04

Dark Matter cosmological production

Freeze-in Dark Matter and Axions

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2022

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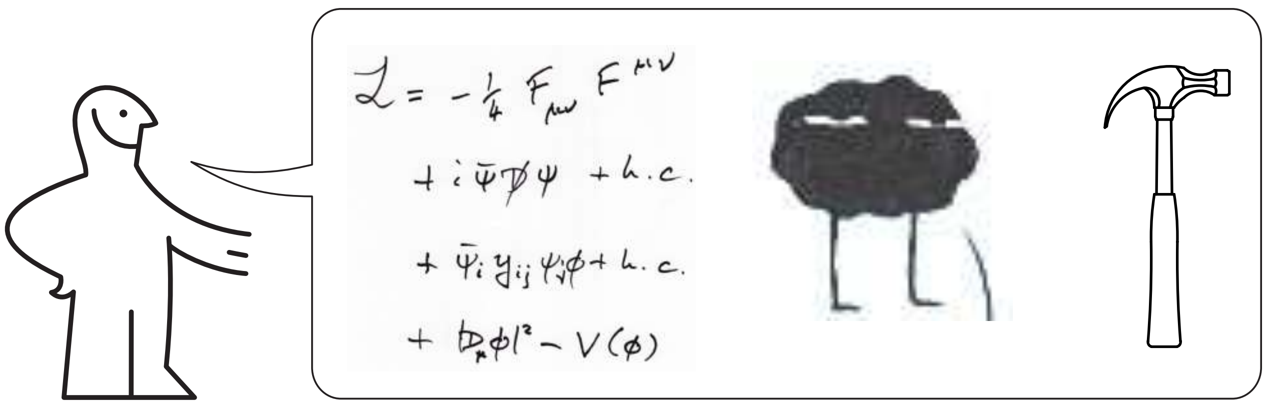
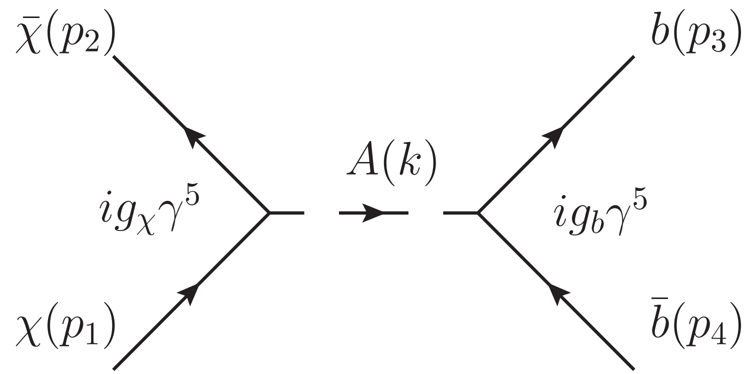
MÖRK MATERIA MODELL



A simple example: fermion DM + Pseudoscalar mediator + SM

Let us assume that the DM particle is a fermion X, which connects to SM particles through the exchange of a pseudoscalar A



$$\mathcal{L} = i\left(g_\chi \bar{\chi}\gamma^5\chi + g_b \bar{b}\gamma^5 b\right) A$$

Is it viable?

- Is the relic density correct?

$$\langle \sigma v \rangle_{ij} = a_{ij} + \frac{b_{ij}}{x} = a_{ij} + b_{ij} v^2$$

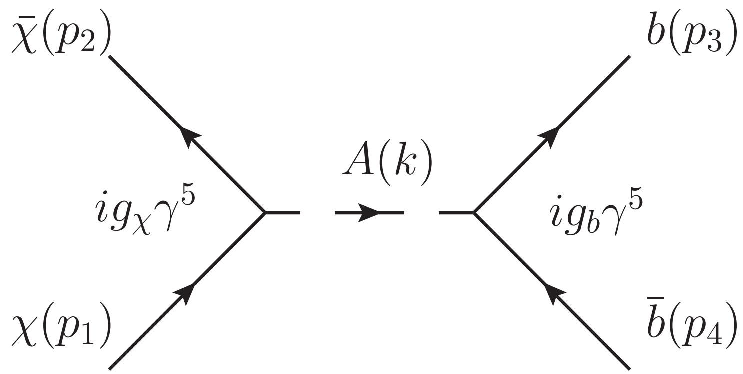
$$a_{ij} \quad = \quad \frac{1}{m_\chi^2}\left(\frac{N_c}{32\pi}\beta(s, m_i, m_j)\frac{1}{2}\int_{-1}^{1} d\cos\theta_{CM}|\mathcal{M}_{\chi\chi\to ij}|^2\right)_{s=4m_\chi^2}$$

$$\beta(s, m_i, m_j) = \left(1 - \frac{(m_i + m_j)^2}{s}\right)^{1/2}\left(1 - \frac{(m_i - m_j)^2}{s}\right)^{1/2}$$

