Quantum Science & Technology: where we are, where we are headed

18th-19th April 2024
The Italian Academy
1161 Amsterdam Ave, NYC 10027 – New York

Program
(version 1.0 – March 8, 2024)

	Thursday 18 April 2024	Friday 19 April 2024
09:30 - 10:15	**Giuseppe Santoro**	**Alessandro Zavatta**
10:15 - 11:00	**Jeff Thompson**	**Emily Davis**
11:00 - 11:30	Coffee Break	Coffee Break
11:30 - 12:15	**Marcello Dalmonte**	**Dries Sels**
12:15 - 13:00	**Sebastian Will**	**Ugo Marzolino**
13:00 - 14.00	Lunch Break	Lunch Break
14:00 - 14:45	**Ana Asenjo-Garcia**	**Latha Venkataraman**
14:45 - 15:30	**Dominik Schneble**	**Andrew Millis**
15:30 - 16:00	Coffee Break	Coffee Break
16:00 - 16:45	**Mauro Paternostro**	**Colin Nuckolls**
16:45 - 17:30		**Martina Dell'Angela**

UNIVERSITÀ DEGLI STUDI DI TRIESTE

COLUMBIA UNIVERSITY
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FOR ADVANCED STUDIES IN AMERICA

Titles & Abstracts

Ana Asenjo-Garcia - Columbia University New York

Title: Universal scaling laws for correlated decay of many-body quantum systems

Abstract: A key challenge in scaling up quantum systems is the potential for correlated decay, which can significantly reduce the lifetime of states of interest. This talk answers the following question: what is the maximal decay rate of a quantum system, and how does it scale with system size? Addressing this question, especially for systems comprising a large number of particles, is challenging due to the exponential increase in complexity of the Hilbert space. I will present a method that circumvents this difficulty by reformulating the problem into finding the ground state energy of a generic spin Hamiltonian. By establishing strict upper and lower bounds on this energy, we discover universal scaling laws that depend solely on the system's size, dimensionality, and interaction range. These laws serve as upper limits on how fast any quantum state can decay, and offer valuable insights for research in quantum optics and quantum information processing.

Marcello Dalmonte - ICTP Trieste

Title: Magic - From quantum computers to many-body systems

Abstract: Quantum resources have entered the many-body stage over the last two decades. Apart from the prototypical case of entanglement, relatively little is known about how such resources relate to physical phenomena, a question that is of pivotal importance for the understanding of quantum simulators and computers as many-body systems.

In this talk, I will show how magic - a type of resource that is fundamental in determining quantum advantage - is directly related to many-body phenomena. First, I will review recent developments in quantum information theory that have introduced stabilizer Renyi entropies as measures of magic. Based on that, I will present method(s) to measure magic in tensor network simulations, based on the concept of Markov chains over the Clifford group, and on replicated matrix product states. Finally, I will illustrate a series of applications, including (a) how state magic and long-range magic behave in conformal field theories - illustrating the limit of the former, and the capabilities of the latter; (b) the scaling of magic in two-dimensional systems, showing how the latter detects phase transitions in Z2 lattice gauge theories with a precisions that is considerably better than those of ordinary order parameters; and (c) how it

is possible to have a distinct series of 'complexity transitions' in monitored quantum dynamics. I will close discussing the applicability of our methods to experiments, pointing out possibilities and challenges.

Martina Dell'Angela – CNR-IOM Trieste

Title: Lattice Dynamics in 2D Materials probed by Time Resolved Soft X-ray Spectroscopies at ELETTRA Synchrotron

Abstract: In the fields of optoelectronics there is growing interest in studying the response to optical excitation of 2D materials as these systems are of fundamental relevance for the development of the next generation of environmentally sustainable optoelectronic devices and catalysts. In order to probe the lattice dynamics in such materials down to the sub-nanosecond timescale we developed a setup at the ALOISA beamline of the Elettra synchrotron that exploits the chemical selectivity of X-ray photoemission (XPS) in an optical pump/X-ray probe experiment. In this talk, I will present our results on the study of the early times in the 2H–1T′ phase transition induced by optical excitation 2H-MoTe2. I will discuss hydrogen dehydrogenation of nanoporous graphene obtained by laser heating. Finally, I will present the recent results on the CDW in GdTe3 as seen by core level photoemission.

