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NON-STATIONARY UNIVERSE

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The main steps on our path from the models of Stationary Universe to the models of evolving one are mentioned in this paper. The most significant theoretical models and experimental results that confirm the fact that our Universe is evolving are listed.

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Many people know that over the last hundred years our ideas about the world around us have changed significantly. In this work I will try to list the main stages of the transition from ideas about a stationary World to an understanding that the Universe is significantly evolving.

By the beginning of the twentieth century, the dominant view among experts was that the Universe was infinite, homogeneous and isotropic on large scales, and stationary. To a large extent, based on precisely these ideas, which were commonly called the Absolute Cosmological Principle, Albert Einstein introduced into the equations of the General Relativity Theory (GRT), the so-called lambda term, in the presence of which stationary solutions appeared for these equations.

However, already in 1922, Alexander Friedman drew attention to the fact that even without this non-obvious term, the equations of General Relativity have quite elegant solutions that describe a gradually expanding or contracting Universe. Einstein's initial reaction to Friedman's work was negative. However, after a couple of years, he agreed with A. Friedman's arguments and subsequently

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noted more than once that it was Friedman who was the first to propose a model of the expanding Universe.

Let us note, however, that by the time A.Friedman's work appeared, neither the author of this work nor his opponents had any serious arguments either for or against the non-stationary model of the Universe. At the same time, astronomers already understood that our Galaxy is not at all alone, and beyond its borders there are other giant star systems similar to it. Working during the 1920s at Mount Wilson Observatory and using the largest 2.5-meter telescope at the time, Edwin Hubble did a tremendous job of identifying extragalactic nebulae. Using the already known period-luminosity relationship of long-period cepheids, he was able to estimate the distances to several dozen galaxies and obtain the spectra of these nebulae. As a result, a linear correlation was discovered between the redshift of lines in the spectra of about 30 galaxies with the distances to these objects. This meant that either our Galaxy is located at some singular point in space, from which all surrounding galaxies are moving away, or the entire Universe surrounding us is expanding.

Since in subsequent years the law of increasing red shift of lines in the spectra of extragalactic nebulae with increasing distances to these objects, discovered by Hubble, covered more and more galaxies, the probability that our Galaxy is located at some special point became less and less. However, it was also not easy to give up the idea that our Universe is eternal and unchanging. As a result, several very original explanations of Hubble's law appeared within the framework of a model of an unchanging and stationary Universe. Let's mention two of them here.

The first such explanation was put forward at the very beginning of the 1930s by the outstanding astrophysicist Aristarkh Belopolsky. He doubted that the redshifts observed in the spectra of distant galaxies were caused by the Doppler Effect. Considering that the radiation from the vast majority of objects observed by E. Hubble reaches the observer after millions of years, Belopolsky put forward the hypothesis of "aging of photons". Based on the data Hubble had on distances to galaxies, then to explain the pattern he found by "aging of photons", it was necessary that for every million years a photon would lose $1/600$ of its energy (if we use modern data on the distance scale, then this value will decrease by about 7 times). Therefore, allowing for the possibility of such "aging of photons," one could remain a supporter of a stationary Universe.

The second proposal was put forward around the late 1940s by the English astrophysicist Fred Hoyle, who agreed that the Universe was expanding. However, as he pointed out, this expansion occurs so slowly that in order to keep one of the basic parameters of the Universe constant, namely the average density of matter, it is enough to assume that on average, in every cubic kilometer of the Universe 1 hydrogen atom is spontaneously born in every thousand years. It is hardly possible to verify such a possibility even today, and therefore this hypothesis was also difficult to reject.

Thus, the further development of ideas about the expanding Universe required new bright experimental facts, which began to appear only towards the end of the 1950s, and were associated with the development of radio astronomy. Although Karl Jansky's discovery of cosmic radio emissions took place in the very early 1930s, serious development of radio astronomy research began only after the end of World War II. But by the mid-1950s, when optical identifications of dozens of radio sources located at high galactic latitudes were made, it became clear that radio astronomy makes it possible to probe the distant Universe. Already the first extensive catalogs of radio sources, including many hundreds, and some even more than a thousand, objects, made it possible to perform statistical studies of the distribution of these objects by flux densities. It is not difficult to show that, within the framework of a uniform distribution of radio sources in space, one would expect that the number of objects with flux densities exceeding a certain fixed value (S) would be proportional to $S^{-3/2}$. Approximately this distribution was obtained by a group of Australian radio astronomers led by B. Mills. Another group of radio astronomers, namely, the group at the University of Cambridge (England) led by Martin Ryle, having carried out a survey at a very close frequency, initially obtained the dependence $N(>S) \sim S^{-3}$. However, having soon discovered many false objects in their survey, they modernized their radio telescope, and, having completed a new survey, on the basis of which they compiled the widely known Third Cambridge Catalog (3C-catalogue), already at the very beginning of the 1960s they obtained a new dependence $N(>S) \sim S^{-1.8}$. After several heated debates, Mills's group agreed with this new Cambridge result.

