MASTER IN PHOTONICS – PHOTONICS BCN
EUROPHOTONICS-POESII MASTER COURSE

PROPOSAL FOR A MASTER THESIS

Dates: April - September 2017

Laboratory : QOT
Institution: ICFO
City, Country : Casteldefels (ES)

Title of the master thesis: ***Simulating Cosmological models in optical lattices***

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Summary of the subject (maximum 1 page) :

In this thesis, we propose to study the evolution of a gas of relativistic Dirac fermions in time dependent metrics in two spatial dimensions. The simplest example of the latter (Friedman-Lemaître-Robertson-Walker metric) describes the expansion or the collapse of a homogeneous and isotropous universe. If the gas is not interacting the model can be studied analytically as it is described in terms of a time-dependent single particle Dirac Hamiltonian $H(t)$.

The goal is to investigate the lattice version of this Hamiltonian, which is a generalized Hubbard model, and can be thought as a deformation of artificial graphene [1]. As in real graphene, relativistic Dirac fermions are emerging low-energy excitons around the Dirac points, namely cone like singularities of the energy bands.

The main tasks will be

- To find the appropriate choice of the coordinate frame and the simplest lattice formulation of $H(t)$ that are suitable to be implemented within the scheme and setup proposed in [2] and [3], respectively;
- To consider the continuum limit of the lattice model and the role of lattice doubling in cosmological evolution;
- To define suitable observables that describe interesting phenomena like the “particle creation” and cosmological horizon;

- To compare the results for fermions with respect with the one obtained in analogue models of cosmological expansions with bosons, namely Bogoliubov excitations in a Bose-Einstein condensate, e.g. *cf.* [4]

[1] L.Tarruell *et al., "Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice",* Nature 483 (7389), 302-305 (2012).
[2] O. Boada, A. Celi, J.I. Latorre, and M. Lewenstein, *"Dirac equation for cold atoms in artificial curved spacetimes"*, New J. Phys. 13 (3), 035002, (2011).
[3] J. Rodriguez-Laguna, L. Tarruell, M. Lewenstein, and A. Celi*, "Synthetic Unruh effect in cold atoms"*, arXiv:1606.09505.
[4] C. Barceló, S. Liberati, and M. Visser, *"Living Rev. Relativity"*, 8, 12 (2005). http://relativity.livingreviews.org/Articles/lrr-2011-3/

Keywords : Quantum Simulation, Ultracold atoms, optical lattices, artificial graphene, Quantum field theory in curved spacetime

Additional information :
* Required skills: quantum mechanics; basic notion of special relativity and band theory;
* Miscellaneous: