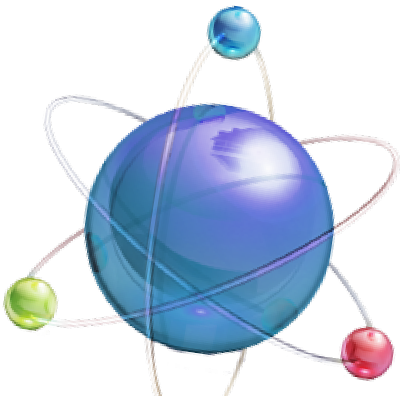
The 50th Anniversary of the School of Physics & Astronomy

1965-2015

יובל לבית הספר
לפיזיקה ולאסטרונומיה

TEL AVIV UNIVERSITY אוניברסיטת תל-אביב

Contents



Physics at TAU

Past, Present & Future

Physics is arguably the most profound intellectual adventure mankind has undertaken. Our very immodest goal is to try to understand, to no pre-specified limit of depth, what the world is made of, and how it "works". This "world" excludes next to nothing, particularly in the increasingly interdisciplinary forms that Physics has been taking. From the smallest scales probed by the latest generation of particle accelerators to the precision cosmological measurements that have become routine, from the single-atom and single-photon manipulations being achieved in optics, to the study of biological and living systems using the analytic and experimental powers of our discipline, Physics is becoming, more than ever, truly the Science of Everything.

In the last 50 years, TAU Physics has assumed a prominent role in the ever-growing relevance of our field. Like the city of Tel-Aviv that hosts us, Physics at TAU has always been young, dynamic, cosmopolitan, innovative and forward-looking. I remember well the sense of awe and excitement when I was first exposed to the wonders of our profession as an undergraduate at TAU. As a graduate student here, I learned the thrill of scientific discovery. Coming back to TAU as a faculty member, I experienced the deep satisfaction of introducing undergraduates to the beauty of Physics, and guiding bright graduate students on their own paths of research and discovery. As I begin my term as the new head of our school, I feel a combination of pride, exhilaration, and a sense of privilege at being a part of this great adventure.

Looking ahead, the future looks brighter than ever. We are steadily strengthening our ranks with young and dynamic new researchers (often themselves graduates of TAU), who have established themselves as trail blazers in some of the hottest new disciplines in Physics. I truly believe that the best scientists also make the best teachers, and the world-class physics education provided by our School is now better than ever. Whether we are string theorists advancing to the next levels of abstract foundational understanding of nature, astronomers mapping the existence of earth-like extrasolar planets that could host life, or condensed-matter experimentalists studying materials that could bring the next revolutions in engineering and medicine, we are all on a magical journey of learning and discovery. The adventure continues.

Prof. Dan Maoz, Head of the School of Physics & Astronomy

50 Years of Progress & Excellence

I dedicate this Jubilee publication to the memory of our School's founding father, the late Prof. Yuval Ne'eman - one of the most prominent scientists Israel has produced, whose association with the School continued for over 40 years.

Our faculty

Founded 50 years ago, TAU's School of Physics & Astronomy is internationally recognized as a leading academic institution for both research and teaching. Our 40 senior faculty members and a few dozen emeriti faculty are leaders in scientific research in all fields of modern physics, from the sub-atomic world of elementary particles and nuclear physics, through condensed matter physics, biophysics, nano-technology, optics and applied physics to cosmology and the study of the universe. Providing a thriving and exciting academic environment for both researchers and students, the School also conducts many interdisciplinary activities in collaboration with other universities and institutes worldwide. In the last decade we are witnessing a changing of the guards, as the founding generation gradually retires, replaced by a new dynamic generation, setting new and challenging directions in both basic and applied research.

Our students

We place great store by our students, whom we view as our successors - the next generation of scientists and researchers. Year after year, the entering class of over 100 freshmen is considered the best in the country, and our physics curricula are among the most challenging on campus. Our 200 MSc and PhD students are actively engaged in research and teaching, consistently making invaluable contributions to the School's fast-growing list of achievements. Graduates of our programs are well-prepared for academic research as well as for leading R&D positions in the high-tech sector.

Our study programs

Our 500 students – both undergraduates and graduates – enjoy a wide variety of academic programs and research venues. Over the last two decades, responding to the growing need for interdisciplinary knowledge and skills, the School has made major changes in its curriculum – complementing the comprehensive single-major physics program with a wide range of double-major programs that combine physics with mathematics, computer science, geoscience, chemistry, electrical engineering, life sciences and more.

It makes me proud to see how our School has progressed in every way - from the time when I was a student here in the early 1970s, to the Jubilee we celebrate today. I am confident that the future will be even brighter!

By Prof. David Andelman, Head of the School of Physics & Astronomy 2011-2015

Our History

1974 - Yuval Ne'eman's 50th birthday

Left to right: Gedalia Ne'eman (Yuval's father), student, student, Prof. Yakir Aharonov, Prof. Guy Deutscher, Prof. Avivi Yavin, Prof. Asher Gotsman, Prof. Yuval Ne'eman

1995 - School of Physics and Astronomy 30th Anniversary

Left to right: Prof. Yakir Aharonov, Prof. Yuval Ne'eman, Prof. Benoit Mandelbrot (Wolf Prize Laureate), Prof. Alex Muller (Nobel Prize Laureate), Prof. David Horn, Prof. Tsung-Dao Lee (Nobel Prize Laureate), Prof. Asher Gotsman

Physics Faculty Members & Guests at Tel Aviv University 1967-1968

The Physics Department at Tel Aviv University was officially inaugurated on the new campus in Ramat Aviv in 1965, under the leadership of one of Israel's most prominent scientists, Prof. Yuval Ne'eman. Appointed by TAU President, Dr. George S. Wise, Prof. Ne'eman proceeded to build a strong team of promising young physicists – both experimentalists and theoreticians, alongside modern BSc, MSc and PhD programs, accredited by Israel's Council for Higher Education.

In its early days, research at the Physics Department focused mainly on high-energy, solid-state and nuclear physics. Soon Astrophysics was added as well, and in 1969 the Department's name was changed to the Department of Physics & Astronomy. Over the years the Department grew, peaking at over 60 faculty members in the 1980-90s, and acquiring international recognition for numerous scientific achievements. In 1985 it attained the status of a TAU School – the School of Physics & Astronomy in the Faculty of Exact Sciences.

Today, the School is both a national and international hub of frontline research in all major areas of modern physics. Conducting fruitful collaborations with leading scientific centers worldwide, the School attracts first-rate researchers, excellent students and prominent guests from the all over the world.

Department of Particle Physics (p. 4-11)

- Yuval Ne'eman, who in the early 1960s was a groundbreaking young High-Energy Physicist and Head of the Israel Atomic Energy Commission, laid solid foundations for High-Energy Physics and Nuclear Physics at TAU from the start.
- From the 1970s onwards TAU's High-Energy and Nuclear Physicists played key roles in large international collaborations, working at some of the world's leading particle accelerators - including those at CERN in Geneva, DESY in Hamburg, SLAC at Stanford and TRIUMF in Vancouver. Our scientists' cutting-edge research and discoveries significantly elevated Israel's standing in the global science arena; As a result, Israel was given observer status on the CERN Council in 1991, and a full CERN membership in 2014.
- In 2005, after four decades at the forefront of global research – both experimental and theoretical - the fields of High Energy and Nuclear Physics were merged to form the School's Department of Particle Physics.

Department of Condensed Matter Physics (p. 12-19)

- Condensed Matter Physics, known in the 1960s as Solid State Physics, was one of young Physics Department's earliest anchors. The first Solid-State research laboratory was set up in 1966, and world-leading experimentalists and theoreticians were gathered by the tireless and persuasive Yuval Ne'eman - establishing dynamic operations in many related fields.
- Activities soon included a world-famous low-temperature and superconductivity lab, built and operated with minimal resources; highly productive experimental groups in high-pressure physics, infra-red lasers and mesoscopic physics; and theoretical work on critical phenomena in phase transitions, superconductivity, superfluid helium, composite media, biophysics and soft matter physics. These flourishing, multifaceted endeavors were further enhanced by two waves of immigration from the Soviet Union – in the 1970's and then in the early 1990's – which brought to the Department a number of world-leading physicists, some of them also famous for their courageous stand as anti-Soviet Refuseniks.
- To this day, Condensed Matter Physics at TAU is characterized by great diversity, essentially bringing together researchers who investigate many different types of complex systems - consisting of numerous atoms and molecules – from molecular structures through soft crystals and self-assembling macromolecules to living organisms and many more. Through the years our scientists have made a range of significant contributions to ongoing global research in these areas.

Department of Astronomy & Astrophysics (p. 20-27)

- Early on in the history of TAU's Department of Physics, its founder Prof. Yuval Ne'eman realized that Astrophysics was a crucial discipline in modern-day Physics, and decided to give it the central place it deserved. In 1969, the Department of Physics was renamed the Department of Physics & Astronomy, and for quite a few years this was the only place in Israel conducting academic programs and research in Astronomy and Astrophysics.
- In 1971, TAU established its very own astronomical observatory – the Florence & George Wise Observatory – in collaboration with the Smithsonian Institution. Located in the central Negev, near the town of Mitzpe Ramon, the Observatory offers astronomers the benefits of clear desert skies, modern facilities and a favorable global position (which allows them to track astronomical phenomena when it is daytime at most other observatories on earth). High-impact studies based on Wise observations have focused on binary stars, black holes in other galaxies, novas and supernovas and extrasolar planets. To this day, Wise is the only professional astronomical observatory in Israel.
- Keeping up with the rapid advancement of astronomical research, and studying broad spectrum of topics, TAU's astrophysicists have always worked at frontline observation centers worldwide. At present, these encompass a large array of facilities, on the ground and in space, observing the skies at all wavelengths of the electromagnetic spectrum. Ground facilities include the latest generation of giant optical and near-infrared telescopes and specialized mid-infrared and millimeter-wave facilities in Hawaii, Chile, and Europe; while space telescopes include Hubble, Spitzer, Herschel, Chandra, Kepler, Swift, and Fermi, spanning infrared to gamma-ray energies. At the same time, the Department's theorists use a vast range of modern-day tools – such as analytic calculations and massively parallel numerical computations - to interpret and predict astrophysical phenomena.

The TGC subsystem of the ATLAS detector at the CERN accelerator lab near Geneva. Our scientists contributed significantly to the development and construction of this enormous detector, and are using it in their research.

