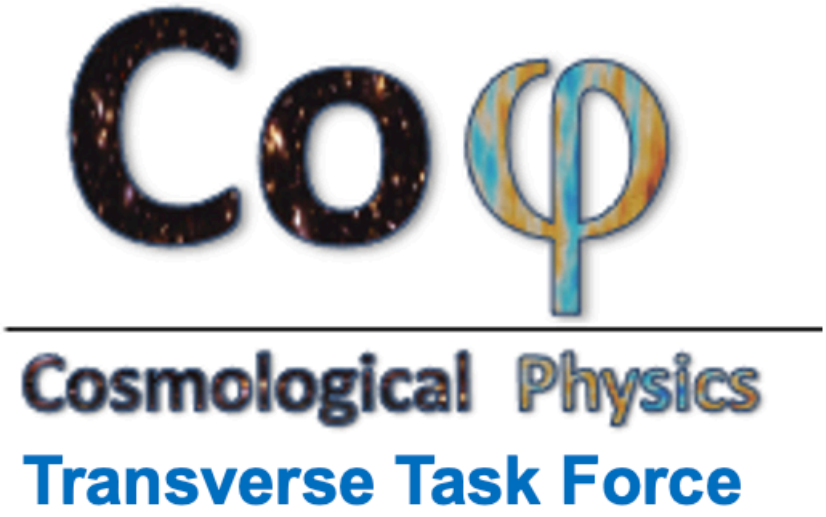
Analogue Gravitation and Cosmology



Report of Contributions

https://indico.ijclab.in2p3.fr/e/9888

Contribution ID: **1** Type: **not specified**

Introduction to the Workshop by M. Jacquet, S. Robertson and G. Rousseaux,

Wednesday, November 8, 2023 9:00 AM (10 minutes)

Presenters: JACQUET, Maxime (Laboratoire Kastler Brossel, Sorbonne Université et CNRS); Mr ROBERTSON, Scott (CNRS (Institut Pprime)); ROUSSEAUX, Germain (CNRS (Institut Pprime))

Contribution ID: **2** Type: **not specified**

Welcome

Wednesday, November 8, 2023 8:45 AM (15 minutes)

Contribution ID: **3** Type: **not specified**

General Discussion and Perspectives for the Transverse Task Force

Thursday, November 9, 2023 11:35 AM (45 minutes)

Contribution ID: **4** Type: **not specified**

From Bossut to Rayleigh-Plesset : how classical mechanics (including hydrodynamics) can shed light on cosmology.

Wednesday, November 8, 2023 11:15 AM (45 minutes)

In this talk, we introduce several analogies between classical mechanics (including hydrodynamics) and cosmology. In particular, we show that the Friedman-Lemaître set of equations at the theoretical roots of the description of the Universe Expansion can be written in a mathematical form akin to the Rayleigh-Plesset equation which rules the dynamics of a bubble in a liquid. Hence the ratio between the speed of the bubble interface to its radius can be considered as an analogue of the Lemaître-Hubble expansion rate parameter. We discussed its interpretation by recalling the example of the varying length pendulum by the Bossut Abbot whose relative rate of lengthening is also an analogue of the (Bossut)-Lemaître-Hubble parameter. We discussed possible implementation of these ideas in laboratory systems for future experiments.

Presenter: ROUSSEAUX, Germain (CNRS)

Contribution ID: **5** Type: **not specified**

Analogue preheating in a 1D condensate

Thursday, November 9, 2023 9:45 AM (45 minutes)

The Analogue Gravity program has had considerable success recently, with ultracold gases playing a particularly prominent role as a system in which quantum aspects of field theory in curved spacetime can be explored. In this talk, I will present the analogy between a modulated 1D condensate and the preheating stage of cosmology, whereby a large number of quasiparticle pairs are excited out of vacuum. Particular attention will be paid to the role played by quasiparticle interactions in the suppression of the growth and the loss of quantum coherence of the produced pairs.

