Hydrodynamic Model of Gravity as Manifestation of Quantum Vacuum Energy Exchange

Dmitry Losinets

October 2025

Abstract

This work investigates the possibility of describing gravitational interaction within the framework of a hydrodynamic model of the quantum vacuum. Nucleons are modeled as toroidal vortices absorbing vacuum energy, leading to a pressure gradient identified with gravity. The model qualitatively agrees with the law of universal gravitation and offers a path toward unification with electromagnetic phenomena. The justification relies on classical ideas of Sakharov's induced gravity (1967) and modern analog models of gravity in hydrodynamics, including the superfluid vacuum theory.

1 Introduction

As shown in works [10, 11], fundamental particles of matter (nucleons) can be modeled as toroidal vortices of the quantum vacuum, represented as a weakly viscous fluid. This approach leads to the unification of magnetic moment and charge of particles, and allows obtaining expressions for acting forces that are structurally identical to Maxwell's equations. It has been demonstrated [12] that this approach also consistently incorporates the mathematical formalism of quantum chromodynamics. Within the current work, we propose to consider the fundamental possibility of modeling gravitational phenomena and their relationship with electromagnetic processes in matter.

The classical foundations of this approach date back to Sakharov's ideas [16, 18] on induced gravity, where gravity arises as a consequence of quantum corrections in matter fields, similar to how hydrodynamics emerges from molecular physics. Modern developments, such as the Superfluid Vacuum Theory (SVT) [17], consider the vacuum as a Bose-Einstein condensate where relativistic gravity manifests as long-wavelength excitations, and spacetime curvature as collective fluctuation modes [20, 4].

Analog models of gravity in fluids [2], including acoustic analogies of black holes, confirm the possibility of simulating quantum gravity effects, such as Hawking radiation, in hydrodynamic systems. As the source of gravitational interaction, we propose to develop a hydrodynamic model of the quantum vacuum where, in addition to flow velocities, there is also internal energy. The toroidal vortex, through a periodic process of compression and expansion of the quantum vacuum, absorbs energy from the surrounding environment. When using an ideal gas model, this leads to a pressure gradient that creates gravitational attraction. Recent works emphasize that quantum vacuum energy can be the source of gravity through an effect analogous to the Casimir effect, where the Newtonian gravitational potential arises from vacuum energy density ρ_{vac} [8].

The successful reduction of electromagnetism to hydrodynamics [10], the linking of previously considered independent particle parameters [11], and the unification with the mathematical formalism of quantum chromodynamics [12] show the promise of using hydrodynamic analogies. The presented work is a first approximation and a declaration of the possibility of such reduction, rather than a strict calculation of effective parameters of the quantum vacuum.

2 Qualitative Description of the Model

Consider a steady-state toroidal vortex. It is assumed that in the small inner ring of the torus, gas compression occurs under the action of centrifugal forces. The motion around the axis of the toroidal vortex accelerates the gas outward, and the meridional motion in the near-axis region drives the gas inward, creating a zone of high pressure and density. Then the gas adiabatically expands, leaving this region, which leads to its cooling and acceleration, analogous to processes in a Laval nozzle.

The cooled gas in the vortex core is heated by the surrounding atmosphere through turbulent heat transfer, absorbing thermal energy. This energy is used to maintain the vortex rotation, which through viscous forces is dissipated in the atmosphere, creating winds. Thus, the model describes a hypothetical cycle of converting thermal energy of the atmosphere into kinetic energy of air masses. Toroidal models of subatomic particles, such as Parson's model (1915) [14], describe electrons and protons as ring structures with circulating charges, where magnetic moments arise from currents and stability is ensured by the balance of electromagnetic forces [5].

It is important to distinguish two levels of consideration:

- **Macroscopic analogy (atmospheric vortices):** Used as a visual metaphor illustrating processes of heat exchange, rotation, and adiabatic expansion.
- **Microscopic vacuum model:** Actual calculation should be conducted at the level of a quantized medium, where "temperature" and "heat transfer" act as effective parameters, analogous to noise temperature in quantum systems.

Thus, the relations described below do not imply literal identity of a nucleon and an atmospheric vortex, but rather set the mathematical apparatus for modeling energy exchange cycles. The hydrodynamic approach to quantum gravity interprets Einstein's equations as hydrodynamics of systems divided into causal diamonds, where subsystems define density matrices with modular Hamiltonians proportional to the boundary area [1].