Emily J. Davis - Harvard University & NYU New York

Title: Interaction-enabled readout of anisotropic quantum projection noise in a two-dimensional ensemble of solid-state spins

Abstract: Achieving full quantum control of materials at the atomic scale is a challenging but exciting prospect. Motivated by this goal, we demonstrate progress towards generating spin-squeezed entangled states in an interacting ensemble of nitrogen-vacancy (NV) centers in diamond. Spin-squeezing describes a reduction in quantum spin projection noise (QSPN) which is useful for metrology, and bringing NV centers into the realm of entanglement-enhanced sensing will build on their well-established strengths as quantum sensors for condensed matter systems.
Harnessing crucial recent developments in sample fabrication [Hughes et al. APL Materials (2023)], I will first present measurements of mean-field quench dynamics generated by power-law XXZ interactions within a two-dimensional ensemble of NV centers. The same dynamics also reshape (squeeze) the QSPN, but because the readout of the spin state is photon-shot-noise-limited, only the mean spin direction can be directly measured. We thus develop and implement a protocol to circumvent this problem and experimentally characterize the variance

of the QSPN using only global measurements of the total spin length. Our method is furthermore broadly applicable to a variety of platforms.
Our measurements reveal that the QSPN of the NV ensemble is indeed reduced during quench dynamics compared to the noise of the initial state, a necessary condition for achieving entanglement-enhanced sensing. I will discuss our current work on the next step: to verify that the spins are entangled by showing that the squeezing parameter, which compares the variance of the QSPN to the length of the total spin vector, is less than one. In particular, I will analyze what limits our current measured value of the squeezing parameter and discuss strategies for improvement.

Ugo Marzolino - University of Trieste

Title: Quantum metrology: from fundamental physics to technological applications

Abstract: Metrology is the science of performing precision measurements. It is therefore at the edge of physics, statistical inference, and technological applications. Quantum metrology addresses the enhancements of metrological schemes achieved by quantum mechanics, for instance using correlated quantum probes or inferring from quantum physical phenomena. I will introduce the basic concepts in quantum metrology, and a comparison with metrological schemes based on classical physics. In particular, I will focus on the quantification of metrological performances and on their attainability. I will then discuss resources for quantum enhanced measurements in two archetypical applications. First, I will discuss interferometric setups where precision phase measurements can be achieved in the presence of probe entanglement or particle indistinguishability. Then, I will describe how enhanced metrological performances are related to phase transitions in models of statistical mechanics. Within this framework, sometimes called critical metrology, I will discuss exemplary protocols to exploit the critical behavior for enhanced metrology.

Andrew Millis – Columbia & Flatiron Institute

Title: Quantum Theory for Quantum Materials

Abstract: ”Quantum materials” exhibit remarkable and potentially useful properties (superconductivity, magnetism, light harvesting and optoelectronics, metal-insulator and spintronic transitions) arising from subtle quantum mechanical correlations amongst their constituent electrons but depending sensitively on classical variables, in particular the positions of the constituent atoms. Understanding the physics of many interacting electrons in realistic solid-state environments is the quantum many-body problem, which for almost a

century following the foundational 1929 paper of Paul Dirac has been one of the grand challenges of science. This talk will outline some of the remarkable progress of the past two decades, driven by the interplay of materials synthesis and measurement on the experimental side and concepts, algorithms, codes on the theory side. Topics covered will include new insights into high transition temperature superconductivity and new developments in the metal-insulator and topological physics of Moire materials, and touch on simulations of dynamics of quantum materials. A perspective for future research will be given.
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Colin Nuckolls – Columbia

Title: TBA

Mauro Paternostro - University of Palermo

Title: A non-equilibrium route to the foundations of quantum mechanics

Abstract: I will illustrate how the framework embodied by non-equilibrium thermodynamics opens up new routes, of thermodynamic inspiration, for the assessment of the foundations of quantum mechanics. In particular, quantities aimed at the characterisation of thermodynamic irreversibility, such as entropy production, are well suited to pinpoint the occurrence of the quantum-to-classical transition. I will show the implications of this approach for the dynamics of mesoscopic quantum systems and discuss the perspectives offered for the assessment of the emergence of objective reality.

Giuseppe Santoro - SISSA

Title: TBA

Dominik Schneble - Stony Brook University

Title: Waveguide Quantum Electrodynamics with Matter Waves

Abstract: Understanding and harnessing light-matter interactions in novel contexts is central to the development of modern quantum technologies. One example is the emerging field of

waveguide quantum electrodynamics (wQED) which investigates the coherent coupling between one or more quantum emitters and an engineered low-dimensional photonic bath. While recent wQED experiments have observed effects such as modified spontaneous emission, bound-state mediated interactions, and superradiance, a clean access to the underlying mechanisms often remains challenging. We approach wQED with an unconventional platform in which artificial quantum emitters, realized with ultracold atoms in an optical lattice, undergo radiative decay by emitting single atoms rather than single photons. I will discuss the unique aspects of our platform and present some recent work on simulating radiative many-body effects at the boundary between quantum optics and condensed-matter physics.

