Non-equilibrium cosmological nucleosynthesis

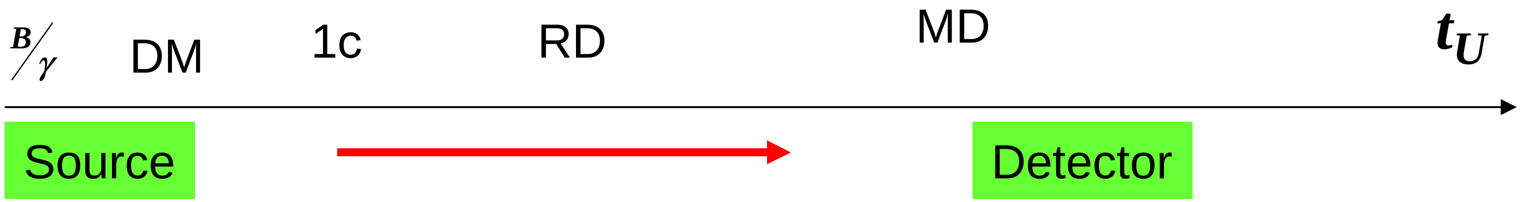
Lecture from course

"Introduction to Cosmoparticle Physics"

Outlines

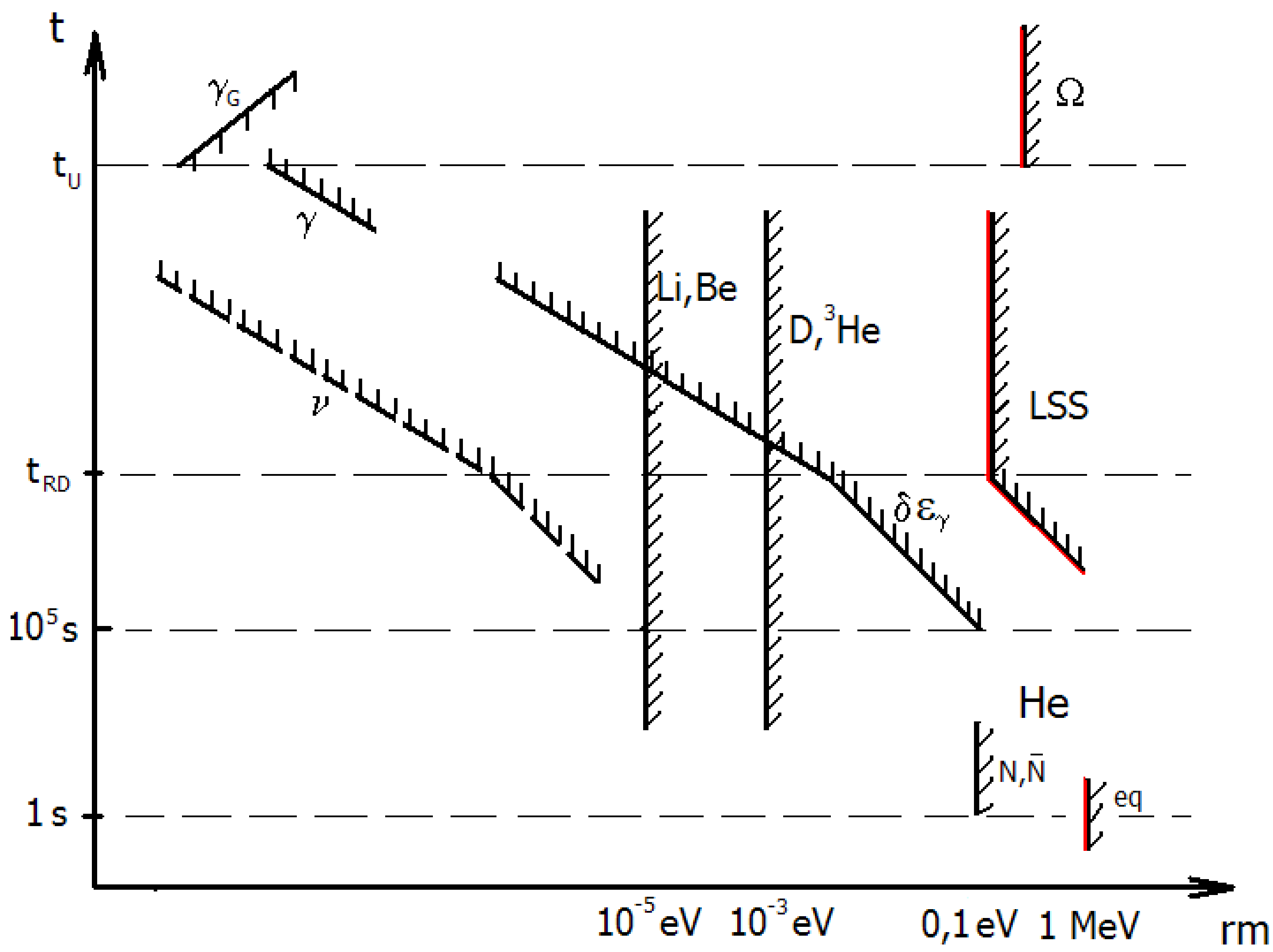
- « Differential detectors » of the Universe
- Non-equilibrium particles
- Experimental nuclear cosmoarcheology
- Astro-nuclear experiment ASTROBELIX
- Problem of primordial gravitino

Cosmoarcheology treats the set of astrophysical data as the experimental sample sheding light on possible properties of new physics. Its methods provide *Gedanken Experiment*, in which cosmophenomenology of new physics is considered as the source, while its effects on later stages of expansion are considered as detector, fixing the signatures for these effects in the astrophysical data.