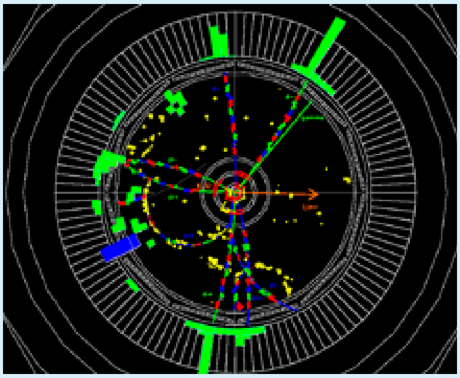
Experimental Particle Physics

Experimental particle physicists are the like explorers of the modern age - forever probing new territory, where no one has ever gone before. Using enormous particle accelerators buried deep beneath the surface of the earth, they unravel the world of elementary particles and pursue the fundamental secrets of the universe.

Our innovative research

TAU's experimental particle physicists play leading roles in large international research projects. Their focal topics of investigation include:

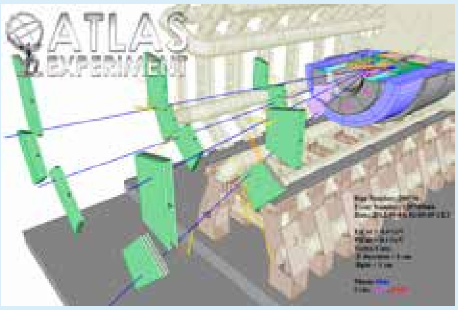
- **High energy physics** – studying Nature under the conditions that existed a billionth of a second after the primordial Big Bang.
- **Searching for new, exotic particles** – using the most powerful accelerators. These discoveries lay the foundations for the next leap forward in our understanding of the physical world.
- **Accurate measurements of the properties of elementary particles** – precisely probing the fundamental laws of physics.
- **Studying complex interactions between colliding particles** – and the forces they exert on one another.
- **Developing advanced particle detectors** – to facilitate future research in the world's leading accelerator facilities.



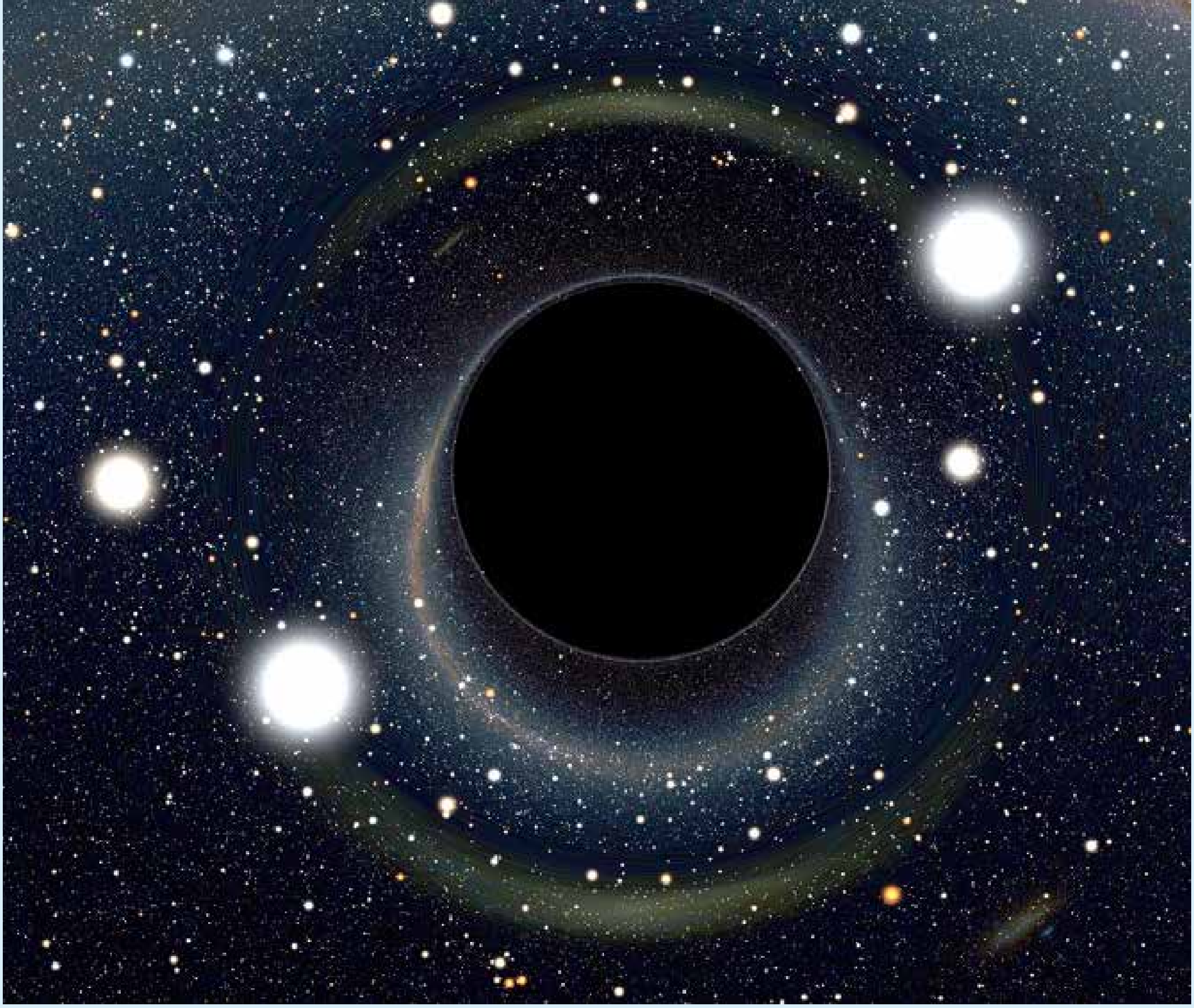
The production and subsequent decay of two B particles within the BABAR detector at the SLAC accelerator lab in California. Such phenomena are central to measurements of small differences between matter and antimatter, which aim to solve the puzzle of the existence of matter in the universe.

Major achievements

- Our scientists have made major contributions to milestones of experimental particle physics, including the discoveries of the Higgs and the gluon, the properties of the Z boson and the structure of the proton.
- Our scientists serve in leadership positions of international collaborations at major particle-physics laboratories, including CERN, DESY and SLAC.
- Our ongoing research helps define the fundamental laws of physics and identify directions for the next breakthrough in particle physics research.
- Our labs were central contributors to the development and testing of major components of CERN's cutting-edge ATLAS particle detector, which were critical for the 2012 discovery of the Higgs particle.
- Our scientific contributions over the years played an important part in a significant achievement of Israeli science: being accepted as the 21st full member of CERN in January 2014 – the first new member state since 1999, and the only one geographically outside of Europe.



A Higgs particle is produced in this high-energy collision of two protons, recorded in 2012 by the ATLAS detector partly developed by TAU scientists. The Higgs decays to four particles called muons, whose trajectories are measured by the detector and shown here as nearly straight blue lines.



A black hole is an object around which gravity is so powerful that even light cannot get out. This happens when a large mass of matter is squeezed into a tiny space. The understanding of black holes must eventually incorporate both General Relativity and Quantum Mechanics – two fundamental theories that so far seem incompatible.

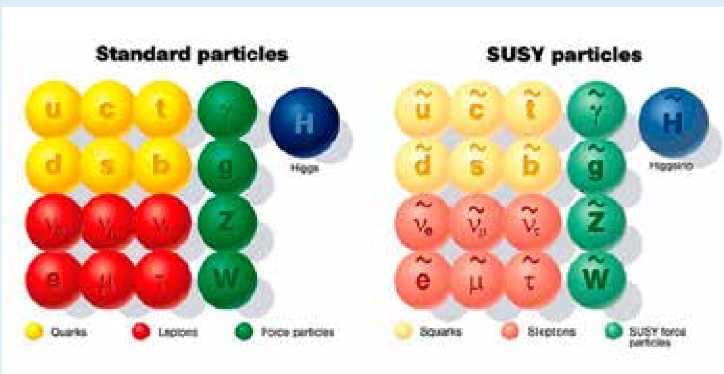
Theoretical Particle Physics

Theoretical particle physicists are the predictors and analysts of this forward-looking discipline. As they probe the consequences of existing theories to test them against experiments, they also envision as yet unknown fundamental constituents and new forces of our Universe, paving new paths for their discovery, and mapping the virgin terrain.

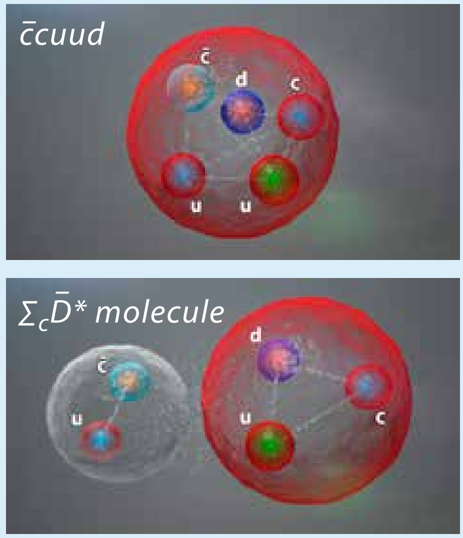
Our innovative research

TAU's theoretical Particle Physicists work hand in hand with their experimental colleagues – proposing new experiments and interpreting actual findings, brought home from leading accelerators worldwide. Our theoreticians' fields of study include:

- **Expanding the Standard Model of Particle Physics** – (the theory organizing all particle phenomena known to date) by predicting new implications, and comparing them with experimental findings.
- **Exploring possibilities beyond the standard model** – by following extensive evidence that this Model, although well established, is not by any means 'the whole story'.
- **Investigating dark matter** – a great unknown of modern science, discovered through astronomic observations.
- **Studying the foundations of quantum theory and possible ways of reconciling it with general relativity** – The reconciliation of these two seemingly incompatible fundaments of 20th century physics is needed to explain physical phenomena, such as black holes. A focal effort to this end is String Theory, to which our scientists are major contributors.
- **Research in Quantum Chromodynamics** – focusing on the strong force that holds quarks together, and is a million times more powerful than the electrical force.



Supersymmetry is a leading contender for an extension of the Standard Model of particle physics. If supersymmetry is realized in Nature, each ordinary elementary particle has a supersymmetric "partner", as shown in the figure.



