The problems of old cosmology

Lecture from the course
« Introduction to cosmoparticle physics »

The problem of magnetic monopoles

In GUTs, magnetic monopoles are predicted with

$$g = (2e)^{-1}$$

$$m_M \sim \Lambda_{\mathrm{GUT}} / \sqrt{\alpha} \qquad (\Lambda_{\mathrm{GUT}} \sim 10^{15}\ \mathrm{GeV})$$

If there existed magnetic monopoles, we would have their huge overproduction. Though historically this problem has stimulated the drastic change of cosmological scenario, it is model dependent. Critical analysis of the old Big Bang scenario revealed a set of basic problems of this scenario, which are not based on the assumption on the GUT physics.

The problem of initial state

1) Singularity: $\varepsilon \to \infty$ at $t \to 0$.

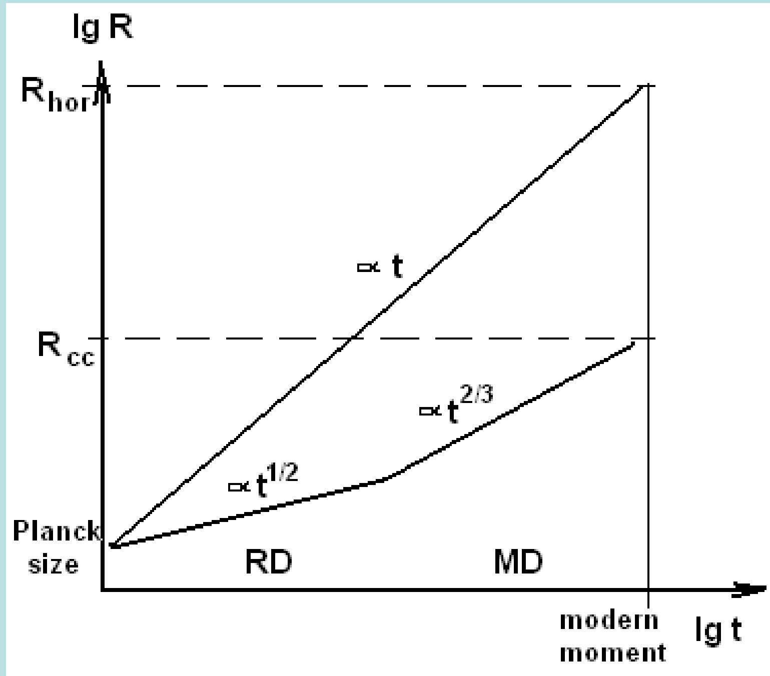
2) Initial impulse: $\vec{v}(\vec{r}, t = 0)$ should be given "by hands" and adjusted in accordance with Hubble law and the scale of modern Universe.

The horizon problem

- Initially causally-connected region grows slower (as scale factor being $\sim t^{1/2}$ at RD stage, $\sim t^{2/3}$ at MD-stage) than horizon $R_{hor} \sim ct$. So 10^{88} regions, initially causally-disconnected at Planck time, are inside modern horizon, while the observed conditions in them are very similar.

$$\left(\frac{R_{\mathrm{hor}}^{(\mathrm{mod})}}{R_{\mathrm{cc}}^{(\mathrm{mod})}}\right)^3 = \left(\frac{l_{\mathrm{Pl}} \cdot t_{\mathrm{mod}} / t_{\mathrm{Pl}}}{l_{\mathrm{Pl}} \cdot a_{\mathrm{mod}} / a_{\mathrm{Pl}}}\right)^3 \sim \left(\frac{t_{\mathrm{mod}} / t_{\mathrm{Pl}}}{T_{\mathrm{Pl}} / T_{\mathrm{mod}}}\right)^3 \sim$$

$$\sim \left(\frac{5 \cdot 10^{17}\mathrm{s} / 0.5 \cdot 10^{-43}\mathrm{s}}{1.2 \cdot 10^{19}\mathrm{GeV} / 2.7\mathrm{K}}\right)^3 \sim 10^{88}$$



The flatness problem

Flatness: the curved Universe initially must be extremely close to flat. At Planck time Ω should be as close to unit as 10^{-59}.

