Many-Body Quantum Optics

Report on the KITP Program, Oct. 29 - Dec. 20, 2024

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Abstract

The **Many-Body Quantum Optics** program at KITP brought together leading theorists and experimentalists to explore the frontier of quantum light-matter interactions, focusing on novel many-body phenomena emerging from photon-mediated interactions. Building on recent experimental breakthroughs, the program tackled the limitations of traditional quantum optical theories, uncovering new paradigms in quantum simulation, entanglement engineering, and non-equilibrium quantum dynamics.

One of the major accomplishments of the program was advancing our understanding of how collective and long-range interactions can be harnessed to generate and control complex quantum states of light and matter. Discussions and collaborations during the program led to significant progress in developing theoretical frameworks for light-induced many-body physics, including extensions of tensor network techniques, effective field theories for dissipative quantum systems, and novel approaches to correlated quantum optics in synthetic photonic platforms. These efforts laid the groundwork for new experimental proposals that can be implemented in diverse platforms including atomic arrays, superconducting qubits, and cavity QED systems.

The program also fostered interdisciplinary connections, bringing insights from condensed matter, AMO physics, and quantum information theory into the realm of many-body quantum optics. The resulting synergy has already led to new collaborations, some of which are expected to result in high-impact publications and experimental proposals. Beyond its immediate scientific output, the program helped shape the future directions of the field by identifying key open questions and formulating strategies to address them. As quantum optical systems continue to push the boundaries of controllability and complexity, the ideas generated at KITP will serve as a foundation for advancing quantum technologies and fundamental physics alike.

Overview

The study of the interaction between light and matter played a prominent role in the foundations of quantum mechanics and continues to be a key ingredient in the development of new quantum technologies. Historically, the investigation of quantum light-matter interactions, and development of corresponding theories, has focused on “simple” scenarios, such as:

(1) Clean systems with a minimal number of degrees of freedom, such as a single atom strongly interacting with a single cavity mode
(2) Regimes where semi-classical or large-spin theories are expected to suffice, such as light interacting with a dilute cloud of atoms in free space

Whereas these traditional regimes of focus are characterized by an absence of complexity, due to impressive experimental advances, we are now at a turning point where complex many-body behavior due to photon-mediated interactions can potentially be engineered and exploited. In particular, a wide range of systems have been recently realized to which our traditional quantum optical theories can no longer be applied. These platforms range from dense atomic media either in the form of ordered arrays or disordered ensembles, to nanophotonic "crystals" made of atoms and light, to quantum electrodynamical circuits coupled to superconducting qubits. Common features of such systems are the capability to strongly alter the dispersion relation of light (e.g., to allow quantum matter to couple to optical band gaps or even topological bands), the ability to reduce the dimensionality or create completely synthetic geometries in which photons and matter interact, and/or the enhancement of multiple scattering phenomena to the point that they become non-perturbative. In such settings, the granular nature of the individual atoms, such as their microscopic positions and their internal "spin" degrees of freedom, strongly affects the coherent or collective dissipative interactions mediated by common photons.

The primary goal of the KITP Program on Many-Body Quantum Optics was to bring together a diverse group of scientists from various fields (e.g., quantum optics, condensed matter, quantum information), to build up novel theoretical tools and concepts to deal with modern emerging complex quantum optical systems. In particular, taking the common features of quantum optical systems such as correlated dissipation, long-range interactions, and out-of-equilibrium character as a starting point, the objectives were to unveil new applications within quantum information science, or new fundamental phenomena, and develop the theoretical framework to treat them. Specific key themes that were heavily explored and discussed include:

- Developing a better understanding of the paradigmatic correlated dissipation phenomena of superradiance and subradiance, at the many-body and beyond mean-field level
- The search for new modalities for quantum metrology and engineering of metrologically useful states
- Treatment of interactions and dissipation beyond the usually studied Markovian regime, accounting for the delay or dispersion of propagating fields
- Quantum optical systems as novel platforms to realize and probe many-body phenomena (e.g., measurement-induced phase transitions, many-body localization, topological order)
- Connecting theory with potential new experiments
- Optical cooling and forces beyond the traditional single-atom regime

Program organization

We elected to structure each non-conference week of our program in a manner that maximized opportunities for informal discussions, while at the same time ensuring that there were organized activities allowing for new participants to meet one another, and also to provide introductions to topics that might not be familiar to all participants. Most weeks started with a “meet and greet” session on Monday mornings. We asked new participants to prepare 1-2 slides introducing themselves and their research interests, and during these meet and greet sessions, had new participants use their slides to introduce themselves. Depending on the number of new participants, we either had all participants introduce themselves, or only the new arrivals for that week. The method for integrating new arrivals seemed to work well, and we used this model throughout the workshop.

