Dark matter from dark gauge groups

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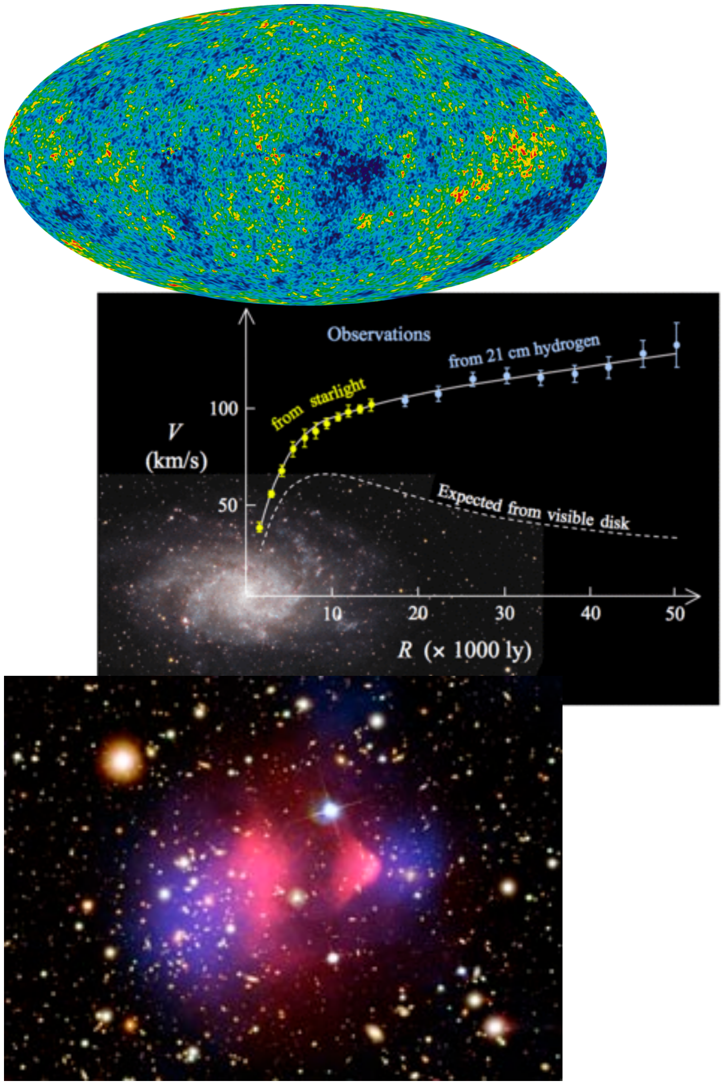
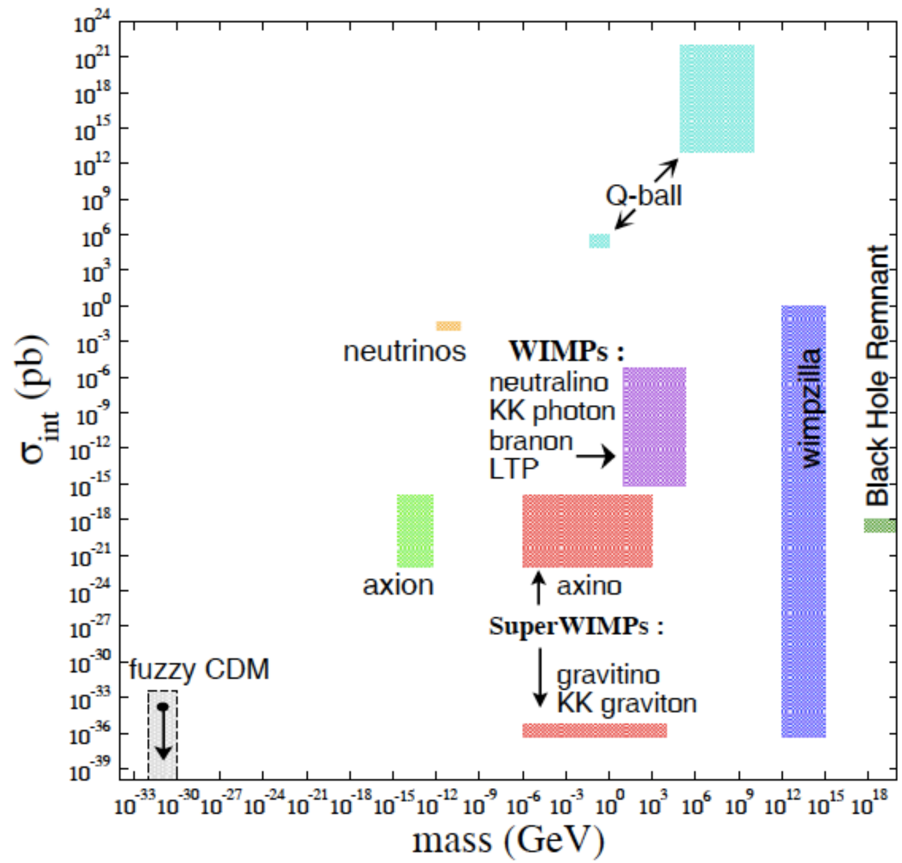
Based on work with G. Arcadi, O. Lebedev, Y. Mambrini, S. Pokorski, T. Toma

We know DM exists:



....but we have no clue what kind of particle(s) DM consists of:



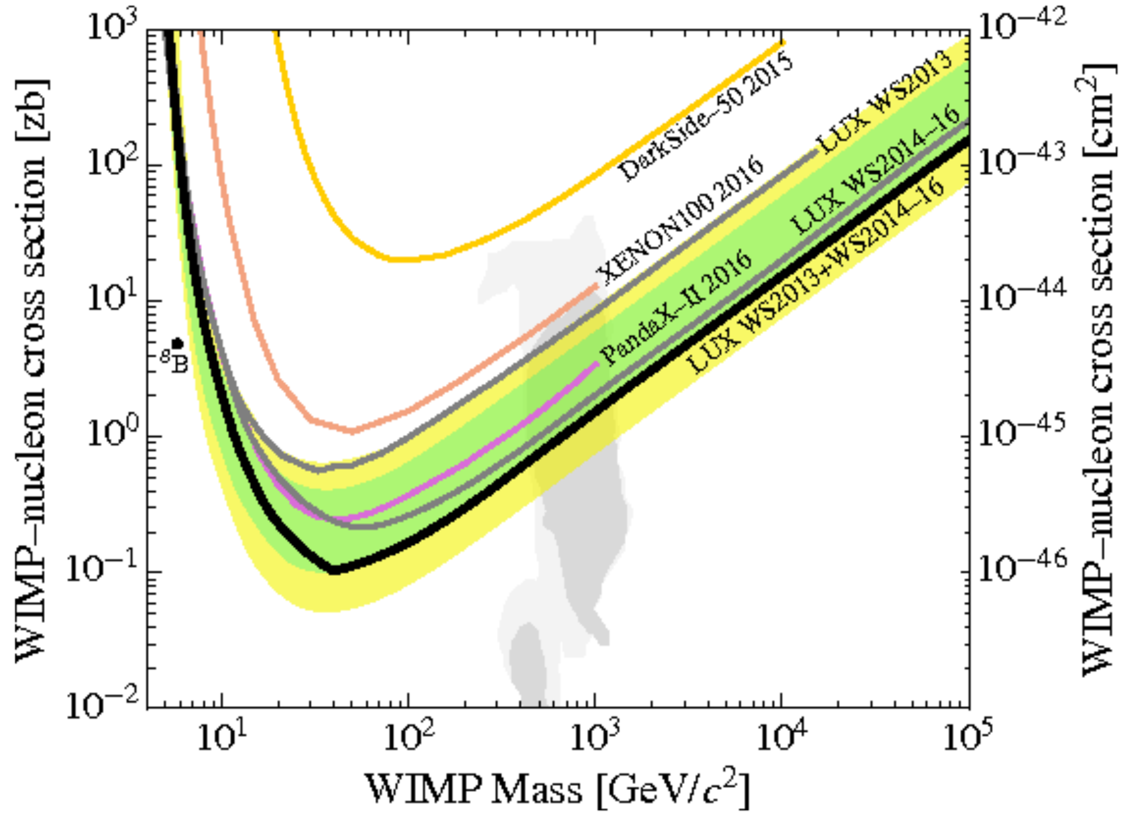
[figure taken from E.-K. Park, contribution to DMSAG report, July 18, 2007. http://science.energy.gov/hep/hepap/reports/]

why WIMPs are popular

- the WIMP miracle

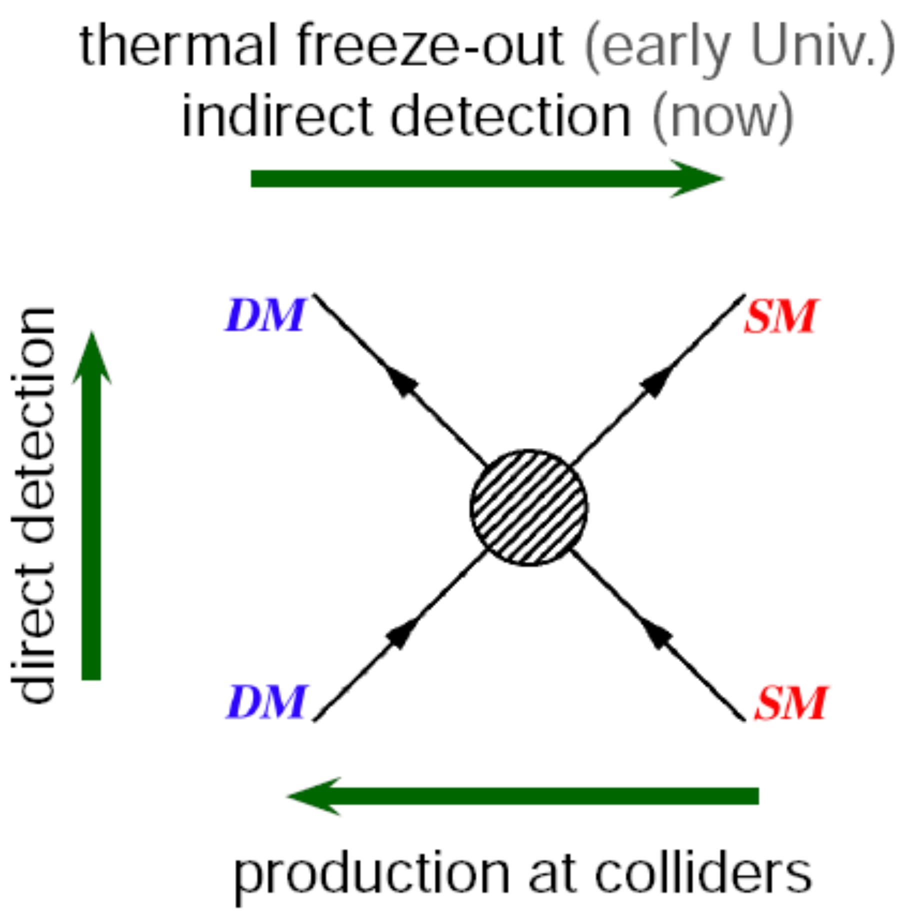
→ link to TeV scale BSM physics

- huge efforts to search for WIMPs in direct detection experiments



[LUX, 1608.07648]