But what could this insignificant but reliably established difference in the exponent from - 3/2 indicate? No one began to explain it by the special position of our Galaxy, and all experts agreed that this is another evidence that the Universe is evolving, namely, that in cosmological epochs preceding the present one, the spatial density of powerful radio sources was higher.

Further studies of counts of increasingly weaker radio sources, which made it possible to determine the cosmological epoch in which the spatial density of radio galaxies and quasars was maximum, are described in detail in the papers and books by Malcolm Longair and the other authors. But we will not delve so deeply into the study of specific models of the evolution of radio galaxies, and will move on to other evidence of the radical evolution of the Universe.

Almost in parallel with the development of more and more detailed analysis of counts of radio sources, searches were undertaken for changes in other parameters of radio sources as their flux densities systematically decreased, and hence the distances to them increased. One of the most convenient parameters for extragalactic radio sources for these purposes was the spectral index, which characterizes the dependence of the flux density of each source on frequency. For the overwhelming majority of extragalactic radio sources, this dependence in a wide frequency range was close to a power-law dependence of the type $S \sim \nu^{-\alpha}$, where α is this spectral index. In fact, it all came down to searching for any noticeable correlation between the spectral indices and the flux densities of the sources.

The first such attempt was made in the work of Conway, Kellerman and Long [1]. The authors had used almost all estimates of flux densities available at that time in a wide range of radio frequencies, obtained by numerous radio astronomers from many countries using a variety of telescopes. It was not possible to find the desired correlation in this work. A second similar work soon followed [2], in which Kenneth Kellermann made another attempt to search the same correlation, using almost the same huge array of data, but only after some adjustment of individual works in order to bring all data to a single scale of flux densities. And, although such correction of the data undoubtedly reduced the systematic errors of various reviews, it was not possible to detect a noticeable dependence of the average values of spectral indices on the flux density of the sources this time either. Finally, in 1968, another similar attempt followed by Kellermann, Pauliny-Toth & Williams [3], in which, in addition to the previous ones, data from the most recent years were used, but it also turned out to be unsuccessful.

In 1964, observations began with the East-West antenna of the cross-type radio telescope of Pushchino Radio Astronomy Station (now Observatory) of the Lebedev Physical Institute. As one of the tasks, it was decided to use this wide-band meridian radio telescope to measure the flux densities of all radio sources of the Third Cambridge Catalog (3C-catalogue) at several meter wavelengths. By the end of 1967, the flux densities of many radio sources in this catalog were measured at 38, 60 and 86 MHz. The most complete and carefully calibrated survey was carried out at a frequency of 86 MHz [4]. It was the data from this survey that was decided to be used for statistical analysis of the distribution of spectral indices of the 3C catalogue's radio sources. For this analysis, we involved only the results of measurements of flux densities of the same sources at frequencies of 750 and 1400 MHz, carried out at the US National Radio Astronomy Observatory [5], as well as data from the 3C- catalogue itself at a frequency of 178 MHz. The results of this analysis are presented in Figures 1 and 2, borrowed from [6]. As can be seen from Fig.1, the spectral indices of radio sources α increase, as the flux densities of radio sources decrease. And from Fig.2 could be seen that this trend is relatively weakly traced for sources identified with radio galaxies, somewhat stronger for those not identified with optical galaxies at that time, and very brightly for sources identified with quasars. From this, we had concluded that the most objects in the group of unidentified radio sources are more distant radio galaxies. Later, when the all radio sources in the 3C-catalogue were identified, this conclusion was confirmed, because the all sources from this unidentified group at the time of preparation of the work [5] were identified with radio galaxies.

