The number density of a charged relic

Federica Palorini
in collaboration with C. F. Berger, L. Covi, S. Kraml

Institut de Physique Nucléaire de Lyon

Second annual School of EU Network
“The Origin of the Universe” - Oxford, September 2008

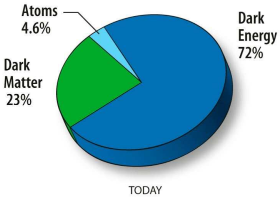
Outline

Dark matter and thermal relics

Properties:

- Does not couple with photons
- Stable on cosmological scales
- Relic density:

$$\Omega_m h^2 = 0.1143 \pm 0.0034$$



Production:

- Thermal production, by scattering in the thermal plasma
- Non thermal production, by the decay of decoupled relics

Number density of a thermal relic

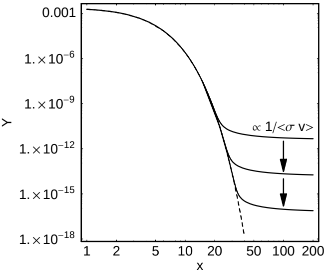
Boltzmann equation:

$$\dot{n}_X + 3Hn_X = \int \frac{dp_X^3}{(2\pi)^3 2E_X}\, \mathcal{C}[f_X]$$

- For a particle with conserved parity (e.g. R parity) collision integral at lowest order just two-particle scatterings

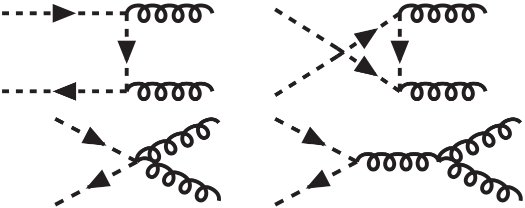
- Actual number of X per comoving volume Y_X:

$$\frac{dY_X}{dx} = -\frac{xs(x)}{H(x)m_X^2}\langle\sigma v\rangle_x \left(Y_X^2 - Y_{eq}^2\right)$$



Annihilation cross section of charged scalar particle

Abelian and non-abelian gauge interactions (depend on few parameters):



Unitarity bound $\Rightarrow$ lower bound on yield:

$$\sigma_{ann} \leq \frac{4\pi(2J+1)(1-\eta_J^2)}{(2s_p+1)^2\,\vec{p}_i^{\,2}}$$

$\Rightarrow$ thermal average for a scalar particle:

$$\langle \sigma_{max} v \rangle_x = \frac{16\pi}{x^2}\frac{K_2(2x)}{K_2(x)^2}$$

Sommerfeld Enhancement

Expansion in terms of coupling close to threshold inadequate where:

$$\beta = \sqrt{1 - \frac{4m_X^2}{s}} \to 0$$

$\Rightarrow$ t-channel (ladder) exchanges of longitudinal gauge bosons.

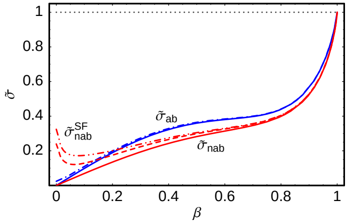
Sommerfeld enhancement:

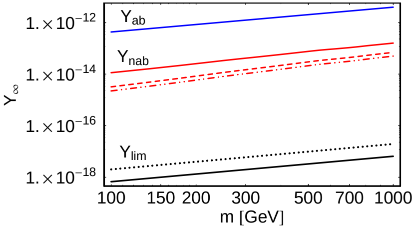
$$E \equiv |\Psi(0)|^2 = \frac{z}{1 - \exp(-z)}, \quad z = \frac{C\alpha\pi}{\beta}$$

Corrected cross section:

$$\sigma^{\rm SF}(\beta, m_X) = E(\alpha(\beta m_X)) \times \sigma^0(\beta)$$

Abelian and non-abelian relics





$$\frac{Y_{ab}}{Y_{nab}} = \frac{7}{27}\,\frac{\alpha_3^2}{\alpha_{em}^2} \approx 40$$

WMAP constraint and unitarity limit:

$$\Omega_X h^2 = m_X Y_{X+\bar{X}}(T_{now}) s(T_{now})/\rho_c \leq 0.13$$

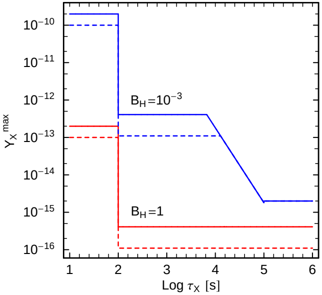
$\Rightarrow$ for a stable scalar particle:

$$m_X \leq 280 \text{ TeV}$$

BBN limits on decaying relics

Maximal values of $m_X Y_{X+\bar{X}}$ (GeV) allowed by BBN

m_X (TeV)	$10^{-1} - 10^{2}$ s	$10^{2} - 10^{7}$ s	$10^{7} - 10^{12}$ s
0.1	2×10^{-11}	5×10^{-14}	10^{-14}
1	1×10^{-10}	10^{-13}	10^{-14}
10	5×10^{-10}	3×10^{-13}	10^{-14}



For $B_H = 1$

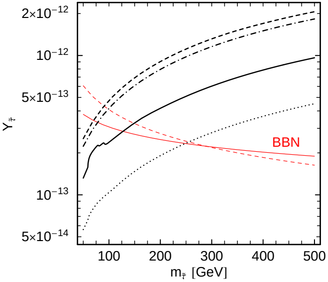
Relic staus

Number density:

- Dashed line for tree level $\tilde{\tau}\tilde{\tau}^* \to \gamma\gamma$ and dash-dotted includes Sommerfeld effect
- Full line includes annihilation into W and Z (other particles decoupled)
- Dotted line the case $m_{\tilde{B}} = 1.1 m_{\tilde{\tau}_1}$

BBN bounds:

- Full line for 0.1–100 s lifetime and $B_H = 0.65$,
- Dashed line for $>$ 100 s lifetime and $B_H = 10^{-3}$.
- If lifetime exceeds $\sim 10^4$ s, $\Rightarrow$ CBBN constraints more important and quickly exclude number densities



Stau NLSP decay into axino or gravitino

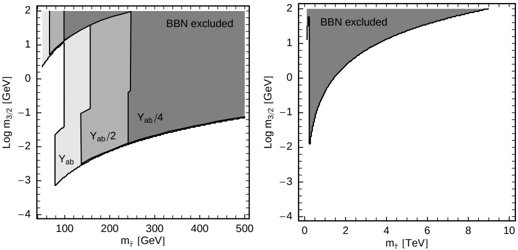
Axino LSP:

$$\Gamma(\tilde{\tau}_R \to \tau \tilde{a}) = (25\ \mathrm{s})^{-1} \xi^2 \left(\frac{m_{\tilde{\tau}}}{10^2\ \mathrm{GeV}}\right) \left(\frac{m_{\tilde{B}}}{10^2\ \mathrm{GeV}}\right)^2 \left(\frac{10^{11}\ \mathrm{GeV}}{f_a}\right)^2 \left(1 - \frac{m_{\tilde{a}}^2}{m_{\tilde{\tau}}^2}\right)$$

$\Rightarrow \tau < 0.1$ s for $m_{\tilde{\tau}} \leq 590$ GeV

Gravitino LSP:

$$\Gamma(\tilde{\tau}_R \to \tau \tilde{G}) = (5.9 \times 10^8\ \mathrm{s})^{-1} \left(\frac{m_{\tilde{\tau}}}{100\ \mathrm{GeV}}\right)^5 \left(\frac{100\ \mathrm{GeV}}{m_{3/2}}\right)^2 \left(1 - \frac{m_{3/2}^2}{m_{\tilde{\tau}}^2}\right)^4$$



Relic stops

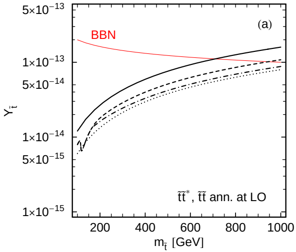
Top:

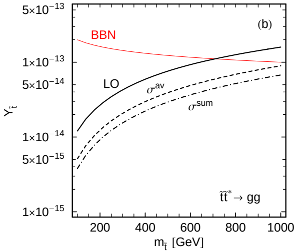
- Solid line for $\tilde{t}\tilde{t}^* \to gg$, dashed line includes all channels into QCD+EW gauge and h bosons
- Dash-dotted line for $m_{\tilde{g}} = 2m_{\tilde{t}_R}$
- Dotted line the limit $Y_{\tilde{t}} = Y_{nab}/2$.

Bottom:

- Full line the tree level $\tilde{t}\tilde{t}^* \to gg$
- Dashed line and dash-dotted for σ^{SF}_{av} and σ^{SF}_{sum}

BBN bound for 0.1–100 s lifetime (red line)





Stop NLSP decaying into axino or gravitino

Stop decay into a stable axino:

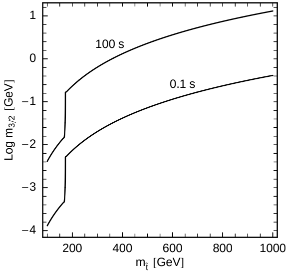
$$\Gamma(\tilde{t}_R \to t\tilde{a}) = (1.3\times10^{-3}\ \text{sec})^{-1}\xi_t^2 \left(\frac{m_{\tilde{t}}}{10^2\ \text{GeV}}\right)\left(\frac{m_{\tilde{g}}}{10^2\ \text{GeV}}\right)^2\left(\frac{10^{11}\ \text{GeV}}{f_a}\right)^2\left(1-\frac{m_{\tilde{a}}^2}{m_{\tilde{t}}^2}\right)$$

- BBN bound never applies for $m_{\tilde{t}}^2 > (m_{\tilde{a}} + m_t)^2$
- for smaller $m_{\tilde{t}}$ virtual t and $\tau \sim 0.1$ s

$\Rightarrow$ BBN bounds completely avoided

Stop decay into a gravitino:

- Same formula as for stau, but width get suppressed for $m_{\tilde{t}} < m_t + m_{\tilde{G}}$
- For $0.1 < \tau < 100$ s BBN limits avoided for $m_{\tilde{t}} < 100$ GeV (see plot before)
- Above 100 s, maybe in accord with BBN thanks to additional annihilation due to QCD phase transition



Conclusions

- Discussed the thermal production of a long lived charged relic
- Number density significantly altered by Sommerfeld enhancement
- Applied to the MSSM with stau or stop NLSP and axino or gravitino LSP
- BBN bounds give strong constraints, can be avoided for light masses
- BBN constraints can be avoided more easily for axino LSP

Berger, Covi, Kraml, Palorini, arXiv:0807.0211 [hep-ph]