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Bohmian field theory on a shape dynamics background and Unruh effect

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A R T I C L E I N F O

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A B S T R A C T

In this paper, we investigate the Unruh radiation in the Bohmian field theory on a shape dynamics background setting. Since metric and metric momentum are real quantities, the integral kernel to invert the Lichnerowicz–York equation for first order deviations due to existence of matter terms turns out to be real. This fact makes the interaction Hamiltonian real. On the other hand, the only contribution to guarantee the existence of Unruh radiation has to come from the imaginary part of the temporal part of the wave functional. We have proved the existence of Unruh radiation in this setting. It is also important that we have found the Unruh radiation via an Unruh–DeWitt detector in a theory where there is no Lorentz symmetry and no conventional space–time structure.

1. Introduction

Shape dynamics (SD) [1–5] (see Ref. [6] for a review) is a theory of gravitation that is based on 3-conformal geometries where time is absent, based on Julian Barbour's interpretation of the Mach's principle [7]. Although SD agrees with general relativity locally (hence passing all the tests in the low curvature regime) it may have global differences: for example the spherically symmetric vacuum solution is not the Schwarzschild black hole but rather a wormhole [8]. Moreover space–time is an emergent phenomenon in SD and it exactly ceases to emerge at the event horizon of the spherically symmetric vacuum solution of SD [8]. This fact may be related to the firewall paradox and its solution. In Ref. [8] this was also speculated in the context of ER=EPR [9] scenario. See Ref. [10] for more speculation on SD resolution of the firewall paradox.

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Bohmian mechanics (BM) [11–13] (see Ref. [14] for a review) is an observer-free interpretation of quantum mechanics. There, the quantum particles have definite positions whereas the whole system is always $|\psi|^2$ distributed. Hence Born's statistical interpretation of quantum mechanics is respected. On the other hand Bohmian *field theory* (BFT) [15–23] is an attempt to give quantum field theory a Bohmian interpretation.

In this paper we give a derivation for the existence of the Unruh effect [24] from the perspective of Bohmian field theory. For this purpose we use a 3-dimensional shape dynamics theory on top of which there is a massive scalar Bohmian field. In order to quantify the existence of Unruh effect, we use the jump rates *i.e.* transition rate explained in Section 5 from Bohmian field theory. For this purpose we summarize SD and BFT in Sections 2 and 5. We give a description of scalar fields on shape dynamics background following [25] in Section 3. In Section 6 we give details on how to put Bohmian fields on a shape dynamics background and show the existence of the Unruh effect in this setting.

2. A brief account of shape dynamics

In this part we give a short review of SD which is originally a theory on compact spaces [2,3]. Its configuration space is the same as that of general relativity [4,5]. In SD, the basic ontology is conformal 3-geometries. Hence the theory is symmetric under (volume preserving) conformal transformations. If the reader is interested in the case of asymptotically flat space, Ref. [26] is a good source. However, in our approach we will closely follow Ref. [25].

Let Σ, N and ξ^a respectively be a compact Cauchy surface, a lapse function and a shift vector field. In the ADM (Arnowitt, Deser, and Misner) formalism [27] the line element of GR is written as follows (in the mostly plus signature):

$$ds^2 = (g_{ab}\xi^a\xi^b - N^2)dt^2 + 2g_{ab}\xi^a dx^b dt + g_{ab}dx^a dx^b. \tag{1}$$

It is found that N, ξ^a turn out to be Lagrange multipliers of the following constraints:

$$S(N) = \int_\Sigma d^3x N\Big(\frac{\pi^{ab}(g_{ac}g_{bd} - g_{ab}g_{cd}/2)\pi^{cd}}{\sqrt{g}} - (R - 2\Lambda)\sqrt{g} + \text{matter terms}\Big), \tag{2}$$

$$H(\xi) = \int_\Sigma d^3x(\pi^{ab}\mathcal{L}_\xi g_{ab} + \pi^A \mathcal{L}_\xi \phi_A), \tag{3}$$

where ϕ_A and π^A stand for matter fields and their conjugate momenta. Time evolution is generated by $S(N) + H(\xi)$. In the Constant Mean Extrinsic Curvature (CMC) gauge fixing of GR ($\pi - \langle\pi\rangle\sqrt{g} = 0$), there is a conformal factor Ω_0 that solves the Lichnerowicz–York (LY) equation:

$$8\nabla^2\Omega = R\Omega + \left(\frac{\langle\pi\rangle^2}{6} - 2\Lambda\right)\Omega^5 - \frac{1}{g}\Omega^{-7}\sigma^{ab}\sigma_{ab} + \text{matter terms}, \tag{4}$$

where $\sigma^{ab} \equiv \pi^{ab} - \pi g^{ab}/3$ is the trace-free part of the conjugate momentum of the metric. It turns out that the York Hamiltonian, $\int_\Sigma d^3x\sqrt{g}\Omega_0^6$, generates time evolution in York time, $\tau = 2\langle\pi\rangle/3$ where $\pi = \pi^{ab}g_{ab}$ and $\langle\pi\rangle = \int_\Sigma \pi / \int_\Sigma \sqrt{g}$. The smeared gauge-fixing condition

$$Q(\rho) = \int_\Sigma d^3x\rho\left(\pi - \frac{3}{2}\tau\sqrt{g}\right) \tag{5}$$

works "as a generator of spatial conformal transformation for the metric and the trace-free part of the metric momenta and forms a closed constraint algebra with the spatial diffeomorphism generator" [25]. Therefore the gauge-fixing condition (5) can be used to map $\pi \to \frac{3}{2}\tau\sqrt{g}$ and from now on τ becomes an "abstract evolution parameter" [25] and the total volume of space, $V = \int_\Sigma d^3x\sqrt{g}$, is a pure gauge entity. This new theory is called as shape dynamics with the Hamiltonian

$$H_{SD} = \int_\Sigma d^3x\sqrt{g}\Omega_0^6[g_{ab}, \pi^{ab} \to \sigma^{ab} + \frac{3}{2}\tau g^{ab}\sqrt{g}, \phi_A, \pi^A]. \tag{6}$$