Baryosynthesis

Lecture from the course
« Introduction to cosmoparticle physics »

The bedrocks of modern cosmology

Our current understanding of structure and evolution of the Universe implies three necessary elements of Big Bang cosmology that can not find physical grounds in the standard model of electroweak and strong interactions. They are:

- Inflation
- Dark matter/energy
- Baryosynthesis

The latter (Baryosynthesis) is the topic of our discussion today

Baryosynthesis

To explain the origin of the observed baryonic matter together with the absence of the symmetric amount of antimatter in the Universe one should assume an initial excess of baryons, which is retained after baryon-antibaryon annihilation (at ~1 ms).

Excess of baryons, as A.D.Sakharov (1967) and then V.A.Kuzmin (1970) supposed, was generated from baryon-symmetric matter in early Universe due to processes, satisfying conditions:

1) $\Delta B \neq 0$

2) CP $\neq 1$

3) out of equilibrium

Baryosynthesis: GUT

In the framework of **GUT** the following scenario is possible.

Let us assume existence of superheavy particles and antiparticles (leptoquarks) which had been present in the early Universe in the equal amounts:

$$X, \quad \bar{X}$$

Let us assume that their decay was out of equilibrium, i.e. was irreversible (for this one needs $\Gamma_X \ll H$), with violation of baryon/lepton number and CP-parity:

$$X \to qq, \ r \qquad \bar{X} \to \overline{qq}, \ \bar{r}$$

$$X \to \bar{q}l, \ 1-r \qquad \bar{X} \to q\bar{l}, \ 1-\bar{r}$$

Here r is branching ratio of respective decay channels. Inequality $r \neq \bar{r}$ is provided by CP-violation, while the total width of particle and antiparticles should be equal due to CPT theorem.

Baryosynthesis: GUT

In the result of decays of leptoquarks we get baryon asymmetry as large as

$$n_B - n_{\overline{B}} \propto (r - \overline{r})n_X$$

In SU(5) GUT model there is a rule for baryon and lepton numbers:

B - L=0

It turns out that the conservation of baryon and lepton numbers can be also violated in the Standard model at high temperatures.

Baryosynthesis: electroweak model

In the framework of electroweak model the following scenario is possible (V.Kuzmin,V.Rubakov, M.Shaposhnikov, 1985).

Baryon and lepton numbers are not conserved at high temperature (T>175 GeV) due to so call sphaleron processes. These processes satisfy condition

B+L=0

Under condition of non-homogeneity of EW phase transition (in space), a non-equilibrium conditions are realized at boundary region of different phases.

CP-violation is introduced in theory explicitly, on the base of experimental data.

So all Sakharov’s conditions can be satisfied in the Standard model too.

However, 1) degree of CP-violation is too small, 2) for realization of necessary non-equilibrium conditions, the mass of Higgs boson is required to be too small (about 50 GeV), being inconsistent with modern data.

Baryosynthesis in Universe can not be realized without going beyond the standard electroweak model,

* **Note**: electroweak physics prevents to create baryon excess by the mechanism of SU(5) GUT model.

