CURRICULUM VITAE

Iannis K. Kominis

DECEMBER 2023

Department of Physics
University of Crete
Heraklion 70013
Greece

ikominis@uoc.gr
www.quantumbiology.gr
ikominis@qubiom.com
www.qubiom.com

BIOGRAPHIC DATA

Place, Date of Birth	Athens, 1972
High School	German School of Athens, Doerpfeldgymnasioum, Abitur 1990
Military Service	Hellenic Air Force, 2001-2002
Languages	Greek (native), English (fluent), German (fluent)

ACADEMIC EDUCATION

1996 - 2001	PhD in Physics, Princeton University
1990 - 1996	BS, MsEng in Electrical Engineering, National Technical University of Athens
1999	US Particle Accelerator School, Vanderbilt University
1997	L3 Collaboration, CERN
1997	US Particle Accelerator School, University of California Berkeley
1995	Solid State NMR Group, University of Leipzig
1994	Advanced Physics School, Department of Physics, University of Crete
1993	Advanced Physics School, NCSR Demokritos

ACADEMIC APPOINTMENTS

2018 - present	Associate Professor
2013 - 2018	Tenured Assistant Professor
2009 - 2013	Assistant Professor
2004 - 2009	Lecturer Department of Physics, University of Crete
2003 - 2004	Postdoctoral Research Fellow Lawrence Berkeley National Laboratory
2002 - 2003	Postdoctoral Researcher Department of Physics, Princeton University
1996 - 2001	Research Assistant Department of Physics, Princeton University


German School of Athens


National Technical University of Athens


Princeton University

ACADEMIC VISITS

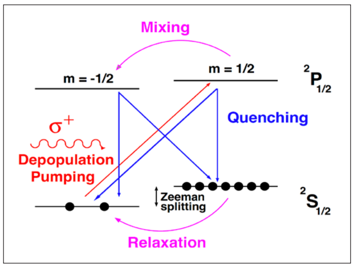
2023	University of Science and Technology of China, Hefei
2023	Institute of Physics, Chinese Academy of Sciences, Beijing
2015	Kastler Brossel Laboratory, Ecole Normale Superieure
2015	Laboratory of Laser Physics, University of Paris 13
2015	Department of Chemistry, University of Konstanz
2015	Institute of Analytical Chemistry, Leipzig University
2014	Kastler Brossel Laboratory, Ecole Normale Superieure
2012	Department of Physics, Princeton University
2008	Department of Physics, University of Fribourg


Lawrence Berkeley National Laboratory

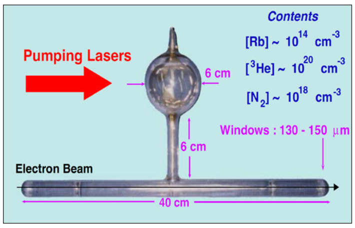

University of Crete

RESEARCH EXPERTISE

Spin-exchange Optical Pumping
Optical pumping of alkali vapors
Spin-exchange optical pumping of noble gases

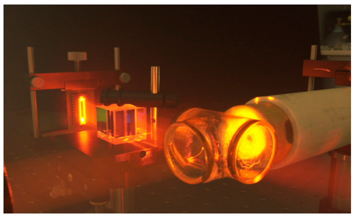


Nucleon Spin Structure
High energy polarized e^- -^{3}He scattering
Spin-exchange optical pumping polarized ^{3}He target

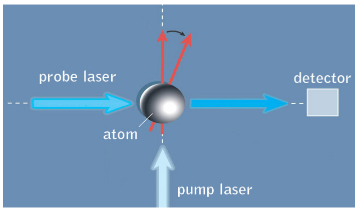


Quantum Metrology
Ultrasensitive atomic magnetometers
Optical magnetometry
Quantum limits to magnetic field detection

Precision Tests of the Electroweak Interaction
Laser cooling and trapping of radioactive atoms

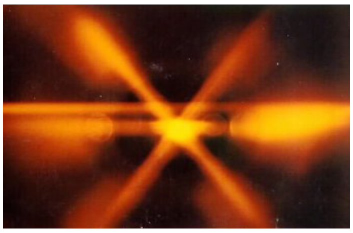


Quantum Noise
Spin noise and spin-squeezing
Spin noise in dual species hot vapors
Spin correlations in hot vapors

