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FULL TEXT OF ARTICLE:

1. [Article by Leonid Grishchuk, doctor of physical and mathematical sciences, chief of department, State Astronomy Institute imeni P.K. Shternberg]

2. [Text] For many decades, scientific policy in our society has suffered distortions and deformations, the more extreme manifestation of which was the persecution not only of individual scientists, but also of entire scientific fields. To make up for this, there was no shortage of optimistic forecasts and expectations that science would become a direct production force and, when this happens, would scatter benefits as though from the horn of plenty.

3. Today, we are realizing our lag behind the world level in a number of directions of basic research, the loss of interest in the achievements of various areas of knowledge, the spread of a skeptical attitude toward scientists, who are forced to substantiate the need to develop science via references to the fact that its current level determines tomorrow's equipment, technology and material progress. Recently, there was talk of a need to stop financing space research. It was saved by showing its contribution to the economy. Of course, this utilitarian approach is in many ways stipulated by the labor structure of our economy. However, we must not forget about the influence that the advancement of knowledge has on man's intellectual and cultural level. In the big picture, this is really the main result of assimilating the achievements of scientific thought!

4. In turn, the attitude toward basic research and the understanding of its role in social progress depend on the level of culture. In a rule-of-law state, this dependency is obvious: the opinion of the

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masses shapes scientific policy.

5. There are serious flaws precisely here. As experience with giving popular lectures indicates, even in an environment of people with higher educations, questions about ''**flying saucers,**'' ''space aliens,'' etc. are most widespread. A segment of the audience believes that basic science studies these things. Another manifestation of the disoriented understanding of science's role and place is the persistent call for its universal conversion to cost-accounting. Here, it must be said that cost-accounting relations in science are needed to some extent, yet they do conceal a threat to basic research. Cost-accounting increases the priority of applied development work, leads to an outflow of capable people and creates a threat to basic work, which does not promise rapid application in the economy. Such an approach could undermine society's intellectual potential. To put it directly, basic science needs and will need state protection and support in a social atmosphere which is favorable toward its development.

6. Under this new situation, we cannot get by with just repeating and illustrating the truth: science is useful. Broad discussion is needed, not only on the problems of effective organization of research and on the moral and social responsibility of scientists, but also, probably, to illuminate the boundaries that have been reached in our understanding of the surrounding world. This was noted at the 19th All-Union Party Conference. There is no shortage of appeals for central publications to set aside more space for the problems of science. However, the matter is at a standstill for the time being.

7. These are the motives which direct me to talk about what the Universe is, as well as about cosmology, the science of the Universe and the subject of my own professional work. I am certain that there is a deep general human interest in its structure, its past and its future.

8. What We Know About the Universe

9. For more than 20 centuries, people put the Earth at the center of the universe, surrounding it with immobile stars. The Sun and planets were given a secondary role. It was believed that the Sun revolved in strictly circular orbits around the Earth. It was hard for people to become accustomed to the idea that the Earth is an ordinary planet.

10. The explanation of the motion of the heavenly bodies and even the prediction of new planets in the Solar System was the triumph of the Newtonian theory of gravitation. Later, the study of the stars and star systems followed. The idea that the Sun is an ordinary star

did not come easily either. Relatively recently, scientists presumed that the Sun was located near the center of our star system, our Galaxy, beyond the boundaries of which, possibly, there was nothing. Nothing was known for sure about the existence of any formations whatsoever beyond our own Galaxy. Only in the 1920s-1930s, thanks to rapid progress in the development of observation equipment, was it finally proven that there are a number of other stellar systems and galaxies outside our Galaxy.

11. Approximately in these years, it was discovered that the Sun is located in a by no means remarkable area, almost on the edge of our own disk-shaped Galaxy. (Looking at its basic mass of stars at night, we see the Milky Way in the sky.)

12. The understanding that things in space are not at all calm also came with difficulty. The stars are moving within the galaxies, and the galaxies are moving relative to each other. Explosive processes, releasing a tremendous amount of energy, often occur in space.

