Our research group is specialist in condensed-matter systems, quantum information, quantum optics, mesoscopic physics with links related to high-energy physics.
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Here are a few challenging enigma we propose. Interested candidates can send a CV and short letter of motivation to karyn.le-hur@polytrechnique.edu. We will then discuss.

- How to solve quantum models in 2D?

Quantum spin models such as the Heisenberg model for spins-1/2 are not yet solved in 2D. A solution is known for the Kitaev spin model on the honeycomb lattice through Majorana fermions [1]. We have generalized solutions for square ladders or wires systems. The new challenging goal is to assemble ladders analytically and go to 2D with applications in codes, engineering quantum spin liquids, Majorana fermions and models of high-energy physics e.g. related to the Sachdev-Ye-Kitaev model [2,3]. We are developing algorithms such as DMRG (density matrix renormalization group). This route is also helpful to address superconductivity in a rigorous approach [4].

[1] A. Kitaev, Annals of Physics 321, 2 (2006)
[2] K. Le Hur, A. Soret, F. Yang, https://arxiv.org/abs/1703.07322
[3] F. Yang, L. Henriet, A. Soret, K. Le Hur, https://arxiv.org/abs/1801.05698
E. Bernhardt, Brian Cheung Hang Chung, Karyn Le Hur https://arxiv.org/abs/2309.03127
[4] K. Le Hur and T.M. Rice, Annals of Physics Annals of Physics 324 1452 (2009).

- Fractional Plateaux and Quantum Hall Physics in Wires

In one dimension, the theory of interacting electrons is described through a simple string model called the Luttinger liquid, a quadratic bosonic action. Fractional charges are flowing in these quantum liquids and have been observed in mesoscopic wires [1]. Recently, colleagues in London have observed curious fractional plateaux in the conductance of wires [2]. We are presently building a model to explain this finding and one goal will be to study transport in the presence of electric fields and compare with datas. Transport can also be developed through DMRG.

[1] H. Steinberg, G. Barak, A. Yacoby, L. N. Pfeiffer, K. W. West, B. I. Halperin, K. Le Hur
https://www.nature.com/articles/nphys810
[2] S. Kumar, M. Pepper, S. N. Holmes, H. Montagu, Y. Gul, D. A. Ritchie, I. Farrer,
https://arxiv.org/ftp/arxiv/papers/1810/1810.09863.pdf

- Spheres' model, Topological Quantum Matter and Axion Electrodynamics

We have recently introduced the 2-spheres' model [1] related to fractional topology and new applications of quantum entangled wavefunctions in topological aspects. One goal is to develop this analysis further through *classification* related to applications in quantum matter and light-matter interaction, e.g. increasing the number of spheres towards the thermodynamical limit [2]. An ensemble of planks (see Sec. 8 of [2]) also provides an interesting platform relating quantum materials to axion electrodynamics that can be developed including a hopping term between planks [3]. Another potential goal is to study applications in *energy* through the quantum dynamo effect [4].

[1] Joel Hutchinson & Karyn Le Hur, https://www.nature.com/articles/s42005-021-00641-0
[2] K. Le Hur, Review https://arxiv.org/abs/2209.15381
[3] A. Sekine and K. Nomura, https://arxiv.org/abs/2011.13601
[4] E. Bernhardt, C. Elouard, K. Le Hur https://arxiv.org/abs/2208.01707

Other possible ideas can be discussed according to interests.