A simple example: fermion DM + Pseudoscalar mediator + SM

This results in

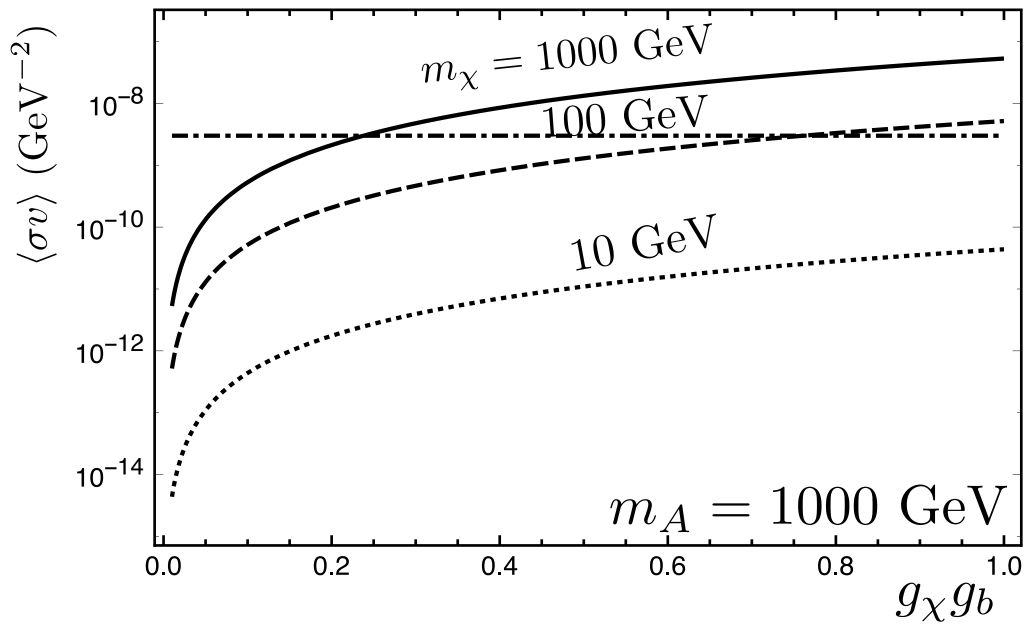
$$\langle \sigma v \rangle \approx \frac{3}{2\pi} \frac{(g_\chi g_b)^2 m_\chi^2 \sqrt{1 - m_b^2/m_\chi^2}}{(4m_\chi^2 - m_A^2)^2 + m_A^2 \Gamma_A^2}$$



Using the expression of the relic density

$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-10}\ \text{GeV}^{-2}}{\langle \sigma v \rangle}$$

$$g_\chi g_b \sim 0.1 - 1$$



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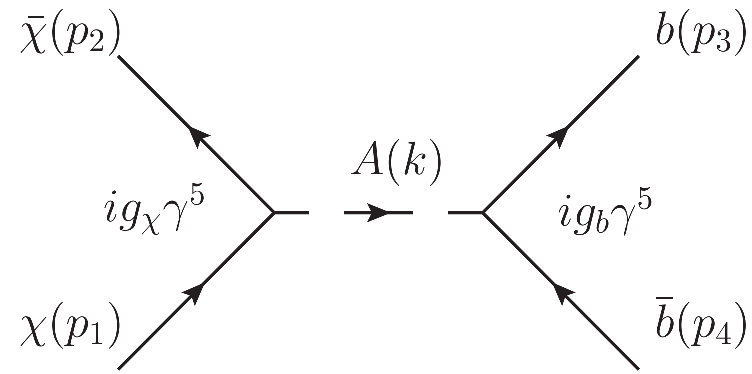

