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PERSONALIA

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Rashid Alievich Sunyaev (on his 80th birthday)

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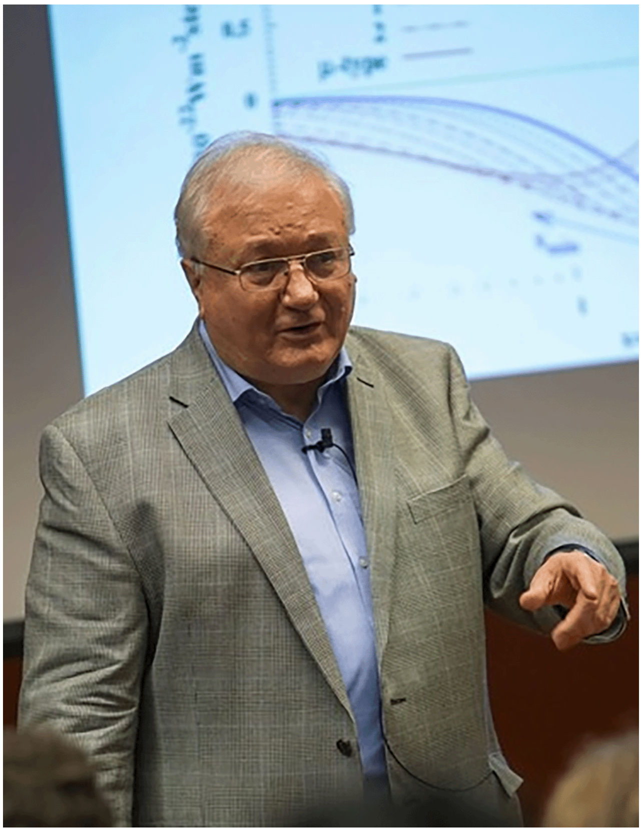
March 1, 2023 was the 80th birthday of one of the leaders of world astrophysics, academician of the Russian Academy of Sciences (RAS) Rashid Alievich Sunyaev. Sunyaev's research covers a wide range of astrophysical problems, from the physics of elementary processes in astrophysical objects to physical cosmology and high-energy astrophysics. A number of fundamental results, now included in textbooks and university courses in theoretical astrophysics and cosmology all over the world, are associated with his name. Among them are Sunyaev–Zel'dovich thermal and kinematic effects, 'acoustic peaks' in the power spectrum of angular fluctuations of relic radiation and 'baryon acoustic oscillations,' the Sunyaev–Titarchuk formula of the comptonization spectrum, and the standard Shakura–Sunyaev accretion disk theory.

The theoretical predictions made by Ya B Zel'dovich and R A Sunyaev in the 1970s–1980s laid the foundation of the modern observational cosmology of relic radiation and fostered its transformation to exact science.

The WMAP and Planck cosmological satellites were launched and unique submillimeter telescopes were constructed at Earth's South Pole and in the high-mountain Atacama desert in Chili to measure the power spectrum of angular fluctuations of cosmic microwave background brightness and to search for 'acoustic peaks' and to discover new clusters of galaxies through the Sunyaev–Zel'dovich effect (SZ effect). The sensitivity bands of the high-frequency HFI instrument on the Planck satellite were chosen so as to optimize the search for clusters of galaxies through the SZ effect. Baryonic acoustic oscillations are detected in the spatial distribution of galaxies in wide-angle (thousand square degrees in area) sky surveys in the optical band, such as the Sloan digital sky survey.

