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1. Gravitational red shift on small scales

Time dilation in a gravitational field, called gravitational red shift, is one of the main predictions of the General Relativity Theory (GRT). This effect was measured not only for cosmic objects but also in laboratory experiments. In particular, Rabi spectroscopy was used in 2022 to measure the time dilation gradient on millimeter scales in an ultracold gas of ^{87}Sr atoms playing the role of a high-precision atomic clock. X Zheng (University of Wisconsin-Madison, USA) et al. have performed a similar experiment, but using five ensembles of ^{87}Sr atoms in a vertical optical lattice located at equal distances of 2.5 mm [1]. Using Ramsey spectroscopy, atomic frequencies were compared simultaneously in all pairs of the ensembles. To eliminate errors associated with the expected outcome of measurements, a 'blind' data processing method was used. The resulting relative frequency shift gradient of $[-12.4 \pm 0.7(\text{stat.}) \pm 2.5(\text{syst.})] \times 10^{-19}\,\text{cm}^{-1}$ coincides with GRT predictions. Relativistic geodesy, using local measurements of gravitational field gradients, offers new opportunities in the search for minerals and for other practical applications.

2. Coherence of solid-state qubits

Quantum qubits based on spin defects in a crystal lattice can be used, for example, in quantum sensors, gyroscopes, and memory cells. As a rule, reading information and controlling the spin of a nucleus in a lattice is carried out using the spins of neighboring localized electrons interacting through hyperfine splitting levels. However, this interaction, as well as quadrupole and other perturbations, limits the quantum coherence time of solid-state qubits to ~ 150 μs. An increase in the coherence time, which is one of the most important tasks, is attained, in particular, with the help of spin echo, which affects nuclear spins and leads to self-compensation of noises. G Wang (Massachusetts Institute of Technology, USA) et al. have improved this method by using an unbalanced spin echo, which affects the auxiliary spins of electrons, and the characteristics of not one, but different noises were used for the compensation [2]. Using the new method in the experiment with an ensemble of 10^{10} NV centers in a diamond (nitrogen-substituted vacancies), the coherence time was increased 20 times at room temperature. For modern quantum technologies, see [3–6].

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3. Topological protection based on nonlinear disclination states

Topologically protected states on the faces or at the corners of samples are of great interest due to their resistance to various disturbances [7, 8]. One course of action is to create optical topological states on disclinations — deformations in a crystal that violate the axial symmetry. Such topological states were earlier investigated in the linear optics regime only. A group of researchers from Xi'an Jiaotong University (China), the Institute of Spectroscopy of the Russian Academy of Science, the Higher School of Economics, and Moscow State University (Russian Federation) has demonstrated for the first time topological states on disclinations in a nonlinear regime, when passing radiation significantly changes the optical properties of the medium and thus undergoes a backreaction [9]. The experiment was carried out in waveguide lattices with pentagonal and heptagonal disclination nuclei created by a femtosecond laser in quartz glass, where topological states arose on the boundary of a hollow disclination nucleus. The authors believe that such nonlinear topological states can also appear in Bose–Einstein and polariton condensates, photon crystals, and other systems.

4. Alice rings in a Bose–Einstein condensate

Grand unification theories predict the existence of one-dimensional structures called Alice strings, in a detour around which elementary particles should turn into anti-particles (for a stationary observer). Such strings could have arisen in the early Universe during phase transitions. Analogues of Alice strings have been observed in superfluid liquids and liquid crystals. A Blinova (Amherst College and University of Massachusetts Amherst, USA) and her co-authors have become the first to observe closed Alice strings in the form of rings in a Bose–Einstein condensate of ^{87}Rb atoms in an optical trap [10]. The magnetic field generated by Helmholtz coils led to the formation of singular vortex points (monopoles) carrying topological charges and turning into Alice rings. After the trap potential was turned off, the condensate cloud expanded in the magnetic field and was observed by the absorption method, which made it possible to identify Alice rings. It is assumed that in Bose–Einstein condensate it will also be possible to observe topological monopoles to convert into anti-monopoles.

5. Reionization of the Universe

When our Universe was several hundred million years old, radiation sources appeared in it causing reionization of neutral hydrogen. The sources could be early galaxies (radiation from their stars) or black holes in active galactic nuclei, but an exact conclusion concerning the nature of the sources has not been made. H Atek (Paris Institute of Astrophysics, France) and his co-authors have carried out a study casting light on this issue and confirming the hypothesis about early galaxies as the cause of the reionization of the Universe [11]. Examined was the strong gravitational lensing of galaxies by the cluster Abell 2744 located on the line of sight. A combination of data from the J Webb and Hubble telescopes revealed eight galaxies with a spectroscopic confirmation at redshift $z \sim 7$. They have a young stellar population generating high-power UV radiation, precisely as required for concluding the reionization of the Universe to $z \sim 6$. A direct spectroscopic measurement of ionizing photon radiation efficiency was performed for the first time to give a larger value than that assumed earlier by a factor of 4.

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