Key assumption: The model considers dry air and does not account for processes related to changes in the state of aggregation of water (evaporation, condensation), which are dominant in real powerful atmospheric vortices. This assumption is valid since at the subatomic level there is no basis to assume the presence of state change processes.

3 Temperature Difference in Adiabatic Expansion

For an adiabatic process, the temperature and volume of gas between the initial (state 1 - before expansion) and final (state 2 - after expansion) states are related by:

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \tag{1}$$

The formula for temperature decrease during expansion ($V_2 > V_1$):

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \tag{2}$$

where γ is the adiabatic index (≈ 1.4 for air).

The temperature (T_1) is approximated by the atmospheric temperature (T_a) at the vortex periphery. The temperature ($T_2 = T_v$) is the temperature in the cooled vortex core. Consequently, the temperature difference created by expansion:

$$\Delta T_{\text{ad}} = T_a - T_v = T_a \left[1 - \left(\frac{V_1}{V_2}\right)^{\gamma-1}\right] \tag{3}$$

The model introduces an effective vacuum temperature, reflecting the average level of fluctuations and the medium's ability to transfer energy to vortex structures. This is not a real thermodynamic temperature, but a parameter allowing the description of energy exchange in analogy with heat transfer. In analog models of gravity, such parameters allow simulation of quantum effects, including excitations of quasi-normal vacuum modes [9].

Vacuum energy is included in the vortex cycle in the form of conditional "heat" maintaining rotation and compensating for dissipation.

4 Power of Heat Absorption from External Atmosphere

The heat flow power (Q) from the atmosphere to the vortex is estimated by the equation:

$$Q = hS\Delta T_{\text{ad}} \tag{4}$$

where:

- $S = 4\pi^2 Ra$ - surface area of the torus,
- $\Delta T_{\text{ad}} = T_a - T_v$ - temperature difference between atmosphere and vortex core,
- h - heat transfer coefficient.

The heat transfer coefficient is expressed through the Nusselt number:

$$h = \frac{\mathrm{Nu}\, k}{a}, \quad \text{where} \quad \mathrm{Nu} = C\,\mathrm{Re}^n, \quad \mathrm{Re} = \frac{va}{\nu} \tag{5}$$

Here k is thermal conductivity, ν is kinematic viscosity, v is characteristic velocity, C and n are empirical constants.

5 Rotation Intensity and Energy Dissipation

The power dissipated due to viscosity is estimated by the formula:

$$P_{\text{diss}} \approx C_d \rho \nu v^2 a \tag{6}$$

where C_d is a dimensionless dissipation coefficient determined by geometry and flow regime.

In steady state, the power used to maintain the vortex and compensate for dissipation must equal the absorbed thermal power multiplied by the cycle efficiency coefficient ($\eta < 1$):

$$P_{\text{diss}} = \eta Q \tag{7}$$

This equation reflects the fact that only part of the absorbed thermal energy is converted into useful work to maintain rotation. In hydrodynamic vacuum models, dissipation can be associated with negative effective mass in regions of low energy, as in recent works on quantum hydrodynamics [15].

6 Relationship Between Expansion Ratio and Flow Velocity

The expansion ratio (V_2/V_1) in the hypothetical "Laval nozzle" of the vortex is not an independent quantity. It is determined by flow dynamics, particularly the balance between centrifugal forces and pressure.

For a toroidal vortex, rotational motion creates a radial pressure gradient described by the radial equilibrium equation:

$$\frac{\partial P}{\partial r} = \rho \frac{v_\theta^2}{r} \tag{8}$$

where v_θ is azimuthal velocity, ρ is medium density, r is distance from the rotation axis.

Integrating this equation for characteristic vortex sizes, we obtain an estimate of the pressure difference between inner and outer regions:

$$\Delta P = P_{\text{in}} - P_{\text{ex}} \approx \rho v^2 \tag{9}$$

For an adiabatic process in a gas with adiabatic index (γ):

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma = 1 + \frac{\Delta P}{P_2} \tag{10}$$

Expressing P_2 through the speed of sound in the medium c_s ($P_2 = \rho c_s^2/\gamma$ for an ideal gas), we obtain:

$$\left(\frac{V_2}{V_1}\right)^\gamma = 1 + \gamma \frac{v^2}{c_s^2} \tag{11}$$

For small Mach numbers ($v \ll c_s$) we linearize:

$$\frac{V_2}{V_1} \approx 1 + \frac{v^2}{c_s^2} \tag{12}$$

Thus, we obtain the dependence:

$$\frac{V_2}{V_1} \approx 1 + \alpha v^2 \tag{13}$$

where $\alpha = 1/c_s^2$ is a coefficient determined by medium properties. In the case of the quantum vacuum, c_s represents the speed of propagation of longitudinal disturbances in this medium. This agrees with the fluid analogy of gravity, where vacuum flow creates gradients analogous to spacetime curvature [7].

