

The Standard Cosmological Model

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Abstract: The progress and problems of standard cosmological model are considered. We analyze geometry and matter composition as well as the origin of initial conditions and dark components in the Universe.

1. Introduction

Discoveries made by observational cosmology have led us to a new understanding of the Universe. Today we know the model at large scales that can explain all available data.. After many years of hypotheses and markets of models we now have the standard cosmological model, yet separated from what we have at small scales — the standard model of elementary particles. Both models progressively converge and interact, still many fundamental questions are left unanswered.

Astronomers see structures unknown to physicists. They cannot touch or test them, they can learn only basic properties of observed matters assuming some theoretical extrapolations (General Relativity, atomic physics, etc.). On the contrary, physicists need experiment to judge things. To understand what astronomers see, physicists are looking in labs for what is unknown to them, since there is not enough information about the target.

What do astronomers see? They observe structures made of invisible matter, *the dark matter*. DM does not interact with light or luminous matter. How is DM observed then? Through its gravitational influence on visible matter.

Fortunately, light is there where DM concentrations are. We explore the non-linear DM halos gravitationally bound in all three directions, measuring the radial velocities of optical galaxies captured by gravitational field of these halos, X-ray gas residing at the bottom of their gravitational wells, and distorted images of the background galaxies that happened to be on the line of sight of DM halos.. At larger scales we study spatial distribution of DM systems analyzing galaxy catalogs and quasar absorption lines. Besides, the DM surface mass density can be reconstructed via its gravitational weak lensing action on numerous background galaxies. Hence, there is more than enough independent probes of dark mass inside and beyond DM halos. We can state that the mean contrast of DM density field is larger than unity at small scale ($< 15 Mpc$) still remaining less than unity at large scale ($> 15 Mpc$). Accordingly, we do not find DM halos exceeding $10^{15} M_{\odot}$.

Thus, we know the current DM density field. Also, we have a map of much younger matter density field using CMB anisotropy. That time ($z \sim 1000$) the mean density contrast was $\sim 10^{-5}$, and no halos had formed yet. Having these two pictures of cosmic matter distribution at different epochs of its evolution and assuming that only gravity is responsible for such evolution, we obtain the DM energy-momentum tensor.

What are DM properties? Actually, they are simple: DM is *weakly interacting massive particles* with cosmological density five times higher than that of baryons. WIMPs should be cold (non-relativistic) long before the equality epoch to be able to form galactic structures that we observe today. Contemporary physics does not know particles with DM properties. It is necessary to go beyond the standard model. But how and in which direction? What should we look for?

Owing to such simple properties, DM has straightforwardly affected the development of the Universe gravitational potential. The DM density contrast was increasing in time due to gravitational instability. Baryons, after they decoupled from radiation, were captured into gravitational wells of DM concentrations. That is why light is there where DM is. Thanks to this remarkable feature of gravitational instability it is possible to study amount, state and distribution of DM in observations ranging from radio to X-ray bands.

The analysis of large scale structure in the Universe has revealed that the amount of non-relativistic DM entering structure is small. The overall mass density of all particles which have been involved in the process of gravitational instability, does not exceed 30% of the critical density. At the same time the characteristics of CMB anisotropy have evidenced the flat spatial geometry of our Universe. It means that the rest 70% of the critical density should be in the form that takes no part in gravitational clustering. What are the

properties of such a stable medium which is not perturbed by gravitational potential of the structure, remains essentially non-clustered and dominates the non-relativistic matter?

Theory gives a clear answer to this question – the pressure-to-energy ratio of this medium, $w \equiv p_{DE} / \varepsilon_{DE}$, should satisfy the following condition:

$$|1 + w| \ll 1. \quad (1)$$

Only under this inequality the medium remains invariable in space and time. We call it *dark energy*. This is all we know about DE.

It is crucial that the process of gravitational instability could be launched in the Friedmann Universe only if the seed density perturbations were present since the very beginning. The existence of primordial cosmological perturbations has nothing to do with DM or any other particles. They are the scalar geometry perturbations that were produced by the Big Bang physics and imprinted in the perturbations of total density. Thus, other important problem arises, the problem of origin of the seed density perturbations which have developed dynamically into DM structures.

