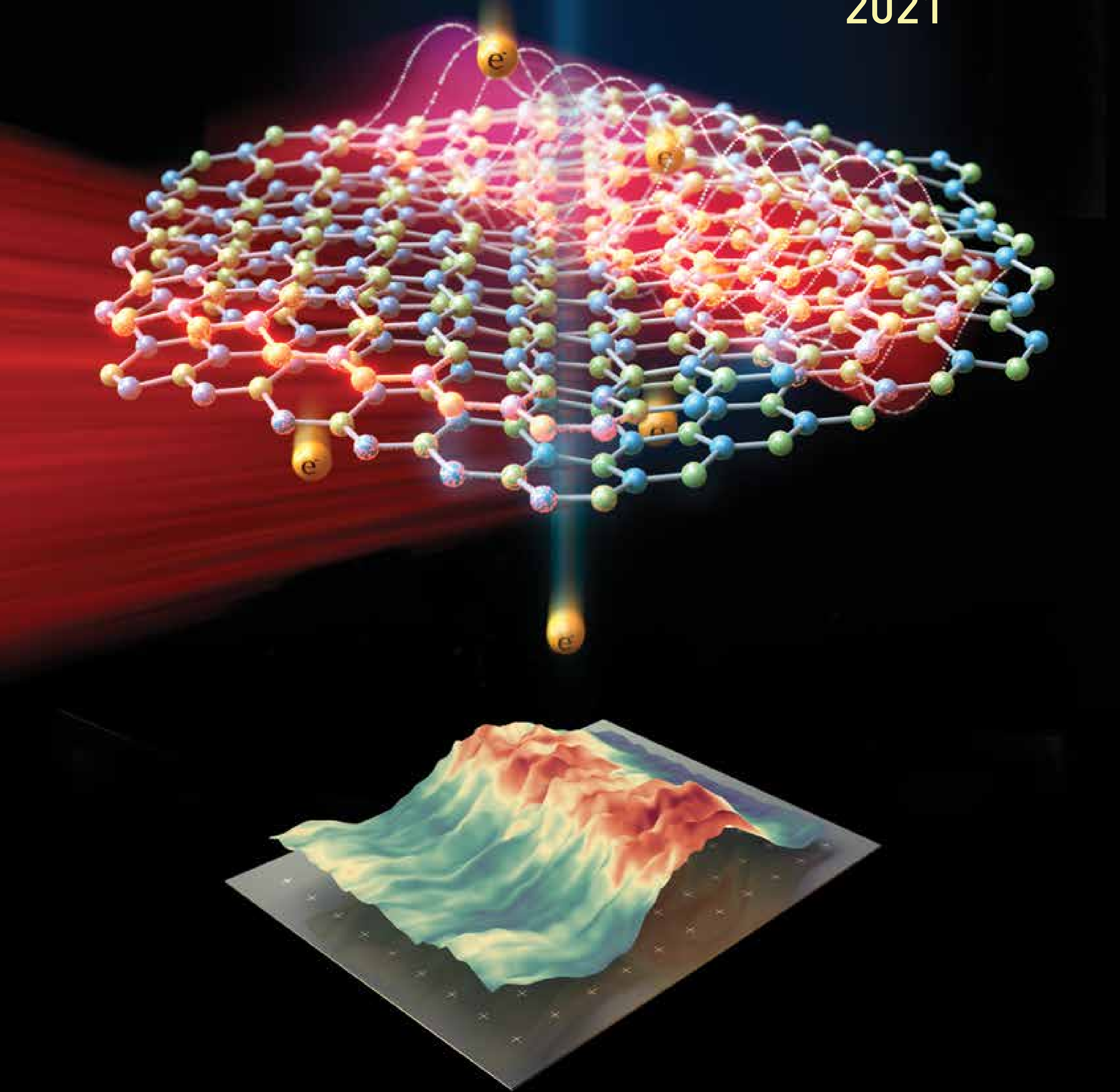
TECHNION | Helen Diller Quantum Center

Quantum Review 2021



TECHNION | Helen Diller Quantum Center

Cover: Illustration of a sound-light wave in 2D materials and how it is measured using free electrons. Illustration from *Science* June 2021 "Spatiotemporal imaging of 2D polariton wave packet dynamics using free electrons," Kaminer et al.

Scientific visualization by *SimplySci Animations*

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The Age of Quantum

Up until the industrial revolution of the 18th century, a young boy could expect to lead the same way of life as the generations preceding him. Today things are very different. The rate of change is rapidly accelerating and the lifestyle of the alpha generation will change significantly more than once during an individual's lifetime.

Will quantum technology trigger the next revolution, replacing the information revolution of the 21st century? Quantum physics already permeates our daily lives: lasers are ubiquitous, MRIs provide superb high-definition 3D medical imaging without dangerous ionizing radiation, and every time we use Waze we rely on atomic clocks.

These technologies are just a sample of what quantum technology has to offer. Quantum communication will enhance cyber security, and quantum sensing will transform medical imaging. Quantum computers will solve problems that could never be handled by conventional computers, such as expediting personalized drug development, climate forecasting, and creating revolutionary green energy technologies.

Schrodinger's cat may be both dead and alive, but the field of quantum science and technology is very much alive and kicking.

Prof. Yosi Avron
Director, Helen Diller Quantum Center

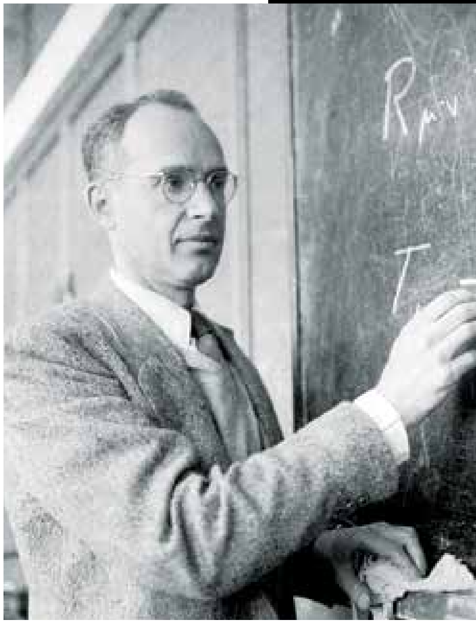
On the Shoulders of Giants

The Helen Diller Quantum Center at Technion is home to a community of researchers dedicated to the academic pursuit of quantum science and engineering. Our mission is to create a quantum ecosystem that advances quantum science and technology; educate and train tomorrow's quantum workforce; and partner with academia, government, and industry.
The research program spans Quantum Computing, Quantum Communication, Quantum Simulation, Quantum Sensors and Quantum Matter. The center incorporates leading laboratories in photonics, non-linear optics, quantum dots, superconducting qubits and cold atoms.

The field of quantum science at Technion was established back in the 1950s by Prof. Nathan Rosen, renowned for his work with Albert Einstein on entangled states and the EPR paradox, and consolidated by his student, Prof. Asher Peres, one of the fathers of quantum teleportation. Building on a Technion tradition of excellence in quantum science, the Helen Diller Quantum Center was founded in 2018 by Profs. Gadi Eisenstein, Moti Segev, and Uri Sivan (now Technion President). In 2019, Prof. Yosi Avron was appointed Director.

The Technion quantum community currently numbers over 50 faculty members and more than 250 graduate students, postdocs, and scientists across the Technion campus.

Integral to the activities of the Center are: advancing research; recruitment of new faculty members and lab managers; and equipping and constructing laboratories and infrastructure centers. Active sponsorship of graduates and postdoc fellowships, the Peres-Rosen Distinguished Lecture Series, and seminars and workshops, ensure a rich environment for academic development. The Center also offers an innovative educational program that integrates quantum science and engineering, with offerings at both the undergraduate and graduate level including advanced teaching laboratories in quantum science and technology.



Prof. Nathan Rosen, collaborated with Albert Einstein on the EPR paradox

QUANTUM FACTS

352
research papers

52
faculty members

8
seed funding research grants

152
graduate students

124
videos of seminars and courses

33
undergrad student projects

1,000
students in quantum-related courses

50
quantum-related courses (2020-21)

40
labs

8
infrastructure centers

43
seminars (2021)

Data correct as of 01.10.21

Helen Diller

In April 2018, Technion announced a $50 million naming gift from the Helen Diller Foundation to support the university's new state-of-the-art Quantum Center. The center was named the Helen Diller Quantum Center.

The gift has positioned Israel as a world leader in Quantum Science and Technology by providing the means for faculty recruitment, hiring lab managers and engineers, equipping and constructing laboratories and infrastructure centers, providing seed funding for research and funding for research and development, and educating a new generation of engineers.

"The Technion is one of the preeminent institutions for technology in the world, and my parents (Helen and Sanford Diller) thought this was an important investment for the future of Israel and humanity."

-Jackie Safier, President of the Helen Diller Family Foundation

Assoc. Prof. Ido Kaminer

Selected Honors & Prizes

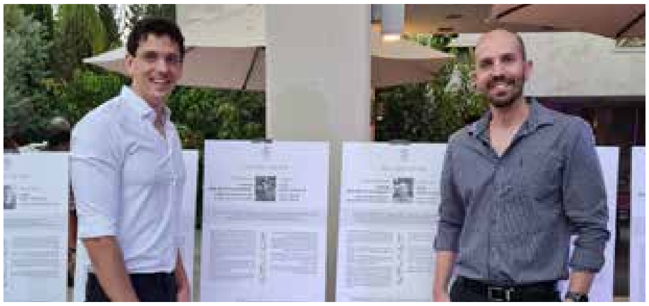
2021 Blavatnik Award

Assoc. Prof. Ido Kaminer was awarded the coveted 2021 Blavatnik Award for Young Scientists in Israel at a formal ceremony in Jerusalem with the participation of the President of the State of Israel, Mr. Isaac Herzog, president of the New York Academy of Sciences, Prof. Nicholas Dirks, and president of the Israel Academy of Sciences and Humanities, Prof. Nili Cohen.

Prof. Kaminer has discovered novel phenomena that demonstrate how light and matter interact in unusual physical settings. He has not only formulated the quantum theories that predict these phenomena, but also designed state-of-the-art experiments that prove their existence. His discoveries have transformed our understanding of the physical foundation of light-matter interaction and hold enormous potential for real world applications, such as miniaturized radiation sources for medical imaging. *Full story on page 12*

Quantum 2021 Krill Laureates

This year the 2021 Krill laureates included two Helen Diller Quantum Center members: Profs. Yoav Shechtman of the Faculty of Biomedical Engineering and Ido Kaminer of the Viterbi Faculty of Electrical and Computer Engineering.


Assoc. Prof. Ido Kaminer *(l)* and Assoc. Prof. Yoav Shechtman *(r)*

Shechtman's research is in novel optical and computational methods to develop the next generation of computational optical microscopy. His applied research includes measuring the dynamics of DNA in live cells and performing ultra-sensitive, single-biomolecule level diagnostics.

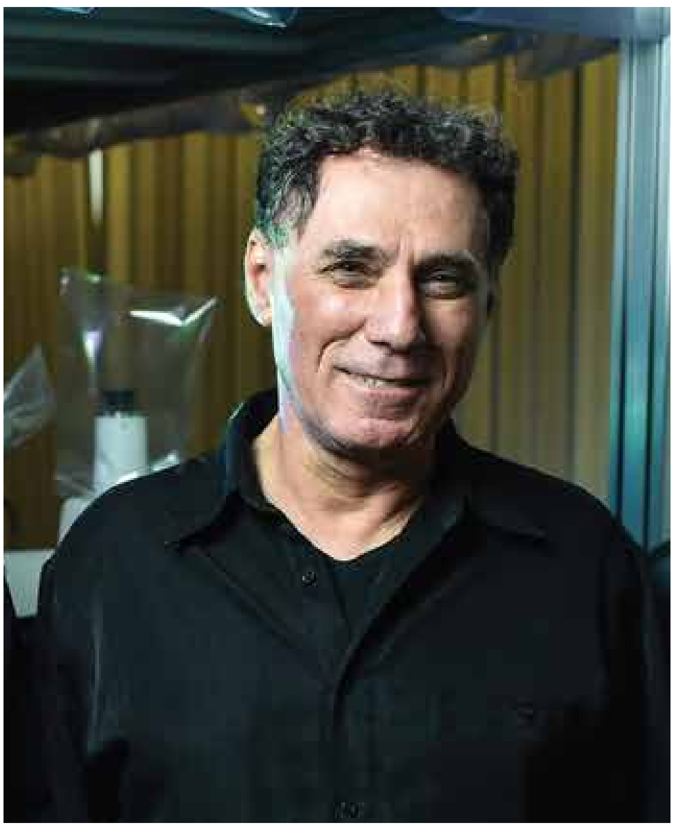
2021 Ruth Arnon Fellow


Dr. Anael Ben-Asher

Dr. Anael Ben-Asher who recently graduated with a PhD in quantum chemistry under Prof. Nimrod Moiseyev, has been awarded the prestigious 2021 Ruth Arnon Fellowship of the Israel Academy of Sciences and Humanities. In the fall of 2021, Ben-Asher will begin her postdoctoral training at the Condensed Matter Physics Center (IFIMAC) at the Autonomous University of Madrid. Her research is in the emerging field of polaritonic chemistry - the manipulation of chemical reactions through strong coupling with confined light modes. Anael is a rising star and has published in leading journals. She received the Schulich Scholarship of Excellence and is an Adams Fellow of the Israel Academy of Sciences and Humanities.

