2021/43/P/ST2/01802

Wavization and quantization of the observables in the universe

WAQOU

Nov 01, 2022

Oct 31, 2024

Funding

This research is part of the project No. 2021/43/P/ST2/01802 co-funded by the National Science Centre and the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie grant agreement no. 945339.

POLONEZ BIS

1,000,352.0 PLN

Description

The observational information we obtain from the sky regarding the brightnesses, the distances and the image distortions resides in the dynamics of a light bundle. The main goal of this project is to establish a theoretical framework to study (i) classical wave effects and (ii) quantum effects on the propagation of a thin light bundle, which are most relevant for the observations on the sky. Even though the main objective is the light propagation, gravitational waves will be our next point of interest in this project. Previously, we studied the general relativistic evolution of a light bundle on a reduced phase space. This was achieved by following a Hamiltonian formalism. Accordingly, the bundle propagation was represented via linear symplectic transformations which are analogous to the transformations in Newtonian optics for paraxial rays. In the current project, we will be utilizing the aforementioned formalism of ours. It is known that, in general, the Maxwell equations do not have explicit, exact solutions in general relativity. Therefore, firstly, we will aim to recover the wave properties of light from the geometric optics limit, without solving the Maxwell's equations up to full order. This will be achieved via the analogies between classical–to–quantum mechanics and ray–to–wave optics. In this protocol, the correspondence between the symplectic transformations and metaplectic operators will be our primary instrument in order to obtain the classical wave spreading. We will then apply our formalism to certain astrophysical and cosmological scenarios like (i) comparison of different spacetimes via their wave optics properties and finding their wave–only observables, and (ii) propagation of light bundles beyond caustics. In addition, geometric optics is relevant for the investigation of gravitational waves at the linear order. Therefore, we will also recover (iii) the wave effects on the propagation of gravitational waves for different cosmological scenarios. Secondly, we plan to quantize the light bundle via a semi–classical method which is already known in the literature but was never used in this context. In this formalism, a translation in the quantum mechanical phase space is obtained by Heisenberg operators and the spreading is obtained via the metaplectic operators. We are also planning to perform an analysis of this method under the hydrodynamic interpretation which is also known as the de Broglie-Madelung-Bohm theory. Our interpretation will be statistical in nature as the classical evolution is indeed coarse–grained. This method will allow us to identify the gravitational phenomena that are responsible for the quantum behavior of the bundle via the so–called quantum potential. Finally, we would like to obtain exact results for our ray bundle propagation matrices. At a first glance, this does not seem to be very likely for generic scenarios, as the acquirement of a ray bundle transfer matrix follows from the computation of an ordered exponential map of the Hamiltonian matrix of the problem. This would mean that the ray bundle transformation matrices can be obtained through a Magnus series expansion calculated via certain numerical methods. However, there exist a new graph theory method in the literature which can in principle be used in our situation. We are planning to implement this new method to our problem in order to obtain exact results for the ray bundle transformation matrices. We are expecting a big impact with this project as there has been an increased interest in the wave effects on the propagation of both the electromagnetic and gravitational waves lately. However, the current literature lacks a generic formalism to study those effects for different scenarios. Our aim is to fill this gap with our current project.

The Project is financed by the Polish National Agency for Academic Exchange under the Foreign Promotion Programme