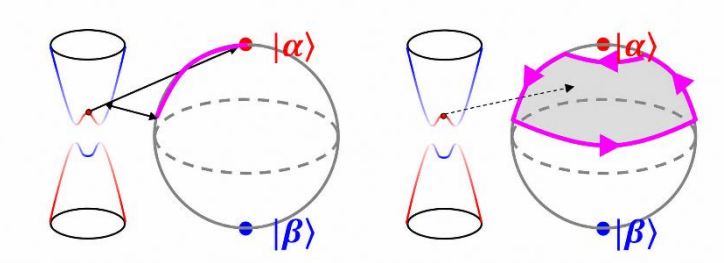
# Quantum geometry and nonlinear transport in oxide two-dimensional electron gases

laboratoire Albert Fert

## Scientific Context




***Quantum geometry illustrated on the Bloch sphere.*** *Electronic states of a two-band system are represented as points on the sphere. Left: the quantum metric measures the distance between nearby states. Right: the Berry curvature is proportional to the oriented area mapped onto the sphere per unit area in momentum space. Its integral over a region gives the Berry phase associated with the bounding loop.*[1]

**How does the geometry of an electron's wavefunction determine how current flows through a material?** Electronic transport is usually described through band energies and scattering processes. However, the evolution of electronic wavefunctions across momentum space carries additional information, encoded in the **Berry curvature and quantum metric**[1]. These complementary components of the **quantum geometric tensor** describe the phase evolution of quantum states and the distance between them, respectively. While Berry curvature underlies phenomena such as the anomalous Hall effect[2], recent experiments have demonstrated that the quantum metric can also generate measurable nonlinear electrical responses in various quantum materials systems including oxide interfaces[3]. Yet, its signatures remain largely underexplored. **Two-dimensional electron gases (2DEGs) based on $SrTiO_3$ and $KTaO_3$** offer a particularly rich setting to explore this physics. Their electronic states derive from several transition-metal *d* orbitals, whose mixing combines with confinement and Rashba spin-orbit coupling to produce complex spin and orbital textures. Near avoided band crossings, wavefunctions can change rapidly with momentum, creating favourable conditions for strong quantum-geometric effects. Crucially, these systems not only offer several ways to detect the various components of the quantum geometry tensor but also to control it electrically. Changing the interface orientation between (001), (110) and (111) modifies the Hamiltonian by lowering the symmetries, and thus decides which transport reponses are allowed. Magnetic field or magnetic order can activate further contributions by breaking time-reversal symmetry, and the Fermi level can be tuned through different bands and regions of strong orbital mixing by electrostatic gating. Together, these controls will allow addressing a central question: **where does quantum geometry at oxide interfaces originate, and how can we identify and tune its various signatures?**

1. Gao, A. et al, Rev. Mod. Phys. 98, 035005 (2026); 2. Lazrak, G. et al. Nano Lett. 26, 8231 (2026); 3. Sala, G. et al. Science 389, 822 (2025).

## Work program & skills acquired during internship

The internship will focus on low-temperature nonlinear magnetotransport in oxide 2DEGs, combining experiments with microscopic modelling. The student will:

- Participate in sample growth and device-fabrication
- Measure longitudinal and Hall voltages at the first, second and third harmonics of an applied current, varying gate voltage, temperature and magnetic-field orientation.
- Analyse the symmetry and scaling of nonlinear signals to distinguish possible quantum-geometric contributions from scattering mechanisms and thermal effects.
- Use tight-binding models, in collaboration with Marc Gabay at the Laboratoire de Physique des Solides, to connect the measured responses to orbital mixing, spin-orbit coupling and electronic band structure.

The main emphasis will be on transport measurements and their physical interpretation. The objective is to establish which electronic states and symmetry conditions favour quantum-geometric transport, then explore whether these contributions can be enhanced or switched electrically.

## Work environment

You will work at the **Laboratoire Albert Fert** with **Manuel Bibes**, **Agnès Barthélémy** and **Hugo Witt**

**Laboratoire Albert Fert**
Located in: Thales Research and Technology
1 avenue Augustin-Fresnel
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Requested background : **Master 2**
Duration : **4-6 months**
Start period : **Feb. 2027**
Possibility of the PhD thesis: **YES**
Contact : manuel.bibes@cnrs-thales.fr

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|---|---|---|---|
| Condensed Matter Physics: | **YES**/NO | Soft Matter and Biological Physics: | YES/**NO** |
| Quantum Physics: | **YES**/NO | Theoretical Physics: | YES/**NO** |