Contribution ID: **269** Type: **Talk**

Role of Derivative Coupling in the Study of Acceleration Radiation in Curved Spacetimes

Friday, 27 June 2025 15:25 (15 minutes)

Since 1970, the phenomena of particle production in curved/ flat spacetime has been of consistent interest to many physicists. This has led us to remarkable findings such as Unruh effect, Hawking radiation, cosmological particle production and many more. Subsequently, to investigate its experimental relevance, the Unruh DeWitt (UD) detector model, based on atom-field interaction, has been widely employed in realistic setting. Aligning with this idea, Scully et al. proposed an alternative mechanism for particle production utilizing quantum optics techniques. This framework suggests that when ground state atomic detectors are accelerated through a high-Q microwave cavity, radiation is produced, and the detector's transition probability can be enhanced by several orders of magnitude compared to that from Unruh radiation.In the context of black hole (BH) spacetime, this alternative scheme of particle production is popularly known as "horizon brightened acceleration radiation (HBAR)". In this model the atomic detectors are minimally coupled with the field such as $H_{int} \sim g\mu(\tau)\phi[x(\tau)]$, where g depicts the coupling strength and $\mu(\tau)$, $\phi(x)$ represent the monopole moment for the atom and matter field respectively. Despite its several lucrative features, a minimally coupled UD detector model is plagued with infrared (IR) divergence for a massless field in $(1+1)$ dimensions. As a resolution, it was shown in the literature that this IR ambiguity can naturally be removed by considering the UD detector linearly coupled to the proper time derivative of the field amplitude. Analogous to the Unruh effect, in this work we investigate how derivative coupling influences the HBAR phenomenon in Schwarzschild spacetime for both point-like and finite size detectors. Remarkably, for the point-like detector we find the transition probability of the system is independent of the frequency of the detector. We suggest that the derivative coupling in the curved spacetime introduces an explicit coupling between the g^{tt} component of the background metric and the detector. The g^{tt} component may reflect some aspects of the gravitational fluctuations, in which case the detector will no longer be sharply tuned to a particular frequency but will be exposed to a range of frequencies due to its direct interaction with gravitational background. We predict that this in turn removes the effect of any particular frequency of the detector from the transition probability. Furthermore we show that this enhances the amplitude of the transition probability than that of the standard HBAR phenomenon as shown by Scully et al. in the context of BH. On the other hand for the finite size detector, we obtain the transition spectrum as dependent on the length/ extent (L), frequency (ω) of the detector. Deriving the equation of motion for the density matrix of the field, we find that the system has a zero steady state solution under the condition $L\omega < \sqrt{2}$. This result indicates that within this parameter space, the system exists in a non-equilibrium thermodynamic state, where standard thermal equilibrium and its consequences will no longer hold.

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Session Classification: Friday Parallel Session F