SoCal Hub Symposium 2025
Quo Vadis Quantum Science?

Final Report

Introduction: Purpose of the Meeting

The 2025 Symposium "*Quo Vadis Quantum Science*" aimed at bringing together leading experts from academia and national laboratories to explore the outstanding challenges and emerging opportunities in the rapidly evolving field of quantum information science and technologies. Over the past few years, significant progress has been made in developing new platforms and techniques for quantum-based technologies, and we find ourselves at a pivotal moment for advancing our understanding and capabilities.

The goal of the Symposium was not just to exchange ideas or present the latest contributions to the field by the participants, but to spark new collaborations, foster interdisciplinary connections, and lay the groundwork for future funding opportunities. The discussion was organized into four interrelated areas driving innovation in quantum science - integrated photonics, integrated materials, many-body quantum sensing, and dynamical quantum control - selected to reflect the diversity and promise of quantum technologies.

This report summarizes the outcomes of the Symposium, identifies the next frontiers in quantum science and technology according to the participants, and highlights promising areas for collaborative research.

The Symposium

The Symposium was held at UC Santa Barbara on January 30-31, 2025. The Technical Organizing Committee (*Appendix A*) met over the Fall quarter to identify themes, meeting format, and invited speakers. UC Santa Barbara Office of Research provided support on all aspects related to logistics and coordination of the event, including the creation of a website (https://www.research.ucsb.edu/socal-hub-symposium). The Concept Paper submitted to SoCal leadership and outlining the scope of the event is attached as *Appendix B*. The final agenda of the meeting is attached as *Appendix C*.

The table below lists the Co-Chairs in each of the four themes. Co-Chairs were responsible for leading the discussion during both plenary presentations (day 1) and breakout sessions (day 2).

Themes	Theme Co-Chairs
1. Integrated photonics for QIS	Galan Moody (UCSB), Elizabeth Peterson (LANL)
2. Advanced materials for QIS	Stephen Wilson (UCSB), Vivien Zapf (LANL)
3. Quantum sensing	Andrew Jayich (UCSB), Tyler Guglielmo (LLNL)
4. Quantum control	David Weld (UCSB), Malcolm Boshier (LANL)

The Symposium was advertised through email campaigns targeting: 1) SoCal leadership, as points of contact of their respective organizations; 2) SoCal mailing list (socalhub@uci.edu); 3) Research Development Offices at the partner UC campuses; 4) personal email invitations to field experts by the Organizing Committee Members; 5) other personal email invitations to key participants by UC Santa Barbara Office of Research. In total, 80 people signed up, with representation from all 5 UC partner campuses, UCOP, LANL, and LLNL.

Theme 1: Integrated Photonics for QIS

The Integrated Photonics for QIS theme kicked off with a plenary talk by Prof. John Bowers (UCSB), who emphasized the importance of leveraging the mature silicon microelectronics and photonics foundry ecosystem for scaling quantum systems. A key part of this ecosystem is heterogeneous and hybrid integration of other materials with silicon photonics, including semiconductor laser and detector, as well as other nonlinear materials such as III-Vs, ferroelectrics, and nitrides for modulators, quantum sources, and frequency converters. The breakout session featured presentations on engineering quantum emitters with optimal optical and spin properties using 2D materials (Han Htoon, LANL), the creation of quantum metasurfaces for engineering light-matter interaction dynamically (Diego Dalvit, LANL), and methods for creating high-rate and high-quality deterministic quantum light sources using quantum emitters and nonlinear photonics (Shayan Mookherjea, UCSD). Through lively discussions, participants identified several pressing challenges that should be addressed to enable impactful quantum photonics systems: (1) the need to reduce the loss in existing photonic materials and interfaces and the search for emerging nonlinear materials (see Theme 2); (2) consideration of the complete electronic-photonic-quantum platform when engineering efficient systems in order to facilitate robustness and deployability for quantum information and sensing applications described in Theme 3; (3) classical and quantum light sources with near-perfect properties that can be seamlessly integrated into quantum systems without introducing additional loss and noise; and (4) dynamic control of quantum properties, which has synergies with the schemes and techniques from Theme 4. Opportunities to address these challenges will leverage existing silicon photonics foundries as well as more niche, rapid prototyping in academic and national lab cleanrooms; the exploration of new optical materials and quantum defects for highly coherent photonic and spin qubits; assessing how classical and quantum photonic systems enable scaling of other quantum platforms; and pursuing spatio-temporal control for dynamically reconfigurable photonics, such as with quantum metasurfaces.

