[https://doi.org/10.69646/bbbs2401]
[Plenary Lecture]

Nobel prizes for physics obtained for astronomical discoveries in XXI century

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Abstract: Nobel prizes for physics in 2002, 2006, 2011, 2013, 2015, 2017. and 2019, obtained for astronomically important discoveries are discussed.

Keywords: Nobel prizes, astronomy, physics

The Nobel Prize in Physics is the most prestigious international prize in this scientific discipline, which is awarded annually by the Swedish Royal Academy of Sciences, as a sign of recognition for great scientific achievements. It was established by the Swedish scientist and inventor Alfred Nobel in 1895, and was awarded for the first time in 1901. The award ceremony is held in Stockholm on December 10, the day of Nobel's death.

Nobel did not provide a prize for astronomers, but a large number of astronomical discoveries were awarded in the field of physics. A series of such awards in the XXI century began in 2002, when one half was awarded to Riccardo Giacconi (1931-2018), the father of X-ray astronomy, and the other was shared by Raymond Davis (1914-2006) and Masatoshi Koshiba (1926-2020), the father of neutrino astronomy.

Herbert Friedman was the first, in 1949, to register extraterrestrial X radiation from the solar corona using instruments on the V2 rocket, and on June 18, 1962, using an Aerobee rocket that flew for 6 minutes, Giacconi discovered the first cosmic X-ray source, X-1 in Scorpio, in the center of our galaxy, and the uniform X radiation of the sky background. Giaconi also initiated the first satellite dedicated to X - astronomy, Uhuru, launched on December 12, 1970, which increased the number of known cosmic sources of X radiation from 40 to 400. He also constructed the first X-ray telescope, launched on July 23, 1999 on the cosmic X observatory *Chandra*. Giacconi's work and his discoveries led to the birth of X-ray astronomy.

Bruno Pontecorvo proposed that high-energy neutrinos from space be hunted based on their reaction with the chlorine atom, which produces an electron and a radioactive isotope of argon. Davis tried that in the early 60s, placing a tank with 615 tons of tetrachlorethylene in an abandoned mine, where 20 argon atoms were supposed to be formed in a month. Hunting for them was considered impossible by many, saying that it is like trying to find twenty specific grains of sand in the Sahara. By 1994, Davis separated about 2,000 argon atoms created by the reaction with neutrinos from the solar core, which was the first detection of cosmic neutrinos, which marked the birth of neutrino astronomy. That was only a third of the number predicted by theory. This is how the puzzle of solar neutrinos arose, which has occupied astronomers for years.

Masatoshi Koshiba constructed a much larger neutrino detector or neutrino telescope and named it *Kamiokande*. It was a huge tank filled with water in which the rare reaction of neutrinos with the nuclei of atoms released electrons and photons, surrounded by photomultipliers that registered them. Unlike Davis's device, *Kamiokande* was able to register both the time and direction of neutrino arrival. With it, Koshiba in 1987, out of a flood of 10^{16} neutrinos from the supernova of that year, managed to capture twelve. Koshiba and Davis received the Nobel Prize in 2002 for the detection of cosmic neutrinos.

The Nobel Prize crowned the astronomical discovery and in 2006. It was obtained by John C. Mather (1946) and George Smoot (1945), who discovered in the background radiation irregularities important for the formation of the first galaxies and that it is the same as black body radiation. Background radiation, which comes from the background of the entire sky, was predicted by George Gamow in the 1940s as a consequence of the cooling of the universe, which occurred when the temperature dropped to the limit when radiation and matter separated and the first light shone through the previously opaque cosmos. The rest of it, background radiation, was discovered by Arno Penzias and Robert Wilson in 1964, and for that they received the Nobel Prize in 1978. Mather and Smoot made their discovery using the COBE (Cosmic Background Explorer) satellite, launched in 1989 specifically for background radiation research. After such measurements and research, cosmology became a precise science with clear results confirming the Big bang theory.

In 2011, Saul Perlmutter (1959), Brian Schmidt (1967) and Adam Riess (1969) received the Nobel Prize for one of the greatest astronomical discoveries of the late twentieth century, which fundamentally shook the cosmology of the time. Two groups of scientists, who observed very distant supernovae, established in 1989 that about five billion years ago the expansion of the cosmos began to accelerate. This led to the concept of dark energy, responsible for this process and significantly changed views on the ultimate fate of the universe.

Two years later, in 2013, François Englert (1932) and Peter Higgs (1929-2024) were awarded, who, independently of each other, theoretically explained how subatomic particles acquire mass. The prize-winning theory is a central part of the Standard

Model of particle physics, which explains what the universe is made of, so that it also indirectly applies to astronomy.

Higgs and Englert included in the theory a field that permeates the entire cosmos and is now called the Higgs field. In interaction with it, fundamental particles, and consequently the matter built from them, gain mass, without which we and the universe as we know it could not exist. The mediator or messenger of this field is the Higgs boson. In 2012, using the Large Collider at CERN, this particle was discovered, which confirmed their theory, which was awarded the Nobel Prize the very next year, in 2013.