A recent breakthrough discovery: the Pentaquark

A 5-quark cluster, predicted by TAU physicists. As shown in the pictures, the five quarks can be arranged in two different ways: in the top illustration, all five quarks are in one cluster; at the bottom, three quarks are in one cluster and two in another cluster. TAU's particle theoreticians successfully predicted the second arrangement, thereby providing strong support for this physical picture.

Major achievements

The Founding Father of our School, the late Prof. Yuval Ne'eman, was the scientist who first brought Particle Physics to Israel in the mid-1960s - establishing our country as a superpower in this vital field of research to this day. A brilliant particle physicist in his own right, Ne'eman discovered the SU(3) symmetry, the ordering principle of hadrons – particles responding to the Strong Force – prompting a global, ultimately successful search for identifiable missing hadrons.

Through the years, our theoreticians have excelled in formulating predictions for new particle phenomena, later verified by accelerator experiments.

The internal structure of nucleons within nuclei. Is it different from that of free nucleons?

Nuclear Physics

Nuclear Physics, one of the first and most fundamental fields of modern physics, dating back to the discovery of radioactivity in 1896, retains its position as a key area of research in the 21st century. Exposing the atom's nuclei and their components to extreme conditions, today's nuclear physicists continually reveal new facts about nuclear systems and the forces that drive the evolution of our universe.

A neutron detector built at TAU, disassembled and shipped off for an experiment at the Jefferson Laboratory electron accelerator in Virginia, USA.

Our innovative research

TAU's scientists work at the forefront of modern nuclear physics, conducting experiments at the world's best facilities and using both theoretical and experimental tools to investigate cutting-edge questions that impact other fields of research as well. Topics addressed by their studies include:

- **Challenging the Standard Model of Particle Physics** – by searching for unknown phenomena and deviations from standard expectations in nuclei under a range of extreme conditions - generated with advanced tools such as particle accelerators, particle traps and high-power lasers. Nuclei play an important role in the study of fundamental properties of interactions and their possible violations.
- **Challenging nuclear understanding at high matter density** – in which the distance between the centers of two nucleon is smaller than the nucleon diameter. These studies help scientists understand the nature and properties of neutron stars, considered the densest and smallest stars in the universe.
- **Challenging nuclear understanding at high energy density** – using high-power lasers to shed light on enigmas regarding the abundance of some elements in the universe.
- **Searching for differences between free and bound nucleons** – by scattering various particles off nucleons bound in nuclei, observing them, and comparing their interactions and properties (such as size and volume) to those of free nucleons.

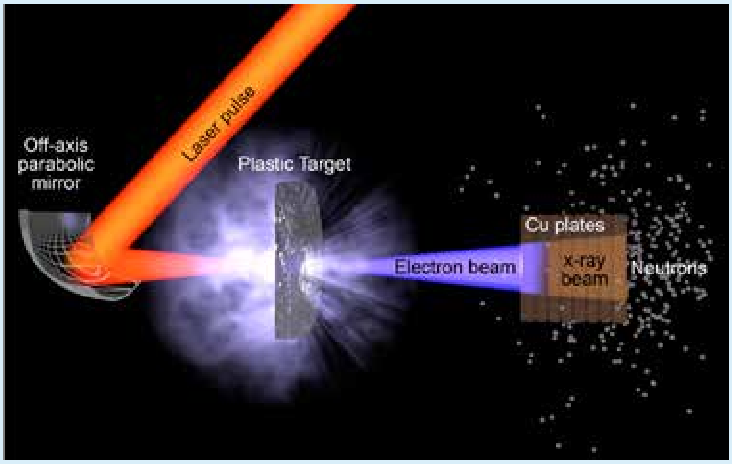
Major achievements

Nuclear physics was one of the first disciplines at TAU's School of Physics, when it was founded in the mid-1960s. From the very beginning, our nuclear physicists were welcomed at particle accelerators worldwide, where they made breakthrough scientific discoveries. Among other achievements, they contributed significantly to the study of pions and their properties, including pion absorption, the role of pions in tying nucleons together, and charge-exchange reactions mediated by pions.

Other pioneering works over the years included: predicting and measuring collective excitations of nuclei (giant resonances); squeezing particles in extreme conditions (color transparency); beta decay of radioactive nuclei – attaining a 'world record' in an interaction that contradicts the Standard Model; and breaking up nucleon pairs within nuclei, sending both nucleons flying out at great speed.

New high-intensity-laser techniques used at TAU may enable the acceleration of electrons, ions and neutrons as a viable alternative for very large and expensive particle accelerators. These friendly and useful technologies are expected to have a vast range of applications – in medicine, industry and research. A medical technique originating from TAU involves two stages of nuclear decay for treating cancer: the administered therapeutic substance remains harmless until it reaches the targeted tumor – where it breaks apart and emits destructive particles.

Finally, an interesting collaboration has been established between our nuclear physicists and TAU's archaeologists, helping date findings unearthed in digs with Carbon-14 technology, based on a radioactive isotope of carbon found in all organic materials. One of the central debates being addressed in this manner concerns the size and importance of the Biblical kingdom of David and Solomon in the 10th century BCE.

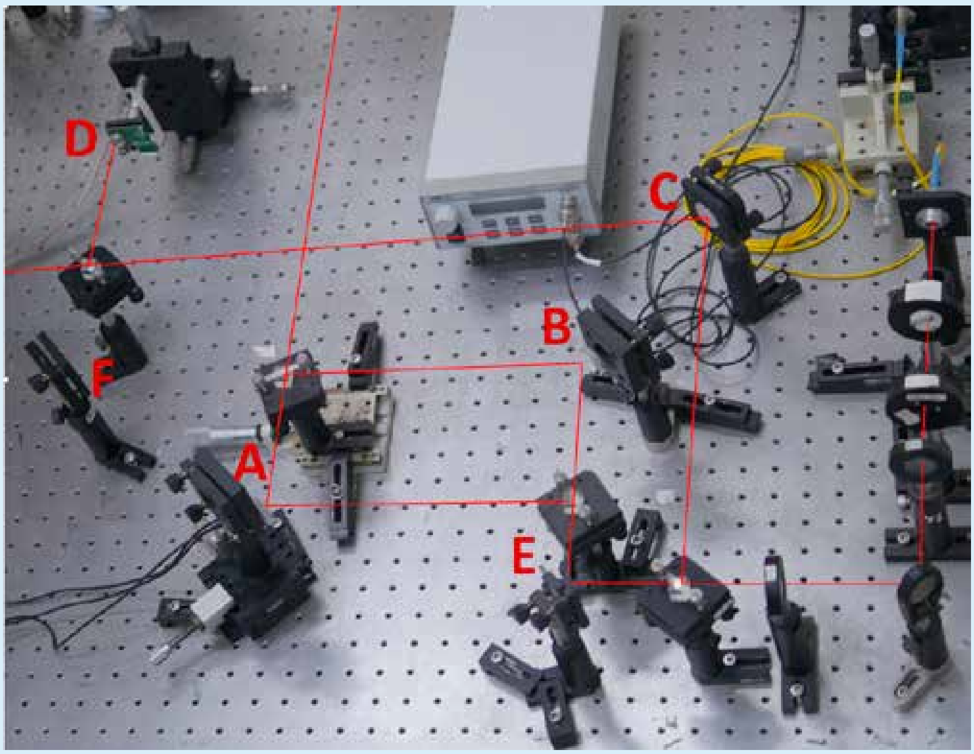


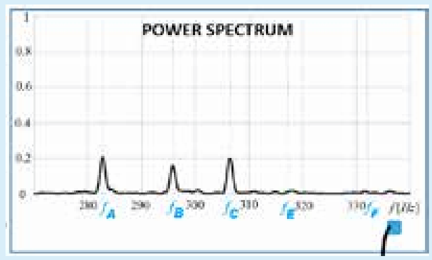
Schematic of a proposed method for accelerating neutrons with high intensity lasers – an approach likely to have many medical, industrial and research applications.

Foundations of Quantum Physics

Quantum Physicists study a world that to many of us may seem like fantasy: a realm in which a particle can be in two different places at once, or leave traces where it has never been...

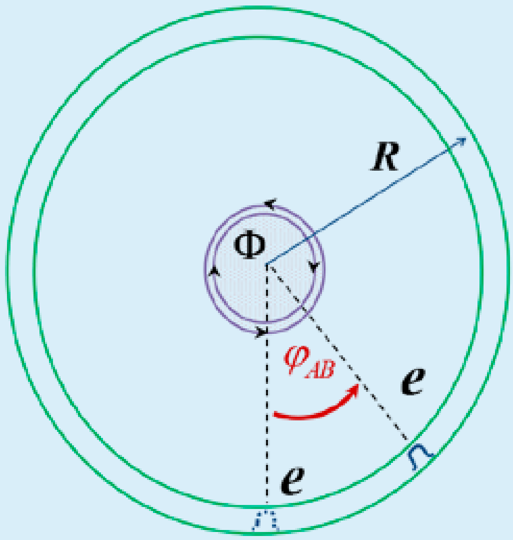
And yet, even though it contradicts some of our basic intuitions, this fundamental field of research underlies numerous innovations and inventions that are changing our tangible and concrete world.





This recent experiment performed at TAU's quantum optics laboratory in the Department of Condensed Matter observes the surprising past history of a photon in an interferometer:

Photons from the light source at the right bounce off mirror **C**, finally arriving at detector **D.** Interfering destructively in the paths **EAF** and **EBF**, the photons cannot pass through the inner interferometer. Nevertheless, the signal detected by detector **D** equally shows the vibration frequencies of three mirrors – **A**, **B** and **C,** suggesting that in some mysterious way, the photons had also been present at **A** and **B** (but not in **E** and **F**).

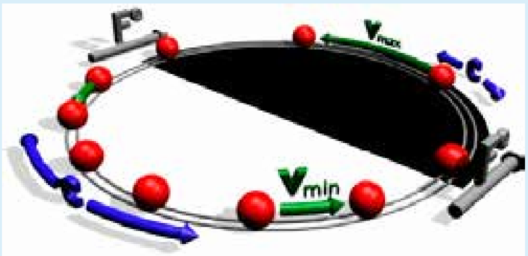


Application of the Aharonov-Bohm Effect for measuring magnetic flux using a single electron moving outside the magnetic field – from a recent TAU study.

