Problem set 8

Tutorial: 13 June 2018, 12:15

Problem 18: The gravitino problem

In addition to production via the SuperWIMP mechanism, gravitinos can also be produced directly in the annihilation of SM particles. Since gravitinos interact only gravitationally, dimensional analysis tells us that the annihilation cross section is approximately given by

$$\langle \sigma v \rangle \sim \frac{1}{M_{\mathrm{Pl}}^2} . \tag{1}$$

a) Show that for temperatures $T \ll M_{\mathrm{Pl}}$ the production rate of gravitinos $\Gamma_{\mathrm{prod}} = \langle \sigma v \rangle \, n_{\mathrm{SM}}$, where n_{SM} is the number density of SM particles, is tiny compared to the Hubble rate and hence gravitinos never enter into thermal equilibrium with the SM.

The out-of-equilibrium production of gravitinos is described by a simplified version of the Boltzmann equation:

$$\frac{1}{a^3} \frac{\mathrm{d}(n_{\tilde{G}} \, a^3)}{\mathrm{d}t} = \langle \sigma v \rangle \, n_{\mathrm{SM}}^2 , \tag{2}$$

where $n_{\tilde{G}}$ is the number density of gravitinos and a is the scale factor.

b) By defining $Y_{\tilde{G}} = n_{\tilde{G}}/s$ with the entropy density s, show that the above equation can be written as

$$\frac{\mathrm{d}Y_{\tilde{G}}}{\mathrm{d}T} = -\frac{\langle \sigma v \rangle \, n_{\mathrm{SM}}^2}{H \, T \, s} . \tag{3}$$

c) Show that the right-hand side of this equation is independent of temperature and that hence the present-day value of $Y_{\tilde{G}}$ is directly proportional to the reheating temperature T_{R}, which is the highest temperature ever reached in the Early Universe.

d) Why does this calculation imply that large reheating temperatures may be problematic for SUSY theories?

Problem 19: Dark photon searches

Let us consider an e^+e^- collider with a centre-of-mass energy of $\sqrt{s} = 10.6\,\mathrm{GeV}$ (like e.g. Belle II) and assume that there is a dark photon with mass $m_{A'} < \sqrt{s}$ that mediates the interactions between the SM and a DM particle with mass $m_\phi < m_{A'}/2$.

a) Consider the mono-photon process $e^+e^- \to \gamma A'$ followed by $A' \to \phi\phi$. Find the distribution of photon energies $\mathrm{d}N/\mathrm{d}E_\gamma$.

b) How does this distribution differ from the corresponding distribution at hadron colliders? Why is this an advantage for e^+e^- colliders?

Consider now the case of secluded dark matter ($m_\phi > m_{A'}$).

c) How does this change the expected experimental signature for the mono-photon signal?

d) Can you think of a more promising experimental search strategy?