American Academy of Arts & Sciences

Distinguished Prof. Mordechai (Moti) Segev is a world leader in nonlinear optics, photonics, solitons, sub-wavelength imaging, lasers, quantum simulators and quantum electronics. He has won numerous glittering international awards and most recently, he was elected to AAAS (American Academy of Arts & Sciences). Segev is a founding father of the Helen Diller Quantum Center. Above all his personal achievements, he takes pride in the success of his graduate students and postdocs, among them are currently 21 professors in leading universities worldwide and in Israel, as well as senior R&D positions in industry. *Full story on page 16*



Mordechai (Moti) Segev is the Robert J. Shillman Distinguished Professor of Physics and Electrical Engineering at Technion

European Research Council

Established by the European Commission

ERC Grant for Next Generation Semiconductors

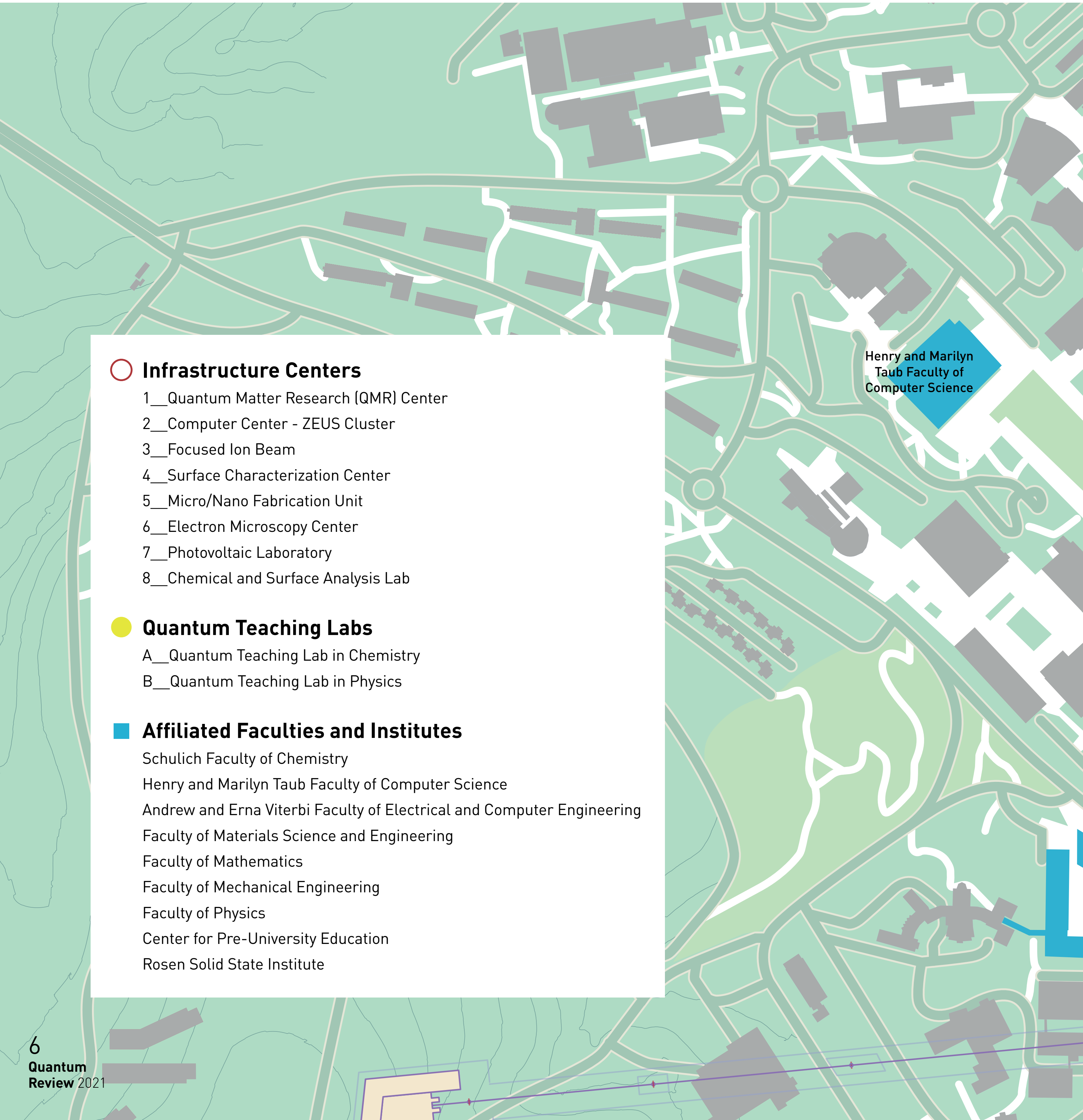
Asst. Prof. Yehonadav Bekenstein of the Faculty of Materials Science and Engineering has been awarded an ERC Starting Grant – a prestigious European grant for young academic faculty. The grants support brilliant young scientists in building winning research teams to conduct pioneering research. Asst. Prof. Michael Krueger of the Faculty of Physics was a recipient of this coveted grant in 2019 to research, "Attosecond space-time imaging of coherent quantum dynamics".

Bekenstein received the grant for the development of halide perovskites materials, which are characterized by high efficiency in energy conversion and are expected to revolutionize optoelectronic applications such as advanced detectors, solar energy, and quantum communication. The ERC funded study focuses on combinations of two-dimensional perovskites with other materials such as oxides and semiconductors to discover new functional properties.

In a recent paper in the prestigious *Nano Letters* journal, Bekenstein and his team reported the discovery of an unusual band contrast pattern on buckled perovskite nanobelts, which may lead to the development of flexible devices for power conversion and optoelectronic applications.

A new discovery by Asst. Prof. Yehonadav Bekenstein *(r)* and grad student Emma Massasa *(l)* is expected to significantly advance the use of solar energy.

The Campus Quantum QueST



Infrastructure Centers

1__Quantum Matter Research (QMR) Center
2__Computer Center - ZEUS Cluster
3__Focused Ion Beam
4__Surface Characterization Center
5__Micro/Nano Fabrication Unit
6__Electron Microscopy Center
7__Photovoltaic Laboratory
8__Chemical and Surface Analysis Lab

Quantum Teaching Labs

A__Quantum Teaching Lab in Chemistry
B__Quantum Teaching Lab in Physics

Affiliated Faculties and Institutes

Schulich Faculty of Chemistry
Henry and Marilyn Taub Faculty of Computer Science
Andrew and Erna Viterbi Faculty of Electrical and Computer Engineering
Faculty of Materials Science and Engineering
Faculty of Mathematics
Faculty of Mechanical Engineering
Faculty of Physics
Center for Pre-University Education
Rosen Solid State Institute

Faculty of Mathematics
A
Schulich Faculty of Chemistry
8
2
1
Faculty of Physics
Andrew and Erna Viterbi Faculty of Electrical and Computer Engineering
5
4
B
Rosen Solid State Institute
7
3
Faculty of Materials Science and Engineering
6
Faculty of Mechanical Engineering
Center for Pre-University Education

Faculty Profiles

Our research into ultracold atoms places us at the forefront of quantum technology.
- Yoav Sagi

Assoc. Prof. Yoav Sagi

Ultracold Atoms for Quantum Computation

The exciting research taking place in Assoc. Prof. Yoav Sagi's lab of the Faculty of Physics and the Solid State Institute is breaking new ground in the field of quantum technology. It is the only lab in the world attempting to use fermionic properties for quantum computation and the only one in Israel studying quantum-degenerate fermionic gases. Fermions are a category of elementary particles that are ultrasmall and can be thought of as the building blocks of matter. Fermions can collide with each other since their spins are not whole numbers, and no two fermions can share a quantum state if they have the same spin. Sagi's cutting-edge research uses ultracold fermionic atoms for two purposes: to perform quantum simulations of multiple-particle systems and to capture individual atoms for quantum computing.

The research team studies the behavior of fermionic atoms and uses this knowledge to benchmark many-body theories. They start with the fermionic isotope potassium 40 at room temperature. The gas is cooled down to within several nano-Kelvins of absolute zero, causing the gas to enter the quantum regime. In these quantum-degenerate gases, fermions with different spins can pair off, and these pairs then undergo condensation and become super fluids. "In this phase, these materials exhibit fascinating phenomena, which we can study in our lab," Sagi notes. These experiments take place in a vacuum chamber, which isolates the quantum systems from the environment. Magnetic fields and lasers inside the chamber precisely manipulate the atoms for parametric investigations and even to control the interaction between atoms with different spins.

The second project uses ultracold atoms for quantum computation by capturing individual atoms in microscopic traps called optical tweezers. These atoms can store quantum information and be used as qubits – the basic unit of quantum computing. The research team attempts to control and measure each atom individually. One of the goals is for two atoms that are close to each other to produce quantum logic gates. The team already knows how to capture and detect an individual atom and is working towards implementing quantum logic.

The solution is to create new quantum states that don't have any classical analogies.
- Anna Keselman

Asst. Prof. Anna Keselman

Quantum States Based on Frustrated Magnetism

The main research focus of new faculty member Asst. Prof. Anna Keselman of the Faculty of Physics, is on strongly correlated electron systems. These are materials in which strong repulsions between electrons play an important role. In particular, they can give rise to insulating states in which the electrons become immobile. The spins of the electrons however can still fluctuate and interact with each other, creating different states. In ferromagnets, for example, all the spins point in the same direction and the material behaves like a magnet. The spins of antiferromagnets, on the other hand, are ordered but cancel each other out. The most interesting states arise when the spins' interaction creates frustration: this is known as frustrated magnetism.

"As a result of this frustration, the spins are not ordered since no pattern suits them energetically. They must find a very different state from the classical, ordered one," Keselman explains. "The solution is to create new quantum states that don't have any classical analogies and are distinguished by their basic excitations that carry degrees of freedom that are fractions of the electrons' original degrees of freedom."

In some cases, the resulting state can be an electronic insulator but still behave like a metal – for example, it could conduct heat as if it were a metal. In others, it can host topological excitations similar to the excitations in topological superconductors which may be useful for quantum computation.

Assoc. Prof. Netanel Lindner

Topological Phases and the Future of Quantum Computing

Topological phases exhibit a fascinating interplay of quantum mechanics and physics of many particles and are possibly the most extreme form of quantum phases of matter. They bring with them not only a new paradigm, deviating from the conventional one that classifies phases of matter through symmetry breaking, but also new types of particle statistics, and the possibility to encode quantum information in a form which is resilient to interaction with the environment. Thanks to these fascinating properties, they stand at the forefront of fundamental research in condensed matter physics, and concurrently considered to be attractive candidates for future platforms for performing quantum computation tasks.

This scientific beauty, however, is not uncovered easily: topological phases of matter are challenging to work with both on the theoretical and experimental front. Much has yet to be learned and understood about the theory underlying these phases of matter, and the challenge of experimentally harnessing them is at a very early stage. Prof. Netanel Lindner, a theoretician affiliated with the Faculty of Physics, and his research group of seven post-docs and graduate students, search for new manifestations of topological phenomena in quantum matter; propose routes for realizing them; and develop and optimize methods to probe, control, and utilize them. They have already identified many topological phases and have suggested detailed instructions on how to realize and verify them in a lab. “Many of our ideas have been realized in actual physical systems in labs around the world,” he points out.

Some of the more remarkable topological phases have been found by Prof. Lindner’s group in systems which are out of thermal equilibrium. They force the systems out of thermal equilibrium by injecting energy with an external driving field, typically using a laser. These systems exhibit unique phases of matter that cannot exist in thermal equilibrium. Since systems usually heat up when

> **We suggested a completely new type of system that can allow for topological quantum computing: parafermions. We found that there is a topological model for these parafermions, and we proposed a method to realize them in the lab.**
> -Netanel Lindner

energy is injected, the team had to find a way to prevent this. One solution is to exploit localization – a quantum phenomenon occurring when the system is disordered, and the particles feel a random potential. According to Prof. Lindner, such disordered systems exhibit many remarkable topological phases with great potential for future applications.

