Status of WIMPs

Experimental situation and implications for “the Theory”

Journée Matière Sombre 2017, LPNHE

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What I'll try to summarise

- WIMPs: where we stand and where to go

Why WIMPs ?

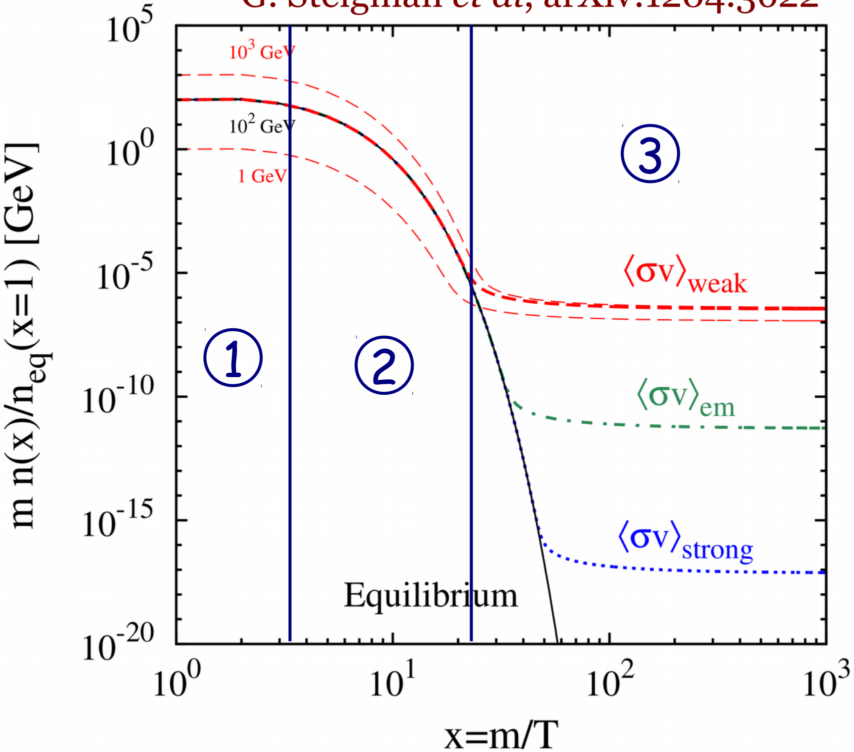
Why have WIMPs received so much attention?

· Things happens at the EW scale (Z, Higgs...) and some BSM physics could exist nearby.

· If a particle couples strongly enough to the SM, it was once in equilibrium with it.

· Such species freeze-out and the abundance of frozen-out WIMPs is the one observed by Planck.

G. Steigman *et al*, arXiv:1204.3622



Physically:

① DM + DM ↔ SM + SM efficient in both directions.

② DM + DM ← SM + SM disfavoured.

③ $n_{DM} <\sigma v> < H$: Equilibrium lost → Freeze-out.

Moreover:

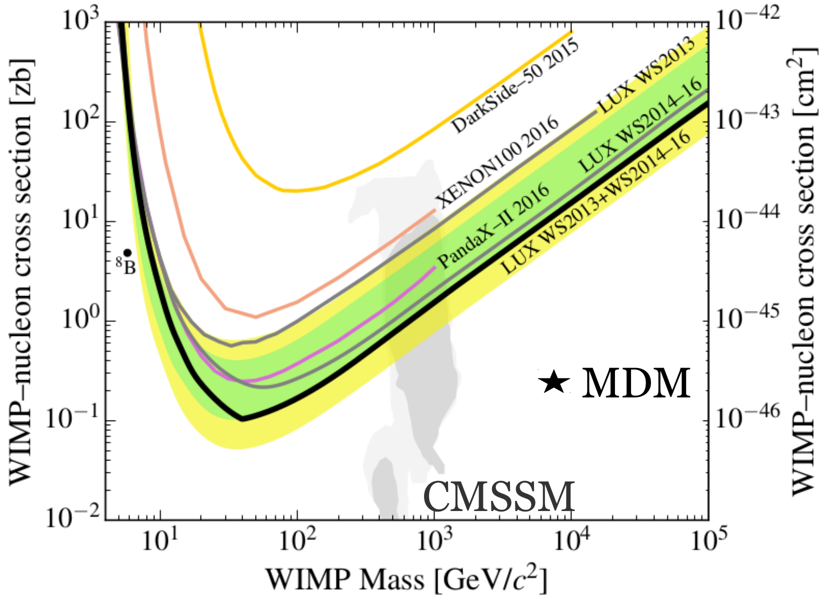
WIMP models predict observable signals

(well, sometimes...)

