The theory of optical black hole lasers

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The event horizon of black holes and white holes can be achieved in the context of analogue gravity. It was proven for a sonic case that if these two horizons are close to each other their dynamics resemble a laser, a black hole laser, where the analogue of Hawking radiation is trapped and amplified. Optical analogues are also very successful and a similar system can be achieved there. However, the conditions in the optical case are different than those in the sonic one.

In this work, we present a theoretical description of the optical black hole laser (OBHL) following the approach of Corley and Jacobson [1], that is, by providing a WKB description of the evolution of frequency modes through a cavity and allowing mode conversion processes at the horizons. In the optical context, the cavity is formed by a pair of light pulses. In particular, we study the Hawking process also for a bosonic field, in this case photons, but in the normal dispersion regime. This fact forces an inverse order of the horizons (a BH–WH order) to get the proper kinematic behavior. Moreover, the change of velocity is now due to dispersion, and not as a consequence of modifications in the fluid flow. Hence, is Hawking radiation amplified in the optical analogue? And if so, under what conditions?

In addition, we derive the forward propagation of modes and, in this way, the heuristic argument for the amplification is easier to follow. Furthermore, it is known that the amplification depends mainly on the phase difference of the modes in both horizons. Here, we develop a method to approximate this phase difference and study its behavior. Finally, we present some numerical simulations of the OBHL based on the nonlinear Schrödinger equation (NLSE) including negative frequencies, which are usually not considered in this kind of simulations but that are necessary to obtain the correct modes of the black hole laser and its amplification [2].

[1] S. Corley, T. Jacobson. "Black hole lasers", Phys. Rev. D **59,** 124011 (1999).
[2] J.L. Gaona-Reyes, D. Bermudez. "The theory of optical black hole lasers", Ann. Phys. **380**, 41–58 (2017).

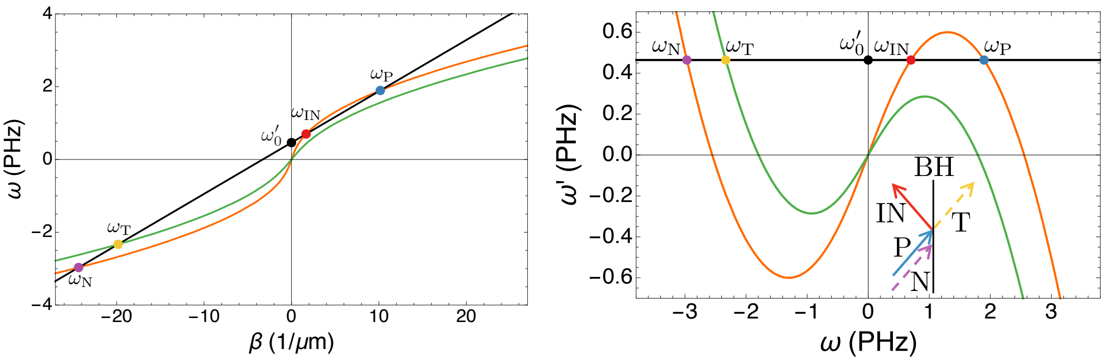

Figure 1 : Modes corresponding to a fixed value of the co-moving frequency ω_0' in the laboratory frame (left) and in the co-moving frame (right). The three modes IN, P, and N are found for the dispersion relation with $\delta n = 0$ (orange line) and the T mode for $\delta n = \delta n\text{max}$ (green line).