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# School of Modern Astrophysics — 2009

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The fifth annual School of Modern Astrophysics took place in summer 2009 at Pushchino Radioastronomical Observatory of the Astro-Space Center of the P N Lebedev Physical Institute (LPI). Solar physics and the physics of the Solar System were the main topics of the school, which continues fully covering the most relevant problems of space physics and astrophysics. As in previous years, the main goal of the School was to raise the qualifications of postgraduate students and young researchers. Let us recall that the School was organized by the Astro-Space Center and I E Tamm Theoretical Department of LPI, by the Scientific Council on Astronomy of the Russian Academy of Sciences (RAS), and by the Scientific–Educational Center 'Fundamental Particles and Astrophysics' of the Moscow Institute of Physics and Technology (MIPT) and the Educational–Scientific Complex of LPI. The program committee, headed by Academician V L Ginzburg, included D A Varshalovich, V V Zheleznyakov, L M Zelenyi, 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.

We should directly say that the organization of the fifth School would have been impossible without the support of the Federal Agency on Science and Innovations. In particular, this support made it possible to invite several participants from remote Siberian cities including Irkutsk, Krasnoyarsk, and Novosibirsk. Appreciable support was also obtained from the traditional sponsors — the Russian Foundation for Basic Research, the Foundation for the Support of Fundamental Physics, the D B Zimin Dynasty Foundation, and the Educational–Scientific Complex of LPI.

For two weeks forty participants from sixteen scientific centers in Russia heard the following fundamental lecture courses:

- V D Kuznetsov (IZMIRAN): "Solar physics";
- O L Vaisberg (IKI): "Solar wind and the heliosphere";
- R R Rafikov (Princeton): "The dynamics of Solar System small bodies";
- L V Ksanfomality (IKI): "Planetary systems around the Sun and other stars".

Most importantly, for the first time seminars and tests were organized for participants (V S Beskin, Yu D Zhugzhda, R R Rafikov, I V Chashei). This allowed, on the one hand, the most active participants to be awarded, and on the other hand, the shortcomings in the educational level of young researchers to be uncovered.

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Lecture courses on solar physics given by the director of IZMIRAN V D Kuznetsov and seminars on the physics of the Sun conducted by Yu D Zhugzhda consecutively touched upon problems of the formation and evolution of the Sun as a star, including late stages (red giant and white dwarf) and the internal structure of the Sun. Using helioseismological data, a picture of interior motions of matter in the Sun was given; these motions are responsible for solar dynamo and magnetic field generation, and the appearance of the 11-year solar cycle and its main characteristics (Wolf numbers, Sperer's law, Hale's law). The Maunder minimum and other anomalies of solar activity were considered.

Next, solar magnetic fields and their classification were reviewed, including the general field of the Sun, local and large-scale fields, and magneto-plasma formations. Equations of solar magneto-hydrodynamics were written and problems of the MHD equilibrium and stability of magnetic configurations in the solar atmosphere were considered. The most powerful manifestations of solar atmosphere activity, including flashes, coronal mass ejections, and eruptive protuberances were described. Observations and models of these phenomena were considered, the theory of current sheets and magnetic reconnection and particle acceleration was given, and the emission from solar flashes and their secondary effects, including their impact on the Earth, were analyzed.

Finally, the main methods and devices for solar studies were discussed, including solar spectroscopy, Zeeman, Stark and Doppler effects, spectral line broadening, magnetograms and magnetic field reconstruction in the corona, ground-based solar instruments (optical and radio solar telescopes, coronagraphs, radio spectrographs), and methods and instruments for local measurements and distant observations of the Sun from space. A review was given of the recent achievements in space research on the Sun by spacecraft, and future projects of space solar research were discussed [1]. The lectures were accompanied by many illustrations and movies taken by Yohkoh, SOHO, TRACE, KOPONAS-F, ULYSSES, STEREO, Hinode, RHESSI, and KORONAS-Foton spacecraft.

