Quantum vacuum emission from a moving refractive index front

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Quantum fluctuations at the event horizon result in a steady thermal flux of light being emitted by black holes [1], a phenomenon commonly known as Hawking Radiation. It connects the realms of quantum physics, Einstein's theory of relativity, and thermodynamics. However, it is essentially impossible to observe in astrophysics because of its low temperature which depends on the inverse of the mass of the black hole. For example, a solar-mass black hole has a temperature well below that of the cosmic microwave background. Fortunately, moving wave media can be used to realize gravity analogues.

An artificial event horizon can be created by moving a refractive index front (RIF) in a dispersive optical medium at the speed of light [2]. The RIF could be created by a pulse of light that modifies the index by the optical Kerr effect. Light under the pulse will be slowed and thus the front of the pulse exhibits -for some frequencies- a black-hole type horizon capturing light. The back of the pulse acts as an impenetrable barrier, a white-hole horizon. Both event horizons separate two discrete regions: under the pulse, where light is slow and the pulse moves superluminally and outside the pulse, where the pulse speed is subluminal.

We use a fully quantized and analytical model [3] to calculate the quantum vacuum emission from all modes at any frequency and change of refractive index δn. Our moving RIF is modeled as an infinitely steep refractive index boundary between two homogenous media, as in fig. 1. We show that, over a certain frequency interval, the scattering of incoming into outgoing waves by the RIF is a black-hole-type emission. Indeed, no light from modes that live in the high refractive index region is allowed to propagate across the RIF into the low refractive index region. In the latter region, only one mode propagates away from the boundary, thus allowing light to escape the horizon. Moreover, some of the incoming and outgoing modes are found to have negative frequency. During the scattering process, waves are thus partially converted into pairs of waves with a different sign of frequency: the vacuum state for in- and out-going waves is different and particles are created in the outgoing waves.

We analytically calculate the spectrum of emission at the RIF in the frame moving with it as well as the laboratory frame. We investigate the influence of the strength of the refractive index change on the particle flux. As a result, the emission spectrum is highly structured into intervals of emission with black hole, white hole and no horizons, as shown in fig. 2. We find that the emission is strongest in the negative optical frequency mode and unique escaping mode. We also find that the total emission rate in this escaping mode for low refractive index changes rises with the third power, whereas the single mode emission rises quadratically, as in fig. 3.

In the laboratory frame, we see that the presence of optical horizons leads to an enhancement of the emission on the background of a horizonless emission that decays from the ultraviolet to the infrared. The largest spectral densities are obtained in the UV and visible range, and correspond to emission in the negative frequency mode and uniquely escaping mode respectively.

These detailed calculations are an essential step towards experimental observation of analogue Hawking Radiation.

FIG. 1. Refractive index front between two homogeneous region as seen from the moving frame

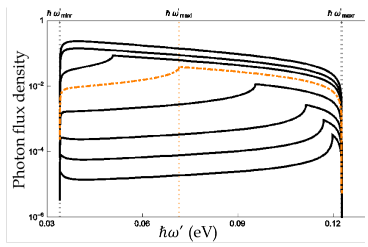

FIG. 2. Photon flux into the uniquely escaping mode for different change of refractive index

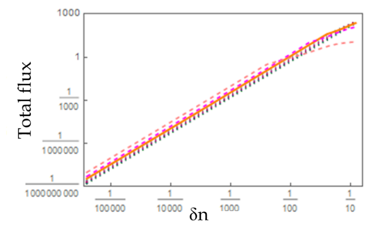

FIG. 3. Number of photons created in the uniquely escaping mode as a function of the change in refractive index

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