In fact, from Friedman's equations for total density one can get

$$\boxed{\Omega \equiv \frac{\varepsilon}{\varepsilon_{cr}}}$$

$$\Omega - 1 = \frac{K}{\dot{a}^2} \propto K \cdot \begin{cases} t \propto a^2 \text{ at RD-stage,} \\ t^{2/3} \propto a \text{ at MD-stage.} \end{cases}$$

$$\Omega_{\mathrm{Pl}} - 1 \approx (\Omega_{\mathrm{mod}} - 1)\left(\frac{T_{\mathrm{Pl}}}{T_{\mathrm{RD}}}\right)^2 \frac{T_{\mathrm{RD}}}{T_{\mathrm{mod}}} \sim 10^{-59}(\Omega_{\mathrm{mod}} - 1)$$

Note: closeness of Universe to flat in the past justifies the use of adopted approximation (K=0) in description of its evolution (for RD- and MD-stages).

The problem of initial fluctuations

- Initial inhomogeneities: the amplitude of density fluctuations cannot be explained stochastically and should be put “by hands” in old cosmology framework.

- In fact, data on anisotropy of CMB tells that initial fluctuations (of baryonic matter) were of the order of

$$\frac{\delta\varepsilon}{\varepsilon} \sim 10^{-4}$$

While, statistical fluctuations for galactic cluster are of the order of

$$\frac{1}{\sqrt{N_{\text{atoms}}}} \sim \frac{1}{\sqrt{10^{68}}} \sim 10^{-34}$$

The problem of baryon excess

If there were equality between baryons (nucleons) and antibaryons then we had (roughly)

$$n_B^* = \frac{H^*}{\langle \sigma_{\text{ann}} v \rangle}$$

$$T_* \sim m_N / 10 \approx 100\,\text{GeV}$$

$$n_B^{\text{mod}} = n_B^* \left(\frac{a_*}{a_{\text{mod}}} \right)^3 = \frac{H^*}{\langle \sigma_{\text{ann}} v \rangle} \cdot \frac{n_\gamma^{\text{mod}}}{n_\gamma^*} \frac{\kappa_s^{\text{mod}}}{\kappa_s^*} \sim \begin{pmatrix} H^* \sim m_{\text{Pl}}^{-1} T_*^2 \\ n_\gamma^* \sim T_*^3 \\ \langle \sigma_{\text{анн}} v \rangle \sim m_\pi^{-2} \end{pmatrix} \sim \boxed{10^{-20} \, n_\gamma^{\text{mod}}}$$

More accurate estimation gives 10^{-18}.

While we observe $$n_B^{\text{mod}} \approx \boxed{0.6 \cdot 10^{-9} \, n_\gamma^{\text{mod}}}$$

Approximately the same takes place for leptons (electrons).

The problem of baryons' deficit

Estimation of baryonic density: estimations of the modern density of baryons (ordinary matter) show that visible baryons correspond to about ¼ of total baryon density. The total baryon density does not exceed 0.04 of critical density.

In fact, observations give for visible baryons

$$\Omega_{B\,\mathrm{visible}} \sim 0.01$$

Cosmological analysis of chemical composition and of CMB anisotropy give for total baryon density

$$\Omega_{B\,\mathrm{tot}} \sim 0.044(4)$$

The problem of dark matter

Estimation of density of matter in galaxies: the matter concentrated in galaxies (referred below to as “matter”) composes

$$\Omega_m \sim 0.22(3)$$

The hidden mass of galaxy clusters.

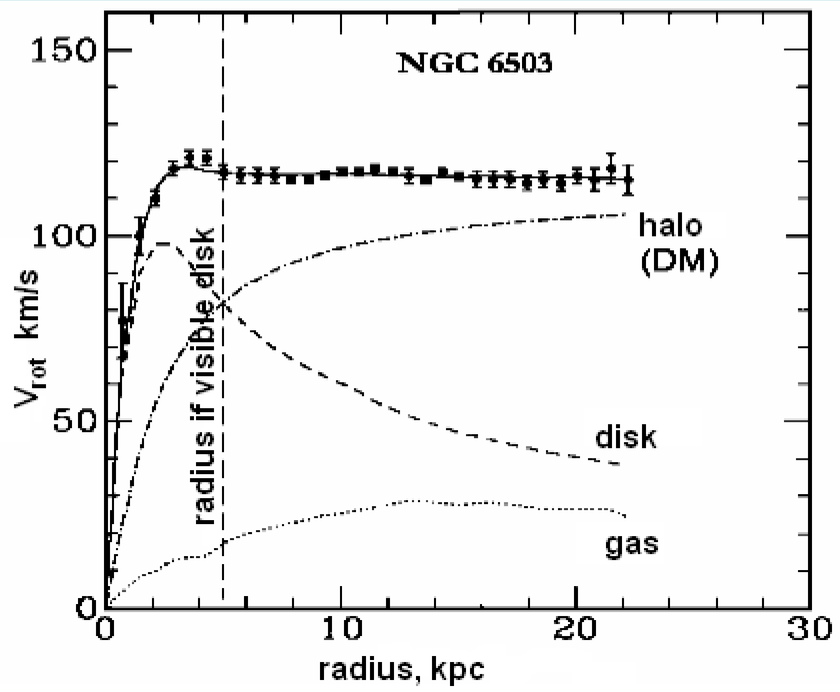
In fact, as early as 1933, F.Zwicky observed Coma cluster of galaxies and concluded according virial theorem that M/L ~100 $M_{\text{Sun}}/L_{\text{Sun}}$.