Beyond the meet and greet, each week typically had 3 organized talk sessions, each being roughly 1.5 hours. We typically split these sessions into two, allowing two program participants to present their work during each session. While there was initially some discussion on having more talks per week, our impression after the first few weeks was that participants were very happy with having more time for informal discussions, often on topics seeded by the more formal presentations. This also matched the feedback we received from participants (both informally, and from the mid-program surveys). We were extremely happy from the very wide range of informal discussions and collaborations that appear to have been seeded during the program, including those between researchers that did not previously know one another, or that worked on fairly different topics.

In addition to sessions devoted to talks from program participants, we had a number of special sessions that aimed to foster more wide ranging discussions. One of these was a lively discussion on the future of many-body quantum optics, hosted by Prof. Jamir Marino. This was an extremely participatory discussion where program participants discussed the things they found most exciting in terms of potential future research, as well as areas that they believed were perhaps over-hyped or somewhat less fruitful. The discussion here was very lively and stimulating, but always respectful and inclusive. The session also benefited from various strategies Prof. Marino used to make things as participatory as possible. This session was a key highlight of the program, and represents the kind of activity that could not have been accomplished without having so many researchers in this area in one place at the same time.

Another set of special activities that was well-received was the sessions organized to foster discussions between our program and researchers in the simultaneously running Active Solids program. While the programs would at first glance seem to be completely different, both groups were interested in non-equilibrium many-body physics in driven systems (whether classical or quantum), and also interested in more specific topics like the unique many-body physics of systems with non-reciprocal interactions. Our program participant Prof. Sebastian Diehl led an interesting discussion on the use of field theory methods to describe many-body quantum optical systems, and how this naturally connects to the classical non-equilibrium field theories used by researchers in the active matter community. This presentation and discussion was specifically crafted to be accessible to both groups, and to foster discussions. Complementing this, we also had a presentation and discussion led by Prof. Ramin Golestanian from the Active Solids program, who discussed work on non-reciprocal active matter, and how there were certain parallels to quantum systems. Again, these activities and discussions are things that could not have been accomplished in any other venue, as it was a unique opportunity to have so many leading researchers in both these areas in the same place at the same time.

Finally, we also made sure that there were regular organized social activities to help further ensure that members of the program got to know one another (and especially to integrate early career researchers, who might not already know as many program participants coming in). We had an organized BBQ each week, with program organizers chipping in to provide food and help with grilling. This complemented the otherwise pot-luck style of the BBQs. We received many positive comments on the atmosphere at these social gatherings, and feel that they played an excellent role in fostering a collegial spirit of interaction and collaboration between nearly all participants.

Program goals and accomplishments

Below, we describe in detail the main program goals and accomplishments achieved during the program, organized by research theme.

Many-body super- and subradiance

Superradiance is a paradigmatic example of a many-body effect involving correlated dissipation in atom-light interfaces, and occurs nearly universally across different platforms. During superradiance, an ensemble of excited atoms develops coherences between atoms during the spontaneous emission process. This accelerates their emission, resulting in a few famous signatures such as a maximum emission intensity that occurs sometime during the middle of the dynamics, and a super-extensive scaling of the maximum emission rate with atom number. There is no general exact solution, however, and one theme of active discussion is how to treat superradiance in realistic scenarios.