Our innovative research

The important works of TAU's quantum physicists play a major role in the quantum revolution now spreading throughout the scientific world. Our groundbreaking works include:

- **The Aharonov-Bohm Effect** – a basis for modern gauge theories of the interactions of elementary particles, and a major tool for precision measurements in solid state physics.
- **Time-symmetric quantum mechanics** – a formalism which provides simple explanations for numerous quantum paradoxes and allows scientists to design ultrasensitive measurements of tiny quantum effects.
- **Quantum cryptography** – a means for forming codes that cannot be broken by any technology.
- **Quantum simulations** – proposing experiments with small quantum systems of ultra-cold atoms or trapped ions, in order to predict the behavior of larger quantum systems.
- **Nonlocal measurements & operations** – related to intuitively "impossible" links between distant particles.
- **Interaction-free measurements** – proposing a peculiar method for finding objects without touching them, seeing them, or probing for their presence in any other way.
- **Harvesting entanglement from the vacuum** – surprising results indicating that the source of nonlocal quantum correlations is present even in an empty space.
- **Interpretations of quantum mechanics** – probing and explaining the still unfathomed basics of the century-old quantum theory; One TAU interpretation - a version of the Many-Worlds Interpretation- assumes the existence of parallel worlds, thereby removing the enigmas of randomness and action at a distance from quantum mechanics.



This quantum simulation of ions sheds light on gravitational effects in a black hole.

Major achievements

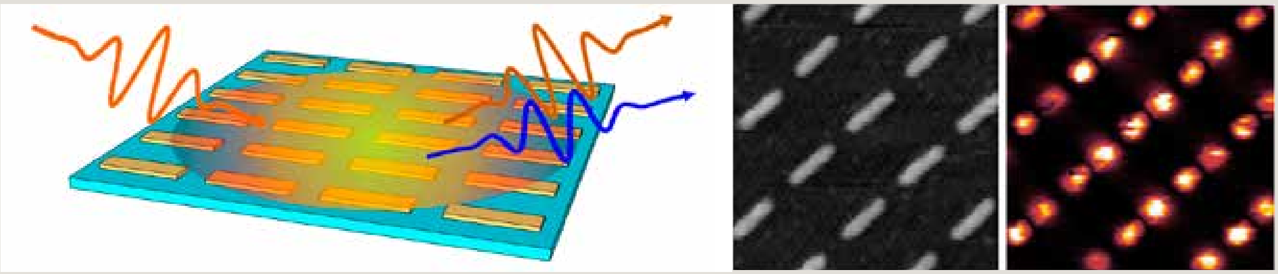
The foundations of quantum mechanics has been an active field of research at TAU for more than four decades, since the early beginnings of the Physics Department. At the time, this was one of very few quantum centers active anywhere in the world. In the following years, the theoretical works of our quantum physicists played a major part in a revolution that eventually generated a highly active and field of research, flourishing today at numerous quantum centers worldwide.

The theoretical proposals coming from TAU, which are still being implemented in quantum labs the world over, include: the Aharonov-Bohm magnetic and scalar effects, quantum simulations, continuous variable teleportation, cryptography with orthogonal states, interaction-free measurements, weak measurements and many more. These provide invaluable tools for the rapidly developing field of quantum information technology: the future of data storage, secure communication, and possibly, fast computation.

An illustration of how nanoscale light-matter interaction changes optical properties of a material – in this case its color. Such principles of plasmonics were applied unknowingly by medieval artists who mixed gold and silver nanoparticles in glass to create magnificent multicolored stained glass windows. The same nanophotonic properties also underlie the chameleon's ability to change its colors – when nanoparticles in their scales respond to pressure and temperature.

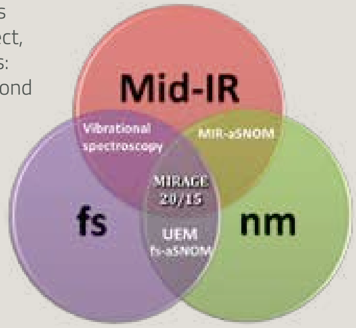
Atomic, Molecular & Optical Physics (AMO)

AMO Physics is the modern-day meeting ground of light and matter - where scientists probe the miniscule world of atoms, photons, their dynamics and the interactions between them, thereby opening new windows for scientific exploration and countless potential applications.



Color generation at the nanometric level – images of gold molecules arranged on a Silica substrate. An image obtained with atomic force microscopy (AFM), showing the shape and height of the miniscule gold bars; Top right: the same structures seen at the advanced TAU lab with scattering near field microscopy (SNOM), showing how the light concentrates at both ends of the bars, influenced by the particles' controllable geometry;

The goal of the ERC's MIRAGE 20/15 project, led by TAU physicists: combining femtosecond and nanometric technologies to produce images with extreme spatio-temporal resolution in the mid-infrared range.



Our innovative research

Working to overcome the barriers to the minute world of atoms and photons, our AMO researchers envision the scientific and technological breakthroughs - of their future inventions and discoveries. Their areas of investigation include:

- **Observing and manipulating ultrafast dynamics** (on a femtosecond timescale) – accessing the quantum world in solid compounds and 2D materials, to capture and control events occurring within and between molecules and photons.
- **Nanophotonics** – investigating the behavior of light at the nanometric scale, much smaller than the wavelength of light - a field of research that has extensive applications in high resolution microscopy, sensing, chemistry, nanoscale energy harvesting and nanotechnology.
- **Plasmonics & metamaterials** – studying the interaction of light with metals and semiconductors at the molecular level, in order to control dynamics in nanometric structures and produce novel designed-to-order metamaterials with useful applications.
- **Nonlinear quantum dynamics** – understanding fundamental nonlinear processes and quantum effects in various condensed matter systems, using nonlinear optics, light detection and pulse-shaping schemes.
- **Photonic fluids** – using a nonlinear medium in which the propagation of photons mimics the flow of a liquid to create situations that are analogous to other physical systems currently inaccessible to experimental physics. Examples include interactions in complex electronic and magnetic systems, and gravitational phenomena in the universe, especially in the vicinity of black holes.
- **Quantum optics** – observing the quantum behavior of photons in interferometric devices, using quantum weak measurements.
- **Developing novel Femto** – Nano technologies - combining very short timescales measured by femtoseconds (10^{-15} second) with nanoscale sizes and distances, to provide researchers with extreme temporal-spatial resolutions in observing and controlling events and dynamics at the molecular level.

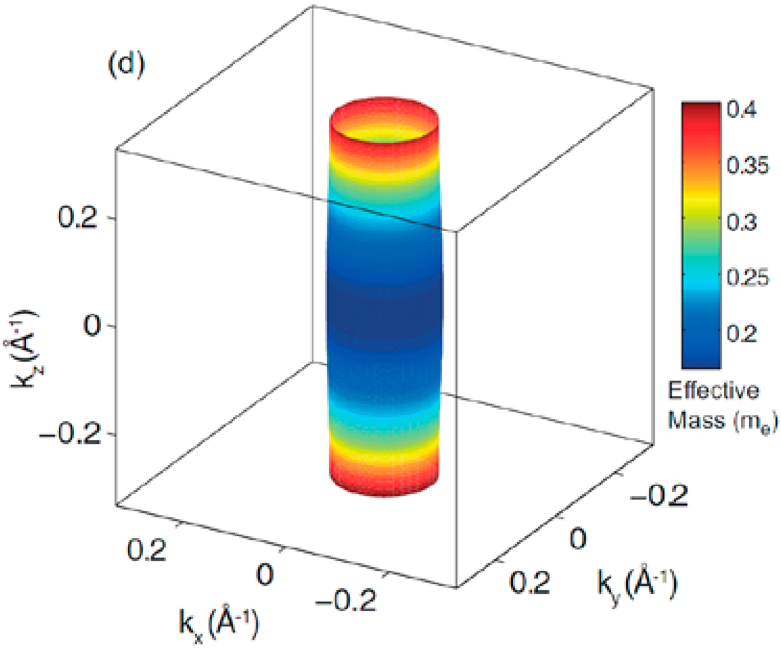
Left: a caustic formed in a photonic fluid. A caustic is defined as the envelope of light rays reflected or refracted by a curved surface. Right: similar phenomena may be seen, for example, as webs of light at the bottom of swimming pools on sunny days.

Major achievements

Our scientists have been instrumental in introducing and utilizing advanced femtosecond techniques and pulse-shaping methodologies for both basic and applied research in a broad spectral range.

Today TAU physicists lead the ERC's (European Research Council) MIRAGE 20/15 project, developing a technology that combines 20 fs (femtoseconds) temporal resolution and 15 nm (nanometers) spatial resolution – thereby merging extreme time and space resolutions in the mid-IR wavelength range (the optical regime in which molecular vibrations are widely used for material identification). They plan to use this technology to control and study ultrafast nanoscale phenomena, expected to enhance a range of essential technologies in many areas, including infrared spectroscopy, materials science, chemical and biomolecular sensing, security and industry.

Ultimately, the ability to manipulate quantum dynamics and interactions between photons and atoms may have endless applications: harvesting energy from high temperatures produced in these interactions, developed-to-order metamaterials, novel sensing and imaging technologies, destroying cancer cells via focused heating, delivering medications within the body and releasing them at the designated site, and perhaps eventually even a Harry-Potter-style 'invisibility cloak' employing advanced optical features.

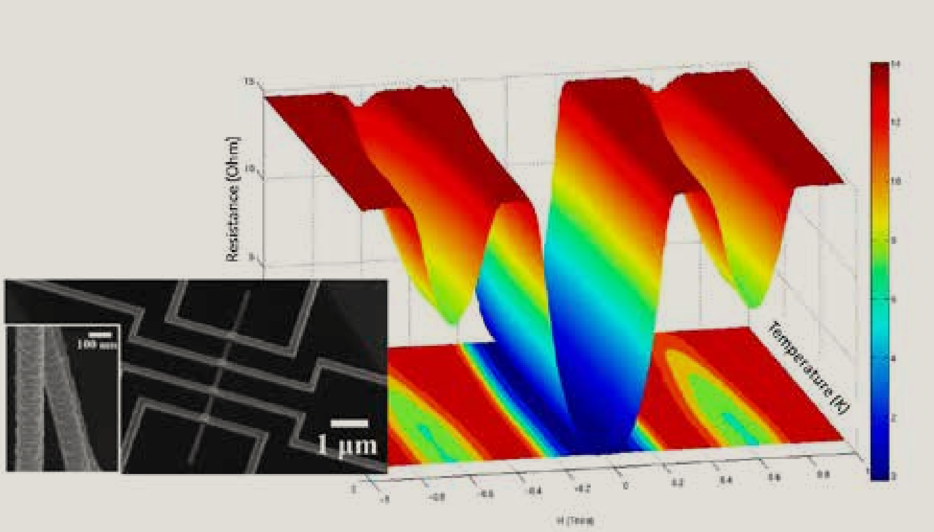


Topological insulator

The conducting cylindrical surface of the topological insulator Bi2Se3 (a compound of the chemical elements bismuth & selenium) - as inferred from a quantum oscillations measurement.

