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1. Quantum entanglement of the order of events in a gravitational field

In the classical General Relativity Theory, the sequence of possible causes and effects depends on the mass distribution on the initial spacelike hypersurface because of the effect of gravitational time dilation. The question of accordance between the quantum superposition of states and the effect of massive-body gravitation on time flow has not yet been completely answered. M Zych (University of Queensland, Australia) and colleagues have shown a possible approach to this problem. They considered a thought experiment with two events and a massive body and constructed the probability amplitude describing a quantum superposition of states with different metrics (different positions of the massive body) and simultaneously a quantum superposition of the temporal order of events separated by a timelike interval. It was shown that such systems can be quantum entangled in the sequence of events. The authors also formulated analogues of Bell inequalities that might be used to check the quantum character of the indicated entanglement.

Source: *Nature Communications* **10** 3772 (2019)
https://doi.org/10.1038/s41467-019-11579-x

2. Quantum mechanics in a noninertial reference frame

An experimental study of quantum phenomena in noninertial reference frames is of great interest, as it cannot be ruled out that new fundamental effects will be revealed. M J Padgett (University of Glasgow, Great Britain) and his colleagues have performed an experiment examining optical quantum phenomena on a rotating laboratory table. Investigated was a combination of the Sagnac effect and quantum mechanical interference in a Hong–Ou–Mandel interferometer. As distinct from experiments with the pure Sagnac effect, at the input there is no splitter but instead a nonlinear crystal with down-conversion of laser radiation photons and photon pair production in a quantum-entangled state. One of the two photons of the pair described a circle clockwise along the optical fiber and the second photon moved in the backward direction. At the output, a splitter was located with two single-photon detectors operating in the coincidence circuit. As was expected, a uniform rotation leads only to a path-length difference in the two directions. This diminishes the degree of indistinguishability of the photons from the pair and modifies the picture of quantum interference, in accordance with the predictions of quantum mechanics. At the current level of precision, no new effects were found. The authors suggest performing such an experiment using satellites in Earth's orbit.

Source: *Phys. Rev. Lett.* **123** 110401 (2019)
https://doi.org/10.1103/PhysRevLett.123.110401

3. Demonstration of quantum Darwinism in an experiment

It is not yet known why the quantum state of a system turns into the classical state in the process of a measurement or decoherence. One of the proposed versions is 'quantum Darwinism'. According to this conception, states that can proliferate themselves most widely in the environment, which resembles biological evolution, become classical. T Unden (University of Ulm, Germany) and co-authors have observed experimentally such a change-over to the classical description with the proliferation of quantum information. An NV-center (a nitrogen-substituted vacancy) in a diamond surrounded by carbon ^{13}C nuclei that are present as an impurity among ^{12}C nuclei was under study. A set of nonzero-spin ^{13}C nuclei modeled the environment. After the action of a laser pulse on the NV center, the state of the electron changed, and its magnetic interaction with the surrounding ^{13}C nuclei, registered by detectors, generated emissions in the microwave range. Thus, by observing the set of ^{13}C nuclei one could investigate the proliferation of quantum information from the NV center to the environment without perturbing the quantum system itself. The results of the experiment correspond to the quantum Darwinism conception. Indeed, a process was observed in which, beginning at some moment, a set of measurements gave one and the same answer concerning the state of the quantum system, which corresponded to the change-over to the classical picture as information proliferated in the medium.

Source: https://arxiv.org/abs/1809.10456

4. Fermion excitations in YbB_{12}

The topological insulators SmB_6 and YbB_{12} have recently attracted increased attention, as the first of them showed quantum oscillations of magnetization (de Haas–van Alphen effect) and the second exhibited quantum oscillations of conductivity (Shubnikov–de Haas effect). These nontrivial properties, testifying to the presence of a Fermi surface in strong magnetic fields, led to discussions and the appearance of a number of theoretical models based on different effects. In their new experiment, Y Sato (Kyoto University, Japan) and co-authors measured electric conductivity, heat capacity, and thermal conductivity of low-temperature (up to 0.6 K) YbB_{12} crystals without a magnetic field and in magnetic fields. The analysis of the obtained data is indicative of a probable presence in YbB_{12} of new quasi-particles — moving gapless fermionic excitations interacting with the magnetic field in spite of the absence of an electric charge in them.

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Possibly, it is these neutral fermions that are responsible for the unconventional properties of SmB_6 and YbB_{12}.