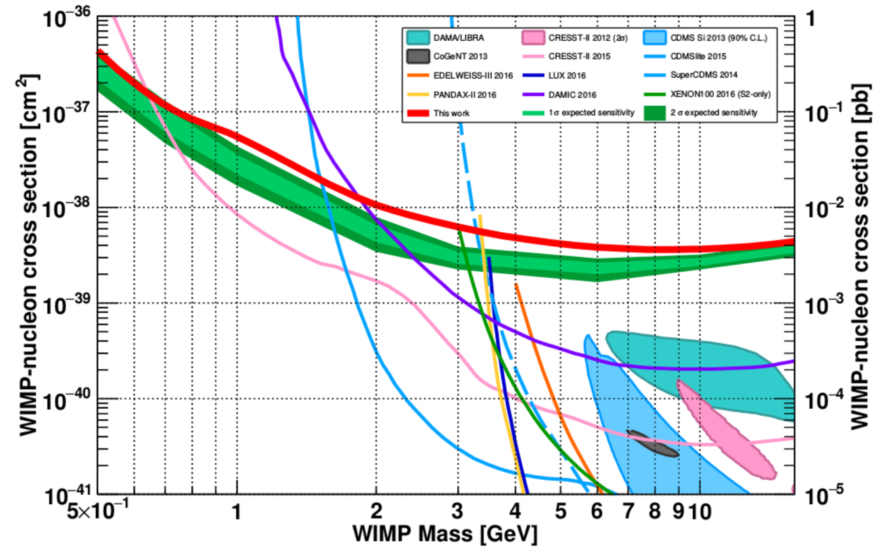
Direct detection

State-of-the-art of conventional DD searches

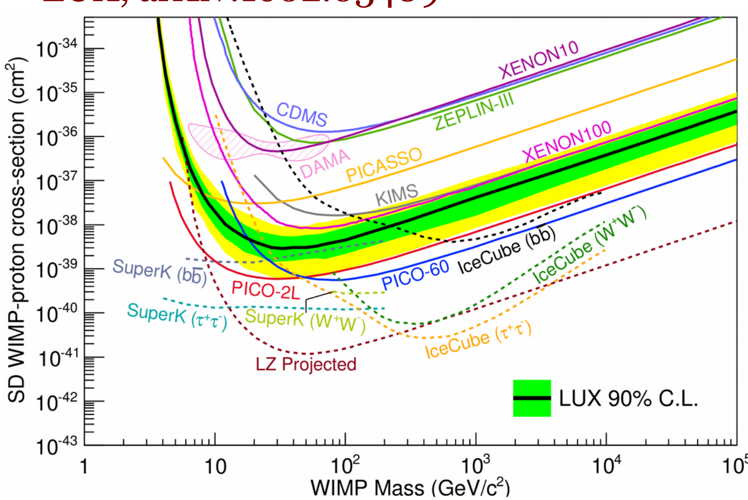
LUX, arXiv:1608.07648

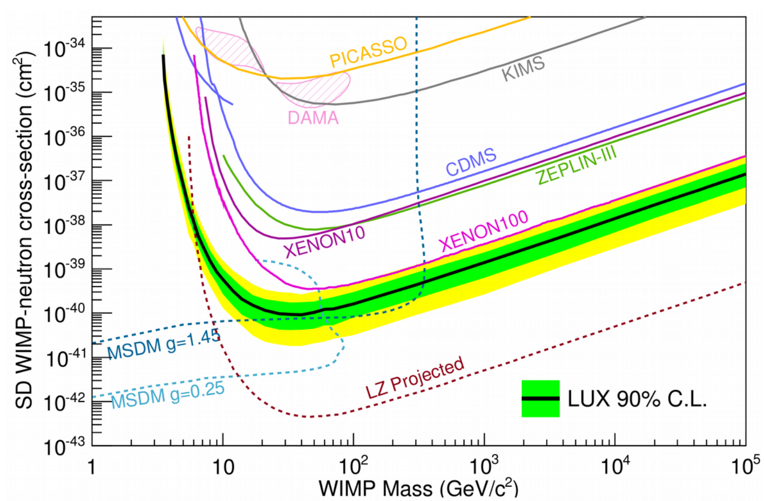


NEWS-G, arXiv:1706.04934



LUX, arXiv:1602.03489





Testing actual (“well-motivated”) dark matter models!

