Dark Matter and the Baryon Asymmetry of the Universe

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Motivation

$$\frac{n_B}{n_\gamma} = 6.5^{+0.4}_{-0.3}\ 10^{-10} \quad \& \quad \frac{\Omega_{DM}}{\Omega_B} = \frac{\rho_{DM}}{\rho_B} = 4.83 \pm .87$$

$n_B \leftrightarrow$ baryogenesis
$n_{DM} \leftrightarrow$ relic freeze-out.

Why are ρ_{DM} and ρ_B similar?

Possible answer:

- DM carries baryon number,
- Baryon number is conserved $B_X\left(n_{\bar{X}} - n_X\right) = n_B$.

Basic idea

Assume one component DM (m_X and B_X fixed).

$n^0_{\bar{X}} - n^0_X$ determined by B_X, ⟵ (Baryon symmetry)

$n^0_{\bar{X}} + n^0_X$ determined by Ω_{DM}/Ω_B.

'reverse engineering':

to get the ρ^0_{DM} right $\longrightarrow T^{f.o.}_{\bar{X}}, T^{f.o.}_X$ are determined (CP violation necessary);

freeze-out temperatures then determine $\sigma^{ann}_{\bar{X}}, \sigma^{ann}_X$.

In detail..

- $B_X(n_{\bar{X}} - n_X) = (n_N - n_{\bar{N}}) = \frac{\rho_B}{m_N}.$ (no net baryon number)

- $\rho_{DM} = m_X(n_X + n_{\bar{X}}).$ (one component DM)

$$\varepsilon = \frac{n_X}{n_{\bar{X}}}.$$

$$\frac{\Omega_{DM}}{\Omega_B} = \left(\frac{1+\varepsilon}{1-\varepsilon}\right)\frac{m_X}{m_N B_X}.$$

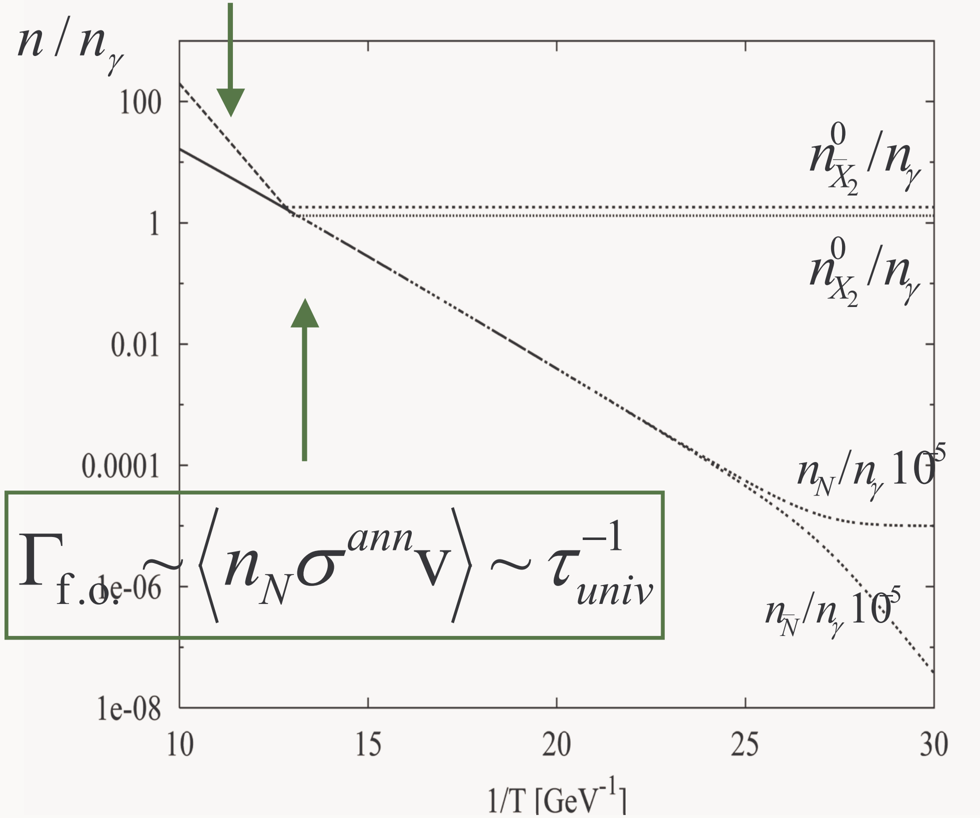
→ m_X and B_X are model parameters, ε determined.

→ $(1+\varepsilon)/(1-\varepsilon) \geq 1$ => $m_X \leq 4.5\ B_X$ GeV.

→ natural for $\Omega_{dm} \approx \Omega_B$.

$$n_X^{n.r.} = g_X \left(\frac{m_X T}{2\pi} \right)^{3/2} \mathrm{e}^{-m_X/T}.$$

$$\frac{n_X^{n.r.}(T_X)}{g_{*s} n_\gamma (T_X)} = \frac{n_X^0}{g_{*s}^0 n_\gamma^0} \text{ measured} \rightarrow T_X$$



$$\Gamma_{f.o.} \sim \langle n_N \sigma^{ann} \mathrm{v} \rangle \sim \tau_{univ}^{-1}$$

$$(1-\varepsilon) \frac{\pi^2 g_X u_X^{3/2} \mathrm{e}^{-u_X}}{2\varsigma(3)(2\pi)^{3/2}} = \frac{10.75}{3.91} \frac{n_N^0}{n_\gamma^0 B_X}$$

where $u_X = m_X / T_X$.

Model	T_{Xbar} [MeV]	T_X	σ_{Xbar} [cm^2]	σ_X
X2	86.3	84.5	2.2 10^{-41}	2.8 10^{-41}
X4	180	159	3.3 10^{-45}	3.7 10^{-45}

CP violation about 20%.

Behave as Cold Dark Matter

- σ_{XN} negligible compared to σ_{NN},
- $X\bar{X}$ do not bind to nuclei,

→ nucleosynthesis works the same as with standard CDM.

Particle physics of the X

- $B_X = 1$, $m_X \leq 4.5$ GeV.
- 6-dim interaction in the low energy effective theory:

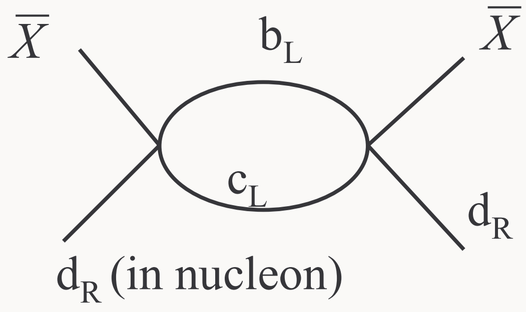
$$\kappa\left(\overline{X} b_L \overline{d}^c_R c_L - \overline{X} c_L \overline{d}^c_R b_L\right) + h.c.$$

- X is a singlet under all SM interactions (Y=0); the only interaction with SM is ↑.
- Prior to freeze-out X in equilibrium through: $d + \overline{X} \leftrightarrow \overline{b} + \overline{c}$
- $\sigma_{\overline{X}d \leftrightarrow \overline{b}\,\overline{c}} \propto \kappa^2 \frac{m_X T^{\mathrm{f.o.}}_{\overline{X}} m_b m_c}{(m_b + m_c)^2}$ and σ^{ann} fixed → coupling $\kappa \approx 10^{-9} - 10^{-10}\ \mathrm{GeV}^{-2} = k\, 10^{-10} \mathrm{GeV}^{-2}$.

→ If $\kappa = g^2/M_{BSN}^2$ and $g \leq 1$ → $M_{BSM} \leq 100$ TeV.

Detection of the X

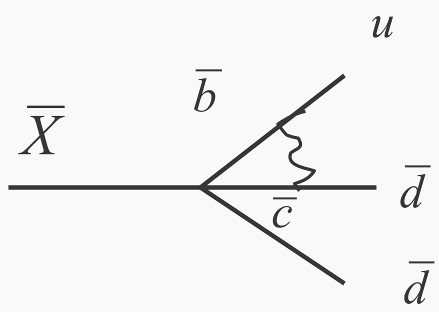
- DM (WIMP) searches — elastic scattering:



$\sim G_{FZ}^2 (m_X m_N)^2/(mX+mN)^2 \approx k^4 (\Lambda_{TeV})^4\ 10^{-56}\ cm^2.$

where: $G_{FZ}=\kappa^2\Lambda^2$

- Decay of X, Xbar:



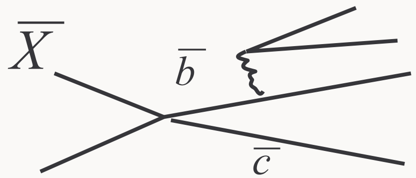
$\overline{X} \rightarrow \overline{N} + \text{mesons}$

$\Gamma \propto \kappa^2 G_F^2 \left| V_{ub} V_{cd} \right|^2$

Essentially stable, $\tau \geq \tau_{universe}$

Work in progress

- Annihilation against nucleons:



$$\propto G_{FZ}^2 G_F^2 \Lambda^2 m_X m_N$$
$$\approx 10^{-65}\,\mathrm{cm}^2.$$

  – In the detector: but capturing flux by the Earth is low, $\Phi_{cap}^{Earth} \approx 3\,10^{-7}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$.

  [code by Edsjo et al., 2004]

  In SuperK annihilation lower than the background for $\sigma_{\overline{X}N}^{ann} \leq 10^{-39}\,\mathrm{cm}^2$
  → no signal.

  – In Sun/Earth: equilibrium established for $\tau_{\mathrm{ann}} = \left\langle \sigma^{\mathrm{ann}} n_N \mathbf{v} \right\rangle^{-1}$ (evaporation negligible).
  True for $\sigma_{\mathrm{Earth}}^{\mathrm{ann}} \geq 5\,10^{-49}\,\mathrm{cm}^2$,
  $\sigma_{\mathrm{Sun}}^{\mathrm{ann}} \geq 10^{-52}\,\mathrm{cm}^2$.
  → no equilibrium, neutrino signal below the background.

The H di-Baryon as a Baryon-Antibaryon DM

- QCD particle (postulated by Jaffe,74).
- M=2 GeV, B_X=1 (uuddss).
- Lifetime longer than $\tau_{universe}$, does not bind to nuclei, OK with experimental searches. [G.R.Farrar, G.Z., 2003]
- Stays in the equilibrium through $\overline{H}N \to K\overline{\Lambda}$, $H\overline{N} \to \overline{K}\Lambda, \ldots$
- Naturally has cross section $\sigma \leq \sigma_{hadronic}$
- But, excluded as DM from the heat production in Uranus. [G.R.Farrar, G.Z., 2004]

Summary

- *Baryon asymmetry* may only be baryon number *segregation* between visible and dark sectors.

- DM may carry baryon number and $m_X \leq 4.5\ B_X$GeV,

- X coupling to matter suggests BSM scale ≤ 100 TeV.

- Signal of $X\bar{X}$ DM hard to measure, work in progress.