OPENING ADDRESS

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The goal of the symposium is a broad discussion of 1) the composition, structure and motion of matter in the Universe now and around us ; 2) its evolution — in the observable region and within the time when the well–known physical laws are applicable and 3) the very far past — inflation — and how it explains the nearly past and today situation.

I will give a simulated historical sketch, without pretenses on completeness and priorities claims. The history should help to understand the underground streams determining the development of our Science. Perhaps even an explanation will emerge, why were forgotten ideas, published too early — ideas which blossomed lated.

So I will begin with the impact the Einstein's general relativity 1915 has given to astronomy.

In parentheses it is appropriate to quote Einstein himself : he was proud of his 1903–1905 fluctuation theory, thermodynamics as consequence of statistical mechanics, photon as "particle of light" theory and special relativity. But thermodynamic–statistic links were done before him by Gibbs, photon and special relativity would be done by other people 2 or 3 years later, if not earlier, by some other scientists, so was Einstein saying. For general relativity he made an exception : perhaps one should wait 50 years for some other to find the idea of Riemannian geometry as explanation of gravitation.

At once cosmology became geometrized. I am going over the unsuccessful idea of a stationary closed Universe (Einstein 1918) though it gave some useful mathematical ideas. Most important were the 1922–1924 papers by Alexander (Szandor in Hungarian) Friedmann. Perhaps they would go unnoticed — but Einstein made publicity for them when he published in Zeitsehrift für Physik two short notes. The first : Friedmann's work is wrong, the second : Einstein has made a mistake, Friedman is right !

Friedmann solution confirmed by Hubble law has shown a possible type of motion $\vec{u} = H_{\vec{r}}$ which does not single out the origin $\vec{r} = 0, \vec{u} = 0$. All points and

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directions are equivalent. It turned out also, that the local properties – $H(t), \rho(t)$ (density) could be obtained by Newtonian equations for a uniform star distribution. It concerns even the perturbation theory — formation of galaxies and their clusters. Friedmann theory was not done in the XVIII or XIX century for lack of courage, because of the self–similarity theory and the transformations to moving and accelerated systems were not developped.

Now the usual picture for all cosmological books brings in strong anthropomorphic ideas ! It is assumed that the scale of hyperbolic or that of closed world is of the order of the horizon. For closed world it is assumed that its age now at the birth of civilization is smaller but of the order of its total existance span up to collapse : just like in human society the age of maturity 20 years is smaller but of the order of magnitude of the average total life span 80–100 years. We shall see that probably all these order of magnitude evaluations are invalid, the Universe is much larger than the horizon and we are at its infancy. Moreover $| 1 - \Omega | \ll 1$ and therefore we are in the age when the three classical Universes are indistinguishable. To end with this part I should stress the remaining uncertainty about the Hubble constant value 50 of Sandage–Tammann or 100 of de Vaucouleurs in kilometer per second per megaparsec units. Perhaps the new X–ray measurements together with radio observations will give the answer. A new direction of research emerged with the discovery of microwave background radiation. A gifted man of tragic fate, Gamov, predicted closely its temperature from wrong premises. He has given 6 K instead of 2.8 K but the error in T^4 is 25 times. The thermal story of the Universe was reconstructed, later together with the story of nucleosynthesis. From the abundances of D, ^{3}He, ^{4}He, ^{7}Li one is sure that the total density of all nuclei today (in stars, gas, black holes) is less than 5.10^{-31} g/cm^3.

This is much less (10–30 times) that what is needed for Ω=1, it is much less than what is needed for galaxies structure today (Ostriker, Peebles, Einasto), it is much less than what is needed for perturbation growth — for the formation of structure. So the problem of dark matter comes !

