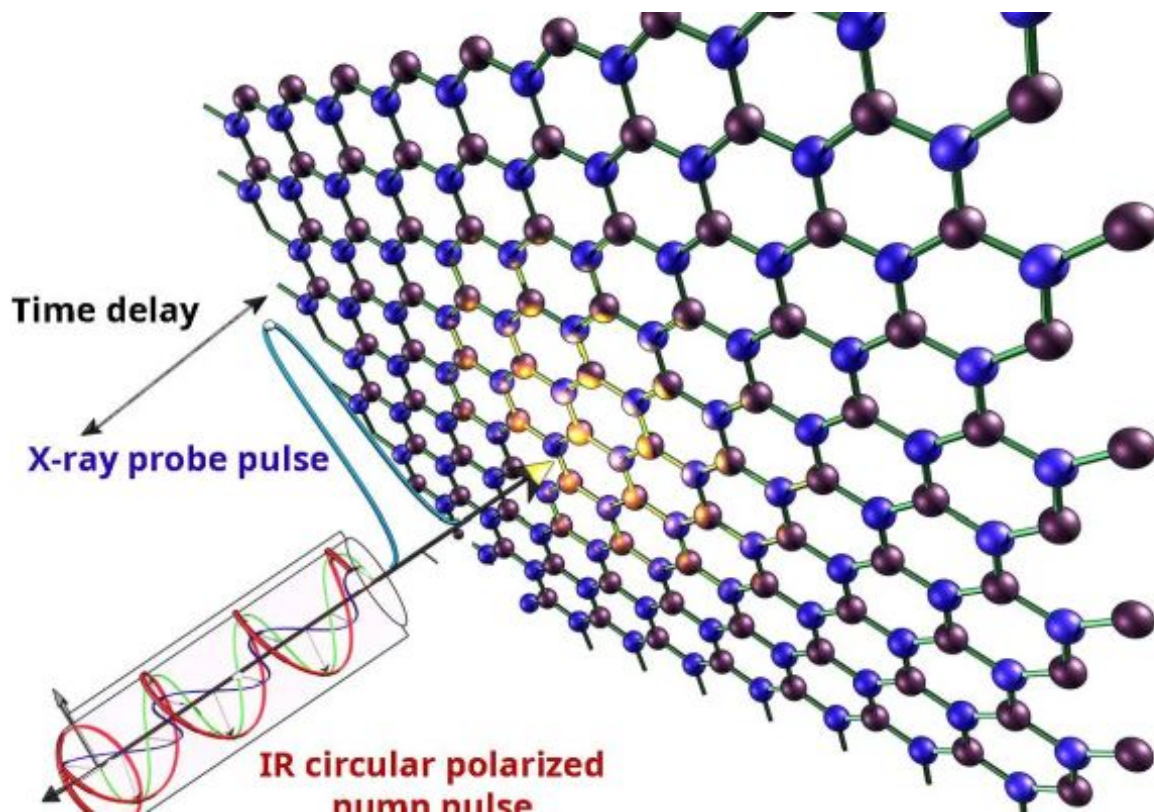




Tracing topological phase transitions with X-ray absorption techniques

An international team of researchers present in **Reports on Progress in Physics Original Research** a numerical experiment that demonstrates the possibility to capture topological phase transitions via an x-ray absorption spectroscopy scheme. By overcoming previous energy resolution limitations, the method will enable further investigations on relevant systems for optoelectronics applications.

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The atoms of solids, liquids, and gases exhibit very different arrangements and behavior. In solids, atoms are tightly packed in a regular pattern; in liquids, atoms are close together but randomly arranged and with some freedom to move; and in gases, atoms are further apart and can move freely. These features define the conventional phases of matter.

When one enters the quantum world, other phases of matter, which have nothing to do with atomic distribution or mobility, emerge. These are the **topological phases**. In this realm, some properties of the particles within a material (like atoms or electrons) can become connected

through a phenomenon known as long-range entanglement. When a pair of particles is entangled, changing or measuring one of them immediately affects the other, regardless of the distance between them. These particles might be entangled in a complex pattern, spanning the entire system. Different 'entanglement patterns' of the material's electrons or other quantum particles define different topological phases. Thus, altering the way particles are entangled, rather than changing their spatial arrangement leads to a phase transition.

Topological states of matter offer the potential to create exotic materials, which can be, for instance, insulators in the bulk but hold conducting states on the surface. In the last years there has been enormous progress in the development of these modern materials. For example, some topologically non-trivial insulators could be induced by using ultrashort intense lasers. However, these light-induced topological insulators exist only while the laser pulse is on, that is, around several femtoseconds (10⁻¹⁵ seconds). This imposes a strong requirement to study and characterize them since an ultrafast probe in the femtosecond timescale is needed in order to capture the ultrafast topological phases.

Despite the significant progress in this direction, some challenges remain. For example, angle-resolved photoemission spectroscopy (ARPES) has proved to be effective in probing these topological systems, but it faces a drawback: the shorter the probe pulse duration (and, consequently, the closer for capturing the material's ultrafast nature), the lower the photoelectron energy resolution.

Recently, a team led by [Universidad Autonoma de Madrid](#), with the collaboration of researchers from [ICFO](#), **Dr. Emilio Pisanty**, **Dr. Alexandre Dauphin** and **ICREA Prof. Maciej Lewenstein**; [M. N. Mikheev Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences](#); [King's College London](#); [University of Salamanca](#); [Max Planck POSTECH/KOREA Research Initiative](#) and [Condensed Matter Physics Center \(IFIMAC\)](#), presented a complementary scheme to ARPES in Reports on Progress in Physics Original Research. In a numerical experiment supported by a theoretical model, the team demonstrated that **X-ray absorption spectroscopy can directly capture topological phase transitions**.

The method employs ultrashort probe pulses that do not suffer from energy resolution reduction. This approach enables further studies of relevant systems for optoelectronics applications, whose investigation had so far been held back by the duration/resolution trade-off.

Topological phase transitions leave an absorption trace

The researchers simulated the action of two ultrashort pulses, separated by a time delay, on a hexagonal boron-nitrate monolayer (hBN). One of them was a linearly-polarized x-ray pulse and the other a circularly-polarized intense infrared pulse. By changing the circular [polarization](#) of the latter from left- to right-handed, the absorption of the sample also changed. This dependence enabled them to infer the topological phase of the material.

Our ultrafast scheme was very sensitive to topological phase transitions. When the topological phase changed, there was a sign imprinted in the absorption spectrum¹, explains ICREA Prof. Maciej Lewenstein. Therefore, this method could be used to study topological phases and identify topological phase transitions within some materials. Now, we need an experimental design to be able to demonstrate it in a real-case scenario

Reference:

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