Although Lindner's work is theoretical, his work on non-Abelian topological systems has pioneered a way to apply these systems to quantum information processing, based on their ability to manipulate and store quantum information in a robust form that is insensitive to the environment. "We suggested a completely new type of system that can allow for topological quantum computing: parafermions. We found that there is a topological model for these parafermions, and we proposed a method to realize them in the lab," he elaborates.

Prof. Lindner notes that topological phenomena play an increasingly important role in our understanding of the collective quantum behavior of electrons. His research includes investigating the role of topology in condensed matter physics, as well as how to probe condensed matter systems exhibiting topological phenomena. His work on transport measurements, and specifically the electronic conductivity tensor, has provided techniques to probe the properties of strongly correlated systems. Another research field that Lindner is advancing is how to utilize semiconductor photon sources, such as quantum dots, to generate multi photon entangled states for quantum computation. His research includes characterizing the decoherence arising from the interaction of the semiconductor source with its environment and designing optical circuits for utilizing and verifying these multi-photon states.

In addition to his research at Technion, in 2020 Prof. Lindner cofounded the startup QEDMA Quantum Computing together with Prof. Dorit Aharonov from the Hebrew University of Jerusalem and Dr. Asif Sinay. Although the technological potential of quantum computing is clear, the actual realization of quantum computers and using them to obtain a computational advantage requires overcoming significant challenges. QEDMA's main goal is to develop algorithms and protocols that will enable manufacturers of quantum computing hardware to overcome these challenges and provide means for the end users to unleash the computational power that this technology offers.

> **In addition to our scientific findings, we developed a ground-breaking measurement technique that will be critical to many more scientific discoveries.** - Ido Kaminer

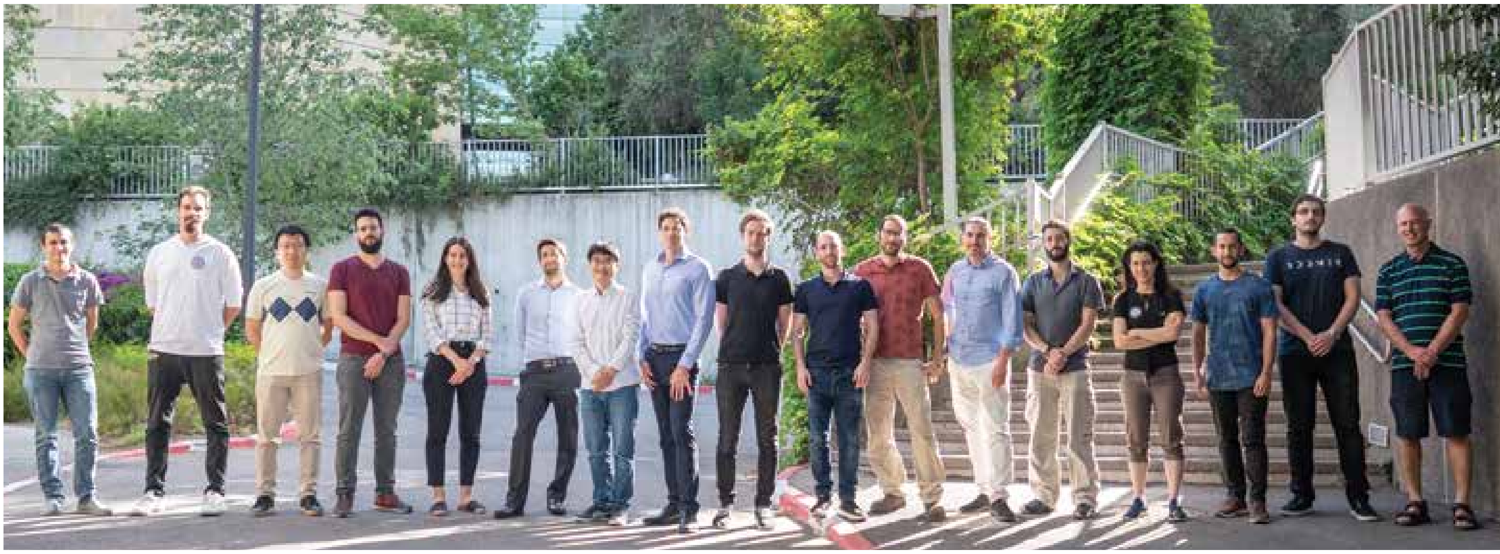
Assoc. Prof. Ido Kaminer

Light-Matter Interactions

Assoc. Prof. Ido Kaminer of the Andrew and Erna Viterbi Faculty of Electrical and Computer Engineering and the Solid State Institute, has discovered novel phenomena that demonstrate how light and matter interact in unusual physical settings. He has not only formulated the quantum theories that predict these phenomena, but also designed state-of-the-art experiments that prove their existence. His discoveries have transformed our understanding of the physical foundation of light-matter interaction and hold enormous potential for real world applications.

Prof. Kaminer and team made a dramatic breakthrough in the field of quantum science, by developing a quantum microscope that records the flow of light, enabling the direct observation of light trapped inside a photonic crystal. “We have developed an electron microscope that produces the best near-field optical microscopy in the world. Using our microscope, we can change the color and angle of light that illuminates any sample of nano materials and map their interactions with electrons, as we demonstrated with photonic crystals,” explained Kaminer. “This is the first time we can actually see the dynamics of light while it is trapped in nano materials, rather than relying on computer simulations,” added postdoc Dr. Kangpeng Wang.

Using this ultrafast transmission electron microscope, his team were the first to record the propagation of combined sound and light waves in atomically thin materials. “Most measurements of light in 2D materials are based on microscopy techniques that use needle-



Assoc. Prof. Ido Kaminer *(eighth from left)* and research group

like objects that scan over the surface point-by-point, but every such needle-contact disturbs the movement of the wave we try to image. In contrast, our new technique can image the motion of light without disturbing it. Our results could not have been achieved using existing methods. In addition to our scientific findings, we developed a ground-breaking measurement technique that will be critical to many more scientific discoveries."

Kaminer's team is planning experiments to measure light vortices, experiments in Chaos Theory, and simulations of phenomena that occur near black holes. Their work may lead to atomically thin fiber-optic "cables", and optical communication through atomically thin layers.

Another focus of Kaminer's research is to develop a miniaturized, low-cost, and tunable X-ray source, which has been a long-standing challenge in physics and engineering. He showed that light and X-rays can be generated by shooting high-speed free electrons onto the surfaces of two-dimensional materials and nanomaterials. He even managed to adjust the spectrum of the output X-ray by controlling the composition of the materials being hit by the free electrons. This was the first highly tunable X-ray source that didn't require expensive, kilometer-long, particle accelerators. His discovery is expected to find a wide range of applications in biomedical imaging and security scanning.

Kaminer is also known for revitalizing research interest in the Cherenkov Effect and utilizing it to efficiently detect high energy particles. First observed in 1934 and recognized with a Nobel Prize in 1958, the Cherenkov Effect occurs when charged particles (such as electrons) travel through a gas, liquid, or solid medium at very high speeds, giving rise to a brief flash of light. For over 80 years, it had been widely believed that everything about it was fully understood. Recently, Kaminer revealed how the quantum nature of the charged particles could alter the photons emitted by the Cherenkov Effect and can be used to track high energy particles. Kaminer is collaborating with CERN to design next-generation particle detectors inside the world's largest, most powerful particle accelerator.

The experiments were performed in the Robert and Ruth Magid Electron Beam Quantum Dynamics Laboratory.

“Quantum science is the key to engineer new materials for quantum devices.”
- Maytal Caspary Toroker

Assoc. Prof. Maytal Caspary Toroker

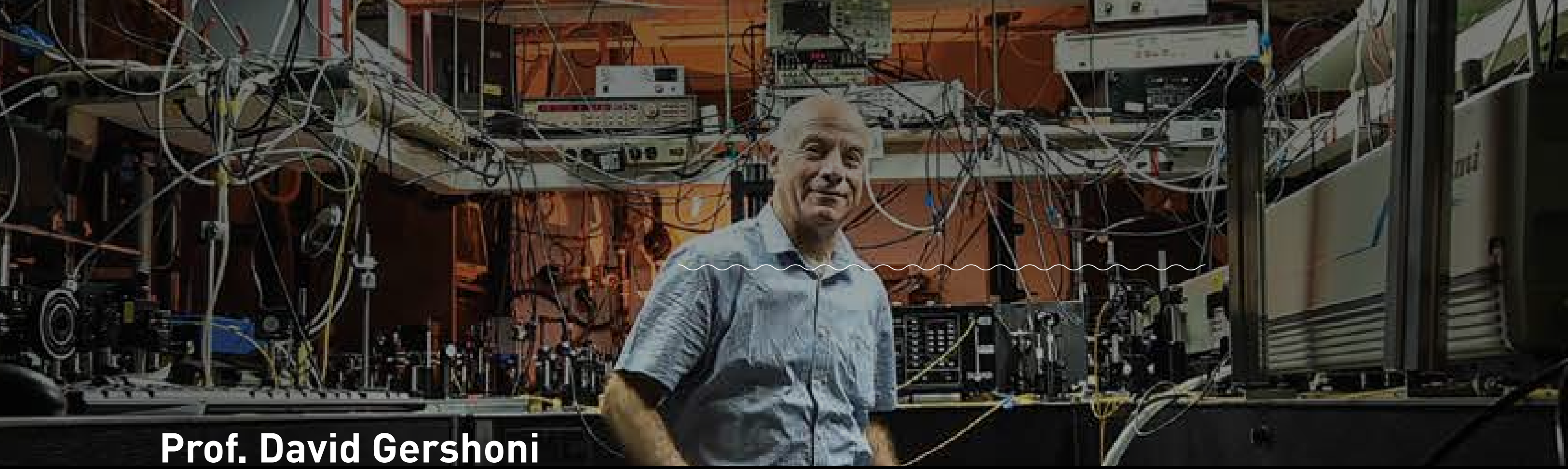
Simulating and Engineering New Quantum Materials

Assoc. Prof. Toroker and her team use quantum simulations to identify important quantum effects of various materials, with the goal of engineering more efficient materials for quantum computing and other applications.

The materials studied by Caspary Toroker of the Faculty of Materials Science and Engineering include metals, oxides and solid-state non-organic materials that can serve as components in electronic devices. The goal of the simulations is to describe the material’s structure and properties, based on physical laws and interactions, so that the researchers can optimize the material and structure for each specific device.

The research team, including 12 graduate and PhD students and 2 post-doctoral fellows, look for flaws that can generate “noise” that can impact the transmission of charge carriers through interfaces. The simulation models individual atoms and predicts how the atomic structure influences noise during measurement, and limits electrical conductivity.

Prof. Caspary Toroker collaborates with experimental researchers both at Technion and around the world, including at Cornell University and University of Oregon.



Prof. David Gershoni

Generating Entangled Photons from Artificial Atoms

For decades, Prof. David Gershoni from the Physics Faculty has been pushing the limits of science in general, and quantum optics in particular. In his laboratory in the Solid State Institute he has successfully been using artificial atoms made of semiconductor nanostructures to produce photon clusters with unique quantum correlations (or "entanglement"), a breakthrough which may facilitate the transfer of quantum information using a quantum repeater.

"There is a global quest to create a quantum repeater that is required to distribute quantum information among remote nodes, where this information is processed. We are developing ways to meet this challenge," Prof. Gershoni confirms.

Gershoni was the first to successfully demonstrate emission of a single photon on demand from a quantum dot, an artificial atom that is made of semiconductors. Unlike actual atoms, which cannot be isolated and are difficult to control, quantum dots form real devices which can be controlled optically (with lasers) and electronically (using contacts). "If we know how to direct a light pulse exactly at the energy difference between two electronic states, we can excite the quantum dot deterministically to an excited electronic level. This is very difficult to do with a single atom, since it cannot be isolated and kept in the same position for a long enough time to form a device. Quantum dots on the contrary, are artificial atoms that can be isolated and accurately controlled," he elaborates.

Gershoni's team has shown that it is possible to create a whole cluster of entangled photons on demand using a quantum dot. "We have demonstrated a new way of producing deterministically a cluster state of entangled photons. We can produce one photon at a time, and it will be entangled with the next photon, and the next one after that, and so on. The ability to produce an infinite amount of entangled photons has never been demonstrated before," Prof. Gershoni explains.

"Since electrons confined in the quantum dots have two possible spin states," Gershoni explains, "we found a way to control the electron in such a way as to create a coherent superposition, whereby the electrons exist in the two different spin states simultaneously. Moreover, we found a way to create an entangled state between the coherent superposition of the electron spin and the emitted photon polarization. The electronic coherent superposition that we generate evolves over time, in a way that can be controlled with an adjustable external magnetic field. By choosing the exact timing for a short optical laser pulse, the quantum dot emits another photon that will be entangled with the prior photon, and with the evolving electronic spin. By repeating this procedure continuously, we create a chain of individual photons, which are all entangled," Gershoni elucidates. The group has recently succeeded to produce entangled photons at a record rate, exceeding 10^9 (one billion!) entangled photons per second.