Presenter: ROBERTSON, Scott (CNRS (Institut Pprime))

Contribution ID: **6** Type: **not specified**

Pause

Wednesday, November 8, 2023 10:55 AM (20 minutes)

Contribution ID: **7** Type: **not specified**

Pause

Wednesday, November 8, 2023 3:30 PM (20 minutes)

Contribution ID: **9** Type: **not specified**

Pause

Thursday, November 9, 2023 10:30 AM (20 minutes)

Contribution ID: **10** Type: **not specified**

Looking for the black hole LASER effect in Hydrodynamics

Wednesday, November 8, 2023 2:45 PM (45 minutes)

The black hole LASER effect is a theoretical prediction in General Relativity proposed by Vilenkin in 1978 for one horizon [1] and rediscovered in Analogue Gravity by Corley and Jacobson in 1999 for two horizons [2]. According to them, the superadiance effect (with rotation) or Hawking effect (without rotation) could be amplified by a "laser cavity" formed by either one horizon (a "super-reflecting mirror") and a reflecting mirror or two time-reversed horizons (an outer horizon and an inner horizon in the case of a charged black hole for instance). The amplification is caused by both the presence of negative energy modes (of rotating or draining types), i.e. antiparticles in astrophysics, and a dispersive correction which converts the trapped modes into bouncing modes in between both boundaries of the LASER cavity. Therefore, theoretical proposals emerged for analogous systems like in optics with no experimental realization in any analogue system despite false alarms, as dispersive analogous systems allow for superluminal or subluminal corrections or even subluminal followed by superluminal correctios [3-5]. In interfacial hydrodynamics, to construct an experimental analogue black hole laser effect, several horizons are needed, and a non-dispersive horizon is constructed with an accelerating or decelerating flow until the Froude number, defined as the ratio of the velocity of the flow, U, to the velocity of the long gravity waves, (where g is the gravity field and h the water depth), is equal to 1. Experimentally, an obstacle is placed in a free-surface channel to accelerate or decelerate a flow depending on the value of the upstream Froude number and make horizons. We will present our recent works on open channel flows over two successive obstacles (in order to create a white horizon and a successive black horizon with subluminal correction) in canal of a metric size in order to look for hydrodynamical regimes that would accommodate the laser effect manifesting itself as a hydrodynamic instability [6]. We will finish with a presentation of our more recent work on reproducing the Nice experiments [7] and the influence of dispersive horizons on Hawking radiation [8].

References:
[1] Vilenkin, A. (1978). Exponential amplification of waves in the gravitational field of ultrarelativistic rotating body. Physics Letters B, 78(2-3), 301-303.
[2] Corley, S., & Jacobson, T. (1999). Black hole lasers. Physical Review D, 59(12), 124011.
[3] Faccio, D., Arane, T., Lamperti, M., & Leonhardt, U. (2012). Optical black hole lasers. Classical and Quantum Gravity, 29(22), 224009.
[4] Leonhardt, U., & Philbin, T. G. (2007). Black hole lasers revisited. Quantum analogues: from phase transitions to black holes and cosmology, 229-245.
[5] Peloquin, C., Euvé, L. P., Philbin, T., & Rousseaux, G. (2016). Analog wormholes and black hole laser effects in hydrodynamics. Physical Review D, 93(8), 084032.
[6] Coutant, A., & Parentani, R. (2010). Black hole lasers, a mode analysis. Physical Review D, 81(8), 084042.
[7] Rousseaux, G., Mathis, C., Maïssa, P., Philbin, T. G., & Leonhardt, U. (2008). Observation of negative-frequency waves in a water tank: a classical analogue to the Hawking effect?. New Journal of Physics, 10(5), 053015.

Presenter: BOSSARD, Alexis (Université de Poitiers (Institut Pprime))

Contribution ID: **11** Type: **not specified**

Free Lunch Time

Wednesday, November 8, 2023 12:00 PM (2 hours)

Contribution ID: **12** Type: **not specified**

End of the Workshop

Thursday, November 9, 2023 12:20 PM (1 minute)

Contribution ID: **14** Type: **not specified**

Towards analogue black hole merger

Thursday, November 9, 2023 9:00 AM (45 minutes)

We study the effects of the wavevector-dependent losses on polariton condensates. We demonstrate that because of these losses, a single vortex becomes a center of a convergent flow, which allows describing it by an analogue Kerr black hole metric with a dynamically evolving origin. For a pair of vortices, we find an analogue of the 3rd Kepler's law and estimate the emission rate of the gravitational waves. We simulate an analogue of the inspiral phase of a black hole merger. Our work therefore suggests that polariton condensates with quantum vortices represent a setting with a fully self-consistent dynamical metric for broad analogue studies.