Theme 2: Advanced Materials for QIS

One of the frontier challenges for next-generation quantum information science application is to develop the requisite materials that can host highly coherent and entangled states in a manner that protects their decoherence. The materials challenge spans both the development of materials that make existing quantum technologies more robust and scalable as well as the search for new materials that can enable new modalities of manipulating quantum information. This need for advanced materials spans the fields of quantum computing, quantum sensing, and quantum communication, and there are key, materials-enabled opportunities in each subfield. A crucial synergy necessary for advancing the field is a union of the quantum materials and quantum information communities. New materials developed and studied by quantum materials researchers can have transformative impacts in quantum information applications---A key example here is the idea of topological quantum computing where unconventional quasiparticles known as non-Abelian anyons are predicted to form in unusual forms of superconductors and quantum magnets. Similarly, key tools and concepts developed by researchers in the quantum information field can provide unique insights into understanding the electronic states formed in quantum materials and their continued development. In quantum materials a key challenge remains: how to rapidly assess the presence of exotic states? Whereas in QIS, a key challenge remains: how does one rapidly assess fidelity of interfaces, design new processing techniques to make new materials viable? New techniques for materials synthesis developed in both the quantum materials and quantum information communities can similarly benefit one another, and an expanded search/development of "conventional" materials for quantum technologies (ie. decoherence resilient superconductors for transmons) is a near-term goal. Hybrid conventional and topological quantum materials are another largely unexplored frontier with considerable promise as well as the use of AI in targeted materials discovery and development in QIS.

Theme 3: Quantum Sensing

The quantum sensing breakout session featured presentations on electric field sensing near material surfaces (Wilson Ho, UCI), exotic materials (such as topological insulators) and physics sensing (Prineha Narang, UCLA), as well as the detection and analysis of signals from gravity sensing in cluttered environments (Stephen Libby, LLNL). The discussion covered an extremely wide range of quantum sensing applications and use cases – from bleeding edge sensing in controlled environments to end user sensing and data filtering. The breadth of presented work exemplified how differentiated the field is, especially considering the differing needs of national laboratory missions and academic research. Despite these differences, significant overlap exists, providing fertile ground for future collaborations. For example, the material surface sensing work under development at UCI will be an important tool for material characterization at small distance scales and will be a crucial probe of materials subjected to extreme environments. Sensor development at UCLA may also inform or deploy the next generation of dark matter detection devices. National labs provide an ideal testing and deployment environment for end use cases where final customers require integration of sensor data and signal processing to extract relevant signals in real-world environments – as such, academic/national laboratory collaboration will be a high leverage partnership in the years to come.

Theme 4: Quantum Control

The quantum control breakout session featured presentations on error correction for precision measurement (Wes Campbell, UCLA), coherence in controlled quantum matter (Sagar Vijay, UCSB), and navigating noise in quantum systems (Katarzyna Krzyżanowska, LANL). Outcomes of the resulting discussions revealed some cross-cutting themes and new frontiers for endeavor. A continuum between single-atom and many-body control and decoherence protection schemes was identified, as well as a general "observe, learn, manipulate" scheme of quantum control which can be applied to goals ranging from state preparation to error correction to autonomous decoders to the observation of new many-body phenomena. Connections to other themes of the workshop included postprocessing-based quantum sensing schemes and the use of control or controllability as a many-body diagnostic of advanced materials. Inspiration for new quantum control modalities may come from the rich world of classical control, feedback, and steering. Collaborative UC-lab opportunities at the frontiers of quantum control sometimes bridge the quantum-classical divide, for example using synchronous supercompute for coherent quantum feedback, or leveraging national lab capabilities in high-performance FPGA electronics and machine learning.

APPENDIX A

Organizing Committee

SoCal Hub Symposium 2025
Quo Vadis Quantum Science?

