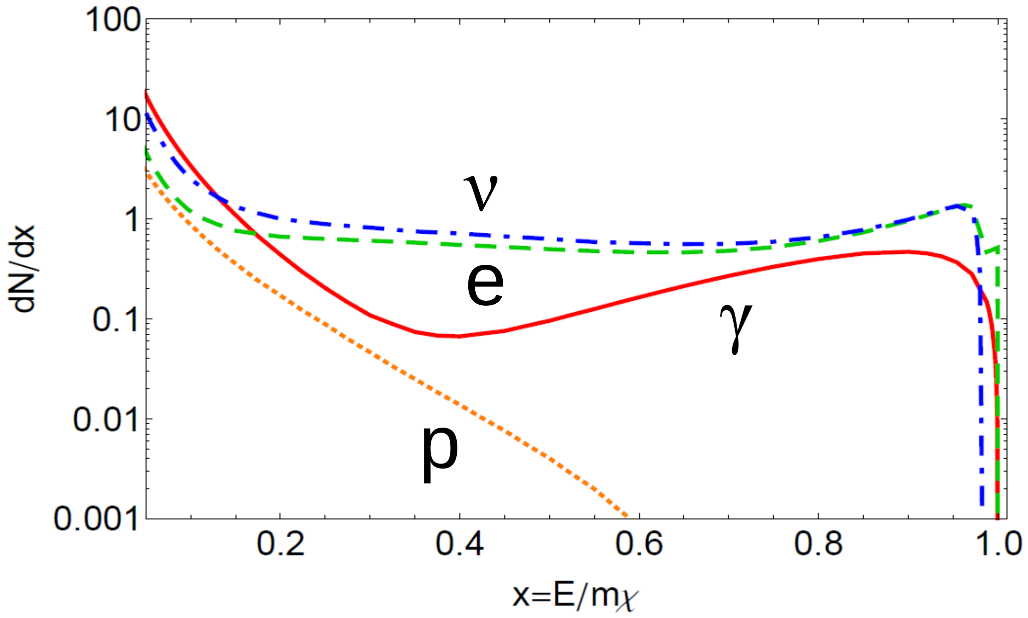
→ Enhancement of up to 3 orders of magnitude