It cannot be ascribed to intergalactic gas. Temperature of this gas confirms the “virial paradox”.

Gravitational lensing measures the total mass of clusters.

Rotation curves of galaxies

Observation of rotation curves (dependence of star rotational velocity from radius inside galaxy) confirms the conclusion on the existence of hidden mass in galaxies.



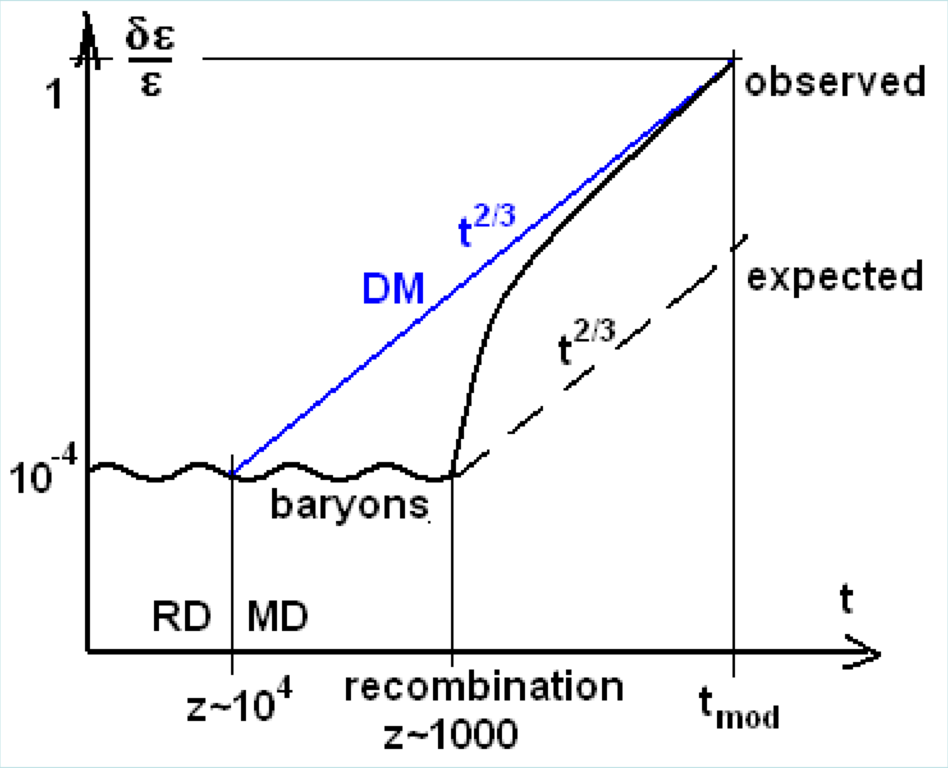
$$\frac{m\upsilon^2}{R} = \frac{GmM}{R^2}$$

$$\upsilon(R) = \sqrt{\frac{GM}{R}}$$

The problem of LSS formation

Theory of galaxy formation, combining the data on the Large Scale Structure (LSS) of the Universe and on the anisotropy of CMB, comes to the conclusion on the existence of dominating non-baryonic matter that formed the structure of the Unvierse.

