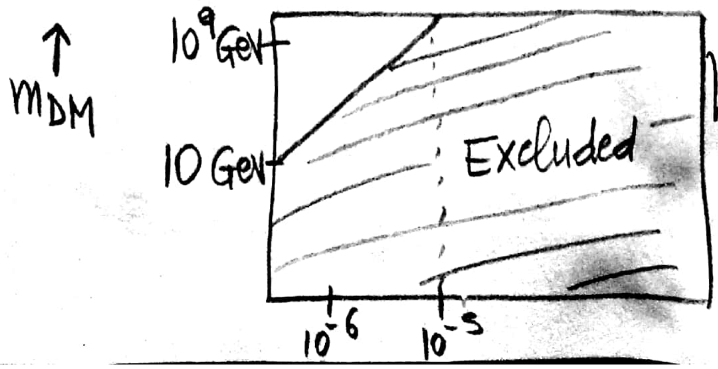
# Building a DM candidate

DM Flash-School
19/11/2018

What we need to keep in mind to build a DM candidate?
- Lot of negatives
- No idea of what DM is (many candidates)

## (Important) Properties

1. Massive (not radiation)
2. Nearly pressureless ($w \simeq 0$) @ $T \sim$ keV $\Rightarrow$ COLD since then
3. Neutral (electrically)
   → need to ensure that the EM contact between DM & plasma do not delay pert. growth until recombination




hep-ph/0311189

Another possibility → maybe DM is neutral bound state as hydrogen (H-like)

Heavy hydrogen searches

$$\text{frac} \lesssim 4\times 10^{-14} \quad \text{for}$$

of H in heavy-H form

$$\underbrace{5m_p}_{5\,\text{GeV}} \lesssim m_{DM} \lesssim \underbrace{1600\, m_p}_{1.6\,\text{TeV}}$$

Aside: can DM be colored (= strongly interacting)?

1801.01135 shows that it is possible if heavy enough ($m_{DM} \sim 12$ TeV) if $\chi$ = octect of $SU(3)_c$

4. Interactions → for sure with gravity ✓ (exp. obs.)

→ maybe with SM (necessity if thermally produced)

→ maybe with itself (in addition to grav.)

$$\frac{\sigma_{DM\text{-}DM}}{m_{DM}} \lesssim 1\ \text{cm}^2/\text{g} \quad \text{[Bullet cluster]}$$

5. <u>Stable</u> How much? At least over the age of universe

1606.02073 DM → inv. particles

$$f_{dDM} \cdot \Gamma_{dDM} \lesssim 0.086 / \tau_{universe}$$

↳ fraction of decaying DM

<u>That's about what we know</u>

How can we implement this in a model?

Framework → <u>QFT</u> DM → associated w/ a field (scalar, fermion, vector...) whose excitations we interpret as a DM particle

Key object to do computations → $\mathcal{L}$

SM → non-abelian gauge theory (massless vectors) with SSB (some vectors become massive)

Theory completely determined once we give its

- symmetries $SU(3)_c \times SU(2)_L \times U(1)_Y$
- particle content

$$\text{SM} \begin{cases} q = (3,2,\frac{1}{6}) \\ l = (1,2,1/2) \\ u^c = (\bar{3},1,-2/3) \\ d^c = (\bar{3},1,-1/3) \\ e^c = (1,1,+1) \end{cases}$$

Stable particles in SM $\rightarrow p, e, \nu$

Only DM candidate $\rightarrow \nu$ [inside $l = \begin{pmatrix} \nu \\ e \end{pmatrix}$]

BUT $\Omega_\nu \simeq 0.005$ vs. $\Omega_{CDM} \simeq 0.12$

+ $\nu$ is hot candidate (rel. @ decoupling)

$\Rightarrow$ we need to add something new to the SM
[evidence for physics Beyond SM]

How do we implement the properties listed before?