Presenter: SOLNYSHKOV, Dmitry (Université Clermont Auvergne)

Contribution ID: **15** Type: **not specified**

Simulating orbiting bodies: can a soap film make a good spacetime replica?

Wednesday, November 8, 2023 4:50 PM (20 minutes)

The intricacy of general relativity has fostered the creation of numerous simplified models and representations, that are founded on the principle of a stretched membrane distorted by bodies moving on its surface. However, an inherent limitation in these systems is that these bodies are solid discrete masses, hence limiting their potential for representing complex merging dynamics like those witnessed in galaxies. In this talk, we investigate the potential of a new system based on a horizontal soap film, stretched over a circular frame, to shed light on these phenomena. Indeed, if a drop of water is placed on such a film, it creates a lens that distorts it as a result of gravity, with steady dimensions for durations of the order of a minute. Hence, it is possible to have multiple lenses interact, allowing them to mutually attract each other under the influence of the film's deformation, before merging in complex dynamics. Currently, our team is developing models to study this system, and our aim is to investigate its potential and limitations for conducting analog cosmology experiments in the future.

Presenter: MARTISCHANG, Jean-Paul (Université de Lille)

Contribution ID: **16** Type: **not specified**

Correlated phonon pairs in a cosmological simulation using a Bose-Einstein condensate

Thursday, November 9, 2023 10:50 AM (45 minutes)

In standard cosmological models, inflation is driven by a quantum field, the inflaton, whose constant energy density drives the superluminal expansion of the universe. When inflation stops, the universe has an extremely low density but the inflaton field starts to oscillate around its minimum of energy and decays into entangled pairs of particles. This is known as the pre-heating phase. Created pairs of particles then start to interact leading to decoherence and thermalization: the re-heating stage.
Although in situ observation of inflaton particle creation process is impossible, pair pro- duction through parametric amplification is analogous to the creation of phonon pairs in a Bose-Einstein (BEC) condensate whose interaction strength is temporally modulated. Modulating the stiffness of a dipole trap of a cigar shaped BEC is equivalent to modulating the effective one-dimensional interaction strength in a BEC, and thus we are able to probe the correlation of entangled metastable helium atoms by the use of a micro-channel plate detector (MCP). Our experimental procedure is the following: we modulate in time the trap stiffness of the dipole trap laser and then release the trap. The number of phonon pairs is expected to depend on the duration of the excitation, its amplitude, and the excitation frequency. However, the parameter range over which the entanglement of the phonon pairs can be observed is expected to be quite narrow. We report on our investigations of the entanglement and correlations of the pairs.

Presenter: GONDRET, Victor (Institut d'Optique Graduate School)

Contribution ID: **17** Type: **not specified**

Update on rotating geometry experiments with polaritons

Wednesday, November 8, 2023 2:00 PM (45 minutes)

QFT on curved geometries has predicted a number of pair-emission processes like rotational superradiance. These occur when the acoustic field in a quantum fluid scatters on some intangible surface of the fluid. For example, superradiance results from the scattering of acoustic waves (possibly in their vacuum state) at the surface where the total velocity of the fluid exceeds the speed of sound. The twist in the fluid flow induced by the transition from sub- to supersonic velocities creates an energetic instability that yields entangled acoustic excitations on either side of the surface. Fluid acceleration and twists allow us to engineer bespoke curved geometries in the laboratory to investigate outstanding QFT effects.
At Laboratoire Kastler Brossel, we use the acoustic field in a quantum fluid of light as a model for QFT on curved geometries. The fluid of light is realised with microcavity exciton-polaritons, whose flow can be controlled all-optically while all quantum statistics of emission may be measured with spectroscopy and homodyne detection.
In this talk, I will review the basic arguments supporting the modelling of QFT in our experiment, explain how polaritons are created and manipulated in the lab and present new theoretical results on entanglement from superradiance and advances with the experiments.