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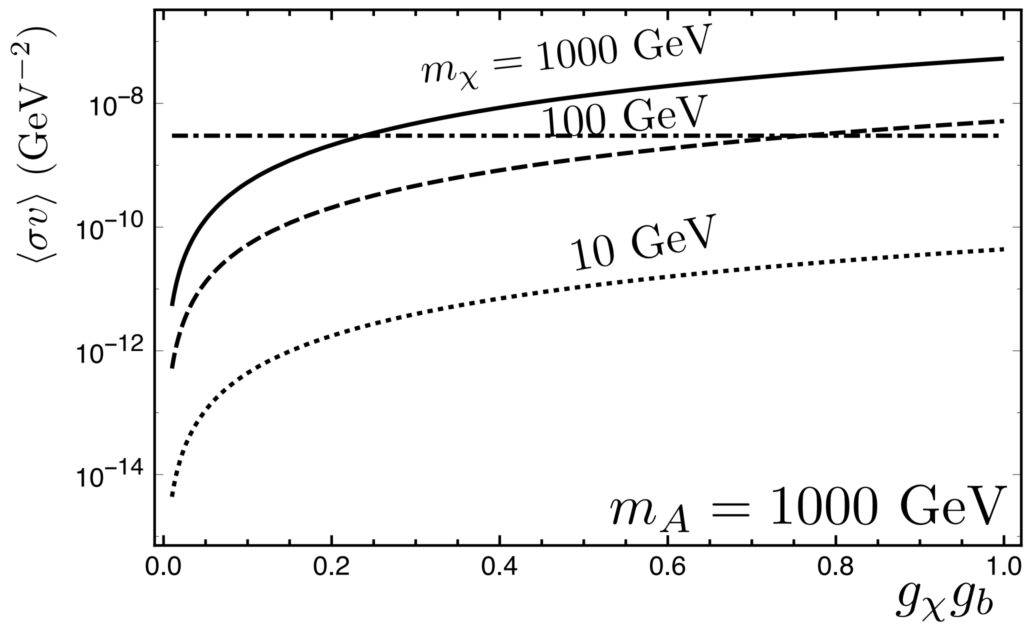

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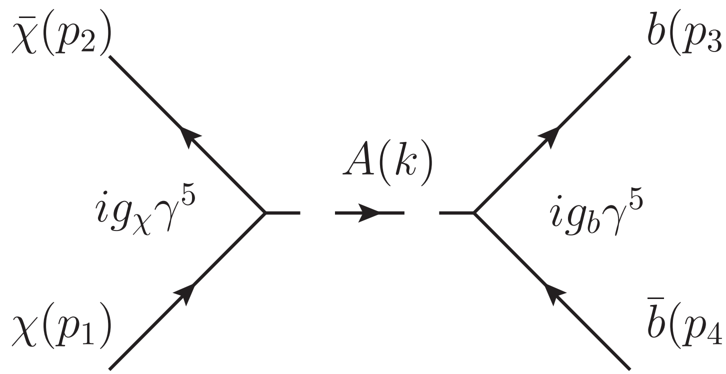

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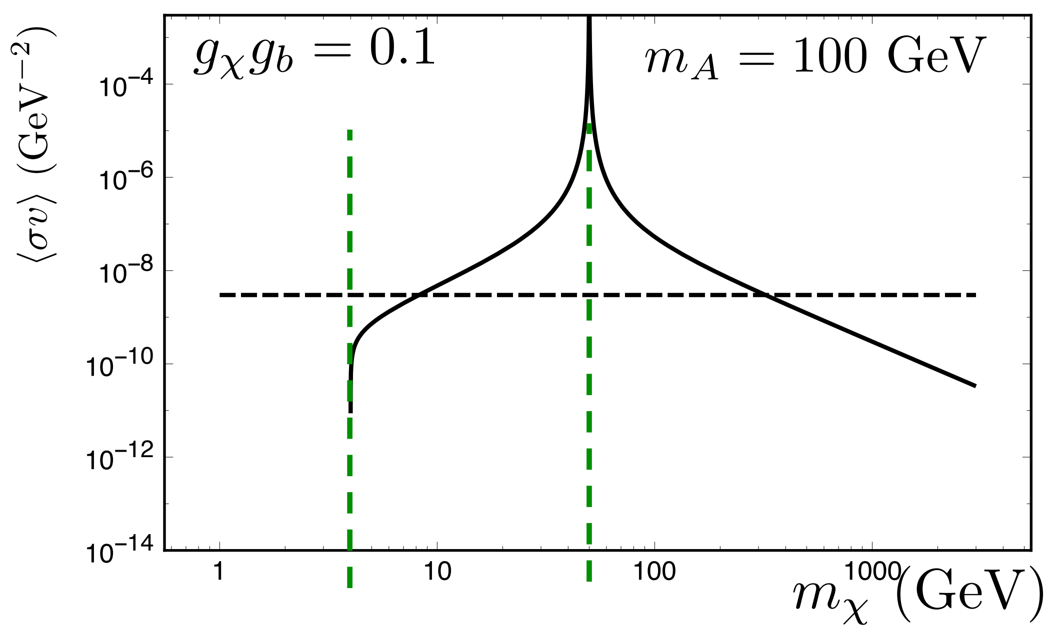
Production threshold

