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CONFERENCES AND SYMPOSIA

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International Conference on Cosmology and High Energy Astrophysics (Zel'dovich-90) Moscow, 20 – 24 December 2004

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The year 2004 marked what would have been the 90th birthday of Academician Yakov Borisovich Zel'dovich, a scientist unique in the scope of his interests, whose huge and often pioneering contributions to physics range from the Soviet nuclear project and the theory of burning to elementary particle physics and astrophysics. Many of Zel'dovich's ideas led to revolutionary breakthroughs in the fields where he worked and indeed were instrumental in determining the top priority research areas of modern science as a whole.

As part of a whole series of Zel'dovich memorial meetings on chemistry, astrophysics, and cosmology, a conference on cosmology and high-energy astrophysics was held at the RAS Space Research Institute on December 20 – 24, 2004. The title themes of the conference were central to Zel'dovich's interests from the 1960s through the 1980s — so much so that his name is familiar to anyone in cosmology and astrophysics: recognized experts and newcomers alike. Zel'dovich's 'pancakes' (the first nonlinear structures in the Universe), the Zel'dovich – Harrison spectrum of primordial perturbations in the Universe, the spectrum and distortions of the cosmic microwave background (including the acoustic peaks of the kind that were observed in the BOOMERANG and MAXIMA-1 balloon experiments and are now being explored in detail with the WMAP satellite), and finally black holes glowing due to accreting gas — these are only a fraction of Zel'dovich's fundamental contributions to modern astrophysics. Once only beautiful theories, today many of Zel'dovich's ideas are powerful tools of modern science.

Bringing together an international body of leading cosmologists and astrophysicists, all greatly influenced by the ideas and work of Zel'dovich, the SRI conference went beyond paying tribute to the great scientist's hard-to-overestimate role in cosmology and astrophysics — it also aimed at discussing the most recent developments in these fields. The Conference Committee — including leading Russian experts, Zel'dovich's colleagues and students — was presented with more than 200 paper proposals, of which, to conform with the five-day conference format, about 50 were selected for oral presentations and more than 50 for posters.

The conference opened with a review of the latest results obtained with SPITZER and GALEX, currently the 'youngest' orbital observatories at work. The Lyman Spitzer infrared observatory was launched in 2002 to complete the work program of NASA's 'grand' observatories. The lead scientist of the project, T Soifer of the California Institute of Technology, demonstrated unique images and spectra of extragalactic sources of high-power infrared radiation, most of them regions where intense star formation is taking place.

It should be noted that the closely related problems of star and galaxy formation are one of the most rapidly developing research areas in astrophysics. Along with infrared radiation, another manifestation of intense star formation is the high-power ultraviolet radiation from young and massive stars — which is the subject of study by the GALEX (Galaxy Evolution Explorer) observatory. The striking contrast of both the UV images of spiral galaxies (shown by GALEX project leader K Martin of Caltech) and of the infrared images from SPITZER once again demonstrates the huge progress observational astronomy has made in these wavelength ranges, raising expectations for near-future breakthroughs in the study of star formation processes in the Universe.

A large block of conference presentations was organized around cosmic background radiation — a research area that is currently providing the most accurate data on the cosmological parameters of our Universe, such as the Hubble constant, dark matter and dark energy contributions to the average mass density, etc. A joint review by the leaders of two major projects, L Page (Princeton, WMAP satellite) and A Reedhead (Caltech, ground-based 5-km-elevated interferometer in Chile), analyzed fluctuations in the cosmic background angular spectrum, whose measurements improve the accuracy of many of the Universe's fundamental characteristics and suggest using subtle theoretical predictions for building an ever more accurate and detailed picture of its evolution. A further qualitative breakthrough in this direction is to be achieved by launching the European PLANCK satellite and ground-based experiments, like the QUIET project, for example. The results to be expected from these projects were discussed by K Gorsky and C Lawrence, both of

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Caltech Jet Propulsion Laboratory. The interaction of cosmic background radiation with the hot gas that fills galaxy clusters (the Zel'dovich – Sunyaev effect) also remains one of the major areas of research (R Knisle, Cavendish Laboratory, Cambridge), as witnessed by the construction of special supersensitive telescopes and interferometers at the South Pole, in Chile, Hawaii, California, and Great Britain.