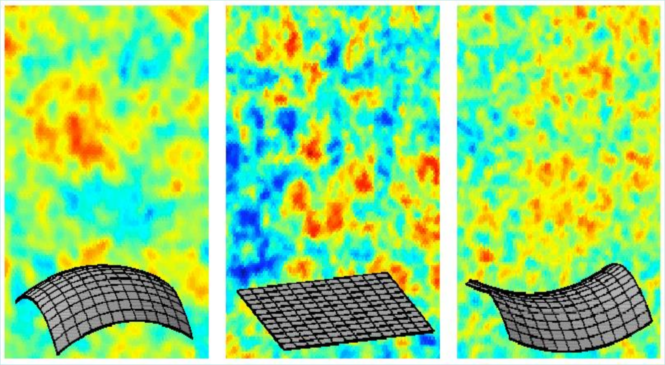
In fact, at RD stage $\delta\varepsilon/\varepsilon$=const, at MD stage $\delta\varepsilon/\varepsilon$ evolves (until <<1) as $t^{2/3}$~a~$(z+1)^{-1}$.

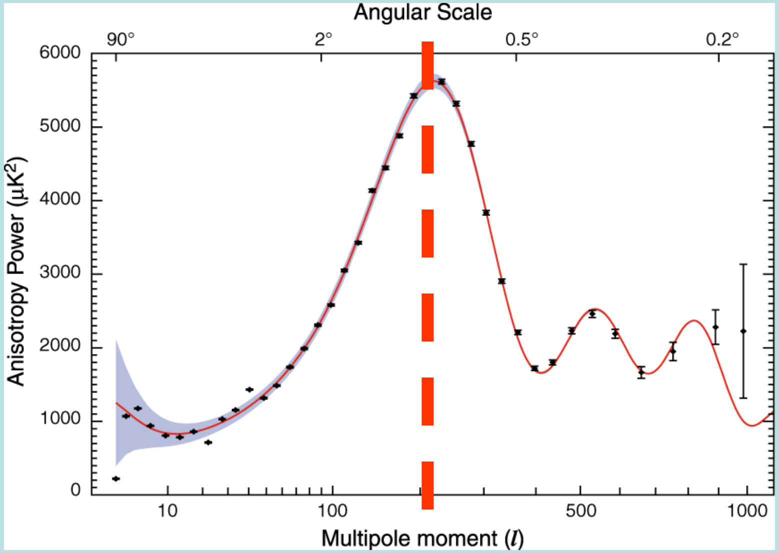


The problem of the total density

Measurement of total density: total density defines geometry of Universe. Respective analysis of data on anisotropy of CMB gives

$$\Omega_{tot} \sim 1.00(2)$$





The problem of dark energy

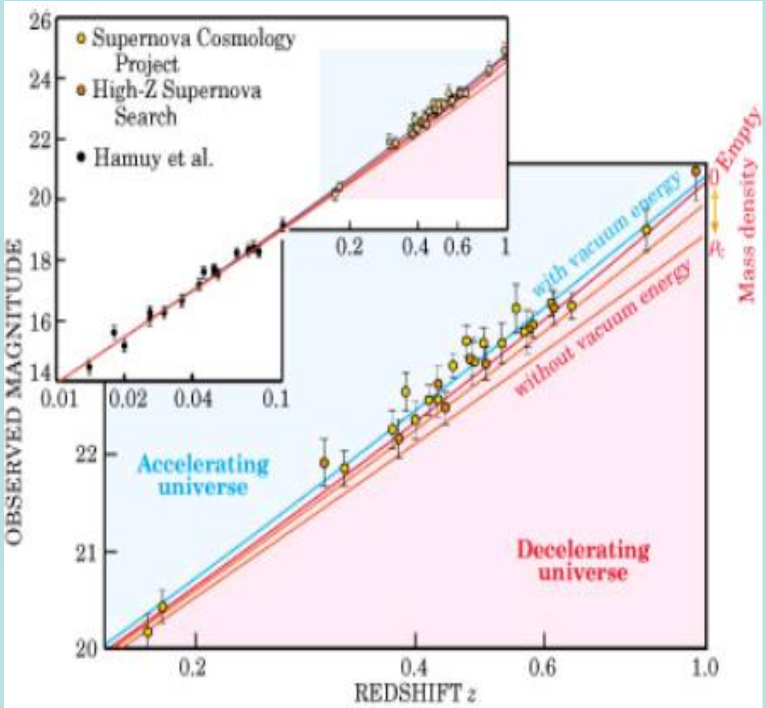
Evidences of dark energy: several evidences favour existence of Λ-term or dark energy with equation of state

