WORKSHOP SCIENTIFIC REPORT

TITLE:

New trends in the physics of the quantum vacuum: from condensed matter, to gravitation and cosmology

DATES:

June 26th - July 1st, 2011

ORGANIZERS:

- Iacopo Carusotto (INO-CNR BEC Center, Trento, Italy)
- Roberto Balbinot (Università di Bologna, Italy)
- Alessandro Fabbri (Univ. de Valencia-CSIC, Spain)
- Cristiano Ciuti (Université Paris 7, France)

NUMBER OF PARTICIPANTS

49

SUMMARY AND MAIN TOPICS

The workshop had a very interdisciplinary focus and addressed a number of aspects of the "quantum vacuum" concept through its manifestations in the different contexts of gravitational physics, cosmology and condensed matter physics. The aim was to establish a common language and identify useful connections between originally distinct research lines.

More specifically, the main covered subjects were:

- Quantum field theories on curved space-time
- Physics of astrophysical black holes and Hawking radiation
- Quantum fluctuations in cosmology
- Dynamical Casimir effect
- Condensed matter analogue models
    - Bose-Einstein condensates of ultracold atoms and of exciton-polaritons in semiconductor devices
    - nonlinear optical systems

    - circuit QED in superconducting devices
    - ultrastrong light-matter coupling and sub-optical-period modulations
- Quantum hydrodynamics of analogue black/white holes in a flowing fluid, black hole lasing

SCIENTIFIC REPORT

The main objective of the present workshop was to establish long-lasting scientific links among scientists working on different aspects of the physics of the quantum vacuum. Although a huge number of conferences focussed on specific topics are already taking place on a regular basis, an interdisciplinary forum was still missing. The goal of the present workshop was to fill this gap bringing together distinguished scientist active in the different fields and stimulating the establishment of new collaborations. The numerous and active participation of a number of top-level scientists with very different backgrounds is a good witness of the interest of such an initiative for a broad community.

The workshop was organized with a restricted number of long talks by world-class experts giving tutorial overviews of the different fields, followed by shorter talks by younger fellows on more specific subjects of present-day research. This organization turned out very efficient in conveying to a broad audience both the general concepts of each field and a glimpse of the presently hottest problems. All speakers were strongly encouraged to make a specific effort in order for their presentations to be understandable by the whole audience: the outcome of these efforts was remarkable, with people from very different backgrounds being constantly active in discussing the different topics during the sessions as well as in informal discussions during the free time. A crucial contribution in this direction was the structure and organization of ECT*, which favoured socialization and scientific exchanges during coffee-breaks as well as during meals.

The simultaneous presence of theorists and experimentalists allowed a fruitful and bidirectional exchange of ideas: theorists discussed the fundamental problems and the conceptual framework that can be used to understand them; experimentalists presented a number of systems where these problems are being investigated and pointed out the new questions that the experiments are raising.
The success of the workshop has opened the discussion on how to continue the series of these quantum vacuum workshops after the first edition of the workshop in Valencia in early 2009 and the present second edition at ECT*. We indeed expect that the rapid advances in the experimental study of analogue black holes will soon raise a number of new questions on the physics of quantum fields on curved space times as applied to condensed matter systems

and that new perspectives in quantum field theories will be opened by the developments in the realization and manipulation of solid-state QED devices on sub-optical-period timescales. A third edition of the workshop will be the ideal forum for a broad community to continue discussing this physics from an interdisciplinary point of view.

RESULTS AND IMPACT

Atomic Bose-Einstein condensates are among the most promising analogue models to which quantum field theories in curved space times can be applied in a condensed matter context. At the workshop, the general concepts of QFT on curved space times were reviewed by W. Unruh, one of its founders.
Two recent experiments were then reported where a black hole configuration in a flowing atomic condensate is created and where peculiar density correlations are detected after suitable manipulation sequences. According to theoretical work, a combination of these two features is likely to be essential in view of getting a conclusive evidence of analogue Hawking radiation in a condensed matter system.
A number of theoretical talks have addressed the rich dynamics of artificial black and white holes in atomic condensates at both classical and quantum level: the peculiar properties of white holes have been illustrated in connection to on-going experiments in classical hydrodynamical systems and in nonlinear optics. The black hole lasing instability in paired black and white hole horizons has been characterized.
The overview on quantum fluids was completed by a long review talk on the hydrodynamics of Bose-Einstein condensates of exciton-polaritons in semiconductor devices, which efficiently stimulated the discussion on the promise of these novel quantum fluids in order to create and study artificial black hole configurations. Several theoretical groups are presently undertaking the challenge of pushing forward this research direction.