- How low can we go?

Indirect detection : gamma-rays

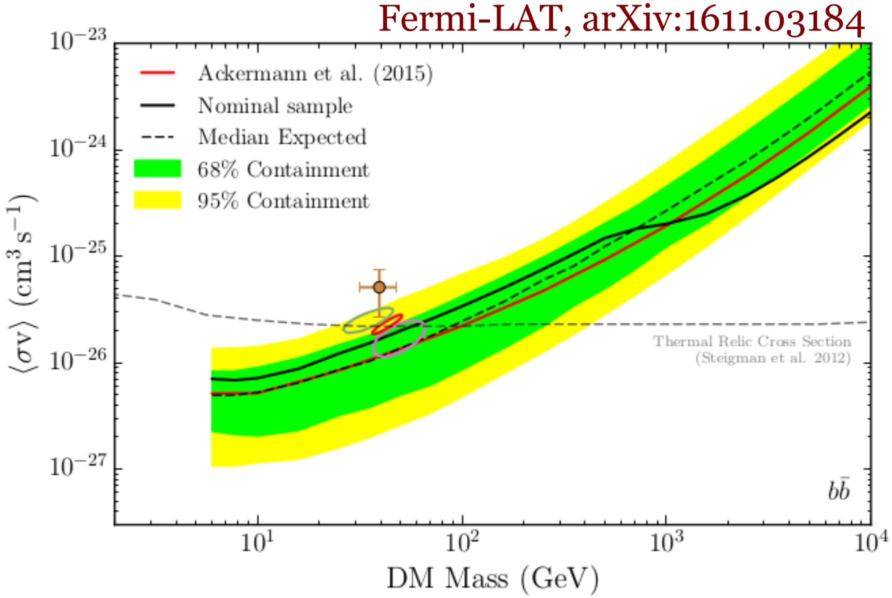
Expected gamma-ray flux

$$\Phi_\gamma(E\gamma, \Omega) = \underbrace{\left[\frac{dN_\gamma}{dE_\gamma}(E_\gamma)\frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\right]}_{\text{Particle physics}} \underbrace{\int_{\text{los}} \rho^2(l, \Omega) dl}_{\text{Astrophysics}}$$

Continuum

Fermi-LAT limit from dSPhs

Fermi-LAT, arXiv:1611.03184

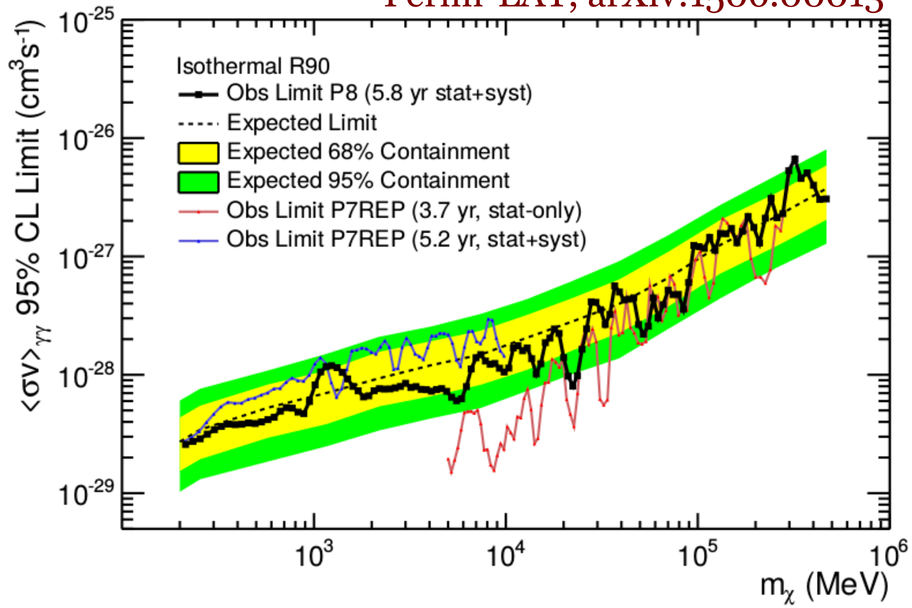


Currently probing the WIMPy regime

Spectral features

Fermi-LAT limit from Galactic Centre

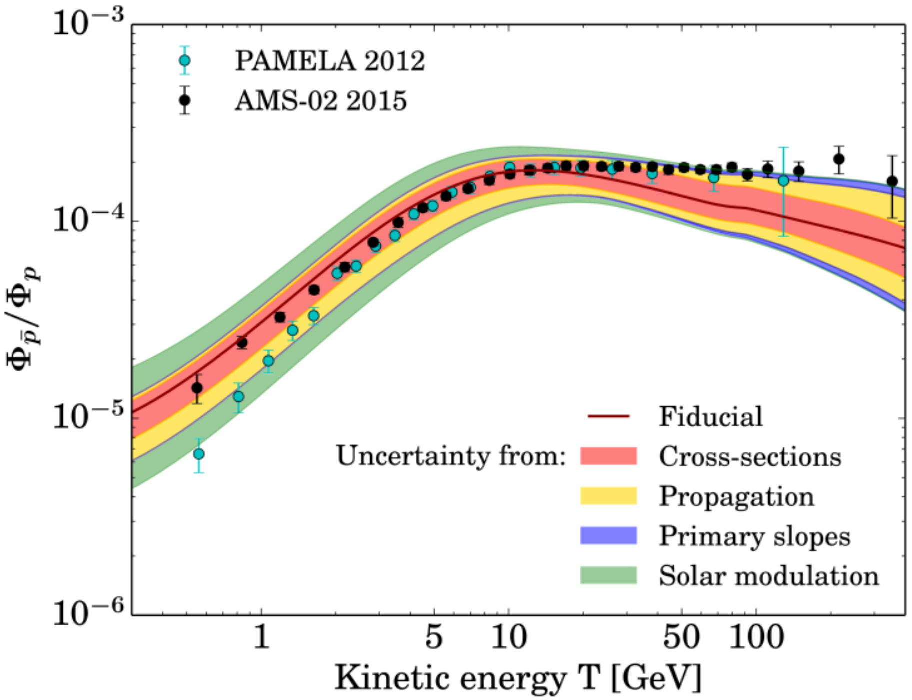
Fermi-LAT, arXiv:1506.00013



(Limit stronger by up to one OOM for cuspier halos.)

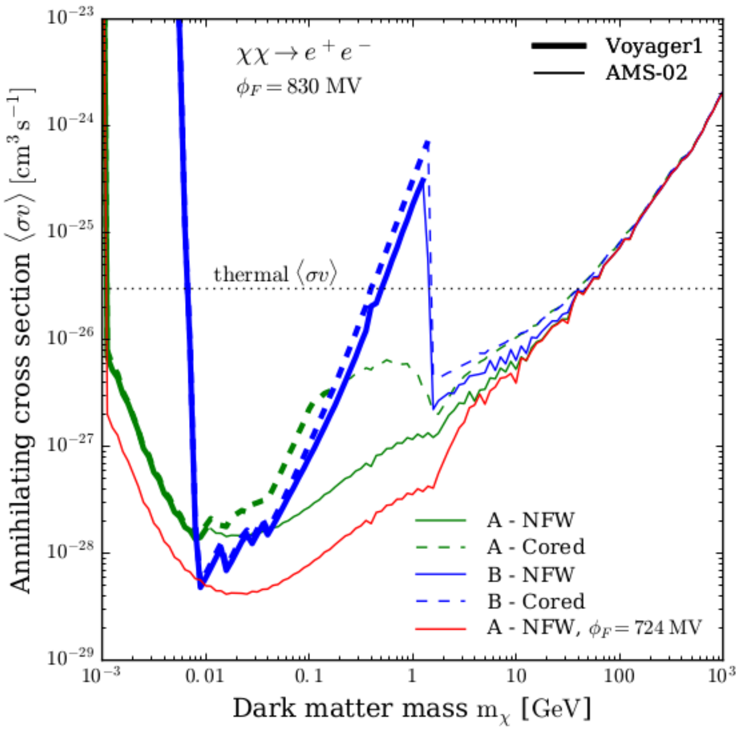
Indirect detection : cosmic rays

Antiprotons



G. Giesen *et al*, arXiv:1504.04276
cf also R. Kappl *et al*, arXiv:1506.04145

Positrons



M. Boudaud, J. Lavalle, P. Salati, arXiv:1612.07698

· Ensuing constraints comparable to those from dSPhs.