The lion's share of the information from cosmic microwave background measurements directly relates to one particular moment in the history of the Universe — the $z \sim 100$ recombination epoch, the subject of a detailed 1968 study by Zel'dovich, V G Kurt, and R A Sunyaev. Modern measurements, however, are accurate enough to extrapolate our knowledge of the Universe all the way to the very early stage of its expansion (known as the inflationary stage). Unfortunately still off-limits to direct astronomical study, the inflationary stage is the subject of intriguing investigations, and these were given detailed coverage at the conference. Gravitational waves generated in the very early Universe were addressed in a talk by L P Grishchuk. A A Starobinskii reviewed current theoretical perspectives of the formation of primordial matter density fluctuations. Various aspects of the theory of the inflationary stage were discussed by D Podol'skii, F Perrotta, and A Kamenshchik, all of whom also addressed the related question of the nature of dark energy. A talk by A D Dolgov was concerned with how the Zel'dovich – Gershtein idea can be used today to set 'cosmological' limits on the neutrino mass.

Along with providing insights into the very earliest stages of the Big Bang, cosmic microwave background measurements in fact determine the initial conditions for the subsequent evolution of the Universe — from small primordial perturbations to nonlinear structures of different masses that correspond to the familiar objects of today's Universe, such as stars, galaxies, and galaxy structures. The study of this evolution is one of the priority tasks of both purely theoretical (M Kamiyonkovsky, Caltech) and 'computer' astrophysics aimed at reliably reproducing the key episodes the Universe went through following the primordial recombination of matter. Particularly weakly studied is the epoch between the $z \sim 100$ recombination and the formation of the first objects — quasars and first-generation stars near $z \approx 10$. The study of this epoch is largely possible through observations of 21-cm hydrogen radiation redshifted to meter wavelengths. A Loeb of Harvard showed what huge volumes of information can potentially be obtained with these observations, expected to become technically feasible in the nearest future. The powerful ultraviolet radiation produced by early galaxies and quasars caused most of the material in the Universe to be reionized. N Gnedin presented astonishingly accurate computer calculations of this process, whereas S P Oh of the University of California, Santa Barbara spoke on the prospects for first-generation astronomical objects to be studied observationally.

Continuing on the theme of computer astrophysics, A Kravtsov addressed the process of galaxy cluster formation late in the evolution of the Universe. Highly sophisticated numerical methods combined with the power of modern computers have provided an excellent match between the 'virtual' and real cluster properties. With a reliable computer-tested theory of cluster formation in hand, observational data on real objects can be used for cosmological measurements — amply complementing microwave background studies, as reported in a talk by A Vikhlinin. Performing cosmological measurements requires that there be no systematic errors in determining major cluster characteristics. The correct way of determining the integral temperature of a cluster was discussed in a talk by P Mazzotta (University of Rome 'Tor Vergata').

Galaxy clusters are also the arena of interesting astrophysical processes. Radiatively cooled intergalactic gas accretes onto a supermassive black hole of the central galaxy — a process that releases energy in the form of radiation and relativistic jets, which in turn interact with the cooling gas. CHANDRA's and XMM-NEWTON's X-ray images demonstrated by Harvard's C Jones and W Forman reveal beautiful structures that form as a result. Merging galaxy clusters produce powerful shock waves with their associated nonthermal processes of various kinds (generation of an intergalactic magnetic field, acceleration of relativistic particles, etc.). The radio and X-ray observations of these phenomena were presented in a talk by M Markevich, who discovered a cloud of ordinary matter lagging behind a gravitationally lensed lump of dark matter when traveling supersonically in a galaxy cluster. XMM-NEWTON images of two galaxy clusters were presented by F Durret of the Paris Institute of Astrophysics, and the discussion by A Finogenov was on how the global observational parameters of clusters may be affected by merger processes. Theoretical results on the generation of magnetic fields in dilute astrophysical plasmas were discussed by M Medvedev. One of the next major steps in the experimental study of intergalactic gas in galaxy clusters will be launching the Japanese ASTRO-E2 mission (Ya Tanaki, Imperial Academy of Japan), which, equipped with cryogenic capabilities and bolometers, will provide high X-ray spectral resolution (up to 6 eV in the range 0.5 – 10.0 keV), enabling gas motions on different scales to be studied.