On the other hand, it is widely believed that the dynamics of superradiance is largely describable by mean-field or collective-spin approximations, or variations thereof. Another theme was then how it might be possible to evade superradiance, such as through the choice of initial conditions or through sufficiently strong interactions. And if superradiance were to shut off, what is the new resulting “universality class” of dynamics – would it be possible to arrive at strongly correlated states beyond collective spin physics, and are there some general principles that govern this regime? A related question, given the super-extensive scaling of superradiant emission rates, is whether under certain conditions, superradiance might always win in the thermodynamic limit, and prevent another universality class from kicking in at any finite density of excitations. Key advances that transpired during the program include:

- There were a number of collaborations that were initiated to investigate the interplay of superradiance and strong interactions, including between D. Wild, L. Rossi, and D. Malz, and between V. Walther and M. Silveri.
- L. Rossi discussed with UCSB faculty member M. Srednicki, on whether the subradiant regime of dynamics might fall into a universality class governed by eigenstate thermalization hypothesis (ETH). In particular, as subradiance is characterized by a long time between photon emission events, ETH might dictate that the system effective relaxes into a Gibbs state during subradiance, which would provide a strong guiding principle to understand subradiant dynamics.
- Along similar lines, D. Chang initiated collaborations with several participants to investigate whether the emergent temperature that arises as the system relaxes might decrease as a function of time, thus constituting a form of "evaporative cooling" for the internal atomic "spin" degrees of freedom, particularly in atom arrays. D. Chang and C. Kollath established a new collaboration to apply her projection operator formalism to more precisely identify the effective Hamiltonian to which ETH might apply, and to identify strongly correlated phases that evaporative cooling might be used to reach. D. Chang and I. Bloch also discussed a possible experimental collaboration to investigate this subradiant evaporative cooling mechanism using ultracold atoms in Mott insulating phases.

Quantum metrology

One of the major established research lines within quantum optics is the use of quantum atom-light interfaces for quantum metrology and sensing, with major examples being atomic magnetometry or optical lattice clocks. Historically, these interfaces also pioneered the generation of quantum states with metrological advantage, most notably spin squeezed states and squeezed light. These squeezing protocols have relatively simple theoretical descriptions, in terms of a large collective spin representing an ensemble of atoms interacting uniformly with light, along with simple models of independent dissipation to account for limiting mechanisms for squeezing.

A key theme within the program was to search for new and more powerful modalities for quantum-enhanced metrology, such as involving discrete, controllable atoms undergoing correlated dissipation. There were several new collaborations established during the program along these lines, including between A.M. Rey and H. Ritsch; between A.M. Rey, J. Thompson, and E. Shahmoon; between A.M. Rey and D. Chang; and between R. Trivedi, H. Pichler, and A. Gonzalez Tudela. The participation of R. Trivedi was particularly useful, as he brought a unique quantum information theoretical perspective to the dynamics of open quantum systems. The promising directions established within the program include:

- R. Trivedi used the program to develop novel methods "to characterise the quantum metrological potential of the photon states that are emitted from quantum emitters via a collective decay process and understanding when these photons have quantum advantage." In a collaboration with H. Pichler and A. Gonzalez Tudela, they explored protocols to create photonic states with realistic Markovian and non-Markovian systems, which can exhibit Heisenberg-limited scaling.

- A.M. Rey has been investigating the quantum metrological advantage of atoms prepared in states resembling resonating valence bond wave functions. She discussed potential realizations related to the work of D. Chang, to realize similar states as spin-liquid ground states of atom arrays in cavities.
- The paradigmatic problem involving the Dicke "driven-dissipative phase transition," where atoms experience a uniform coherent driving and a single channel of collective decay, is well-known to exhibit strong spin squeezing in its steady state. However, it is largely a toy model, neglecting the additional non-permutation symmetric interactions and dissipation channels that real atomic systems experience. A.M. Rey, J. Thompson, and E. Shahmoon have developed a new collaboration based on the intuition that this Dicke model could essentially be realized in realistic settings of arrays of atoms interacting with light in free space, and in particular that the additional non-symmetric interactions might be considered irrelevant in certain regimes.

<u>Non-Markovian effects</u>

An exciting new theme that was not necessarily anticipated at the start, but which emerged during the course of the program, was on the influence of non-Markovian effects associated with retardation in light-matter interactions. In particular, several participants were interested whether non-Markovian effects could lead to different classes of behavior, as compared to the Markovian regimes or the simple "strong coupling" regimes of single-mode cavity QED that are traditionally studied within quantum optics, and what theoretical techniques could be applicable in this more challenging setting. This question is relevant due to a number of new platforms where quantum systems are connected via long-distance optical or microwave transmission lines, or highly dispersive lines (e.g., coupled cavity arrays).