7 Analytical Relationship Between Heat Absorption and Flow Velocities

Substituting into the power balance equation (7) the expressions for Q and P_{diss}:

$$C_d \rho \nu v^2 a = \eta \left(C \frac{k}{a} \left(\frac{va}{\nu} \right)^n \right) (4\pi^2 Ra) \Delta T \tag{14}$$

Simplifying, we express the required temperature difference for balance ΔT_{bal}:

$$\Delta T_{\text{bal}} = \frac{C_d \rho \nu^{n+1} v^{2-n} a^{1-n}}{4\pi^2 R \eta C k} \tag{15}$$

This temperature difference must be provided by the vortex itself through adiabatic expansion, i.e., $\Delta T_{\text{bal}} = \Delta T_{\text{ad}}$. Equating equations (3) and (15) and substituting into (3) the relation (13), we obtain:

$$T_a \left[1 - \left(\frac{1}{1 + \alpha v^2} \right)^{\gamma - 1} \right] = \frac{C_d \rho \nu^{n+1} v^{2-n} a^{1-n}}{4\pi^2 R \eta C k} \tag{16}$$

This equation relates the characteristic vortex velocity v with system parameters and environment (T_a, ρ, ν, k) and geometric parameters (R, a). Its solution allows finding the self-consistent vortex velocity determined by the balance between adiabatic cooling, heating from the atmosphere, and energy dissipation.

Qualitative analysis: For small v, the left side of equation (16) behaves as $\approx T_a \alpha (\gamma - 1) v^2$, and the right side as $\sim v^{2-n}$. Thus, the existence of a nontrivial solution ($v > 0$) depends on the exponent n and system parameters. The model predicts a threshold effect: for vortex formation, it is necessary to exceed some critical value of atmospheric temperature T_a or other parameters.

Equations 3-16 should be understood as effective relations. In particular, the closure equation 16 describes the self-consistent vortex state where rotation speed is determined by the balance between "adiabatic cooling" (effective) and dissipation. This echoes the hydrodynamic approach where subsystems in causal diamonds lead to Einstein's equations as hydrodynamics [1].

8 Gravitational Interaction as a Consequence of Vacuum Energy Absorption

Within the model where nucleons represent toroidal vortices in the quantum vacuum, treated as a weakly viscous gas, gravitational interaction arises as a macroscopic manifestation of energy absorption and dissipation processes at the microlevel. The idea of gravity as a pressure gradient in the vacuum finds support in recent works where vacuum energy generates the Newtonian potential through RG-flow of constant G [8].

8.1 Energy Density Flux Field of Vacuum

Each toroidal vortex (nucleon) in steady state operates as a sink of vacuum energy. The absorption power per nucleon, according to the balance equation (16), is Q. For a macroscopic body containing N nucleons, the total absorption power is $Q_{\text{total}} = NQ$. Since the body mass m is proportional to N, we can write:

$$Q_{\text{total}} = \kappa m \tag{17}$$

where κ is a constant characterizing the absorption efficiency per nucleon.

Energy absorption creates a stationary energy density flux field $\vec{S}$ in the surrounding vacuum. For a point sink of power Q in an unbounded medium, the solution of the continuity equation for energy flux gives:

$$S(r) = \frac{Q}{4\pi r^2} \tag{18}$$

where r is the distance from the sink. The vector $\vec{S}$ is directed radially toward the sink center.

8.2 Gravitational Force as a Result of Pressure Gradient in Vacuum

In the hydrodynamic vacuum model, energy flux $\vec{S}$ is related to momentum flux. For an isotropic medium at large distances from the vortex, it can be considered that energy flux creates a radial gradient of scalar pressure P in the vacuum.

The energy flux from a sink (nucleon) is spherically symmetric:

$$S(r) = \frac{Q}{4\pi r^2} \tag{19}$$

In the hydrodynamic approximation, energy flux is related to pressure through the speed of propagation of longitudinal disturbances in the vacuum c_s:

$$\frac{dP}{dr} = -\frac{S(r)}{c_s} \tag{20}$$

Substituting the expression for $S(r)$:

$$\frac{dP}{dr} = -\frac{Q}{4\pi c_s r^2} \tag{21}$$

Integrating over radius:

$$P(r) = P_0 - \frac{Q}{4\pi c_s r} \tag{22}$$

This agrees with classical ideas of Dirac about the ether as a fluid [6] and modern models where gravity is a fluid phenomenon in a superfluid vacuum [7, 19].