13. In the area of space accessible to modern optical and radio telescopes, many, many millions of galaxies are observed. Although they differ in terms of form, mass, and star content, they can be considered the basic structural units of the Universe. Galaxies are combined into groups, accumulations and structures on an even greater scale. In the distribution of a number of conglomerations, stretched and flat elements are being discovered, as well as great empty spaces where, with the achieved level of sensitivity of observation equipment, no galaxies at all are visible. Graphically speaking, the distribution of galaxies has a porous or net-like structure, i.e., the empty areas alternate with ''walls'' and ''threads,'' where the basic share of luminous matter is concentrated. The galaxies themselves are fairly flat and distinctly outlined formations, but as one moves to structures ever greater in scale, the outlines and localization of these structures become ever more vague. There is no designated place whatsoever in the distribution of these galaxies that could be considered the center of the Universe, and there is no designated direction whatsoever that could be considered an axis of symmetry for the Universe. On this grounds, we say that the observable Universe is homogeneous and isotropic.

14. The most distant of the observable objects is about 10 billion light-years away us. It is several light-years to the closest stars in our own galaxy. The intermediate distances could be described as follows: the diameter of our galaxy is almost 100,000 light-years. This number exceeds the distance to the nearest stars by a factor of several tens of thousands, and our galaxy is not one of the smaller ones. The dimension of the average concentration of galaxies is even larger, by a factor of 100, and may exceed tens of millions of light

years. The dimensions of the most distinct details in the distribution of ''thread'' type galaxies and of empty areas is greater still, by a factor of 10 or several tens. However, the sizes of these parts are nonetheless smaller by a factor of 50-100 than the sizes of the entire observable part of the Universe. According to existing data, the hierarchy of structures does not continue without limit, but gradually disappears.

15. There are data about the possible existence of nonluminous matter in the Universe, the so-called hidden mass. Its average density may exceed the average density of luminous matter, concentrated in stars and galaxies, by a factor of about 10. For the time being, it is unknown in what form this matter (concealed mass), which is hard to observe, exists and whether or not its spatial distribution coincides with the distribution of galaxies.

16. It is an observed fact of great significance that the system of galaxies is not static, but expanding. Of course, individual galaxies and compact concentrations form stable gravitationally-related systems and do not expand. The law of expansion is more clearly established for the system of accumulations of galaxies. Usually, the brightest members of these accumulations, usually located at the center, and individual galaxies, which are not part of groups or accumulations, are visible. The sum total of all such galaxies forms a sort of grid, extending uniformly on all sides. From a tremendous number of observations, it follows that for any pair of such objects the speed of their separation from each other is proportional to the distance between them. We can at least apply this simple law to galaxies for which the speed, entering into this correlation, is less than the speed of light. For more remote objects, the effect of the special and general theories of relativity are important and the concepts of speed and distance require elaboration.

17. The coefficient of proportionality between the speed of dispersion of galaxies and the distance between them is called the Hubble constant. The inverse value has the dimension of time and is called the age of the Universe. This name is used because, in flying apart with a constant relative velocity, any pair of objects would in this time manage to increase the reciprocal distance from zero to the value now observed. According to contemporary data, the age of the Universe is about 10-20 billion years. Independent estimates of the age of individual astronomical systems are known: of the Solar System, the stars, stellar concentrations, and galaxies. These estimates are based on data about their relative content of different chemical elements and on the theory of stellar evolution. The estimated age of the Solar System is five billion years, and the age of the oldest spherical stellar accumulations and, indirectly, of the galaxies is 11-13 billion years.