Electronic Systems

Electronic systems, based on the properties of electrons and the interactions between them, are the foundation of much of humankind's modern technology – past, present and future. From power grids to futuristic nanometric devices – electrons are everywhere.



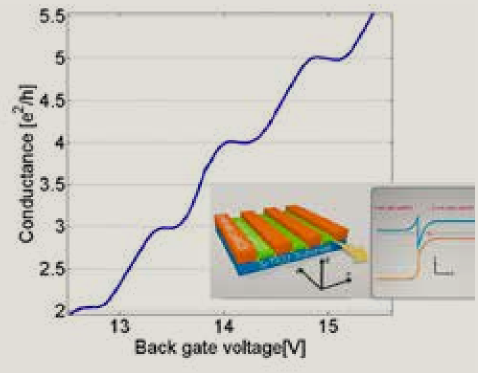
Superconducting nanowire

Resistance oscillations of a nanowire covered by a superconductor, subjected to a magnetic field at various temperatures.

Our innovative research

Our physicists, both theoreticians at their desks and experimentalists working in their laboratories, apply cutting-edge scientific concepts and methods to the study of interacting electrons in condensed matter. Their fields of interest include:

- **Magnetic materials** - currently used for example in magnetic memory elements such as hard disks, where a magnetic domain can be in either the 1 or 0 state.
- **Strongly correlated electron systems** - in which electrons interact strongly with each other, and therefore minor changes – in temperature, pressure and magnetic or electric fields, may induce dramatic changes in physical properties – for instance, turning the material into a superconductor or a ferromagnet.
- **Oxide Interfaces** – two-dimensional surfaces of atomic thickness which, formed between two insulating nanometric crystals, exhibit surprising new electronic properties - such as high conductivity, superconductivity, strong polarization, magnetism and even rare combinations like superconductivity and magnetism. Other interfaces are one-dimensional, creating nanometric wires with strong spin-orbit interaction, in which researchers can control the spin of the electrons by acting on their momentum.
- **Topological insulators** – a new, recently discovered state of matter: materials acting as insulators in the interior bulk, while their outside 2D surfaces behave as exotic conductors.
- **Mesoscopic physics** – studying quantum mechanical effects that become evident in 1D & 2D semiconductor and oxide-interface-based devices.
- **Systems under extreme conditions** – focusing on small diamond-cells that mimic the extreme pressure existing at the interiors of stars and planets.
- **Unconventional superconductors** – carry currents without dissipation, and therefore are expected to have a tremendous impact on the way energy is transferred and use. The search for new superconductors and the effort to understand unconventional superconductors is alive and kicking – both at TAU and elsewhere - even after almost a century of scientific effort.

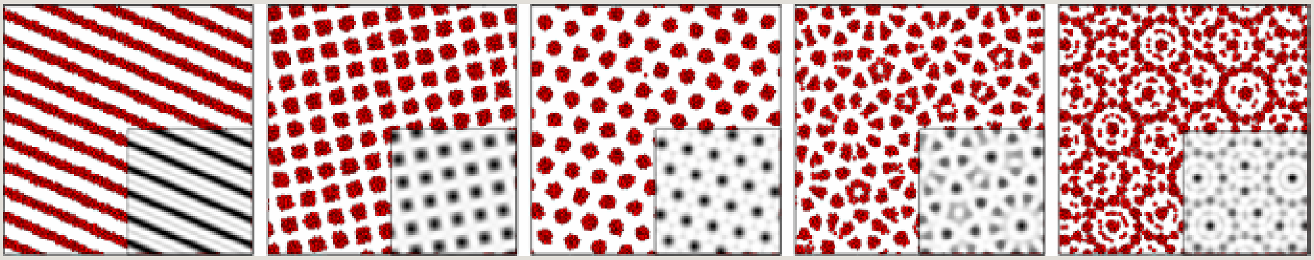


Quantum wires from 1D oxide interface

Conductance steps of a quantum wire formed at the boundary between two oxide interfaces. Each step corresponds to an additional electron moving in the wire.

Major achievements

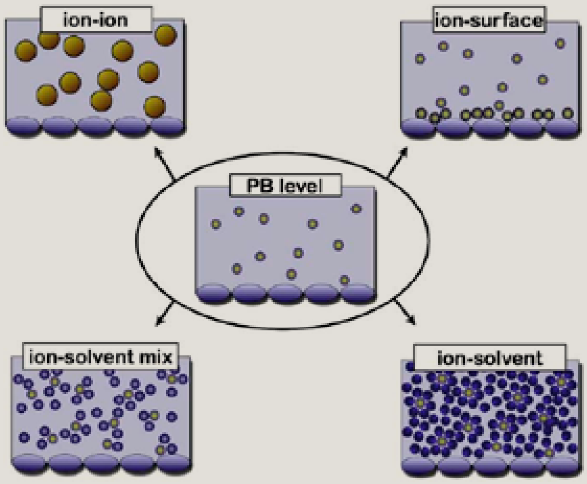
Our scientists are responsible for many pioneering discoveries in all the fields described above. Examples are: developing a unique way to read a magnetic memory bit, insights on unconventional superconductors, and measurements of newly designed 1D quantum wires and nanostructures.



Model for controlled self-assembly of soft periodic crystals and quasicrystals – devised by TAU physicists – explaining the thermodynamic stability of soft quasicrystals, and resulting in the discovery of a novel form of matter called cluster quasicrystals.

Soft Condensed Matter

Soft condensed matter is defined as a class of materials that are easily deformable at room temperature – including everything from liquid crystals, gels, foams, emulsions and colloidal suspensions to nanoscopic and biomolecular assemblies – and displaying an enormously rich array of novel physical properties and interactions. These may serve as the key to future generations of many devices - such as plastic electronics and novel screens, batteries, solar panels and fuel cells – that may significantly impact our way of life in the coming decades.



Modern statistical-mechanics theories of electrolytes and ionic liquids take into account a range of different interactions occurring within the system: electrostatic interactions, interactions between ions and a solvent, and specific interactions of ions close to the surface, due to the ions' own chemical properties. Such studies lead the way to numerous applications in energy materials – including fuel cells and novel battery technology.

Our innovative research

TAU's soft matter researchers, working at the forefront of modern condensed-matter physics, explore the enormous potential of a range of novel materials and phenomena, including:

Soft matter systems

- **Block copolymers** – materials with a molecular structure combining the chemical building blocks of two or more different materials, which self-assemble into a wealth of periodic nanostructures with many applications – such as nanolithography.
- **Controlled self – assembly of soft periodic crystals and quasicrystals** – novel ways for designing and producing new materials and metamaterials based on large, flexible molecules, exhibiting desired structures and properties such as advanced photonic features.
- **Ions and electromagnetic interactions in soft materials** – studying the interactions of electric charges that are omnipresent in the aqueous environments of colloidal suspensions, biopolymers, membranes and charged surfaces, in order to elucidate the interconnection between structure and function in these complex systems.

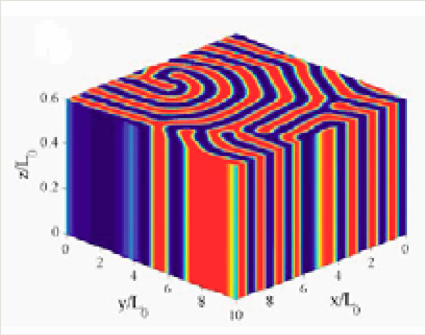
Modern statistical mechanics

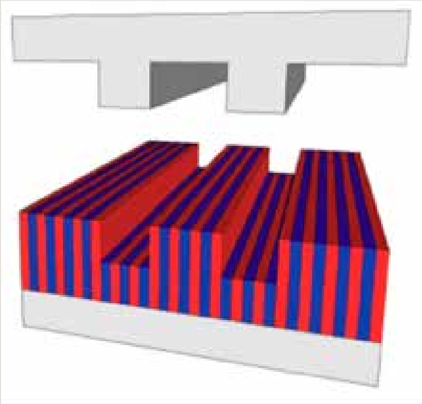
- **Statistical mechanics of polymers** – simulation and analytical study of polymer conformations and their dynamical properties, to ultimately enable the manipulation of the features and behavior of polymeric materials.
- **Dynamics of collective excitations and defects in quasicrystals** – analytical studies, simulations, and analysis of experimental data revealing the unique behavior of defects and phonon and phason excitations, in aperiodic crystals.
- **Granular and glassy materials** – studies of packing dynamics and phase transitions in condensed granular, jammed and glassy materials.

Major achievements

The outcomes of our cutting-edge research on various forms of complex soft matter systems may be used to develop numerous future products, made of novel materials and metamaterials – specially engineered-to-order, with unique properties that cannot be found in nature.

TAU physicists have also contributed significantly to the statistical mechanics of processes related to single-macromolecule manipulation - a widely used modern experimental technique revealing quantitative properties, conformations and interactions of polymers such as DNA.



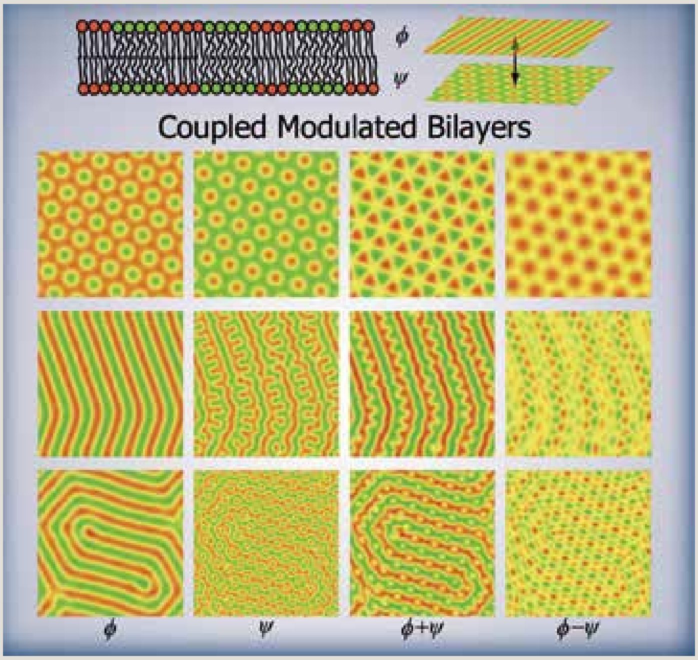


Block copolymers form nanostructures that may be used in the future as templates for nanolithography - potentially replacing present-day photolithography in the microchip industry. In their regular formation, the domains are not fully ordered and have many defects (top). One way to eliminate these undesired defects is to press a top guiding surface against the film, causing its domains to order (bottom).

