



**HAL**  
open science

## Quantum vacuum excitation of a quasi-normal mode in an analog model of black hole spacetime

Malo Joly, Luca Giacomelli, Ferdinand Claude, Elisabeth Giacobino, Quentin Glorieux, Iacopo Carusotto, Alberto Bramati, Maxime J. Jacquet

► **To cite this version:**

Malo Joly, Luca Giacomelli, Ferdinand Claude, Elisabeth Giacobino, Quentin Glorieux, et al.. Quantum vacuum excitation of a quasi-normal mode in an analog model of black hole spacetime. *Physical Review Letters*, 2023, 256 (11), pp.08005. 10.1103/PhysRevLett.130.111501 . hal-03420625

**HAL Id: hal-03420625**

**<https://hal.science/hal-03420625v1>**

Submitted on 17 Oct 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

# Quantum vacuum excitation of a quasi-normal mode in an analog model of black hole spacetime

Maxime J Jacquet<sup>1,\*</sup>

<sup>1</sup>Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, Paris 75005, France

**Abstract.** Vacuum quantum fluctuations near horizons are known to yield correlated emission by the Hawking effect. In this talk, I will explain how a 1 dimensional flow of microcavity polaritons may be engineered to produce an effective curved spacetime with a black hole horizon. I will present numerical computations of correlated emission on this spacetime and show that, in addition to the Hawking effect at the sonic horizon, quantum fluctuations may result in a sizeable stationary excitation of a quasi-normal mode of the field theory. Observable signatures of the excitation of the quasi-normal mode are found in the spatial density fluctuations as well as in the spectrum of Hawking emission. I will explain how the driven-dissipative dynamics of the polariton fluid are key to observing the quantum excitation of the quasi-normal mode. Nonetheless, this observation suggests a general and intrinsic fluctuation-driven mechanism leading to the quantum excitation of quasi-normal modes on black hole spacetimes.

## 1 Introduction

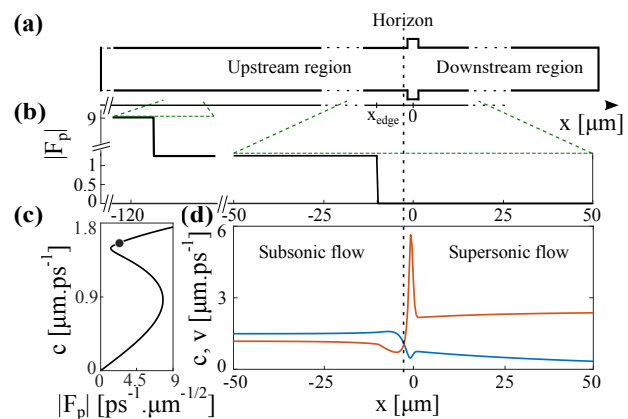
Quantum fluctuations of fields in the vicinity of the event horizon of black holes (BHs) are predicted to cause the emission of correlated waves by the Hawking effect (HE): while Hawking radiation propagates away from the horizon to outer space, the partner radiation falls inside the horizon. Since signalling from inside the horizon is impossible, only the out-going Hawking radiation is observable and quantum correlations with the in-falling partner waves cannot be accessed.

The HE may also be observed in the laboratory thanks to analogue gravity setups [1], namely condensed matter or optical systems, engineered in such a way that their collective excitations propagate on effectively curved spacetimes [2]. This idea has been experimentally demonstrated in a variety of platforms: for example, a horizon for sound waves forms in a one-dimensional trans-sonic fluid where the flow velocity of the fluid exceeds the speed of sound. Crucially, observation on both sides of the horizon is possible with analogue setups and the HE has been detected via density correlations between Hawking radiation and its partner [3] in experiments based on both classical and quantum fluids.

## 2 Novel physics in a driven-dissipative fluid

In this talk, I use of a specific realisation of an effective spacetime in a driven-dissipative quantum fluid of exciton-polaritons in a semiconductor microcavity [4] to push forward the theoretical study of quantum fluctuations in the

vicinity of horizons. I show how a one-dimensional trans-sonic configuration features a horizon and explain how the spatial shape of the quantum fluid and the external potential may be optimised together to maximize the strength of the HE [5], see Fig. 1. In addition to the typical signatures of the HE in the spatial correlation of sound waves, new features evidence the coupling of propagating waves with a localized mode living near the horizon, namely a quasi-normal mode (QNM) of the acoustic field.



**Figure 1. Acoustic horizon in a trans-sonic polariton fluid.** A step-like laser field pumps polaritons, creating a trans-sonic fluid flow across an attractive obstacle. (a) Sketch of the polariton wire with a defect at  $x_d = 0$ . (b) Optical bistability of the spatially homogeneous polariton fluid. (c) Spatial profile of the pump near the defect. The pump intensity  $|F_p|$  [ $\text{ps}^{-1} \cdot \mu\text{m}^{-1/2}$ ] drops abruptly to 0 at  $x_{edge} = -10 \mu\text{m}$ . (d) Spatial properties of the fluid near the defect: orange, fluid velocity  $v$ ; blue, speed of excitations  $c$ . Figure adapted from [4].

\*e-mail: maxime.jacquet@lkb.upmc.fr

### 3 Quasi-normal modes in analogue gravity

Typically, localized modes have a finite lifetime due to radiative decay into waves propagating away from the horizon, for instance gravitational waves.

While classical ring-down oscillations of a scalar field have been observed experimentally at the surface of a rotating bathtub flow configuration [6] and the HE spectrum has been theoretically calculated in more complex flow geometries in conservative fluids [7], this work [4] establishes that QNMs of quantum fields get naturally excited by the same quantum fluctuations that are responsible for the HE. Translated back to the astrophysical context, these results suggest a general and intrinsic fluctuations-driven mechanism leading to quantum excitation of BH spacetimes.

#### References

- [1] M.J. Jacquet, S. Weinfurtner, F. König, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences **378**, 20190239 (2020)
- [2] W.G. Unruh, Physical Review Letters **46**, 1351 (1981)
- [3] I. Carusotto, S. Fagnocchi, A. Recati, R. Balbinot, A. Fabbri, New Journal of Physics **10**, 103001 (2008)
- [4] M.J. Jacquet, L. Giacomelli, Q. Valnais, F. Joly, M. Claude, E. Giacobino, Q. Glorieux, I. Carusotto, A. Bramati, arXiv:2110.14452 [gr-qc, physics:quant-ph] (2021)
- [5] M.J. Jacquet, M. Joly, L. Giacomelli, F. Claude, E. Giacobino, Q. Glorieux, I. Carusotto, A. Bramati, arXiv:2201.02038 [gr-qc, physics:quant-ph] (2022)
- [6] T. Torres, S. Patrick, M. Richartz, S. Weinfurtner, Physical Review Letters **125**, 011301 (2020)
- [7] I. Zapata, M. Albert, R. Parentani, F. Sols, New Journal of Physics **13** (2011)