18. During expansion, the average density of matter decreases and, consequently, it was denser and hotter in the pre-galactic epoch. It is possible to say with certainty that 10-20 billion years ago the Universe was not at all like that which we now observe. This conclusion is persuasively confirmed by the existence of the so-called relic radiation, discovered using radio telescopes in 1965. It is distinguished from the radiation of isolated objects by the fact that it comes not from separate sources, but from all directions, uniformly filling the entire celestial sphere. Its temperature is about three degrees on the absolute scale. The properties of this radiation are identical everywhere, regardless of at which point in the sky the instruments are aimed. Only slight variations in temperature have been discovered, on the level of a tenth of a percent, caused by the movement of the Sun and Earth relative to the background of this radiation. In the direction in which the Solar System is moving, the temperature is slightly greater, and in the opposite direction--slightly below average. The relic radiation could not have been created by the activity of individual stars and galaxies, but remains as a trace (relic) from the pre-galactic epoch. In this epoch, the average density of matter was greater by a factor of billions, and the temperature of radiation was greater than it is now by a factor of a thousand. During the expansion of pre-galactic matter, the relic radiation cooled down and its temperature decreased to the value now observed. Due to gravitational instability, slight heterogeneities developed in the matter itself, which finally led to the formation of separate objects and the now-observed structures in the distribution of galaxies and conglomerations of them.

19. The idea that pre-galactic matter was quite homogeneous is confirmed by the high degree of similarity of the temperature of the relic radiation on all angular scales. It should be recalled that light and radio waves, which give the basic observational information about the Universe, travel at a finite velocity, the speed of light. Therefore, the further away their source is located, the earlier the stage of existence at which we see it. To put it figuratively, in observing a source, far from us at a great distance, we are looking into the past. Relic radiation covers tremendous distances, spreading virtually without absorption or dispersion. It actively interacted only with the primary pre-galactic plasma, after which it began to spread freely. If there had been significant variations in density and temperature in pre-galactic matter, right now the observed temperature distribution would be heterogeneous and ''spotty.''

20. Yet another set of observed information, an important component part of our concepts about the contemporary and early Universe, concerns the chemical make-up of the matter surrounding us. The most

common element is hydrogen. It makes up about 75 percent of the overall mass of matter. Virtually all the rest is helium. The numerous light and heavy elements encountered in nature are represented only in parts of a percent. Altogether, they barely contribute two percent to the overall mass of matter. From this point of view, planets and life on them, built out of heavy elements, are an extraordinarily great rarity.

21. Elements from carbon to iron arise as a product of thermonuclear reactions in the cores of stars during the calm stage of their evolution. The heavier elements are formed during supernova-type explosive processes. As the result of the explosions of massive stars, rapidly ending their evolution, various chemical elements enter the interstellar gases.

22. Helium and certain other light elements have pre-stellar origins. This follows from the fact that, during the entire existence of the Galaxy, only roughly 15 times less helium, than that which is in fact observed, could have appeared. The required quantity of helium could easily have been formed in the epoch of so-called primary nucleosynthesis, when the density of pre-galactic matter reached values typical of the density of nuclear matter. Let us recall that relic radiation began to spread freely about 10-20 billion years ago.

23. Theory and Extrapolations

24. The basic physical theories form the theoretical foundation for cosmology. Historically, the concept of a nonstationary universe was first suggested by our fellow countryman A.A. Fridman, even before experimental evidence of the phenomenon of ''dispersion'' of galaxies. In his theoretical works, A.A. Fridman proceeded from the simplest assumptions about the homogeneity and isotropy of the continuous distribution of matter with a positive density and a very slight pressure. Using the equations of A. Einstein's relativistic theory of gravitation, A.A. Fridman proved that the corresponding solutions mandatorily depend on time. It was not immediately realized that the non-stationary nature of such systems is completely natural and inevitable. It is identically warranted both in relativistic theory, as well as in the usual Newtonian theory of gravitation. In the absence of decreases in pressure or any other forces capable of opposing gravity, no ordinary substance can be eternally in a state of rest. Depending on initial conditions, it can either slowly expand or contract. The final fate of an expanding gravitational system depends on whether the average density of matter is great enough that the forces of gravity will slow down the expansion and, in the future, turn expansion into compression. If the average density of matter is greater than a certain value, called the

critical value, expansion will be replaced by compression: otherwise it will continue without limit. Obviously, the critical value of density is determined by the rate of expansion and is expressed in the Hubble constant. According to contemporary data, the average density of all types of matter (including the hidden mass) in the observed Universe is close to the critical value.