A bacterial colony grown in a lab. Working together, these tiny creatures are able to sense their surroundings, process information and make decisions, thereby thriving even in unfriendly environments.

Physics of Living Systems

Lessons learned from condensed matter systems and statistical mechanics enable us today to study complex biological systems. These studies include whole new terrains and previously unimaginable insights – from the social intelligence of colonizing bacteria, through the self-assembly, structure and function of biomolecules, to the depths of life surveyed by the tools of bioinformatics.



Biophysical model of multi-composition cell membranes in different domain morphologies.

Our innovative research

Working at the forefront of their respective fields, our Biophysicists study the physical principles of biological and living systems, including:

Biological macromolecules

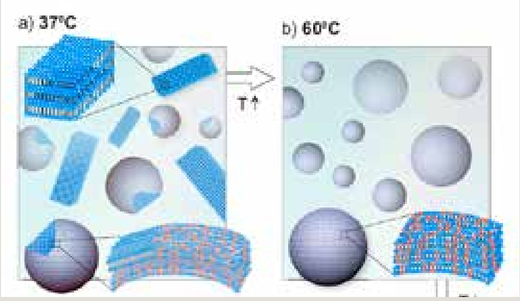
- **DNA & RNA** – carrying the basic genetic code of all known forms of life.
- **Intermediate filament proteins** – structural components of the cell skeleton, specific to different types of cells.
- **Intrinsically disordered proteins** – proteins that do not fold into specific 3D structures, and yet play functional biological roles.
- **Amphiphilic lipids** – the basic building blocks of the cell's membrane.

Bioinformatics

- **RNA editing** – a phenomenon in which RNA molecules, responsible for copying the DNA and producing proteins based on this information, deviate from the precise 'recipes' coded in the DNA.
- **Functions of proteins** – attempting to deduce as yet undeciphered functions of proteins from their DNA sequences.
- **Housekeeping genes** – responsible for the cell's basic maintenance functions, such as metabolism, energy supply etc.

Living Networks

- **Bacterial colonies** – providing evidence of many surprising abilities and characteristics of single-cell living organisms: self-organization, communication, cooperation, social and collective behavior, colony-colony competition and more.
- **Complex living networks** – such as the human brain, neural networks, gene networks, immune networks and even the stock market – how they work and process information, and what they tell us about the origins of cognition.



A metastable drug-carrying mechanism developed by biophysicists at TAU.

Major achievements

A new TAU-developed nanoscale drug-carrying mechanism uses supercooled materials that remain stable in liquid form as they travel through the body, and finally crystallize to release the medication at a predetermined time and place.

Our scientists were the first to discover, in 2003, that RNA editing is not a rarity but a common phenomenon, especially typical of the human genome. In a more recent study, they found intensive RNA editing in many types of malignant tumors, and were able to link between the degree of editing and the patients' prognosis.

TAU physicists have also contributed significantly to the statistical mechanics of processes related to single-macromolecule manipulation - a widely used modern experimental technique revealing quantitative properties, conformations and interactions of polymers such as DNA.

Neuronal intermediate filaments that constuct the nerve cell skeleton, observed via techniques of high-resolution microscopy and small-angle X-ray scattering.

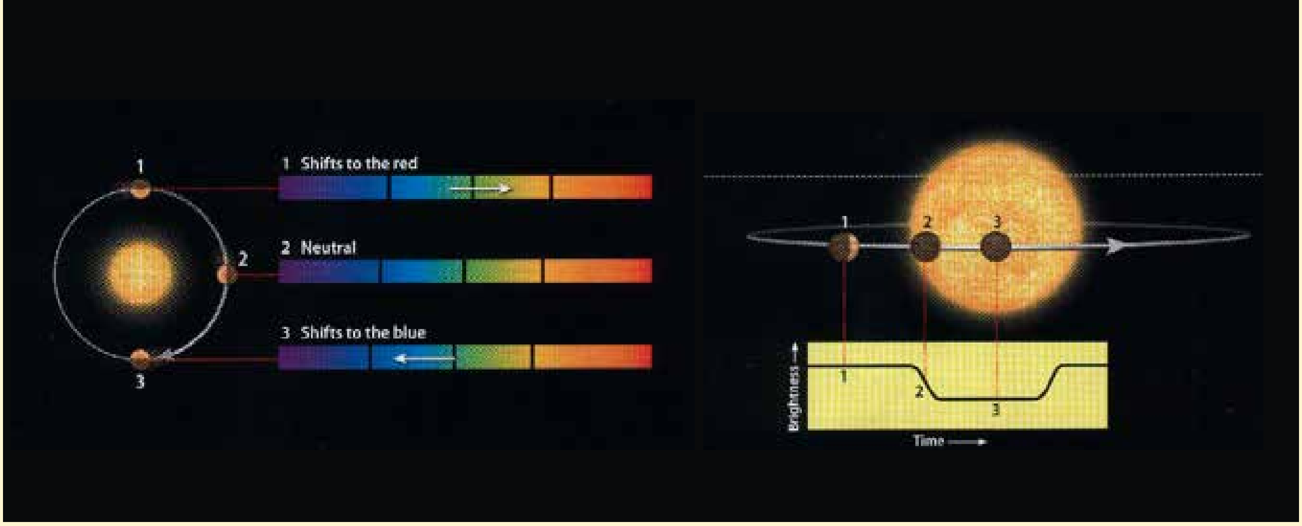


Illustration of the 'radial velocity' (left) and 'transit' (right) methods for discovering distant exoplanets

Extrasolar Planets

Gazing into the reaches of outer space, astronomers try to find planets orbiting other stars, far beyond our own solar system. Some of these may be viable candidates for the development of life – from microbes to intelligent beings.

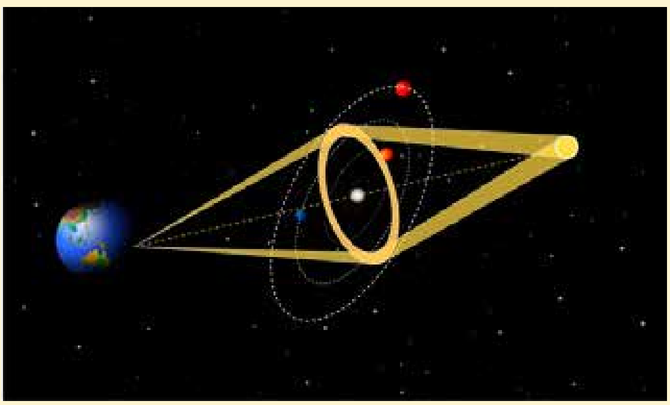


Illustration of the 'gravitational microlensing' planet-finding method

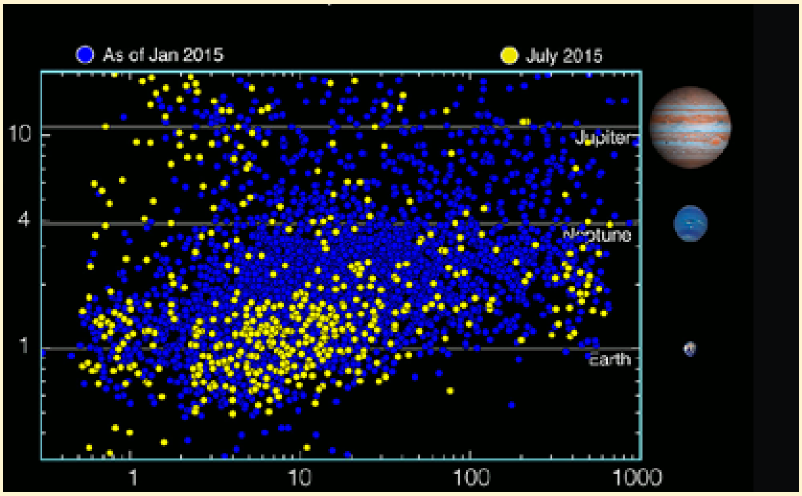
Our innovative research

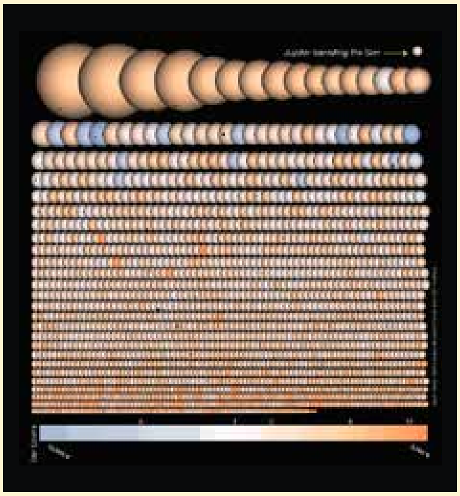
TAU's astrophysicists use advanced telescopes worldwide and employ sophisticated data analysis approaches to discover and investigate planets around distant suns. Over the years, their efforts have included:

- **Searching for extrasolar planets** – based on detecting the distant star's reflex motion, induced by the unseen planet's gravitational pull. Employing this technique, our researchers were party to the discovery of dozens of exoplanets.
- **Implementing the 'transit' method** – which measures minute changes in the stellar intensity caused by planets crossing in front of their parent stars as seen from Earth. Through this technique, which can examine as many as 100,000 stars at once, TAU's physicists took part in the discovery of tens of extrasolar planets to date.
- **Using 'gravitational microlensing'** – a third method for discovering exoplanets, in which relativistic bending of the light trajectory from a background star is used to deduce the presence and properties of planets around a foreground star along the line of sight; with observations at TAU's Wise Observatory in the Negev, our astronomers have contributed to the discovery of many planets using this method.
- **Developing efficient algorithms** – for processing large quantities of data in astronomical images to identify possible planets.

