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# Physics news on the Internet: December 2024

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## 1. t-quark production in heavy ion collisions

In the early Universe, high-temperature quarks and gluons were free (were in the state of deconfinement) and formed quark–gluon plasma. These conditions can already be partially reproduced with accelerators. The ATLAS collaboration has presented new data on $\bar{t}t$-quark pair production in lead ion Pb + Pb collisions at the Large Hadron Collider with a center-of-mass energy of 5 TeV [1]. In the experiment, quark–gluon plasma has a very short lifetime ($\sim 10^{-23}$ s), and therefore it is examined through registration of particles born in plasma and flying out. Selected were events of t-quark decay into b-quarks in a low-background dilepton channel — together with electrons and muons. The selection criterion was also the presence of two jets. As a result, t-quark production in the quark–gluon plasma was registered with $5\sigma$ significance, $\sigma_{t\bar{t}} = 3.6^{+1.0}_{-0.9}(\text{stat.})^{+0.8}_{-0.5}(\text{syst.})$ μb, and their measured production cross section was consistent with the results of theoretical calculations. This study shows, that in the early Universe, the quark–gluon plasma contained all types of quarks. In Russia, the accelerator complex NICA (Nuclotron-based Ion Collider fAcility) has begun operating at JINR (Dubna), where collisions of heavy ions with protons and fixed targets will be actualized to examine the properties of dense baryon matter.

## 2. Shadow of a light beam

A common belief is that it is only objects consisting of atoms that can cast a shadow. R A Abrahao (University of Ottawa, Canada and Brookhaven National Laboratory, USA) and his co-authors have become the first to demonstrate the occurrence of a shadow when two light beams intersect inside a ruby crystal $Al_2O_3$:Cr [2]. A green laser beam with a wavelength of 532 nm was an object, while a blue beam with a wavelength of 450 nm crossed it, and a silhouette of the green beam was seen on the screen in the blue beam with a contrast of 22%. This effect is explained by the nonlinear process of inverse absorption saturation. In most substances, transparency increases ('antishadow' might occur) under laser radiation, while in ruby it, on the contrary, decreases. This occurs due to the interaction of two quantum levels by means of phonons. Rapid transitions between these levels, which can be called the decay of the upper level, lead to absorption of blue light photons. Although photon interaction through a nonlinear medium has already been observed, the new experiment demonstrated for the first time all the main attributes of the shadow. For instance, the shadow follows the shape of an object and can be seen by the naked eye.

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## 3. Test of General Theory of Relativity (GTR)

Observations with the help of the RadioAstron space telescope, operating in the very long base interferometer mode, have yielded many important scientific results [3]. But, in addition to radioastronomy, the communication signals of RadioAstron, which it exchanged with Earth, provided an opportunity to verify the general relativistic effect of gravitational redshift under new conditions. The satellite moved along an elliptic orbit, reaching a distance of 350 thousand km from Earth at its apogee. The difference in gravitational potentials $U$ led to a difference in the speed of the atomic clock on the satellite and at the ground-based tracking station. In the previous Gravity-Probe A experiment, the hydrogen time standard was raised on a rocket to a height of $10^4$ km, and the accuracy of measuring the gravitational redshift reached $\approx 1.4 \times 10^{-4}$, while the accuracy with the Galileo satellites was $\sim 3 \times 10^{-5}$. V N Rudenko (Sternberg Astronomical Institute of Moscow State University) and his colleagues from several Russian organizations could achieve in the RadioAstron experiment an accuracy $\varepsilon = (1.57 \pm 3.96) \times 10^{-5}$, with the parameter $\varepsilon$ characterizing the deviation from the GTR predictions in the form $\Delta f/f = (1+\varepsilon)\Delta U/c^2$, where $c$ is the speed of light [4]. The measurement technique was used with the first-order Doppler effect compensation with a change in the synchronization modes (switching over between single- and double-path modes). Also solved was a complex problem of allowing for other effects causing a frequency shift, such as tidal potentials of the Moon and the Sun, the influence of Earth's nonsphericity, the atmospheric shift (including the ionosphere and troposphere), flicker noise, and the effect of detuning of two standard frequencies. The obtained value $\varepsilon = (1.57 \pm 3.96) \times 10^{-5}$ agrees with the zero value predicted by GTR. This result is also quite consistent with the Galileo measurements. However, the positional invariance of the gravitational redshift effect was verified at RadioAstron on a much larger scale (350 thousand km) compared to the Galileo measurements ($\approx 20$ thousand km), which makes the described result a new important achievement. For other interesting possibilities of experimental GTR verification, see [5].

## 4. Early formation of galaxies

James Webb Space Telescope observations have shown that galaxies in the early Universe were formed earlier in a larger number than predicted by the standard cosmological ΛCDM model, and this divergency has not yet been reliably explained. Part of this problem is the presence of already formed large galaxies at large redshifts. M Xiao (University of Geneva, Switzerland) et al. have obtained a spectroscopic confirmation for three more such galaxies at redshifts $z \sim 5-6$ [6]. The baryon matter in them must have been converted to stars two to three times more efficiently than in typical galaxies at smaller $z$. Their stellar mass makes up approximately $10^{11} M_{\odot}$, that is, 50% of all baryons must have been converted to stars, which can hardly be explained in currently available models. S S McGaugh (Case–Western–Reserve University, USA) and their co-authors performed a new analysis of the available observational data and the results of several numerical simulations. They have concluded that it is quite probable that the mechanism of formation of at least part of the galaxies is not in a hierarchic manner (as a result of coalescence of smaller galaxies or protogalaxies), but by the so-called monolithic mechanism, when a galaxy with stars is formed already at the early epoch and remains unchanged till later times [7]. According to the authors of paper [7], such galaxy formation is possible in the modified gravitation theory MOND. Although MOND cannot yet explain the whole array of observational data concerning dark matter, in this case it predicts the early galaxy formation by the monolithic mechanism. Models with a nonstandard perturbation spectrum and those with primordial black holes were also proposed for solving the problem of early galaxy formation.

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