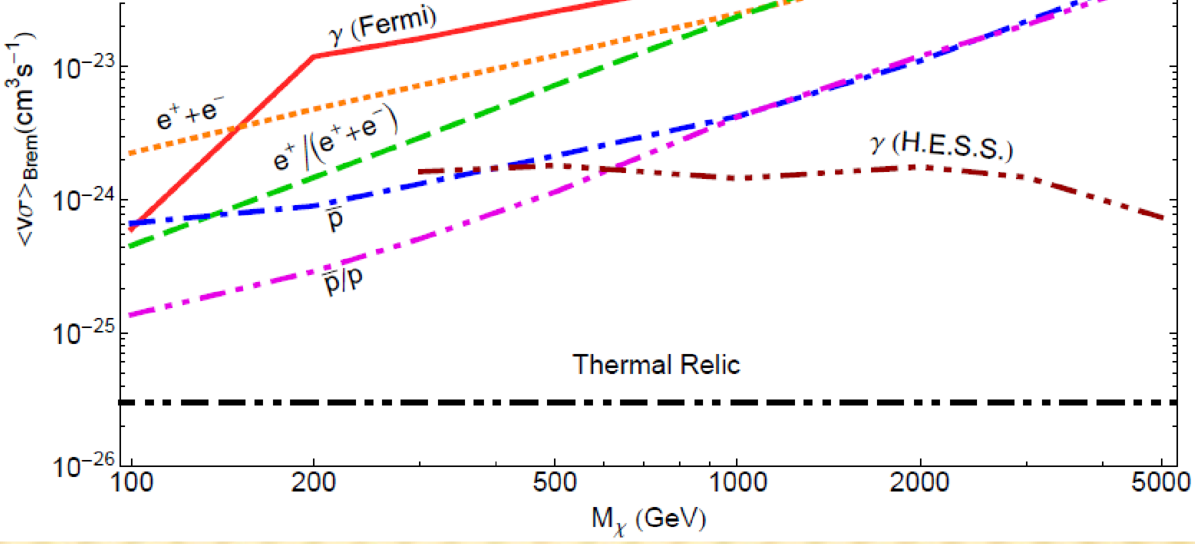
(v~10^{-3}c, Galactic ha

Bell, Dent, Galea, Jacques, Krauss & Weiler, arXiv:1104.3823

Annihilation spectra and cross section limits



Bell, Dent, Jacques & Weiler, arXiv:1101.3357



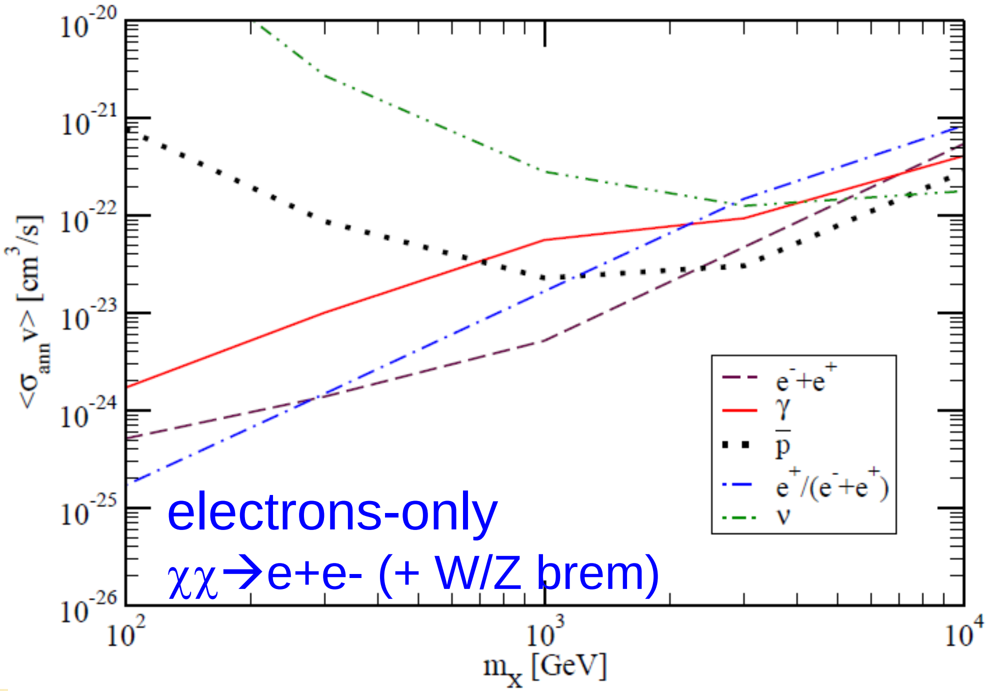
→Bremsstrahlung can't make significant contribution to e+ flux, without overproducing antiprotons

Models with no helicity suppression

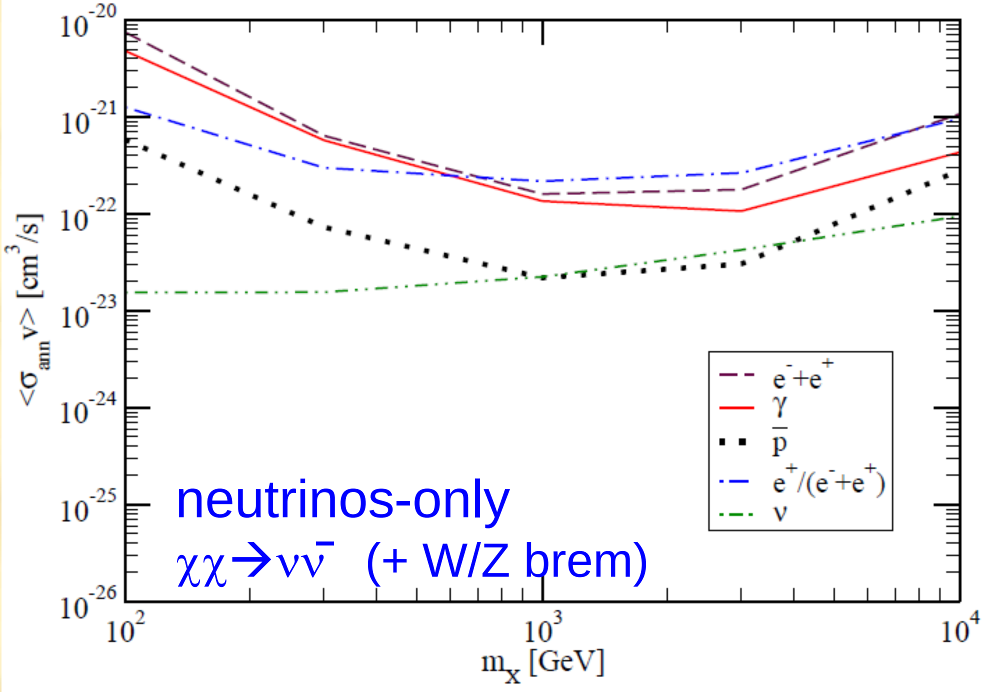
→EW-brem still occurs, but is subdominant

→W/Z decays ensures there is at least a minimal yield of hadrons, photons, charged leptons and neutrinos.

Kachelriess, Serpico and Solberg
PRD 2009.



electrons-only
$\chi\chi \rightarrow e^+e^-$ (+ W/Z brem)



neutrinos-only
$\chi\chi \rightarrow \nu\bar{\nu}$ (+ W/Z brem)

Higgs Bremsstrahlung

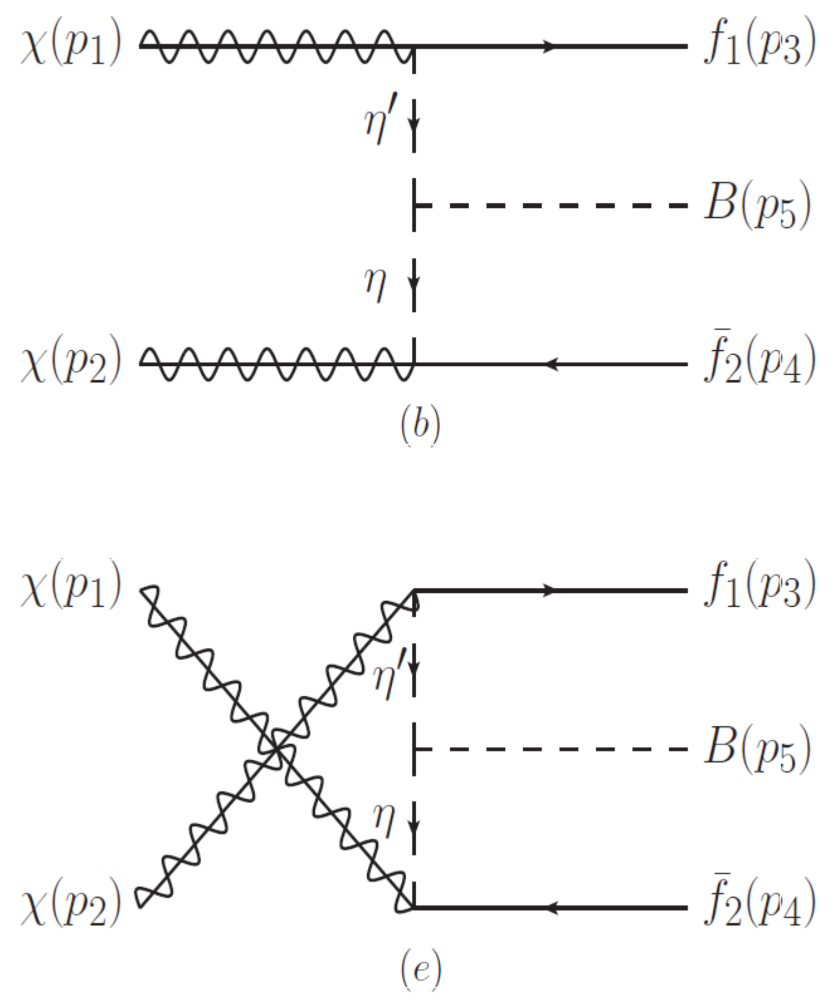
Can also open up an s-wave by radiating a Higgs boson!

