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School of modern astrophysics

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Russia is rich in diamonds, but lean in brilliants.... As is well known, secondary and higher education in Russia has so far remained at a fairly high level. However, postgraduate education as a whole in the leading American and European universities is appreciably more advanced than in this country. Astrophysics is no exception. The Russian astrophysical school has always been solidly based on physics, which made it known world-wide. Currently, the shift in research towards numerical experiment has inevitably led to a decrease in the role of rigorous analytical results, including those in the education process. Hence, the idea emerged to organize the annual School of Modern Astrophysics, aimed at helping to preserve the enormous potential accumulated in the past. The main purpose of the school was to 'polish the skills', mostly for postgraduates and young research workers, not for students.

The school was initiated by the Scientific Council on Astronomy of the Russian Academy of Sciences (RAS), the Astrospace Center (ASC) of P N Lebedev Physics Institute (LPI) and the I E Tamm Department of Theoretical Physics (DTP) of LPI, as well as the Chair of Physical and Astrophysical Problems of the Moscow Institute of Physics and Technology (MIPT). The Program Committee, headed by Academician V L Ginzburg, included D A Varshalovich, V V Zheleznyakov, L M Zeleny, A V Gurevich, N S Kardashev, V V Kocharovsky, A M Cherepashchuk, A O Barvinsky, V S Beskin, V A Dogel', V N Lukash, D I Nagirner, and D G Yakovlev. It was stipulated that the main focus should be on the consistent discussion of the essence of physical processes under way in the phenomena considered.

The first School of Modern Astrophysics took place in July 2005 in Pushchino, Moscow region, at the Radioastronomical Center of ASC LPI. Over two weeks, four courses were given, each including ten lectures encompassing a full semester course:

V S Beskin (DTP LPI): "Axially symmetric stationary flows in astrophysics";

V A Dogel' (DTP LPI): "The kinetics of cosmic rays";

V N Lukash (ASC LPI): "The very early Universe";

D G Yakovlev (A F Ioffe Physical-Technical Institute, RAS) "Structure of neutron stars".

More than 40 participants from 15 institutes located in 10 Russian cities (*inter alia* Moscow, Saint-Petersburg, Ekaterinburg, Nizhny Novgorod, Kazan', Volgograd, Yaroslavl', and Rostov-on-Don, as well as the Special Astrophysical Observatory of RAS) attended the school. All participants were given the detailed notes for the lectures (100 – 200 pages), which could be used for more careful study if necessary. Lectures were given daily from Monday to Saturday, with two 1.5-hour lectures in the morning and afternoon separated by a three-hour lunch. Such a schedule proved to be optimal.

The fundamental character of these courses should be especially stressed. In fact, the lectures employed basic methods of theoretical physics including hydrodynamics (magnetic hydrodynamics), the kinetics and physics of plasma, general relativity, and atomic and nuclear physics. Thus, in addition to astrophysical applications, the audience had the opportunity to refresh in memory (and for some maybe to learn for the first time) their knowledge of the basics of theoretical physics. In our opinion, modern astrophysics, which has unlimited natural applications, is capable of maintaining other sciences in good working conditions.

On the other hand, the lectures reflected the latest achievements both in theory and in observations. This was possible because all the lecturers were well-known specialists in their fields and have been giving lectures to students at leading Russian higher education establishments for many years. They have participated many times in such schools abroad. But this was the first time that they had haven the opportunity to give lectures in Russian for such a large audience of young scientists.

For example, an appreciable part of Beskin's lectures was devoted to the discussion of how energy can be liberated from a rotating black hole embedded in an external magnetic field. It became clear only quite recently that the mechanism of energy liberation is not due to the action of external forces at the horizon, as is, in fact, postulated in the framework of the membrane paradigm (and indeed occurs in the unipolar inductor), but is determined by the action of gravitomagnetic forces outside the event horizon. The emerging electromotive force is the source of the electric current circulating in the black hole magnetosphere, which ultimately leads to energy flux outflow from the black hole to infinity [1, 2].

In Dogel's lectures it was clearly demonstrated how progress in plasma physics and particle physics (the theory of runaway electrons, magnetic hydrodynamics, the theory of plasma turbulence) can be successfully applied to explaining the mechanism of acceleration and propagation of cosmic rays, as well as the nature of diffuse galactic gamma-ray emission.

The lectures by Lukash, which were primarily focused on the evolution of primordial cosmological perturbations and large-scale structure formation of the Universe, were essentially based on the latest data on cosmic microwave background anisotropy obtained by WMAP. Combined with the results of distant supernova SN Ia observations pointing to the accelerating expansion of the Universe, the WMAP data

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have enabled putting stringent constraints on the Standard Model parameters and, in particular, measuring the spectrum of primordial perturbations with a high accuracy. Observations imply inevitably that ordinary matter constitutes only a few percent of the total mass of the Universe, and most of the Universe consists of dark matter (which presumably relates to yet undiscovered elementary particles) and 'dark energy' (which, in fact, relates to nontrivial properties of a vacuum).

