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1. Cosmological scenarios in the Horndeski theory

The inflationary paradigm, according to which an exponential Universe expansion preceded the stage of reheating, reigns in modern cosmology. Nevertheless, this class of models cannot yet be thought of as final, and the Universe may have evolved in some other manner. One of admissible and widely discussed versions of a cyclic Universe is the model of the cyclic Universe with alternating compressions and expansions. The cyclic evolution is realized in different versions of the scalar-tensor Horndeski gravitation theory, including the Einstein General Relativity Theory as a particular case. However, in the framework of the Horndeski theory, the cyclic Universe has difficult problems, such as ghost and other instabilities, which, generally speaking, may occur at a certain stage of the Universe's evolution. One of the ways to evade the above-mentioned obstacles is to consider a version where the effective Planck mass tends to zero in an asymptotical past. But, in this case, the strong coupling problem occurs (inapplicability of the classical description) at early times [1]. In 2021, Yu A Ageeva, P K Petrov, and V A Rubakov proposed an elegant solution to these problems [2]. Their model with 'strong gravity in the past' had not been applied earlier in cosmological scenarios within the Horndeski theory. Yu A Ageeva, P K Petrov, and V A Rubakov were the first to construct several cosmological models in the framework of such an approach, both including and excluding the inflation stage. The obtained models are stable, and the perturbations above the background in them are not superluminal. In their new paper [3], Yu A Ageeva, P K Petrov, and V A Rubakov have substantially developed and justified this class of models. They show that cosmological primordial perturbations can be generated in them with a spectrum which is necessary for galaxy formation and is observed in relic radiation perturbations. It is interesting that perturbations in model [3] are generated at the stage of previous compression before the contemporary expansion. Thus, it was shown that the Universe may have evolved in nontrivial ways, and, being consistent with the observational data, the new wide class of cosmological models is admissible.

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2. Fulde–Ferrell–Larkin–Ovchinnikov state in a superconductor

In the conventional BCS mechanism, Cooper pairs of electrons have a zero total momentum. However, the possibility of a nonzero pairing momentum was predicted in 1964 in two independent papers (P Fulde, R A Ferrell and A I Larkin, Yu N Ovchinnikov) [4, 5]. Such nonstandard superconductors must be stable in a magnetic field higher than the paramagnetic Pauli limit. The occurring Fulde–Ferrell–Larkin–Ovchinnikov state is characterized by a periodic spatial change of the order parameter and by anisotropy with respect to the electron pair momentum direction. Although signs of the Fulde–Ferrell–Larkin–Ovchinnikov state have already been noticed in experiments, the indicated anisotropy has not been observed. Anisotropy corresponding to the Fulde–Ferrell–Larkin–Ovchinnikov state has been registered for the first time by S Imajo (Institute for Solod State Physics of the University of Tokyo, Japan) and their co-authors in a layered organic d-wave type superconductor with the help of a new supersonic method developed by them [6]. Anisotropy was seen in the anisotropic acoustic response to ultrasonic pulses, and it was reliably confirmed for the first time. For the role of the Fulde–Ferrell–Larkin–Ovchinnikov state in superconducting spintronics, see [7].

3. Test of helium-4 microsamples

The properties of many substances in large volumes differ substantially from those of the same substances in the form of small particles or in microcavities. The scale-dependent effect, important for technical applications, becomes especially obvious in phase transitions in which the coherence length increases. This also takes place in superfluid ^{4}He near the superfluid transition point. In their experiment, E Varga, C Undershute, and J P Davis (University of Alberta, Canada) have performed an experiment observing a decrease in the density of the superfluid component ^{4}He in channels 25 and 50 nm wide [8]. Reconstruction of the volume excitation spectrum with varying coherence length was realized, and the superfluid component density was measured at different temperatures through changing pressure. The density decreased with cooling from the superfluid transition temperature to 0.6 K. The authors of the study believe that this is due to the appearance of roton-like excitations (quasiparticles) with an energy gap of 5 K localized near the channel walls.

4. Nonlinear photon interaction in a waveguide

H Le Jeannic (University of Copenhagen, Denmark) and her co-authors have performed an experiment [9] with nonlinear quantum photon-photon interaction in a nanophoton waveguide (a photon crystal) mediated by a quantum emitter — a semiconductor quantum dot. A high-efficiency quantum coherent light–matter interface occurred in this device, and certain quantum correlations between photons appeared. Two different experimental possibilities were realized. In the first case, one photon in the waveguide could control passage of the second photon. In the second case, there was a two-photon interaction with complex time correlations. Quantum nonlinear optics is highly promising in the field of quantum information, for example, in creating quantum qubits and quantum repeaters, as well as in fundamental research.

5. Mechanism of secondary laser generation in nitrogen

When propagating in air, powerful laser pulses can undergo nonlinear self-focusing processes inducing ionization and plasma filamentation. In these filaments, secondary laser radiation is generated owing to transitions between inversely populated levels (a larger number of atoms at higher levels than at lower ones). It remained unclear, however, what levels receive an inverse population. C Kleine (Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Germany) and their co-authors performed a new experiment [10] which clarified the composition of levels with inverse population in nitrogen. Nitrogen was exposed to laser pulses with a wavelength of 800 nm with a peak intensity of 4.5×10^{14} W cm^{-2}. The results of ionization were observed using femtosecond soft X-ray spectroscopy. The obtained results testify to the existence of an inverse population between the layers $B^2\Sigma_u^+$ and $A^2\Pi_u$. In the tunnel regime, the ionization rate has been expected to decrease exponentially with increasing electron binding energy, and therefore the mechanism of occurrence of inverse population remains unclear.