$$m_\chi = m_b$$

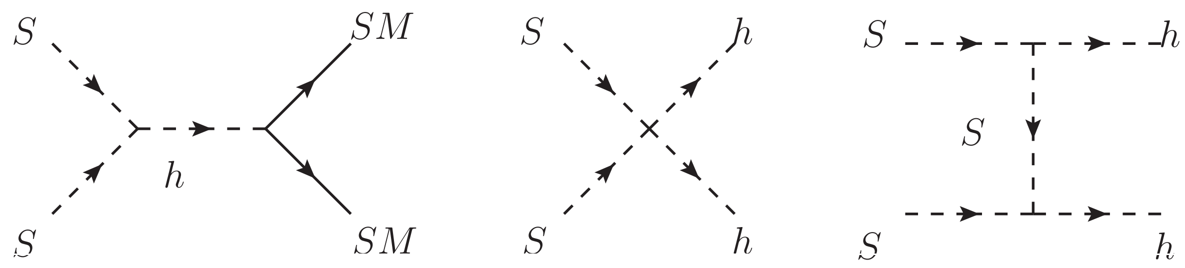
Resonance

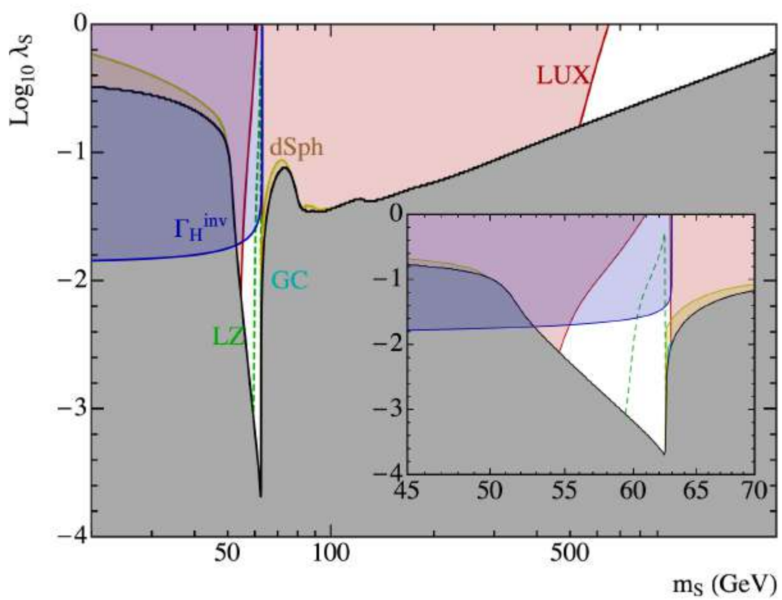
$$m_\chi = \frac{1}{2} m_A$$



Tension in some simplified models

The singlet scalar Higgs portal is extremely constrained by a combination of direct-indirect-LHC constraints