$$p = -0{,}97(8)\varepsilon$$

and composing the difference between Ω_{tot} and Ω_m

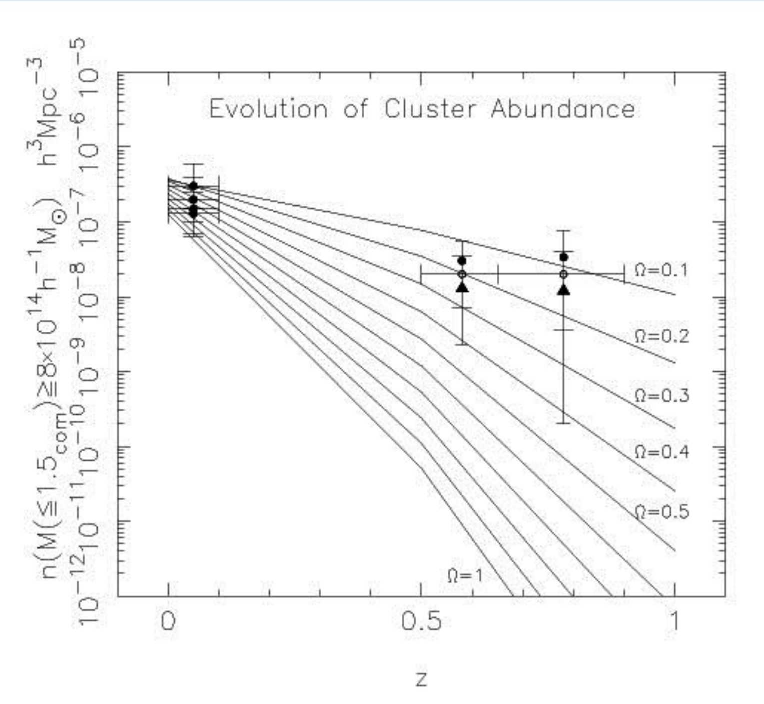
$$\Omega_\Lambda \sim 0.75(5)$$

a) Observation of supernova of type Ia tells in favour of accelerating expansion for last period z<0.7 (for greater z, an fainting is observed).



The problem of slow LSS evolution

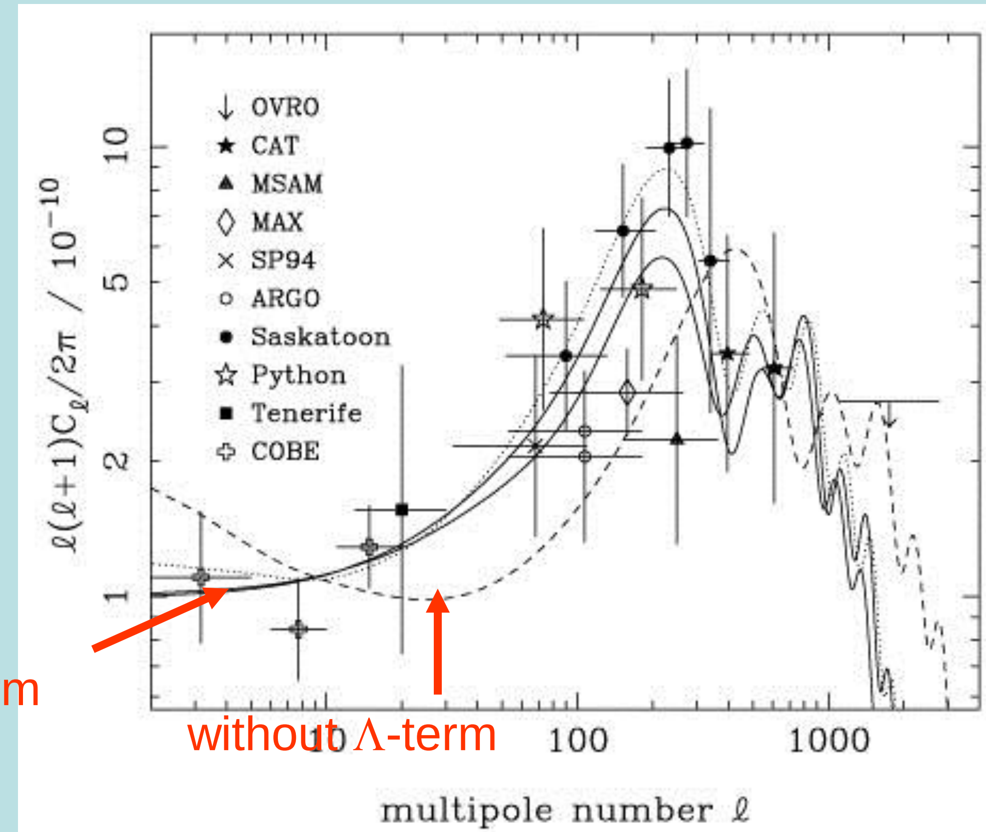
The data on LSS exhibit delay in late evolution of galaxy, indicating either on physical slowing down of this evolution or on its relative slowing down (on the background of accelerated expansion, favouring the existence of vacuum energy, e.g. of Λ-term).