These hot topics — searching for unknown matter and determining the initial conditions for structure formation — display new physics and are expected to be solved in near future. In this short review we dwell upon them.

2. Geometry of the Universe

What we see today is a product of start conditions and evolution. Available observational data made it possible to determine characteristics of cosmological density field at different epochs of its development. It allowed us to separate information about the initial conditions and development conditions, thus giving rise to independent investigations of the early and late Universe physics.

In modern cosmology the term "early Universe" stands for the final period of the inflationary *Big Bang* stage with subsequent transition to hot period of cosmological expansion. Currently we have no model of the early Universe as we do not know BB parameters: there are only upper bounds (see eq.(16)). However, we have a well-developed theory of quantum-gravitational parametric generation of the cosmological perturbations. Using this theory, we can derive the spectra of primordial density perturbations and cosmic gravitational waves as functions of cosmological parameters, and constrain them from observational data.

Our knowledge of the late Universe is quite opposite. We have rather precise model — we know the main matter components and cosmological parameters, the evolution of the Universe and the theory of structure formation. But we do not understand how the matter components have originated.

The properties of the visible Universe allow us to describe the geometry of both late and early Universe in the framework of perturbation theory as there is a small parameter here $\sim 10^{-5}$, the amplitude of initial cosmological perturbations.

The main tool of geometry is metric tensor. To zero order the Universe is Friedmannian and described with only one function of time $a(t)$, the scale factor. The first order is a bit more complicated. The metrics perturbations are the sum of three independent modes -- the scalar one $S(k)$, the vector one $V(k)$, and the tensor one $T(k)$, each of them being described by its spectrum, the function of the wave number k . The scalar mode describes the cosmological density perturbations, the vector mode is responsible for vortical matter motions and the tensor mode presents gravitational waves. If the first order fields are Gaussian then the entire geometry of our Universe is described with only four positively defined functions, $a(t)$, $S(k)$, $T(k)$ and $V(k)$. Currently we know the first two of them in some ranges of definition.

BB was a catastrophic process of rapid expansion accompanied by intensive time varying gravitational field. Under this gravitational action the real cosmological perturbations of metric and density were being parametrically born from vacuum fluctuations. It is very general and fundamental effect of creation of any massless degree of freedom in external coupled non-stationary field.

Observational data confirm the quantum-gravitational origin of seed density perturbations responsible for structure formation in the Universe. The basic properties of the perturbation fields generated according to this mechanism are the following: the Gaussian statistics (random distribution in space), the preferred time phase ("growing" branch of evolution), the absence of characteristic scales in a wide range of wavelengths, a non-zero amplitude of gravitational waves. The latter is crucial for building-up the BB model as gravitational waves couple the simplest way to the background scale factor.

Evolution of S -mode has resulted in formation of galaxies and other astronomical objects. The CMB anisotropy and polarization have emerged long before galaxies under the joint action of all three perturbation

modes (S , T and V) on the photon distribution. Analysis of the observational data on galaxy distribution and the CMB anisotropy allowed us to relate S and $T+V$ modes. Making use of the fact that the sum $S + T + V \cong 10^{-10}$ is known from the CMB anisotropy we obtain the upper bound for the vortex and tensor perturbation modes in the visible Universe:

$$\frac{T+V}{S} < 0.2 \quad (2)$$

In case the latter inequality were violated the density perturbation value would not be sufficient to form the observed structure. The detection of T and V (e.g. cosmological magnetic field) will become possible only with further increase of observational precision.

3. From late to early Universe

Let us consider zero order geometry more detailed.

