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Editorial: Generalized uncertainty relations: existing paradigms and new approaches

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Editorial on the Research Topic
Generalized uncertainty relations: existing paradigms and new approaches

Introduction

This volume brings together a series of papers on the Research Topic of Generalized Uncertainty Relations (GURs). These works are chosen to provide a broad and timely overview of the current status of this important field, some 30 years after its initial development, including both phenomenological applications and foundational issues. Critical analyses of unsolved problems are also presented.

Scope and aims of the project

Our aim is to collect, in a single volume, a series of works that are representative of the current state of the art, and which, with the benefit of nearly three decades of hindsight, can contribute to the ongoing critical assessment of the field; its methods, models and techniques. We hope, therefore, that this modest collection will serve as a valuable resource and point of reference for future researchers, and, perhaps, even a small but significant mile stone in the development of the GUR research program.

After 30 years, we face the question: *quo vadis* generalized uncertainty principle? (Bosso et al., 2023) A further aim of this project is to stimulate debate about the future direction of GUR research, in particular, regarding the suitability of the current widely-used approach, of implementing modified relations via modifications of the canonical Heisenberg algebra. Despite nearly 30 years of effort, it remains unclear whether this method is conceptually and mathematically self-consistent, or whether new methods and techniques for studying GURs must be found.

For this reason, we present a variety of perspectives. Some papers in this volume explore the implications of traditional modified commutator models, while others present purely phenomenological analyses. The latter may be expected to hold, regardless of which mathematical formalism is used to describe the GURs, whereas the former are more model-specific, in general. Some papers explore well known GURs, such as the generalized uncertainty principle (GUP) and extended uncertainty principle (EUP), while others present new forms of modified relations, based on different physical assumptions. Still others explore alternative mathematical formalisms for the GUP and EUP, and investigate their phenomenological consequences. Whatever the research interests or perspectives of the individual reader, we hope that they will find something of interest to them here.

Call for papers

The non-gravitational interactions of microscopic particles are governed by the laws of quantum mechanics and so obey Heisenberg's uncertainty principle. This may be derived rigorously from the canonical quantum formalism or introduced, heuristically, via the Heisenberg microscope thought experiment. Extending the thought experiment argument to include the effects of gravitational attraction between particles and/or a background dark energy density leads to generalized uncertainty relations, which contain additional non-Heisenberg terms, but how to embed these within an extended quantum formalism remains an open problem in fundamental physics.

Two of the most widely studied relations, proposed in the phenomenological quantum gravity literature, are the generalized uncertainty principle (GUP) and extended uncertainty principle (EUP). The GUP incorporates the effects of attractive gravity and implies a minimum length scale of the order of the Planck length, whereas the EUP accounts for the effects of repulsive vacuum energy and implies a minimum momentum of the order of the de Sitter momentum. This is the momentum a canonical quantum particle would have if its de Broglie wavelength were of the order of the de Sitter radius, which is comparable to the present day radius of the Universe. Expanding the Heisenberg microscope argument to include the effects of canonical gravity and dark energy implies the extended generalized uncertainty principle (EGUP) which predicts the existence of both a minimum length and a minimum momentum scale in nature.

For almost three decades the most common method used to construct generalizations of the Heisenberg uncertainty principle has been to introduce modified commutation relations. These then lead, directly, to modified uncertainty relations, via the standard Schrödinger-Robertson relation. Unfortunately, despite its widespread use, this approach remains fraught with difficulties and modified commutator models lead to several well known pathologies, including:

(a) Violation of the equivalence principle,
(b) Reference-frame dependence of the "minimum" length,
(c) Violation of Lorentz invariance in the relativistic limit,
(d) The inability to construct sensible multi-particle states, known as the soccer ball problem.

This strongly motivates new approaches to the field, as well as critical analyses of traditional models, or their possible refinements, which aim to address these vital issues head-on.

In this Research Topic, we seek papers exploring all approaches to generalized uncertainty relations and their phenomenological implications. We aim to provide a broad overview the subject including summaries of the major approaches presented, to date, in this important field, as well as summaries of non-standard approaches based on new models.

Though many studies focus on the familiar GUP, EUP and EGUP formulae, which include position and linear momentum, we especially welcome explorations of generalized uncertainty relations for time, energy, angular momentum, quantum mechanical spin, and entropy, motivated by quantum gravitational phenomenology. Proposals for new relations, which have not yet been explored in the existing literature, are also warmly welcomed, and will be considered without prejudice.

Published papers

1. *Dark matter as an effect of a minimal length*, Bosso et al.
2. *Generalized uncertainty principle and burning stars*, Moradpour et al.
3. *Weak equivalence principle in quantum space*, Gnatenko and Tkachuk.
4. *Comments on the cosmological constant in generalized uncertainty models*, Bishop et al.
5. *The Generalized Uncertainty Principle and higher dimensions: Linking black holes and elementary particles*, Carr.
6. *Generalized uncertainty relations from finite-accuracy measurements*, Lake et al.
7. *Problems with modified commutators*, Lake and Watcharapasorn.
8. *New deformed Heisenberg algebra from the μ-deformed model of dark matter*, Gavrilik et al.
9. *Dimensionally-dependent uncertainty relations, or why we (probably) won't see black holes at the LHC, even if large extra dimensions exist*, Lake et al.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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