why simple WIMP DM models are under pressure

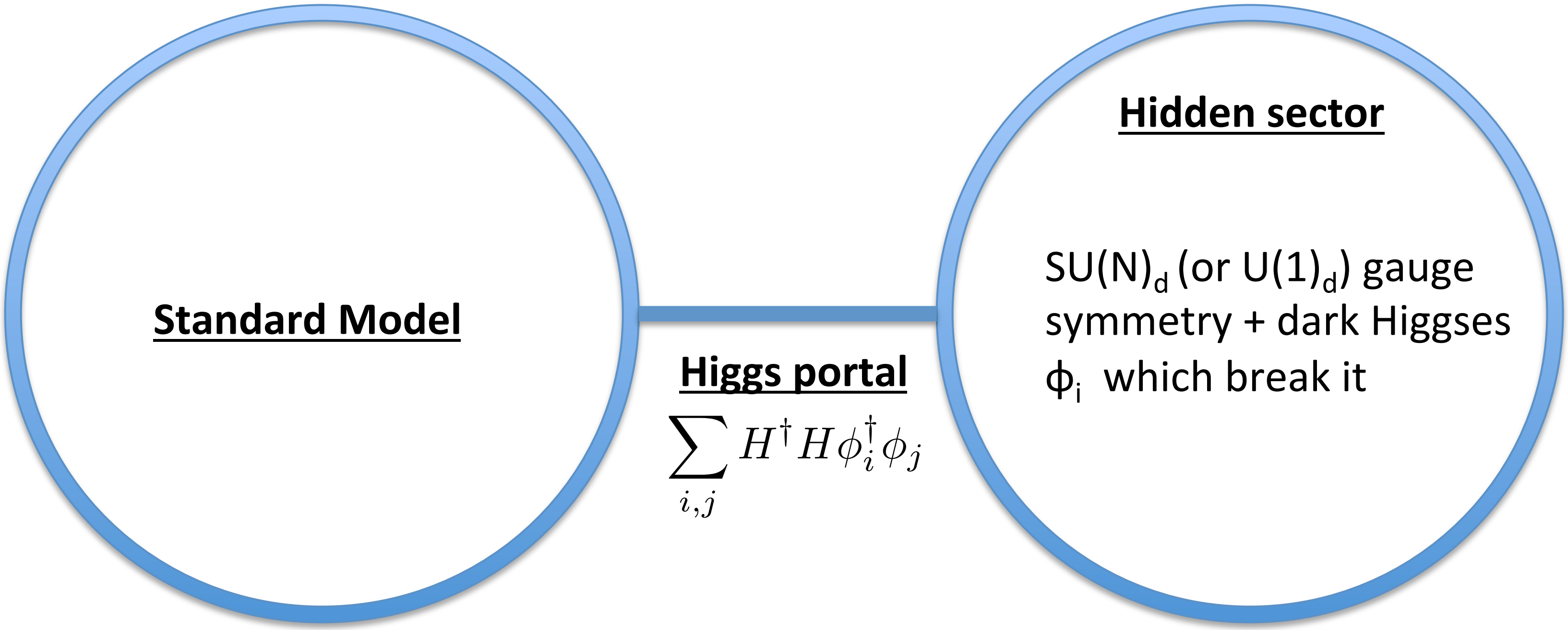


[image: www.mpi-hd.mpg.de/lin/research_DM.en.html]

- reason for tension in simplest models:
  DD limits require small coupling
  → small <σ v>
  → WIMPs overabundant due to $\Omega \propto 1/\langle \sigma v \rangle$

- need to break the `crossing symmetry', e.g. by:
  - resonant DM annihilation
  - additional annihilation channels into the dark sector
  - cancellation among different direct detection diagrams
  - ...

WIMP DM from hidden gauge groups



[Alternative to spontaneously broken $SU(N)_d$: Confining hidden sector → hidden glueball DM]

plan for the rest of the talk:

① why the massive gauge fields are stable

② three ways to naturally reconcile direct detection limits and relic abundance

stability $U(1)_d$ vector dark matter

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$$

ϕ: complex scalar
$\phi = \frac{1}{\sqrt{2}}(\tilde{v} + \rho)$ in unitary gauge

A_μ is stable due to charge-conjugation symmetry:
$$\begin{cases} \phi \to \phi^* \\ A_\mu \to -A_\mu \end{cases}$$

[Lebedev,Lee,Mambrini, 2011]

stability $SU(2)_d$ vector dark matter [cf. Hambye, 2008]

$$\mathcal{L}_{\text{dark}} = -\frac{1}{4}\sum_{a=1}^{3} F^a_{\mu\nu} F^{a\mu\nu} + |D_\mu \phi|^2 - V(\phi)$$

ϕ: **2** of $SU(2)_d$

$\phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \tilde{v} + \rho \end{pmatrix}$ in unitary gauge