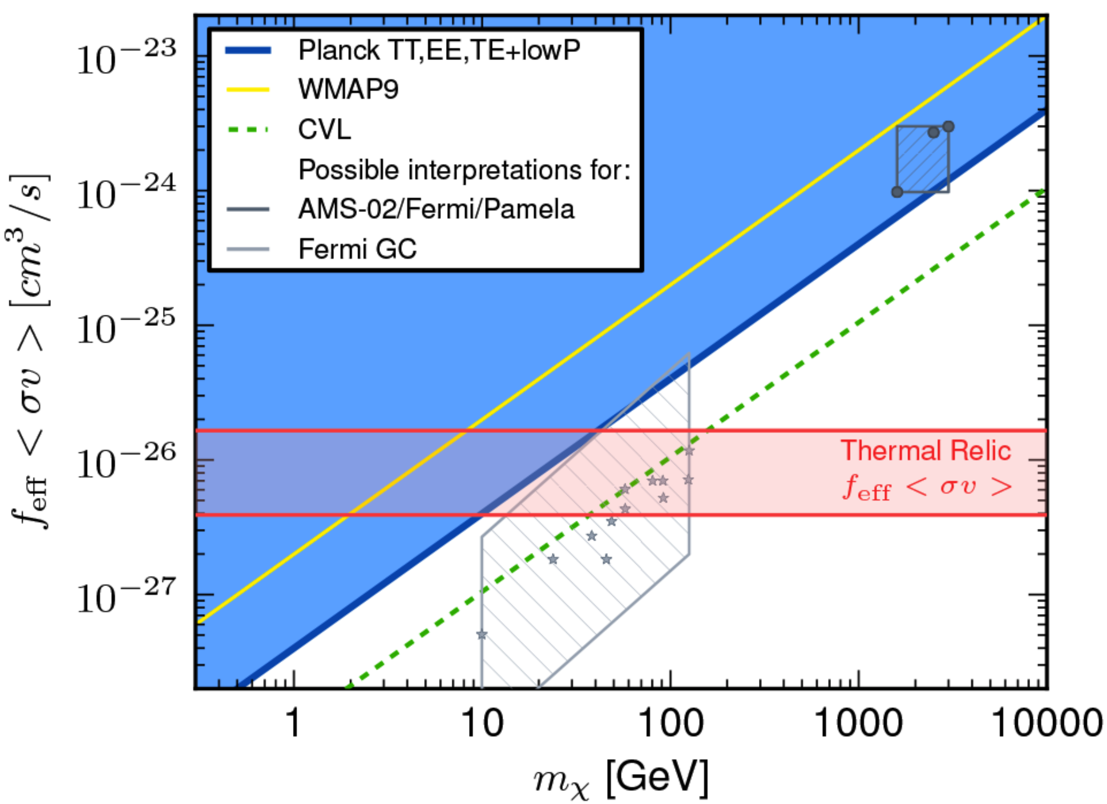
· But more uncertain (cross-sections, propagation).

· Constraints on low-mass WIMPs from combination of AMS-02 and Voyager.

CMB constraints on DM annihilation

The CMB doesn't only provide a measurement of the DM abundance, it can also constrain dark matter annihilations at the time of its formation.

