Reference-Scientific Contributions:

Wigner's elementary systems in de Sitter spacetime

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Quantum elementary systems correspond to (projective) unitary irreducible representations (UIRs) of the relativity group, or one of its covering groups. This foundational perspective was first introduced by Wigner in the context of Einstein-Poincaré relativity in his seminal paper [Ann, Math., 40, 149 (1939)] and further elaborated in [Rev. Mod. Phys., 21, 400 (1949)]. Wigner demonstrated that the rest mass m and spin s uniquely characterize the UIR of the Poincaré group, which governs the symmetries of flat Minkowski spacetime. Subsequent researchers expanded this framework to include Galilean, de Sitter (dS), and anti-de Sitter (AdS) systems. For an in-depth exploration of these developments, refer to my recent collaborative book.

In line with Wigner's pioneering work, my research focuses on constructing elementary systems within the global structure of (A)dS spacetime. It is based on: the principles of the (A)dS$_d$ representation theory (in the Wigner sense); the Wightman-Gärding axioms; and the essential analyticity prerequisites in the complexified pseudo-Riemannian manifold.

The works submitted for this competition are organized into three thematic sets to reflect different aspects of this research. Each set should be evaluated within this theoretical context.

Set 1: Covariant Quantization of the Graviton Field in de Sitter Spacetime:

This first set emphasizes our work on the covariant quantization of the graviton (massless spin-2) field in dS spacetime. Key papers include:

1. Pejhan, H., Bamba, K., Rahbardehghan, S., Enayati, M. (2018). Massless spin-2 field in de Sitter space. Physical Review D, 98(4), 045007.

2. Bamba, K., Rahbardehghan, S., Pejhan, H. (2017). Vacuum states for gravitons field in de Sitter space. Physical Review D, 96(10), 106009.

3. Pejhan, H., Rahbardehghan, S. (2016). Covariant and infrared-free graviton two-point function in de Sitter spacetime. II. Physical Review D, 94(10), 104030.

4. Pejhan, H., Rahbardehghan, S. (2016). Covariant and infrared-free graviton two-point function in de Sitter spacetime. Physical Review D, 93(4), 044016.

5. Pejhan, H., Tanhayi, M. R., Takook, M. V. (2010). Auxiliary massless spin-2 field in de Sitter universe. International Journal of Theoretical Physics, 49(9), 2263-2277.

These studies contribute a rigorous, covariant formulation of the graviton two-point function in dS spacetime, addressing infrared finiteness and advancing the understanding of massless spin-2 fields in a curved, dS background.

Set 2: Exploration of Conformal Symmetry and the dS Graviton Field in an Expanded Symmetry Context:

The second set of papers broadens the scope to include conformal symmetry, of which dS symmetry is a subgroup, thus situating the dS graviton field in a wider symmetry framework:

1. Rahbardehghan, S., Pejhan, H., Elmizadeh, M. (2015). A group theoretical approach to graviton two-point function. The European Physical Journal C, 75, 1-9.

2. Tanhayi, M. R., Pejhan, H., Takook, M. V. (2012). Conformal linear gravity in de Sitter space II. The European Physical Journal C, 72, 2052.

These papers examine the implications of conformal symmetry on the graviton field, providing insights into the broader symmetry structures that encompass dS spacetime.

Set 3: Krein Space Quantization and Vacuum Energy Problem

The above body of work highlights a unique form of gauge invariance in the context of the graviton field in dS spacetime, which, at the quantum level, reveals an anomaly that destabilizes the theory's internal consistency. This "gauge anomaly" leads to the absence of well-defined, dS-invariant Euclidean/Bunch-Davies vacuum states, necessitating a fundamental shift in approach. To address this issue, a framework that extends beyond the traditional Hilbert space formalism is required, leading to the adoption of a Krein space structure — characterized by an indefinite inner product rather than a positive-definite one. This Krein quantization approach ensures that the theory retains all the critical features of a free field in the high-symmetry setting of dS spacetime, including the positivity of the norm for all physical states, adherence to causality, full covariance, and positivity of the energy operator.

This approach naturally raises questions regarding vacuum energy within the Krein quantization framework. In semiclassical quantum gravity, the expectation values of the energy-momentum tensor are crucial, as they act as the source of gravity in the Einstein equation. Thus, understanding vacuum energy in this context is essential for self-consistent models that incorporate gravitational dynamics.

To explore these implications, the following papers are devoted to investigating the vacuum energy within the Krein quantization context:

1. Pejhan, H., Bamba, K., Enayati, M., Rahbardehghan, S. (2018). A small non-vanishing cosmological constant from the Krein–Gupta–Bleuler vacuum. Physics Letters B, 785, 567-569.

2. Pejhan, H., Rahbardehghan, S. (2016). Casimir energy-momentum tensor for a quantized bulk scalar field in the geometry of two curved branes on Friedmann-Robertson-Walker background. Physical Review D, 94(6), 064034.

3. Pejhan, H., Rahbardehghan, S. (2016). Examining a covariant and renormalizable quantum field theory in de Sitter space by studying "black hole radiation". International Journal of Modern Physics A, 31(11), 1650052.

4. Rahbardehghan, S., Pejhan, H. (2015). The Krein–Gupta–Bleuler quantization in de Sitter space-time; Casimir energy-momentum tensor for a curved brane. Physics Letters B, 750, 627-632.

5. Pejhan, H., Tanhayi, M. R., Takook, M. V. (2014). Casimir effect for a scalar field via Krein quantization. Annals of Physics, 341, 195-204.

These studies provide a comprehensive analysis of the vacuum energy problem within the Krein quantization approach, advancing our understanding of quantum field theory in dS spacetime and its implications for gravitational dynamics.