DECENTRALISING SCIENCE: A MORAL DUTY AND A HUGE OPPORTUNITY

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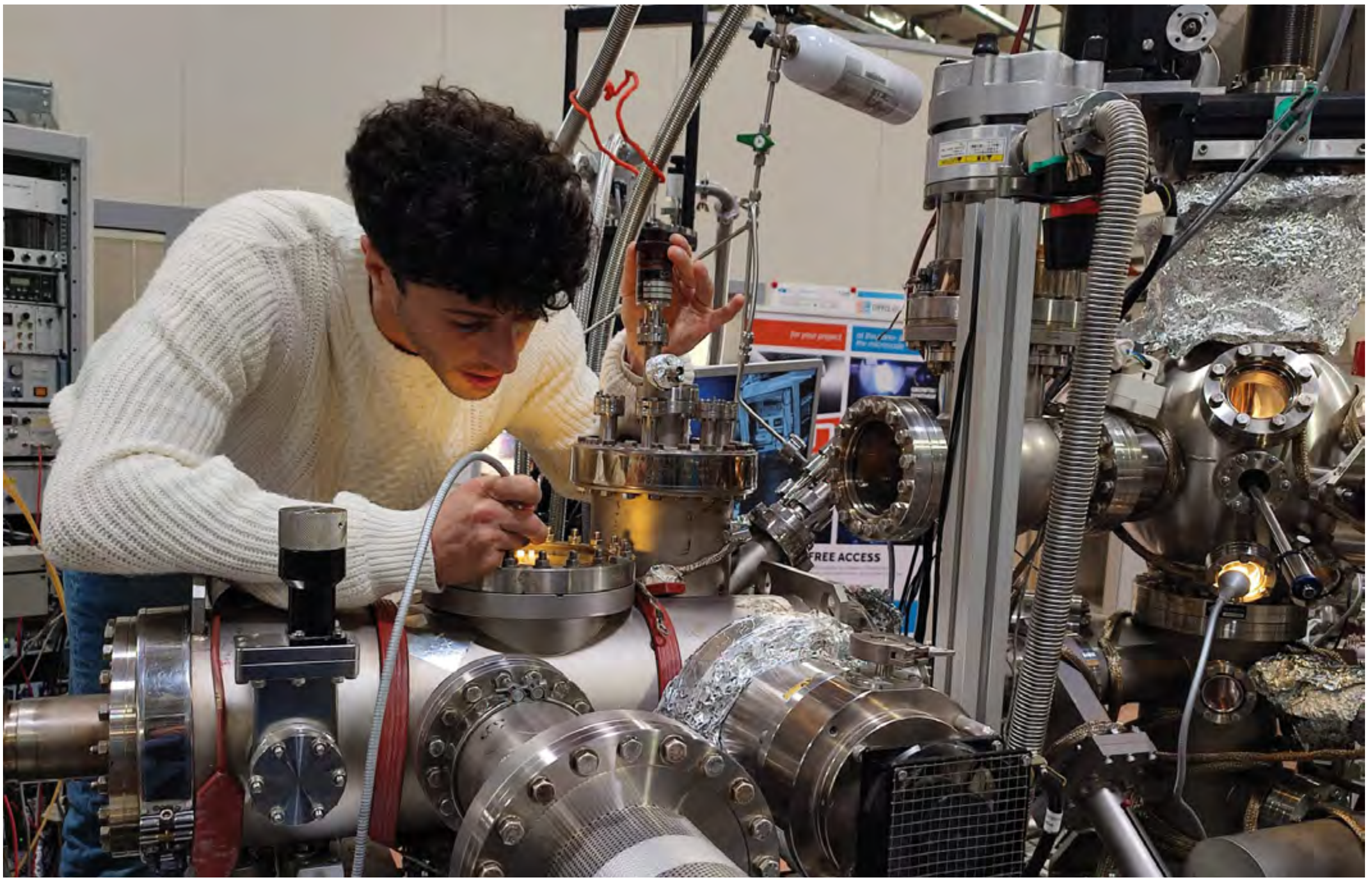
Symmetries have always been important in the description of natural phenomena. From the structure of various materials and the ordered fashion of the atoms, many properties can take place and many others can be modulated. In particular, the electronic properties of a certain system are tightly connected to the system's crystal structure. Hence, magnetism, transport of carriers, and the intertwining between these effects strongly rely on the underlying symmetries of a material.

Understanding such symmetries is a goal of paramount importance because it can help us in discovering new hidden physical parameters and to use these for targeted applications.