Planck collaboration, arXiv:1502.01589



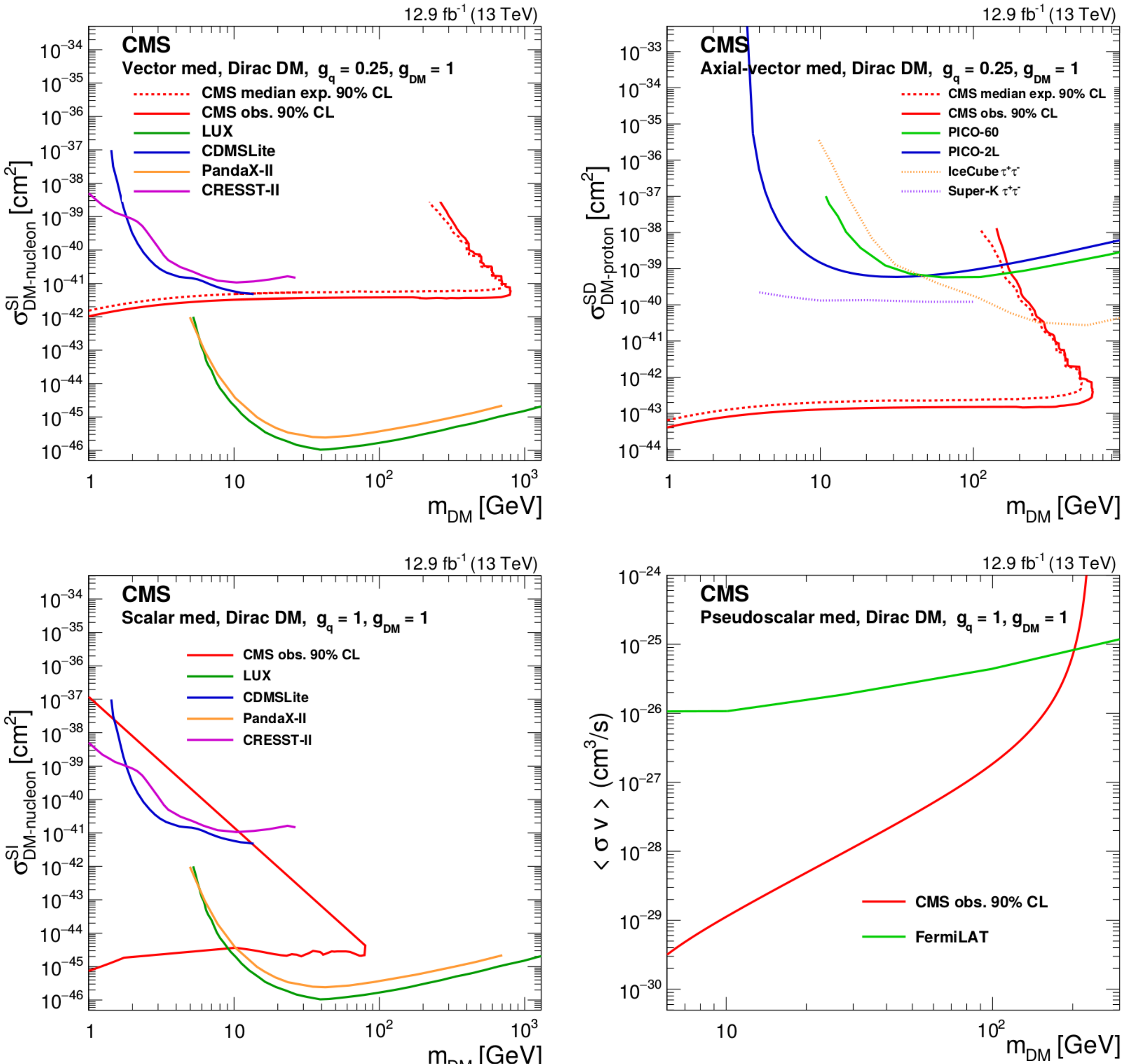
· Robust bound from modification of recombination history due to DM annihilation – induced energy injection.

· Excludes m_{DM} < 10 GeV assuming *s*-wave annihilation, unless dominant annihilation into neutrinos.

Global note for bounds on <σv> : Indirect detection constrains $\langle\sigma v\rangle_{today}$. The CMB $\langle\sigma v\rangle_{CMB}$. These can be different than $\langle\sigma v\rangle_{freeze\text{-}out}$ (larger/smaller).

Large Hadron Collider: dark matter searches

Most celebrated LHC dark matter searches: mono-X



CMS, arXiv:1703.01651

- Crucial assumption: $m_{DM} < m_{Med}/2$.

  Otherwise these limits vanish

- Robust handle on light DM.

  As long as the previous assumption holds

- Relatively insensitive to the underlying Lorentz structure.

  Very strong point, notice how the y-axes change!

