Congratulations to New ICFO PhD Graduate

Dr. Sergi Batlle Porro graduated with a thesis entitled "Near-field photocurrent in correlated 2D moire materials"

May 30, 2025

We congratulate Dr. Sergi Batlle Porro who defended his thesis this morning in ICFO's Auditorium.
Dr. Batlle Porro obtained his MSc in Physics from the University of Luxembourg, before joining the Quantum Nano-Optoelectronics research group led by ICREA professor at ICFO Dr. Frank Koppens. His thesis titled " Near-field photocurrent in correlated 2D moire material " was supervised by Prof. Dr. Frank Koppens and Dr. Petr Stepanov

ABSTRACT:

Since the discovery of graphene, two-dimensional (2D) materials have garnered significant attention from the condensed matter physics community owing to their potential to engineer new physical, optical, and mechanical properties. The 2D material class now includes

insulators (hexagonal boron nitride, hBN), semiconductors (transition metal dichalcogenides, TMDs), superconductors (NbSe2), topological insulators (Bi2Te3), and ferromagnets (CrI3). Beyond their inherent properties, layered materials allow for new characteristics through vertical stacking. Recent developments have led to the discovery of moire materials, in which electronic properties are significantly altered by twisting adjacent 2D layers.
The discovery of superconductivity in magic-angle twisted bilayer graphene (MATBG) marked a milestone in moire physics, initiating a rapidly growing field. The resulting phase diagrams of other high-Tc superconductors, MATBG, serve as a platform for exploring highly tunable strongly correlated states. At a twist angle of approximately 1.1°, the "magic angle,i¿½ MA BG shows significant band flattening near the Dirac points, reducing the Fermi velocity nd making the kinetic energy smaller than the repulsive Coulomb interactions. This results in superconductivity and various emergent phases dominated by many-body physics, includ ng correlated insulators, orbital magnetism, nematic orders, and topological stat s. Moire materials with large superlattice unit cells facilitate the exploration of stron ly correlated phenomena at low charge carrier densities. Local back-gate electrodes ena le capacitive tuning between strongly correlated states in-situ, a unique feature not available in other high-Tc superconductors. Advances in scanning probe techniques have allo ed researchers to determine local properties at the sub-nanometer scale. Scattering-t pe scanning near-field optical microscopy (s-SNOM) is particularly suited for exploring MA BG because it can measure scattering and photovoltage signals at the nanometer scale wh le simultaneously probing mesoscopic electron transpo t. Utilizing a groundbreaking cryo-near-field nanoscopy method, we will conduct s-S OM measurements at cryogenic temperatures (as low as 8 K) to assess the optical nd photovoltage near-field responses. This approach employs energies in the mid-infrared (M R) and terahertz (THz) ranges, which align with the anticipated optical transition energies in he band structures of these materia s. The primary objectives of this thesis are to ascertain the pertinent optical and thermoelect ic coefficients in twisted moire materials, evaluate the impact of inhomogeneities thro gh gate-tuned near-field photovoltage and optical measurements, visualize correla ed phenomena and broken symmetry states, and comprehend the nature of dephased signals in various measurements. This dissertation seeks to highlight crucial advancements in quan um phases, quantum nano-optoelectronics, and thermoelectricity, while supporting interest in unresolved questions, such as the characteristics of low-temperature correlated stat s. Additionally, it outlines future objectives for near- and far-field photovoltage experimen

Thesis Committee:

Prof. Dr. Justin Chien Wen Song, Nanyang Technological University

Prof. Dr. Carmen Rubio Verdu, ICFO

Prof. Dr. Maria Elena Bascones Fernandez de Velasco, Instituto de Ciencia de Materiales de Madrid