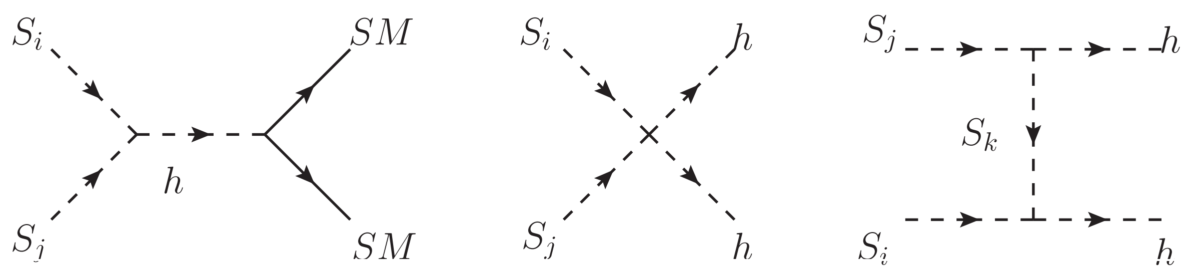


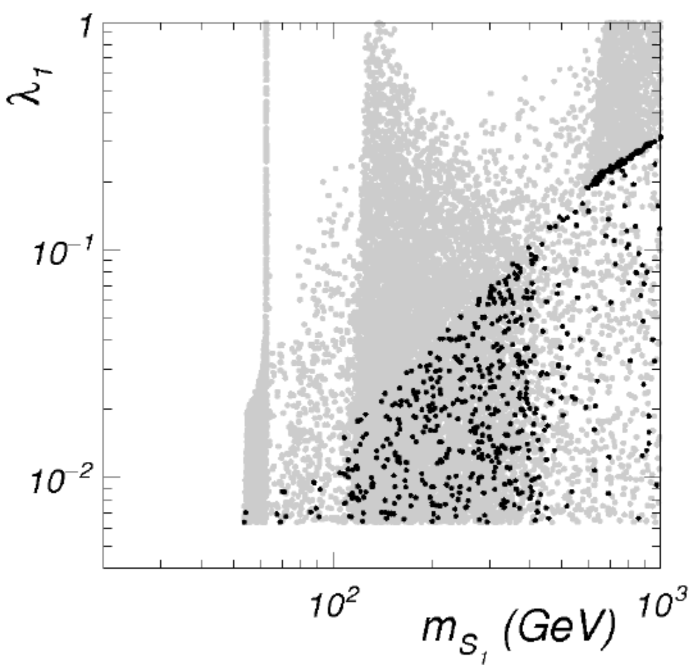
Casas, DGC, Moreno, Quilis 1701.08134
See also GAMBIT 1705.07931

- Best bounds are from direct detection (LUX, XENON1T)
- Future LZ completely explores it below ~1TeV
- Indirect constraints from Fermi-LAT to explore resonance region

Tension in some simplified models

This tension can be alleviated with the inclusion of a second scalar Higgs





- Direct detection bounds can be less effective
- DM particles as light as ~100 GeV are possible

Casas, DGC, Moreno, Quilis 1701.08134

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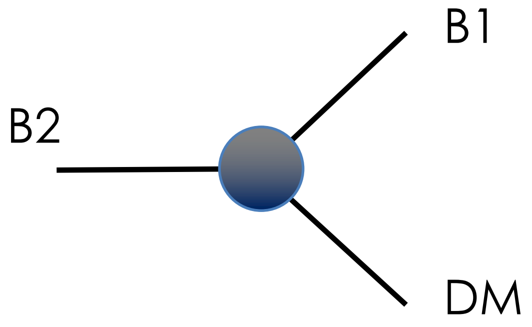
Freeze-in paradigm

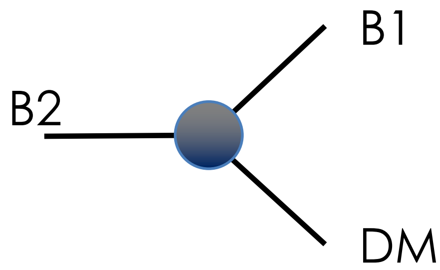
If the DM-SM coupling is extremely small, the annihilation rate is insufficient for thermal equilibrium.