Table 1 presents average values of the cosmological parameters obtained from astronomical observations (with 10% accuracy). With these parameters, we get from the Friedmann equations the Hubble function, $H \equiv \dot{a}/a$, and its time derivative, $\gamma \equiv -\dot{H}/H^2$:

$$\frac{H}{H_0} = 10^{61} \frac{H}{M_p} = \left(\frac{10^{-4}}{a^4} + \frac{0.3}{a^3} + 0.7 \right)^{1/2} \quad (3)$$

$$\gamma = -\frac{d \ln(H \ell_p)}{d \ln a} = \frac{3(\varepsilon + p)}{2\varepsilon} = \frac{2 \cdot 10^{-4} + 0.4a}{10^{-4} + 0.3a + 0.7a^4} \quad (4)$$

where $H_0^{-1} = 14 \text{ Gyr} = 10^{33} \text{ eV}^{-1}$ is the inverse Hubble constant, $M_p = \ell_p^{-1} = 10^{19} \text{ GeV} = 10^{33} \text{ cm}^{-1}$ is the Planck mass or inverse Planck scale (hereafter $c = \hbar = 1$). γ -function relates the Hubble size of the Universe with redshift, $z + 1 \equiv a^{-1}$..

Eqs.(3) and (4) evidence that all transitions from radiation to matter and to DE dominated expansions occurred at small energies pretty well known to atomic physics ($T_{rad} = 2.5 \cdot 10^{-4} / a \text{ eV}$). Extrapolating eqs.(3) and (4) to earlier times (or higher energies) we learn the following properties of our Universe:

- The Universe is large, $(H_0 \ell_p)^{-1} \approx 10^{61}$. At the beginning of the expansion (3) and (4) the physical size of the Universe was a factor 10^{30} higher than Planckian size ($a/H_0 \geq$ the current length of relic quanta). Such a big factor can be explained by a pre-existed short inflationary stage with $\gamma < 1$ (BB).
- The cosmological perturbations are acausal (scales enter horizon at $\gamma > 1$). Eqs.(3) and (4) describe decay of γ from 2 to 0.4. To explain acausality, one has to admit a pre-existed period of cosmological expansion with γ rising from values smaller than unity (BB stage).

Table 1. Basic cosmological parameters

| | |
|-------------------------------------|-------------------------|
| Hubble parameter | $H = 0.7$ |
| CMB temperature | $T = 2.725 \text{ K}$ |
| 3-space curvature | $\Omega_\kappa = 0$ |
| cosmological density of baryons | $\Omega_b = 0.05$ |
| cosmological density of dark matter | $\Omega_{DM} = 0.23$ |
| cosmological density of dark energy | $\Omega_\Lambda = 0.72$ |
| power-spectrum index | $n_s = 0.96$ |

Within 14 billion years the Universe was at least once at radiation dominated state, once at matter dominated stage, and twice in state of inflation ($\gamma < 1$ by the definition): at BB and DE stages.

4. In search for dark matter particles

DM are WIMPs which were non-relativistic long before the structure formation in the Universe (back to $T_{rad} > 10 \text{ keV}$). We do not know whether WIMPs have decoupled from the thermal bath of particles or never been in equilibrium with other particles at all. There are several hypotheses on the origin of DM, but none of them has been confirmed so far.

There are messages from observational cosmology indicating that DM mystery is related with baryon asymmetry in the Universe. Two of them are the most appealing:

- The energy densities of both non-relativistic components, baryons and DM, are close to each other since the moment of their generation.
- The characteristic scales of spatial distributions of baryon and DM are identical in the early Universe (the cosmological horizon at equal densities of radiation and matter = the sound horizon of hydrogen recombination).

The two matter components knew something about each other at the moments of generation.

Where is dark matter? We know that luminous constituent of matter is observed as stars residing in galaxies of different masses and in the form of X-ray gas in clusters of galaxies. However, a greater amount of ordinary matter is contained in rarefied intergalactic gas with temperatures from several to hundred eV and also in MACHO-objects which are the compact remnants of star evolution and the objects of small masses. Since these structures mostly have low luminosity they are traditionally called *dark baryons*.

Several scientific groups (MACHO, EROS and others) carried out the investigation of the number and distribution of compact dark objects in the halo of our Galaxy, which was based on micro-lensing events. The combined analysis resulted in an important bound — no more than 20% of the entire halo mass is contained in MACHO-objects of masses ranging from the Moon to star masses. The rest of the halo DM consists of unknown particles.

Where else is non-baryonic DM hidden? The development of high technologies in observational astronomy of the 20th century allowed us to get a clear-cut answer to this question -- non-baryonic DM is contained in gravitationally bound systems (DM halos). Unlike baryons, DM particles do not dissipate whereas baryons are radiationally cooled and settle near the halo centers attaining rotational equilibrium. DM stays distributed around the visible matter of galaxies with characteristic scale ~ 200 kpc. For example, in the Local Group of galaxies more than a half of all DM belongs to Andromeda and Milky Way.