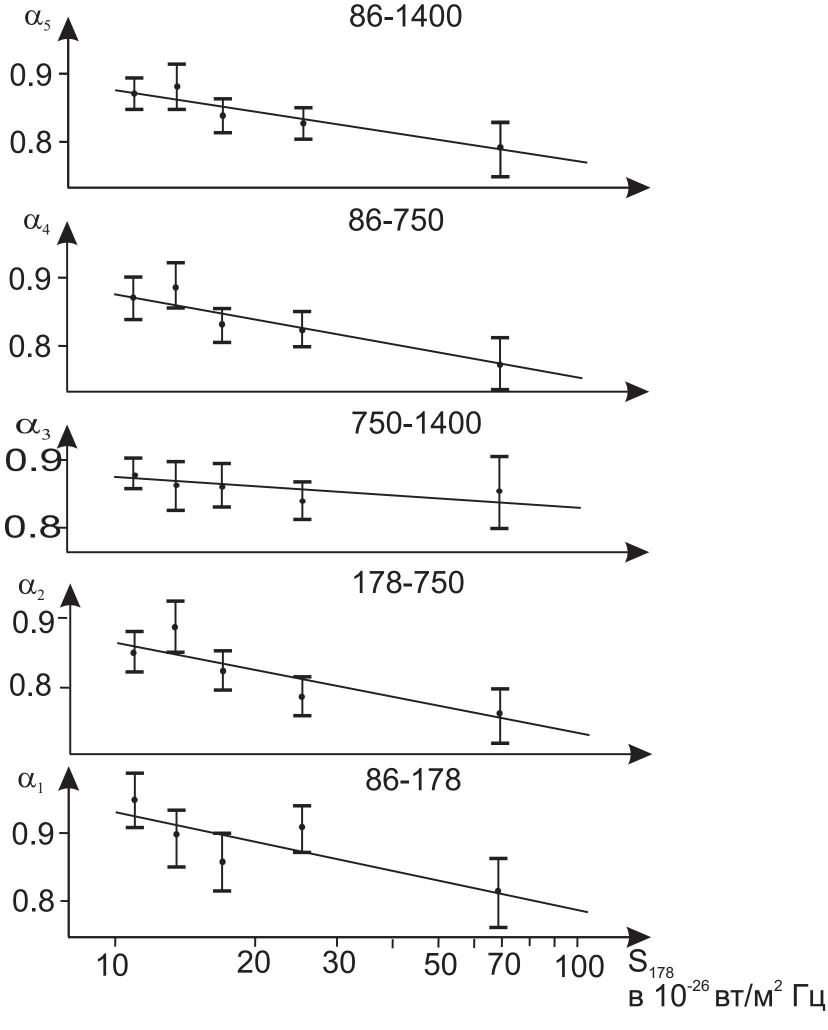

Fig. 1. Dual-frequency spectral indices of 3CR sources as a function of S_{178}.

Since redshifts there were known for all quasars, the distribution of this group radio sources on the $z - \alpha$ plane was also studied, which is presented in Fig. 3 from [7]. This diagram confirms the main conclusion of the studies described, which is that at large cosmological distances the objects with steeper spectra are dominate. Research on the dependence of spectral indices on flux density was continued 12 years later by Indian colleagues. The first of their paper [8], published a dozen years after [6], completely confirmed the dependence presented in Fig. 1,

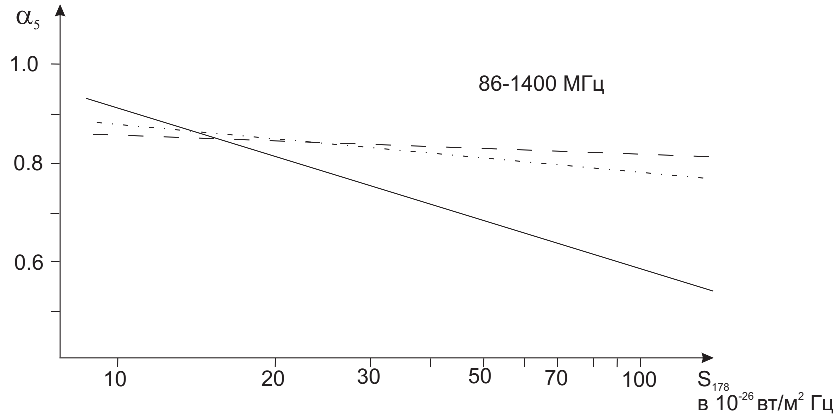

Fig. 2. Dual-frequency spectral indices – flux density relation for radio galaxies (dash line), unidentified sources (dash-dotted line) and quasars (solid line).

and subsequent articles extended this dependence into the region of weaker flux densities.

