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PERSONALIA

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In memory of Nikolai Semenovich Kardashev

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The distinguished radio astronomer Nikolai Semenovich Kardashev passed away on August 3, 2019 in Moscow.

In the first decade after the Second World War, radio astronomy soared headlong onto the front line of studying the Universe. This was a complicated process in a far from simple period — even the most successful astronomers, physicists, and engineers could not always keep pace with the rapidly transforming science. But it was much more difficult to take part directly in this development, to say nothing of being a driving force in the creation of this new area of astronomy, all the more one whose verbal description requires a logarithmic scale. Kardashev was precisely one of the key players in the formation of the young radio astronomy science and a "person of truly logarithmic scale."

Kardashev was born on April 25, 1932 in Moscow, where he lived with his parents only to the age of five. In 1937, at the height of Stalin's repressions, his father Semen Karlovich Brike, an employee in the Comintern and Central Committee of the VKP(b) (All-Union Communist Party (bolsheviks)) and the author of several books on economics, was arrested and executed as an 'enemy of the people', and his mother Nina Nikolaevna Kardasheva, a graduate of higher courses for women, was arrested as the wife of an 'enemy of the people' and was sent to a camp for 'family members of traitors of the motherland' and then exiled. Nikolai's younger sister died in the camp. Nikolai was dispatched to an orphanage, but his aunt, his mother's sister, managed to take him from there. Nikolai met his mother again only in 1954 after 17 years of separation when she was still in Murom in exile.

From his early years, Kardashev was greatly interested in the natural sciences, especially in astronomy. He said that he first visited a planetarium at the age of six. It was a lecture about Giordano Bruno. When he was 12, he began attending a group of young astronomers at the Moscow Planetarium. Through all of his life, he remained committed to astronomy.

In 1955, Kardashev graduated from the Astronomy Department of Mekhmat (Faculty of Mechanics and Mathematics) at Moscow State University (MSU). His student years coincided with the period of rapid transformation of astronomy into a science encompassing all wavelengths. In the USSR, this new nontraditional astronomy was focused on radio waves and attracted the young energetic astrophysicist Iosif Samuilovich Shklovsky, who became one of the world leaders in radio astronomy. The Mekhmat class at MSU attended by Kardashev was the first class where Shklovsky delivered lectures on radio astronomy. Kardashev was fascinated by the beauty of this new science and no less by Shklovsky's charisma and enthusiasm. During the following 30 years, until Shklovsky's death in 1985, the teacher and his student remained colleagues and close friends. In an interview that Kardashev gave already in the 21st century, he said that the most amazing event in his life was that he managed to study at MSU in the 1950s in spite of his familial 'initial conditions'.

Nikolai Semenovich Kardashev
(25.04.1932 – 03.08.2019)

In 1963, with Shklovsky as his advisor, Kardashev defended his candidate (PhD) thesis consisting of several topics. In one of them, he discussed the evolution of cosmic radio source spectra and demonstrated that the shape of the synchrotron radiation spectrum can be used to estimate the radio-source age. During the following several decades, Kardashev's analysis was the basis for theoretical studies of radio sources. In another section of the thesis, based on his paper published in 1959, Kardashev analyzed the phenomenon of recombination radio lines in detail. Their existence was confirmed by observations in the USSR and USA only several years later, in 1964–1966. In 1988, Kardashev together with colleagues from the Lebedev Physical Institute (FIAN) in Moscow, Pulkovo Observatory in Leningrad, and the Kharkov Institute of Radio Astronomy was awarded the USSR State Prize for the discovery of recombination radio lines.

In 1965, Kardashev's brilliant candidate thesis was accepted as a doctoral thesis as an exception according to a decision of the Academic Council of the Sternberg Astronomical Institute (GAISh) made at a meeting in 1963.

At approximately the same time, Kardashev published a paper where he described the behavior of the magnetic field of a collapsing star leading to the formation of a neutron star with a magnetic field up to 10^{12} G. The pulsars in fact

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predicted in this paper, albeit with a different magnetic field structure, were discovered several years later.

In the 1950s–1960s, in spite of numerous achievements, radio astronomy suffered from low angular resolution compared to traditional optical astronomy. However, in 1967, with the introduction of the method of very-long-baseline interferometry (VLBI) to radio astronomy, a considerable increase in angular resolution was achieved, which ultimately exceeded the sharpness of view of optical astronomy by three orders of magnitude. Although the first observations using VLBI in 1967 were performed in Canada and the USA, the idea of replacing ordinary signal transmission lines with the transport of signals recorded on an intermediate magnetic tape and the use of independent reference signal generators (frequency standards) was first described two years before, in 1965, in a paper by three authors: Leonid Matveenko, Nikolai Kardashev, and Gennadii Sholomitsky.

Beginning in the 1960s, Kardashev, together with Shklovsky and other Soviet scientists, initiated a new area of science: the search for extraterrestrial life and its intelligent forms. The first edition of Shklovsky's book, *Vselennaya, Zhizn', Razum* (*Universe, Life, and Intelligence*) published in 1962, marked the beginning of active theoretical and experimental SETI (Search for Extra Terrestrial Intelligence) research. Kardashev actively joined his teacher in scientific studies in this field. In his classical study of 1964, Kardashev gave a classification of civilizations based on the level of their energy consumption spanning 20 orders of magnitude. Since that time, it has been universally referred to as the 'Kardashev scale'.