We are studying the Universe without any knowledge of what is made from the 90 % of its content : some particles and/or fields not yet found on accelerators are needed — and the modern physics accepts gladly the possible existence of very weak interacting and perhaps very heavy particles. The idea of neutrino with rest–mass, advocated by G. Marx and A. Szalay in astronomical context and supported by Ljubinov et al. experiment is also not excluded today (October 1987). We understand the general trend of MBR spectrum to be the equilibrium one. We know that absorption, emission and scattering of photons make them converge to Planckian blackbody radiation.

The more are interesting the (small) deviations of spectrum from the equilibrium one. They could be due to peculiar motion in the plasma, to other energy sources like heavy particles decay, to strong motion (mentioned latter) I hope that we will discuss these deviations.

There can be also in principle the deviation of radiation from isotropy, which shows us the amplitude of density perturbations at decoupling (of photons

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from gas) at z∼1000. These are the initial conditions for galaxies and superclusters of galaxies formation. The small amplitude of $\Delta T/T$ means that gravitational instability must be strong enough to give first galaxies and quasars at $z \geq 4$. This is an extra argument for the existence of "dark matter". There are by now several difficult calculations of the formation of structure from small initial perturbations, with various assumptions about the initial perturbations and the dark matter. To obtain the unique solution of the inverse problem (i.e. to determine the dark matter nature) is even much more difficult but still one works on it. The first step here is to characterize the observable structure by some numbers and functions, here the long term work of Jim Peebles on correlation functions of galaxies should be mentioned. Measurements of more than 10^4 redshifts has given a 3D picture, voids were discovered, (even if not investigated enough, especially in evolution) ; see Huchra et al. New mathematical methods of analysis — cluster analysis (Einasto), percolation (Shandarin) are used to characterize the structure. You will hear thereabout during the Symposium. A fundamental qualitative question remains : ideally we should say that the today Universe is the result of evolution from given initial conditions. They were very peculiar including violent but smooth initial expansion. In chemical or nuclear explosions we investigate how the initial charge at rest obtains its immense kinematic energy. It is due to pressure gradients, the ambient pressure being equal to zero. In expanding hot Universe Big Bang we explain the expansion now by stronger but smooth expansion at an earlier time ! The smoothness of expansion of the Universe was explained by inflationary theory by Alan Guth. The main point is written simply, for observers, not theoreticians, in my paper in 5 vol. Soviet–American Sci. Reports (Gordon and Breach) in a paper on scalar field. The point is that a scalar field ψ has energy density

$$\varepsilon = \frac{1}{2}(\frac{\partial\psi}{\partial t})^2 + \frac{1}{2}(\mathrm{grad}\psi)^2 + V(\psi).$$

But its pressure is

$$T_{\mu v} = \frac{1}{2}\frac{\partial\psi}{\partial t}^2 \delta_{\mu\nu} + \frac{\partial\psi}{\partial x^\mu}\frac{\partial\psi}{\partial x^\nu} - V(\psi)$$

In the simplest case $\partial\psi/\partial t = 0, \partial\psi/\partial x^\mu = 0, \psi = \mathrm{const}$

$$\varepsilon = V, p = -V = -\varepsilon.$$

But the general relativity teaches (for uniform ψ distribution and small sphere R with volume $\omega = \frac{4\pi}{3}R^3$, mentally cut out of uniform field)

$$\frac{d^2R}{dt^2} = -\frac{GM_2}{R^2}, \qquad M_e = \frac{V}{c^2}(\rho + \frac{3P}{c^2})\omega = \frac{4\pi}{3}\frac{R^3}{c^2}(\varepsilon + 3P) = -\frac{8\pi}{3}\frac{1}{c^2}VR^3$$

$$\frac{d^2R}{dt^2} = -[-\frac{8\pi G}{3c^2}VR] = \frac{8\pi G}{3c^2}VR.$$

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One obtains gravitational repulsion ! (instead of usual attraction), generating Hubble flow.

The negative pressure occurs never in equilibrium phase, but it is totally possible and self consistent in the expansion phase. What about energy with density $\varepsilon = V$?

If we take a closed world its total energy, $\varepsilon - G\int \frac{M_1 M_2}{R_{12}} dM_2$ is zero ! Here the second integral term is the negative gravitational energy of the order of $G\varepsilon R^5/c^2$ over all volume.

Expansion with negative pressure pumps energy into scalar field. The work is done by gravitational repulsion, the energy is conserved due to increase of negative gravitational energy accompanying that of positive scalar field energy. The scenario of inflation involves exponential scale growth $a = a_o \exp(H_o t)$ or $a \cdot \exp(\int H dt)$ for slow changing H. Here one can begin from $a_o = a_{pe} = 10^{-33}$ cm and obtain easily $a \gg a_o \exp(100)$. Thereafter the non–equilibrium scalar field energy is transformed into hot plasma energy and usual Big Bang begins. The scalar field was introduced by Yukawa in 1937 to explain nuclear forces. Soon it came in disrepute. The protons and neutrons are now build of quarks and gluons — an analogue of electromagnetism — binds them. Forces between neutrons and protons in a nucleus are like chemical forces i.e. small changes of gluonic fields when the composite proton and neutrons are brought together. But for other subtle purposes "Higgs" scalar fields with peculiar $V(\psi)$ were introduced. Kirznits and Linde were beginning the use of these fields in cosmology, Starobinsky pointed out that a similar effect can be achieved by the vacuum polarization in the curved space.

First it was sought necessary to have a metastable situation to obtain the long enough and strong enough inflation.

But it appeared, that the very expansion works as a brake on ψ–falling. One can take $V(\psi) = 1/2m^2\psi^2$ or $1/4\lambda\psi^4$ (Fig. 3) and ψ initial of the order of 3–4 Mpc (with $V(\psi) \ll m_{pe}^4$ if $m \ll M, \lambda \ll 1$) to give the needed inflation. The next step was the investigation of quantum zero point oscillations. In another context it was Sakhorov in 1965 who was the first to consider the inevitable quantum zero oscillation (connected with Heisenberg uncertainty) as a source for galaxies formation.

In the 1980 the zero oscillations were considered on the background of inflationary scalar field.

The quantum mechanics teaches that $E \equiv H \equiv 0$ in vacuum is impossible just like the oscillator having $x = p(= mv) = 0$ is impossible because $\Delta x \cdot \Delta p \sim \hbar$. In the field case every wave is similar to an oscillator. Their energy are not zero in the lowest energy state .

Being the lowest level it can not give energy to any particles. The scalar field must be (as a moment shot) imagined with a fractal–type distribution due to zero point oscillations (ZPO). So would be even at $\bar{\psi} = 0$. These oscillations are (for electromagnetic field) confirmed by experiment–Lamb shift changes of levels

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and of magnetic moment of the electron. The infinite energy of these oscillations is already included in the energy density of the vacuum and we know that the total sum of zero–energies for all fields (including negative contribution of fermions) is equal to zero (the cosmological constant) or at least very small, in the flat space. The idea of zeropoint inevitable oscillations or fluctuations is applied to the scalar field also.

It is the expansion of the space which changes the situation. First of all, beginning with a mixture of various fields, the scalar field survives when other fields vanish. The second point is that the ZPO are stretched. When their wavelength is larger than the horizon they are no more "oscillations" — they are perturbations superimposed on flat $\bar{\psi}$. This can be treated as particle formation in time–dependent metric. But there is another point of view advocated the last time by Starobinsky and Linde. When the wavelength is larger than the horizon the Fourier analysis of very long waves is obsolete. The distant regions of the wave are no more interacting. We split the total volume into acausal parts and observe the growth of the number of these parts $\frac{dV}{dt} = 3HV$. Further we see that $\bar{\psi}$ in every volume (averaged over this volume) are subject to stochastic changes superimposed on the lawful decrease. At large $\bar{\psi}$ these changes can even be larger than the decrease, the $\phi(t)$ in some minivolumes can grow over the $\psi(t + \Delta t, N_i)$. The next nonlinear effect coming into play is the dependence of growth factor of volume from ψ if you have some ψ distribution it will change also due to this effect. In total it is assumed now, that an everlasting very inhomogeneous Universe is possible — with some parts being still now in inflation period, before transformation of scalar field into plasma.

