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Field theory description of surface and vorticity waves incident on an analogue black hole

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Analogue Gravity [1] enables the replication and investigation of phenomena normally associated with (Quantum) Field Theory in Curved Spacetime through meticulously controlled tabletop experiments. In the particular system of a classical open channel flow, gravity waves on the surface of an inviscid, incompressible and irrotational fluid serve as a means to simulate phenomena akin to those observed around black holes within laboratory settings [2]. The flow, if transcritical, plays the role of an effective spacetime featuring a horizon. This approach provides a pathway to experimentally investigate various classical instabilities associated with black (and white) holes [3-7].
While the assumption of an irrotational flow is necessary to construct the analogy, it is in practice a strong assumption. Friction on the bottom of the channel tends to induce a boundary layer where the flow velocity drops rapidly to zero [6], while flow recirculation tends to occur in the downstream wake of an obstacle [7]. It is thus an experimentally relevant question to determine how the wave propagation is altered by a non-trivial depth-dependence of the flow.
In this presentation, we propose a novel approach to construct an analog model incorporating gravity waves while considering the effects of vorticity. Our model involves an incompressible and inviscid fluid flowing in two layers: one characterised by constant vorticity at the bottom and another with vanishing vorticity at the top, with perturbations applied to the interface between the layers and
on the free surface. Using this method, we derive new equations of motion for both the scalar field associated with the potential velocity and a new scalar field linked to the variation of vorticity. We
develop a new Lagrangian, define a novel scalar product, and deduce WKB-like solutions [8] for the fields. Finally, we compute the scattering coefficients associated with modes falling into an analogue
black hole [6].

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Primary authors: BIONDI, Alessia (CNRS, Institut Pprime); ROUSSEAUX, Germain; ROBERTSON, Scott James (CNRS, Pprime)

Presenter: BIONDI, Alessia (CNRS, Institut Pprime)

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