Lectures given by O L Vaisberg were devoted to solar-terrestrial relations. Solar activity is determined by the 11-year cycle of solar magnetic field variations, especially by changes in the number of solar spot groups with a complex structure of magnetic fields at the surface of the photosphere, in the chromosphere, and in the solar corona. The energy of these fields is spontaneously transformed into the energy of plasma, hard electromagnetic radiation, and accelerated charged particles. The characteristics of the solar wind outflowing from the corona are also determined by the coronal magnetic field structure. During magnetic field restructuring, coronal mass ejections frequently arise with a strong frozen magnetic field. In the interaction of the solar wind with the coronal mass ejections, the energy, momentum, and mass are transferred from the ambient flux to the terrestrial magnetosphere. The magnetic field frozen in plasma and directed to the south has the strongest impact on the diurnal magnetosphere due to the reconnection of the magnetic field carried by the ambient solar wind with the magnetosphere field directed to the north. A restructuring of the magnetosphere thus occurs, leading to the appearance of magnetic storms, auroras, charged particle accelerations in the radiation belts, ionospheric perturbations, and other active phenomena in the near-Earth space. These active events, collectively referred to as space weather, act on complex technical systems on Earth and are the focus of scientific research.

The lecture course was completed by seminars conducted by I V Chashei (LPI). First of all, experimental data on the solar wind parameters, and its global structure and dynamics in the course of the solar activity cycle were discussed. In the analysis of modern theoretical models of the solar wind, most attention was given to coronal sources of different fluxes, the energy balance of the solar corona, and coronal-wind relations. Observational data on solar wind turbulence, its power spectrum, and characteristic scales, obtained by both local measurements from spacecraft and radar sounding experiments, were presented. MHD waves in solar wind plasma and nonlinear processes leading to the formation of quasistationary power spectra of turbulence were considered. Possible reasons for different turbulence regimes in the wind formation region and stationary flux were discussed. The main concepts of the heliosphere interface that arises in the interaction region of the solar wind with the local interstellar medium were formulated and the effect of the captured ions on the thermodynamics of the outer solar wind and mechanisms of suprathermal tail formation in the ion distribution function was discussed.

Lectures given by R R Rafikov were devoted to the sequential consideration of the basics of small Solar System body dynamics. The ever-increasing capabilities of ground-based and space astronomy, as well as spacecraft flights to the outer giant planets, have led to a revolution in our understanding of the orbital architecture and dynamics of the Solar System. During the last decades we have discovered the Kuiper belt, numerous objects between the orbits of Jupiter and Neptune (the so-called centaurs), Trojan satellites of Neptune, and families of small outer satellites of the giant planets. Space missions to the outer planets of the Solar System have allowed us to study in unprecedented detail the complicated dynamic interactions between planetary satellites and their rings. At the same time, the development of analytical methods and numerical simulations have stimulated deeper understanding of the complex dynamic phenomena in small body systems, including resonance structure in the Kuiper belt, chaos in the asteroid belt, and the evolution of the cometary Oort Cloud. Further development of Solar System theory is impossible without a deep understanding of the basics of celestial mechanics and methods of perturbation theory, which were also presented in these lectures.

Seminars accompanying these lectures were used for detailed consideration of the modern theory of the formation of Solar System planets and exoplanets. The state-of-the-art of observations and the theory of protoplanetary disks were presented; both these fields are rapidly developing at present due to great progress in infrared astronomy. Then questions of the formation of Earth-like planets from the planetesimal disk were considered: the kinetic theory of evolution of random velocities of planetesimals, their growth in collisions, different regimes of growth of the protoplanetary cores, the formation of inhomogeneities in planetesimals disks, etc. Finally, the modern theory of giant planet formation, focused on the detailed description of two main models, nuclear instability and gravitational instability, was presented. The results of testing showed a good level of perception and understanding of these problems by participants in the School.

Finally, lectures delivered by L V Ksanfomality were devoted to modern concepts of the origin of planetary systems and the search for life in the Solar System and beyond [2, 3]. Like planets around other stars, Solar System planets represent a complex conglomerate of solids and liquids, neutral gas and plasma, with dust grains accreting from the ambient medium, and high-energy charged particles. The theory of star and planetary disk formation was developed quite long ago, but today, due to advances in theoretical astrophysics and observational astronomy, processes of planetary system formation have become much more clear. In 1995, the discovery of the first extrasolar planet 51 Peg b opened a new field of physics of extrasolar planets. Researchers obtained new unique experimental material that allowed them to look anew at the accretion processes. The discovery of massive exoplanet migration down to low circumstellar orbits, which was apparently somehow avoided in the Solar System, turned out to be a very important factor for the accretion theory. The radial velocity method has enabled the discovery of many giant exoplanets with masses comparable to that of Jupiter. However, the search for direct analogues of Earth-like planets still remains beyond the current technical feasibility. Important results have been obtained on giant planets unexpectedly found in very low orbits around stars. The Keplerian velocity of the Sun due to the action of the Earth is as small as 0.09 m $s^{-1}$, which is 10–30 times below the best measurements currently available. Nevertheless, the first exoplanets with masses of several times the Earth mass have already been discovered, although in very low orbits. The statistical data concerning the orbital and mass parameters of exoplanets have provided solid tests for new theories being devised.