F.Luo & T.You, arXiv: 1310.5129

$$\chi\chi \rightarrow H f \bar{f}$$

$$\lambda_D(\Phi^\dagger\Phi)(\eta^\dagger\eta) + \lambda_F(\Phi^\dagger\eta)(\eta^\dagger\Phi)$$

$\lambda_D=1$



Higgs Bremsstrahlung

F.Luo & T.You, arXiv: 1310.5129

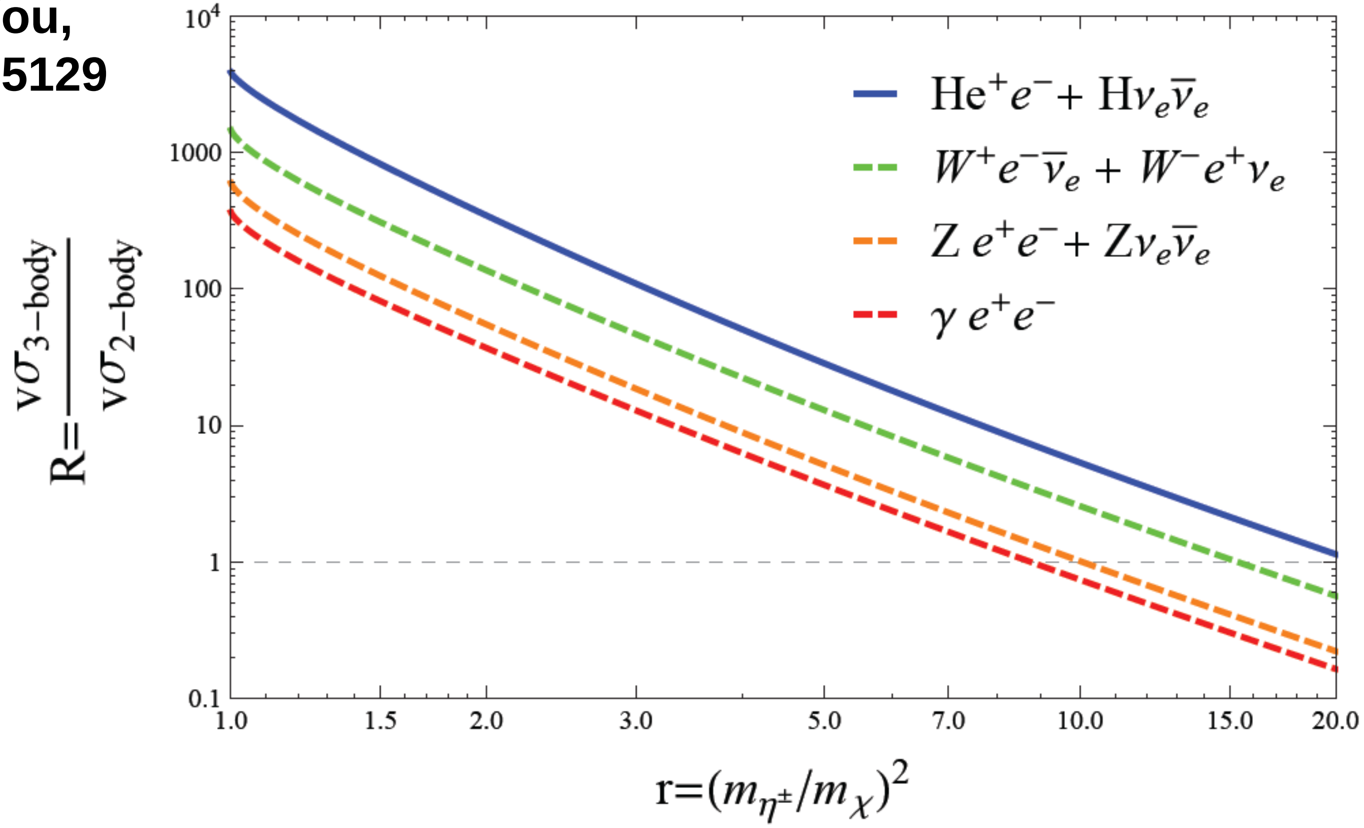


Figure 2: *DM annihilation cross-section to three-body final states* $H, W^\pm, Z, \gamma$ *by descending order of importance, normalised by the total two-body rate* $\sigma v(\chi\chi \to e^+e^-) + \sigma v(\chi\chi \to \nu_e\bar{\nu}_e)$*, as a function of various values of the mass of the mediating scalar* η *parametrised by* r*. Here* $m_\chi = 300\ GeV$, $\lambda_D = 1$, $\lambda_F = 0$ *and* $v = 10^{-3}$.