$A^a_\mu \rightarrow - A^a_\mu$ is <u>not</u> a symmetry, due to triple gauge boson vertex

stability $SU(2)_d$ vector dark matter [cf. Hambye, 2008]

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since the generators are $\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$

charge conjugation symmetry acts as

$$Z'_2: \begin{cases} \phi \to \phi^* \\ A^1_\mu \to -A^1_\mu \\ A^3_\mu \to -A^3_\mu \end{cases}$$

- Z'_2 reflects gauge fields corresponding to <u>real</u> generators T^a
- Reason for invariance of $(F_{\mu\nu})^2$: $T^a \rightarrow -(T^a)^*$ is an automorphism of SU(N)

stability $SU(2)_d$ vector dark matter [cf. Hambye, 2008]

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$$Z_2: \begin{cases} A^1_\mu \to -A^1_\mu \\ A^2_\mu \to -A^2_\mu \end{cases}$$

- Z_2 reflects gauge fields corresponding to generators T^a with nonzero off-diagonal entries in the first row
- Underlying reason for invariance: it's a remnant of $SU(N)_d$ gauge symmetry

stability $SU(N\geq3)_d$ vector dark matter

assuming CP invariance and minimal hidden Higgs sector:
have Z_2 x Z'_2 symmetry, analogous to $SU(2)_d$

→3 DM particles
(3 vectors or 2 vectors and 1 CP-odd scalar)

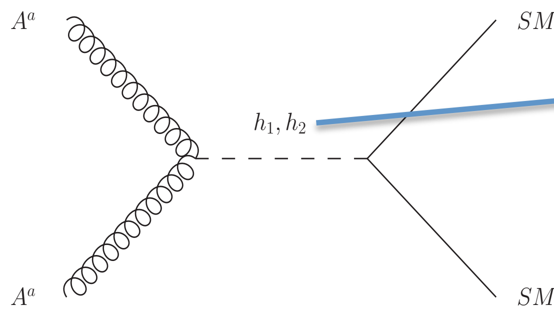
plan for the rest of the talk:

① why the massive gauge fields are stable

② three ways to naturally reconcile direct detection limits and relic abundance

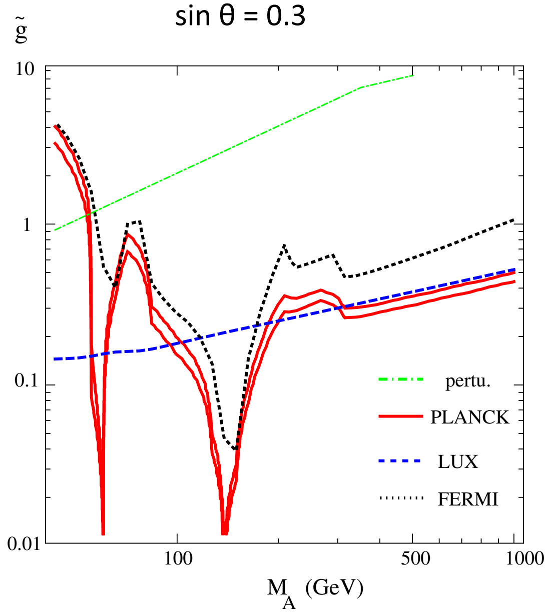
a) DM annihilation via (broad) resonances

DM annihilation
vis s-channel Higgses:

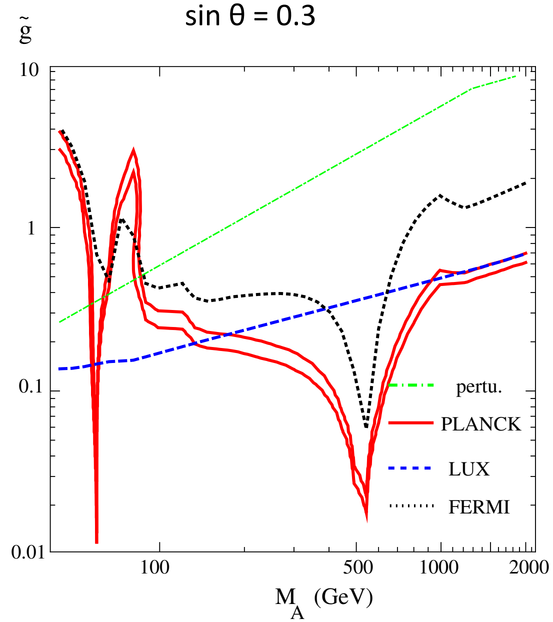


h_1, h_2: mass eigenstates of dark Higgs and $SU(2)_L$-Higgs, with mixing sin θ

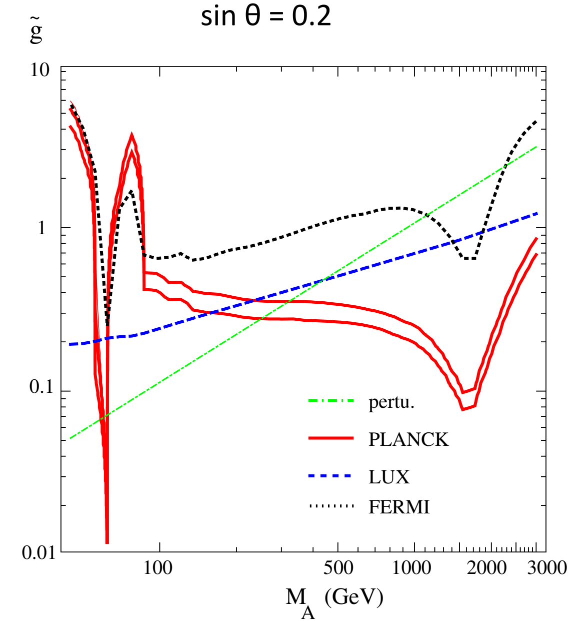
m_{h2} = 280 GeV
sin θ = 0.3



m_{h2} = 1 TeV
sin θ = 0.3



m_{h2} = 3 TeV
sin θ = 0.2

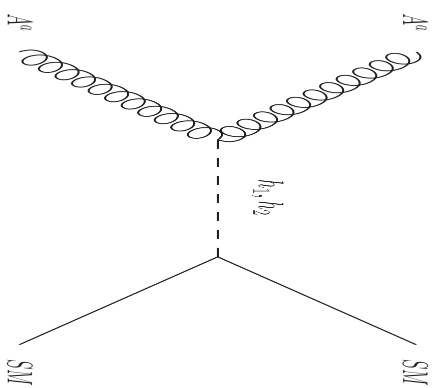


b) DM annihilation mostly into hidden sector

The basic mechanism is known as <u>secluded DM</u>: [Pospolov, Ritz, Voloshin, 2007]
DM annihilation into dark sector states may provide an efficient extra annihilation channel. This breaks the correlation between DD and annihilation cross section.

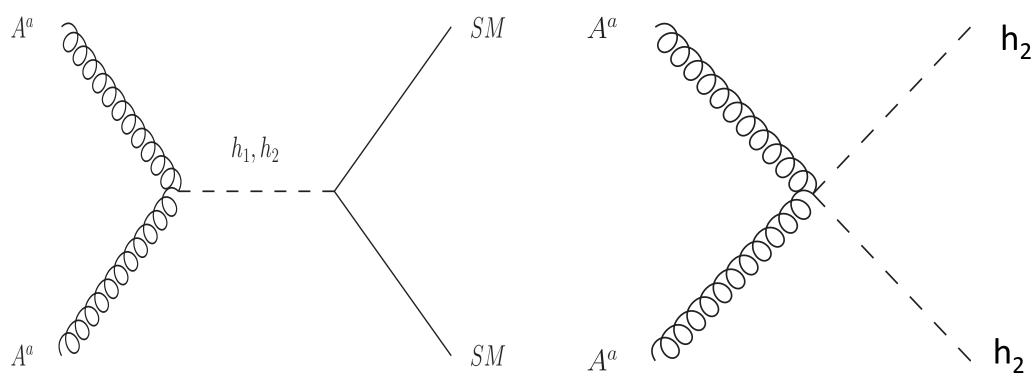
The scalar sector of spontaneously broken hidden gauge groups automatically contains such dark sector states into which DM may annihilate: the hidden sector scalars

