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1. Direct registration of gravitational waves

Gravitational waves from the merger of two black holes have been registered directly for the first time by the gravitational wave detector LIGO. Gravitational waves were theoretically predicted by Albert Einstein in 1916, but their existence up to now has been revealed only indirectly by a change in the orbit of binary pulsar PSR B1913 + 16. The first direct registration took place on 14 September 2015 by two independent laser interferometers located in USA at a distance of 3 thousand kilometers from each other. The signal, designated as GW150914, was registered by two detectors with a time lag of 7 ms caused by gravitational wave propagation at the speed of light. With allowance made for this time shift and different orientations of the detectors, the signal shape at the two detectors coincides up to an accuracy of measuring noises. The principle outline of the interferential experiment for gravitational wave detection realized in LIGO detectors was proposed by M E Gertsenstein and V I Pustovoit in 1962, and a fundamental contribution to the development of the method of registering superweak signals was made by V B Braginskii, K Thorne, and their colleagues [see, e.g., the reviews in *Sov. Phys. Usp.* **8** 513 (1966), *Phys. Usp.* **43** 691 (2000), *Phys. Usp.* **44** 1 (2001)]. The detectors are modified Michelson interferometers with 4-km arms thoroughly isolated from seismic and other noises. A gravitational wave changes the arm length, thus causing a phase shift of the laser signals propagating along them, which results in a shift of the observed interference pattern. The sensitivity of LIGO interferometers makes noticeable the extension of their arms by a mere 10^{-17} cm. The GW150914 signal frequency during the observation time (~ 0.2 s) increased from 35 to 250 Hz and had a peak amplitude $h = 1.0 \times 10^{-21}$. The shape of GW150914 corresponds exactly to the prediction of General Relativity for the last stage before the merging of two black holes rotating around each other along the orbit and for the signal from damping oscillations of the rotating black hole formed after merging. It was revealed that black holes with masses of $36M_{\odot}$ and $29M_{\odot}$ had merged at a distance of 410^{+160}_{-180} Mpc from Earth. In these observations, the signal-to-noise ratio reached 24 and the statistical significance of signal registration made up 5.1σ. Thus, the existence of binary systems that consist of black holes with nearly maximum masses was demonstrated, which might have occurred in explosions of supernovae collapsing in the course of standard star evolution. It cannot be ruled out, however, that the black holes were born as a result of collapses of massive pregalactic stars or the merging of smaller-mass black holes in dense star clusters. As a concomitant result, the restriction was obtained on the graviton mass $m_{\rm g} < 1.2 \times 10^{-22}$ eV. This restriction is, however, smaller than that obtained earlier from the dynamics of galactic clusters and weak lensing. Localization of GW150914 in the sky according to the LIGO data had the shape of a band 600 square degrees in area. A weak gamma-ray burst from that band was registered by the Fermi gamma-ray burst monitor (GRM) in a cosmic observatory 0.4 s after emerging GW150914 signal. No ground-based or astrophysical sources of the burst have been observed. It is not yet clear how a gamma-ray signal could be generated upon the merging of two black holes if it was not an accidental projection. The observation of GW150914 opens the era of gravitational-wave astronomy and will make it possible to verify modifications to General Relativity in the future. Russian researchers from MSU and the Institute of Applied Physics, RAS (Nizhny Novgorod) participate in the LIGO Collaboration.

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2. Tetraneutron

The possibility of the existence of stable or short-lived bound states of four neutrons — tetraneutrons (4n) — has long been studied both theoretically and experimentally, but it is only in one experiment (F M Marques et al. 2002) that the 4n bound state was observed in the reaction $^{14}\mathrm{Be} \rightarrow {}^{10}\mathrm{Be} + 4\mathrm{n}$. However, this result has not been confirmed in subsequent studies. K Kisamori (University of Tokyo and the Institute of Physical and Chemical Research, RIKEN, Japan) and colleagues have carried out a new experiment and possibly registered the birth of the 4n resonant state in the reaction $^{4}\mathrm{He}(^{8}\mathrm{He}, {}^{8}\mathrm{Be})$. The ^{8}He ion beam was produced in the interaction of an ^{18}O beam with a beryllium target, after which the beam collided in turn with a liquid-helium target. ^{8}He and the final reaction products, namely, two alpha particles into which ^{8}Be decayed, were registered by the coincidence method. The 4n systems were not registered directly but were revealed on the basis of conservation laws. The discovered maximum in the spectrum of the reaction products is likely to correspond to the 4n resonant state, although the stable state cannot be ruled out, as well. Four 4n production events were registered and the statistical significance of the result was estimated to be at the level of 4.9σ. The results of the experiment are consistent with the data reported by F M Marques et al., but independent experiments are needed for their verification.

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3. Quantum-limited long-distance heat conduction

Quantum mechanics sets a fundamental limit (quantum of heat conduction) on the maximum heat flux that can be transferred through one channel. In previous experiments, heat near the quantum limit could only be transferred through small distances of less than 100 μm. M Mottonen (Aalto University, Finland) and his colleagues were the first to demonstrate heat transfer with a flux approaching the quantum limit through macroscopic distances up to 1 meter. Photons of microwave radiation transferred through a superconducting volute waveguide were used as heat carriers. Photons are electrically neutral, and therefore their interaction with the surrounding substance is weaker, which reduces the loss compared to electrons. Superconducting tunnel contacts were used as sensitive thermometers. The results of the experiment agree well with theoretical predictions and can be applied to cool elements in nanoelectronics.

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4. RadioAstron observations with an angular resolution of 21 μs as

The first results of interferometric observations with a very long base (VLBI), which were performed using the 10-meter space radio telescope RadioAstron and a ground array of 15 radio telescopes. RadioAstron, aboard the Russian Spektr-R satellite, makes up a base 7.9 Earth's diameters long, which allowed observations with the now record angular resolution of 21 microarcseconds (μas). The jet structure was observed in BL Lacertae — an active-nucleus galaxy which provided the name for the whole class of galaxies — blazars. At distances of 40, 100, and 250 μas from the jet base, nodes can be seen that could be due to shock waves. Two polarized radiation components are observed at a distance of 0.5 milliarcsecond from the nucleus. A gradient in the measurement of Faraday rotation was revealed in ground-based space observations at different frequencies. This indicates the presence of a spiral magnetic field in the jet. It was concluded that the magnetic field and the radiating particles show no energy equipartition, because the brightness temperature in the nucleus exceeds 3×10^{12} K. The RadioAstron project is implemented by research workers at the Astro Space Center of the P N Lebedev Physical Institute (ASC LPI) in collaboration with Russian and foreign colleagues.

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