Ania Jayich
Professor, UCSB Physics

Galan Moody
Associate Professor, UCSB Electrical and Computer Engineering

David Weld
Professor, UCSB Physics

Stephen Wilson
Professor, UCSB Materials

Kristi Beck
Physicist & Livermore Center for Quantum Science Director, Lawrence Livermore National Lab

Yujin Cho
Quantum Physicist, Lawrence Livermore National Lab

Heather Erpenbeck
University Collaborations Office Leader, Los Alamos National Lab

Filip Ronning
Director, Institute for Materials Science, Los Alamos National Lab

Eric Schwegler
Director of Academic Engagement Office & Science Education, Lawrence Livermore National Laboratory

APPENDIX B

"QUO VADIS QUANTUM SCIENCE" CONFERENCE WHITE PAPER

Introduction And Workshop Goals

Here we propose to convene a workshop with key university, laboratory, and industry stakeholders exploring outstanding challenges and new frontiers in the burgeoning field of quantum information science and technologies. A number of crossroads and new opportunities have been identified in recent years regarding new platforms for quantum-based technologies and for approaches to controlling quantum coherence across a broad spectrum of physical systems. Quantum photonics, extended solid-state systems, trapped atom networks, and engineered quantum defects all present exciting new opportunities, and the goal of this workshop is to convene leaders across these fields to discuss open challenges and next steps across the field. The conference will be organized into four interrelated thrusts, covering some of the main avenues of present and future rapid development in quantum science: integrated photonics, integrated materials, many-body quantum sensing, and dynamical quantum control. Anticipated outcomes will be new research collaborations, teaming for future federal/state funding opportunities, and cross fertilization of ideas across disciplines.

Integrated photonics for QIS: In the last decade, advances in photonic materials and manufacturing have enabled table-top experiments to be scaled down to compact chips with improvements in efficiency, robustness, scalability, and key performance metrics. These advances include chip-scale classical and quantum light sources, modulators, switches, memories, detectors, and light-matter interfaces that can be combined into modular systems for quantum information processing, chip-to-chip networking, quantum sensing, and optical beam delivery for interfacing with other quantum elements. To continue making breakthroughs in scalable and robust photonic platforms for quantum applications, the next decade will require addressing several challenges, including hetero-integration of different photonic materials, co-integration of photonics and electronics, ultra-low-loss photonic interconnects and packaging at scale, and the exploration of new materials, hetero-interfaces, and fabrication methods that can support these advances.

Integrated materials for QIS: Advances in the control of quantum coherence and entanglement in the solid state often rely on the nature of the materials hosting the quantum states and the fidelity of interfaces between these materials within devices. Ultrahigh purity bulk and thin materials are required as hosts for tailored quantum defects with robust coherence, and new material types are broadly sought that can host intrinsically protected quantum information. Discovering these new materials classes and interfaces capable of hosting novel, protected quantum states and perfecting the integration of known materials classes and interfaces into devices are both required steps for progress at this frontier. The coming years will require breakthroughs in these areas for continued advances in solid-state quantum devices.

Many-body quantum sensing: While sensing has long been a key application of a variety of quantum platforms, there are still major improvements to be made by utilizing many-body entanglement and correlations. Control of interactions among many quantum elements opens up new possibilities in this area, yet remains an outstanding challenge for many sensing-ready platforms. A key example would be entanglement-assisted sensing in which dipolar or cavity-mediated interactions among an ensemble of spins leads to metrologically useful entangled states, enabling measurement sensitivity beyond the standard quantum limit. Schemes for generating and utilizing many-body states need to be theoretically and experimentally evaluated, in particular in the presence of real sensing targets.

Dynamical quantum control: Control of quantum systems away from equilibrium is a crucial element of modern quantum technologies, from pulse engineering to quantum error correction. The isolation and tunability of modern quantum information processing platforms opens up new possibilities in nonequilibrium quantum control, the transport of quantum information, the control of thermalization, and the development of dynamical control protocols which are intrinsically robust against decoherence. As one example of cutting-edge topics in this area, a largely unexplored frontier for quantum many-body physics involves the use of measurement and feedback to drive phase transitions and create new states of matter.