direct detection



~ sin θ cos θ

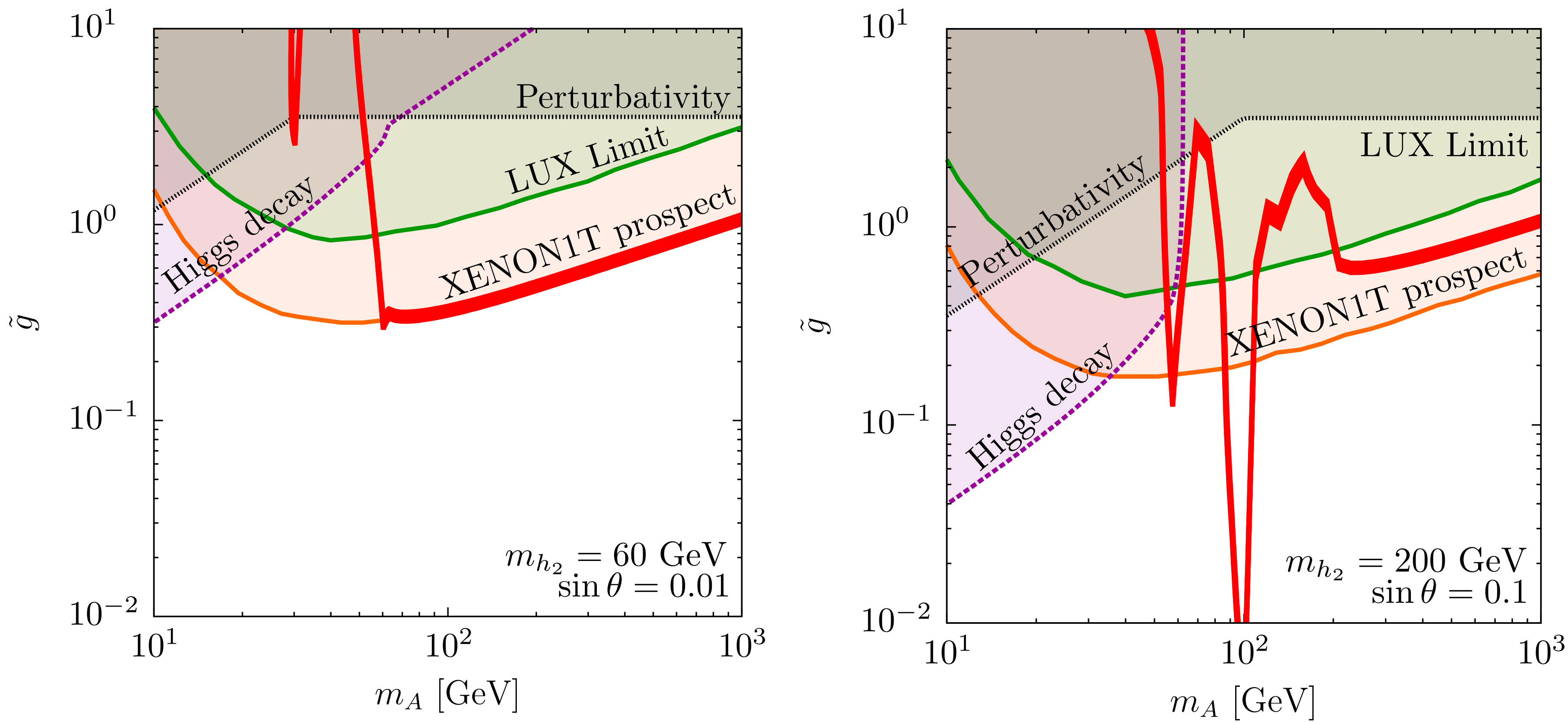
DM annihilation



~ sin θ cos θ

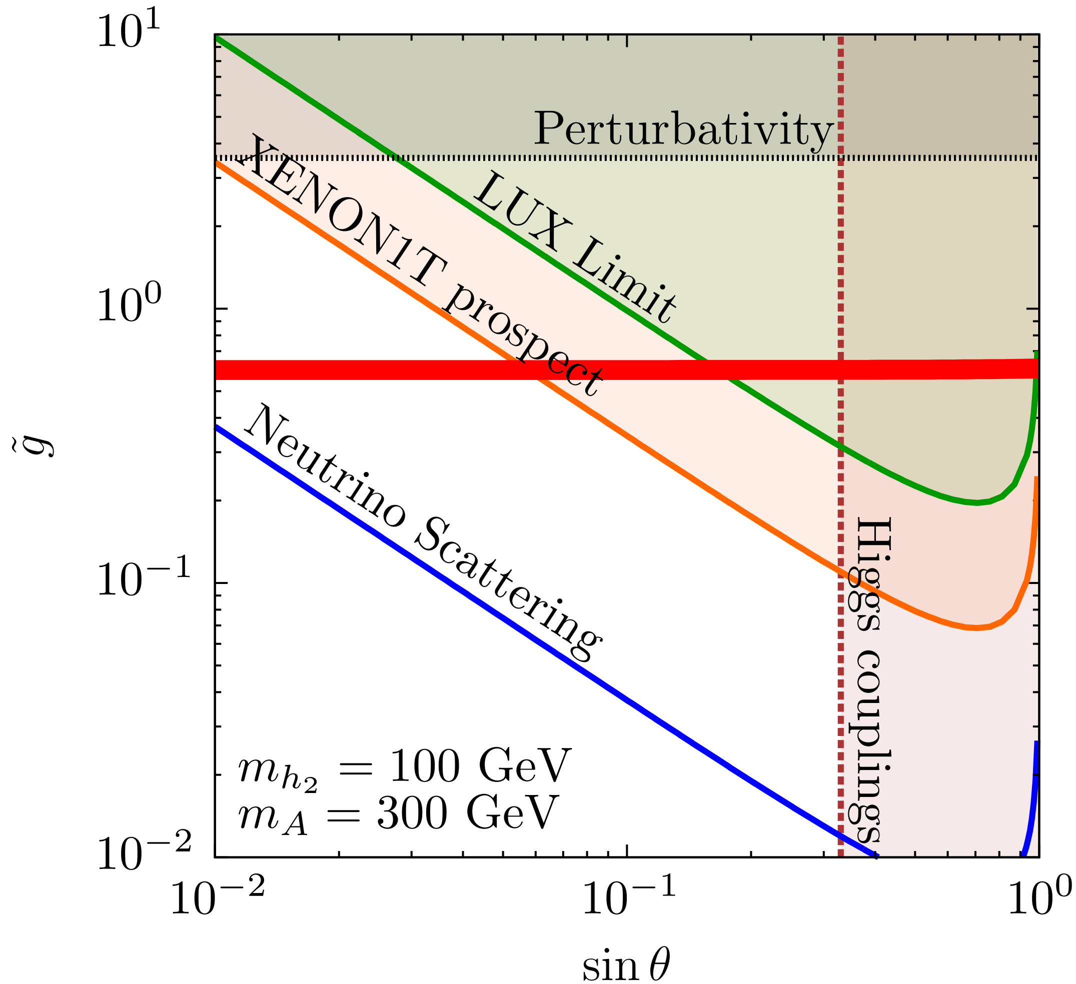
no sin θ suppression!

b) DM annihilation mostly into hidden sector



The coupling required to obtain the correct relic abundance drops dramatically as soon as the dark annihilation channel opens up. The smaller sin θ is, the stronger this effect is.