Another class of systems that hold strong promise in view of experimental studies of analogue Hawking radiation are based on ultra-fast optics techniques: by means of a suitable short and intense pulse of light, a moving perturbation of the refractive index is generated in a nonlinear optical medium, which is expected to give rise to a pair of horizons. Two groups have presented their experimental observations and the theoretical interpretation of their data in a sequence of four talks. These presentations triggered intense exchanges on the actual meaning of the observations and on the next steps to be performed in order to obtain more conclusive results: all these discussions will be of extreme utility in order for the new generation of experiments to focus onto the clearest signatures of quantum vacuum physics.
The session was closed with two more theoretical talks investigating other possible configurations to generate artificial black holes in nonlinear optical systems.

The interest in the dynamical Casimir effect has received a strong boost in the last year thanks to on-going experiments using superconducting circuits. A first claim of an observation of the effect has been presented at the workshop together with the corresponding theoretical model: the presence of several experts in the dynamical Casimir physics has made the workshop the ideal location where to discuss those few features of the experiment that are still under debate. This discussion was completed by a series of talks on QED effects in the so-called ultra-strong coupling regime of light-matter interaction: the peculiar properties of the QED quantum vacuum beyond the rotating wave approximation have been illustrated as well as the observation of novel physical behaviours when the properties of an optical systems are modulated in time on a sub-optical-period time-scale. The scientific contacts that have been created between experts in the Casimir effect and condensed matter physicists exploring novel regimes of electrodynamics of material media is expected to open new angles to the research on Casimir effects and, more generally, on the quantum physics of the electromagnetic field.

Several talks were finally dedicated to illustrating different scenarios where quantum vacuum effects play an important role in cosmology and in particle physics. The conversion of quantum fluctuations into real modulations during the inflationary age is the main candidate to explain the largest scale structures of the universe as observed from the anisotropies of the CMB radiation: the underlying mechanism appear very similar to the one that is active in the above-mentioned experiments with ultracold atoms. The cosmological counterpart of the trans-Planckian features of Hawking radiation from black holes were also discussed, as well as the behaviour of mini-black holes that may be created in elementary particle accelerators. After all these talks, the low-energy part of the audience has got aware of the kind of fundamental questions that condensed-matter analogue models may help to address in the next future, from the non-Gaussianities of the CMB spectrum due to back-reaction effects, to the actual signatures of the UV "trans-Planckian" physics onto the Hawking spectrum from black holes.

FULL LIST OF SPEAKERS

• Bill Unruh	Univ. British Columbia, Canada
• Renaud Parentani	Univ. Orsay, F
• Marc Jaekel	LPT-ENS, F
• Cristiano Ciuti	Univ. Paris 7, F
• Sandro Stringari	Univ. Trento, I
• Chris Westbrook	Univ. Orsay, F
• Luis Garay	Univ. Complutense, Madrid, ES
• Ruth Durrer	Univ. Geneva, Switzerland
• Jerome Martin	IAP Paris, F
• Nemanja Kaloper	U.C. Davis, USA
• Jeff Steinhauer	Technion, Haifa, Israel
• Caterina Braggio	Univ. Padova, I
• Simone De Liberato	Univ. Paris 7, F
• Iacopo Carusotto	INO-CNR BEC Center, Trento, I
• Carlos Mayoral	Univ. Valencia, E
• Nicolas Pavloff	LPTMS Orsay, F
• Victor Fleurov	Univ. Tel Aviv, Israel
• Francesco Marino	Univ. Firenze, I
• Silke Weinfurtner	Univ. British Columbia, Canada
• Pasquale Calabrese	Univ. Pisa, I
• Stefano Liberati	SISSA, I
• Robert Johansson	RIKEN, Japan
• Rupert Huber	Univ. Regensburg, D
• Per Delsing	Chalmers Univ., Sweden
• Daniel Faccio	Univ. Insubria, I
• Sergio Cacciatori	Univ. Insubria, I
• Alberto Bramati	LKB-Paris 6, F
• Daniele Sanvitto	CNR, Lecce, I
• Alberto Amo	LPN, Paris, F
• Carlos Barcelo	Univ. Granada, ES
• Susanne Kehr	Univ. St. Andrews, UK
• Piero Nicolini	Univ. Frankfurt, D
• Stefano Giovanazzi	Univ. Heidelberg, D
• Stefano Finazzi	SISSA, I
• Simon Horsley	Univ. St. Andrews, UK
• Ivar Zapata	Univ. Complutense, Madrid, ES
• Ariel Guerreiro	Univ. Porto, Portugal
• Scott Robertson	Univ. Pavia, I
• Anatoly Kamchatnov	Univ. Moscow, Ru