8.3 Interaction Force Between Two Bodies

Consider two macroscopic bodies with masses m_1 and m_2, separated by distance R. In first approximation, each body creates a pressure field around itself. However, for dense macroscopic bodies, shielding is inevitable - a phenomenon where outer layers of matter partially absorb the energy flux directed toward inner layers.

This leads to effective reduction of absorption power for deeply located nucleons. We introduce a shielding coefficient $0 < \xi \leq 1$, so the effective absorption power for a body is:

$$Q_{\text{eff}} = \xi \kappa m \tag{23}$$

For a small body 2 located in the pressure gradient created by body 1, the resulting force is estimated as:

$$F = -\gamma Q_{\text{eff2}} \nabla P_1 \tag{24}$$

Substituting expressions considering shielding:

$$F = -\gamma(\xi_2 \kappa m_2) \left(\frac{\xi_1 \kappa m_1}{4\pi c_s R^2} \right) \vec{e}_R = -G \frac{m_1 m_2}{R^2} \vec{e}_R \tag{25}$$

where the gravitational constant $G = \frac{\gamma \xi_1 \xi_2 \kappa^2}{4\pi c_s}$.

8.4 Model Consistency Check

Let us check whether the model can be reconciled with the observed gravitational constant by introducing reasonable parameters. For simplicity, assume all coefficients are on the order of unity and shielding equals one.

1. **Initial data and target values:**

$$\begin{aligned} G &\approx 6.67 \times 10^{-11}\,\text{m}^3/(\text{kg} \cdot \text{s}^2) \\ v &= 3 \times 10^8\,\text{m/s} \\ \rho &= 8.85 \times 10^{-12}\,\text{kg/m}^3 \quad \text{(vacuum density according to [10])} \\ m_p &= 1.67 \times 10^{-27}\,\text{kg} \end{aligned}$$

2. **Estimate of lower bound for speed of sound**
From [10] we get $q = \rho v S = 1.6 \times 10^{-19}$ kg/s. Then the speed of sound in the modeled medium will be not less than the flow velocity.

$$c_s \geq \frac{1.6 \times 10^{-19}}{(8.85 \times 10^{-12})(1.26 \times 10^{-29})} = 1.44 \times 10^{21}\,\text{m/s} \tag{26}$$

(indirectly confirmed by quantum effects that propagate nonlocally or with far superluminal speed).

From [13] it can be concluded that the vacuum energy density is at least 10^{35} J/m^3. A similar value was obtained in work [3], which investigated outward-directed pressure inside protons. It is fair to assume that in space external to the proton, the pressure should be similar. For a near-ideal gas, the expression for sound speed is valid:

$$c_s = \sqrt{\frac{\gamma P}{\rho}} \tag{27}$$

Then the sound speed estimate is:

$$c_s \approx \sqrt{\frac{1.4 \times 10^{35}}{8.85 \times 10^{-12}}} \approx 1.26 \times 10^{23}\,\text{m/s} \tag{28}$$

3. **Determination of κ from gravitational constant:**
From the formula $G = \frac{\kappa^2}{4\pi c_s} \approx \frac{\kappa^2}{1.58 \times 10^{24}}$ it follows:

$$\begin{aligned} \kappa^2 &\approx G \times 1.58 \times 10^{24} \approx 6.67 \times 10^{-11} \times 1.58 \times 10^{24} \approx 1.05 \times 10^{13} \\ \kappa &\approx 1.03 \times 10^7\,\text{W/kg} \end{aligned}$$

4. **Absorption power per nucleon:**

$$Q = \kappa m \approx 1.03 \times 10^7 \times 1.67 \times 10^{-27} \approx 1.71 \times 10^{-20}\,\mathrm{W} \tag{29}$$

5. **Estimate of kinematic viscosity ν:**
   From the dissipation formula:

$$\begin{aligned}
P_{\text{diss}} &\approx \eta C_d \rho \nu v^2 a \\
1.71 \times 10^{-20} &\approx \eta \times 1 \times (8.85 \times 10^{-12})\nu(9 \times 10^{16})(0.25 \times 10^{-15}) \\
1.71 \times 10^{-20} &\approx \eta \times 1.99 \times 10^{-10}\nu \\
\nu &\approx \frac{8.61 \times 10^{-11}}{\eta}\,\mathrm{m}^2/\mathrm{s}
\end{aligned}$$

The range of permissible ν values turns out to be quite wide $\geq 8.61 \times 10^{-11}$, however these values do not contradict experimental data and correspond to initial premises. This estimate shows that the model can be mathematically reconciled with the observed gravitational constant. This agrees with models where G depends on scale and vacuum energy [8].