The completion of five Schools allows us to summarize the first results. Over these years, a total of 150 participants from almost 40 research institutions in Russia and Ukraine have attended the School. Three main groups can be clearly defined. As expected, 12–14 participants have came from leading astronomical institutes in Moscow and St. Petersburg State Universities, as well as from the P N Lebedev Physical Institute and Space Research Institute of the RAS. Five to seven participants have represented Volgograd, Kazan, and Yaroslavl State Universities and the Moscow Institute of Physics and Technology, as well as the Institute of Astronomy (Moscow), Applied Physics Institute (Nizhny Novgorod), A F Ioffe Physical-Technical Institute (St. Petersburg), and the RAS Special Astrophysical Observatory (Nizhny Arkhyz, Karachaevo-Cherkessiya), i.e., from institutes of the RAS carrying out active astronomical research. Another twenty institutes have been represented by 1–2 participants. Each time the participants were different. In particular, there is no one who attended all five or at least four Schools, and only seven participants attended three Schools.

One should specially note the fundamental character of the lecture courses given. In fact, during five schools all the main methods of theoretical physics were presented, including hydrodynamics (magnetohydrodynamics), kinetics and physics of plasmas, general relativity, and atomic and nuclear physics. Thus, in addition to astrophysical applications, participants in the School have had the opportunity to review (and, possibly, for some, to hear for the first time) in detail the basics of theoretical physics. In our opinion, therein lies one more important role of modern astrophysics: having an almost unbounded field of application, it allows other sciences to maintain themselves in an active state. On the other hand, the most recent achievements both in theory and observations were presented. This became possible because all the lecturers not only have long taught at the leading universities, but also are the leading researchers in their fields. In the past, they many times participated in the work of similar schools abroad. But the chance to deliver advanced lecture courses in their native language appeared here for the first time.

Generally, the level of the School has been very high, confirmed by both the high level of education and the high level of participants (the latter can be judged by the fact that all the participants attended all the lectures and asked many questions). The new format of the School, first realized at Pushchino, turned out to be successful. Never before in Russian astrophysical schools had such detailed lecture courses enabling deep understanding been given. And the successful inclusion of seminars in the program of the School raised it to an even higher level. In our opinion, only with the independent work of students can the school pursue its main goal: to learn how to work in a new field. The full financial support of the School, of course, has been of the most importance for its successful work.

On the other hand, the School uncovered some shortcomings in the education of young researchers. It is clear that the level of education of students at MSU, SPbSU, LPI, APP, and Ioffe FTI is traditionally higher than at other universities in Russia. Participants from these institutes (and, it is worth noting, from Volgograd SU) showed the best results after testing. At other universities, the level of education turned out to be worse. In particular, basics of plasma physics and general relativity are among the weak points. And this is not surprising. The number of institutes where these subjects are studied in detail in one-semester courses, to say nothing of two-semester courses, can be counted on one hand. But it is impossible to work successfully in modern astrophysics without the knowledge of the basics of plasma physics and general relativity.

The success of the first five Schools gives us hope that they can be continued in the future. The scope of the School must change continuously by encompassing new fields of astrophysics and hence attracting new participants. In particular, after the Schools devoted to star formation (2006), compact objects (2007) [4], radiation processes (2008), and the physics of the Sun and Solar System (2009), dedicated schools on nuclear and plasma astrophysics, cosmology, and numerical methods in astronomy are planned. It is also important to stress that lecture courses given at these Schools have already stimulated the writing of new fundamental textbooks [5–9]. Information on the School is available through the Internet at http://www.prao.psn.ru/conf/School_2009/ann1.html.

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