Dries Sels - NYU New York

Title: Quantum enabled sampling and inference for real world applications

Abstract: Remarkable progress has been made in increasing the complexity of quantum devices and improving their quality. Surprisingly, one of the central challenges for quantum technologies is the search for useful applications of current quantum machines. In this talk, I will discuss how one can achieve robust quantum speedup in solving statistical inference problems by combining methods from classical machine learning and quantum computing.
I will focus on two problems in particular: (i) model inference for nuclear magnetic resonance (NMR) spectroscopy, which is important for biological and medical research and (ii) Monte Carlo sampling, which is a ubiquitous tool in physics and beyond. I will also stress current limitations of quantum technologies and provide a road map for future developments.

Jeff Thompson - Princeton University

Title: Quantum computing with Yb Rydberg atoms

Abstract: Neutral atom quantum computing is a rapidly developing field. Exploring new atomic species, such as alkaline earth atoms, provides additional opportunities for cooling and trapping, measurement, qubit manipulation, high-fidelity gates and quantum error correction. In this talk, I will present recent results from our group on implementing high-fidelity gates on nuclear spins encoded in metastable 171Yb atoms [1], including mid-circuit detection of gate errors that give rise to leakage out of the qubit space, using erasure conversion [2,3]. I will conclude by discussing several new directions including spectroscopy and modeling of 171Yb Rydberg states and interactions, and the construction of high-speed modulators for local gate addressing [4].

[1] S. Ma, G. Liu, P. Peng, B. Zhang, S. Jandura, J. Claes, A. P. Burgers, G. Pupillo, S. Puri, and J. D. Thompson, High-Fidelity Gates and Mid-Circuit Erasure Conversion in an Atomic Qubit, Nature 622, 7982 (2023).
[2] Y. Wu, S. Kolkowitz, S. Puri, and J. D. Thompson, Erasure Conversion for Fault-Tolerant Quantum Computing in Alkaline Earth Rydberg Atom Arrays, Nat. Commun. 13, 1 (2022).
[3] K. Sahay, J. Jin, J. Claes, J. D. Thompson, and S. Puri, High-Threshold Codes for Neutral-Atom Qubits with Biased Erasure Errors, Phys. Rev. X 13, 041013 (2023).
[4] B. Zhang, P. Peng, A. Paul, and J. D. Thompson, Scaled Local Gate Controller for Optically Addressed Qubits, Optica 11, 227 (2024).

Latha Venkataraman – Columbia

Title: Ultrahigh Conductance in Radical Based Long Molecular Wires

Abstract: Molecular one-dimensional topological insulators (1D TIs), which conduct through energetically low-lying topological edge states (or radical states), can be extremely highly conducting and exhibit a reversed conductance decay, affording them great potential as building blocks for nanoelectronic devices. In this talk, I will present experimental results from recent works where we demonstrate that molecular wires can behave as one-dimensional topological insulators. I will first focus on a family of oligophenylene-bridged bis(triarylamines). These wires can undergo one- and two-electron chemical oxidations. The oxidized wires exhibit high reversed conductance decay with increasing length, consistent with the expectation for the Su-Schrieffer-Heeger-type one-dimensional topological insulators. I will then show how we can extend the length at which these anomalously high conductance can be observed in topological oligo[n]emeraldine wires where we use short 1D TIs as building blocks. For this series, we find that as the wire length increases, the number of topological states increases, enabling an increased electronic transmission along the wire.

Sebastian Will – Columbia

Title: Creating and exploring Bose-Einstein condensates of dipolar molecules

Abstract: We have recently created the first Bose-Einstein condensates of dipolar molecules [1]. We efficiently cool gases of NaCs molecules from 700 nK to less than 10 nK, deep into the quantum degenerate regime. The lifetime of our molecular BECs is almost 2 seconds, reaching a level of stability similar to ultracold atomic gases. These advances became possible by establishing "double microwave shielding", a method to dramatically reduce inelastic collisions of molecules by four orders of magnitude, building on our earlier demonstration of microwave shielding [2]. In this talk, I will discuss our experimental methods [3,4] and share our latest insights. Ultracold gases of dipolar molecules are on the verge of becoming a new

modality for quantum simulation and quantum information. The NaCs molecules used in our work are strongly dipolar and offer exciting prospects to realize dipolar quantum matter in regimes that have been inaccessible so far.

[1] Bigagli, Yuan, Zhang, et al., Observation of Bose-Einstein condensation of dipolar molecules, arXiv:2312.10965 (2023)
[2] Bigagli, et al., Collisionally stable gas of bosonic dipolar ground state molecules, Nature Physics, 19, 1579-1584 (2023)
[3] Stevenson, et al., Ultracold gas of dipolar NaCs ground state molecules, PRL 130, 113003 (2023).
[4] Yuan, Zhang et al., A planar cloverleaf antenna for the creation of circularly polarized microwave fields, RSI 94, 123201 (2023).

Alessandro Zavatta – CNR-INO Florence

Title: TBA

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