This research may lead to the development of a quantum repeater, which would amplify optical signals, without loss of quantum information, thereby revolutionizing the transfer of quantum information.

L to r: Eran Lustig, Prof. Moti Segev, Alex Dikopoltsev, Dr. Yaakov Lumer

Dist. Prof. Mordechai (Moti) Segev

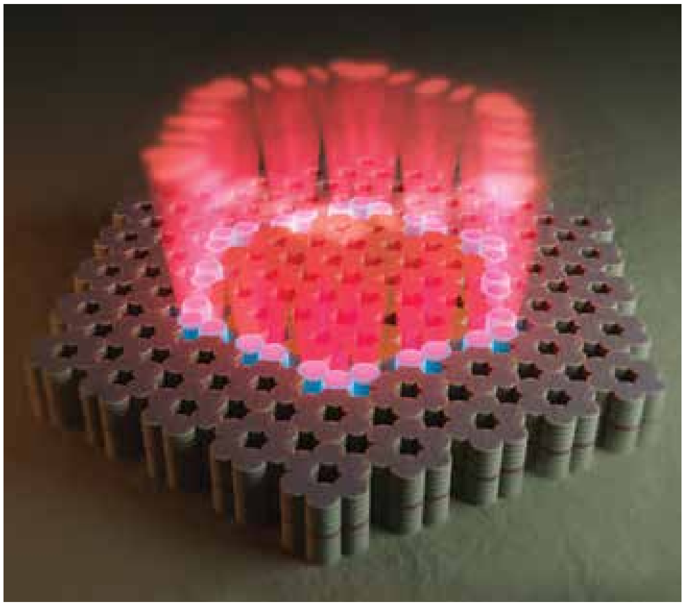
Nonlinear Optics, Photonics, Solitons, Sub-Wavelength Imaging, Lasers, Quantum Simulators and Quantum Electronics

Moti Segev is the Robert J. Shillman Distinguished Professor of Physics and Electrical Engineering. Both a theoretician and an experimentalist, Distinguished Prof. Segev's research interests focus on nonlinear optics, photonics, solitons, sub-wavelength imaging, lasers, quantum simulators and quantum electronics.

He has won numerous international awards, among them the Quantum Electronics Prize of the European Physics Society, the Max Born Award of the Optical Society of America, and the Arthur Schawlow Prize of the American Physical Society, which are the highest professional awards in the field. He is a member of the Israel Academy of Sciences and Humanities, and the National Academy of Science (NAS) of the United States of America, and the American Academy of Arts and Sciences (AAAS). Segev won the Israel Prize in Physics and Chemistry and the EMET Prize.

Segev's most recent paper in *Science* reports on the realization of a topological vertical-cavity surface-emitting laser (VCSEL) array. Together with a team from Wurzburg University, Segev's team developed a way to force an array of vertical cavity lasers to act together as a single laser – a highly effective laser network the size of a grain of sand. For years, scientists have sought to enhance the power emitted by semiconductor lasers by combining many tiny VCSELs and forcing them to act as a single coherent laser, but with limited success. Segev's breakthrough uses a different scheme: it employs a photonic topological insulator platform, with a unique geometrical arrangement of VCSELs on the chip that forces the light to flow in a specific path.

This groundbreaking research demonstrates that it is theoretically and experimentally possible to combine VCSELs to achieve a powerful, robust, and efficient coherent laser, paving the way towards new applications for medical devices, communications, and a variety of real-world applications.



A single coherent light beam (pink) is emitted by an array of 30 individual lasers.

Scientific visualization by *SimplySci Animations*

From topological insulators to topological lasers

Topological insulators are revolutionary quantum materials that insulate on the inside but conduct electricity on their surface, without energy loss. In 2013, Segev's team introduced topological insulators into photonics, and demonstrated the first Photonic Topological Insulator, where light travels around the edges of a two-dimensional array of waveguides, insensitive to defects or disorder. This opened a new field, known as Topological Photonics, and today hundreds of groups actively research this topic, worldwide. In 2018, the Technion group found a way to use the properties of photonic topological insulators to force multiple micro-ring lasers to lock together and act as a single laser. However, that system still had a major bottleneck: the light circulating in the photonic chip was confined to the same plane used for extracting the light, subjecting the system to a power limit. Segev's latest breakthrough uses a different scheme: the lasers are forced to lock together within the planar chip, but the light is now emitted through the surface of the chip from each tiny laser and can easily be focused.

Prof. Aharon Blank

Detecting and Controlling Quantum States of Electron Spins

Prof. Aharon Blank of the Schulich Faculty of Chemistry is focused on developing critical technologies for enabling quantum computing, quantum sensing and other applications.

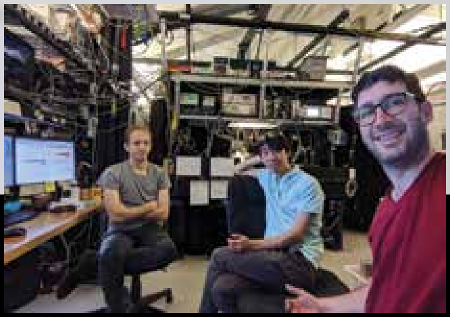
A key technology is the ability to detect and control quantum states of electron spins. Although these spins are usually either in the direction of the magnetic field or in the opposite direction, they can be made to spin in both directions simultaneously. In order to use these spins for applications such as quantum computing, they must be detected, analyzed, and controlled in a spatially selective manner. This is the challenge facing Prof. Blank and his research team: How can one change the quantum state of each spin out of a large ensemble in a controlled manner? And if there are two electrons close together, how can one of them be controlled without affecting the other?

Blank's lab is developing two techniques to detect spins in materials, such as silicon and diamonds, and to control the quantum states of individual electrons. These techniques involve spatially and time-varying magnetic fields, as well as microwave pulses to control the electrons' quantum states.

"Two technologies that we are developing – based on optic and microwave – enable us to detect small numbers of spins, but not yet just one at a time," Prof. Blank elaborates. "We still need to improve the sensitivity in order to detect individual spins." For now, the researchers were able to detect a few tens with spins with 150 nanometer resolution, and the goal is to improve the spatial resolution and sensitivity in order to be able to detect single spins that are as low as 20 nanometers apart.

Prof. Blank's lab is also developing fundamental technologies for quantum amplification of microwaves. This is a collaborative project with ELTA, Israel's premier manufacturer of radar and wireless communication systems. The objective is to develop innovative quantum devices that amplify very weak microwave signals with ultra-low noise, using diamond color centers. A prototype amplifier has been developed and is being characterized and refined.

> **We will leverage molecular ion technology to answer the fundamental question of why we observe symmetry breaking in nature between molecules of different chirality.**
> - Asst. Prof. Yuval Shagam



Asst. Prof. Yuval Shagam

Generating Entangled Photons from Artificial Atoms

Asst. Prof. Yuval Shagam, a rising star in quantum chemical physics, recently returned to Israel to join the Helen Diller Quantum Center after a four year postdoc at the renowned JILA, a joint institute of the University of Colorado Boulder and the National Institute of Standards & Technology (NIST).

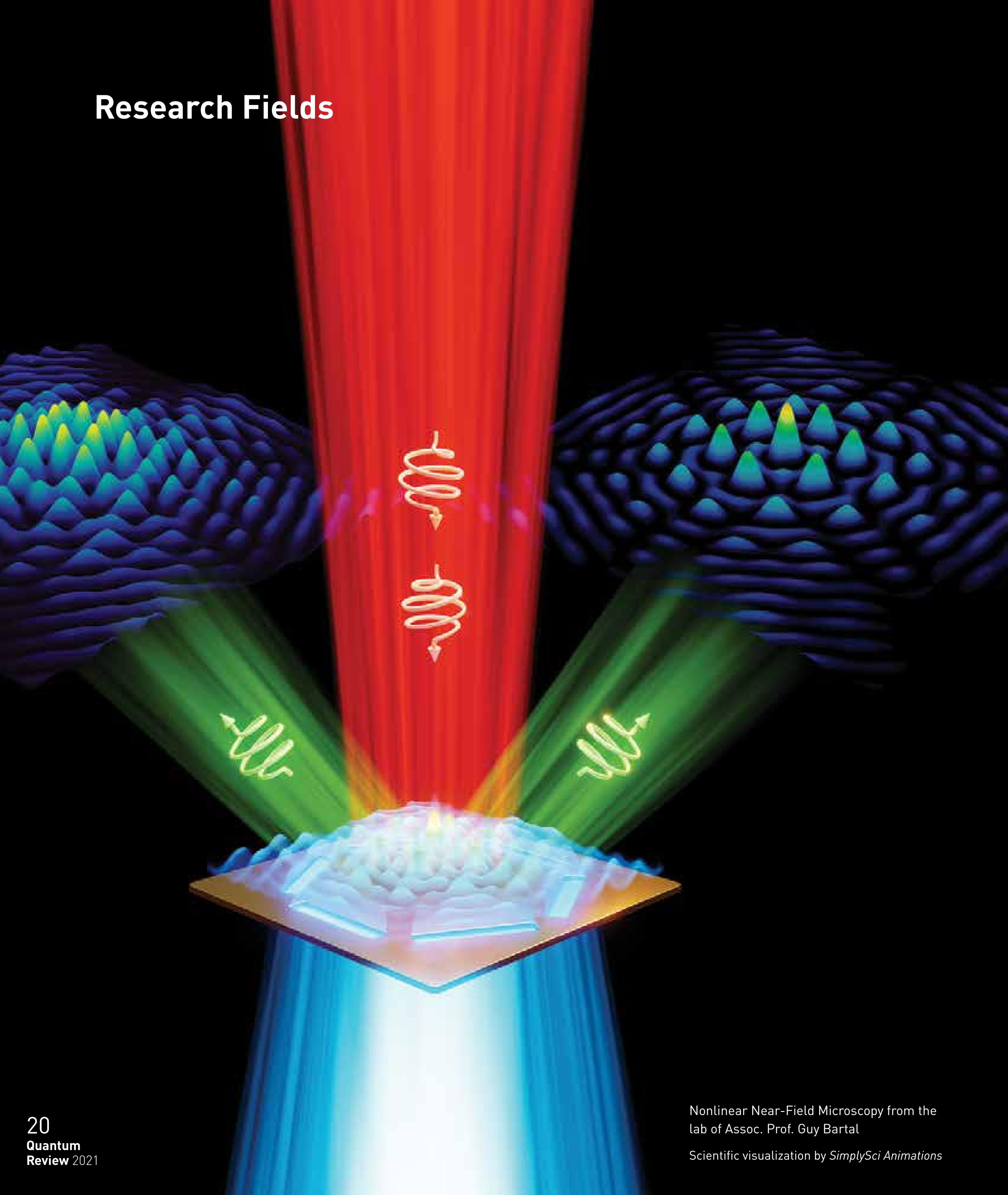
With funding from the Center, Shagam is establishing a new laboratory to study parity violation in chiral molecules and cold inelastic scattering between ions and neutrals.

Many molecules in living organisms are either right-handed or left-handed, and an object or a system is chiral if it is distinguishable from its mirror image. Yuval hopes to discover the fundamental force that gives molecules a preference for right-handedness or left-handedness. “We will leverage molecular ion technology to answer the fundamental question of why we observe symmetry breaking in nature between molecules of different chirality. We will tackle this question on a quantum-state-resolved scale by developing quantum interference-based detection to achieve pristine chirality-specific measurements that will eclipse the capabilities of techniques available today in sensitivity and allow quantum state-resolved detection.”

Affiliated with the Schulich Faculty of Chemistry and the Solid State Institute, Shagam is pioneering a new approach to study cold quantum ion-neutral collisions that will reveal their quantum nature. At the heart of the method is an ion trap with velocity map imaging (VMI) capabilities. The aim is to manipulate the mean velocity of a trapped ion cloud relative to a cold fast-moving molecular beam. “Supersonic beams are an excellent tool for achieving cold temperatures for a large variety of atoms and molecules. Decades of research has failed to effectively control neutral beam velocities, but we plan to overcome this hurdle by accelerating ions to the same frame as the moving beam. Our method enables the collision energy to be tuned using the particle charge, and this will provide a wider variety of ion-neutral systems to study.”

Shagam’s research will leverage his past achievements at JILA, that advanced the precise measurement of the electron's permanent electric dipole moment using trapped molecular ions. In collaboration with prominent physicists Jun Ye and Nobel laureate Eric A. Cornell, he increased the coherence time by an order of magnitude. “We developed a noise-immune detection method by causing our molecules to break up according to their orientation in space. This gave us a 50-fold more precise error bar.”

Research Fields



Nonlinear Near-Field Microscopy from the lab of Assoc. Prof. Guy Bartal

Scientific visualization by *SimplySci Animations*

Quantum Communication

With cybersecurity breaches disrupting governments, financial institutions, and computer networks around the world, the advent of absolute secure communications would be a game-changer for the defense and financial establishments. The worst-case, communication failure scenario is that in which information transmitted between two friendly computer systems is intercepted by an enemy, but neither the transmitting nor the receiving partner knows that the information has been compromised. Quantum principles can prevent this scenario entirely since tapping into a quantum communication link will destroy the information, so that the enemy will not obtain the information and the communicating partners will know that an intercept was attempted. Only quantum technology can provide this level of secure communication, conventional cryptographically coded systems cannot offer a similar degree of security.

Quantum key distribution
Tal Mor
Meir Orenstein
Moshe Nazarathy
Gadi Eisenstein

Quantum optics
Moti Segev
Oren Cohen
Jeff Steinhauer
Eric Akkermans
Gadi Eisenstein
Ido Kaminer
Erez Hasman
Nimrod Moiseyev

Superconducting photon detectors
Eyal Buks
Yachin Ivry
Alex Hayat

Non-classical light sources
David Gershoni
Meir Orenstein
Alex Hayat

Quantum amplifiers for quantum radar
Aharon Blank

Quantum Sensing

A wide range of high-performance sensors are critical to security and defense applications, as well as medical monitoring devices. Quantum sensors can be used as imaging detectors and actuators that guide unmanned airborne, land and sea vehicles, as well as antimissile protection systems. Other practical applications include ultrasensitive night vision systems, ultraviolet sensors for early detection of missile launches, and highly accurate timing devices (also known as atomic and optical clocks) that are imperative for synchronizing multiple systems. Sensors to detect traces of poisonous chemical, biological and nuclear materials, as well as efficient quantum-based energy-harvesting components used for remote surveillance systems are also being developed. Technion researchers have demonstrated that barcoded chemotherapy-loaded nanoparticles can be used to predict the optimal cancer treatment choice. Building on these achievements, quantum sensor research may lead to improved in-body diagnostics and super-resolution medical imaging.

Magnetometers
Meir Orenstein
Erez Hasman

Atomic clocks
Gadi Eisenstein

Ultrafast quantum dynamics
Oren Cohen
Michael Krueger
Ido Kaminer

Algorithmic cooling
Tal Mor

Semiconductor and superconductivity devices
Alex Hayat
Gadi Eisenstein
Guy Bartal
Yuval Yaish
Eyal Buks
Elad Koren

Sensing by NV centers in diamond
Aharon Blank
Eyal Buks
Meir Orenstein

Quantum nanomechanical devices
Yuval Yaish
Eyal Buks

Spin-Optics
Erez Hasman

Quantum dynamics
Lev Chuntonov

Quantum Computing

Quantum computers are fundamentally different from binary digital computers based on transistors, in which data is encoded into binary digits, with each bit represented by 0 or I. In quantum computing. the simplest units of information are "qubits," which operate according to quantum mechanical principles, enabling them to represent either 0 of 1, or both 0 and I (and all points in between). This ability to exist in multiple states simultaneously gives quantum computers the potential for enormously enhanced computing power and the capability of solving problems that are impossible for the supercomputers of today, such as large-scale simulations of hurricane formation and huge optimization problems involving millions of integer variables. Quantum computers also have potential applications in cryptography, specifically for breaking codes that are impenetrable to supercomputers. Quantum computers will enable scientists to model interactions between materials at a molecular level, with unsurpassed accuracy.

Cluster state
David Gershoni
Netanel Lindner

Entanglement
David Gershoni
Netanel Lindner
Itai Arad
Ari Turner
Moti Segev
Jeff Steinhauer
Ido Kaminer
Erez Hasman
Nimrod Moiseyev

Superconducting Qubits
Shay Hacohen Gourgy
Eyal Buks

NMR computing
Aharon Blank

Spin based quantum computing
Aharon Blank
Amit Keren
Efrat Lifshitz

Quantum Algorithms
Itai Arad
Tal Mor
Nimrod Moiseyev

Complexity
Itai Arad

Qubits in NV centers
David Gershoni
Aharon Blank
Meir Orenstein
Alon Hoffman
Eyal Buks
Maytal Toroker

Quantum verification
Itai Arad
Netanel Lindner

Error corrections
Netanel Lindner
Itai Arad

Quantum computation with single fermions in micro-optical tweezers
Yoav Sagi

Optical interface for superconducting qubits
Eyal Buks
Shay Hacohen Gourgy

Distributed quantum computing
Yosi Avron, Ofer Casper and Ilan Rozen

Quantum Materials

A new family of quantum materials, including graphene, hexagonal boron nitride and molybdenum disulfide, and nitrogen vacancy centers in diamond, are at the forefront of recent scientific research. They are being explored for their unusual electronic, optical and magnetic properties with special interest in their potential uses for sensing, information processing and memory. Such materials may usher in a new era for integrated circuit boards that will overcome the limitations of Moore's Law. They may lead to numerous other applications such as electronic desks for charging devices like cell phones wirelessly; ceilings that light up to replace traditional lighting; windows that double as transparent displays; large area distributed speakers; and sensors everywhere.

Graphene
Yuval Yaish
Efrat Lifshitz
Yehonadav Bekenstein
Yachin Ivry
Ilya Goykhman
Elad Koren
Ido Kaminer
Erez Hasman

Majorana and other non-abelian excitations
Netanel Lindner
Daniel Podolsky
Ari Turner

Quantum phase transitions
Assa Auerbach
Daniel Podolsky
Ari Turner
Netanel Lindner
Amit Kanigel
Erez Hasman
Gad Koren
Nimrod Moiseyev

Topological materials
Assa Auerbach
Efrat Lifshitz
Daniel Podolsky
Ari Turner
Netanel Lindner
Kanigel Amit
Alex Hayat
Erez Hasman
Gad Koren

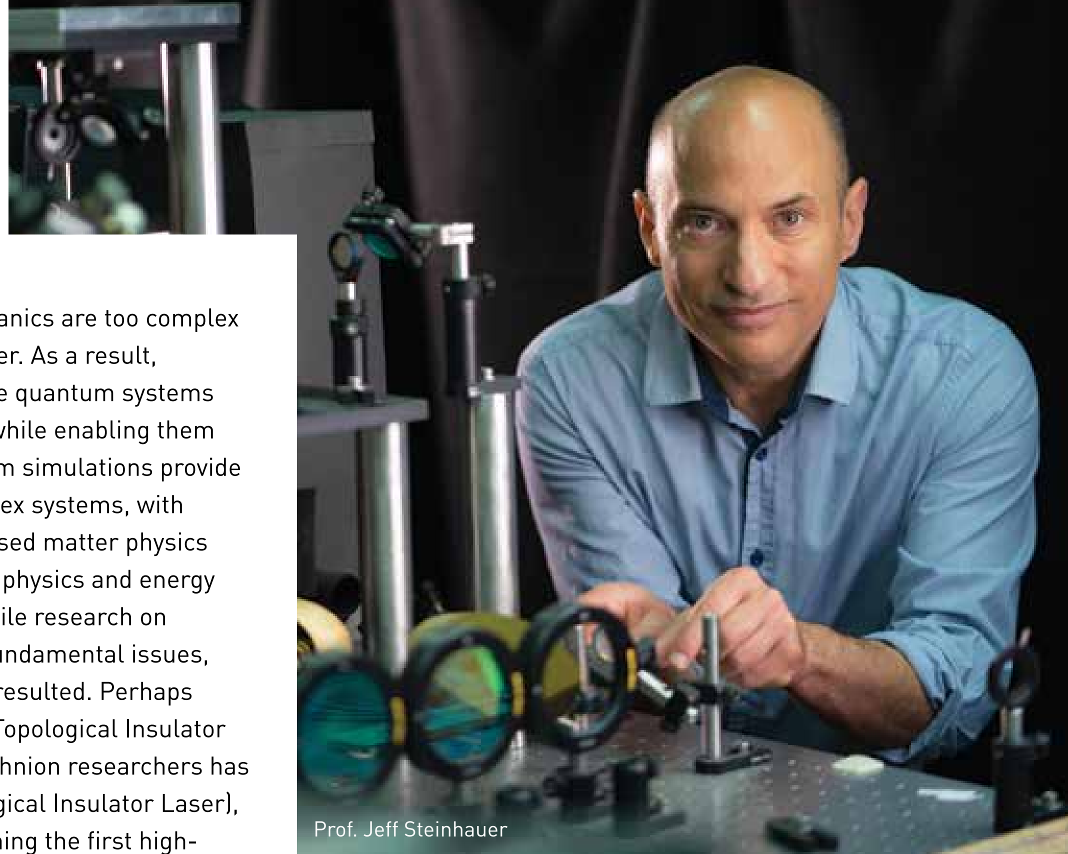
2D materials
Yehonadav Bekenstein
Amit Kanigel
Yachin Ivry
Assa Auerbach
Daniel Podolsky
Ari Turner
Netanel Lindner
Amit Kanigel
Efrat Lifshitz
Ilya Goykhman
Alex Hayat
Elad Koren
Ido Kaminer
Maytal Toroker
Erez Hasman
Eitan Ehrenfreund
Gad Koren

Quantum coherence in matter condensates
Yoav Sagi
Jeff Steinhauer
Alex Hayat
Gadi Eisenstein

Diamond, NVs
Alon Hoffman

Quantum Simulators

Many problems in quantum mechanics are too complex to simulate on a classical computer. As a result, researchers are developing simple quantum systems that simulate a specific problem while enabling them to control its parameters. Quantum simulations provide insights into phenomena of complex systems, with applications ranging from condensed matter physics to statistical physics, high-energy physics and energy transfer in biological systems. While research on quantum simulators focuses on fundamental issues, many practical applications have resulted. Perhaps the best example is the Photonic Topological Insulator whose discovery by a group of Technion researchers has led to a new laser system (Topological Insulator Laser), which holds the promise of becoming the first high-powered semiconductor laser.



Prof. Jeff Steinhauer

Optical quantum simulators
Moti Segev
Nimrod Moiseyev

Cold atoms
Yoav Sagi
Jeff Steinhauer
Nimrod Moiseyev

Black hole simulators
Jeff Steinhauer

Free-electron quantum simulators
Ido Kaminer

Simulating materials
Maytal Toroker

Quantum Chem/Bio
Avi Schroeder

Dist. Prof. Moti Segev

The Superconducting Quantum Circuits Lab
in the Faculty of Physics headed by Asst.
Prof. Shay Hacohen-Gourgy

Asst. Prof. Shay Hacohen-Gourgy *(l)* of the Physics Faculty is experimentally investigating a novel conceptual basis for a quantum computer, using circuits made of aluminum superconductors that emulate atoms and qubits. For the experimental setup to emulate quantum devices, it must be cooled to extremely low temperatures of about 10 milliKelvin (minus 273 degrees Celsius). The main goal of the first experiment will be to create an interaction between 4 non-communicating qubits through local control and global measurements.

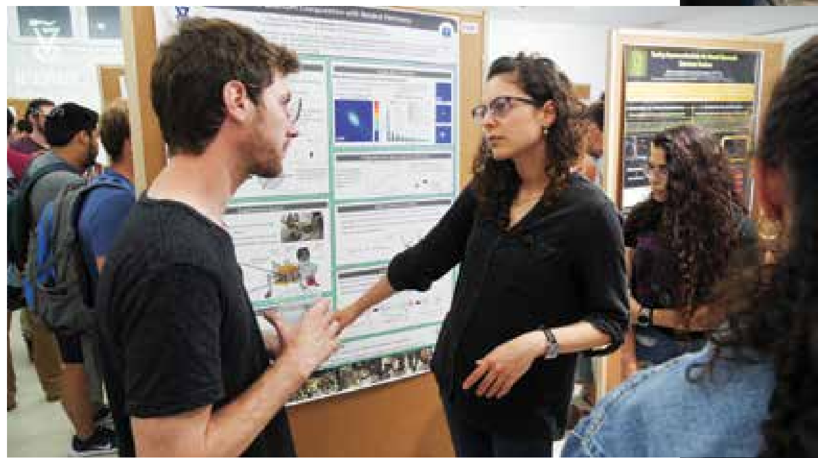
Hacohen-Gourgy is also optimizing quantum amplifiers for quantum computers, by increasing the number of quantum states in cost-effective ways that include manipulations on the rest of the system's components.

Seed Funding

The quantum seed fund, launched in 2020, encourages researchers to collaborate on out-of-the-box projects in quantum science and technology. Successful projects are expected to lead to the development of disruptive technologies and attract significant external funding. Eight research projects have been funded to date. One of the teams awarded seed funding (pictured here) is a powerful synergy of Profs. Amit Kanigel and Shay Hacohen-Gourgy's labs collaborating on "Superconducting qubits as a probe for novel solid-state materials for next generation qubit devices."