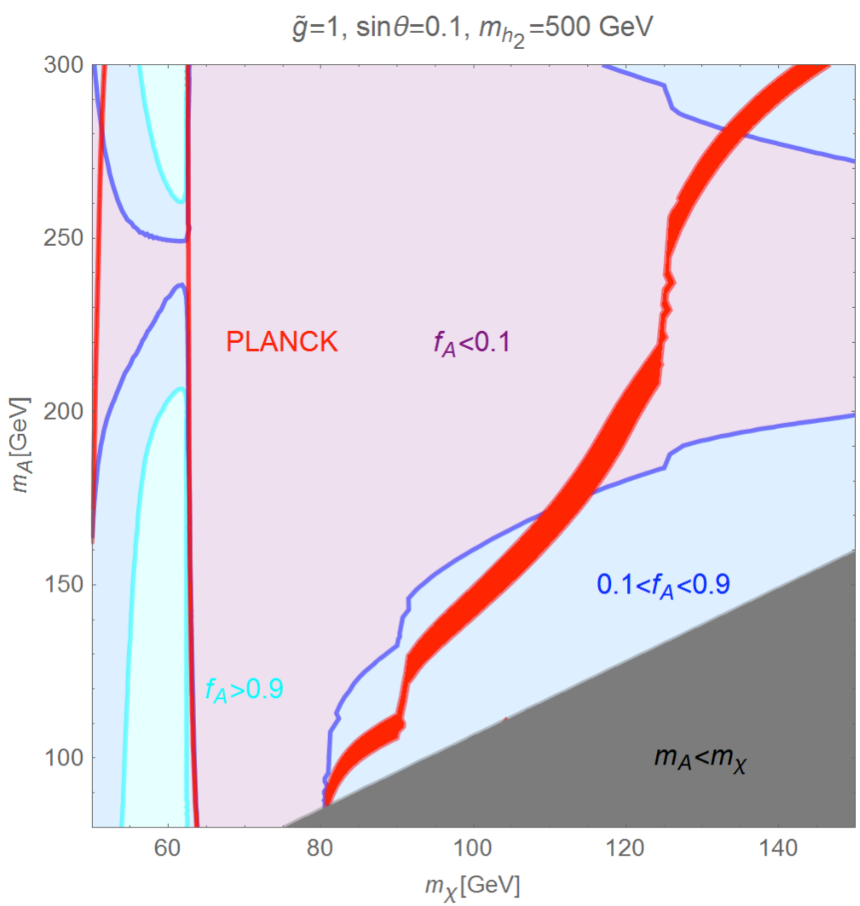
b) DM annihilation mostly into hidden sector



The direct detection rate is almost uncorrelated with the annihilation cross section for $m_A > m_{h2}$

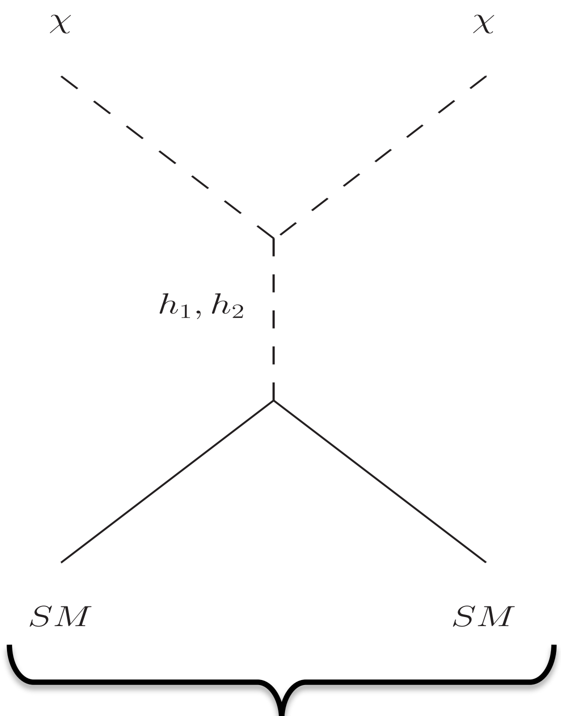
c) cancellation among direct detection diagrams

- for $SU(N\geq3)_d$ may also have mixed vector-scalar DM
- Both components may be dominant, depending on parameters:

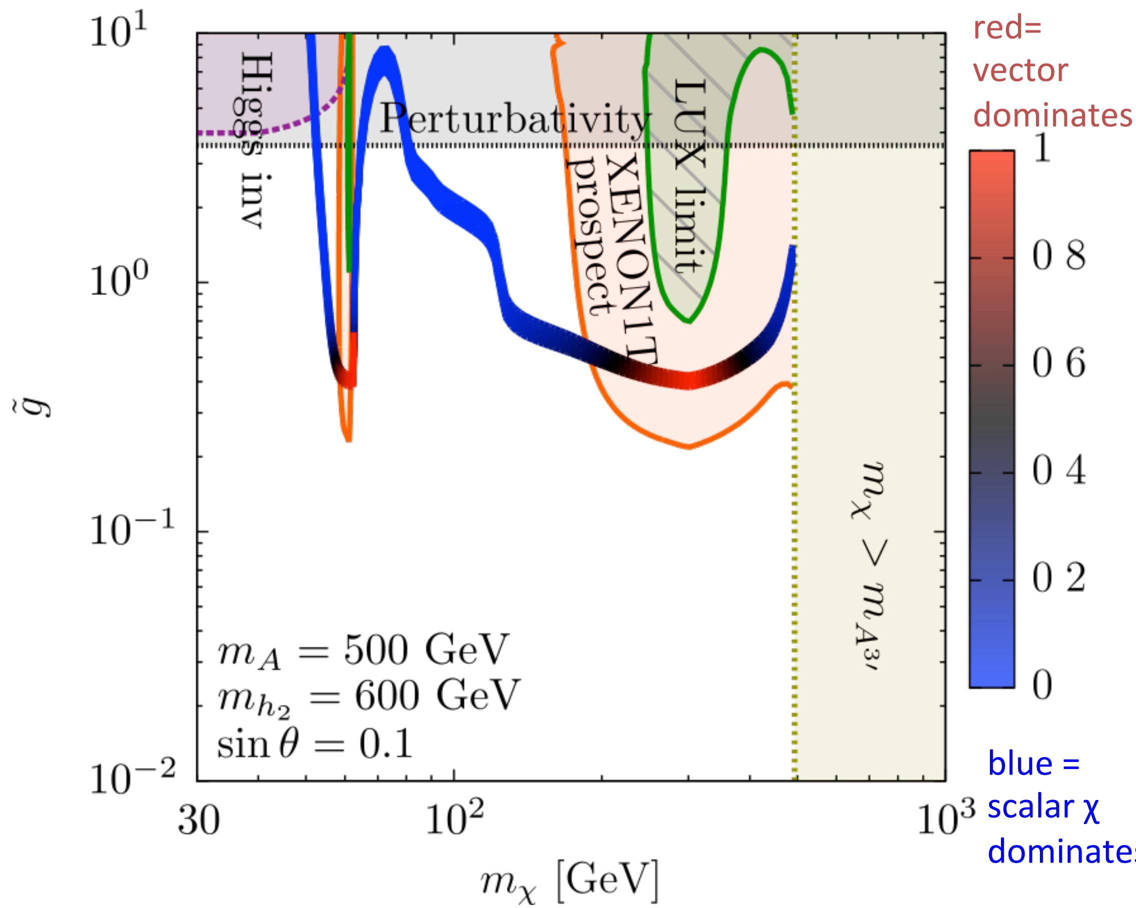


- shown: relative contribution of vector DM to total DM: $f_A=\Omega_A/\Omega_{total}$
- since, very roughly, $\Omega_{total} \propto 1/\langle\sigma v\rangle_A + 1/\langle\sigma v\rangle_\chi$ component with smaller $\langle\sigma v\rangle$ dominates
- this explains e.g. behaviour when one of the components annihilates resonantly

c) cancellation among direct detection diagrams

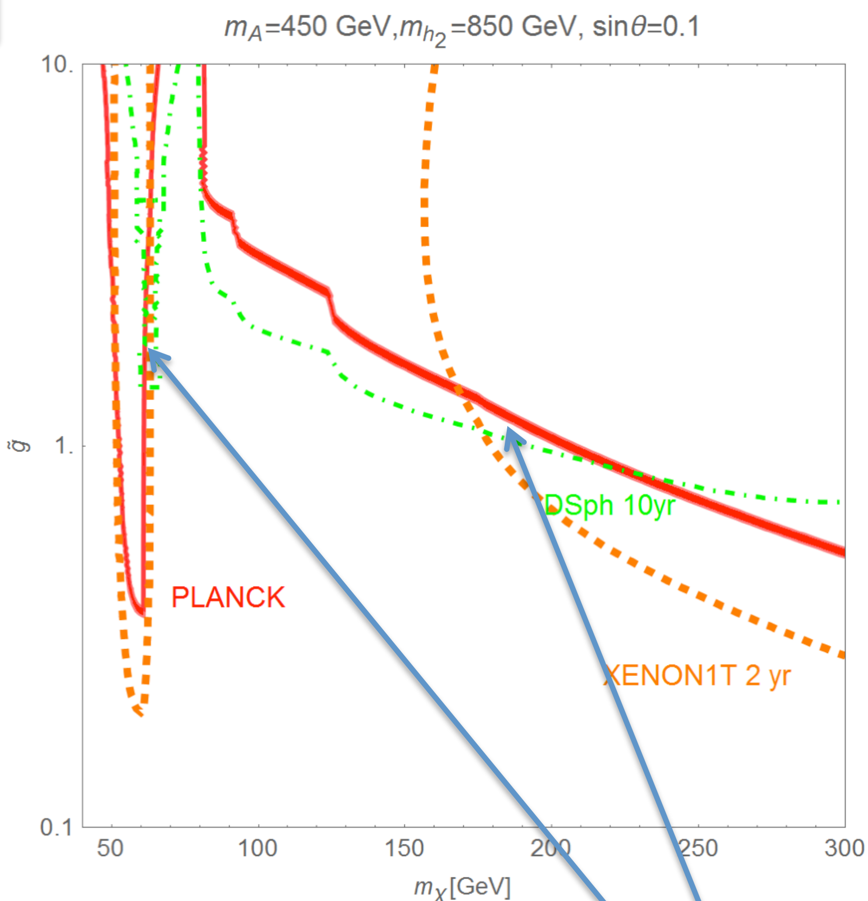


couplings <u>automatically</u> lead to perfect cancellation in scattering of χ-DM on nuclei!



-→ WIMPs can be completely invisible in direct detection

side remark:
in the mixed scalar-vector DM case, one might be able to see one DM component in indirect detection and the other in direct detection



basic point:

- χ is invisible in DD, but might be observable in ID (if its DM fraction is large enough)
- on the other hand: vector component could be visible in DD, but is hardly visible in ID because main annihilation (often) into dark sector (A A → χ χ)

two regions where testing this scenario might be possible with future data

Summary

- Gauge fields of a spontaneously broken $SU(N)_d$ (or $U(1)_d$) are viable DM candidates
- Stability of DM is due to a $Z_2 \times Z'_2$ symmetry (Z'_2 in case of $U(1)_d$) that automatically arises for minimal CP-conserving Higgs sectors
- several ways to reconcile relic abundance and direct detection limits:
  - annihilation via (broad) resonances
  - annihilation dominantly into dark sector
  - automatical cancellation among direct detection diagrams