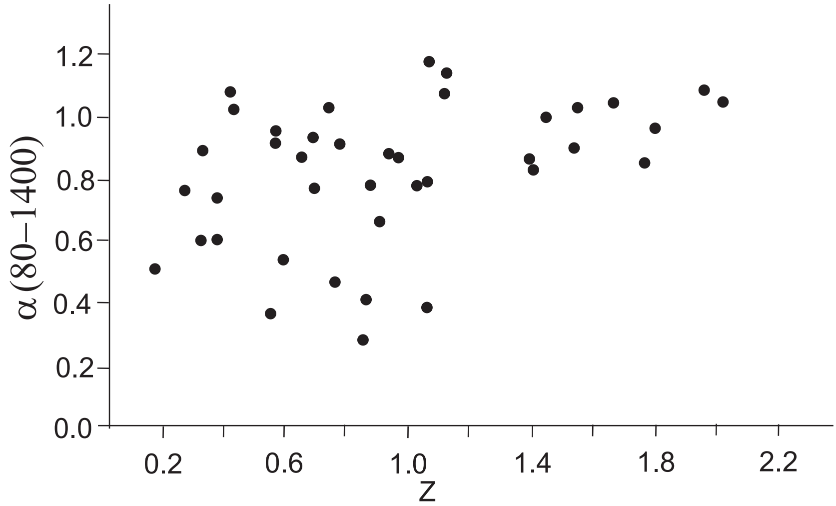

Fig. 3. Dual-frequency spectral index $\alpha(86-1400)$ of quasars as a function of their redshift z.

While we were studying the spectra of radio sources, another remarkable discovery was made in 1965. While studying the characteristics of horn antennas, American engineers Penzias and Wilson discovered very weak background radiation. Further discussion had shown that this background radiation could correspond to the residual radiation of the very intensive radiation that filled all the space in the early stages of the hot Universe model suggested back in the

1940s by G. Gamow. Gamov had proposed this model to somehow explain the relative abundance of a number of light chemical elements observed in the world, those could not be formed in the process of nuclear reactions occurring inside the stars. At an early stage in the evolution of such hot Universe the space was filled with very hot ionized plasma and radiation at the same temperature. But, as the Universe expanded, the temperature decreased, and when it reached a value of about 3000 K, the era of recombination began, when electrons combined with atomic nuclei, forming electrically neutral atoms. From that moment on, the Universe became transparent to the cooled radiation, which began to expand without interacting with matter. Gamow had predicted the approximate temperature (several degrees Kelvin) that this residual weak thermal radiation should have in the modern era.

The fact that the cosmic microwave background radiation, which we will further call CMB (Cosmic Microwave Background) was discovered completely by accident (as an interfering factor during purely technical measurements), is due to the fact that in the middle of the last century the opinion of a cold expanding Universe dominated among astrophysicists, and the paper by G. Gamow was almost forgotten. When the nature of this weak thermal radiation with a temperature of about $2.7^\circ K$ was understood, it became clear how important it was to study all its characteristics. Indeed, the spectrum of spatial fluctuations of the CMB should also carry information about the spectrum of spatial fluctuations of all matter in the Universe during the era of recombination. And although the expected root-mean-square amplitude of such fluctuations was estimated by experts of only 10^{-5} from the average temperature (that is from $\sim 3^\circ K$), several groups of scientists immediately began to work on special projects to estimate the amplitude and spatial distribution of these fluctuations.

Since the maximum thermal radiation with a temperature of about $3^\circ K$ occurs at a wavelength of ~ 1 mm, the corresponding measurements were carried out only from spacecraft. Before moving on to measurements of weak spatial fluctuations, it was necessary to take into account the contribution of the background radiation of our Galaxy and the dipole component of the CMB, that is due to the relative speed of our Solar system in outer space. The remarkable space projects WMAP (2001) and Planck (2009) made it possible to investigate the distribution of CMB fluctuations.

Even before the discovery of the CMB, A.D. Sakharov calculated the spectrum of quantum density fluctuations for the model of a cold expanding Universe. And these so called “Sakharov oscillations” look like some kind Bessel-functions depending from the parameters of the Universe. Fortunately, in a model of a hot Universe, this spectrum should look almost the same. It is with these “Sakharov oscillations” that the results of numerical processing of data from the WMAP and Planck projects are now compared in order to determine specific values of the parameters of hot Universe model.

So, we briefly discussed how our ideas about the surrounding World have changed over the last hundred years, mainly in terms of the fairly reliably established continuous evolution of this World. Over approximately the same years, serious changes have occurred in our understanding of the average density and composition of the matter filling our Universe. Such concepts as "dark matter" and "dark energy" appeared. But talking about this goes far beyond the scope of this article. Therefore, we will end this work with a strong statement: "And yet, our Universe is evolving!"

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