25. The averaged, smoothed-over distribution of matter of the galaxies in the observed Universe is well described by Fridman's cosmological solutions and Fridman's models. Why we are observing precisely expansion, and not compression, is a separate question, which cosmologists are now examining.

26. According to Fridman's solutions, it is possible to calculate the course of the change in both density and temperature in the future, as well as in the past. Using these calculations, G. Gamov designed a theory of primary (pre-stellar, pre-galactic) nucleosynthesis and predicted that the contemporary Universe ought to be full of electromagnetic radiation at a temperature of about six degrees. Although the actual discovery of three-degree (relic) radiation occurred accidentally, beyond any connection to G. Gamov's prediction, in principle its existence was expected. Interpretation of the relic radiation has not caused serious difficulties, the more so since the actual value of the temperature does not differ too greatly from the predicted value.

27. The successful prediction of the relative content of chemical elements, coinciding with the content actually observed, also relies considerably on the laws for the change of density and temperature with time. In turn, these laws on the whole depend on the forces of gravity, since precisely gravity determines the behavior of large masses of matter. Thus, gravitation field theory plays an important role in cosmology.

28. It is possible to roughly describe the volumes of the Universe with small dimensions using ordinary classical mechanics and the Newtonian theory of gravity. However, for distances comparable to the scale of the observable Universe, the Newtonian theory is not suitable. Cosmology has to be relativistic and relies on the conclusions of the special and general theories of relativity. Here, the concepts of time and space hold an especially important place.

29. The special theory of relativity has changed the old concepts of pre-relativistic physics concerning time and space. Absolute time, ''flowing uniformly and independent of anything external,'' turned out to be overly idealized. According to the special theory of relativity, the judgments of observers about the interval of time and the segment of distance between one and the same pair of events

depends on the movement of the observers. For different observers, the time intervals and segments of distance between one and the same pair of events, generally speaking, are different. There is no one correct set of values whatsoever: all sets of values are right, and each of the observers is correct to an equal extent. Only a certain combination, consisting of the time intervals and segments of distance, remains identical for all. Therefore, it is said that unified space-time has an independent value, but not time or space separately. The change of views of space and time has occurred, in part, because the procedure itself for measuring spatial segments and time intervals has been analyzed.

30. The general theory of relativity, i.e., the relativistic theory of gravitation, introduced even more cardinal changes in the concept of space and time. Once again, certain questions hold an important place in understanding it: What, with what and how is it measured? Observers who are resting with respect to each other, yet are located in places where the gravitational field is different, will discover by comparing their observations that the rate of flow of time for them is different. Such conclusions also occur with regard to segments of length. The conclusions of the general theory of relativity conform quite well to all existing experimental data, both under laboratory conditions, as well as in space.

31. Judgments about the geometric properties of a given surface are made on the basis of correlations between segments of length which connect points of this surface. Judgments about the geometric properties of space-time are made on the basis of how the time intervals and segments of length between events in space-time behave. Since, in the presence of a gravitational field, length and durations do not behave as they do in the absence of a gravitational field, the geometric properties of space-time change. That is why the concept of warped space-time, the idea of its curvature, arises. Giving a detailed description of a gravitational field is the same as giving a detailed description of the geometric properties of space-time.

32. In cosmology, the concept of warped space-time plays a central role. In geometric terms, one could say that the cosmological model in which the average density of matter is greater than the critical value conforms to a closed space, similar to the surface of a sphere. A model in which the average density of matter is less than the critical value conforms to the so-called open or Lobachevskiy's space. On the boundary between these two cases, i.e., in a situation where the average density of matter equals the critical density, there is a model where space has ordinary Euclidean geometry. As already mentioned, the estimates of density in the observed Universe give a value, close to the value of the critical density. For now, it is impossible to choose between these three geometries of space. In

any case, the definition of the geometry of space would be local in nature, i.e., it would directly relate only to the observed part of the Universe.