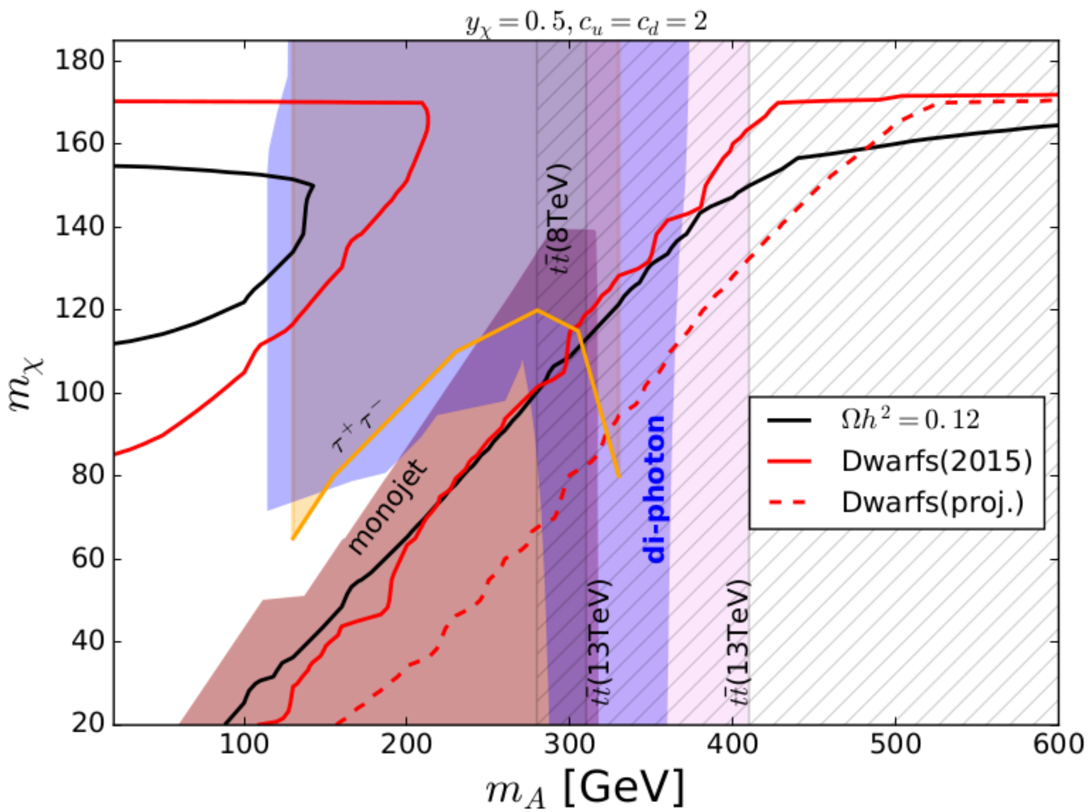
- When direct detection works, it dominates.

  But sometimes it doesn't work

What about the off-shell region?

Large Hadron Collider: mediator searches

In the off-shell region, standard LHC searches for resonances become relevant:



S. Banerjee, D. Barducci, G. Bélanger, B. Fuks, A. G., B. Zaldivar, arXiv:1705.02327

· Simple model of Majorana dark matter χ + Higgs-like pseudoscalar mediator A.

· Limits from: monojets, di-t/b + MET, di-t, di-τ, γγ, indirect detection.

· Bounds can be relaxed by reducing the mediator couplings to the SM.

· To keep in mind: light mediators are the trickiest ones.

LHC searches complementary with direct/indirect detection but also amongst *themselves*!

So, what's the status of WIMPs ?

For a recent review *cf* also G. Arcadi et al, arXiv:1703.07364

Remember that overcoming constraints is what BSM theorists do for a living. This said:

· It is not possible to couple DM to the visible sector only through the SM Higgs, unless $m_{DM} \sim m_h/2$ or $m_{DM} > 1\text{-}2$ TeV.

Direct detection + invisible Higgs width, limit even stronger for fermion DM, will be probed by LZ.

· Coupling DM to the visible sector only through the SM Z imposes very specific Lorentz structures.

Direct detection + invisible Z width, scalar DM completely excluded unless multi-TeV, vector DM allowed for some cases if mDM > 800 GeV, will be probed by LZ. Less constrained: fermion DM w/ axial vector couplings, will be partly probed by LZ (SD).

· Generic scalar mediators are excluded up to 300-500 GeV and m_{DM} is pushed in the few hundred GeV region.

Direct detection, exact numbers are model-dependent, can be improved substantially.

· Generic vector mediators are much more constrained (mediator + DM > TeV).

Due to couplings to u,d, LHC + direct detection.

· Pseudoscalar mediators are less constrained, but there *are* constraints.

Indirect detection + LHC.

So, what's the status of WIMPs ?

Remember that overcoming constraints is what BSM theorists do for a living.

However, we *should* keep this in mind: the situation can be substantially more complicated in actual dark matter models (combinations of couplings, additional annihilation channels and so on). Simplified models are there to give *a general idea* about where we stand!