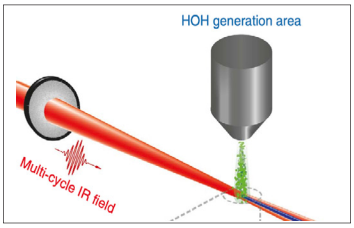


Quantum Optics & Attosecond Science
Coherence & entanglement in high-harmonic generation

Quantum Biology
Spin chemistry & avian compass
Biochemical magnetometers
Quantum measurements in radical-ion-pair reactions
Photosynthesis & light harvesting
Charge and spin transport in photosynthetic reaction centers
Chemically induced dynamic nuclear polarization

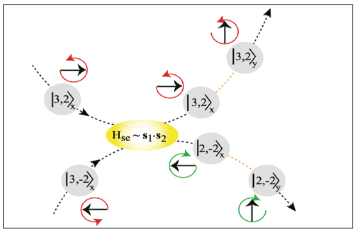


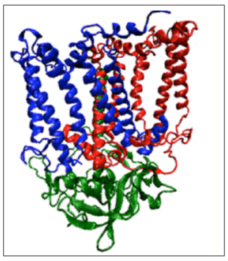
Quantum Vision
Quantum optical probes of human vision
Retina quantum biometrics
Quantum pupillometry

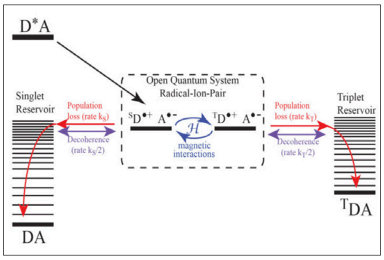


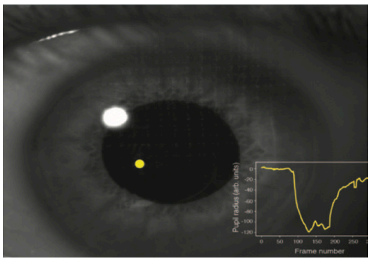
Quantum Magnetometers
Earth's field atomic magnetometers
Magnetometer networks

Applied magnetic measurements
Precision viscometry with magnetometers









$$|d\psi\rangle = -i\,dt\,\mathcal{H}_g|\psi\rangle + \sum_{j=1}^{3}\left(\langle L_j^\dagger\rangle_\psi L_j - \tfrac{1}{2}\langle L_j^\dagger\rangle_\psi\langle L_j\rangle_\psi - \tfrac{1}{2}L_j^\dagger L_j\right)|\psi\rangle dt + \sum_{j=1}^{3}(L_j - \langle L_j\rangle_\psi)|\psi\rangle d\eta_j,$$

$$d\langle S_y\rangle = \omega_L\langle S_x\rangle_0 e^{-t/T_2}dt - \frac{dt}{2T_2}\langle S_y\rangle + \Delta S_y\frac{d\eta}{\sqrt{T_2}}$$

$$d(\Delta S_y)^2 = -\left[(\Delta S_y)^2 - \frac{N}{4}\right]\frac{dt}{T_{nc}},$$

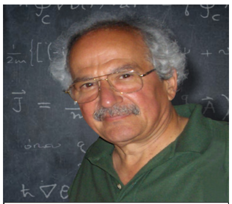
GENERAL SCIENTIFIC EXPERTISE AND RESEARCH STYLE

I do not consider myself an experimentalist nor a theorist, but a highly motivated hybrid, who equally enjoys experimental and theoretical work. My research is strongly based on intuition rather than formality, hence I go for projects that appear to me exciting and scientifically rewarding, whether they are theoretical or experimental. Starting with experimental nuclear and atomic physics, over several years I built an appreciation for seemingly simple experiments, requiring however a demanding theoretical analysis. I then worked on theoretical quantum biophysics, inpired by the wonderful conceptual framework of quantum information applied within the complexity of biology. The topics I work on are quantum science & technology, quantum biology & biophysics, quantum optics & photonics, atomic & laser physics, quantum metrology, quantum sensing & magnetometry, precision measurements, understanding and dealing with measurement noise, data acquisition and statistical analysis, numerical & stochastic simulations. I can design and realize sophisticated experiments involving a number of technologies, and I can define and carry out theoretical projects spanning different fields. I deeply appreciate the scientific opportunities of interdisciplinary research, and have educated myself to be open to and able to communicate with scientists from disciplines like chemistry, biology & life sciences.

