Contribution ID: **1159**   Type: **Talk**

Mixing of positive and negative frequency waves at the optical horizon

Tuesday, 22 August 2017 17:00 (20 minutes)

There exist various conditions under which waves of positive and negative Klein-Gordon norm can be made to convert into each other.
For example, upon propagating on a curved background, waves of positive and negative norm mix to generate outgoing waves.
As a result of this scattering process, field quanta are spontaneously emitted from the vacuum — the most famous instance of this effect undoubtedly is the mixing of positive and negative norm waves at the horizon of black holes, which results in a steady thermal flux to be emitted from the hole, Hawking radiation [1].

The event horizon of the black hole is the point at which the curvature of spacetime is such that the escape velocity out to infinity becomes superluminal, thus restricting wave propagation to one direction only: toward the central singularity.
Wave propagation on a curved background geometry is not restricted to astrophysics: it is possible to realise an effectively curved geometry with moving wave media in the laboratory, and, in particular, the kinematics of waves at the horizon [2].

An artificial event horizon can be created when a refractive index front (RIF) is moving at the speed of light in a dispersive optical medium [3].
The RIF could be created by a pulse of light that modifies the refractive index by the optical Kerr effect — a nonlinear effect by which the refractive index depends upon the square of the electric field in the medium.
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 reveal the properties of spontaneous emission from the vacuum at a moving refractive index step in a dispersive dielectric by expanding on an analytical model for light-matter interaction [4]. We establish the conditions for event horizons as a function of the speed and height of the step in the medium, and study the various configurations of modes of the field in the vicinity of the step with and without analogue horizons. We then analytically calculate the emission spectra from all modes of positive and negative norm in the laboratory frame [5]. We find that, as a result of the various mode configurations, the spectrum is highly structured into intervals with black hole-, white hole-, and no horizon.

The emission spectrum in the laboratory frame is found to be a combination of emissions corresponding to different frequencies in the frame moving with the pulse, leading to a characteristic shape. In particular, the existence of a peak in the ultraviolet, associated with emission into a mode with negative norm, is an interesting feature of our spectrum.
We show how emission in this peak may be stimulated by scattering a coherent wave at the horizon.

We also report on an experiment to study the dynamics of waves at the optical horizon.
A weak CW-probe is made to scatter on a RIF created by an intense, ultrashort pulse in a photonic crystal fibre under fine-tuned horizon-like conditions.
As a result of mode conversion at the horizon, light at different wavelengths is generated: the probe is partially shifted in frequency — positive-to-positive norm conversion occurs as predicted by our theory.
Furthermore, we investigate the companion effect of stimulated emission in a negative norm wave.

The effect of mode conversion is clearly shown to be a feature of horizon physics.
This experiment is a stimulated version of the spontaneous quantum effect at the heart of Hawking radiation.

[1] S. Hawking, Nature 248, 30 (1974).
[2] W.G. Unruh, Phys. Rev. Let. 46 (1981).
[3] T.G. Philbin et al Science 319, 1367 (2008).
[4] S. Finazzi and I. Carusotto, Phys. Rev. A 87, 023803 (2013).
[5] M. Jacquet and F. Koenig, Phys. Rev. A 92, 023851 (2015).

Topic:

Mini-workshop: Continuous Variables and Relativistic Quantum Information

Summary

We analytically calculate the laboratory-frame spectrum of light spontaneously emitted from the vacuum as a result of the mixing of waves with positive and negative norm at an optical horizon in a dispersive medium. We perform a stimulated experiment in which energy is converted from a positive-norm continuous wave to outgoing waves of different frequency.

Author: Dr JACQUET, Maxime (University of St Andrews)

Co-authors: SINGH, Vyome (University of St Andrews); Dr KOENIG, Friedrich (University of St. Andrews)

Presenter: Dr JACQUET, Maxime (University of St Andrews)

Session Classification: Workshop on continuous variables and quantum information

Track Classification: Workshop on Cont. Variables and Rel. Quantum Information