Particles with required properties are absent in the standard model of particle physics. An important parameter that cannot be determined from observations due to the Equivalence principle is the mass of particle. The main candidates are listed in Table 2 in ascending order of their masses.

Table 2. Candidates for non-baryonic dark matter particles.

| Candidate | Mass |
|-------------------------|--------------------------------|
| Gravitons | $10^{-21} eV$ |
| Axions | $10^{-5} eV$ |
| "sterile" neutrino | 10 keV |
| mirror matter | 1 GeV |
| Neutralino | 100 GeV |
| super-massive particles | $10^{13} GeV$ |
| monopoles and defects | $10^{19} GeV$ |
| primordial black holes | $10^{-16} - 10^{17} M_{\odot}$ |

One of the versions on agenda — the neutralino hypothesis — rises from minimal supersymmetry. This hypothesis can be verified in CERN at LHC that will run in 2008. The expected mass of these particles is ~ 100 GeV, and their density in our Galaxy is a particle per a cup of coffee.

DM particles are being searched in many experiments all over the world. Interestingly, the neutralino hypothesis can be independently verified both in underground experiments on elastic scattering and by indirect data on neutralino annihilation in Galaxy. So far the positive signal has been found only in one of the underground detectors (DAMA), where a season signal of unknown origin has been observed for several years now. But the range of masses and cross-sections associated with this experiment has not been confirmed in other experiments, which makes reliability and meaning of the results quite questionable.

Neutralino give an important possibility of indirect detection by their annihilation gamma-ray flux. During the process of hierarchic clustering these particles could form mini-halos of small masses with sizes comparable to that of the Solar system. Some of these mini-halos could stay intact till now. With high probability the Earth itself is inside one of these halos where the particle density is as much as tens of times higher than the mean halo density. Hence, the probability of both direct and indirect detection of DM gets higher. Availability of so different search techniques gives a solid hope that the physical nature of at least one version of DM will soon be verified.

5. How can dark energy be measured

There are three main hypotheses of physical nature of DE: vacuum, superweak field, and modified gravity. The vacuum hypothesis ($w = -1$) raises severe problems of new fundamental scale ($\rho_V^{1/4} = 10^{-3} eV$) and density coincidence ($\rho_V \approx \rho_m$) that cannot be solved within framework of standard model. The other two hypotheses do not face such problems, however the identification of their physical parameters is there. Physical DE model can be found when we learn the intrinsic property of DE governed by the function $w = w(a)$. The latter is a matter of experiment:

$$w(a) = -1 + c_0 + c_1 \varepsilon + \frac{1}{2} c_2 \varepsilon^2 + \dots, \quad \varepsilon = a - 1 = \frac{z}{1+z}, \quad (5)$$

where the coefficients c_n ($n = 0, 1, 2, \dots$) can be compared with theoretical predictions.

The best way to detect $w(a)$ is precise measurements of large scale structure as function of redshift. DE strongly affects the evolution of structure formation in the Universe. Fig 1 presents the growth factors of linear density perturbations, $g(a)$, and peculiar velocities of matter, $v(a)$, for $c_n = 0$ [1]. In the modern era the function $v(a)$ is in its wide maximum that indicates the period of the most intensive structure generation. The position of the maximum corresponds to $z = 0.2$, ninety percent from the maximum value is taken at $a = 0.5$ and 1.4 while the half maximum is at $a = 0.1$ and 4. Therefore the modern era is an era of maximum peculiar velocities and consequently the most intensive structure formation processes (the function $v(a)$ will decay as much as two times by the moment when the Universe will be 35 billion years old). We can use the weak lensing, baryonic acoustic oscillations and other observational methods to estimate quantitatively the evolution of the large scale structure formation with time and to reconstruct the function $w(a)$ for $a \leq 1$ from these data.