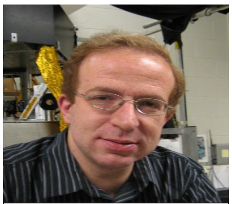
I place particular emphasis on the quality of research output, and on seeing the projects I take on through completion, delivering tangible results clearly articulating the advance beyond the state-of-the-art. Over the years I developed the ability to navigate away from potentially detrimental bottlenecks and lead my projects to completion and delivery.

MENTORS

My academic career is largely due to the fortunate circumstance of coming across and interacting with amazing mentors during my formative years. Starting from my undergraduate years, the late Prof. Sofronios Papadopoulos instilled to me through his lectures and innumerable discussions the very first passion for physics, the adherence to academic integrity, and the outlook for graduate studies in the US. While at Princeton, as a graduate student and later as a postdoc, I was trained as a professional physicist by three prominent scholars, Prof. Gordon Cates, Prof. Will Happer, and Prof. Mike Romalis. It is from them that I learned, to the best of my abilities, to think as a physicist, to appreciate the importance of detail and hard work, to understand, seek and adhere to scientific quality, and to conduct myself with the highest standards of academic integrity.


Prof. Sofronios Papadopoulos


Prof. Gordon Cates


Prof. Mike Romalis


Prof. Will Happer

BRIEF DESCRIPTION OF RESEARCH BEFORE JOINING UNIVERSITY OF CRETE

PhD Research at Princeton

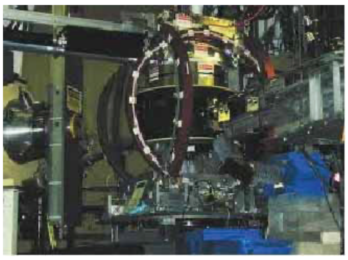
Under the supervision of Prof. Cates I developed a new polarized 3He target facility used at the TJNAF accelerator for the first low-energy polarized-electron polarized 3He scattering experiments, which tested of QCD sum rules at the transition regime between the hadronic and the quark degrees of freedom. As a direct result of my efforts, a broad 3He program was launched at TJNAF, with several fixed-target scattering experiments successfully completed.

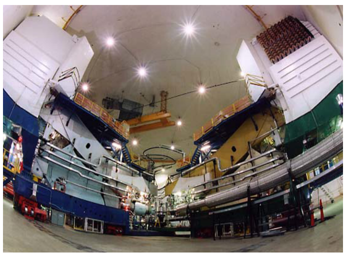
Postdoctoral Research at Princeton

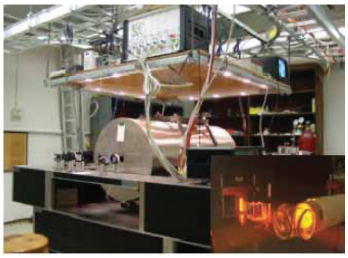
Under the guidance of Prof. Romalis I developed a new atomic magnetometer that set a record sensitivity in detecting feeble magnetic fields. Its performance has surpassed SQUID magnetometers which dominated sensitive magnetometry for the last 30 years. As stated by Prof. Dmitry Budker (Nature 422, 574, 2003), "The work of Kominis et al. continues a productive tradition in atomic physics of synergy between fundamental and applied science".

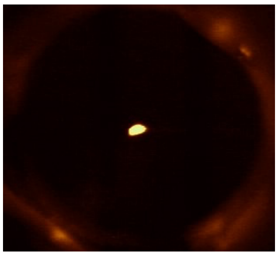
Postdoctoral Research at Berkeley

Under the guidance of Prof. Freedman and Dr. Vetter I worked on laser cooling and trapping of radioactive atoms in order to perform sensitive tests of the Standard Model of weak interactions. In parallel I also worked on a project to laser cool ions in a superconducting Penning trap.