Linking dark matter and baryogenesis

Killing two birds with one stone…

Can we connect (i) Relic DM abundance
(ii) baryon-antibaryon asymmetry

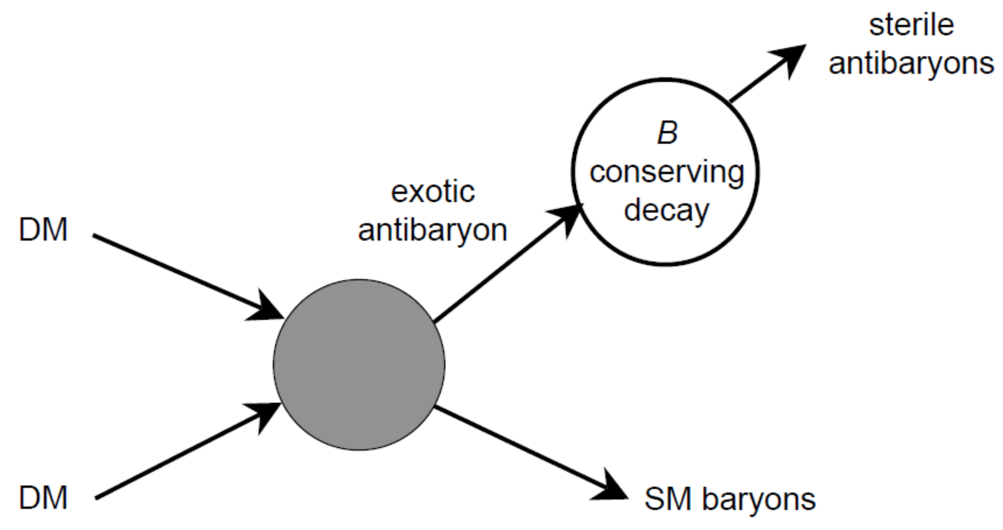
Various ideas: Asymmetric dark matter, WIMPy baryogensis, Baryomorphosis, DM assimilation, ……

	Asymmetric dark matter	WIMPy Baryogenesis
WIMP miracle	✗	✓
Explain $\Omega_{DM} \approx 5\Omega_b$	✓	✗

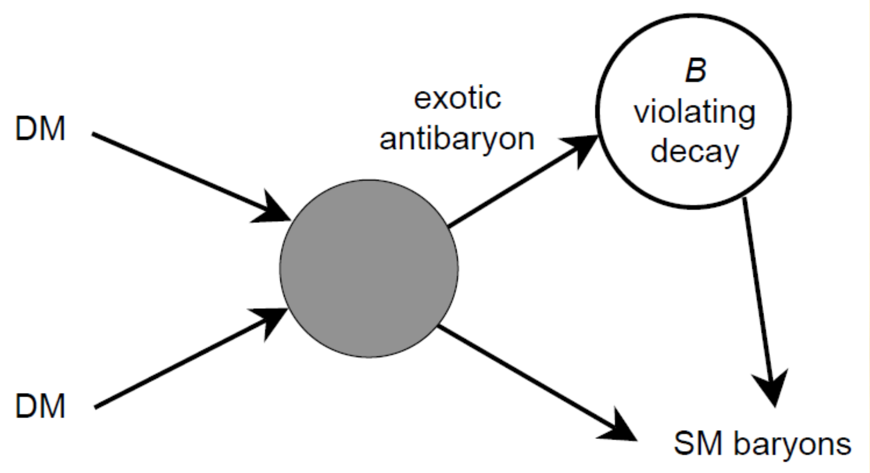
ADM: Many papers! See reviews by Petraki and Volkas 1305.4939 and Zurek 1308.0388.
WIMPy baryogenesis: Cui, Randall and Shuve, 1112.2704; Bernal et al., 1210.0094, Bernal et al., 1307.6878; Kumar & Stengel, 1309.1145
Baryomorphosis: McDonald 1009.3227 Dark matter assimilation: D'Eramo et al., 1111.5615

WIMPy Baryogensis

Require WIMP annihilation satisfy the Sakharov conditions
→ a baryon asymmetry can be generated from DM annihilations



DM annihilation creates asymmetry in exotic antibaryons, then sequestered in sterile sector



Asymmetry in exotic antibaryons, which decay to SM baryons

Cui, Randall and Shuve, 1112.2704

Asymmetric Dark Matter

Motivation: $\Omega_{DM} \approx 5\Omega_b$

Assume DM density set by a matter anti-matter asymmetry of the same size as the baryon asym.

then $n_{DM} \approx n_b$ (assuming complete asymmetry)

and $m_{DM} \approx 5m_b \approx 5$ GeV

❖ADM replaces $\Omega_{DM} \approx \Omega_b$ puzzle, with a $m_{DM} \approx m_b$ puzzle

Asymmetric Dark Matter

Requirements:

- A mechanism to simultaneously create B(visible) and B(dark) asymmetries, or create an asymmetry in one sector and communicate it to the other.

- A sufficiently large DM annihilation cross section to annihilate the symmetric part (to leave only particles and no antiparticles).