However, annihilations or decays of particles in the bath can produce DM particles (that are out of equilibrium)

See e.g. Hall et al. 0911.1120



One can solve the associated Boltzmann equation



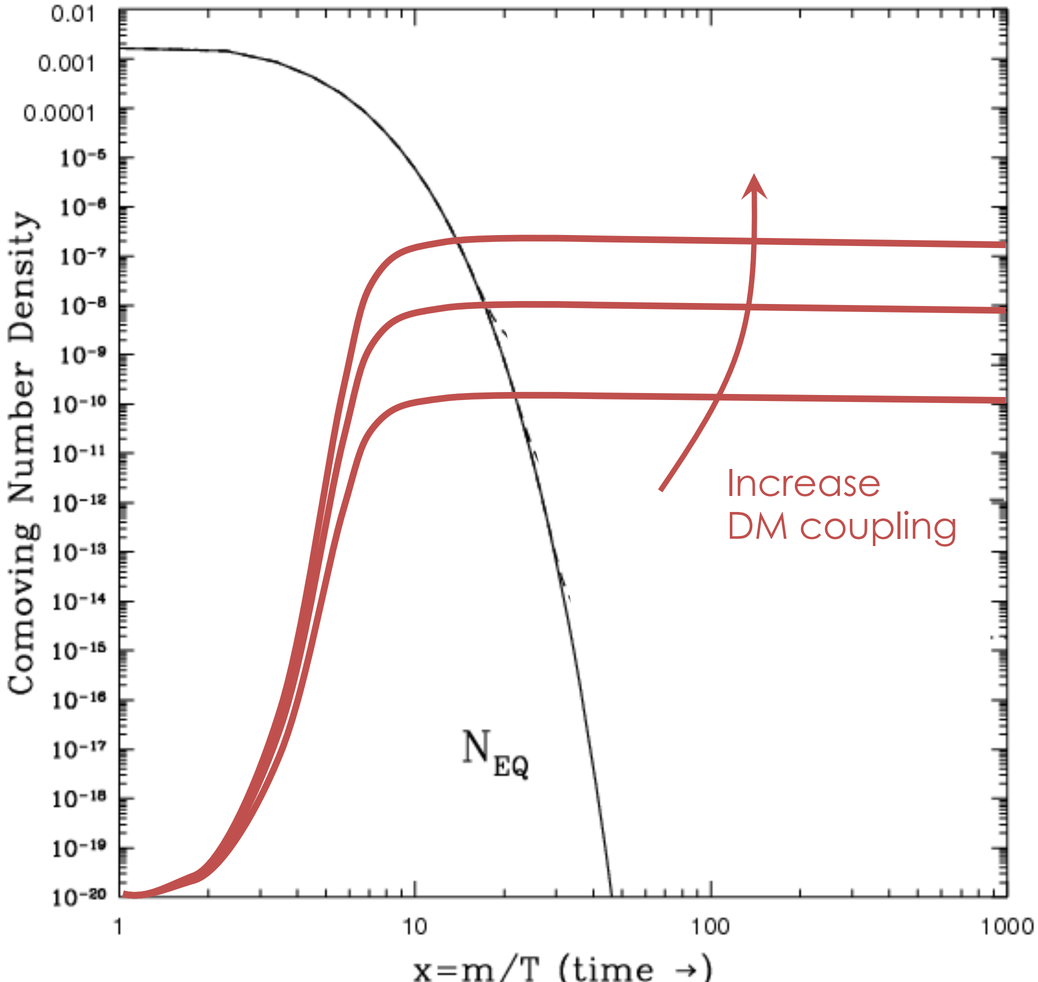
$$\frac{dn}{dt} + 3Hn = \frac{g}{(2\pi)^3} \int \frac{C[f]}{E} d^3\mathbf{p}$$

$$= \int d\Pi_{B_1} d\Pi_{B_2} d\Pi_\chi \, (2\pi)^4 \delta^4 \left(p_{B_2} - p_{B_1} - p_\chi\right) \times$$
$$\left[\left|\mathcal{M}_{B_2 \to B_1 \chi}\right|^2 f_{B_2}(1 \pm f_{B_1})(1 \pm f_\chi) - \left|\mathcal{M}_{B_1 \chi \to B_2}\right|^2 f_{B_1} f_\chi (1 \pm f_{B_2})\right]$$
$$= \int d\Pi_{B2} \Gamma_{B2} 2 g_{B2} m_{B2} f_{B2} \, . \tag{2.64}$$

$$Y = \frac{45 g_{B_2} M_p \Gamma_{B_2}}{4\pi^4 (1.66) m_{B_2}^2 g_*^S \sqrt{g_*}} \int_{x_{min}}^{\infty} K_1(x)\, x^3 \, dx$$