Source: *Nature Physics* **15** 954 (2019)
https://doi.org/10.1038/s41567-019-0552-2

5. Investigation of microprocesses in biophysics

Y Wang (Nanjing University, China) and colleagues have developed a new method of biophysical studies of microprocesses allowing, in particular, identification of single molecules. In the method, called DiffusiOptoPhysiology, processes are investigated by an optical technique in nanometer-scale pores without the use of measuring electrodes. Fluorescent radiation of Fluo-8 dye molecules was observed. They were bound to Ca^{2+} ions, which made it possible to observe an ion flux moving through nanopores. In this method, electrodes are only applied to produce an effect of electrophoresis — the total flux of matter. Registration of single molecules of cyclodextrin, PEG1500, and dsDNA in an ion flux was demonstrated. Nanopores are widespread, being present in biological membranes for substance transport. The new method allows the simultaneous observation of thousands of nanopores, which makes it highly efficient. The device for DiffusiOptoPhysiology can be assembled on a small chip and can be widely applied in different fields of clinical diagnostics and in scientific research.

Source: *Science Advances* **5** eaar3309 (2019)
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6. Quantum dot energy generator

G Jaliel (University of Cambridge, United Kingdom) and co-authors have constructed a microscopic thermo-electric generator on two quantum dots using the effect of resonant electron tunneling. For the device's operation, the presence of a temperature gradient will suffice. Thermo-electric generators on quantum dots have already been designed earlier, but they had low efficiency. In the new device, constructed using a setup proposed by A N Jordan (University of Rochester, USA) and co-authors, two quantum dots, 310 nm in diameter each, were realized on a GaAs/AlGaAs heterostructure on either side of a hot-electron reservoir. The energy levels of the quantum dots were different — they corresponded to low-energy electrons on one side and to higher-energy electrons on the other side. Thus, selective electron transport between the two dots took place, and the temperature difference was converted into electric energy. The new device can generate a thermal power of 0.13 fW for a temperature difference across each dot of about 67 mK. Its efficiency amounts to at least 10% of the ideal Carnot heat engine.

Source: *Phys. Rev. Lett.* **123** 117701 (2019)
https://doi.org/10.1103/PhysRevLett.123.117701

7. Unidentified gamma-ray sources

The gamma-ray survey of the sky performed by the space telescope Fermi-LAT revealed many unidentified sources of unknown origin. In other ranges, including optical ones, these objects are invisible. The H.E.S.S. complex of Cherenkov gamma-ray telescopes located in Namibia was used to carry out new observations of four of the unidentified sources at energies $\geqslant 100$ GeV. The observations of ground-based Cherenkov detectors supplement the Fermi-LAT observations, because they allow a long-exposition survey of the high-energy part of the spectrum. These sources turn out to be invariable in gamma rays, and their hard spectrum is close to the one to be generated in annihilation of dark-matter particles with masses less than or equal to 0.4 TeV/c^2. In these features, the sources are very similar to the dark matter clumps in which annihilation takes place. The existence of such clumps (subhalo) is predicted in the hierarchical picture of galaxy formation, where small objects merge to form larger ones up to the formation of galactic halos and galactic clusters. Nevertheless, it cannot be stated confidently that unidentified sources are dark matter clumps, and therefore further studies are needed.

Source: https://arxiv.org/abs/1909.01072

8. New constraints on primordial black holes

The possibility of primordial black hole (PBH) formation in the early Universe was predicted by Ya B Zeldovich and I D Novikov in 1967. Interest in PBH has recently been considerably renewed because the merging of PBH pairs might explain some of the gravitational wave bursts observed by the LIGO/Virgo detectors. Many constraints were obtained on PBH distribution in the Universe, which almost ruled out the possibility of PBHs constituting all dark matter. However, some of these constraints are model-dependent, and the limits become weaker when PBHs show a wide mass distribution. In particular, the PBH mass interval $M_{\rm PBH} \sim 20-80M_\odot$ and the region near $\sim 10^{-10}M_\odot$ have not been definitively excluded. A group of astrophysicists from Italy and Switzerland obtained new constraints on PBH. If PBHs exist, their gravitation would create additional inhomogeneities in the intergalactic gas, and these inhomogeneities must affect the Lyman-α forest — the set of absorption lines observed in the quasar spectra. R Murgia and colleagues have used MIKE and HIRES spectrometer data, and gas hydrodynamics was simulated numerically with allowance for PBHs. The absence of a considerable influence on the Lyman-α forest gives a constraint excluding a notable part of the interval of $\sim 20-80M_\odot$ on the side of large masses.

Source: *Phys. Rev. Lett.* **123** 071102 (2019)
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