For example, these questions constitute a major new research line within the group of J.J. Garcia Ripoll. He used the program as an opportunity to "discuss with colleagues about the new theoretical tools and models we have developed for studying such non-Markovian regimes. The feedback provided has helped me in developing those models further, improving the methodology and consolidating an application to the study of super- and subradiant regimes of particles in waveguide-QED setups with superconducting circuits." Garcia Ripoll and K. Sinha established a collaboration to apply his non-Markovian modelling tools and exact diagonalization codes to her multiphoton dynamics studies in 1D waveguides. He also established a collaboration with A. Asenjo-Garcia, on developing bounds on the maximum allowed correlated emission rates in non-Markovian models, extending her previous work on Markovian systems. Likewise, H. Alaeian and F. Ciccarello initiated a new collaboration to investigate non-Markovian effects within cavity QED.

<u>Connecting quantum optics with many-body physics</u>

A major goal of the program was to connect experts within quantum optics and condensed matter physics together, with the goal of creating new frameworks to understand many-body phenomena within quantum optical systems, and to develop new theoretical tools to treat them. The diverse makeup of the participants enabled promising connections to be made between quantum optics and concepts within condensed matter physics such as many-body localization, measurement-induced phase transitions, topological order, and Lieb-Robinson bounds:

- R. Fazio continued a collaboration with A.M. Rey, and discussed with J. Marino and A. Clerk on unique opportunities that quantum optical systems could offer to measurement-induced phase transitions: “A key challenge in observing measurement-induced phase transitions is the mitigation of the postselection barrier, which causes the reproducibility of specific sequences of measurement readouts – the trajectory – to be exponentially small in system size. Recent studies suggest that some classes of monitored infinite-range systems alleviate this problem by exhibiting a fast saturation of entanglement, resulting in only a polynomial post-selection overhead.”
- A.M. Rey and H. Ritsch developed a new collaboration on realizing dynamical gauge fields in cavities
- M. Kolodrubetz was able to advance his efforts to understand many-body localization (MBL) in the presence of realistic dissipation channels: “A particular problem I worked on heavily was a disordered MBL system in an open cavity, where we have initial results suggesting localization survives cavity loss. Aided by local discussions, I came up with an atom-only model of the dissipative system at high cavity frequency and shifted from Rabi to Jaynes-Cummings model based on experimental reality. I made significant progress on this, which I’ve been stuck on for some time, based on discussions.”
- M. Kolodrubetz and K. Sinha initiated a collaboration on localization physics within optomechanical systems: “With Kanu Sinha, we have discussed optomechanical organization of atoms in a 2-mode cavity, where one mode is red-detuned and one is blue-detuned. The idea is that, under certain conditions, the blue-detuned cavity can act like a dynamical quasiperiodic potential for the self-organized lattice of atoms enabled by the red-detuned cavity. Then self-organization competes against quasiperiodic localization, bringing ideas in localization physics into the optomechanical realm.”
- H. Ritsch and K. Sinha also developed a new collaboration on many-body localization dynamics in multimode cavities
- D. Chang has a major new research line in his group to exploit long-range cavity-mediated interactions to realize and probe topological quantum spin liquids. His discussions with condensed matter theorists proved very helpful. For example, he and S. Gopalakrishnan initiated a collaboration to more systematically understand how locality could emerge from the type of long-range interactions considered by the Chang group. He also discussed with UCSB faculty member Cenke Xu on possible measurements that cavity systems could realize on spin liquids, and he and A. Gonzalez Tudela initiated a new collaboration on the preparation of resonating valence bond spin-liquid wave functions using collective dissipation.
- On the same topic, M. Oehlgrien discussed with UCSB postdoc A. Lavasani, an expert on Lieb-Robinson bounds and topological order, on whether his proofs of the robustness of topological degeneracy might be extendable to long-range interacting systems featuring an emergent locality.

New experimental routes

The program aimed to promote active discussions between theorists and experimentalists, in order to identify promising experimental routes toward observing novel many-body quantum optical phenomena, and to establish concrete new experimental collaborations. Promising developments during the program include:

- The possible collaboration between D. Chang and I. Bloch mentioned above, on subradiant “evaporative cooling” in quantum gas microscope setups
- The collaboration mentioned above between E. Shahmoon, A.M. Rey, and J. Thompson on observing the Dicke driven-dissipative phase transition in free-space setups
- A new collaboration between theorists C. Tabares and A. Muñoz de las Heras and experimentalist A. Vrajitoarea was established. The goal is to progress toward the implementation of variational quantum simulation using waveguide QED systems proposed by the theorists using superconducting qubits, and specifically “to design experiments that will validate these new protocols, potentially demonstrating a new set of techniques useful for quantum simulation with light and matter systems.”
- There were also active efforts to expand the realm of many-body quantum optics toward solid-state platforms, particularly excitons in 2D materials. A new collaboration was established along these lines between V. Walther and D. Wild, and between V. Walter and UCSB faculty member V. Vlcek to investigate many-body screening in 2D semiconductors and their influence on Rydberg excitons.
- C. Rusconi has an ongoing collaboration with the experimental group of D. Stamper-Kurn on atomic self-organization within cavity QED. During the program, a new theoretical collaboration between M. Kolodrubetz and Rusconi was established regarding possible new experimental directions. In particular, “we have discussed dynamical critical scaling of cavity output in their recent work with the Stamper-Kurn group on finite size self-organization. The idea is that the system can be readily parked near the critical point in a controllable manner and the resulting cavity signal – which is readily seen in experiments – should show temporal fluctuations with characteristic scaling form that is related to the underlying mean-field exponents of the model.”

Collective cooling and forces

Several participants were interested in whether collective atom-light interactions could provide novel forces or cooling mechanisms for atoms:

- A new potential collaboration was established between H. Ritsch, A.M. Rey, and C. Rusconi, to investigate improved atom cooling techniques in subwavelength arrays based on collective effects
- A new potential collaboration was established between E. Shahmoon and K. Sinha on collective van der Waals and Casimir forces

Other positive impact

The overwhelming consensus expressed within the participants' activity reports was that the program provided a highly stimulating and welcoming environment for discussions, the exchange of ideas and knowledge especially across different fields, and the establishment of new collaborative research projects again connecting different fields. Several senior researchers expressed that the program aided in advancing new research lines within their groups or in consolidating ideas for future grant proposals. Early stage researchers generally also expressed the very positive impact of meeting and interacting with senior researchers in the field. Some specific comments by participants include:

- D. Chang: "Overall, my participation in the program is expected to have significant impact on my future research, both by pointing me to completely new directions to explore that I am not familiar with, and through concrete suggestions on current research problems that should accelerate our progress by several months to one year."
- J.J. Garcia Ripoll: "Attending both the program and the conference has been very enlightening for me at a moment in which I am reconfiguring my group's research lines, emphasizing the strongly-correlated phenomena in quantum optics and applications to the design of superconducting quantum networks. Here the feedback of colleagues has been very productive and useful, and is also guiding my application to a professorship position in Spain."
- M. Kolodrubetz: The program opened "new lines of research which should be important for future papers and grants. One thing in particular I found helpful is to re-orient ideas for submitting a "renewal" of my NSF CAREER award on Floquet physics in cavity QED."
- J. Marino: Interactions with colleagues in the Active Matter program "led me to consider to submit a joint interdisciplinary program at KITP in the coming years."
- M. Serbyn: "Participation in the program helped me to refine the ideas for the ERC Grant proposal that I am working on."
- E. Shahmoon: "This was an absolutely terrific and fruitful experience of the highest professional level. I would love to come back for something similar and rate this program as one the best scientific events I attended."
- R. Trivedi: "I believe that this workshop has provided me, as an early career researcher, with the opportunity to network with leading experts in Quantum optics, and form collaborations with them."
- D. Wild: "I benefited greatly from the program. As a junior researcher looking for a tenure-track position, I am grateful for the opportunity to introduce myself to many senior researchers."

Publications

To date, the program has led to the following publications that acknowledge KITP:

- Znidaric, M. (2024). Inhomogeneous SU(2) symmetries in homogeneous integrable U(1) circuits and transport. arXiv:2412.09371.