From this point of view our existence in a rather homogeneous and isotropic part of space is a mere occasion ; of course a happy occasion, without which the life and civilization would not occur (and this is perhaps the answer to the question why we are in a normal region $\bar{\psi} = 0$)). I would like to emphasize, that in this picture the total Universe is not at all Friedmannian–like, its part is Friedmannian–like just because it is a small part, like a small part of elephant skin, which is quasi flat. In the Higgs transformation into plasma defects — walls, strings, monopoles can remain. Today one can hypothesise many different string types. All this will be discussed in other reports of the Symposium.

I should point two important relevant topics, not mentioned in the agenda

1) baryogenesis. It is an inescapable part of the total picture. Laboratory experiments failed, but new theoretical ideas going from Hooft and Rubakov and also Aflike and Dyne are worked out.

2) the spontaneous (quantum) birth of a closed world with large ψ from nothing — a sort of quantum tunneling — as an alternative to eternal existence of inflating volumes.

One speaks about astrophysicists "Never in doubt often in error". If you take young theories they are often changed. But parallel at the same time a Stonewall of eternal knowledge is slowly built. We are in a difficult position knowing that we study directly a small part of the Universe as a whole, and

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knowing that unknown yet physics of very high energy is involved.

One needs courage. But one needs also delicateness and precision.

I would call it Leon Tolstoi principle : a detailed courageous study of his own heart and mind helped him to understand others hearts and minds — that of Anna Karenina, that of a horse.

So let us find in our vicinity the landmarks of unusual processes and far away regions.

Yakov Borisovich ZELDOVICH
(1914-1987)

Ya.B. Zeldovich was one of the most illustrious physicist of the modern era.

He started his scientific career working in physical chemistry at the age of 17. He created a model for the propagation of burning waves and explosions. Later he obtained fundamental results in the theory of shock wave propagation, which was published with Raizer in two volumes that have become standard reference works.

He worked for several years on nuclear physics, then published a series of papers in particle physics, on the theory of weak interactions, lepton charge conservation, prediction of neutral heavy mesons, Pseudo-Conserved axial current.

He was the first to point out that accretion onto black holes and neutron stars will lead to emission of X-rays. He had several other important results concerning the physics of black holes and neutron stars.

His work in physical cosmology helped enormously to turn it into a real science. He made fundamental connections between particle physics in the early universe and the subsequent stages of evolution. It has been realized over the past few years that as a consequence of inflation the Zeldovich-Harrison spectrum of fluctuations provides an attractive explanation for the origin of large scale structure. He was also one of the first to discuss cosmic strings as an alternate possibility for galaxy formation.

His work on cosmic pancakes and the elegant approximate theory for nonlinear collapse that is recognized as the Zeldovich approximation has generated an enormous advance in our understanding of the large scale structure. His vision of the topology of the universe has guided cosmology for several decades. The collaboration with his student Rashid Sunyaev on the Compton distortions of the microwave background predicted new types of observations, stimulated entire generations of astronomers to pursue these ideas.

He has been a wonderful teacher, sparkling with ideas, and igniting everyone around him, to work day and night on the frontiers of physics. He founded the science of modern cosmology in the Soviet Union. He had a unique career, living through one of the most exciting times in physics ever. His interests spanned the entire range of physics and he left a significant contribution on every subject on which he worked. His papers also reflect his wonderful, warm personality.

The whole physics community, his students, his friends all miss him. Those of us fortunate enough to have had contact with him will never forget his exuberant character and intellectual vigour.

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