Implications:

- Light DM.
- No indirect detection (nothing to annihilate with)
- The physics that connects the dark and visible sectors may or may not be at an experimentally accessible energy scale.
- Large annihilation cross section means either sizeable couplings with SM particles, or else new light degrees of freedom.

ADM annihilation cross section

WIMPs - relic density set by annihilation cross section
ADM – relic density set by asymmetry, *provided annihilation cross section is big enough to remove the symmetric part* → still need a WIMP-like cross section!

Fractional asymmetry:

$$r \equiv \frac{n(\bar{\chi})}{n(\chi)}$$

$$r_\infty \approx \exp\left[-2\left(\frac{\sigma_0}{\sigma_{0,\mathrm{WIMP}}}\right)\left(\frac{1-r_\infty}{1+r_\infty}\right)\right] \xrightarrow{r_\infty \ll 1} \exp\left[-2\sigma_0/\sigma_{0,\mathrm{WIMP}}\right]$$

For $r_\infty < 0.1$, require:

$$\sigma_0 \gtrsim 1.4\,\sigma_{0,\mathrm{WIMP}}$$

Graesser et al., arXiv:1103.2771

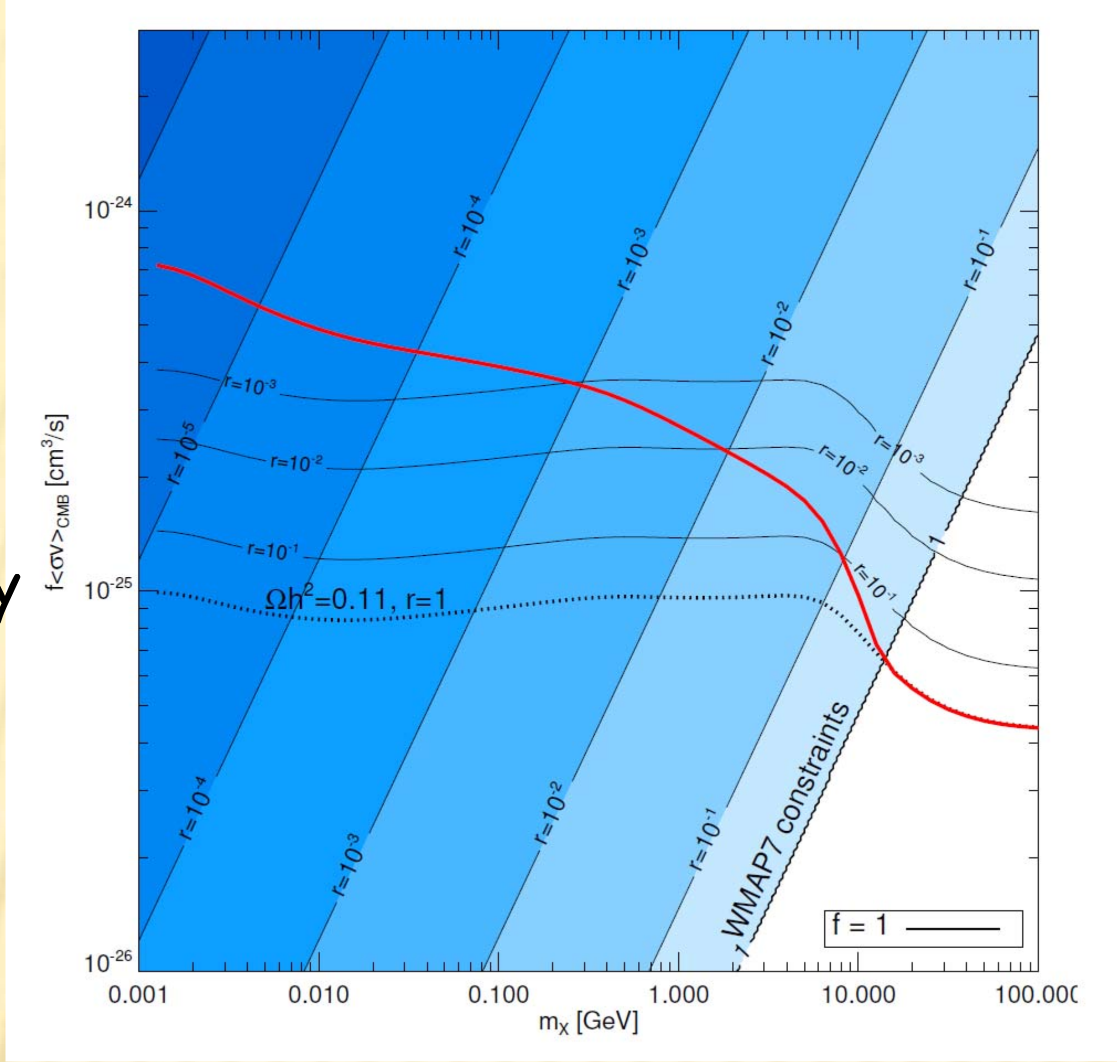
ADM and indirect detection

No indirect detection if r_∞ =0.

For $r_\infty \neq 0$,
suppression factor of:

$$\frac{\sigma_0}{\sigma_{0,\mathrm{WIMP}}} \frac{4\,r_\infty}{(1+r_\infty)^2}$$

Need small r_∞ to satisfy CMB indirect detection constraints
→ *Lower limit on σ*



Lin et al., arXiv:1111.0293

ADM and neutron stars

DM-nucleon scattering → capture of DM by neutron stars

ADM (or other non-annihilating DM) would accumulate with no cap, eventually causing collapse to a black hole.