Quantum Education

To educate and train a new generation of quantum scientists and engineers, the Helen Diller Quantum Center has established an ambitious Quantum Education Program, while providing new certifications of mastery in quantum, accelerating progress towards traditional academic degrees. By promoting the development of new undergraduate and graduate curricula that bridge traditional academic disciplines, future quantum engineers will have the skills and knowhow required for the coming quantum revolution.



The undergraduate quantum fair is designed to encourage students to delve into the world of quantum and pursue a final project in QST as part of their degree. The fair offers students an opportunity to meet the QST faculty and learn more about the projects available and meet peer students interested in the field.

Degree Programs

Specialization in Quantum Computing

The Taub Computer Science Faculty and the Viterbi Electrical and Computer Engineering Faculty, in conjunction with the Helen Diller Quantum Center, offer a secondary specialization in Quantum Computing to provide undergraduates with a professional certification in the fields of quantum computing and quantum information, including quantum communication and cryptography.

Specialization in Quantum and Molecular Technology

The Schulich Faculty of Chemistry offers an MSc program with a certificate of specialization in Quantum and Molecular Technology. The Molecular Quantum Technology program focuses on aspects of QST that are relevant to Chemistry, such as molecular quantum computers, magnetic resonance quantum sensors, applications of quantum computers in theoretical chemistry, and quantum mechanics theory in molecular aspects.

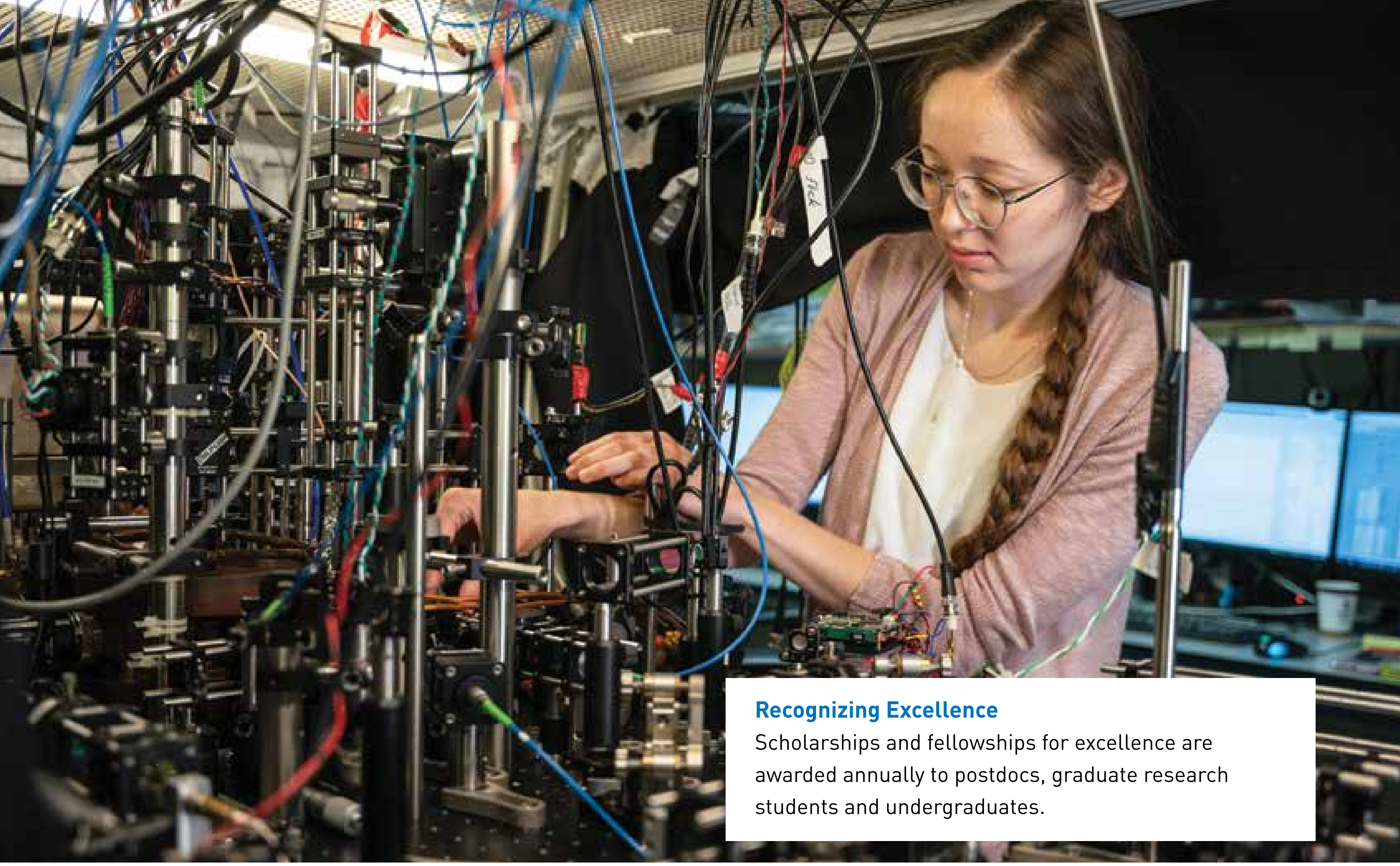
Specialization in Quantum Science and Technology

The Faculty of Physics offers an MSc program with a certificate of specialization in Quantum Science and Technology including core courses and labs in quantum information theory, quantum programming, quantum theory of light and matter, quantum optics, and the physics of cold atoms.

Undergraduate Projects

A quantum center educational initiative encourages undergraduate students from the Faculties of Mathematics, Chemistry, Physics, Computer Science, Mechanical Engineering, Electrical and Computer Engineering, and Materials Science and Engineering to pursue a final high-level project in QST as part of their degree. A wide range of projects is offered by QST labs on the latest research topics from different faculties and industry such as: inverse-design of quantum gates; on-chip quantum nonlinear optics; characterization of novel laser sources for attosecond microscopy; the use of color centers in diamond as building blocks for quantum computers; quantum detection for cold chiral molecular ions; quantum computing; optical sources for quantum metrology; deterministic manipulation of nitrogen atoms in diamond for quantum application; atomic-scale photonics; and nanocrystal qubits manipulation using near field ultrafast pulsed laser.

Prizes are awarded for the most outstanding undergraduate final projects in the field.



Recognizing Excellence

Scholarships and fellowships for excellence are awarded annually to postdocs, graduate research students and undergraduates.

Robert and Ruth Magid Quantum Education Program

To prepare a new generation of scientists and engineers to face the challenges of the era of Quantum Science and Technology (QST), the Technion has revolutionized the curriculum and introduced new courses and teaching labs in QST. The new curriculum offers science and engineering undergraduates a comprehensive education in QST. Over 1,000 students were registered in 2020/21 in 50 quantum-related courses at Technion.

In addition to the standard undergraduate courses in Science and Engineering and in Quantum Mechanics, students also get a unique opportunity to take part in state-of-the-art teaching labs in QST and to participate in new and unique courses such as quantum information, quantum technologies and quantum programming.

Robert and Ruth Magid, Australian Jewish philanthropists, generously support the university's campuswide QST Education Program, including the Quantum Odyssey Program, the Quantum Computing Primer School, equipment and teaching labs.

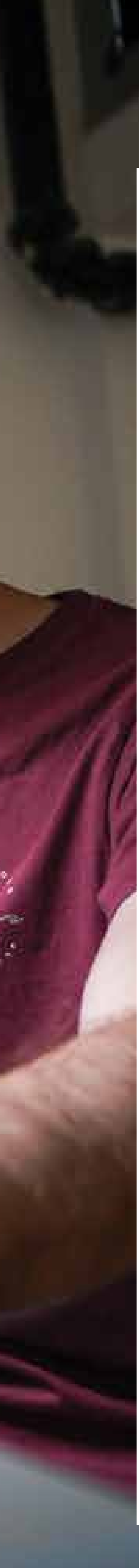
The curriculum necessitated the development of courses which address the practical and theoretical aspects of QST, including quantum computing, the theory of quantum information, quantum cryptography, and quantum sensing.

QST Teaching Labs

We are exposing students to quantum phenomena that they previously only learned about in theory Now we enable BSc and MSc students to gain up-to-date experience in the techniques at the forefront of quantum technology.

- Yaron Artzi, PhD student and quantum experiment designer

The Quantum Mission



QST Teaching Labs

Launched in 2020, the Center's cutting-edge quantum science teaching laboratories include benchmark experiments in QST, which will familiarize the students with fundamental experimental techniques involving:

- photonics qubits and entangled photons,
- the control of qubits in NV centers,
- superconducting qubits.

The laboratories enable students to experience the difficulties and complexities of the counter-intuitive quantum phenomena. They are the first such laboratories in Israel and are provide an invaluable hands-on training for students specializing in QST. The teaching laboratories are located in the Schulich Faculty of Chemistry and the Faculty of Physics and were the joint initiative of Chemistry Prof. Aharon Blank and Physics Prof. David Gershoni. They are staffed by doctoral students and postdoctoral fellows who supervise and mentor the students on the experiments in quantum science.

The labs currently offer three experimental setups: quantum optics with single photons, quantum bits (qubits) in nitrogen vacancy in diamonds, and nuclear spin qubits in nuclear magnetic resonance (NMR). In the future, two additional student laboratories are planned with more experimental setups, allowing more students to be trained simultaneously.

The Quantum Why?

Quantum technology is an emerging field of science that makes use of unique quantum mechanical properties, such as entanglement and wave particle duality, for practical applications, such as quantum sensing, quantum communication and quantum computation. Prime examples for useful quantum entities are qubits which can be implemented by single photons, electrons, and nuclear spins.

Quantum mechanics is deeply rooted in the heart of modern physics but contradicts our experiences in the real world. Therefore, the importance of exposing students to experiments that demonstrate the basic principles of quantum physics is essential to appreciate QST.

Nitrogen Vacancy in Diamond Experiment

Summary:

The nitrogen vacancy (NV) center in diamond crystal can be used as a quantum bit, quantum sensor, and as a source of single photons. The students experiment with NVs as quantum bits as well as quantum sensors for static magnetic fields.

Experimental Setup:

The NV setup enables the students to recreate some of the most recent experimental works presented in contemporary scientific literature that uses NVs for important quantum technological applications.

Learning Goals:

- Familiarization with the theory and physics of a pseudo 2-level system – a qubit
- Familiarization with optical detection of magnetic resonance spectroscopy of NV centers
- Rabi oscillations for a qubit
- Relaxation and dephasing time of qubits (T1, T2, T2*)
- Dynamical decoupling for extending the dephasing time T2
- The use of NVs as quantum sensors of small static magnetic fields.

Quantum Evangelists

The Center reaches beyond the campus to promote QST to students of all ages, from high school all the way to industry. The multifaceted program is designed to inspire youth, foster engagement, teach quantum literacy and expand quantum expertise in the workplace.

Quantum Computing Primer School

In its first year of operation, Technion's "Quantum Computing Primer School" was inundated with applicants. The week-long intensive online course, held last October, was the first in Israel with over 220 registered students. The participants were introduced to the foundations of quantum computing theory and given hands-on experience programming the IBM quantum minicomputer. The program did not assume prior knowledge of quantum mechanics or programming, enabling applicants from diverse backgrounds to participate. The school director is Prof. Netanel Lindner who was joined by a large team of outstanding lecturers to teach the interactive online course.

The hands-on part of the course trained the participants to write software for quantum computers, and was taught by PhD student Tasneem Biadsy and Dr. Yossi Weinstein. All the lectures are available online in a dedicated website with course notes and tutorials.

Quantum MOOCs

The Center launched a series of professionally produced online lectures by Technion quantum expert educators in, introducing basic concepts in QST. The short lectures in Hebrew are designed to expose the wider public to the fascinating world of quantum science and the research underway at the Helen Diller Quantum Center. The lectures introduce topics such as: qubits; quantum gates and circuits; quantum teleportation; entangled photons; and superconducting quantum circuits.

PodQuantum

PodQuantum, the Hebrew-language podcast series, is the brainchild of PhD student Shai Tsesses. In each hour-long podcast, Shai hosts a different Technion QST expert covering the professor's personal and professional bio, their research focus and thoughts on quantum science and engineering.

To appeal to a wider audience, Shai Tsesses plans to interview the Center's invited international speakers. Tsesses also plans to increase exposure via popular platforms such as Apple Podcast and Spotify. Stay tuned!