In the first half of the 1960s, Kardashev initiated investigations of celestial radio sources of different spectral types with the use of the Deep Space Communication Center, quite modern and well equipped at that time, not far from Yevpatoria in the Crimea. In 1965, Sholomitsky, who was the head of the observation group in Yevpatoria, reported the discovery of a surprisingly rapid change in the radio emission intensity of the celestial object CTA 102. This discovery generated a whole wave of reports in the world mass media saying that the detected signals had come from extraterrestrials. However, both Kardashev and Shklovsky remained cautious as to such an extreme interpretation of the signal (CTA 02 is now known as a quasar). They considered this discovery to be an important motivation for the further development of methods of radio astronomical observations with a high spatial and temporal resolution.

On graduating from MSU in 1955, Kardashev began working at GAISh (which was part of MSU) in the department headed by Shklovsky. In 1967, Shklovsky was invited to be head of the Department of Astrophysics in the newly founded Space Research Institute (IKI) of the USSR Academy of Sciences. Kardashev, together with other former students of Shklovsky, went to work at IKI, where he first headed the Laboratory of Cosmic Radio Astronomy and then, starting from 1977, held the post of deputy director.

During almost a quarter of a century of work at IKI, Kardashev initiated several space radio astronomical projects, from the Relikt project, which was the first observatory studying the cosmic microwave background and operating in orbit in 1983–1984, to the futuristic 'infinitely expandable space radio telescope'. In 1979, Kardashev headed the radio astronomical part of the experimental program of the space radio telescope KRT-10 deployed aboard the Soviet durable orbital station Salyut-6. For this experiment, Kardashev, among the group of scientists and engineers, received his first USSR State Prize.

The KRT-10 experiment helped prepare the next steps in the development of space radio astronomy tools, in particular, Earth–space VLBI systems. In 1978, before the completion of the KRT-10 project, Kardashev began to devise an idea that ultimately was transformed into a grandiose project of an Earth–space radio interferometer, RadioAstron, carried out with the spacecraft Spektr-R. It was launched into a geocentric orbit in July of 2011 and completed the observational program in 2019. Owing to its high-elliptical orbit with an apogee almost equal to the distance to the Moon, RadioAstron could reach a record high angular resolution in the studies of galactic and extragalactic radio sources. Realization of this project was drawn out for over 30 years because of disintegration of the USSR and the difficult economic and social conditions surrounding the change from the socialist 'planned' economy of the USSR to the market economy of contemporary Russia. Owing to the persistence of Kardashev and his team and their dedication to the goal, the RadioAstron project continued developing in this hard period and ultimately was successfully implemented. RadioAstron, which united practically all radio astronomers and all radio observatories around the world, became one of the key projects of modern world observational astrophysics.

In the 1990s, the Department of Astrophysics of the Space Research Institute became part of FIAN. Kardashev became director of the newly founded Astro Space Center (ASC) of FIAN. The ASC was the leading organization in the RadioAstron project and took the lead in several other projects in observational astrophysics.

Kardashev was famous for his surprising ability to make breathtaking and at the same time strictly sound scientific predictions in both theoretical and experimental astrophysics. As an example, we can mention a 1995 paper about a space supercollider and an estimate of the maximum particle energy in the interaction with a black hole. According to Kardashev's calculation, this energy, which can be referred to as the 'Kardashev limit', is only an order of magnitude lower than the Planck energy. In more recent years, Kardashev and I D Novikov seriously studied the theory of wormholes and their possible manifestations in observations. Their last paper on this subject, which is published in this issue of *Physics–Uspekhi*, is devoted to the possible existence of wormholes with nearby entry and exit.

During more than the 10 last years of his life, Kardashev persistently fostered the design of the space radio telescope Millimetron for studies in the millimeter and submillimeter wavelength ranges. The team of scientists and engineers formed by Kardashev at the ASC continues working on realizing the project. Many of Kardashev's ideas are to be realized in the nearest decades, embodying his scientific foresight.

Kardashev was a corresponding member (starting from 1976) and a full member (starting from 1994) of the Russian Academy of Sciences (RAS). He held the post of chair of the RAS Committee on Astronomy (from 1999 to his last days) and vice president of the International Committee on Space Research (COSPAR, 1982–1986) and the International Astronomical Union (IAU, 1997–2003). In 2012, he was awarded the Grote Reber Gold Medal for his innovative contribution to radio astronomy, and in 2014 received the

Demidov Prize. Kardashev worked on numerous national and international committees and commissions, where he always demonstrated dignity and dedication to science. But in spite of all his posts and obligations, he remained first of all the schoolboy Nikolai fascinated by astronomy, a scientist with a true passion for science, and a man of quiet kindness and absolute decency.

One day, in the context of SETI, Kardashev proclaimed his credo: "The concepts of morality and kindness are universal like the Pythagorean theorem. Civilizations do not survive if they do not follow these concepts." We still do not know whether any extraterrestrial civilization exists. But we know for certain that Nikolai Semenovich Kardashev, a man who vividly exemplified this simple principle, lived among us.

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