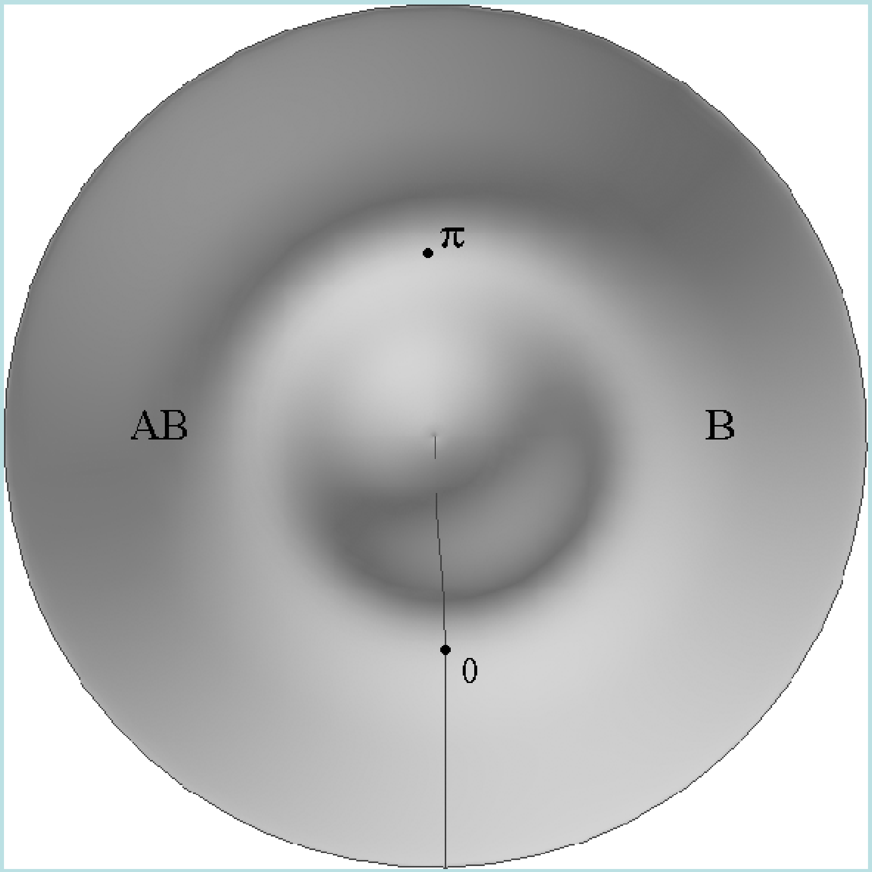
Baryosynthesis: SUSY model

In the framework of supersymmetry (SUSY) the following scenario is possible (I.Affleck, M.Dine 1985, Linde 1985).

Conservation of baryon and lepton numbers are not required in supersymmetry as well as in electroweak model. Moreover, some superpositions of scalar fields (of SUSY partners of ordinary quarks and leptons) that possess non-zero baryon/lepton numbers can have a wide range of energetically equivalent nonzero amplitudes (their potential is flat until supersymmetry is not broken). So, these fields can get arbitrary initial amplitudes with nonzero B and L. After SUSY breaking, a condensate of respective scalar particles appears. It decays afterwards, producing baryon (and lepton) excess.

This mechanisms is analogous to one of the mechanism of axion production in early Universe. Two stages take place: violation of $U(1)_{PQ}$ and axion field gets energetically equivalent, arbitrary magnitudes; then QCD phase transition removes energetic degeneracy [~SUSY breaking] and condensate appears. If the first step of symmetry breaking takes place on inflationary stage and the B and L non-conserving channels of decay for the field are possible, spontaneous baryosynthesis can take place.

Spontaneous baryosynthesis



Model of spontaneous baryosynthesis

$$L = -\frac{f^2}{2}\partial_\mu\theta\partial^\mu\theta + i\bar{Q}\gamma^\mu\partial_\mu Q + i\bar{L}\gamma^\mu\partial_\mu L$$
$$-m_Q\bar{Q}Q - m_L\bar{L}L + (\frac{g}{\sqrt{2}}f\bar{Q}L + h.c.) + \partial_\mu\theta\bar{Q}\gamma^\mu Q$$

leads to generation of baryon excess in the rolling of the field to the state of minimum of its potential

Sufficiently large domains of antimatter survive to the present time

Baryosynthesis from leptogenesis: in model of Majorana neutrino mass

In see-saw mechanism of Majorana neutrino mass we have two neutrino states: light left-handed Majorana neutrino, and heavy right-handed one (N_R).

Baryosynthesis can be realized with the help of N_R analogously to mechanism in GUT model in combination with mechanism in electroweak model.

1) N_R decays with violation of L and CP => L-synthesis (like B-synthesis in GUT)
2) Synthesized lepton number is re-distributed between B and L due to sphaleron processes (with B+L=0)

Baryosynthesis from transitions between ordinary and mirror particles

- If there are transitions between ordinary and mirror particles O< -- >M, nonequilibrium character of such transitions can lead to generation of excess of baryons, which is related with excess of mirror « antibaryons » (Berezhiani et al).

It is not the complete list of models for possible origin of baryon asymmetry of the Universe. The problem is to make a choice between them and special methods of cosmoparticle physics are developed to probe these ideas.

Conclusions

- Baryosynthesis relates the observed baryon asymmetry of the Universe to physical processes in the early Universe.
- Methods of cosmoparticle physics can provide probes for various mechanisms of baryosynthesis.
- These methods are the subject of our further discussions