**Bogolyubov Institute for Theoretical Physics**
**of the National Academy of Sciences of Ukraine**

# Bogolyubov Readings 2025

## 25 November 2025

*11:00* – Opening

*11:05- 12:00* – **Erik Aurell** (KTH Royal Institute of Technology, Stockholm, Sweden)
**“Operators with super-exponential spectral growth and quantum black holes”**

*12:00- 12:30* – **Sergei Sharapov** (BITP of the NAS of Ukraine, Kyiv, Ukraine)
**“Sagnac and Mashhoon effects in graphene”**

*12:30- 13:00* – **Vadym Kovtoniuk** (BITP of the NAS of Ukraine, Kyiv, Ukraine)
**“Hybrid Bell nonlocality”**

*13:00- 14:00* – ***Break***

*14:00- 14:30* – **Musfer Adzhymambetov** (BITP of the NAS of Ukraine, Kyiv, Ukraine)
**“Relativistic Hydrodynamics in Heavy-Ion Collisions”**

*14:30- 15:20* – **Volodymyr Vovchenko** (University of Houston, USA)
**“Phase Structure of Strongly Interacting Matter under Extreme Conditions”**

To participate online via Zoom platform, please fill out the registration form: https://forms.gle/W6YsKvCTVN3TAVYeA

# Operators with super-exponential spectral growth and quantum black holes

**Erik Aurell**

*KTH Royal Institute of Technology, Stockholm, Sweden*

The quantum nature of black holes has remained a key problem in fundamental physics since the discovery of Hawking radiation, now more than half a century ago. It was early on pointed out by Bekenstein and Mukhanov that if black holes are quantum objects with a density of states corresponding to Bekenstein-Hawking entropy, then the density of states of those objects must grow as $exp(E^2)$. While natural objects with sub-exponential or exponential spectral growth, i.e. $exp(E^a)$ with $a \leq 1$, are known in mathematics and in physics, to the best of our knowledge no concrete natural mathematical object displaying super-exponential spectral growth is known.

I will present a simple physical toy model which does have super-exponential growth, though it obviously cannot be a reasonable model of a quantum black hole as all states are very delocalized. I will then use this observation as starting point of a discussion of why it is hard to construct models of compact objects with super-exponential spectral growth, and what this may perhaps tell us about quantum black holes.

The talk is based on joint work with Satya N. Majumdar [arXiv:2504.06623], published as Phys. Rev. Research 7, 043165 (2025).

# Sagnac and Mashhoon effects in graphene

**Sergei G. Sharapov**

*Bogolyubov Institute for Theoretical Physics of the NAS of Ukraine*

The Sagnac effect refers to the phase shift between two coherent waves, such as light, traveling in opposite directions within an interferometer mounted on a rotating disk. The magnitude of the phase shift is directly proportional to the area enclosed by the light rays, the frequency of the light, and the angular velocity of the interferometer's rotation. Given that material particles also exhibit wave-like properties, the Sagnac effect has been experimentally observed in free electrons in vacuum, neutrons, and even atoms. Moreover, when the Sagnac effect is realized on electrons, the resulting phase shift in the interference pattern is roughly a million times larger than that for light. This prompted a theoretical question: how would the Sagnac effect manifest in solid-state interferometers using free electrons in monolayer graphene? Graphene is known for its zero effective carrier mass and linear electron dispersion, properties that closely resemble those of light.

We investigate the Sagnac and Mashhoon effects in graphene, taking into account both the pseudospin and intrinsic spin of electrons, within a simplified model of a rotating nanotube or infinitesimally narrow ring. Based on considerations of the relativistic phase of the wave function and employing the effective Larmor theorem, we demonstrate that the Sagnac fringe shift retains a form analogous to that for free electrons, governed by the electron's vacuum mass. As a result, the effect in graphene remains approximately a million times stronger than in light-based interferometers. In the case of a narrow ring, an additional $\pi$-phase shift arises due to the Berry phase associated with the honeycomb graphene lattice. The Mashhoon fringe shift, which characterizes the dynamics of intrinsic spin, retains its conventional form in graphene, with its dependence on the Fermi velocity. Our analysis highlights both the similarities and differences between spin and pseudospin degrees of freedom in graphene.

References: A. Fesh, Yu.V. Shtanov, and S.G. Sharapov, Phys. Rev. B 110, L121402 (2024); Yu.V. Shtanov T.-H.O. Pokalchuk, and S.G. Sharapov, Preprint arXiv:2508.07718

# Hybrid Bell nonlocality

**Vadym Kovtoniuk**

*Bogolyubov Institute for Theoretical Physics of the NAS of Ukraine*

Bell nonlocality, as the strongest type of correlations in two-mode systems, is an indispensable resource for various applications, such as quantum communication. However, a rigorous analysis of experimental data becomes infeasible as the numbers of measurements and their outcomes increase. As for the continuous systems, many of the traditional theoretical methods to test Bell nonlocality are inapplicable. We propose a necessary and sufficient condition of nonlocal correlations in the systems where continuous measurements are performed on one mode and discrete measurements on the other one. This condition enables one to test nonlocality of states of light with continuous measurements like balanced homodyne detection.

# Relativistic Hydrodynamics in Heavy-Ion Collisions

**Musfer Adzhymambetov**

*Bogolyubov Institute for Theoretical Physics of the NAS of Ukraine*

Modern and future collider experiments aim to explore the phase diagram of quantum chromodynamics at high baryon densities. According to theory, two different forms of strongly interacting matter—the hot quark–gluon plasma and the hadron resonance gas—are separated by a phase transition that should end at a critical point. In actual heavy-ion collisions, however, the observable signatures of these features are strongly suppressed by the small size of the system and its extremely rapid expansion, making the detection of critical behavior particularly challenging. To interpret experimental signals reliably, a realistic dynamical description of the system’s evolution is essential.

Relativistic hydrodynamics provides a powerful framework for modeling how the matter created in such collisions expands and cools. Recently, we developed a new version of the Integrated hydrokinetic model designed to simulate nuclear collisions in the GeV energy range. This approach combines viscous hydrodynamics with microscopic kinetic theory, allowing us to describe the entire evolution of the system—from the moment two nuclei collide to the detection of the produced hadrons. In this talk, I will introduce the main ideas behind the model and present our first results.

# Phase Structure of Strongly Interacting Matter under Extreme Conditions

**Volodymyr Vovchenko**

*University of Houston, USA*

One of the key open questions in studies on strongly interacting matter is the phase structure of QCD and the nature of the transition between ordinary hadronic matter and the deconfined quark-gluon plasma (QGP) at extreme temperatures exceeding trillions of Kelvin. This talk will cover how the properties of strongly interacting matter can be studied in the laboratory through ultrarelativistic heavy-ion collisions and through phenomenological approaches. Particular emphasis is placed on the search for the QCD critical point in the phase diagram separating ordinary matter and QGP through the analysis of event-by-event fluctuations. I will discuss the constraints on the QCD critical point coming from recent theoretical approaches, data from Au-Au collisions at the Relativistic Heavy Ion Collider in Brookhaven, and future perspectives.