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*CONFERENCES AND SYMPOSIA*

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# Scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (28 February 2001)

A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (RAS) was held on 28 February 2001 at the P L Kapitza Institute for Physical Problems, RAS. The following reports were presented in the session:

(1) **Novikov I D** (Astro Space Center, P N Lebedev Physical Institute, RAS, Moscow) "Big Bang' echo (cosmic microwave background observations)";

(2) **Karachentsev I D** (Special Astrophysical Observatory, RAS, Nizhniĭ Arkhyz, Karachaevo-Cherkessia, Russia) "Hidden mass in the Local Universe";

(3) **Cherepashchuk A M** (P K Sternberg Astronomical Institute, M V Lomonosov Moscow State University, Moscow) "Searches for black holes: the recent data";

(4) **Yakovlev D G** (A F Ioffe Physical Technical Institute, St.-Petersburg) "Superfluidity in neutron stars".

Summaries of the four papers are given below.

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## 'Big Bang' echo (cosmic microwave background observations)

I D Novikov

The more than 60 successful projects on measuring the cosmic microwave background (CMB) anisotropy that have been carried out in the last 10 years have resulted in qualitative changes in observational cosmology. Starting from the pioneering papers [1 – 5], there has been steadily growing attention to this rapidly developing field of astrophysics. The importance and topicality of CMB anisotropy measurements are due to the unique possibility of obtaining 'precision' data on very important parameters of the modern Universe, such as the Hubble constant $H_0 = 100h$ km s$^{-1}$ Mpc$^{-1}$, the fraction of the baryon ($\Omega_{\rm b}$) and 'hidden' (dark) ($\Omega_{\rm m}$) mass, the cosmological constant $\Omega_\Lambda$ (all the quantities are in units of the critical density), the spectral index of pre-galactic inhomogeneities $n_{\rm s}$, and some others.

The first successful results of this program were obtained by the COBE project [6], in which the CMB temperature fluctuations on the celestial sphere were first recorded at a level of $\Delta T/T \approx 10^{-5}$ at frequencies of 53 and 90 GHz with an angular resolution of FWHM = 7°. The corresponding part of the spectrum of perturbations that give rise to the CMB anisotropy on angular scales $\theta > 7°$ is related to spatial fluctuations on scales $\lambda > 300$ Mpc, which far exceed the typical size of the observed structures in the Universe. After COBE, special attention has been given to data obtained in ground-based, balloon, and space experiments, which provide a detailed signal structure with a higher angular resolution than that of COBE, down to FWHM≈ 3′.

Among them, such projects as Sascatoon, QMAP, MSAM, CBI, BOOMERANG, MAXIMA 1, etc. should be particularly noted (see [7] for a detailed description). Note that today the cosmological parameters have been determined with a record accuracy from the CMB anisotropy data obtained in the last two experiments (the corresponding errors in the anisotropy spectral characteristics do not exceed $\delta c_{\rm l}/c_{\rm l} = 10\%$ in the range of angles $0 \leqslant \theta < 1°$).

On the whole, the data on the total density obtained by BOOMERANG and MAXIMA 1 are in good agreement with the inflation theory prediction that the present-day total density of all forms of matter should be close to the critical value: $\Omega_{\rm b} + \Omega_{\rm m} + \Omega_\Lambda = 1.09 \pm 0.07$ [8]. However, these data yield a relatively high baryon content, $\Omega_{\rm b}h^2 = 0.031 \pm 0.005$, which exceeds the optimal value $\Omega_{\rm b}h^2 \approx 0.02$ derived from the observed cosmic abundance of $^4$He, deuterium, and hydrogen. Essentially, the analysis of the data of the MAXI – BOOM collaboration leads to the conclusion that the 'standard' $\Lambda +$ CDM cosmological model ($\Omega_{\rm m} + \Omega_{\rm b} + \Omega_\Lambda = 1$; $\Omega_{\rm b}h^2 = 0.019$; $\Omega_{\rm m} = 0.3$; $h = 0.65$, and $n_{\rm s} = 1$) falls outside the data optimum at the 95% confidential level [8]. The models with 5 – 10% deviations from the Harrison – Zeldovich spectrum ($n_{\rm s} \approx 1.05 \pm 0.09$) or with the recombination occurring at redshifts $Z \approx 10 - 15$ are preferable. However, as was shown in [9], the above modifications of the standard ΛCDM cosmology are characterized by virtually the same rms deviation $\chi^2 \approx 6.75 - 6.79$, including the model with 'delayed' recombination [9]. In practice, this means that it is impossible to make a choice between the models at the current accuracy level of discriminating the signal from noises of different origins. However, even with growing accuracy, the situation may change insignificantly, since, for example, the level of fluctuation suppression at small angles due to the 'red' spectral slope $n_{\rm s} = 0.95$ and the level of fluctuation weakening due to the secondary ionization turn out to be very close. The above 'degeneracy' problem can be solved in two principal ways. First, in any case, it is necessary to increase the accuracy of the determination of the anisotropy spectrum both by increasing the sky coverage by observations (the so-called 'cosmic variance problem') and by decreasing the internal noise level of detectors. Second, it is of fundamental importance to measure the polarization fluctuations along with the CMB anisotropy. It is these two directions that will be realized both in the framework of the next launches of the MAXI – BOOM collaboration, and in the most promising space projects MAP and PLANCK. Note that, unlike the