6. Instability in tokamaks

Controlled thermonuclear fusion is destined to open a new era in energetics. One of the research areas is design of tokamaks — devices where a hot plasma is confined in a toroidal magnetic field — and the international thermonuclear experimental reactor ITER is planned to be launched in the nearest future [11, 12]. However, a problem with tokamaks is instability [13], responsible for plasma ejection onto the chamber walls, which causes their destruction. Among the most dangerous instabilities are so-called localized edge modes carrying plasma particles and heat onto a divertor (the part of the chamber aimed at removing impurities in plasma) along the magnetic field lines. G F Harrer (Vienna University of Technology, Austria) and his colleagues have investigated the mechanism of the appearance of these instabilities and possible methods of their suppression [14]. The experimental part of the study was performed at the ASDEX tokamak at the Max Planck Institute for Plasma Physics in Garching, Germany. The optical radiation generated in the plasma-gas interaction in the divertor was registered and the observational data were compared with the results of mathematical simulations. The instability turned out to weaken with increasing plasma density. A possible reason is the decrease in the local current and lowering of the pressure gradient at the plasma boundary, which is the dominating factor of instability. A change in the magnetic field topology (a change in the coil pitch of the lines of force) was also found to heighten the instability threshold.

7. Muon radiography of atmospheric cyclones

Muons generated in Earth's atmosphere by cosmic ray fluxes exhibit a high penetrability and are used in radiography — to illuminate various objects so as to investigate their internal structure, which is often inaccessible to other methods [15]. Muon radiography has been applied in practice to examine ore mines, the pyramids in Egypt, and volcanoes. It can also help in examining the structure of large air masses in the atmosphere. Time variations of atmospheric pressure have already been measured using vertically moving muons. H K M Tanaka (University of Tokyo, Japan) and his colleagues have applied muon radiography for the first time to explore atmospheric cyclones [16]. Their vertical profile was measured with muons flying at small angles to Earth's surface. From 2016 to 2021, the 3D structure of seven typhoons (mature tropic cyclones) near the Japanese town of Kagoshima was investigated with muon radiography. Three-layered muon scintillation detectors screened by a lead and steel layer were used. The successive images obtained from a ground-based network of such detectors showed the presence in the cyclone centers of warm low-density cores surrounded by colder dense air layers. The trajectories of those cores corresponded to the cyclone trajectories and atmospheric pressure oscillations registered at ordinary meteorological stations. Atmospheric muon radiography may be applied to predict cyclone nucleation and to give prior warning of dangerous weather phenomena.

8. Unusual gamma-ray burst

On October 9, 2022, the space telescopes Fermi and Swift detected gamma-ray burst GRB 221009A with a photon energy up to 99 GeV — the maximum energy for the entire period of observations by these telescopes. In the first seconds, the burst resembled typical long gamma-ray bursts from explosions of some supernovae, but this one lasted over 4000 seconds and had an unusual light curve with numerous dips. Thirty-three minutes after the beginning of the gamma-ray burst, the LHAASO detector in China detected gamma-ray photons with energies up to 18 TeV from the same region. And then, an hour later, the Carpet-2 detector registered a photon with an energy of 251 TeV — the maximum energy for the entire period of gamma-ray burst observations [17]. The photon nature of this signal is confirmed by the fact that it was not followed by muon detector activation. These observations have not yet been theoretically explained. According to the optical observations of the burst post-glow, it occurred at a cosmological distance (redshift $z = 0.151$), and therefore the radiation from the TeV region could not reach Earth because of cosmic background emissions absorption. A hypothesis was put forward that photons became axion-like particles that passed the greater part of the way, to then be transformed into photons again. This would allow the photons to avoid absorption. It cannot be ruled out either that the interpretation of this event as a gamma-ray burst is erroneous and that it was some catastrophic process in our Galaxy at a close distance. In favor of this hypothesis is the fact that the signal came from a region with numerous stars. Another possible explanation recently put forward suggests that the burst GRB 221009A is cosmological, but ultra-high-energy cosmic rays were generated in its source and the observed high-energy gamma-ray photons may have resulted from the interaction of these cosmic rays with background emissions rather close to our Galaxy.

9. Observation of 'hot spots' in the radio frequency band

Near the supermassive black hole in the center of our Galaxy, radiation flares are observed, obviously caused by reconnection of magnetic lines of force in a magnetized plasma. At the reconnection point, energy is released and hot spots (heated gas regions) appear, moving around the black hole. M Wielgus (Max Plank Institute for Radio Astronomy, Germany, Nicolaus Copernicus Astronomical Center, Poland, and Harvard University, USA) and their co-authors used ALMA radio telescopes to investigate the motion of a hot spot resulting from a strong X-ray flare in the millimeter radio frequency band [18]. A spot radiation polarization plane twist with a characteristic time scale of 70 min was observed. This corresponds to the fact that the hot spot orbit has a radius equal to five Schwarzschild radii. An indication exists that the black hole rotation is prograde to the hot spot orbital motion. The observed picture of the hot spot motion is consistent with the results obtained earlier in the GRAVITY experiment for the IR range.

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