From a beautiful theoretical idea, which was far beyond the sensitivity of radio telescopes threshold in the late 20th century, the Sunyaev–Zel'dovich effect became one of the most productive methods of observational cosmology in the 21st century, opening the possibility for determining the main cosmological parameters, establishing the role of 'dark energy' in the Universe and the direct measuring of the Hubble constant. Thomson scatterings of microwave background photons by hot electrons of intergalactic gas in clusters of galaxies lead to specific distortions in the cosmic microwave background spectrum — for an observer in the centimeter and millimeter wavelength ranges, the clusters are 'negative sources,' casting their 'shadow' on the map of the microwave background. With the help of the SZ effect, the Planck satellite, the South Pole Telescope, and the Atacama cosmology telescope detected over 7000 galactic clusters, the farthest being located at redshift $z = 1.75$. Owing to the fact that the brightness and the spectrum of the SZ effect do not depend on the redshift, microwave observations are effective in the search for the most distant clusters of galaxies — over one thousand of them are already known at redshifts $z > 0.5$. This opens a unique possibility of investigating the growth of the large-scale structure of the Universe in the epoch of 'dark energy' dominance. In the next decades, new submillimeter telescopes are expected to reveal practically all the massive clusters of galaxies in the observable part of the Universe, thus competing with X-ray astronomy.



Rashid Alievich Sunyaev

Observations of cosmic microwave background in the direction of clusters of galaxies also allow measuring peculiar velocities of their motion relative to the microwave background using the kinematic SZ effect. While the thermal effect is caused by the thermal motion of intergalactic gas electrons, the kinematic SZ effect describes the relic radiation spectral distortion caused by the Doppler effect through the peculiar velocity of a cluster of galaxies as a whole. It allows measuring the clusters of galaxies peculiar velocity relative to the local coordinate system, where relic radiation is isotropic.

During the previous decade, the kinematic SZ effect was detected by the Planck satellite, the South Pole Telescope, and the Atacama Cosmology Telescope, both in the stacked signal from several hundred thousand galaxies and in individual clusters of galaxies using the BOLOCAM and NIKA2

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instruments. The low measured peculiar velocities of clusters of galaxies (or the upper limits obtained using the kSZ effect) compared to the Hubble flow velocities for the same objects are a direct experimental confirmation of Copernic principle validity for our Universe up to redshifts $z \sim 1.5$.

In 1970, Sunyaev and Zel'dovich predicted the existence of acoustic peaks in the angular distribution of relic radiation. Along with the SZ effect, this discovery had great influence on the development of modern observational cosmology. The position and relative intensity of the first Doppler peaks are determined by the values of the key parameters of the Universe, namely, the Hubble constant, the baryon density and the density of dark matter and energy in the Universe. In 2000, the first acoustic peaks were detected in balloon experiments, and the WMAP and PLANCK satellites investigated them in detail.

Sunyaev paid great attention to physical processes in the early Universe: kinetics of hydrogen recombination, thermalization of relic radiation, and processes leading to a deviation of its spectrum from the Planck one. Together with Zel'dovich, Sunyaev determined the position of the 'black-body photosphere' of our Universe and the 'last scattering surface' of relic photons. Together with Ya B Zel'dovich and V G Kurt, he calculated the hydrogen recombination kinetics in the early Universe and showed that this process is controlled by two-photon decay of the 2s level. In 2000, these studies were continued jointly with J Chluba, R Khatri, and others using computational capabilities of modern computers.

The Shakura–Sunyaev theory of accretion disks became conventional in describing matter transport and energy release in accretion disks in close binary systems with black holes or neutron stars, in accretion onto supermassive black holes, and in protoplanetary disks. In 2023, the paper "Black holes in binary systems. Observational appearance" by N I Shakura and R A Sunyaev, the most cited paper in the world of world theoretical astrophysics with over 11,200 citations, will commemorate its 50th anniversary. Accreting neutron stars and black holes in binary stellar systems are observed as powerful X-ray sources. The main mechanism of formation of their X-ray radiation is comptonization of low-frequency photons in the course of multiple Thomson scatterings by high-temperature electrons. The Sunyaev–Titarchuk formula made it possible to describe for the first time the radiation spectra formed via comptonization in hot plasma clouds. In the 1970s–1980s, formulated and solved together with M M Basko, Yu N Gnedin, A F Illarionov, N A Inogamov, Yu E Lubarsky, V M Lyuty, N R Sibgatullin, A M Cherepashchuk, and others were some problems concerning the physics of X-ray binary systems, such as polarization of X-ray radiation of accreting neutron stars, the formation of gyrolines in their spectra, the occurrence of an accretion column and the possibility of super-Eddington luminosity of accreting neutron stars with strong magnetic fields, the 'propeller effect,' the boundary layer (spreading layer) near the surface of a weakly magnetized neutron star, the importance of reflected radiation in X-ray binary stars, and many others. The above-mentioned studies are well-known in the world of astrophysics and have not lost their importance today.