1.— we need to be able to write a mass term

$\rightarrow$ not difficult

$\mathcal{L} \supset -m^2 \chi^\dagger \chi$ ($\chi$ scalar)

$\mathcal{L} \supset -m \chi\chi$ ($\chi$ fermion, Majorana mass)

$\mathcal{L} \supset -m \chi^c \chi$ ($\chi$ fermion, Dirac mass)

2 — Neutral $\quad Q = T_L^3 + Y$

• If $\chi$ is $SU(2)_L$ singlet ($T_L^3 = 0$)

$\Rightarrow Y = 0$

• If $\chi$ is $SU(2)_L$ multiplet ($T_L^3 \neq 0$)

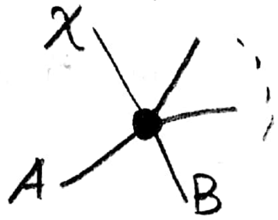
$\Rightarrow$ need to ensure a neutral component inside the multiplet

3 — Stable. Let's make $\chi$ <u>COMPLETELY STABLE</u>

Aim: avoid decay $\chi \to A + B + \dots$

Decay happens when $m_\chi > m_A + m_B + \dots \quad (*)$

and comes from an interaction




Eq.(*) automatically not satisfied if (at least) one between A, B, ... is $\chi$ itself

because $m_\chi \geq m_\chi + m_B + \dots \Rightarrow 0 \geq m_B + \dots$

absurd!

$\Longrightarrow$ If we guarantee that all interaction vertices contain at lest 2 $\chi$, then $\chi$ = stable

Scanned by CamScanner

Super easy way → introduce new parity, $\chi$ odd

$$\begin{cases} \chi \to -\chi \\ SM \to SM \end{cases}$$

$$\mathcal{L} \supset \lambda \chi \, SM_1 SM_2 \dots \xrightarrow{\text{parity}} -\lambda \chi \, SM_1 SM_2 \dots$$

NOT INVARIANT

$$\mathcal{L} \supset \lambda \chi \chi \, SM_1 SM_2 \dots \xrightarrow{\text{parity}} \lambda \chi \chi \, SM_1 SM_2 \dots$$

INVARIANT
CONTAINS 2 $\chi$
$\Rightarrow$ $\chi$ STABLE

Other way → charge $\chi$ under a continuous group (i.e. $U(1)$) avoids interactions containing one $\chi$ only.

Possible caveat: it is believed that gravity does not respect global, continuous symm.

But it can arise as accidental symm (like B or L numb. in SM)

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What you need to be able to compute?

1. Production mechanism (ensuring $\Omega_{DM} \simeq 0.12$)
2. Exp. bounds on cross section w/ nucleons
3. Exp. bounds on annihilation cross-section

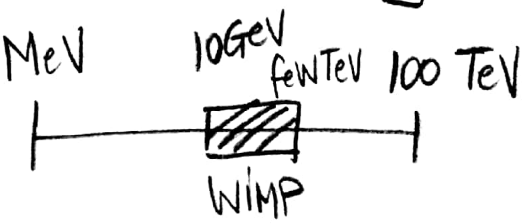
# Production mechanism

## Thermal

DM was in eq. with SM thermal bath

FREEZE OUT (see KOLB-TURNER or DODELSON)

$\langle \sigma v \rangle_{\chi\chi \to SMSM}$ relevant quantity




## Thermalish

intermediate (not quite in eq., or in eq. only for a while, or trying to reach eq. ...)

- INCOMPLETE THERMALIZATION
- FREEZE-IN
- 3 → 2 PROCESSES (SIMP DM) (CANNIBLE DM)
- FORBIDDEN DM

$\langle \sigma v \rangle$ relevant quantity

## Non-thermal

DM production not dictated by thermal contact with SM bath

- ASYMMETRIC DM (1308.0338)
- COHERENT OSCILL.

usually nothing to do with $\langle \sigma v \rangle$

## Relevant quantities

$\langle \sigma v \rangle$

- production
  (except non-thermal)
- CMB bound
- ID

$\sigma_n \; (\chi n \to \chi n)$ — nucleon

- DD

Since DM non-rel
@ decoupling
we can expand in $v \ll 1$
(equivalent to partial wave expansion)

$$\langle \sigma v \rangle = \underbrace{\sigma_0}_{\text{s-wave}} + \underbrace{\sigma_2}_{\text{p-wave}} v^2 + \underbrace{\sigma_4}_{\text{d-wave}} v^4 + \dots$$