NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2025-2026

High pressure tuning of competing magnetic, electronic and superconducting orders in layered $Ln_{n+1}Ni_nO_{3n+1}$ nickelates

General Scope:

In the last 5 years a new family of unconventional superconductors has emerged, with some of them showing high T_c values, the layered nickelates, which are cousins of high T_c superconducting copper oxides. Superconductivity (SC) in nickelates was first evidenced in 2019, in thin films of $(Ln_{1-x}AE_x)NiO_2$ (Ln: Lanthanide, AE: Alakline Earth element), with maximum $T_{c\ onset}$ approaching now 40 K in $Sm_{0.75}Eu_{0.20}Ca_{0.05}NiO_2$ films. Those infinite-layer nickelates are built from NiO_2 planes with Ni^{1+} cations having a $3d^9$ electronic filling configuration (for x = 0), i.e. the one adopted by Cu^{2+} ions in layered superconducting high-T_c cuprates.

Surprisingly, in 2023, signatures of high T_c SC exceeding 80 K has been observed under high pressure (HP > 14 GPa) in single crystals of $La_3Ni_2O_7$ (La327), a double layered nickelate of the $La_{n+1}Ni_nO_{3n+1}$ Ruddlesden Popper series with an average electron occupancy of $3d^{7.5}$ ($Ni^{2.5+}$). Soon later, the trilayer nickelate $La_4Ni_3O_{10}$ (La4310) with an average $Ni^{2.67+}$, was also discovered to be superconducting above 15 GPa, with T_c up to 30 K in crystals grown by the floating zone method or in flux. On the contrary of infinite-layer nickelates, these bi- and tri-layers compounds show a mixed valency state $Ni^{2.5+}$ (i.e. d^7/d^8) and several theoretical scenarios have been proposed to understand the related high T_c superconductivity mechanism but the question is not yet resolved. Like cuprates, they show a $3d_{x^2-y^2}$-based Fermi surface but also an additional pocket involving $3d_{z^2}$ orbitals which is potentially crucial. In fact, superconductivity occurs just above a structural phase transition at P* ~ 10-14 GPa, where the Ni-O_{apical}-Ni angle, closely related to oxygen 2p/nickel $3d_{z^2}$ orbitals hybridization, changes from 165-168° to 180° [see Fig. 1 for La327]. For $La_2NiO_{4+\delta}$ nickelate, with one isolated NiO_2 plane, SC was not observed under pressure but the stoichiometric (i.e. $\delta = 0$) orthorhombic compound, presumably altermagnetic, has been predicted to undergo a structural phase transition around 8-13 GPa (arxiv: 2506.23823).

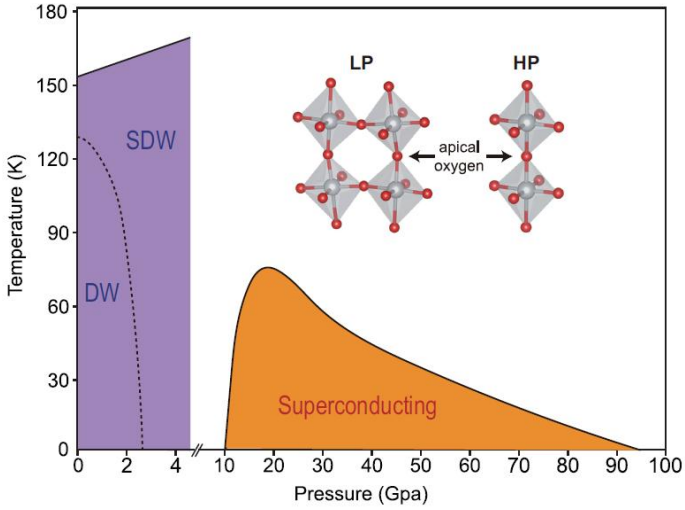

Fig. 1 P,T phase diagram of La327 [arxiv: 2509.08386 (review)].

Research topic and facilities available:

SC has also been realized at ambient pressure with T_c onset up to ~50 K in epitaxially strained La327 thin films substituted with Sm/Pr. A correlation between T_c and relevant structural parameters (like a-axis) was attempted but such relation is not straightforward. At Néel Institute we have studied the P,T phase diagram of La327 and La4310. This internship will focus on the pressure study of the bilayer nickelates with lower defects levels ($La_2LnNi_2O_{7-\delta}$, Ln = Pr or Sm) and of the monolayer La_2NiO_4. It will include potential diffraction experiments at neutron source and/or synchrotron facility and the development of magnetization measurement/HP. A last objective will be to try to stabilize SC in these layered nickelates at (nearly) ambient pressure thanks to adequate chemical substitution and/or the use of new synthesis techniques. Possible resistivity or Raman spectroscopy measurements under HP in collaboration with MagSup (Néel) or IMAPEC (PHELIQS/CEA) groups could be planned.

Possible collaboration and networking: The intern will benefit from active scientific interactions with other teams in the lab. In addition, we have currently a joint research ANR project on nickelates subject with CRISMAT in Caen and several laboratories in Parisian region.

Possible extension as a PhD: this internship will be extended into a PhD where potential superconductivity in palladates will also be explored. Funding may be obtained via the physics doctoral school of Grenoble.

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Required skills: A good background in material science and condensed matter physics is required.

Starting date: Spring 2026.

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