My current research focuses on uncovering the deepest relationship between symmetries and electronic properties of quantum systems. In particular, I am interested in understanding the role of the electron spins, topology, and unconventional forms of transport in mediating a particular behaviour of the charges. To do this, I use photoelectron spectroscopies: X-rays shines on a surface and the electrons which reside in the material can be emitted. This process exploits the photoelectric effect, which was introduced by Einstein in 1905 and reason for • • •



▼ FIG. 1: Author at work.

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which Einstein won the Nobel prize in 1921. The main idea is to take "snapshot" of the electron states and to decode the information that such photographs contain. As a matter of fact, the electrons in a lattice can interact with each others, can couple to lattice vibrations (called phonons), can couple to magnetically induced spin-waves (called magnons), can scatter against the material's impurities and defects. All these interactions are responsible for a very complex picture which deviates from the behaviour described by standard textbooks. We are spectators of a many-body problem, which from the one hand complicates the understanding of certain phenomena, from the other hand it paths the way to discover new physical quantities. NFFA has been a beneficial tool to develop this kind of research, helping me with resources and infrastructures to perform high quality scientific research. This was particular important in the context of infrastructures: I used NFFA to access synchrotron radiation, which compared to standard laboratory has the enormous advantage of being focused, variable in energy, and variable in polarisation. These are all necessary elements for the research I am carrying out, which, as mentioned above, is aimed at understanding the role of symmetries in mediating the electronic (and magnetic) properties of quantum materials.

In general, all crystals have some symmetries which are a reflection of the ordering of the atoms which form them. Examples are inversion symmetry, rotational symmetry, mirror symmetry, and combinations of these. If the system is non-magnetic it also has time-reversal symmetry. When a symmetry is broken, physical phenomena can occur. One example is the well-known Rashba effect: at the surface of a bulk material the inversion symmetry is broken and the electronic states lose the spin-degeneracy. Effectively, electrons redistribute by separating themselves according to their spins. If the system is non-magnetic, the time-reversal symmetry is preserved and the overall magnetisation is zero. Instead, when magnetism is turned on, the time-reversal symmetry is broken and a net magnetisation can form. When symmetries break, there is an effect on the charges, on the electron spins, on the transport, and on the magnetic properties of a system. Identifying the hallmarks which describe a symmetry breaking is often very challenging. Sometimes, such a certain phenomenon is only local and macroscopically not observable. One can think that there are hidden parameters which are not easy to access with standard tools. Recently, we have developed a methodology to tackle these ordered parameters, which combines the use of photoelectron spectroscopy and synchrotron radiation. Ultimately, the physics I am interested in resides in many degrees of freedom which are sensible to small changes of the underlying symmetries: spins, orbitals, and many-body effects. In order to achieve information from these degrees of freedom we need to develop strategies to measure them. To probe the orbital character, for example, I change the light polarisation vector which couples effectively to the parity of the orbitals of a material. One project that was recently developed undertaken the NFFA project was aimed to tackle the spin-Berry curvature in a family of kagome metals. The spin-Berry curvature is a quantity which contains information about the topology of the system. In particular, the aim was to probe the topological nature of a spin-orbit induced gap which opens in the system between spin-degenerate bands. For the current work [1] we used circularly polarised light from the synchrotron to couple to the orbital and angular momentum of the material, Lz, and thought the use of a VLEED spin detector we were able to separate the single contributions from the electron spin.

The objective of this project was to check the robustness of the topology in a charge-density wave material: the spin orbit coupling, which confers non-trivial nature to the gap of this metal, is an adiabatic phenomenon. It is a relativistic effect which couples the electron spin to the orbital motion. However, a lattice distortion occurs in the same system. Such a lattice distortion gives rise to the formation of a charge density wave. The question we wanted to address is: Will the charge density wave suppress the topological nature of the gap? Our study, which was only possible through the combination of infrastructures offered by NFFA, has demonstrated the robustness of the topology in this very emergent class of materials. NFFA, for me, offers a great opportunity to develop high-quality research projects also in the absence of large individual funding as it allows to integrate in situ capabilities of highly controlled thin film growth by pulsed laser ablation and molecular beam epitaxy, structural, morphological and electrical characterization, advanced sample preparation methods (e.g exfoliation in controlled atmosphere and UHV transfer), optical, opto-magnetic, Raman, photoelectron spectroscopy and spin-polarimetry also in time resolved mode (50-300 fs) and the possibility, as European user to access the full network of NFFA-Europe/NEP. I think that it is a great way of decentralising science and offering the opportunity to everyone to perform cutting edge research. ■

About the Author

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Reference

[1] Di Sante *et al.*, *Nat. Phys.* **19**, 1135 (2023)