The development of X-ray astronomy in the country and the success of the Soviet and Russian orbital observatories of high-energy astrophysics with the wide participation of foreign scientists — RENTGEN (in the *Mir* space station's Kvant module) and GRANAT are associated with the name of R A Sunyaev. R A Sunyaev carried out scientific leadership in the selection and design of equipment for these observatories, the choice of parameters of their orbits, and determination of their observational programs. He is scientific leader from the Russian Federation (RF) of the current international orbital gamma-ray INTEGRAL observatory and the X-ray SPECTR-RG (SRG) orbital observatory. All four of the above-listed orbital observatories were launched by PROTON rockets from the Baikonur cosmodrome (now Kazakhstan).

The INTEGRAL gamma-ray observatory of the European Space Agency now continues its successful work. Russian scientists receive 25% of the observing time of this observatory for its launch into a high-apogee orbit by Roscosmos. Among its results are spectrum measurements and maps of annihilation radiation of ortho- and parapositronium in a large region around the center of our Galaxy, where over 10^{43} positrons a second annihilate. INTEGRAL discovered the gamma-ray lines of radioactive cobalt-56 decay from the supernova SN2014J, Ia type supernova, the brightest and closest to the Earth in the last 42 years. This was the first experimental confirmation of iron synthesis (0.6 of the solar mass) in the thermonuclear explosion of an accreting white dwarf or two merging white dwarfs.

On July 13, 2019, the SRG observatory was launched onto the orbit around the Lagrangian L2 point of the Sun–Earth system, located at a distance of 1.5 mln km from Earth. The observatory carries two X-ray telescopes: the Russian M Pavlinsky ART-XC, sensitive to X-rays in the range of 4 to 30 keV and the German eRosita, with a sensitivity from 200 eV to 8 keV. S A Lavochkin SPA (scientific and production association) was responsible for the creation of the above-mentioned observatory and its operation in orbit. Both the telescopes are equipped with grazing incidence X-ray mirrors and with excellent position-sensitive X-ray detectors. The scientific leader of the observatory from the Russian Federation is R A Sunyaev. To date, after more than two years of scanning the sky, the SRG/eRosita telescope has constructed the world's best X-ray map of the entire sky; discovered in the entire sky are over two million active nuclei of galaxies and quasars (and these are accreting supermassive black holes of a mass from a million to billions of solar masses), half a million stars with active coronas, and nearly 50 thousand clusters of galaxies (about half of such objects expected in the observable part of our Universe). Teams of astrophysicists in Russia and Germany are working with the data obtained and have already made many interesting discoveries. The ART-XC telescope is now scanning the plane of our Galaxy in X-rays.

Rashid Alievich was born in Tashkent into a family of natives of the Penza province — engineer Ali Sunyaev and pharmacist Saida Kildeeva. According to R A Sunyaev, because of their origin and the family's exile, his father could not get an education in specialties of interest to him, and all his life he was engaged in self-education and was a person of encyclopedic knowledge. A close relation with his father greatly influenced the schoolboy and sparked his interest in books and then the desire to do science. In the spring of 1960, Rashid Sunyaev took first place at the mathematical Olympiad of the four republics of Central Asia (now Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan) and Kazakhstan. The same year, he finished school with a medal and entered the Moscow Institute of Physics and Technology (MIPT). In 1966, he graduated from MIPT with honors. The supervisor of his pre-graduate practice, diploma work, and also postgraduate study at MIPT was one of the greatest Soviet theoretical physicists, thrice Hero of Socialist Labor, academician Ya B Zel'dovich. The meeting with Ya B Zel'dovich in March 1965 was a great stroke of luck for the student Sunyaev. Yakov Borisovich was an excellent scientific advisor. Their close scientific cooperation lasted until Ya B Zel'dovich's death in 1987.