Detailed constraints depend sensitively on whether:
-fermionic/bosonic DM
-repulsive/attractive DM self interactions
-possible annihilations or co-annihilations

Kouvaris and Tinyakov; McDemott Yu and Zurek; Guver, Erkoca, Reno and Sarcevic, Bramante, Fukushima and Kumar; Bell, Melatos and Petraki; Bertoni, Nelson and Reddy.

Evolution of DM in a neutron star

- Capture - DM-nucleus scattering

- Thermalisation – energy loss from further scattering, DM accumulates in a small thermal sphere.

- Self gravitation (and BEC formation) – occurs when enough DM has accumulated to overwhelm the NS gravity (in the small thermal sphere). Bosonic DM can form a Bose-Einstein condensate → self gravitation occurs sooner

- Collapse – when number of self gravitating DM particle exceeds Chandrasekhar limit.

- The black hole grows by accretion or evaporates

Chandrasekhar limits

Bosons:

$$N^b_{\rm Cha} \approx \frac{2M^2_{\rm Pl}}{\pi m^2}$$

Bosons
+ repulsive self interactions

$$N_{\rm Cha} = \frac{2M^2_{\rm Pl}}{\pi m^2_\chi}\left(1 + \frac{\lambda_4}{32\pi}\frac{M^2_{\rm Pl}}{m^2_\chi}\right)^{1/2}$$

Self interactions dominate if:

$$\sigma \gg M^4_{\rm Pl}/m^2 \sim 10^{-104}\,{\rm cm}^2 (m/{\rm GeV})^{-2}$$

Fermions:

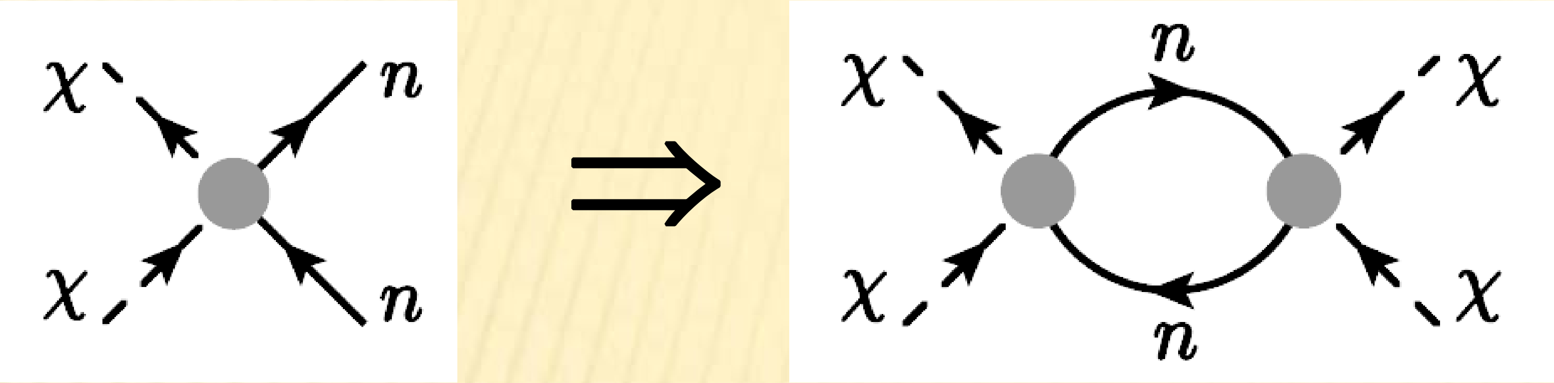
$$N^f_{\rm Cha} \approx \left(\frac{M_{\rm Pl}}{m}\right)^3$$

