Congratulations to New ICFO PhD Graduate

Dr. Anubhav Kumar Srivastava graduated with a thesis entitled "Quantum simulations of spin systems for optimal quantum metrologyï¿½

June 29, 2026

We congratulate Dr. Anubhav Kumar Srivastava who defended his thesis this morning in ICFO's Elements Room.

Dr. Srivastava obtained his MSc in Physics from the Indian Institute of Science Education and Research, before joining the Quantum Optics Theory research group led by ICREA professor Dr. Maciej Lewenstein. His thesis titled "Quantum simulations of spin systems for optima quantum metrology" was supervised by ICREA Prof. Dr. Maciej Lewenstein and Dr. Marci Plodzien

ABSTRACT:

Quantum mechanics both constrains and empowers precision measurement: the uncertainty principle imposes fundamental limits on parameter estimation, which quantum resources

such as entanglement and superposition can saturate. Quantum metrology develops protocols that exploit non-classical probe states and optimal data processing to surpass the standard quantum limit. In practice, however, realizing this advantage requires solving three problems: designing experimentally feasible many-body probes with near-optimal sensitivity, certifying metrological resources from incomplete measurement data, and implementing optimal readout schemes that remain tractable at scale. This thesis develops a unified framework for all three challenges, combining quantum simulation, convex optimization, and classical-shadow techniques to bring quantum-enhanced metrology closer to experimental reality.

The first part addresses quantum thermometry at nano- and sub-nanokelvin scales. Using the quantum Fisher information (QFI) as the sensitivity measure, we show that an experimentally accessible system of spinless fermions in a one-dimensional optical lattice, described by the Rice-Mele (RM) model, realizes a near-optimal local quantum thermometer approaching the fundamental Cramer-Rao bound. We characterize how the topological and trivial regimes, the lattice filling, and a tunable staggered potential control its sensitivity, and show that the probe equilibrates with a coupled bath without perturbing it. We further analyse a global thermometry scheme based on classical-shadow tomography of thermal states, comparing its sample complexity with standard protocols.

The second part develops two complementary tools for quantum-enhanced sensing and its certification. We introduce a sensor based on a frustrated Kitaev trimer whose nonlinear spectral response implements a thresholded rectifying detector: for a zero-mean omnidirectional signal, the accumulated phase vanishes below a tunable threshold and, above it, is proportional to the signal's second moment. Entangled multi-trimer configurations attain Heisenberg-limited sensitivity. We then formulate a semidefinite programme (SDP) that computes the minimal QFI compatible with incomplete expectation-value data, yielding rigorous lower bounds without full state tomography. Applied to multi-headed cat states generated by one-axis-twisting dynamics, the SDP certifies metrological usefulness from low-order moments more tightly than conventional squeezing inequalities.

The third part addresses the gap between optimal measurement schemes and the measurements achievable on current quantum platforms. The optimal observable saturating the quantum Cramer-Rao bound is generically a highly nonlocal operator whose Pauli weight grows with system size. We introduce Clifford lensing, a framework in which classically simulable Clifford circuits map the optimal observable onto an operator of reduced Pauli weight, refocusing distributed phase information onto fewer qubits. We establish a correspondence between quantum error-correcting codes and interferometric constructions enforcing deterministic phase kickback, and develop metrologically sufficient partial-shadow tomography protocols that preserve the full QFI. The resulting schemes require exponentially fewer samples than naive shadow estimation and are validated on liquid-state nuclear magnetic resonance (NMR) systems of up to 15 qubits.

Together, these results demonstrate that near-optimal quantum metrology is achievable with accessible probes, data-efficient certification, and scalable readout, providing a unified route from fundamental metrological bounds to practical quantum-enhanced sensing.

Thesis Committee:

Prof. Dr. Jordi Tura I Brugues, Universitat de Leiden

Prof. Dr. Antonio Acin, ICFO?

Prof. Dr. Maria Moreno Cardoner, Universitat de Barcelona