The abundance of **FIMPs** builds up and eventually stabilises

$$Y \approx \frac{135\, g_{B_2}}{8\pi^3 (1.66) g_*^S \sqrt{g_*}} \left(\frac{\Gamma_{B2} M_p}{m_{B_2}^2} \right)$$

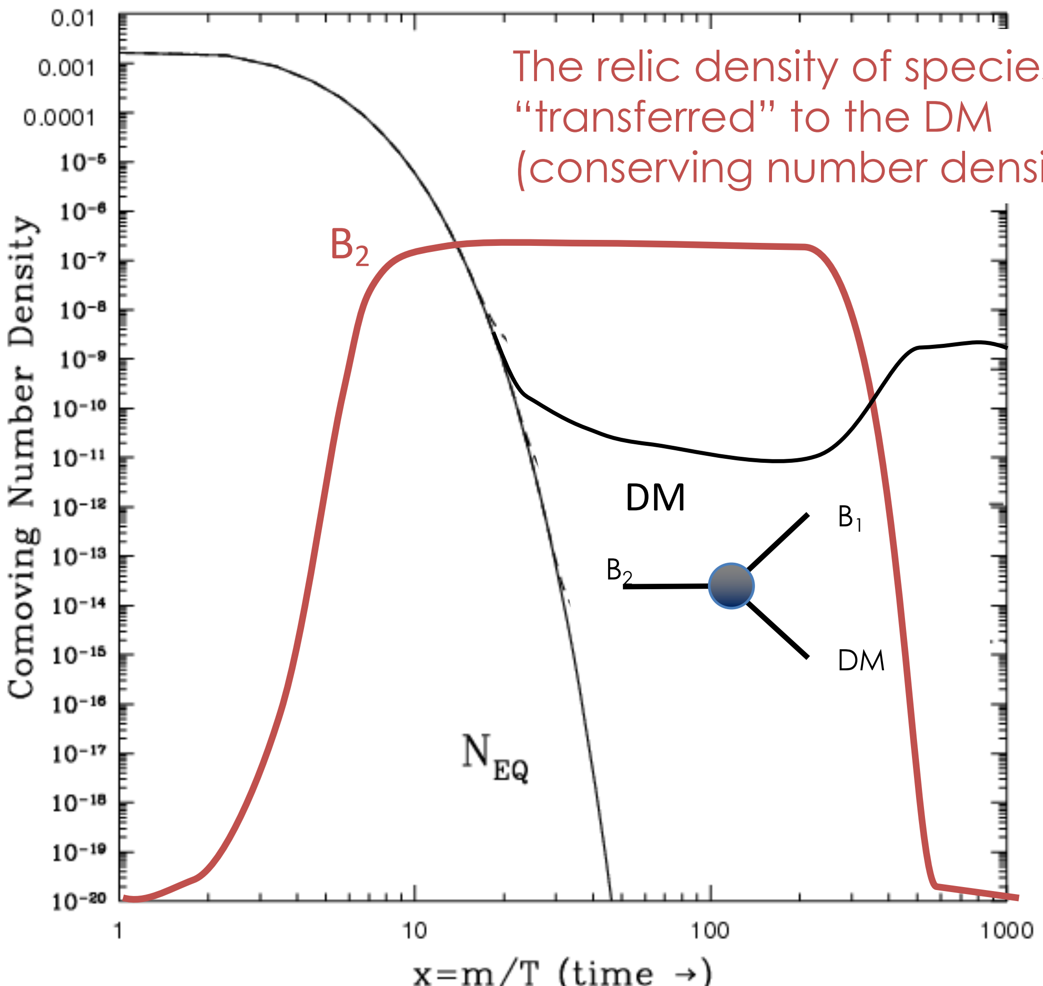


The relic density is proportional to the SM particle decay rate.

Depending on the actual process, the correct relic abundance can be obtained for

$$\lambda \approx 10^{-13}$$

One can also have "mixed" scenarios in which a particle that has decoupled decays (late) into the DM



The relic density of species B_2 is "transferred" to the DM (conserving number density)

$$\Omega_{\mathrm{DM}} h^2 = \Omega_{\mathrm{B}_2} h^2 \frac{m_{\mathrm{DM}}}{m_{\mathrm{B}_2}}$$

The DM therefore can have "thermal" and "non-thermal" contributions

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Axions

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