Presenter: JACQUET, Maxime (Laboratoire Kastler Brossel, Sorbonne Université et CNRS)

Contribution ID: **18** Type: **not specified**

Cosmology and inflation: where do we stand?

Wednesday, November 8, 2023 9:10 AM (1 hour)

Presenter: MARTIN, Jérôme (IAP)

Contribution ID: **19** Type: **not specified**

Optical white-black hole horizons and entanglement

Wednesday, November 8, 2023 4:10 PM (20 minutes)

The entanglement shared by the emitted particle fluxes is the very quantum signature of the Hawking process. Stimulated and spontaneously generated Hawking radiation has been experimentally investigated in several platforms, but measuring entanglement has proven to be elusive, due to its faint and fragile character. In this talk, I will discuss the main results of my work on optical analog white-black hole pairs sharing an interior and produced within a nonlinear optical material. In particular, I will discuss the tunability of entanglement based on the input quantum state. For instance, the use of single-mode squeezed states increases the amount of entanglement in the Hawking process in a controllable way which opens a promising avenue for confirming the quantum origin of the Hawking effect in the lab. To make contact with experiments, I explore the effects of ambient noise, such as thermal fluctuations, and detector inefficiencies on quantum correlations. Interestingly, we find that entanglement generated in the optical setups is naturally shielded against thermal fluctuations being at rest in the laboratory frame. Finally, I investigate the optical lasing configuration and utilize it as an alternative way of amplifying the amount of entanglement in the Hawking process.

Presenter: KRANAS, Dimitrios (LPENS, ENS Paris)

Contribution ID: **20** Type: **not specified**

Measures of entanglement and quantum nonlocality in a Bose-Einstein acoustic black hole

Wednesday, November 8, 2023 10:10 AM (45 minutes)

In this talk I will present several measures of entanglement in an acoustic black hole realized in the flow of a Bose-Einstein condensate. I will specifically address (1) the resilience of the signal to a finite temperature and (2) how the specifics of the setting we consider enable to study tripartite observables of nonlocality.

Presenter: CILIBERTO, Giorgio (LPTMS, Paris-Saclay University)

Contribution ID: **21** Type: **not specified**

Quenches and quantum fluctuations in a fluid of light

Wednesday, November 8, 2023 4:30 PM (20 minutes)

Hot atomic vapors are widely used in non-linear and quantum optics due to their large Kerr non-linearity. This non-linearity induces effective photon-photon interactions allowing light to behave as a fluid displaying quantum properties such as superfluidity. Quantum fluids of light rely on the analogy between the non-linear Schrödinger equation (NLSE) describing the propagation of light in non-linear media and the Gross-Pitaevskii equation (GPE) describing a weakly interacting Bose gas. By studying the effect of interaction quenches of the nonlinear index term in the fluid, we evidence the dynamical Casimir effect i.e the spontaneous emission of correlated pairs of phonons. This has profound implications for analogue physics since our evolution equation can be mapped onto a space-time metric, it is then possible to reinterpret this emission as the emission of acoustic waves (Sakharov oscillations), similarly to the early universe

Presenter: ALADJIDI, Tangui (LKB)

Contribution ID: **22** Type: **not specified**

Effective field theory of Analogue Gravity

Wednesday, November 8, 2023 3:50 PM (20 minutes)

In this talk, we introduce a novel method for building an analog model with a Bose-Einstein condensate, in which the analogue metric is obtained using an effective field theory and a microscopic Lagrangian with a quartic interaction. The microscopic Lagrangian that we introduce is obtained first assuming that our system is described by a complex massive scalar field, and and then requiring that there must be a spontaneously broken global U(1) symmetry. Using the developed method, we obtain two main original results. The first original result is the calculation of the next-to-leading order Lagrangian in terms of the microscopic Lagrangian's parameters and of the dispersion law for phonon pairs in the presence of an acoustic horizon generated by the BEC's flow. We will study, in addition, a particular case. The second relevant result is the design of an original procedure to calculate the density-density correlation function through the field theory tools.

Presenter: BIONDI, Alessia (Università di Pisa)