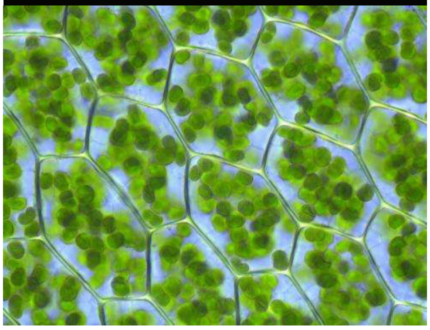


BRIEF DESCRIPTION OF RESEARCH AFTER JOINING UNIVERSITY OF CRETE

QUANTUM BIOLOGY

QUANTUM FOUNDATIONS OF THE RADICAL-PAIR MECHANISM

QUANTUM SPIN DYNAMICS IN PHOTOSYNTHESIS

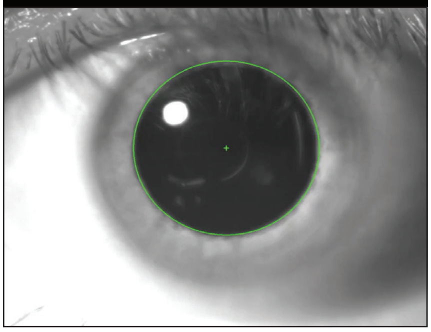


QUANTUM SENSING

SPIN NOISE SPECTROSCOPY WITH HOT ATOMIC VAPORS

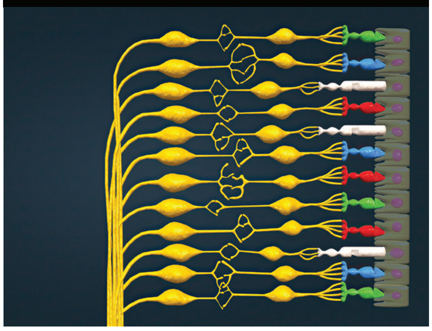
QUANTUM VISION

QUANTUM PUPILLOMETRY



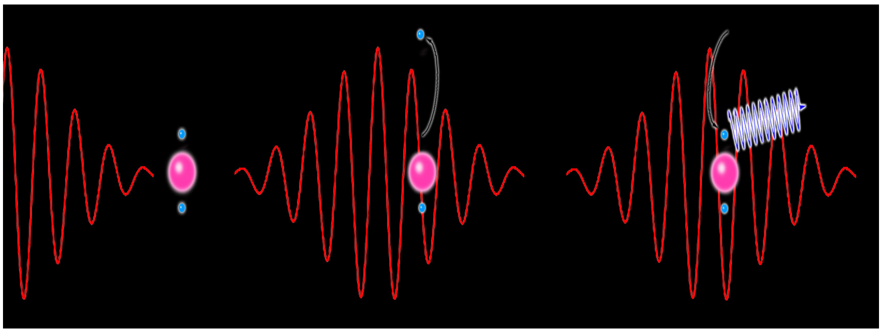
QUANTUM BIOMETRICS

PROBING VISION WITH QUANTUM LIGHT



MAGNETIC VISCOMETRY

QUANTUM OPTICS IN ATTOSECOND SCIENCE



My research after joining the University of Crete in 2004 started with quantum sensing experiments with hot atomic vapors. In 2008 my research shifted to quantum biology, in which I have made pioneering contributions. I unwaveringly believe in the long-term scientific promise of quantum biology, the new synthesis of quantum science with the phenomenological richness and complexity of biological systems, therefore quantum biology is a major focus of my research.

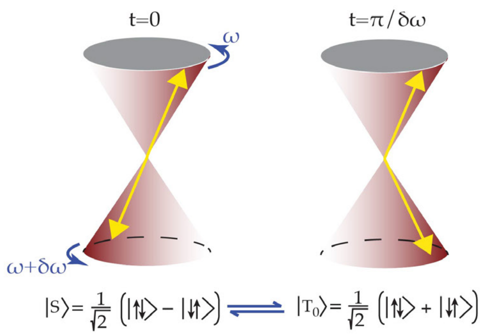
More recently I ventured into quantum vision, another promising synthesis of quantum optics with the physiology of human vision. At the same time I continue research on quantum metrology of atomic spin magnetometers and spin noise. Thus, three directions of research have crystalized over the years, quantum biology, quantum sensing, and quantum vision. They cross-fertilize and inspire each other, providing the group members with an appreciation for important unifying aspects of science.