Major achievements

Our scientists were among the first to initiate the modern search for extrasolar planets. Commencing this effort in the mid-1980s, they used the 'star reflex motion' method to discover the first known candidate for an extrasolar planet, labeled HD114762b. This 1989 discovery signaled the beginning of intensive activity in this relatively new branch of astronomical research, which has grown constantly ever since. Our astrophysicists are key partners in major space telescopes, including the Kepler and CoRoT missions, both dedicated to the search for extrasolar planets via the transit method.





Left: 4,696 new exoplanet candidates discovered by NASA's Kepler mission as of July 23, 2015.
Right: planet candidates discovered by Kepler are ordered by their size, with colors indicating temperatures of their respective stars.

A newly formed cluster of stars, whose radiation excites and reflects off the gas and dust of its birth cloud.

Cosmology, Star and Galaxy Formation

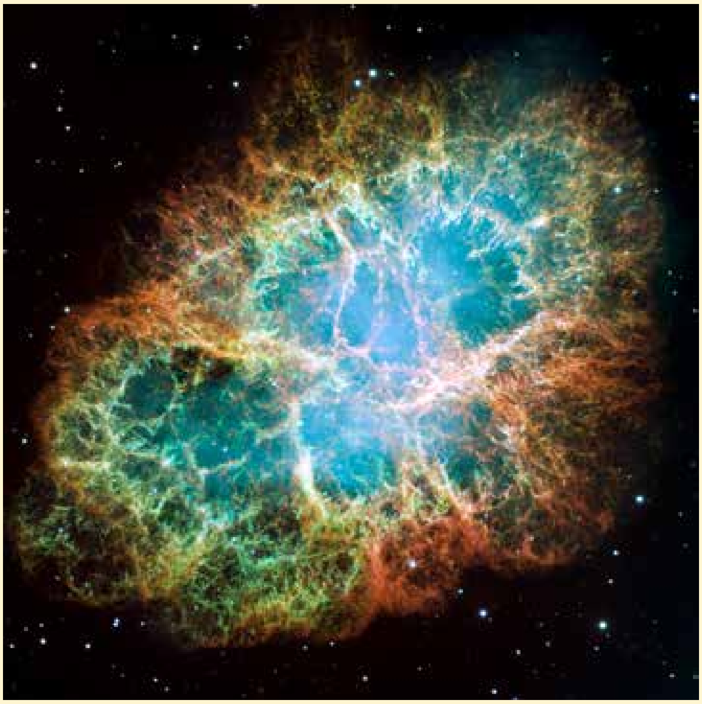
Cosmologists study the 13.8-billion-year history of our evolving universe: the evolution of galaxies, the formation of stars, the interstellar and intergalactic mediums and the fundamental atomic and molecular processes that lie at the base of these processes. Analytical physical-mathematical methods together with sophisticated computer modeling and simulations enable predictions and interpretation of manifold astronomical observations.

Our innovative research

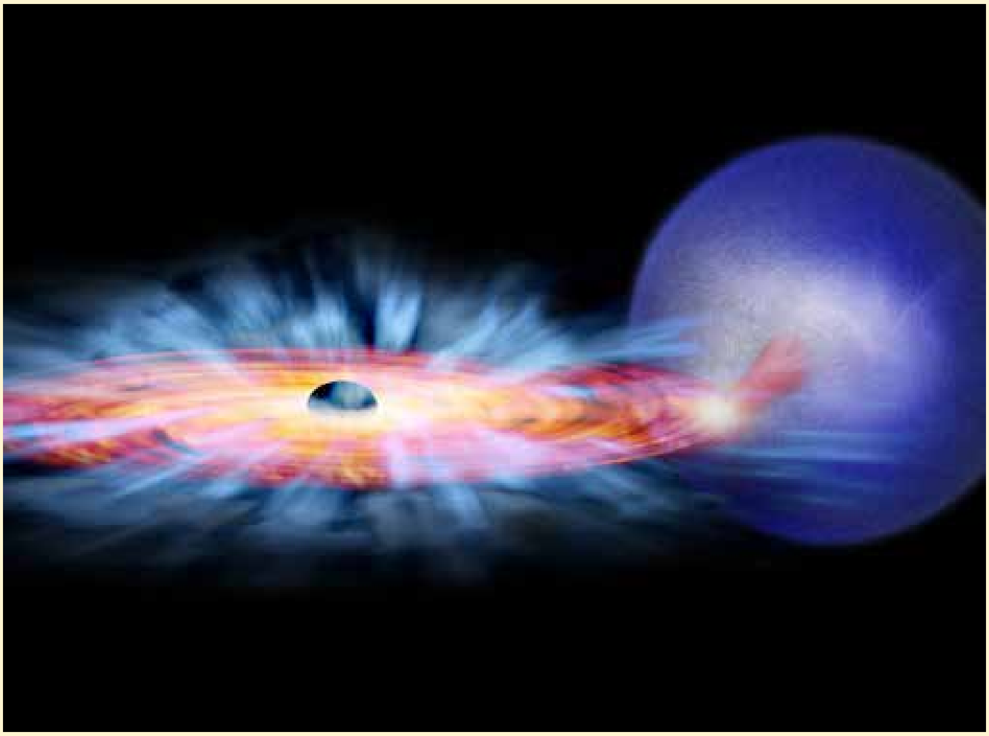
Our School's cosmologists focus their efforts on the many yet unsolved mysteries of the early and evolving universe. These include:

- **The Dark Ages of the universe** – mapping the ancient universe, before the birth of the first stars and galaxies.
- **21 cm tomography of the early universe** – developing methods to use the emission from the neutral hydrogen atoms in the early universe to map the emergence of the first stars and galaxies.
- **The birth of galaxies** – understanding the formation of the first stars, the emergence of large-scale cosmic structures, and the evolution of galaxies and galaxy clusters; what are the dynamics of the intergalactic medium and the interstellar medium that ultimately lead to the emergence of a galaxy?
- **Massive black holes and active galactic nuclei** – what are the co-evolution history and physics of galaxies and the billion-solar-mass black holes that lurk at their centers?
- **Astrochemistry & star-formation** – connecting between the atomic, molecular and radiation physics of interstellar gas and dust, the properties of the stars formed from them, and the stars' feedback on their birth clouds, from the early universe to the present day.

Dust, stars and unseen dark matter orbit around the center of the 'Black Eye Galaxy' M64, at a distance of 17 million light years from earth.



The Crab Nebula - the expanding remnant of a supernova explosion that occurred in the year 1052. The massive exploded star left behind it a "pulsar", a fast-spinning and extremely dense "neutron star", which provides energy that lights up the surrounding debris. The debris, flying out at thousands of kilometers a second, is highly enriched with new elements synthesized by the explosion. This material seeds the surrounding gas with the constituents of future generations of stars.



A stellar-mass black hole accreting matter from a companion star (right). Such systems appear as binary X-ray sources, occasionally ejecting relativistic jets.

High Energy Astrophysics

High-Energy Astrophysics probes the most extreme and violent phenomena in the universe. This involves observing very high-energy particles, powered by the densest and most compact objects in the cosmos - black holes and neutron stars - in which quantum mechanics and Einstein's Theory of General Relativity play a dominant role.

Our innovative research

TAU High-Energy Astrophysicists strive to understand a range of observed astronomical phenomena, using advanced theoretical and numerical tools. Their fields of study include:

- **Powerful jets of plasma** – ejected from the vicinity of black holes and neutron stars, at speeds close to the speed of light, emitting high-energy radiation. Such jets are seen in a variety of astrophysical systems over a large range of scales, including: supermassive black holes in active galaxies, whose mass can be as great as a billion times that of our sun; binary stellar systems, in which one star is a black hole or a neutron star; collapsing stars that release enormous amounts of energy in a few seconds; and pulsars - rotating neutron stars that emit pulses of radio emission.
- **Cosmic explosions** – arising from the collapse of a massive star, the detonation of a white dwarf, or the merger of binary neutron stars, and appearing as various types of supernovae, as well as intense flashes of gamma rays, termed gamma-ray bursts - during which energy in excess of that emitted by our sun over 100 billion years is released with several seconds
- **Gravitational waves emitted by compact objects** (like binary neutron stars and core collapse supernovae) – predicted by the General Theory of Relativity, but so far undiscovered by observational means. Future detection of these waves will provide a direct confirmation of the fundamental theory, telling us a great deal about the central engines that power cosmic explosions.
- **The origin of cosmic rays** – energetic particles from outer space that bombard the Earth. The cosmic ray spectrum extends to energies well beyond those accessible by the largest particle accelerators ever built by man. The origin of cosmic particles is still a mystery, and considerable observational and theoretical efforts are devoted to identifying their sources.

Major achievements

Our scientists have gained international recognition for their contributions to research on cosmic explosions and black hole magneto-hydrodynamics. They were involved in several breakthroughs in the study of gamma-ray bursts, and are currently among the world leaders in developing the theory of shock breakout leading to early emission with core-collapse supernovae.

Radio image of the quasar 3C175, exhibiting jets of magnetized plasma that emanate from the vicinity of a putative supermassive black hole at the center of a galaxy, and propagate at nearly the speed of light.

