INTERNSHIP PROPOSAL

Laboratory name: Institut Néel
CNRS identification code: UPR2940
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Internship location: Grenoble

Thesis possibility after internship: YES
Funding: NO

Unconventional liquid-like physics in frustrated metamaterials

General Scope. The liquid state occupies an intermediate phase between the ordered solid (crystalline) state at low temperatures and the disordered gaseous state. In liquids, thermal fluctuations disrupt positional order over distance at the atomic or molecular level. An analogous disorder arises in certain systems with geometric frustration—where spins cannot simultaneously minimize all pairwise interactions with neighboring spins. Such frustrated systems often exhibit counterintuitive properties. For example, depending on the lattice geometry and interaction range, spins can effectively split into two components: one that orders and another that behaves like a liquid [1]. Alternatively, the ground state may divide into topological sectors, where energy-degenerate spin configurations can only transition between one another through highly unusual spin dynamics [2]. Our approach introduces a novel statistical physics perspective, enabling direct visualization of these phenomena. This is achieved through the fabrication of two-dimensional magnetic metamaterials [3-4].

Research topic and facilities available. The internship will center on a macroscopic 2D metamaterial we recently developed: arrays of interacting magnets (see figure). This platform is uniquely suited for exploring and engineering frustration effects, as it allows precise control over each individual meta-spin while enabling full spatial resolution of the overall spin configuration and real-time tracking of its evolution. With this capability, we aim to uncover unconventional emergent phenomena—such as phase separation effects, typically studied in combinatorial mathematics, or charge separation, transport, and recombination, which are central to condensed-matter physics.

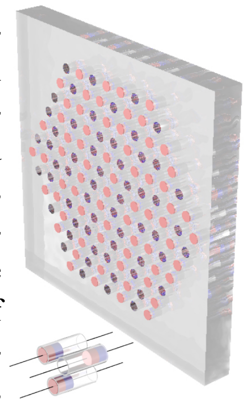

Figure: *A macrosocopic frustrated metamaterial. Magnets are placed on a triangular lattice. They repeal each other, but cannot all maximize their distance due to the geometry (see bottom cartoon: only two pairs of magnets out of three have optimal distance).*

[1] Canals et al. *Fragmentation of magnetism in artificial kagome dipolar spin ice.* Nature Communications 7, 11446 (2016)
[2] Dangoisse et al. *Probing magnetic correlations in space and time within predefined topological sectors of a macroscopic spin liquid.* Nature Communications, DOI:10.1038/s41467-026-76906-5 (2026).
[3] Rougemaille et al. *Artificial kagome arrays of nanomagnets: a frozen dipolar spin ice.* Phys. Rev. Lett. 106, 057209 (2011)
[4] Perrin et al. *Extensive degeneracy, Coulomb phase and magnetic monopoles in artificial square ice*. Nature 540, 7633 (2016)

Starting date: First half of 2027.

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:
Condensed Matter Physics: YES Soft Matter and Biological Physics: NO
Quantum Physics: NO Theoretical Physics: NO