- King, E.C. et al (2025). Optimal spatial searches with long-range tunneling. arXiv:2501.08148.
- Kundu, A. et al (2025). Cooperative effects in thin dielectric layers: long-range Dicke superradiance. arXiv:2501.14913.
- Gonzalez-Garcia, G et al (2025). Dynamical complexity of non-Gaussian many-body systems with dissipation. arXiv:2502.05658.
- Tabares, C. *et al* (2025). Programming optical-lattice Fermi-Hubbard quantum simulators. arXiv: 2502.05607
- Abbasgholinejad, E. et al (2025). Theory of quantum-enhanced interferometry with general Markovian light sources. arXiv:2504.05111.
- Mikheev, A. N. et al (2025). Prethermalization of light and matter in cavity-coupled Rydberg arrays. arXiv:2504.06267.
- Hosseinabadi, H. et al (2025). Making Truncated Wigner for dissipative spins plain easy. arXiv:2503.17443.
- Roy S. et al (2025). Causality, localization, and universality of monitored quantum walks with long-range hopping. arXiv: 2504.12053 (2025)

Diversity

Our program was organized from the start with diversity being a key goal, both in terms of participant backgrounds, but also in terms of career stage of researchers (early-career versus more established experts), research domains (quantum optics theorists, condensed matter theorists, experimentalists), and institutional backgrounds (large research-active universities, smaller more teaching-focused universities). To achieve this, we actively contacted diverse groups of researchers (via email etc.) to make sure they were aware of our program and that their participation would be very welcome. We believe we were largely successful in achieving the above goals, with the caveat of course that like many areas of theoretical physics, our field suffers from limited demographic diversity (e.g. in terms of gender). In the end we note that of our 71 program participants, 15 were women, and of the 25 conference speakers, 8 were women.

We also helped foster an inclusive and welcoming atmosphere during the program by prioritizing talks from early-career researchers and under-represented groups. This was beneficial for the program as a whole, as it allowed participants to hear from new speakers and researchers, and also greatly helped ensure that newer members of our community could effectively engage with others.

Scientific and programmatic impact of conference

The **New Perspectives in Many-Body Physics with Quantum Optical Systems** conference, held at KITP from October 29 to November 1, 2024, served as a critical launching point for the main program. Compared to the program itself, the conference featured a higher ratio of experimental to theoretical presentations, offering theorists an invaluable opportunity to engage directly with the latest experimental developments, including several unpublished results.

Some of the experimental highlights related to AMO physics were Markus Greiner's talk, where he presented new experimental results on super- and sub-radiance beyond the Dicke limit in ordered atomic arrays; Johannes Zeiher reported on quantum optical switches in atomic arrays, demonstrating the potential for controlling light with strongly interacting Rydberg atoms; Monika Schleier-Smith's work on programmable photon-mediated entanglement; and Dan Stamper-Kurn talking about the recent integration of tweezer arrays and cavity QED platforms. Beyond these AMO platforms, other setups were also discussed like circuit QED emulations of emitter-photon lattices by Alicia Kollar or superconducting qubit arrays by Andrei Vrajitoarea.

A number of AMO theory talks provided timely results on applications and fundamental phenomena in modern platforms. These included Ana Maria Rey, who discussed entanglement generation via dissipation using strong symmetries, and Jamir Marino, who explored the quantum-to-classical crossover in spin glass dynamics within cavity QED simulators. A number of condensed-matter theorists, like Sarang Gopalakrishnan, Rosario Fazio or Rahul Nandkishore, provided complementary theoretical viewpoint on phenomena related to the conference topic, which proved very fruitful in seeding subsequent discussions at the interface of quantum optics and condensed matter.

Overall, by bringing together leading experimentalists and theorists in a highly interactive format, the conference set the stage for the rest of the program, ensuring that early discussions and collaborations could take root. This deliberate scheduling at the start of the program helped catalyze new research directions and provided a broad overview of the field's most pressing open questions. The interplay between theoretical models and cutting-edge experimental results fostered an environment of deep scientific exchange, positioning the program for long-term impact in shaping the future of many-body quantum optics.

Suggestions

Our experience organizing and participating in the KITP program was truly seamless, and we have very few suggestions for improvement. One area that could be enhanced is the interaction between concurrent programs. While some participants self-organized to hold a joint talk — highlighting field-theoretic methods as a common thread between many-body quantum optics and active matter — stronger incentives or structures for cross-program exchange could be beneficial. For example, KITP could consider encouraging or even requiring a set of joint pedagogical lectures or informal tutorials aimed at making each field more accessible to the other. This could promote more spontaneous conversations and fruitful interdisciplinary collaborations.

Additionally, we believe it would be highly valuable to offer more structured support for PhD students, particularly through an expanded affiliate program.