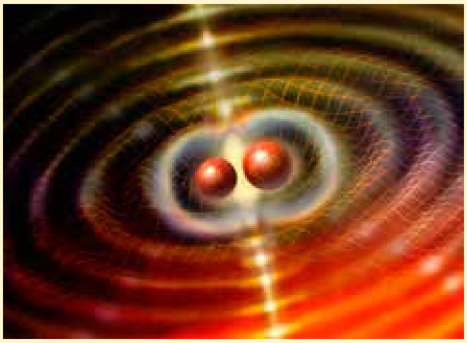
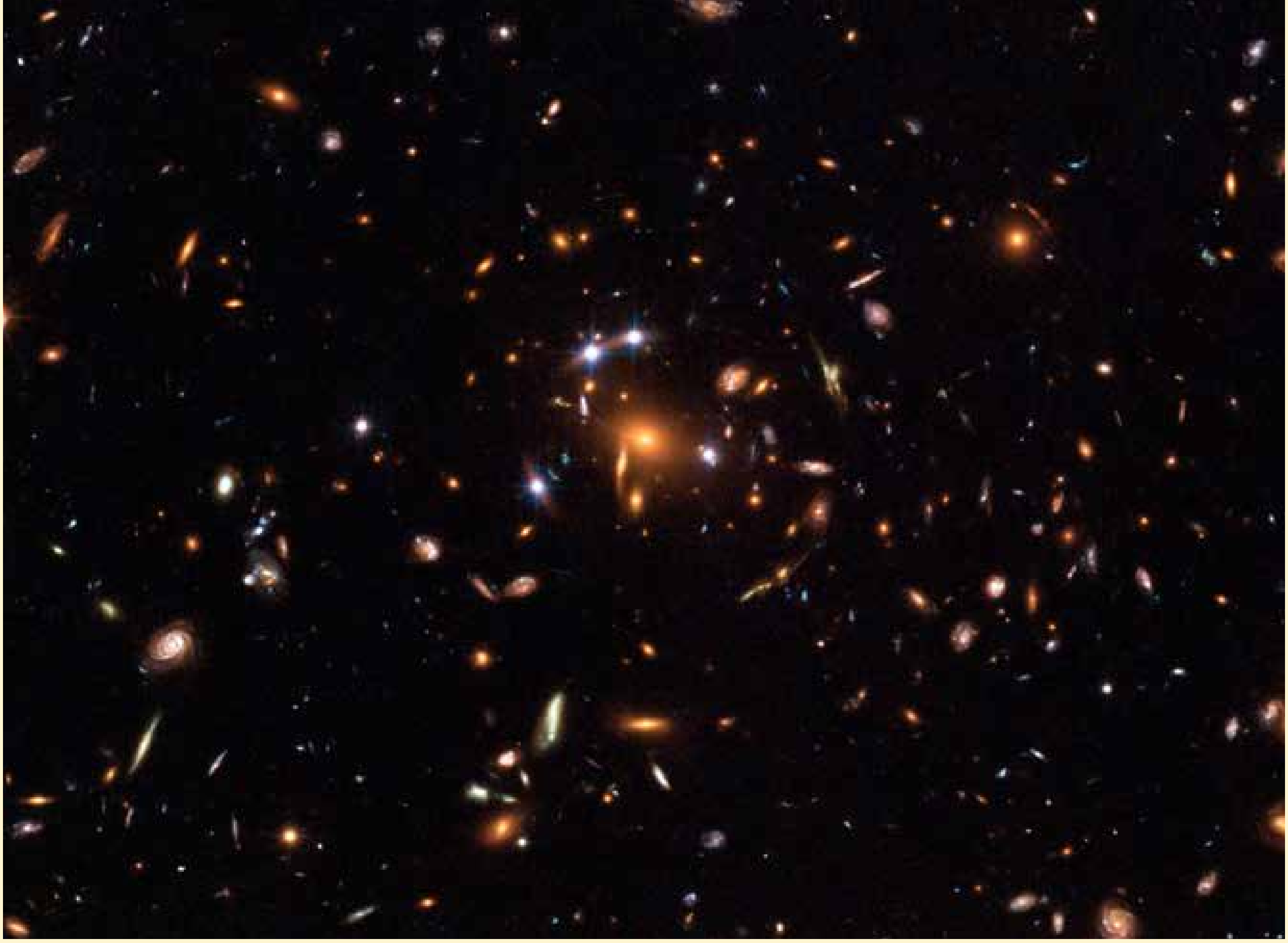


Illustration of gravitational wave emission at the merging of neutron stars. The collision of the neutron stars during the final stage of their binary evolution produces a short burst of gamma radiation, detectable by space observatories.



Hubble Space Telescope image, obtained by TAU astronomers, of the massive cluster of galaxies SDSS1004+4112, 7 billion light years away. The combined mass of the cluster, made of both luminous and dark matter, creates a 'gravitational lens' that magnifies and distorts the light from sources far behind the cluster. Among the 'lensed' background images seen here is a blue star-like distant quasar (a supermassive black hole feeding on material from its host galaxy) - of which this gravitational 'mirage' has made four identical images surrounding the center.

Observational Astronomy

Humans have gazed at the stars and wondered about the firmament above ever since they first walked the earth. As modern science emerged, Astronomy took its central place as a consistent driver for physics as a whole - from the times of Galileo and Newton, all the way to the recent discoveries of dark matter and dark energy.

TAU's Wise Observatory near Mitzpe Ramon in the Negev. The circles are the trailed images of stars, which appear in long photographic exposures as a result of the earth's rotation, as the stars circle around the north celestial pole. A straight meteor trail is also visible.

Our innovative research

TAU astronomers lead a range of cutting-edge global observational endeavors, including:

- **Discovering and mapping the super-massive black holes** – that lurk in quasars and at the centers of large galaxies, including our own Milky Way, and the relativistic phenomena in their surroundings. Understanding the physics, properties and rates of the cataclysmic
- **stellar explosions** called **supernovas** and **gamma-ray bursts** – that have, over cosmic time, synthesized the elements in the periodic table. The remnants of these explosions are likely sites for acceleration of ultra-high-energy cosmic ray particles.
- **Uncovering the population of extrasolar planets** – and their demography, using a variety of techniques, including stellar transits, radial velocity wobbles, and gravitational microlensing. Growing numbers of earth-like planets are being found, with an eye to future searches for biomarkers signaling the presence of life.
- **Probing the physics of star-forming regions** – whether locally, in extreme starburst galaxies, or in the young Universe's era of 'first light'.
- **Mapping the dark matter** – and the hot gas in massive clusters of galaxies, through their gravitational lensing and photon scattering effects.

Image of the center of galaxy NGC 1512, 30 million light years away, obtained by TAU astronomers using NASA's Hubble Space Telescope. The image combines data at optical, ultraviolet and infrared wavelengths using three different cameras on Hubble. It highlights a ring of massive star formation around the galaxy's nucleus, concentrated in bright blue and red 'super star clusters'. Each cluster consists of young stars totaling a million masses of our own sun.

Observations – past, present & future

Observational astrophysics was introduced to Israel at TAU, with the construction in 1971 of the Wise Observatory near Mitzpe Ramon in the central Negev, and the subsequent training of generations of observers. Today, Israel is among a limited number of nations having a prominent presence in astronomical observations, with TAU Physics still leading in this field among the local departments.

While Wise Observatory has kept pace in terms of its telescopes and instrumentation, and has produced a steady yield of valuable science, TAU astrophysicists have expanded their tool kit to the most powerful facilities in the world - including the giant ten-meter-class optical and infrared telescopes in Hawaii and in Chile, radio and microwave interferometric arrays in the US, Europe, Chile, and Antarctica, and multiwavelength, infrared through gamma-ray observatories in space. Looking to the future, our astronomers plan to join one or more of the upcoming mega-projects in astronomy, such as the next generation of 40-meter-diameter telescopes.

Faculty Members & Their Fields of Research at the School of Physics and Astronomy

Prof. Halina Abramowicz - Experimental particle physics.

Prof. David Andelman - Theory of soft matter and biological physics.

Prof. Shimshon Bar-Ad - Modern experimental optics: Nonlinear and quantum optics, ultrafast optical spectroscopy, optical analogs of hydrodynamics, gravity, and Hawking radiation.

Prof. Renan Barkana - Formation and evolution of the first stars.

Prof. Sara Beck - Star formation; Radio-Infrared supernebulae; astro-chemistry.

Dr. Roy Beck-Barkai - Experimental biophysics and soft-condensed matter using small angle X-ray scattering: Self-assembly, nanostructure, and dynamics of biomolecules and hybrid particles.

Dr. Noah Brosh - Formation and evolution of galaxies.

Prof. Yoram Dagan - Experimental study of strongly-correlated electrons: High-Tc and unconventional superconductivity, quantum wires, two-dimensional electron liquids, topological insulators.

Prof. Eli Eisenberg - Non-equilibrium statistical mechanics; Bioinformatics, RNA editing.

Prof. Erez Etzion - Experimental particle physics.

Prof. Victor Fleurov - Nonlinear optics; Analog gravity in optical and cold atom systems; Tunneling dynamics.

P**rof. Alexander Gerber** - Condensed matter systems under high magnetic fields; Spintronics; Nano-scale magnetism; Magnetic sensors and memory devices.

Dr. Moshe Goldstein - Theory of low-dimensional and nanoscale electronic and photonic systems.

Prof. Nissan Itzhaki - String theory and cosmology.

Prof. Yacov Kantor - Statistical mechanics; Physics of polymers; Entropy-dominated systems.

Prof. Marek Karliner - Theoretical particle physics.

Prof. Amir Levinson - High-energy astrophysics.

Prof. Jechiel Lichtenstadt - Experimental nuclear physics.

Prof. Ron Lifshitz - Physics of aperiodic crystals; Nonlinear, mesoscopic, and quantum dynamics of nanomechanical systems.

Prof. Dan Maoz - Gravitational microlensing planet searches; supernovae and their white dwarf progenitors.

Prof. Ehud Nakar - High-energy astrophysics.

Prof. Yaron Oz - String theory, theoretical particle physics.

Prof. Alexander Palevski - Experimental low-temperature physics: Superconductivity, magnetic order and strong spin-orbit interaction in heterostructures, interfaces, and topologically protected materials.

Prof. Eliazer Piasetzky - Experimental nuclear physics.

Dr. Ishay Pomerantz - Experimental High Intensity Lasers and Nuclear Physics.

Dr. Dovi Poznanski - Supernovae, cosmology, astronomical data mining, dust and the interstellar medium.

Prof. Benni Reznik - Foundations of quantum mechanics, quantum information.

Dr. Eran Sela - Theoretical condensed matter physics: Low dimensional systems, quantum wires, quantum dots, and Topological phases.

Dr. Amit Sever - Theoretical particle physics.

Prof. Abner Soffer - Experimental particle physics.

Prof. Jacob Sonnenschein - String theory, theoretical particle physics.

Prof. Amiel Sternberg - Physics and chemistry of the interstellarmedium, star-formation, and galaxy evolution.

Dr. Haim Suchowski - Nonlinear control of light-matter interaction: Ultrafast phenomena at the nanoscale, nonlinear metamaterials, quantum coherent control, and adiabatic dynamics.

Prof. Benjamin Svetitsky - Theoretical particle physics.

Prof. Lev Vaidman - Foundations of quantum mechanics, quantum information.

Dr. Tomer Volansky - Theoretical particle physics.

Emeriti

Prof. Yakir Aharonov
Prof. Amnon Aharony
Prof. Gideon Alexander
Prof. Jonas Alster
Prof. Daniel Ashery
Prof. Naftali Auerbach
Prof. Mark Azbel
Dr. Gideon Bella
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Prof. David Bergman
Prof. Aharon Casher
Prof. Reuven Chen
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Prof. Samuel Dagan
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Dr. Yehiel Distanik
Prof. Ora Entin
Prof. Leonid Frankfurt
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Prof. David Horn
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