9 Relationship Between Gravity and Electromagnetism in a Unified Hydrodynamic Picture

9.1 Consistency of the Model with Electromagnetic Properties of Nucleons

As shown in work [10], the velocity of the quantum vacuum can be identified with the vector potential $\vec{A}$, and its potential with the scalar potential ϕ. As shown in work [11], the neutron, despite having zero net charge, has a complex charge distribution inside the vortex, explaining its gravitational interaction on par with the proton. In the toroidal model, such properties arise from the helical charge structure [5].

9.2 Unified Mechanism of Interactions

In the proposed model:

- **Electromagnetic interaction** arises from the direct effect of vortex velocity and pressure fields on other vortices through vector and scalar potentials [10, 11, 12].
- **Gravitational interaction** is a secondary, statistical effect arising from the creation of a pressure gradient in the vacuum during energy absorption by nucleons.

Both interactions have a common hydrodynamic nature but manifest at different scales and through different components of vacuum dynamics. This echoes Sakharov's induced gravity, where gravity arises from quantum fields [16, 18].

10 Experimental Predictions and Research Directions

To transfer the model from the category of speculative constructions to the area of testable scientific hypotheses, the following program of experimental research is proposed. It aims to validate the key tenets of the theory, in particular, the idea of vacuum energy absorption and the emergence of a pressure gradient. Analog simulations in fluids can be used for testing, including observation of Hawking radiation and Penrose superradiance [2].

10.1 Verification of the Fundamental Energy Absorption Mechanism

Instead of testing the speculative "shielding," experiments should be directed at directly testing the hypothesis that nucleons are sinks of vacuum energy.

Hypothesis: If nucleons absorb vacuum energy, then a dense array of nuclear matter can create a detectable gradient in the surrounding vacuum.

Experimental setup: Use highly sensitive atomic interferometers or micro-mechanical resonators to search for anomalies in the behavior of atoms or particles near massive high-density objects (e.g., near compact samples of tungsten or depleted uranium). **Measurement** concerns potential deviation from predictions of standard quantum mechanics for non-interacting particles.

Model falsification criterion: If under controlled conditions no statistically significant deviation from background noise is detected, the hypothesis of a stationary energy flux toward matter will be called into question.

10.2 Search for Deviations from the Law of Universal Gravitation

The model predicts that the inverse square law may be violated at distances comparable to the effective size of the nucleon vortex structure or with the scattering length of "energy fluxes" in the vacuum.

Hypothesis: At ultrasmall distances (from femtometers to nanometers), gravitational interaction ceases to be purely radial and its force deviates from $\sim 1/r^2$ dependence.

Experimental setup: Conduct high-precision **measurements** of gravitational force in the range from 100 nm to 10 microns using torsion balances or microelectromechanical systems (MEMS). Such experiments are already being conducted to search for traces of extra spatial dimensions, but within our model they are interpreted as testing the hydrodynamic nature of the vacuum.

Falsification criterion: Absence of any deviations from Newtonian gravity in the investigated distance range would testify against the idea that gravity is a macroscopic manifestation of processes having a characteristic micro-scale.

10.3 Investigation of the Relationship Between Gravity and Quantum Fluctuations

This direction tests whether the "vacuum temperature" in the model is merely a metaphor or whether it is related to real, controllable quantum fluctuations.

Hypothesis: The intensity of gravitational interaction may be modulated by locally changing the energy of quantum vacuum fluctuations.

Experimental setup: Conduct precision measurements of the gravitational constant G under conditions of active influence on the vacuum. A key experiment is placing test masses in a powerful electromagnetic field (to polarize the vacuum) or under Casimir effect conditions (to limit the fluctuation spectrum).

Falsification criterion: If changing the configuration of quantum fluctuations (e.g., changing the gap in Casimir plates) does not have any statistically significant effect on the measured attraction force, this would weaken the model's position postulating a deep connection between the "thermal" energy of the vacuum and gravity.

10.4 Unification: Search for Gravitational-Electromagnetic Correlations

Since the model claims a common hydrodynamic nature of interactions, it should predict new effects at their interface.