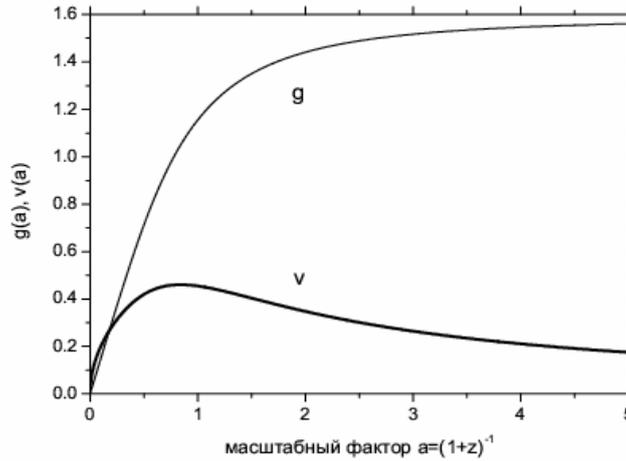


Fig. 1 Growth factors of density perturbations (thin line) and peculiar velocities of matter (solid line) in the Universe.

6. In the beginning was sound

Let us consider the first order geometry more detailed.

The effect of the quantum-gravitational generation of massless fields is well-studied. Matter particles can be created with this effect (see [2], [3] etc.) (although the background radiation photons emerged as a result of the BB proto-matter decay in the early Universe). The gravitational waves [4] and the density perturbations [5] are generated in the same way since they are massless fields and their creation is not suppressed by the threshold energy condition. The problem of the vortical perturbation creation is waiting for its researchers.

The theory of the S and T perturbation modes in the Friedmann Universe reduces to a quantum-mechanical problem of independent oscillators $q_k(\eta)$ in the external parametrical field $\alpha(\eta)$ in Minkovski space-time with the time coordinate $\eta = \int dt/a$. The action and the Lagrangian of the elementary oscillators depend on their spatial frequency $k \in (0, \infty)$:

$$S_k = \int L_k d\eta, \quad L_k = \frac{\alpha^2}{2k^3} (\dot{q}^2 - \omega^2 q^2).. \quad (6)$$

A prime denotes derivative with respect to time η , $\omega = \beta k$ is the oscillator frequency, β is the speed of the perturbation propagation in the vacuum-speed-of-light units (henceforth, the sub-index k for q is omitted). In the case of the T mode $q \equiv q_T$ is a transversal and traceless component of the metric tensor,

$$\alpha^2_T = \frac{\alpha^2}{8\pi G}, \quad \beta = 1. \quad (7)$$

In the case of the S mode $q \equiv q_S$ is a linear superposition of the longitudinal gravitational potential (the scale factor perturbation) and the potential of the 3-velocity of medium times the Hubble parameter [4]:

$$q_S = A + H\nu, \quad \alpha^2_S = \frac{a^2 \gamma}{4\pi G \beta^2}, \quad (8)$$

where $A \equiv \delta a / a$, and $\nu \equiv \delta \varphi / \dot{\varphi}$ is the potential of the 3-velocity of medium (see eq.(9)).

As it is seen from eq.(7), the field q_T is minimally coupled with background metrics and does not depend on matter properties. On the contrary, the coupling between q_S and the external field (8) is more complicated: it includes also derivatives of the scale factor and some matter characteristics (e.g. the speed of perturbation propagation in the medium). We know nothing about proto-matter in the Early Universe. There are only general suggestions concerning this problem.

Commonly, ideal medium is considered with the energy-momentum tensor depending on the energy density ε , the pressure p , and the 4-velocity u^μ . For the S mode, the 4-velocity is potential and represented as a gradient of the 4-scalar φ :

$$T_{\mu\nu} = (\varepsilon + p)u_\mu u_\nu - g_{\mu\nu}, \quad u_\mu = \varphi_{,\mu} / w, \quad (9)$$

where a comma denotes the coordinate derivative, and $w^2 = \varphi_{,\nu} \varphi_{,\mu} g^{\mu\nu}$ is a normalizing function. The speed of sound is given by "equation of state" and relates comoving perturbations of pressure and energy density:

$$\delta p_c = \beta^2 \delta \varepsilon_c, \quad (10)$$

where $\delta X_c \equiv \delta X - \nu \dot{X}$.