These « detectors of the Universe » can be « integral » (sensitive to very existence of new forms of matter) and « differential » (sensitive to some particular effect of such forms of matter)

Laboratory of the Universe



$$r \equiv \frac{n_X}{n_\gamma}$$

Differential detectors

Indicators of specific modes of new particle decay

Non-equilibrium particles

- Decays of unstable particles, antimatter domain annihilation, PBH evaporation… are the source of particles with energy E>>T or of such particles, which are absent in equilibrium at this temperature T (e.g. antiprotons in baryon asymmetrical Universe after the first microsecond of expansion).
- Late sources of non-equilibrium particles directly contribute in fluxes of cosmic rays.
- If the source of particles acts sufficiently early, interaction of non-equilibrium particles with plasma and radiation can lead to observable effect

Nuclear cosmoarcheology

- **After BBN primordial chemical composition is created in the Universe: 75% H, 25% He-4 with a small fraction of other elements:**

$$X_D = 2.5 \cdot 10^{-5}; X_{^3He} = 4.2 \cdot 10^{-5}; X_{^7Li} = 2 \cdot 10^{-9}$$

- **Destruction by non-equilibrium particles of even small fracion (<1%) of primordial He-4 can lead to excessive abundance of light elements (D and He-3). Antinucleons in the Universe after BBN (from sources of nucleon-antinucleon pairs or survived in antimatter domains) are a profound example of non-equilibrium particles:**

$$\bar{p} + {}^4He \Rightarrow n + ...; n + p \Rightarrow D + \gamma; \bar{p} + {}^4He \Rightarrow D + N + pions$$

$$\bar{p} + {}^4He \Rightarrow {}^3H + pions; \bar{p} + {}^4He \Rightarrow {}^3He + pions$$

Experimental nuclear cosmoarcheology

- **There was an incomplete link in the cosmoarcheoLOGICAL chain between comophenomenology of new physics and observed light element abundance. The yield of D,T and He-3 was not known in reactions**

$$\bar{p}+{}^4He \Rightarrow D+N+pions$$

$$\bar{p}+{}^4He \Rightarrow {}^3H+pions$$

$$\bar{p}+{}^4He \Rightarrow {}^3He+pions$$

This information was obtained in special experiment PS179 at Low Energy Antiproton Ring (LEAR) in CERN. The measured yield of He-3 (20%) provided a set of severe constraints on the sources of nonequilibrium particles after BBN.

- **Analysis of Li and Be formation by nonequilibrium nuclear fragments (D, He-3, T) strengthened these constraints by 2 orders of magnitude. The progress was achieved in the result of Astro-nuclear experiment ASTROBELIX**

$$\bar{p}+{}^4He \Rightarrow D+...;D+{}^4He \Rightarrow {}^6Li+\gamma$$

$$\bar{p}+{}^4He \Rightarrow {}^3H+...;{}^3H+{}^4He \Rightarrow {}^6Li+n$$

$$\bar{p}+{}^4He \Rightarrow {}^3He+...;{}^3He+{}^4He \Rightarrow {}^7Be+\gamma$$

Astro-nuclear experiment ASTROBELIX

- The project was aimed to join astronomers and physicists in studies of nuclear cosmoarcheology
- Measurement of momentum distribution for secondary He-3, D, T from antiproton-helium interaction in experiment OBELIX at LEAR CERN.
- Astronomical measurement of pregalactic abundance of light elements (by narrow band distorsions in CMB spectrum).
- Theoretical analysis of nuclear cosmoarcheological chain

Gravitino in SUSY models

- Local SUSY models predict SUSY partner of graviton with spin 3/2 – gravitino, having semi-gravitational interaction $\propto 1/m_{Pl}$
- In a wide variety of models gravitino mass is determined by SUSY breaking scale (~100 GeV)
- In such models gravitino is unstable with lifetime

$$\tau = a\left(\frac{m_{Pl}}{m_G}\right)^3 \frac{1}{m_{Pl}} \approx 10^8 s\left(\frac{100GeV}{m_G}\right)^3$$

- If created in early Universe it should decay at $t = \tau$ and give rise to non-equilibrium particles from decay channels

$$G \to g\tilde{g}; \gamma\tilde{\gamma} \Rightarrow g \to hadrons$$

Problem of primordial gravitino

- **Due to superweak semi-gravitational interaction gravitino could not be in equilibrium in early Universe, but it could be produced in reactions with SUSY particles.**
- **Abundance of primordial gravitino mass is determined by reheating temperature**

$$r_G = \frac{n_G}{n_\gamma} \approx \frac{T_{reheating}}{m_{Pl}}$$

- **Hadronic cascades from gravitino decay induce Li production**

$$G \rightarrow \tilde{g}g \Rightarrow g \rightarrow N\bar{N} \Rightarrow \bar{N}\,{}^4He \rightarrow T + \ldots \Rightarrow T + {}^4He \rightarrow {}^6Li + n$$

- **From observed lithium abundance follows** $T_{reheating} < 4 \cdot 10^6\, GeV$
- **Problem of primordial gravitino (baryogenesis?)**

Conclusions

- **« Differential detectors » of the Universe are sensitive to non-equilibrium particles.**
- **Results of non-equilibrium cosmological nucleosynthesis directly depend on cross sections of reactions with such particles.**
- **Problems of nuclear cosmoarcheology imply new level of relationship between experimental particle physics and cosmology and give rise to experimental nuclear cosmoarcheology**
- **Any given cosmoarcheological chain constrains new physics from the astrophysical data. To provide realistic scenario all the data should be reproduced.**