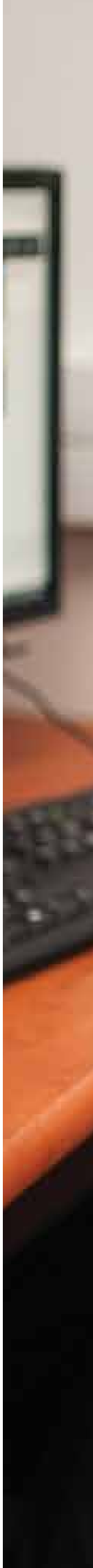
The Quantum Odyssey

Gifted high-school students in Technion's prestigious Odyssey program recently completed the unique course on "Quantum Computing – Theory and Practice," taught for the first time in 2020-21. The semester-long course provided the 11th and 12th graders with a window into the world of quantum computing.

"It was a pedagogic challenge. We were interested in making complex material accessible to everyone," says Dr. Ohad Zohar, who spearheaded the course's development and curriculum design. The lectures presented the mathematical model underlying quantum computing in a clear and simple way, enabling participants to understand key concepts and results. In addition to theoretical lectures, the young students also had the opportunity to program an IBM quantum computer. "This is a world first where a quantum computing course, without prerequisites, includes not only theory but also hands-on experience," Zohar added. The course was taught by Dr. Yossi Weinstein and TA Yotam Lifshitz.

The participants receive credit points towards an undergraduate degree at Technion.

> **People have psychological barriers when it comes to quantum. The podcasts make the subject more accessible.**
> - Shai Tsesses, founder of the PodQuantum series



Quantum Computing **Primer School**

> **The course gives participants an opportunity to research and discover by themselves the possibilities that are hidden in the world of quantum computing.**
> - PhD student Tasneem Biadsy, teaching assistant for the Quantum Computing Primer School program

Outreach programs are supported by the **Robert and Ruth Magid Quantum Education Program**.

Quantum Retreat 2021 held in Zichron Yaakov

Events

Quantum ReTREAT

The Quantum Retreat 2021 held in Zichron Yaakov energized Technion's quantum community. It was the first time, in over a year, that faculty members and students met face-to-face as a research community. The event was held according to Health Ministry regulations and capacity was limited to 75 people. Demand was high and the event was streamed live, enabling interactive online participation for the rest of the community. Prof. Ido Kaminer, the retreat academic manager, recalls the event with great enthusiasm: "This was one of the first live Technion research gatherings in the past year. It was an exceptional event, generating great interactions and discussions." A special aspect of the retreat was that the presentations were given by students, rather than by faculty. The two exceptions were new faculty members, Asst. Profs. Michael Krueger and Yuval Shagam, who introduced their research to the Technion quantum community.

Peres-Rosen Distinguished Lecture Series

The Peres-Rosen Distinguished Lecture Series, in memory of two Technion giants in the field of quantum science, made a successful debut in 2020 with opening lectures by Prof. Michel Devoret of Yale University and Prof. Christopher Monroe of the University of Maryland. The 2021 lectures were delivered online by Prof. Mikhail Lukin of Harvard University and Prof. Peter Zoller of the University of Innsbruck. All lectures drew a wide audience from universities and industry throughout Israel.

Quantum Journal Club

The newly launched quantum journal club is open to the quantum graduate student and postdoc community on campus. At each meeting a student presents a paper of his or her choice within the center's scope of interest. The paper may be the latest and greatest in a specific field or a seminal paper in quantum science. The brainchild of Prof. Yuval Shagam, the meetings are led by doctoral students Eran Lustig and Raz Firanko. The club is also intended to strengthen the sense of community and interaction among the quantum research student population.

Seminars

The Helen Diller Quantum Center hosts an online weekly seminar series during the academic year, given by leading scientists from Europe and the United States. The audience includes scientists from Technion, other Israeli universities, and overseas, who contribute to a lively question-and-answer session after each lecture. All lectures are available online on the Center's YouTube channel.

International Quantum Seminar Series *(Online)*
Academic year 2020/21

Prof. Vladimir Manucharyan
Quantum electrodynamics of superconductor-insulator transitions in Josephson junction chains
University of Maryland

Prof. Jainendra K. Jain
Fractional quantum Hall effect: From fermions to composite fermions and beyond
Pennsylvania State University

Dr. Uzi Pereg
An Information-Theoretic Perspective on Quantum Repeaters
Technical University of Munich

Prof. Isaac Chuang
Grand unification of quantum algorithms
Massachusetts Institute of Technology (MIT)

Prof. Andras Gilyen
Exponential advantage of adiabatic quantum computation with no sign problem
Alfréd Rényi Institute of Mathematics

Prof. Brian Swingle
Information Scrambling in Complex Quantum Systems
University of Maryland

Prof. Daniel Gottesman
Maximally sensitive sets of states
California Institute of Technology

Prof. Frank Pollmann
Exploring Topological Phases on Quantum Processors
Technical University of Munich

Prof. Ish Dhand
Xanadu's Blueprint for a scalable photonic fault-tolerant quantum computer
Ulm University

Prof. David Schuster
Building materials from microwave photons
University of Chicago

Prof. Ian B. Spielman
Coherence and decoherence in the Harper-Hofstadter model
National Institute of Standards and Technology (NIST)

Prof. Morten Kjaergaard
Programming a quantum computer with quantum instructions
University of Copenhagen

Prof. Martin Plenio
Quantum Technologies for the Lifesciences
Ulm University

Prof. Lukasz Fidkowski
How Dynamical Quantum Memories Forget
Stony Brook University

Prof. Paris Tzallas
Linking quantum optics with strong laser field physics
Hellas Institute of Electronic Structure and Laser

Prof. Liang Jiang
Bosonic Quantum Information Processing with Superconducting Circuits
University of Chicago

Prof. Cheng Chin
The unexpected observation of Bose fireworks
University of Chicago

Prof. Maria Chekhova
Parametric down-conversion: from faint to bright nonclassical light
Max-Planck Institute for the Science of Light

Prof. Alexey Gorshkov
Dynamics of quantum systems with long-range interactions
University of Maryland

Dr. Assaf Hamo
Imaging phonon-mediated hydrodynamic flow in WTe2 with cryogenic quantum magnetometry
Harvard University

Prof. Steve Simon
Topologically Ordered Matter and Why You Should be Interested
University of Oxford

Faculty Directory

Faculty Member	Faculty	Research
Quantum Computing		
Eric Akkermans	Physics	Statistical mechanics and quantum fields on fractals; Topology of tilings; Quantum phase transitions – Anomalies; Statistical mechanics of out of equilibrium systems; Quantum mesoscopic physics; Cooperative effects and superradiance. Defects in graphene and related materials for quantum computing
Itai Arad	Physics	Entanglement, Quantum Algorithms, Complexity, Quantum verification, Error corrections
Yosi Avron	Physics	Quantum computing, quantum information, entanglement, Lindblad evolutions, geometry of quantum states, anyons
Aharon Blank	Chemistry	Develop and apply new magnetic resonance methodologies, both nuclear magnetic resonance (NMR) and electron spin resonance (ESR)
Eyal Buks	Electrical Eng.	Fields of superconducting devices (resonators, Josephson devices and detectors) and nanomechanics, spins in diamond and magnetoptics
Dudi Gershoni	Physics	Experimental solid state physics. Optical and electronic physical properties of semiconductor systems of lower dimensionality such as quantum wells, quantum wires and quantum dots and their applications in quantum optics and in quantum information processing. Experimental tools: mainly short-pulse lasers and high spatial resolution, low light level optics
Shay Hacohen-Gourgy	Physics	Superconducting qubits, hybrid qubits, and bosonic qubits in superconducting cavities
Erez Hasman	Mechanical Eng.	Atomic-scale photonics, Nanophotonics, Metasurfaces, Plasmonics, Spinoptics, Quantum photonics, Quantum materials, Quantum sensing and devices, Low dimensional materials, 2-D materials and devices, Quantum light sources, Quantum Metamaterials and Metasurfaces, Topological photonics
Alon Hoffman	Chemistry	Physico-chemical properties of surfaces. Nucleation, growth and properties of diamond films and their surfaces
Ido Kaminer	Electrical Eng.	Light-Matter Interactions, X-ray Sources, Improving Scintillation Process with Nanophotonics, Extreme Nonlinear Quantum Optics
Amit Keren	Physics	Experimentalist investigating mostly the properties of magnetic and superconducting material
Anna Keselman	Physics	Topological phases of matter, Frustrated quantum magnetism, Topological superconductivity, Entanglement dynamics; Numerical many-body methods, Density-matrix renormalization group (DMRG)
Efrat Lifshitz	Chemistry	Semiconductor nanostructures and dedicated magneto-optical methodologies
Netanel Lindner	Physics	Many-body systems, topological phases and light-matter interactions & the interface between these physical systems and the theory of quantum information and computation
Nimrod Moiseyev	Chemistry	Basic formulation of non-Hermitian quantum mechanics (NHQM) with emphasis on chemistry, in particular on resonances
Tal Mor	Computer Science	Quantum Information Processing (QIP)
Meir Orenstein	Electrical Eng.	Short reach optical communications, Ultra fast optics, WDM optical communications, Vertical cavity semiconductor lasers
Yoav Sagi	Physics	Strongly interacting Fermi gases
Moti Segev	Physics	Experimental and theoretical projects, within the general area of photonics / lasers / quantum electronics. We are interested in two types of projects: exploring fundamental aspects, with impact on other areas of science (beyond photonics), and profound applications – that can have a real impact on technology
Yuval Shagam	Chemistry	Trapped molecular ions for quantum technology and tests of fundamental science; Quantum sensing for chiral molecules; Cold quantum ion-neutral chemistry
Jeff Steinhauer	Physics	Important analogies between ultracold atoms and other areas of physics.
Maytal Toroker	Materials Science & Eng.	Computational methods and applications to material science, particularly in energy-related areas
Ari Turner	Physics	Condensed Matter & Materials Physics
Quantum Communication		
Eric Akkermans	Physics	Statistical mechanics and quantum fields on fractals; Topology of tilings; Quantum phase transitions – Anomalies; Statistical mechanics of out of equilibrium systems; Quantum mesoscopic physics; Cooperative effects and superradiance. Defects in graphene and related materials for quantum computing
Aharon Blank	Chemistry	Develop and apply new magnetic resonance methodologies, both nuclear magnetic resonance (NMR) and electron spin resonance (ESR)
Eyal Buks	Electrical Eng.	Fields of superconducting devices (resonators, Josephson devices and detectors) and nanomechanics, spins in diamond and magnetoptics
Oren Cohen	Physics	Generation & application of circularly-polarized high-order harmonics and attosecond pulses. New approach for ultrahigh-speed imaging. Induction of long-lived optical waveguides in the atmosphere by laser filaments; Optical spatiotemporal pulse train solitons; Algorithmic sparsity-based super-resolution in microscopy, spectroscopy and diagnostics of ultrashort laser pulses
Gadi Eisenstein	Electrical Eng.	Dynamics of semiconductor nano structures; Ultrafast spectroscopy of quantum dot and quantum dash gain media; Nonlinear Photonic Crystal Waveguides; Nonlinear fiber devices; Optically sensitive nonvolatile memories; High sensitivity broad band MIS; photodetectors and optically controlled varactors

Faculty Member	Faculty	Research
Dudi Gershoni	Physics	Experimental solid state physics. Optical and electronic physical properties of semiconductor systems of lower dimensionality such as quantum wells, quantum wires and quantum dots and their applications in quantum optics and in quantum information processing. Experimental tools: mainly short-pulse lasers and high spatial resolution, low light level optics
Ilya Goykhman	Electrical Eng.	Nano-Optoelectronics, 2D Materials, Nano-Photonics, Device Physics, Hybrid Technologies
Erez Hasman	Mechanical Eng.	Atomic-scale photonics, Nanophotonics, Metasurfaces, Plasmonics, Spinoptics, Quantum photonics, Quantum materials, Quantum sensing and devices, Low dimensional materials, 2-D materials and devices, Quantum light sources, Quantum Metamaterials and Metasurfaces, Topological photonics
Alex Hayat	Electrical Eng.	Quantum & Ultrafast advanced devices
Yachin Ivry	Materials Science & Eng.	Controlling the onset of collective-electron phenomena at the nanoscale, mainly in ferroelectricity and superconductivity
Ido Kaminer	Electrical Eng.	Light-Matter Interactions, X-ray Sources, Improving Scintillation Process with Nanophotonics, Extreme Nonlinear Quantum Optics
Nimrod Moiseyev	Chemistry	Basic formulation of non-Hermitian quantum mechanics (NHQM) with emphasis on chemistry, in particular on resonances
Tal Mor	Computer Science	Quantum Information Processing (QIP)
Moshe Nazarathy	Electrical Eng.	Advanced optical modulation formats and equalization techniques, MIMO techniques over multimode optical interconnects; Translucent optical networks, links and devices controlling light with light – Optical Computing; Quantum Information Processing, Quantum Communication and Quantum Computing; Integrated, Fiber and Wavepacket Optics, GPS satellite navigation systems
Meir Orenstein	Electrical Eng.	Short reach optical communications, Ultra fast optics, WDM optical communications,Vertical cavity semiconductor lasers
Michael Revzen	Physics	The Weyl transformation and the quantum state as a function of the phase space coordinates
Moti Segev	Physics & Electrical Eng.	Experimental solid state physics. Optical and electronic physical properties of semiconductor systems of lower dimensionality such as quantum wells, quantum wires and quantum dots and their applications in quantum optics and in quantum information processing. Experimental tools: mainly short-pulse lasers and high spatial resolution, low light level optics
Jeff Steinhauer	Physics	Important analogies between ultracold atoms and other areas of physics

