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1. Extension of the Standard Model

In spite of an intensive search, no deviations from the predictions of the Standard Model of elementary particles have yet been reliably revealed. However, a number of phenomena cannot be explained in the framework of this theory, e.g., the existence of dark matter. G Ballesteros (University of Paris-Saclay, France) and his colleagues have proposed a simple minimal extension of the Standard Model, called SMASH, that can resolve simultaneously a number of problems in elementary particle physics and cosmology. Some elements of this extension had already been developed by M E Shaposhnikov, I I Tkachev, F L Bezrukov, and other researchers, and G Ballesteros with colleagues unified all these elements into a self-consistent model. The proposed extension adds to the particles of the Standard Model three right-handed neutrinos, two Weyl fermions, and a scalar field σ which breaks the Peccei–Quinn symmetry, and its vacuum expectation value at $\sim 10^{11}$ GeV is a new energy scale of the theory. This model reproduces inflation cosmology and baryogenesis in the early Universe. At low energies, the new model reduces to the Standard Model augmented by the seesaw mechanism of neutrino mass generation and by axions with masses ranging 50–200 μeV. Axions with small momenta can be dark matter particles, and they can be sought in experiments on direct registration. The cosmic background of relativistic axions increases the effective number of the degrees of freedom by $\Delta N_{\nu}^{\mathrm{eff}} \approx 0.03$, and this prediction can also be verified by measurements of relic radiation polarization. At high energies, the new theory is valid up to the Planck energy scale. At the same time, the SMASH theory does not give a solution to the hierarchy problem and does not explain the emergence of dark energy in the Universe.

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2. Bell test with star light

Bell inequality violation has been demonstrated in a variety of experiments, which confirms the absence of 'hidden parameters' in quantum mechanics. Particularly, for the choice of the measurement method, conventional quantum random number generators were utilized under conditions where the choice and the event of measurable particle emission were causally disconnected, i.e., were spacelike separated from the entangled particle creation. The weakness (loop-hole) in the methodology of such experiments 'with a delayed choice' left open the possibility that in the past the states of the device and of the system measured had been specially prepared. Although such an effect from the past looks unlikely, it cannot, in principle, be ruled out and can theoretically imitate quantum statistical correlations in Bell inequalities. D Kaiser (Massachusetts Institute of Technology, USA), A Zeilinger (Institute for Quantum Optics and Quantum Information, Austria), and their colleagues have carried out an experiment in which the choice of the measurement method was triggered by the light from Milky Way stars. The possibility of employing the light from astronomical objects in Bell test has been discussed since the 1970s, and the given experiment was the first where this idea was realized. A pair of quantum-entangled photons was sent from the source to two laboratories located in different buildings. Small telescopes that received the star light were placed on the roofs of these buildings. According to their frequency, randomly registered starlight photons initiated different measurement methods of photon polarization. The Bell inequality violation in the two experiments was confirmed at statistically significant levels of $\gtrsim 7.31\sigma$ and $\gtrsim 11.93\sigma$. Since the light had been moving from stars to Earth for ≈ 600 years, the preparation of states, if at all, must have occurred over 600 years before. The use of the light from distant galaxies or relic radiation photons may postpone the obtained restriction still farther in time.

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3. Optical fiber qubit transmission

B P Williams, R J Sadlier, and T S Humble, researchers from the Oak Ridge National Laboratory (USA), have demonstrated in their experiment a new method of quantum bit (qubit) transmission through an ordinary optical fiber in a hyperentangled (entangled in two degrees of freedom) state. Qubit transmission in a hyperentangled state through a free space was demonstrated in 2007 in an experiment with photons which were quantum entangled in spins and orbital angular momenta. But such photons cannot be transmitted through an optical fiber. Instead of orbital angular momentum, Williams, Sadlier, and Humble exploited the entanglement of photons in the time of their emission. This method was proposed theoretically by C Schuck et al. in 2006. The hyperentanglement and the time delay necessary for it were provided with the aid of an interferometer. In the experiment, they demonstrated the superdense coding over optical fiber links: 1.665 ± 0.018 classical bits per qubit. In the test experiment, a graphical 3.4 kb image was qubit transferred through an optical fiber.

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4. Overstepping the diffraction limit

The resolving power of telescopes and microscopes, their ability to separate two close objects, for example, two stars in a binary system, is typically limited by Rayleigh's criterion when the total signal intensity alone is registered. However, it was known from theoretical work that a higher resolution can be attained using additionally information on the electromagnetic wave phase. Researchers from the University of Toronto, W-K Tham, H Ferretti, and A M Steinberg, have implemented this method in their experiment. Two images were represented by two incoherent light beams that received different phases by transmission through a glass plate. Phase registration by means of measurement of Gauss–Hermit quadratures made it possible to establish the presence of two images and thus to surpass the Rayleigh criterion.

Source: *Phys. Rev. Lett.* **118** 070801 (2017)
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5. Intermediate mass black hole in a globular cluster

Observing pulsars, researchers from the Harvard-Smithsonian Center for Astrophysics (USA) and the University of Queensland (Australia) have shown that a black hole of intermediate mass (between the masses of stellar-origin black holes and supermassive black holes in galactic centers) exists in the center of the globular star cluster 47 Tucanae. Dynamic models imply that pulsar distribution in a cluster depends essentially on the central black hole mass, because its gravity suppresses the mass segregation effect (the concentration of more massive stars closer to the cluster center). Observations of the period retardation rate of 23 pulsars yielded the accelerations of their motions in the cluster, and these data allowed the determination of the central black hole mass as $2200^{+1500}_{-800} M_{\odot}$. This black hole does not radiate noticeably in the radio-frequency and X-ray bands because of the low gas accretion rate.

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