Discussion

The Many-Body Quantum Optics program at KITP was the **first of its kind**, bringing together a diverse community of theorists and experimentalists to explore the rich physics emerging from photon-mediated many-body interactions. Given the overwhelmingly positive feedback from participants, this program has set the stage for future iterations in different venues, which will be essential as the field continues to develop. Many attendees expressed their enthusiasm for making this a recurring event, recognizing the need for a dedicated platform to tackle the rapidly evolving challenges in many-body quantum optics.

A major highlight of the program was the open discussions on the future directions of the field lead by Jarmir Marino, at the third week of the program. These sessions allowed for an honest assessment of the key challenges that will shape research in the coming years. Topics included the path towards the many-body regime in quantum optics, the role of dissipation in many-body systems, and the interface between quantum optics and condensed matter physics. The discussions were highly interactive and forward-looking, helping to identify which problems will be most relevant and impactful for the next decade.

The program's success was also evident in its ability to catalyze new collaborations, involving a diverse scope of researchers. The combination of structured talks and informal interactions led to the formation of new research directions, many of which are already being pursued by participants. This synergy of ideas between different subfields — AMO physics, quantum information, condensed matter, and quantum many-body theory — is expected to have a long-lasting impact on the field.

By fostering deep scientific exchange and identifying key open questions, this program has played a pivotal role in shaping the trajectory of many-body quantum optics. The strong sense of community and collaboration established during these weeks will undoubtedly continue to drive innovation in the field, setting a blueprint for future programs on this topic.

MBQOPTICS24 Program Talks

Speaker	Title	Date
All participants	Meet and greet session	November 4
Helmut Ritsch (Innsbruck)	Quantum Gas Cavity QED	November 5
Zlatko Minev (IBM)	Entanglement-enhanced learning of quantum processes at scale	November 6
Marko Znidaric (Univ. of Ljubljana)	The joys and dangers of non-unitarity: Ruelle-Pollicott resonances and pseudospectra	November 8
Sebastian Diehl (Univ. of Cologne)	Universality in driven open quantum matter (pedagogical talk + discussion to help foster connections with the active matter program)	November 12
Jamir Marino (Univ. of Mainz)	A think tank for many-body quantum optics (discussion)	November 13
Federica Surace (Caltech)	Exploring quantum many-body dynamics with quantum simulation	November 15
Michael Kolodrubetz (UT Dallas)	Floquet topology and dynamics in cavity QED	November 18
Pablo Sala (Caltech)	Exploring Quantum Many-Body Systems under Decoherence and Measurements	November 20
Matti Silveri (University of Oulu)	Super- and subradiance in transmon arrays beyond two-level approximation	November 22
(everyone) ((everywhere))	Weekly meet & greet	November 25
Corinna Kollath (Univ. of Bonn)	The effects of fluctuations for interacting atoms in optical cavities	November 26
Kanu Sinha (Univ. of Arizona)	Collective atom-photon interactions in nanoscale quantum systems and waveguide QED	November 27
Philip Kurian (Howard Univ.)	Non-Hermitian Hamiltonians for biological qubit-light interfaces	December 2
Mohammad Maghrebi (Michigan State Univ.)	Localization from Markovian dissipation: A purifying quantum phase transition	December 3
Zlatko Papic (University of Leeds)	Three incarnations and three mysteries of the PXP model	December 4
Andrew Higginbotham (University of Chicago)	Non-equilibrium cascades and kinetics of photons in a 1D Josephson junction array	December 6
Scott Parkins (Univ. Auckland)	Dicke models with integer-spin atoms: phase transitions, spin squeezing, and nonclassical light	December 9
Charlie-Ray Mann (ICFO)	Emergence of Quantum Spin Liquids from Atom-Cavity Interactions	December 10
Alireza Seif (IBM)	Measurements, Conditional Operations, and Entanglement Dynamics in Open Quantum Systems	December 11
Daniel Malz (Univ. Copenhagen)	Tensor network states of photons and open system dynamics	December 12
Maksym Serbyn (IST Austria)	From quantum many-body scars to optimal steering	December 13
Immanuel Bloch (Max Planck Institute of Quantum Optics)	Quantum Optics and Many-Body Physics with Ultracold Atom in Optical Lattices	December 16
Alejandro Manjavacas (CSIC)	Collective optical modes in two-dimensional arrays of nanoparticles	December 17
Valentin Walther (Purdue University)	Quantum) Many-Body Optics with Rydberg-excited Semiconductors	December 17