The astronomical discovery was also awarded the Nobel Prize in 2015. The topic was again neutrino astronomy, and the laureates were Kajita Takaaki (1959) and Arthur McDonald (1943), who, continuing the work of Koshiba and Davis, successfully solved the puzzle of the small number of solar neutrinos. After *Kamiokande*, Koshiba built an even more perfect neutrino telescope, the *Superkamiokande*, on which Takaaki worked. There are three types of neutrinos: electron, muon and tau. Using Koshiba's *Superkamiokande*, Takaaki discovered neutrino oscillations during which one species transforms into another. This is only possible if they have mass. In the interior of the Sun, electron neutrinos are produced, which were measured by Davis and Koshiba. Unlike *Supercamiocande,* which could only capture electron neutrinos, the new neutrino telescope in Canada was able to register all three types, and a team led by Arthur MacDonald showed that as many electron neutrinos were being produced in the Sun as predicted, but that two-thirds are transformed into muons and tau on the way to Earth, thus solving the puzzle of solar neutrinos.

The 2017 Nobel Prize in Physics was awarded to Rainer Weiss (1932), Barry Barish (1936) and Kip Thorne (1940) for observing gravitational waves. For this purpose, two devices were constructed in the USA as part of the LIGO project, in Hanford, Washington, and in Livingston, Louisiana. A similar device was made in Italy as part of the VIRGO project. It is interesting that two sure candidates for this Nobel Prize, Ronald Drever (1931-2017), co-founder of the LIGO project and Adalberto Giazotto (1940-2017), the father of the VIRGO device, passed away a few months before the selection of the laureate.

The story of the discovery of gravitational waves begins in the eighties of the XIX century when Maxwell described electrical and magnetic phenomena with a unique theory that required electromagnetic waves to propagate in a vacuum with a constant speed *c*. But in classical, Newtonian physics, this is possible only in one coordinate system that is at absolute rest. It was assumed that it is connected to something that fills the entire universe and is called ether.

In order to try to measure the absolute speed of the Earth relative to the assumed ether, Albert Michelson (1852-1931) built the interferometer that bears his name today. Michelson failed to establish any change in the speed of light due to possible motion relative to the ether, which was surprising at the time. The explanation of the results of this experiment was only brought by Albert Einstein and his theory of relativity. For his measurements of the speed of light, and especially for the mentioned experiment and the interferometer, Michelson received the Nobel Prize in 1907.

The two LIGO devices and VIRGO are actually Michelson interferometers but of grandiose proportions and with enormous precision, which made it possible to measure the vibrations of space due to gravitational waves. To make sure that the oscillations are due to these waves, the results obtained on the three devices were compared. The strongest gravitational waves, whose existence was predicted by Albert Einstein a hundred years earlier, are produced by collisions of black holes.

As they begin to approach, they spin faster and faster around their common center of mass until they collide. At the same time, they radiate such waves that deform space-time.

And finally, on September 14, 2015, the LIGO detectors discovered the vibrations of space due to the gravitational waves created by the collision of two black holes of 29 and 36 solar masses, which created a black hole that had 62 solar masses and three solar masses turned into energy of gravitational waves. Thus began the era of gravitational astronomy, which was crowned with the Nobel Prize in 2017.

And 2019 brought another Nobel Prize in physics to astronomers. One half was awarded to James Peebles (1935), for several theoretical results that turned cosmology into a precisely theoretically based scientific discipline, which theoretically and observationally illuminated the history of the universe. Back in 1965, he explained the characteristics of background radiation that behaves like blackbody radiation and predicted that its irregularities are a critical factor in the formation of galaxies. This was confirmed by the analysis of observational data from the *Cobe* satellite, for which John Muther and George Smoot received the 2006 Nobel Prize. In 1970, he calculated and predicted the acoustic oscillations that can be measured and were created together with the irregularities in the background radiation. The *Planck* Space Observatory, which operated from 2009 to 2013, confirmed Peebles' results.

Apart from all this, Peebles showed in 1973 that the halo around our galaxy must have a large amount of non-relativistic cold dark matter for the flat disk to be stable, and in 1984 he returned the so-called cosmological constant, which today actually represents the proportion of dark energy.

The other half of the prize is shared by Swiss astronomers Didier Queloz (1966) and Michel Mayor (1942), who in autumn 1994 discovered the first planet outside the solar system, orbiting around an ordinary star in the constellation Pegasus (51 Pegasi). They published their discovery in 1995, and it triggered an avalanche of new discoveries, so as of August 8, 2024, we have 5743 confirmed planets in 4286 systems of which 961 have more than one. In addition to the planets around the stars, there are also wandering, rogue planets. To date, extrasolar planets have seen rings, in 2013 the first candidate for a planet's satellite was observed, in 2001 the first exoplanet with an atmosphere was observed, some have tails, like comets, and also, volcanic eruptions have been observed.

An overview of the Nobel prizes for astronomical discoveries, awarded in the XXI century, demonstrates a very extensive, revolutionary and explosive progress of this science, which has greatly changed our view on the development and ultimate fate of the universe and revealed many of its secrets, which helped us to better understand the world around us, its history and our place in it.