Hypothesis: Rapid change in the electromagnetic state of matter (e.g., polarization or magnetization) can cause transient (short-term) changes in its local gravitational field, not described by GR.

Experimental setup: Use superconducting quantum interferometers to detect possible gravitational anomalies near superconductors at the moment of their transition through the critical temperature or when exposed to a strong magnetic field. Data analysis should include methods for comparing signals in different operating modes of the setup and identifying weak correlated patterns.

Falsification criterion: Absence of correlation between electromagnetic processes and gravitational sensor readings would indicate that the unifying potential of the model has no experimental basis.

11 Conclusion

The developed hydrodynamic model of the quantum vacuum offers a qualitative mechanism for unifying gravitational and electromagnetic phenomena, deriving the force of gravity not from the geometry of spacetime but from the dynamics of absorption and dissipation of energy by a fundamental medium. The current work focuses on formulating falsifiable predictions that allow transferring the theoretical construction into the plane of experimental science.

The key result of this research is not simply a mathematical analogy, but a concrete plan for validating or refuting the basic postulates of the model. The proposed experiments are aimed at directly testing its fundamental foundations.

Thus, the model becomes a source of new, testable hypotheses. Its main value lies not in final answers, but in the ability to ask clear, verifiable questions. Regardless of the outcome of experimental verification, whether they confirm or refute the model, the obtained data will have fundamental significance for understanding the nature of gravity and vacuum, potentially opening the way to new physics beyond the Standard Model and General Relativity. Further work will focus on a more rigorous quantitative description of the predicted effects for direct comparison with future experimental results.

References

[1] T. Banks. The hydrodynamic approach to quantum gravity. *arXiv*, 2025.

[2] S. L. Braunstein et al. Analogue simulations of quantum gravity with fluids. *Nature Reviews Physics*, 5:612–622, 2024.

[3] A. Burkert et al. The pressure distribution inside the proton. *Nature*, 557:396–399, 2018.

[4] Wikipedia contributors. Superfluid vacuum theory. `https://en.wikipedia.org/wiki/Superfluid_vacuum_theory`, 2025. Accessed: 2025.

[5] Wikipedia contributors. Toroidal ring model. `https://en.wikipedia.org/wiki/Toroidal_ring_model`, 2025. Accessed: 2025.

[6] P. A. M. Dirac. Is there an Æther? *Nature*, 169(4304):702, 1952.

[7] M. Fedi. Gravity as a fluid dynamic phenomenon in a superfluid quantum space. *HAL Archives*, 2016.

[8] I. Fouxon. Quantum vacuum energy as the origin of gravity. *arXiv*, arXiv:2509.02636, 2025.

[9] M. J. Jacquet et al. Quantum vacuum excitation of a quasinormal mode in an analog model of black hole spacetime. *Physical Review Letters*, 130, 2023.

[10] D. S. Losinets. Formal analogy between maxwell's equations and vortex dynamics in weakly viscous media. *Zenodo*, 2025.

[11] D. S. Losinets. Model of the internal structure of nucleons based on a vortex analogy: A self-consistent description of magnetic moments. *Zenodo*, 2025.

[12] D. S. Losinets. Vortex photon model: Program for experimental verification. *Zenodo*, 2025.

[13] E. Margan. Estimating the vacuum energy density - an overview of possible scenarios. *Preprint*, 2018.

[14] A. L. Parson. A magneton theory of the structure of the atom. *Smithsonian Miscellaneous Collection*, 65(11):1–80, 1915.

[15] A. Rizzo. Negative mass and inertia in the quantum vacuum hydrodynamics. *ResearchGate*, 2024.

[16] A. D. Sakharov. Vacuum quantum fluctuations in curved space and the theory of gravitation. *Soviet Physics Doklady*, 12:1040–1041, 1967.

[17] K. P. Sinha, C. Sivaram, and E. C. G. Sudarshan. The superfluid vacuum state, time-varying cosmological constant, and nonsingular cosmological models. *Foundations of Physics*, 6:717–726, 1976.

[18] M. Visser. Sakharov's induced gravity: a modern perspective. *Modern Physics Letters A*, 17:977–992, 2002.

[19] G. Volovik. Vacuum energy: Quantum hydrodynamics vs. quantum gravity. *JETP Lett.*, 82(6):319–324, 2005.

[20] K. G. Zloshchastiev. Spontaneous symmetry breaking and mass generation as built-in phenomena in logarithmic nonlinear quantum theory. *Acta Physica Polonica B*, 42(2):261–292, 2011.