The high observed magnitude of Hubble constant together with the estimated age of the Universe also favour the accelerating expansion due to vacuum energy (by Λ-term, for example).

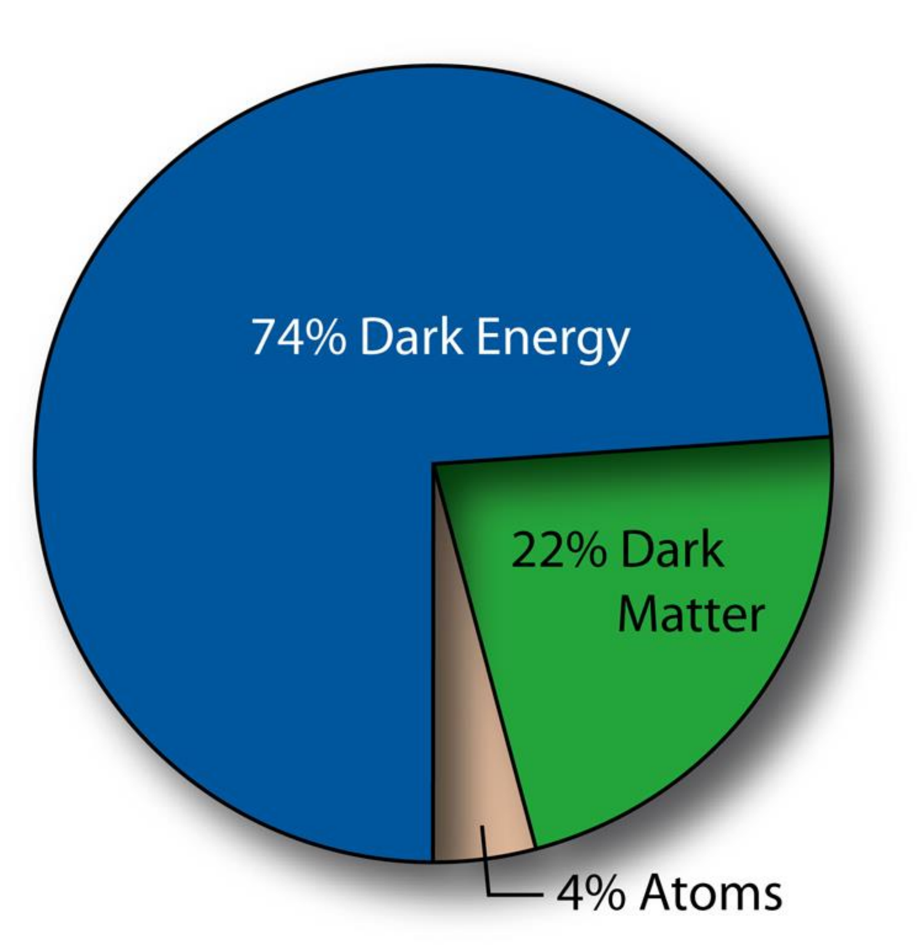
The dark energy from CMB data

Analysis of CMB anisotropy also favours existence of Λ-term.



with Λ-term

Summary on modern Universe composition



Conclusions

- Magnetic Monopole overproduction has instigated critical analysis of the old Big Bang scenario.
- The problems of initial state, horizon, flattness, of the origin of primordial fluctuations and of the origin of baryon excess appealed to the change of scenario of very early Universe.
- Problems of « virial paradox » in galaxy clusters, of « hidden mass » of galaxies and of galaxy formation together with the observed deficit of baryons imply the existence of nonbaryonic dark matter.
- The data on SNIa, LSS and CMB together with the measured value of Hubble constant favour the existence of dark energy – dominance of vacuum energy in the modern Unvierse, leading to its accelerated expansion.