Several conference sessions were held to discuss compact relativistic objects, i.e., neutron stars and black holes. Topics covered in this context included the observational manifestations of these objects, in particular, X-ray variability and spectra (M Gil'fanov, M van der Klis of the University of Amsterdam, and L Titarchuk), the formation of binary neutron stars (van Linden van den Heuvell of the University of Amsterdam), and the search for optical black holes. Crucial to the study of relativistic objects is the physics of the disk accretion of matter onto black holes (N I Shakura). Interestingly, to a large extent, similar ideas underlie the nebula theory of planet formation (R Rafikov). The properties of various types of X-ray binary systems were discussed in talks by A Lutovinov, K Postnov, and Oulu University's J Poutanen, and the observational features of isolated neutron stars were discussed in a talk by Yu Shibanov. J Truemper (Max Planck Institute for Extraterrestrial Physics, a foreign member of the Russian Academy of Sciences) reviewed the current status of X-ray observations of neutron stars and identified problems yet to be solved, and V Simonenko and D Yakovlev discussed the physics of nuclear burning in relation to newly accreted matter on the surface of a neutron star.

Yet another conference theme was nonthermal processes in relativistic jets formed in the most exotic astrophysical objects (E Derishev, V Kocharovkii). The relativistic ejections of matter are one of the most characteristic observational features of supermassive black holes in the centers of many galaxies. A merger of galaxies can lead to a 'binary' system of two supermassive black holes. A possible link between the

evolution of such systems and the observed activity of black holes was the subject of A Lobanov's talk.

A separate session was allocated to discuss the latest results from the orbiting INTEGRAL gamma-ray observatory, which gives 25% of its observing time to Russian astronomers. Along with a summary of major INTEGRAL findings in a talk by S Grebenev, a number of important themes were explored in detail. Observations of the positron annihilation line at 511 keV show that positrons annihilate at a rate of about 10^{43} per second in our Galaxy and that the medium in which this occurs is a relatively cool ($\sim 8000^{\circ}$) and partially ionized gas (E Churazov). But the origin of these positrons is a key and as yet unsolved problem. In another exciting development, the luminosity of a supermassive black hole at the Galaxy's center during a burst hundreds of years ago was measured from the way hard X-ray radiation reflects from the giant molecular cloud Sgr B2 (M Revnivtsev). Finally, the finding by the observatory of a unique gamma burst with the luminosity three orders of magnitude below the canonical value suggests the discovery of a new population of gamma bursts (S Sazonov). Current research on cosmic gamma bursts was reviewed in the talk by R L Aptekar' and R Weiers of the University of Amsterdam.

The progress in modern X-ray detectors will hopefully soon lead to a qualitatively new level in measuring the polarization of hard radiation. What problems such telescopes would potentially solve was discussed by Yu N Gnedin. Polarization (but at radio wavelengths) and the Zel'dovich – Varshalovich effect were also discussed by L I Matveenko in his talk on the supermaser emission of water in dense clouds of interstellar gas. Yu N Pariĭskiĭ spoke of the cosmological implications of the RATAN-600 project and gave some idea of what lies ahead for this research area.

Finally, fundamental problems in hydrodynamics, with ramifications not only for astrophysics but indeed for the whole of physics, were addressed in talks by G S Golitsyn and V E Zakharov.

It is difficult in a short space to list all the themes touched on at the conference. The full text of the conference papers are available at the RAS Space Research Institute website, http://hea.iki.rssi.ru/Z-90. In the common opinion of the participants, the conference was a success in demonstrating the continuing rapid development of cosmology and high-energy astrophysics and highlighting the vital role the ideas of Yakov Borisovich Zel'dovich played and continue to play.