33. Fridman's cosmological solutions postulate homogeneity and isotropy as universal and eternal properties. Direct observational information about the Universe relates only to a limited area, both in time, as well as in space. In the area encompassed by observations, these properties really exist, although only with a certain degree of precision. However, cosmology is interested in the structure of the Universe on the whole, i.e., with the utmost conceivable distances and time intervals. Therefore, extrapolations are often used, true, inevitably of limited trustworthiness. Nonetheless, in using the observational data and a theory, tested in other observations and experiments, it is possible to draw meaningful conclusions about epochs and areas of the Universe which are not observed directly here right now. In this manner, for instance, we succeed in drawing conclusions about the structure of the Universe on scales exceeding its observable dimensions by a factor of 50-100.

34. On the grounds of this analysis, it can be claimed that on the tremendous scales mentioned, inaccessible to contemporary observations, the deviations from homogeneity and isotropy are not overly great. More accurately, the relative deviations of all cosmological values do not exceed one unit. On even greater scales, it is no longer possible to say this. The above argument does not rule out that the properties of the Universe on such great scales may be considerably different. There are interesting theoretical considerations to the effect that, on the utmost greatest scales, the structure of the Universe may be extraordinarily complex. Even violations of the properties of connection of space, the appearance of differences in the dimensionality of space, a change in the numerical values of fundamental constants, etc., are also not ruled out. Although, at this level of knowledge these considerations are highly hypothetical.

35. The question of the structure of the Universe on very large scales is supplemented by the question of the properties of the Universe at the very earliest stage of its evolution. The uncertainty in the answer to this question partly relates to the fact that the properties of matter under tremendous densities, exceeding nuclear density by many orders, are unknown. It would be especially important to clarify the amount and the sign of pressure in this matter. The point is that pressure is capable of creating gravity, just the same as it creates the energy density of ordinary matter. This is an effect of the relativistic theory of gravitation: it does not exist in the Newtonian theory. Under ordinary conditions, pressure is insignificant and additional gravitational forces are small. In any

case, pressure which is positive in sign can only slow the rate of expansion through its gravitational influence. Given other identical conditions, a gas possessing a high positive pressure will expand somewhat more slowly than under conditions of the same energy density, but less pressure. However, the situation changes significantly if states of matter with negative pressure are possible, moreover, great negative pressure in terms of the absolute amount. Then, matter would expand not with deceleration, but with acceleration.

36. Modern elementary particle theories predict that in the very early Universe a state of matter with a negative pressure really could have existed, and it would have been equal to the absolute value of the density of energy. In this case, an accelerated rate of expansion occurs, known as inflationary expansion. If such a stage really occurred in the evolution of the very early Universe, it explains several fundamental facts. Let us point out some them.

37. As already stated above, the temperature of the relic radiation coming from different directions in the celestial sphere is identical with great precision. This fact in itself is rather surprising. According to the ordinary Fridman solutions, not involving the hypothesis of an inflationary stage of expansion, the indicated elements of the primary plasma would not be in a cause-effect relationship to each other. No physical process whatsoever could ensure the identical nature of conditions in these elements, yet nonetheless for some reason they had an identical temperature. Therefore, one must assume that the initial conditions were such. The inflationary expansion hypothesis offers a more natural explanation for this fact. The entire volume of primary plasma could have developed in the stage of accelerated expansion from matter, which had occupied a small cause-effect area. In other words, the causal connection between all elements of the primary plasma, now observable, could have been established in the inflationary stage of expansion. This makes the sameness of the observable temperature more understandable.