APPENDIX C

SoCal Hub Symposium 2025
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January 30, 2025

8:30 Breakfast *(Ground floor courtyard)*

9:30 Welcome and Introductions ***(S. Wilson)*** *(1st floor auditorium, room 1302)*

Shelly Gable, Interim Dean of Mathematical, Life and Physical Sciences

10:00 Plenary followed by Q&A: Integrated Photonics for QIS
Session Co-Chairs: Galan Moody (UCSB) & Elizabeth Peterson (LANL)
"*Challenges and Opportunities in Integrated Photonics for QIS*", John Bowers (UCSB)

11:00 Plenary followed by Q&A: Advanced Materials for QIS
Session Co-Chairs: Stephen Wilson (UCSB) & Vivien Zapf (LANL)
"*Challenges and Opportunities in Advanced Materials for QIS*", Priscila Rosa (LANL)

12:00 Lunch Break *(2nd floor terrace)*

1:00 Plenary followed by Q&A: Quantum Sensing
Session Co-Chairs: Andrew Jayich (UCSB) & Tyler Guglielmo (LLNL)
"*Challenges and Opportunities in Quantum Sensing*", Tarun Grover (UCSD)

2:00 Plenary followed by Q&A: Quantum Control
Session Co-Chairs: David Weld (UCSB) & Malcolm Boshier (LANL)
"*Challenges and Opportunities in Quantum Control*", Michel Devoret (UCSB)

3:00 Coffee Break *(Ground floor courtyard)*

3:30 Internship and Employment Opportunities at National Labs *(1st floor auditorium)*
Heather Erpenbeck (LANL), Eric Schwegler (LLNL)

4:15-5:30 Poster Session and Reception *(Ground floor courtyard)*

January 31, 2025

8:30 Breakfast *(2nd floor terrace)*

9:30 Welcome and Break Out Session Plans and Goals ***(G. Moody)*** *(1st floor auditorium)*

10:15 Breakout Sessions in Parallel *(see themes and locations on the next page)*
10:15 Co-Chair brief remarks
10:20- 11:05 Breakout Presentations (15 minutes- 12-minute talk, 3 minute Q&A)
11:05- 12:00 Panel/Group Discussion moderated by Co-Chairs; notes recorded in community document

12:00 Lunch Break *(2nd floor terrace)*

2:00 Reconvene and Debrief *(1st floor auditorium)*

Breakout Reports from Session Chairs

3:00 Closing Remarks ***(D. Weld)***

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Breakout Sessions Details
January 31, 2025
10:15-12:00

Integrated Photonics for QIS *(3rd floor conference room 3322)*
Co-Chairs: Galan Moody (UCSB) & Elizabeth Peterson (LANL)

- **Han Htoon** (LANL): Creation and Control of Quantum Emitters in 2D Flat Land
- **Diego Dalvit** (LANL): TBD
- **Shayan Mookherjea** (UCSD): Opportunities for Integrated Photonics at the Frontiers of QIS

Advanced Materials for QIS *(1st floor auditorium, room 1302)*
Co-Chairs: Stephen Wilson (UCSB) & Vivien Zapf (LANL)

- **Luis Jauregui** (UCI): TBD
- **Chris Palmstrøm** (UCSB): TBD
- **Leon Balents** (UCSB): Intrinsically entangled quantum materials

Quantum Sensing *(2nd floor Conference room 2318)*
Co-Chairs: Andrew Jayich (UCSB) & Tyler Guglielmo (LLNL)

- **Wilson Ho** (UCI): Quantum Sensing Based on Space-Time Coherence
- **Pri Narang** (UCLA): Applications of Quantum Sensing in Fundamental Physics: From Detecting Time-Reversal Symmetry Breaking to Unlocking New Physics
- **Steve Libby** (LLNL): Distinguishing Between Noise and Environmental Clutter in Quantum Sensing

Quantum Control *(4th floor Conference room 4318)*
Co-Chairs: David Weld (UCSB) & Malcolm Boshier (LANL)

- **Wes Campbell** (UCLA): Quantum Error Correction for Clocks and Precision Measurement
- **Sagar Vijay** (UCSB): Opportunities for quantum coherence in far-from-equilibrium quantum matter
- **Kasia Krzyzanowska** (LANL): Navigating Noise in Quantum Systems: The Relative Robustness of Squeezing, Entanglement, and Mixed States