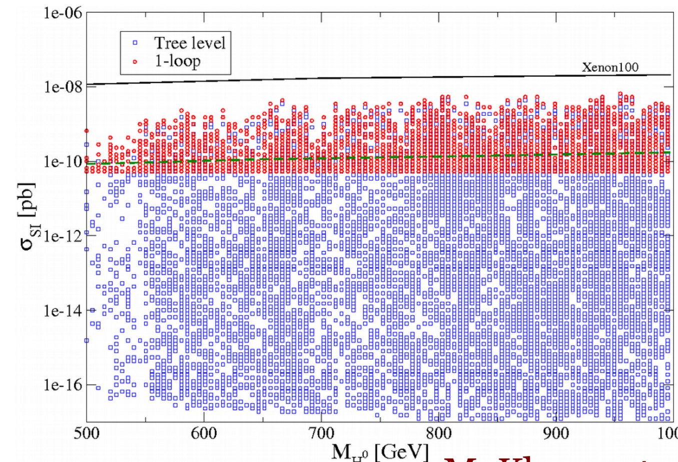
Where do we go from here ?

So what's left of the WIMP parameter space?

· There is still some room to play within the ***O***(10^2 GeV) WIMPy region. But not too much.

· There are "singular points" in most models: coannihilation, funnels.

· But: funnels are regularised by widths and in many cases radiative corrections can be important.



M. Klasen *et al*, arXiv:1302.1657

What about going beyond the traditional WIMP parameter space?

· Heavy (> TeV) dark matter is still a perfectly viable option. Direct detection can constrain it.

· Light (sub-few GeV) dark matter too, especially with light mediators. It's also a ballpark to test new ideas and new technologies (superfluid He, superconducting detectors etc).

…and now for something completely different…

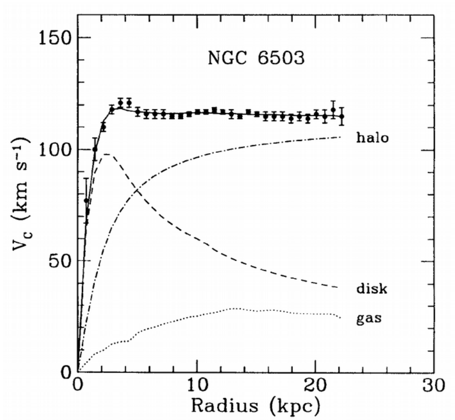
cf Yann’s talk

What we know about dark matter

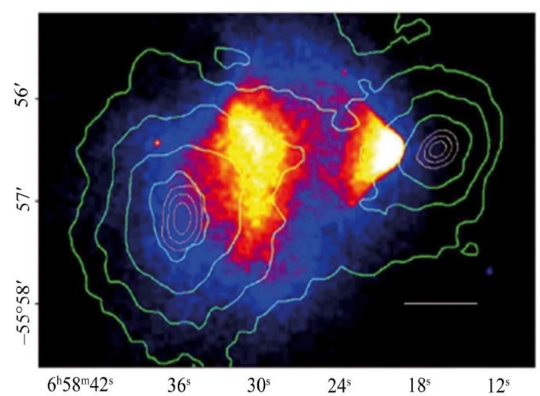
We know a few main things about dark matter :

- It **exists** (multiple scales) and it **gravitates** (all evidence based on gravitational effects)

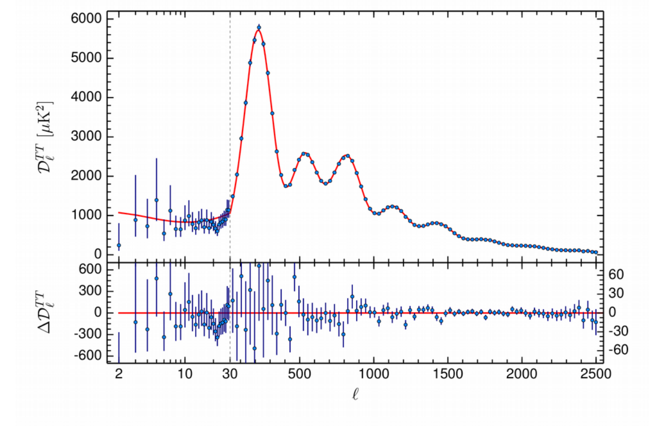
Galaxies



Galaxy clusters



CMB



- It **doesn't interact** with **photons** (much)

- It's **cold** (structure formation), and (pretty) **stable**.

- Its **abundance** within vanilla ΛCDM cosmology: $\Omega_{\rm DM} h^2 = 0.1187 \pm 0.0012$

- If it's made out of ("particle physics") particles, they have to be **BSM** ones