In the linear order of the perturbation theory the ideal medium concept is equivalent to the field concept where the Lagrangian density $L(w, \varphi)$ is ascribed to the material field φ [5]-[7]. In the field approach the speed of the perturbation propagation is found from equation:

$$\beta^{-2} = \frac{\partial \ln |\partial L / \partial w|}{\partial \ln |w|}, \quad (11)$$

which corresponds to eq.(10). To zero order, β is a function of time. In most models of the early Universe one usually assumes $\beta \sim 1$ (e.g. at the radiation-dominated stage $\beta = 1/\sqrt{3}$).

The evolution of the elementary oscillators is given by Klein-Gordon equation:

$$\bar{q}''(\omega^2 - U)\bar{q} = 0, \quad (12)$$

where

$$\bar{q} \equiv \alpha q, \quad U \equiv \frac{\alpha''}{\alpha}. \quad (13)$$

The solution of eq.(12) has two asymptotics: an adiabatic one ($\omega^2 > U$) when the oscillator freely oscillates with the excitation amplitude being adiabatically damped ($|q| \approx (\alpha\sqrt{\alpha})^{-1}$), and a parametric one ($\omega^2 < U$) when the q field freezes out ($q \rightarrow \text{const}$). The latter condition in respect to quantum field theory implies a parametrical generation of a pair of particles from the state with an elementary excitation (see Fig 2).

Quantitatively, the spectra of the generated perturbations depend on the initial state of the oscillators:

$$T \equiv 2\langle q_T^2 \rangle, \quad S \equiv \langle q_S^2 \rangle, \quad (14)$$

where the field operators are given in the parametrical zone ($q \rightarrow \text{const}$). The factor 2 in the tensor mode expression is due to two polarizations of gravitational waves. The state $\langle \rangle$ is considered to be a ground initial state, i.e. it corresponds to the minimal level of the initial oscillator excitation. This is the basic hypothesis of the Big Bang theory. In case the adiabatic zone is there, the ground (vacuum) state of the elementary oscillators is unique [8].

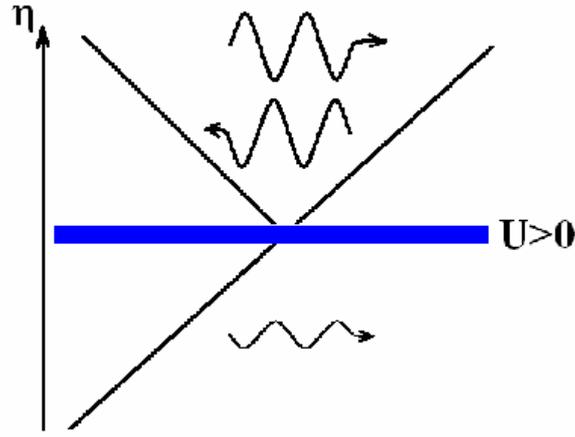


Fig.2 Illustration of solution of scattering of eq.(12).

Thus, assuming that the function U grows from zero with time (i.e. the initial adiabatic zone is followed by the parametric one) and $\beta \sim 1$, we obtain a universal and general result for the $T(k)$ and $S(k)$ spectra:

$$T = \frac{4\pi(2-\gamma)H^2}{M_p^2}, \quad \frac{T}{S} = 4\gamma, \quad (15)$$

where $k \cong aH$ specifies the moment of creation ($\omega^2 = U$). As it is seen from eq. (15), the theory does not discriminate the T from S mode. It is the value of the factor γ in the creation period that matters when we relate T and S . From the observed fact that the T mode is small in our Universe (see eq. (2)) we obtain the upper bound on the energetic scale of the Big Bang and on parameter γ in the early Universe:

$$H < 10^{13} \text{ GeV}, \quad \gamma < 0.05. \quad (16)$$

The latter condition implies that BB was just inflation ($\gamma < 1$).