Quantum Simulation

Shay Hacohen-Gourgy	Physics	Analog and digital simulations using superconducting cavities
Ido Kaminer	Electrical Eng.	Light-Matter Interactions, X-ray Sources, Improving Scintillation Process with Nanophotonics, Extreme Nonlinear Quantum Optics
Nimrod Moiseyev	Chemistry	Basic formulation of non-Hermitian quantum mechanics (NHQM) with emphasis on chemistry, in particular on resonances
Yoav Sagi	Physics	Strongly interacting Fermi gases
Avi Schroeder	Chemical Eng.	Improving patients' quality of life and bettering their treatment by developing innovative medical technologies
Moti Segev	Physics & Electrical Eng.	Experimental and theoretical projects, within the general area of photonics / lasers / quantum electronics. We are interested in two types of projects: exploring fundamental aspects, with impact on other areas of science (beyond photonics), and profound applications – that can have a real impact on technology
Yuval Shagam	Chemistry	Trapped molecular ions for quantum technology and tests of fundamental science; Quantum sensing for chiral molecules; Cold quantum ion-neutral chemistry
Jeff Steinhauer	Physics	Important analogies between ultracold atoms and other areas of physics
Maytal Toroker	Materials Science & Eng.	Computational methods and applications to material science, particularly in energy-related areas

Quantum Materials

Eric Akkermans	Physics	Statistical mechanics and quantum fields on fractals; Topology of tilings; Quantum phase transitions – Anomalies; Statistical mechanics of out of equilibrium systems; Quantum mesoscopic physics; Cooperative effects and superradiance. Defects in graphene and related materials for quantum computing
Lilac Amirav	Chemistry	Photocatalysis via Quantum Materials
Assa Auerbach	Physics	Strongly Correlated Electron, Boson, and Spin Systems in Condensed Matter
Yehonadav Bekenstein	Materials Science & Eng.	Future Materials Science; Lead-Free Perovskites; Lead-Halide Perovskites; Next Generation Scintillators
Lev Chuntonov	Chemistry	Multi-dimensional spectroscopy of ultrafast quantum dynamics
Gadi Eisenstein	Electrical Eng.	Dynamics of semiconductor nano structures; Ultrafast spectroscopy of quantum dot and quantum dash gain media; Nonlinear Photonic Crystal Waveguides; Nonlinear fiber devices; Optically sensitive nonvolatile memories; High sensitivity broad band MIS; photodetectors and optically controlled varactors
Ilya Goykhman	Electrical Eng.	Nano-Optoelectronics, 2D Materials, Nano-Photonics, Device Physics, Hybrid Technologies
Erez Hasman	Mechanical Eng.	Atomic-scale photonics, Nanophotonics, Metasurfaces, Plasmonics, Spinoptics, Quantum photonics, Quantum materials, Quantum sensing and devices, Low dimensional materials, 2-D materials and devices, Quantum light sources, Quantum Metamaterials and Metasurfaces, Topological photonics

Faculty Member	Faculty	Research
Alex Hayat	Electrical Eng.	Quantum & Ultrafast advanced devices
Alon Hoffman	Chemistry	Physico-chemical properties of surfaces. Nucleation, growth and properties of diamond films and their surfaces
Yachin Ivry	Materials Science & Eng.	Controlling the onset of collective-electron phenomena at the nanoscale, mainly in ferroelectricity and superconductivity
Ido Kaminer	Electrical Eng.	Light-Matter Interactions, X-ray Sources, Improving Scintillation Process with Nanophotonics, Extreme Nonlinear Quantum Optics
Amit Kanigel	Physics	Low-dimensional materials, Angle resolved photoemission spectroscopy, Strongly correlated electron systems, Exotic superconductors, Magnetic resonance, Nano-scale phase separation and competing orders in strongly correlated systems
Anna Keselman	Physics	Topological phases of matter, Frustrated quantum magnetism, Topological superconductivity, Entanglement dynamics; Numerical many-body methods, Density-matrix renormalization group (DMRG)
Elad Koren	Materials Science & Eng.	Nanoscale Electronic Materials and Devices
Gad Koren	Physics	High temperature superconductivity, thin films and junctions
Lior Kornblum	Electrical Eng.	Oxide electronics, physics and devices of correlated-electron oxides
Efrat Lifshitz	Chemistry	Semiconductor nanostructures and dedicated magneto-optical methodologies
Netanel Lindner	Physics	Many-body systems, topological phases and light-matter interactions & the interface between these physical systems and the theory of quantum information and computation
Nimrod Moiseyev	Chemistry	Basic formulation of non-Hermitian quantum mechanics (NHQM) with emphasis on chemistry, in particular on resonances
Daniel Podolsky	Physics	Strongly correlated electronic and atomic systems, that is, systems in which the interaction energy of the constituent particles is comparable to their kinetic energy
Ari Turner	Physics	Condensed Matter & Materials Physics
Yuval Yaish	Electrical Eng.	NEMS based on CNTs and Graphene ;Electrical properties of CNTs and Graphene; Chemical and biological sensing at the single molecule regime; 3-dimensional structures composed of CNTs and Graphene

Quantum Sensing & Devices

Faculty Member	Faculty	Research
Guy Bartal	Electrical Eng.	Nonlinear nano-photonics; Topological nano-photonics; Super-resolution microscopy; Optical metamaterial design
Aharon Blank	Chemistry	Develop and apply new magnetic resonance methodologies, both nuclear magnetic resonance (NMR) and electron spin resonance (ESR)
Eyal Buks	Electrical Eng.	Fields of superconducting devices (resonators, Josephson devices and detectors) and nanomechanics, spins in diamond and magnetoptics
Lev Chuntonov	Electrical Eng.	Multi-dimensional spectroscopy of ultrafast quantum dynamics
Oren Cohen	Physics	Generation & application of circularly-polarized high-order harmonics and attosecond pulses. New approach for ultrahigh-speed imaging. Induction of long-lived optical waveguides in the atmosphere by laser filaments; Optical spatiotemporal pulse train solitons; Algorithmic sparsity-based super-resolution in microscopy, spectroscopy and diagnostics of ultrashort laser pulses
Gadi Eisenstein	Electrical Eng.	Dynamics of semiconductor nano structures; Ultrafast spectroscopy of quantum dot and quantum dash gain media; Nonlinear Photonic Crystal Waveguides; Nonlinear fiber devices; Optically sensitive nonvolatile memories; High sensitivity broad band MIS; photodetectors and optically controlled varactors
Ilya Goykhman	Electrical Eng.	Nano-Optoelectronics, 2D Materials, Nano-Photonics, Device Physics, Hybrid Technologies
Shay Hacohen-Gourgy	Physics	Josephson magnetic field sensors and Josephson amplifiers
Erez Hasman	Mechanical Eng.	Atomic-scale photonics, Nanophotonics, Metasurfaces, Plasmonics, Spinoptics, Quantum photonics, Quantum materials, Quantum sensing and devices, Low dimensional materials, 2-D materials and devices, Quantum light sources, Quantum Metamaterials and Metasurfaces, Topological photonics
Alex Hayat	Electrical Eng.	Quantum & Ultrafast advanced devices
Ido Kaminer	Electrical Eng.	Light-Matter Interactions, X-ray Sources, Improving Scintillation Process with Nanophotonics, Extreme Nonlinear Quantum Optics
Elad Koren	Materials Science & Eng.	Nanoscale Electronic Materials and Devices
Michael Krueger	Physics	Ultrafast microscopy of quantum dynamics, nano-photonics, light-wave electronics, attosecond physics, many-body quantum physics
Tal Mor	Computer Science	Quantum Information Processing (QIP)
Meir Orenstein	Electrical Eng.	Short reach optical communications, Ultra fast optics, WDM optical communications,Vertical cavity semiconductor lasers
Yuval Shagam	Chemistry	Trapped molecular ions for quantum technology and tests of fundamental science; Quantum sensing for chiral molecules; Cold quantum ion-neutral chemistry
Yotam Soreq	Physics	Probing physics beyond the standard model
Yuval Yaish	Electrical Eng.	Low Dimensional Electronics

Electrons see the quantum nature of light. Illustration from Science September 2021, "Imprinting the quantum statistics of photons on free electrons," Kaminer et al.

Scientific visualization by *SimplySci Animations*

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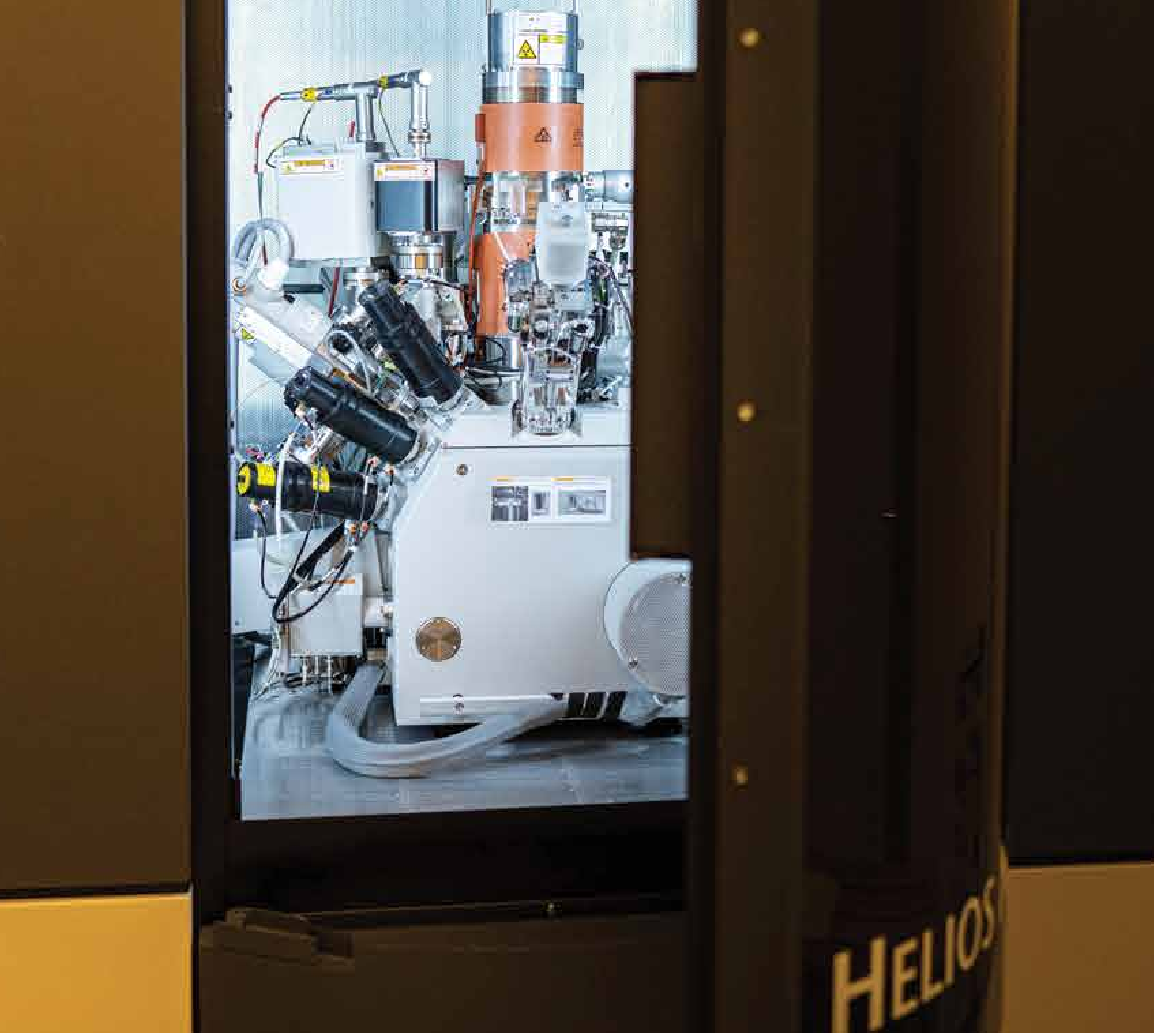

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