Last, the lectures by Yakovlev were concerned with detailed discussion of all questions related to the internal structure of neutron stars, starting from the outer crust (which represents a classical, albeit nontypical, crystal) down to the innermost ultradense regions where such exotic forms of matter like pion condensate and quark–gluon plasma can exist. Special emphasis was given to experimental possibilities of verifying theoretical predictions [3] that have been opened up by the INTEGRAL and Chandra observatories. Much attention was also paid to new tests of general relativity that have become possible after the discovery of a very close binary system containing two radio pulsars in 2003. This is definitely the first time that such a detailed discussion of these problems has been presented to a broad scientific audience in Russia.

It can be stated with satisfaction that the first School of Modern Astrophysics was very successful. It confirmed both the high level of education and the high level of the listeners (the latter can be judged by the fact that nobody missed lectures and there were a lot of questions to the lecturers). The new format of the school, first realized in Pushchino, was also very successful. Never before have such detailed lecture courses, enabling deep description of the topics discussed, been given at the astrophysical schools in Russia. In our opinion, only such schools can fulfill the main goal of learning how to work in the new field of science. Of course, very important was the solid financial support given to the school by sponsors, including the Federal Agency of Science and Innovations, the special program of the Presidium of RAS 'Support of Young Scientists', the foundations 'Advances in Physics' and 'Dynasty', and the Russian Foundation for Basic Research.

The success of the first school enabled us to prepare the next school in the same format. The second school was successfully organized one year later, at the beginning of July 2006. The following lecture courses were given:

A V Zasov [P K Shternberg State Astronomical Institute, Moscow State University (SSAI MSU)]: "Star formation in galaxies";

V G Surdin (SSAI MSU): "The interstellar medium and birth of stars";

A D Chernin (SSAI MSU): "The physics of the Universe";

V I Shishov (PRAO ASC LPI): "Interstellar scintillations of radio sources";

B M Shustov (Institute of Astronomy, RAS): "Formation and early stages of stellar evolution"

(with the last two courses comprising five lectures). As in 2005, the School was attended by more than 40 young astrophysicists, with three of them having come from Ukraine. The new topics allowed a significant change of the audience — only ten participants attended both schools.

As it is clear from the list of lectures, the second School of Modern Astrophysics was primarily dedicated to the physics of the interstellar medium and star formation. The lectures by Surdin discussed in detail the history of star formation studies and provided qualitative consideration of basic physical processes related to star formation [4]. Shustov in his lectures focused mostly on the chemical evolution and the role of turbulence in contracting protostellar clouds. Zasov concentrated on a detailed picture of the star formation process in realistic conditions in galaxies. In particular, he showed that the rate of star formation in galaxies is virtually independent of their morphological types, the presence of spiral arms, and the value of velocity dispersion. Apparently, the most important factor here is the pressure of neutral interstellar gas. These lectures complemented each other and described the latest progress in studies of star formation and evolution of the interstellar medium.

The physics of the interstellar medium and the possibilities of determining its properties were also discussed in lectures by Shishov. However, he was primarily concerned with parameters that can be derived from studies of the interstellar scintillations of radio sources. He presented in detail the procedure of describing the interaction of a wave front propagating through a turbulent medium and discussed the applications of this method. The procedure of determining the spectra of the turbulent interstellar medium was also presented. As an example of the possibilities opened by this method, we mention here the determination of the size of the emitting region in radio pulsars with a record precision to date of about 10 nanoarcseconds.

As for the lectures by Chernin, it contained a thorough analysis of the dynamics of the Universe evolution taking into account the most recent data on the properties of the cosmic vacuum [5]. In contrast to Lukash's lectures (and considering the capacity of the audience), the description was given at a more elementary level than at the first School. In fact, he showed in the first lectures that qualitatively practically all results that follow from general relativity can be reproduced in the framework of Newtonian mechanics. The principal element of these lectures was a painstaking analysis of the most recent observational data suggesting the accelerating expansion of the Universe.

The Organizing Committee plans to organize the School of Modern Astrophysics every year. At present, the program for the next two year is almost complete. In particular, we plan to include in 2007 the following lecture courses:

G S Bisnovatyi-Kogan (Space Research Institute, RAS): "Accretion discs around black holes";

I D Novikov (ASC LPI): "The physics of black holes";

K A Postnov (SSAI MSU): "The physics of gamma-ray bursts";

A M Cherepashchuk (SSAI MSU): "Observations of black holes".

We assume that the topics to be discussed in the future schools will permanently change to include new fields of astrophysics and hence to draw the attention of a new audience. It would be very significant if these lectures stimulated the writing of new fundamental textbooks similar to Refs [2, 4, 6]. Finally, it should be noticed that the positive experience in organizing this School can be expanded not only to other fields of physics (a similar School on the Physics of Fundamental Interactions was successfully organized in August 2006 in Protvino with the support of the 'Dynasty' foundation), but also to other sciences.

Information on the School of Modern Astrophysics is available through the Internet at http://www.prao.psn.ru/conf/School_2006/ann1.html.

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