We have important information on phases: the fields are generated in certain phase, only the growing evolution branch is parametrically amplified. Let us illustrate it for a scattering problem, with $U = 0$ at the *initial* (adiabatic) and *final* (radiation-dominated, $a \propto \eta$) evolution stages (see Fig. 2). For either of the two above-mentioned stages general solution is

$$\bar{q} = C_1 \sin \omega\eta + C_2 \cos \omega\eta, \quad (17)$$

where the constant operators $C_{1,2}$ yield the amplitudes of the "growing" and "decaying" solutions. In the vacuum state the initial time phase is arbitrary: $\langle C_1^{(in)} \rangle = \langle C_2^{(in)} \rangle$. However, the solution of the evolution equations yields that only the growing branch of the sound perturbations takes advantage at the radiation-dominated stage: $\langle C_1^{(fin)} \rangle \gg \langle C_2^{(fin)} \rangle$. This important result can be explained by the fact that only growing solution is consistent with the isotropic Friedmannian expansion from the very beginning. According to it, by the moment of matter-radiation decoupling at the recombination era, the radiation spectrum appears modulated with typical scales $k_n = n\pi\sqrt{3} / \eta_{rec}$, where n is a natural number.

It is these acoustic oscillations that are observed in the spectra of the CMB anisotropy (see Fig 3, the highest peak corresponds to $n=1$) and the density perturbations, which confirms the quantum-gravitational origin of the S mode. We see, the standard cosmological model can begin as follows. "In the beginning was sound. And the sound was of the Big Bang". It differs a bit from the scenario described in the Bible.

The sound modulation in the density perturbation spectrum is suppressed by the small factor of the baryon fraction in the entire budget of matter density. This allows one to determine this fraction independently of other cosmological tests. The oscillation scale itself is an example of the standard ruler that is used to determine cosmological parameters of the Universe.

To summarize we can say that in principle the problem of the generation of both, the primordial cosmological perturbations and the large scale structure of the Universe, is solved today. The theory of the quantum-gravitational creation of perturbations in the early Universe will be finally confirmed as soon as the T mode is discovered, which is anticipated in the nearest future. For example, the simplest BB model (power-law inflation on massive field) predicts the T mode amplitude only 5 times smaller than that of the S mode (which corresponds to $\gamma \approx 10^{-2}$) [9]. Modern devices and technologies are quite able to solve the problem of registering such small signals analyzing observational data on the CMB anisotropy and polarization.

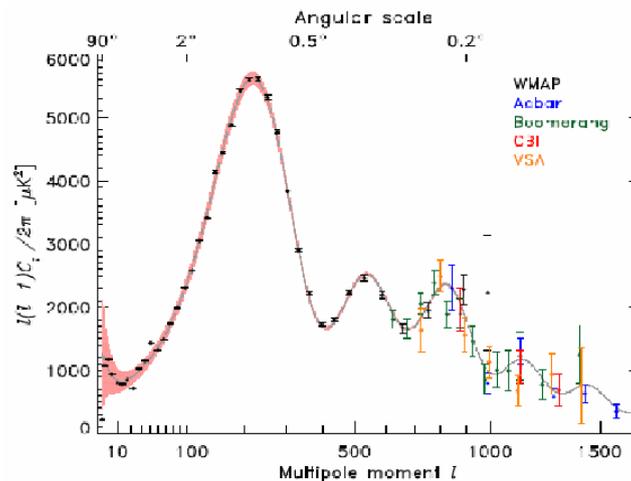


Fig.3 Manifestation of sound modulation in the CMB anisotropy spectrum..

7. Conclusion

Nowadays it became possible to determine separately properties of the early and late Universe from observational astronomical data. We understand how the primordial cosmological density perturbations that formed the structure of Universe emerged. We know crucial cosmological parameters on which the standard model of the Universe is based, and the latter has no viable rivals. However, some fundamental questions of the origin of the Big Bang and of main matter constituents remain unsolved.

Observational discovery of the tensor mode of the cosmological perturbations is a key to building-up the model of the early Universe. In this domain of our knowledge we have a clear-cut theory prediction that is already verified in the case of the *S* mode and can be experimentally verified for the *T* mode in the nearest future.

Giving a long list of hypothetical possibilities where and how to look for DM particles and DE physics theory has exhausted itself. Now it is experiment's turn. The current situation calls to mind great moments in the past history of science when quarks, W- and Z-bosons, neutrino oscillations, the CMB anisotropy and polarization were discovered.

One question is beyond the scope of this review. Why does Nature allow us to reveal its secrets?

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