In April 1968, Sunyaev defended his candidate and in 1973 doctoral thesis at the Sternberg State Astronomical Institute under Lomonosov Moscow State University (MSU). Beginning in 1968, Sunyaev worked at the Institute of Applied Mathematics of the USSR Academy of Sciences in the Department of Astrophysics, headed by Ya B Zel'dovich. In the spring of 1974, academician R Z Sagdeev (who became director of the Space Research Institute (SRI) of the USSR Academy of Sciences) invited Ya B Zel'dovich to organize the Department of Theoretical Astrophysics at SRI of the USSR Academy of Sciences. R A Sunyaev was invited to head a sector in the new department. Since June of 1974, he has been working at SRI (over 48 years). In 1982, R A Sunyaev founded and headed the Department of High-Energy Astrophysics at SRI, which has led all the successful Soviet and Russian projects in X-ray astronomy. From September 1995 to March 2018, R A Sunyaev was simultaneously one of the directors of the Max Planck Institute for Astrophysics in Garching, near Munich in Germany.

In 1984, Sunyaev was elected a corresponding member of the USSR Academy of Sciences, and in 1992, a full member of RAS. He is a foreign member of the national academies of the USA, India, and Germany ("Leopoldina"), the London Royal Society, the Royal Academy of Sciences and Arts of the Netherlands, and the European Academy (Academia Europaea), and an honorary member of the Academy of Sciences of the Republic of Tatarstan and several other academies, a foreign member of American astronomical, physical, and philosophic societies, and the Royal Astronomical Society of Great Britain.

R A Sunyaev is twice a laureate of State Prizes of RF, the Aleksandr Friedmann Prize of RAS, Zel'dovich gold medal of RAS, and the gold medal of Tatarstan Academy of Sciences; the Gruber Prize in Cosmology, the Crafoord Prize in astronomy, and the Klein Medal of the Royal Academy of Sciences of Sweden; the Kyoto Prize (Japan) in astronomy, the Heineman and Bruno Rossi Prizes in physics of the American Astronomical Society, the King Faisal Prize in physics, Karl Schwarzschild medals of the German Astronomical Society, the Dirac Prize of the International Center for Theoretical Physics in Trieste, the Benjamin Franklin Prize in physics, the Gold and Eddington medals of the Royal Astronomical Society of Great Britain, the Max Planck Gold Medal (the highest award of the German Physical Society in theoretical physics), the Caterine Bruce Gold Medal of the Pacific Astronomical Society, and the COSPAR Massey and London Royal Society awards. In 2014, he was elected an Einstein professor of the Chinese Academy of Sciences. Asteroid 11759 was named after R A Sunyaev.

According to NASA ADS, R A Sunyaev's papers have been cited over 113,800 times, and the Hirsch index is equal to 129. In 2017, he was included on the list of the twenty-two most cited researchers, composed annually by Clarivate Analytics Company (earlier Thomson Reuters).

Rashid Alievich is a chief researcher of SRI RAS, director emeritus of the Max Planck Institute for Astrophysics, Maureen and John Hendricks Distinguished Visiting Professor in the School of Natural Sciences at the Institute for Advanced Study in Princeton, an honored professor of the Kazan Federal University and the Ludwig Maximilian University of Munich, and an honored member of the Ioffe Institute. R A Sunyaev is Editor-in-Chief of *Pis'ma v Astronomicheskii Zhurnal* (*Astronomy Letters*) and a member of the Advisory board of the journal *Uspekhi Fizicheskikh Nauk* (*Physics–Uspekhi*).

On the day of his 80th birthday, colleagues, friends, and pupils wish him sound health and the continuation of this fascinating journey in the world of astrophysics and cosmology.

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