



## Attosecond X-ray Spectroscopy in Quantum Materials

Applied Physics Reviews details the state-of-the-art of Attosecond Technology and showcases how Attosecond soft X-ray spectroscopy allows to understand the dynamics of conventional and quantum materials.

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Until recently, most soft X-ray spectroscopy science and experiments were only plausible in synchrotron facilities, limiting the amount of science that could be done and augmenting the cost of these experiments. Thanks to the development of attosecond technology and the emergence of High Harmonic Generation (HHG), table-top X-ray spectroscopy technology, such as x-ray absorption near-edge spectroscopy (XANES) and extended x-ray absorption fine structure spectroscopy (EXAFS), became available and one of the most prominent tools to understand details about the structure and dynamics of composite, quantum, organic materials, as well as twisted bilayer graphene, high-temperature superconductors, and organic electronics, among many others.

In a recent paper published in Applied Physics Reviews, a team of researchers at ICFO, led by ICREA Prof. at ICFO Jens Biegert and first authored by former ICFO researcher Barbara Buades, present a review on the field and the state-of-the-art techniques being used nowadays. The researchers further show that isolated attosecond soft x-ray pulses for x-ray absorption near edge spectroscopy (XANES) provide the element- and orbital-resolved real-time dynamics of the semi-metal TiS<sub>2</sub>.

### **High Harmonic Generation**

HHG is an extreme form of nonlinear optics and the only technique to generate coherent short wavelength radiation. It provides pulsed radiation in the UV to SXR range and with duration of a few attoseconds, thus permitting to resolve sub-femtosecond electronic dynamics in gases, liquids and solids. In the soft x-ray range, HHG gives access to the multiple component absorption edges, which provides information about the lattice, charge and spin dynamics of a material's components all at once. The soft x-ray regime facilitates access to the K and L-edges, related to the electronic structures of transition metal atoms and complexes.

### **The particular case of the Semi-metal titanium disulfide (TiS<sub>2</sub>)**

Titanium disulfide is a semi-metallic material that presents extremely high electron and ion mobility, making it a very interesting material for applications such as information processing, energy harvesting or high energy density storage, e.g., efficient batteries.

Buades et al. investigated TiS<sub>2</sub> and used attosecond soft X-ray XANES to interrogate the 3d binding orbitals of the quantum material and how their electronic properties changed upon absorbing light. Resolving with attosecond precision changes in electronic density of the Ti:3d electrons revealed a real-time view on the light-mediated flow of charge between the sulfur and titanium lattice sites.

The results of this study prove that attosecond XANES is a powerful new method to study and understand in detail the heterostructures of conventional and quantum materials. The powerful new analytical method will be a strong asset to address standing issues of our modern society such as to understand the bottlenecks in light-harvesting devices, high-density batteries, or to address energy dissipation in information storage and transmission devices.

Image citation: Schematic illustration of how the XANES and EXAFS techniques work

o observe and understand the internal orbital dynamics of materials. See figure 1 caption for a detailed description.