Other participants

• Alessio Recati	INO-CNR BEC Center, Trento
• Maurizio Artoni	LENS, I
• Giovanni Carugno	Univ. Padova, I
• Dario Gerace	Univ. Pavia, I
• Pierre-Elie Larre	Univ. Orsay, F
• Massimiliano Rinaldi	INFN Bologna, I
• Hugo Flayac	Univ. Clermont Ferrand, F
• Valentina Baccetti	Wellington Univ., NZ
• Jean-Christophe Jaskula	Palaiseau, FR

	06/27/11	Tuesday, June 28	Wednesday, June 29	Thursday, June 30	July, Friday 1
09:00	**ECT* director & organizers** *Foreword*	**N. Pavloff** *Bogoliubov theory of analog Hawking radiation*	**N. Kaloper** *Vacuum energy of the universe and dark energy*	**C. Ciuti** *The QED vacuum in the ultra-strong light-matter coupling regime*	**P. Calabrese** *Quantum Quenches and Thermalization*
09:30					**S. Liberati** *Emergent gravity*
10:00	**W. Unruh** *Quantum field theories on curved space-time*	**I. Carusotto** *White holes in atomic Bose-Einstein condensates*	**R. Durrer** *The largest structures in the Universe: quantum fluctuations from inflation*	**R. Huber** *How to mix electrons and photons faster than a cycle of light*	**P. Nicolini** *Mini black holes at LHC*
10:30		**C. Mayoral** *Density correlation functions for white holes in BECs*		**S. De Liberato** *Dynamical Casimir effect in condensed matter systems*	**S. Horsley** *Radiation friction effects*
11:00	Coffee break @ ECT* garden				
11:30	**S. Stringari** *Introduction to atomic BECs*	**R. Parentani** *Black hole lasers in Bose Einstein condensates*	**J. Martin** *Transplanckian problem in cosmology*	**R. Johansson** *Dynamical Casimir effect in superconducting microwave circuits*	**A. Guerreiro** *DCE and the generation of Entangled light from the vacuum state*
12:00				**P. Delsing** *Observation of the dynamical Casimir effect in a superconducting circuit*	**organizers** *wrap-up session*
13:00	Lunch @ ECT* Canteen				
14:30	**M.-T. Jaekel** *Dynamical Casimir effect*	**S. Finazzi** *Particle production in stationary BEC without horizons*	**D. Faccio** *Experiments of analog Hawking radiation in nonlinear optics*	**A. Amo** **A. Bramati** **D. Sanvitto** *Experiments with polariton superfluids*	
15:00		**I. Zapata** *Resonant Hawking radiation in atomic BECs*	**S. Cacciatori** *Theory of analog Hawking radiation in nonlinear optics*		
15:30	Coffee break @ ECT* garden				
16:00	**C. Westbrook** *Detecting correlations in ultracold gases*	**S. Giovanazzi** *Entropy Production in Acoustic Analogues of Black Holes*	**S. Kehr** *Fiber-optical Black holes*	**L. Garay** *Artificial black holes in atomic BECs*	
04:30		**A. Kamchatnov** *Formation of "black holes" by flow of BEC past an obstacle*	**S. Robertson** *Theory of fiber-optical Black holes*		
17:00	**C. Braggio** *Experimental studies of dynamical Casimir effect*	**J. Steinhauer** *Experimental realization of sonic black holes in atomic BECs*	**F. Marino** *Possible experiments on acoustic black holes in a nonlinear optical system*	**C. Barceló** *Vacuum states in flowing Bose-Einstein condensates*	
17:20		**S. Weinfurtner** *Measurement of stimulated Hawking emission in an analogue system*	**V. Fleurov** *Optical analogue of Laval nozzle. Luminous fluid*		
20:00	Dinner @ ECT*	Dinner @ La Baracca	Dinner @ Patelli	Soc. dinner @ Piedicastello	Pizza @ Alla Mostra