Minicolloque n° MMPS20 **□ Oral**

Floquet engineering the interference between Cooper pairs in four-terminal Josephson junctions

Régis Mélin
Univ. Grenoble-Alpes, CNRS, Grenoble INP, Institut NEEL, 38000 Grenoble, France

email : regis.melin@neel.cnrs.fr

I will present the recent Harvard group experimental data [1] on four-terminal Josephson junctions evaporated on a sheet of graphene gated away from the Dirac point, thus realizing a two-dimensional (2D) metal connected to four superconducting leads. Overall, the Harvard group experiment is evidence for interplay between the time-periodic Floquet dynamics and the interference between the "standard" three-terminal quartets and the novel four-terminal split quartets [2-6].

The limits of weak [4] and strong [5-6] coupling between the 2D metal and the superconductors will be discussed, and it will be shown that the experiment can consistently be described by a multilevel quantum dot formed in between the contacts on the sheet of graphene. Two physical mechanisms will be discussed:

(i) Quantum superpositions in the Floquet-Andreev bound state dynamics for a 0D quantum dot [5].

(ii) A novel interference phenomenon for the Rabi resonance in a multilevel quantum dot coupled to four superconducting leads, already in the adiabatic limit [6].

The above item (ii) turns out to be more relevant than (i) because of the very low bias voltage and symmetric couplings to the four superconducting leads.

Finally, I will present two slides on a new proposal [7] inspired by unpublished experimental data in the Weizmann Institute group [8]. Ultra-long distance non-locality and quantum correlations of the quartets and octets are conjectured in a three-terminal Josephson junction containing two quantum dots, separated by distance which is orders of magnitude larger than the zero-energy coherence length, as in the Tomasch effect.

These recent theoretical and experimental results [1-8] demonstrate some of the basic phenomena that can emerge in practise, if one wants to quantum-engineer semi-conducting and van-der-Waals multiterminal superconducting hybrids in 0D or 2D geometries.

[1] K.-F. Huang, Y. Ronen, R. Mélin, D. Feinberg, K. Watanabe, T. Taniguchi and P. Kim, *Interference of Cooper quartet Andreev bound states in a multi-terminal graphene-based Josephson junction*, arXiv:1008.0341 (2020).

[2] A. Freyn, B. Douçot, D. Feinberg and R. Mélin, *Production of non-local quartets and phase-sensitive entanglement in a superconducting beam splitter*, Phys. Rev. Lett. **106**, 257005 (2011).

[3] A.H. Pfeffer, J.-E. Duvauchelles, H. Courtois, R. Mélin, D. Feinberg and F. Lefloch, *Sub-Gap Structure in the Conductance of a Three-Terminal Josephson Junction*, Phys. Rev. B **90**, 075401 (2014)

[4] R. Mélin, *Inversion in a four-terminal superconducting device on the quartet line: I. Two-dimensional metal and the quartet beam splitter*, Phys. Rev. B **102**, 245435 (2020).

[5] R. Mélin and B. Douçot, *Inversion in a four terminal superconducting device on the quartet line: II. Quantum dot and Floquet theory*, Phys. Rev. B **102**, 245435 (2020).

[6] R. Mélin, in preparation (2021).

[7] R. Mélin, *Ultralong-distance quantum correlations in three-terminal Josephson junctions*, arXiv:2103.07971 (2021).

[8] Y. Cohen, Y. Ronen, J.-H. Kang, M. Heiblum, D. Feinberg, R. Mélin and H. Shtrikman, *Non-local Supercurrent of Quartets in a Three-Terminal Josephson Junction*, PNAS July 3, **115** (27) 6991-6994 (2018).