Fermions
+ attractive self interactions → decrease N

Bramante et al.
1310.3509

Self interactions are inevitable…

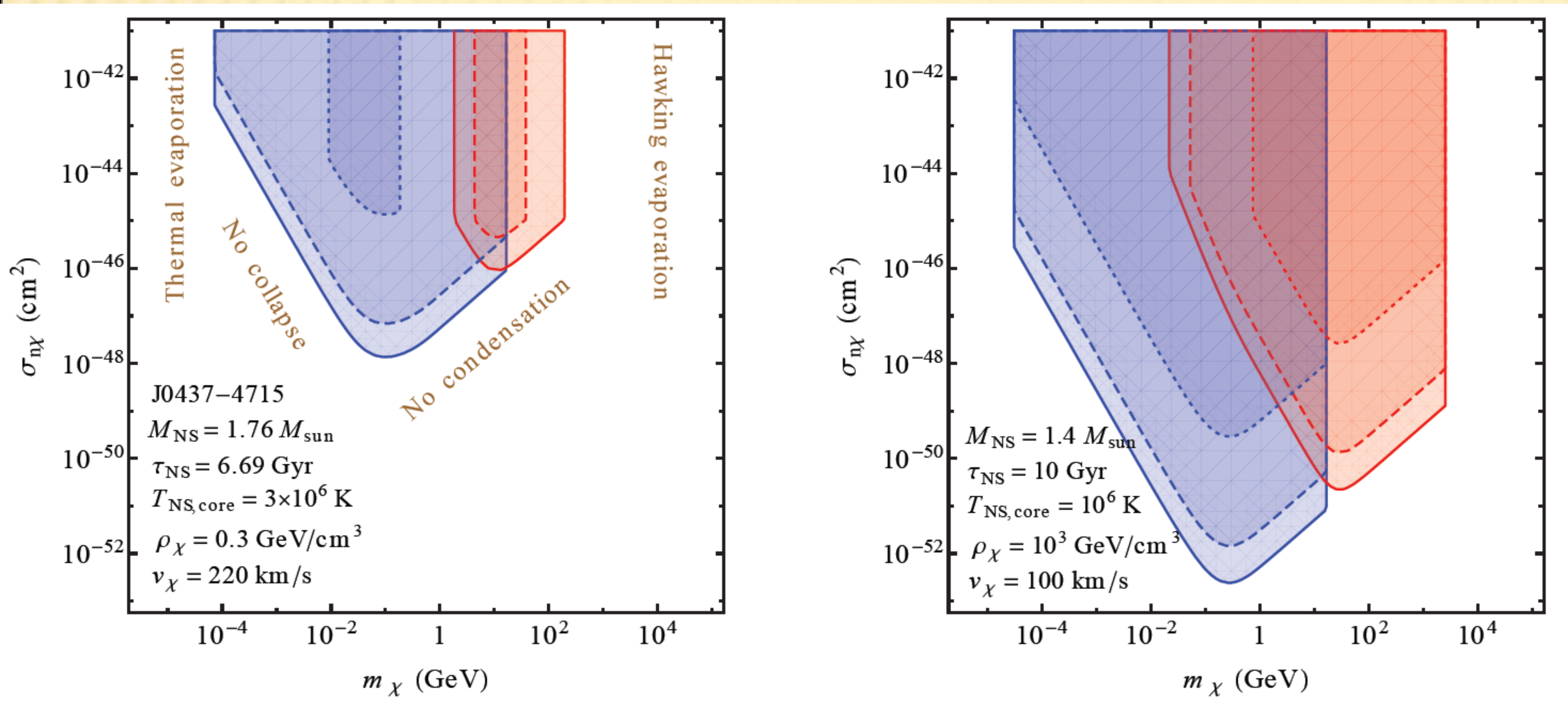
A $\lambda\chi^4$ term cannot be forbidden. Moreover, if DM scatters from nucleons, a $\lambda\chi^4$ term must be generated.



But this is conservative, in many models the DM-nucleon and DM-DM cross section will be of similar size.

Bell, Petraki and Melatos: 1301.6811

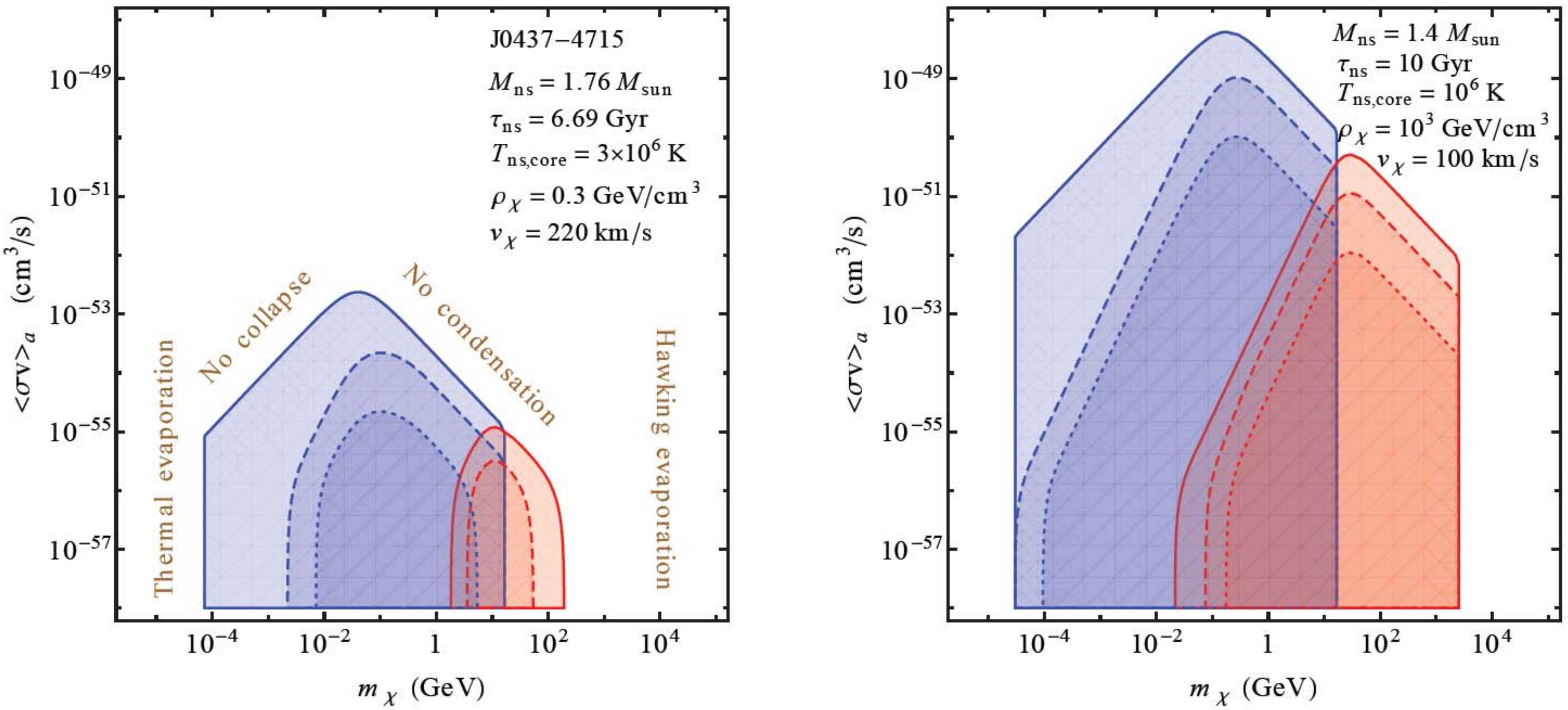
Neutron star bounds on the DM-nucleon scattering cross section



Blue – no self interactions
Red – self interactions

Bell, Petraki & Melatos: 1301.6811

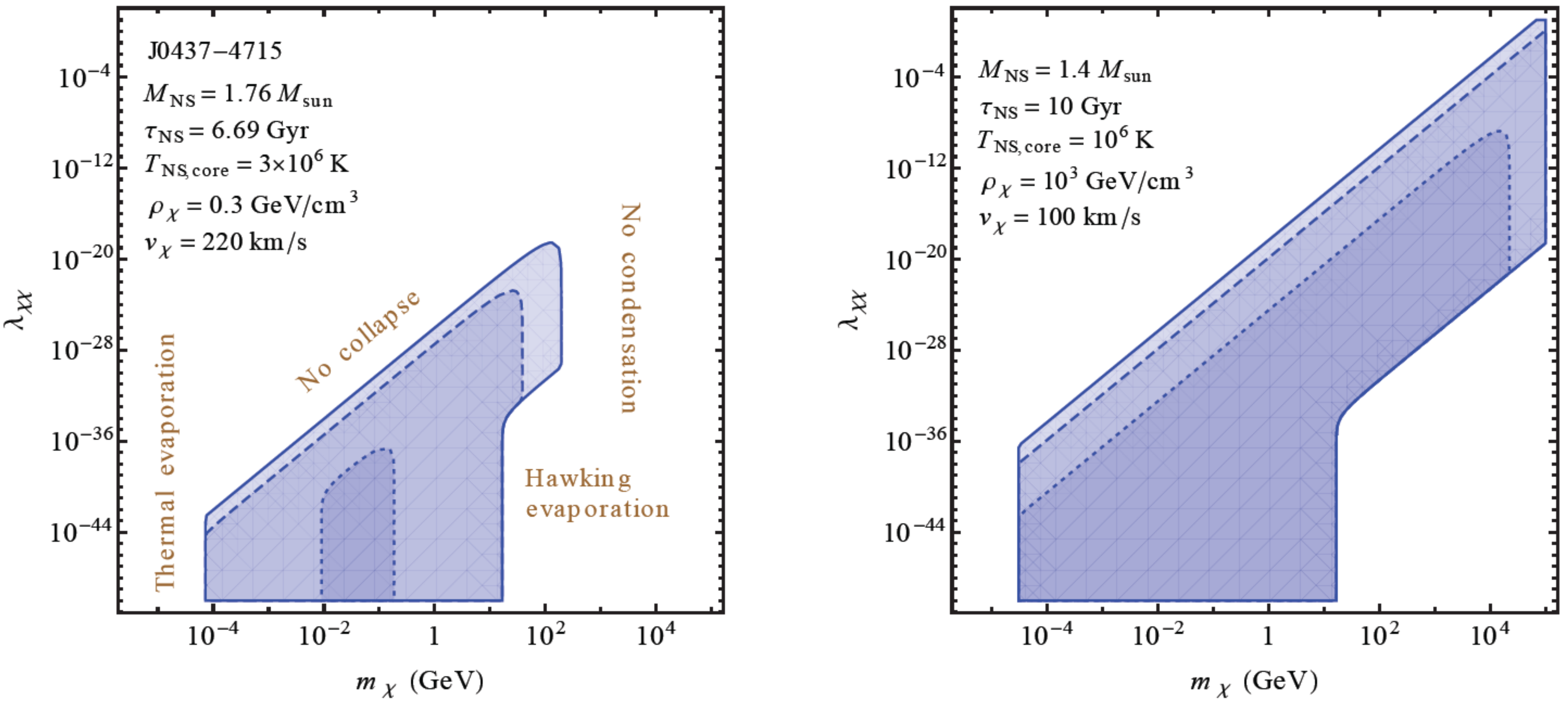
Bounds on the DM-nucleon co-annihilation cross section



Blue – no self interactions
Red – self interactions

Bell, Petraki & Melatos: 1301.6811

Bounds on the DM self-coupling



Bell, Petraki & Melatos: 1301.6811

Neutron star bounds on bosonic DM are not applicable if:

- Repulsive self-coupling is sufficiently large:

$$\lambda_{\chi\chi} \gtrsim \left.\frac{(2\pi)^3 M_{\rm capt}^2 m_\chi^4}{M_{\rm Pl}^6}\right|_{m_\chi \sim 200\ {\rm GeV}} \sim 10^{-18}$$

$$\sigma_{\chi\chi} \gtrsim 10^{-70}\ {\rm cm}^2$$

This is a very tiny cross section!

OR
- Co-annihilation cross section is sufficiently big:

$$\langle \sigma v \rangle_a \gtrsim 10^{-52}\ {\rm cm}^3/\,{\rm s}$$

Note: Similar result for annihilation cross section – Bramante 1301.0036

OR
- DM-nucleon scattering cross section is sufficiently small:

$$\sigma_{n\chi} \lesssim 10^{-48}\ {\rm cm}^2$$

Most of the interesting parameter space is not ruled out!

Outlook

- WIMPs…is this idea compelling, or are we searching under the lamp post?

- ADM…is the similarity of the dark and visible matter densities an important clue, or just a red herring?

- EFT…useful, but limited in validity. Need more collider analyses of UV complete models.

- Colliders…stay tuned to LHC monojet searches AND other exotics searches