Cosmoarcheology

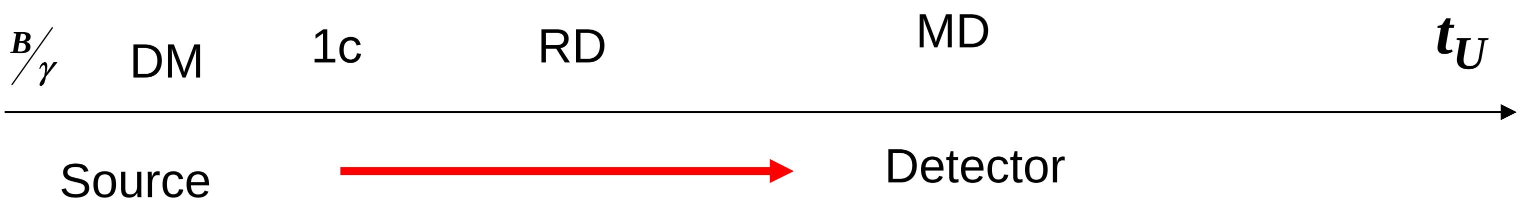
Lecture from course

“Introduction to Cosmoparticle Physics”

Outlines

- « Integral » detectors of the Universe.
- Age of the Universe - measure of the modern density
- Primordial helium – measure of the total density at 1 s
- LSS as detector of unstable particles
- PBHs – probe for physics of very early Universe

Cosmoarcheology treats the set of astrophysical data as the experimental sample shedding light on possible properties of new physics. Its methods provide Gedanken Experiment, in which cosmological consequences of particle theory in the very Early Universe (in the 1 s of expension) are considered as the source, while their effects on later stages of expansion are considered as detectors, fixing the signatures for these effects in the astrophysical data.



These “detectors of the Universe” can be “integral” (sensitive only to the very presence of new forms of matter) and “differential “ (sensitive to some specific effects of these forms).

Detectors of the Universe

- Integral detectors (age of the Universe, primordial He, LSS, PBH) are sensitive to the contribution of a new form of matter (or products of its decay) to the total cosmological density.
- Differential detectors are sensitive to presence of decay products of definite type ($\bar{p}, \gamma, \nu ...$).

Integral detectors

Indicators of the very fact of presence of any form of matter in the Universe

Age of the Universe

$$t_U\left(\Omega, p(\rho)\right)$$

Lower limit on the age of the Universe puts upper limit on the total cosmological density

WMAP, PLANCK: $\Omega = 1$

Any new form of matter can not give larger contribution to the total density. At large value of the Hubble constant the estimated age of the Universe favors the presence of “dark energy” and the acceleration of the modern cosmological expansion

Primordial He and the equilibrium for beta processes

$$\frac{n}{p} = \exp\left\{-\frac{\Delta m}{T}\right\}$$ is in equilibrium at $T < \Delta m = m_n - m_p$

The equilibrium ratio is provided by beta processes

$$\nu_e + n \Leftrightarrow e + p$$

$$\bar{\nu}_e + p \Leftrightarrow e^+ + n$$

When the rate of expansion exceeds the rate of beta processes

$$R = \kappa_0^{1/2} \frac{T^2}{m_{Pl}} \geq (n_l \sigma v) = G_F^2 T^5$$ at

$$T_f = \left(\frac{\kappa}{\kappa_0}\right)^{1/6} \left(G_F^2 m_{Pl}\right)^{-1/3} \approx \left(\frac{\kappa}{\kappa_0}\right)^{1/6} \left(\frac{10^{-10}}{m_p^4} 10^{19} m_p\right)^{-1/3} \approx 10^{-3} m_p \left(\frac{\kappa}{\kappa_0}\right)^{1/6} \approx 1 MeV \left(\frac{\kappa}{\kappa_0}\right)^{1/6}$$

This ratio is frozen out and virtually all the frozen out neutrons go during *the first three minutes* in primordial helium

Primordial He and the number of species of relativistic particles

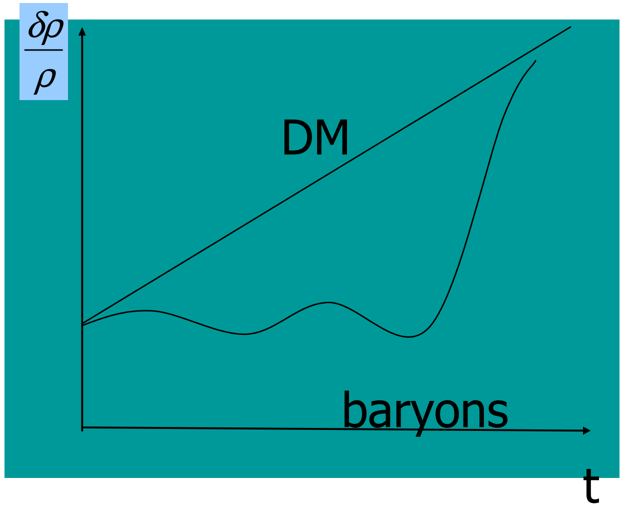
$$\frac{n}{p} = \exp\left\{-\frac{\Delta m}{T_f}\right\}$$ and the freezing out temperature $$T_f \propto \left(\frac{\kappa}{\kappa_0}\right)^{1/6}$$

Any new species of relativistic particles increases the frozen our concentration of neutrons and correspondingly of primordial helium

$$Y_{prim} = 0.25 \Rightarrow \Delta n_\nu < 1$$

For a long time the opinion was widely spread that the abundance of primordial helium does not admit more than 3 types of light neutrinos.
Recently the systematic errors in determination of this abundance acquire more attention and less restrictive limits are discussed.
In any case even the most conservative estimation of primordial helium abundance puts severe constraint on the expansion rate of the Universe at 1 s of expansion and on the presence of any unknown form of matter in this period.

The condition of formation of the cosmological Large Scale Structure (LSS)



$$\frac{\delta\rho}{\rho} \Rightarrow \frac{\delta T}{T}$$

Formation of the Large Scale structure of the Universe due to growth of small initial density fluctuations needs long dust-like stage of expansion, at which these small fluctuations grow.

Unstable particles, decaying in that period to Relativistic particles, should not prevent this growth of density fluctuations.

Primordial Black Holes (PBH) – indicators of physics of very early Universe

- Existence of superheavy metastable particles in the very early Universe leads to stages of their dominance, at which growth of their density fluctuations leads to formation of their gravitationally bound systems, including black holes.
- Black holes, formed at this stage , must retain in the Universe after decay of particles, which have formed them, and at the mass $M > 10^{15} g$ must be present in the modern Universe as a specific form of dark matter.
- Black holes of smaller mass evaporate by mechanism of Hawking
- Effect s of their evaporation are similar to effects of decay of unstable paticles with one important difference – the products of evaporation are all the existing particles with mass, smaller than the temperature of evaporation.

Conclusions

•« Integral detectors » of the Universe are sensitive only to the fact of presence of new particles.

•The age of the Universe puts upper limit on the total density and contribution of new particles in it.

•Primordial He abundance puts upper limit on the existence of new particles at 1 s

•Existence of LSS constrains decays of unstable particles that could prevent its fromation.

•PBHs link contraints on particles with physics of very early Universe