38. Another advantage of the inflationary hypothesis relates to the explanation of the origin of primary perturbations in the density of matter. As already noted, in the pre-galactic epoch of expansion such perturbations should have existed, so that in the future they could lead to the observed objects and structures. In the usual approach, the properties of such perturbations do not proceed from general theory, but are postulated. In particular, the amplitude of perturbations is selected such that we obtain the observed structure. The inflationary hypothesis offers a more natural explanation. In the inflationary stage, it turns out, perturbations could have developed from inevitable fluctuations of a quantum nature. This decreases the

number of necessary assumptions. Comparison of all conclusions from such a concept to what is observed is one of the most actively developing fields of cosmological research today.

39. Finally, the existence of a stage with a great negative pressure gives hope for explaining cosmological expansion itself. As already stated, at this stage the forces of gravitation accelerate expansion, not slow it down. The gravitating system is brought from a state of rest to one of expansion, not of compression.

40. The hypothesis of an inflationary stage of expansion is just one example of the close intertwining between modern cosmology and modern basic physics. The problems relating to the micro- and macro-world connect into a unified set of problems. Possibly, here we must seek an answer to the question of how the Universe was born. In recent years, this has become the object of specific research.

41. There are at least two groups of ideas. First, there is a set of theoretical and observational arguments supporting the idea that the history of the Universe began from a kind of special state, not subject to description within the framework of the classical relativistic theory of gravity. Really, extrapolations of the observed expansion into the past, according to ordinary Fridman solutions, in the end lead to infinite values for all physical quantities: density of energy, pressure, strain of the gravitational field, etc. A state characterized by such values is called a singularity. Classical concepts of length and duration no longer apply for its study. This area of research has been singled out as an independent discipline, quantum cosmology. Thus, a concept arises about the quantum birth of a classical Universe and classical space-time.

42. The second group of ideas relates to persistent attempts by theoreticians to create a unified theory for all physical interactions. The inclusion of gravitation in existing theoretical schemes makes it necessary to involve complex theoretical constructions, such as multidimensional spaces, super-symmetry, super-strings, etc. It is important that, as for other fields, quantum laws should form the basis for describing gravitational interaction. The classical gravitational field and the related classical space-time are approximations, justifiable under certain conditions.

43. Both above-mentioned groups of ideas are being actively developed right now. In the first, the emphasis is placed on cosmology; in the second--on microphysics. It may be possible that the secret of the origin of the Universe will be discovered when both approaches merge into one.

44. The boundaries of the known and the hypothetical, which I have tried to talk about, are very mobile. It is possible that tomorrow they will be different: such are the rates of our renewal of knowledge.

45. It must be said that research on the Universe has always been accompanied by the appearance of questions, going beyond the framework of cosmological science. Let us recall the fate of the Dominican monk Jordano Bruno, burned at the stake by the Inquisition in 1600. The mercilessness of the reprisals against him were not immediately understood. After all, it would seem, the conflict was based on highly abstract ideas about the infinite nature of space and the multiplicity of habitable worlds! It is hard to establish the connection to everyday life. Nevertheless, his opinions undermined established concepts, sanctified by the Church. If the heretic was not condemned, doubts would arise not only in the accepted picture of the world, but also in the infallibility of the Church and power.

46. This tragic page of history illustrates the sharp world-outlook and ideological struggle surrounding cosmological assertions, also occurring in our time, for instance, surrounding the question of the causes of a singular state (is this the work of God?). Man began to think about the origin of the world long ago. The images from the material culture of primitive societies attest to this.

47. Mankind has been living in the space age, started by the flight of Yu. Gagarin, for almost 30 years. We are seeing farther and we know more, we are approaching a fundamentally new understanding of the Universe that is now facing the ''world of men.'' Researching it requires the participation of representatives of almost all sciences, including humanitarians. It is a question both of ensuring space flights, as well as of resolving a whole number of fundamental problems, for instance, the problem of the existence of non-Earth civilizations. Certain experience in interaction and some practical scientific experience has accumulated here. However, this is a topic for yet another author.