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already recorded CMB anisotropy, the polarization of radiation will be studied for the first time at the signal detection level. However, for polarization experiments, in which the signal-to-noise ratio does not exceed a few units (unlike the anisotropy, for which the signal-to-noise ratio is expected to be 10 – 30), of extreme importance are the methods of filtration of galactic and extragalactic noises related to the polarization properties of synchrotron and free-free emission, due to the dust radiation, contribution from point sources, etc. Of special importance for the future polarization experiments is taking into account the anisotropy that is introduced by the receiving tract and depends on the reception frequency due to the apparatus features of the experiment. In this connection, methods of data processing that are capable of maximum cleaning of noise from maps (rather than 'spreading' them over the power spectrum) should play a crucial role in the signal extraction. One such method involves an amplitude – phase analysis [10] based on removing noise not in the amplitude but in the phase space, where non-gaussian noise turns out to appear most significantly. An important role in the noise identification should be played by the method of singular points of the polarization field [11 – 13], which takes into account the fact that the signal structure in the zones without original polarization ('singular points') is determined by noise. The phase analysis of anisotropy and polarization maps is especially important to distinguish the contribution from the receiving tract (antenna + aberrations). By and large, the above methods of cleaning anisotropy and polarization maps will be an invaluable addition to such traditional methods as MEM (maximum entropy method), RC (radical compression), and wavelet analysis.

To conclude, we emphasize that in the next 10 years, undoubtedly, outstanding results will be obtained in experimental studies of the CMB anisotropy and polarization, which will naturally summarize almost half a century of CMB research. Looking into the future, we can say with certainty that the epoch of MAP and PLANCK projects will bring us plenty of bright important discoveries that will advance our understanding of the general laws (and details!) of the structure and evolution of the Universe.

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# Hidden mass in the Local Universe

I D Karachentsev

### 1. Brief history

The history of studies of hidden (dark, obscured) matter in the Universe traces back to 1933, when F Zwicky discovered [1] that masses tens of times higher than the sum of masses of individual galaxies are required to explain the observed velocities of galaxies in rich clusters. Later, the inconsistency between the 'virial' (based on the virial theorem) and individual masses was shown to be typical of galactic systems of different scales, from pairs and groups to clusters and superclusters of galaxies. In the 1970s, Freeman, Sancisi, and Rubin discovered that the rotational curves of many galaxies do not approach the Keplerian asymptotic at large distances from the centers but instead remain 'flat', which requires a substantial mass to be present at the outskirts of the galaxies [3]. Some authors believed that massive dark 'coronae' extend tens of times further than the visible boundaries of galaxies and that their total mass is capable of explaining the 'virial paradox' in clusters [4, 5]. In the 1980s, the X-ray emission of hot gas in galactic clusters with temperatures exactly corresponding to the virial motions of the galaxies was detected [6]. Finally, the most direct determinations of cluster masses from the gravitational lensing effect or shape distortions in the images of more distant galaxies [7] confirmed the presence of large unseen masses in rich clusters. It is firmly established that the estimates of rich cluster masses obtained using both virial motions and X-ray gas-emission properties and gravitational lensing effects agree within 50%.

However, such an agreement has not yet been reached on all scales of the Universe structural hierarchy. Table 1 lists the main mean characteristics of galactic systems of different scales, from single galaxies to clusters: the radius of the system, the root-mean-square velocity of the internal motions, the relative number of galaxies in the system at a given level, the total mass-to-luminosity ratio $M_{\odot}/L_{\odot}$, the mean dark-to-visible mass ratio (DM/LM), and the relative contribution of the galactic system to the total mass density in the Universe. Here the Hubble constant is taken to be $H = 70$ km s$^{-1}$ Mpc$^{-1}$, which corresponds to the critical

**Table 1.** The dark matter distribution.

| Properties | Galaxies | Pairs | Groups | Clusters |
|---|---|---|---|---|
| Radius, Mpc | 0.03 | 0.09 | 0.25 | 1.7 |
| R.m.s. velocity, km s$^{-1}$ | (25) | 35 | 70 | 600 |
| Relative number of galaxies in the system | 0.35 | 0.15 | 0.40 | 0.10 |
| $M_{\odot}/L_{\odot}$ | 20 | 20 | 30 – (200) | 250 |
| Method of estimation | Rotational curves | Orbital motions | Virial motions, sphere $V = 0$ | X-ray, grav. lensing |
| | 2 | 2 | 3 – (27) | 35 |
| DM/LM | 15 % | 6 % | 27 % | 52 % |
| Specific contribution to the total mass | (6 %) | (2 %) | (72 %) | (20 %) |