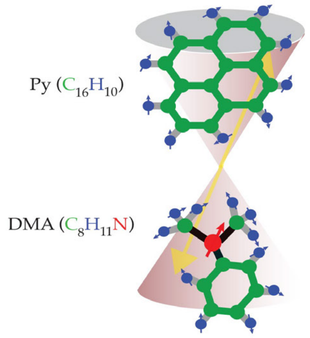
Between 2014 and 2017 I also contributed to the first papers pioneering the synthesis of quantum optics with attosecond science. Most recently I started an applied physics direction on precision viscometry using magnetic measurements. In the next pages I provide a general introduction to my research, to be followed later with more detailed description.

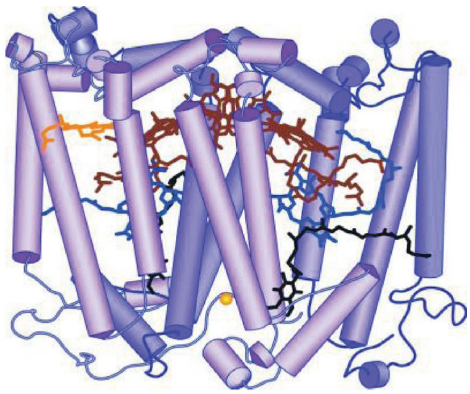
Pioneering work on Quantum Biology

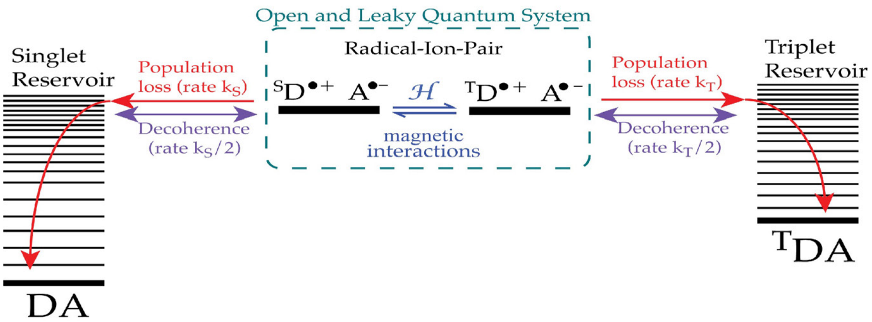
Since 2008 I have been working on quantum biology, a new synthesis of quantum science with biological systems. With few colleagues worldwide, I pioneered this field, demonstrating for the first time that there are certain biological systems exhibiting quantum coherent effects ordinarily associated with carefully controlled quantum systems pertaining to man-made quantum technology.

In particular, my work has focused on spin chemistry, the radical-pair mechanism and the associated avian compass mechanism. Spin chemistry studies the effects of nuclear and electronic spin on chemical reactions. Radical-pair reactions are the central biophysical system of spin chemistry.









Although spin chemistry is a field dating to the 1960's and radical-pair reactions have been studied since then, their quantum-physical underpinnings were *first* unraveled by my group in 2008. This is evidenced by the timeline of publications on the APS server and arXiv. Several quantum optics groups joined this effort after we first unraveled that radical-pair reactions should be described within the formalism of open quantum systems, *thus rendering the radical-pair mechanism the first biological system where the tools of quantum optics, quantum metrology and quantum information can be fruitfully applied.* The premise of quantum biology was thus clearly established.

Along this work, my group has shown that the foundational theory of Spin Chemistry, namely Haberkorn's theory, based on which all experimental observables are described, is only a sketchy description failing to account for the fundamental quantum dynamics of radical-pair reactions. We developed a new theory, using concepts of quantum measurements, quantum coherence quantifiers, the quantum Zeno effect, measurement-induced decoherence and other tools of modern quantum science, and showed that radical-pairs are both an open and a leaky quantum system, requiring a subtle theoretical description. In the limit of large spin relaxation we recover Haberkorn's theory, showing that it is indeed a phenomenological theory valid only in a certain regime, that of strong relaxation.

It has also become evident that the detailed and quantitative understanding of experiments with radical-pair reactions, some of which involve measurements with Chemically Induced Dynamic Nuclear Polarization, is impossible within the context of Haberkorn's theory used since the beginning of the field of Spin Chemistry in the 1960's. Such systems are characterized by relatively low spin relaxation, and thus require a more subtle quantum description.

More recently, using fundamental concepts of quantum information, like the Wigner-Yanase information, I introduced methods whereby the search for quantum coherent effects can be extended to cellular environments. For the first time, biologists are provided with specific measurement protocols of physiological observables able to unravel the quantum coherence of the underlying processes.

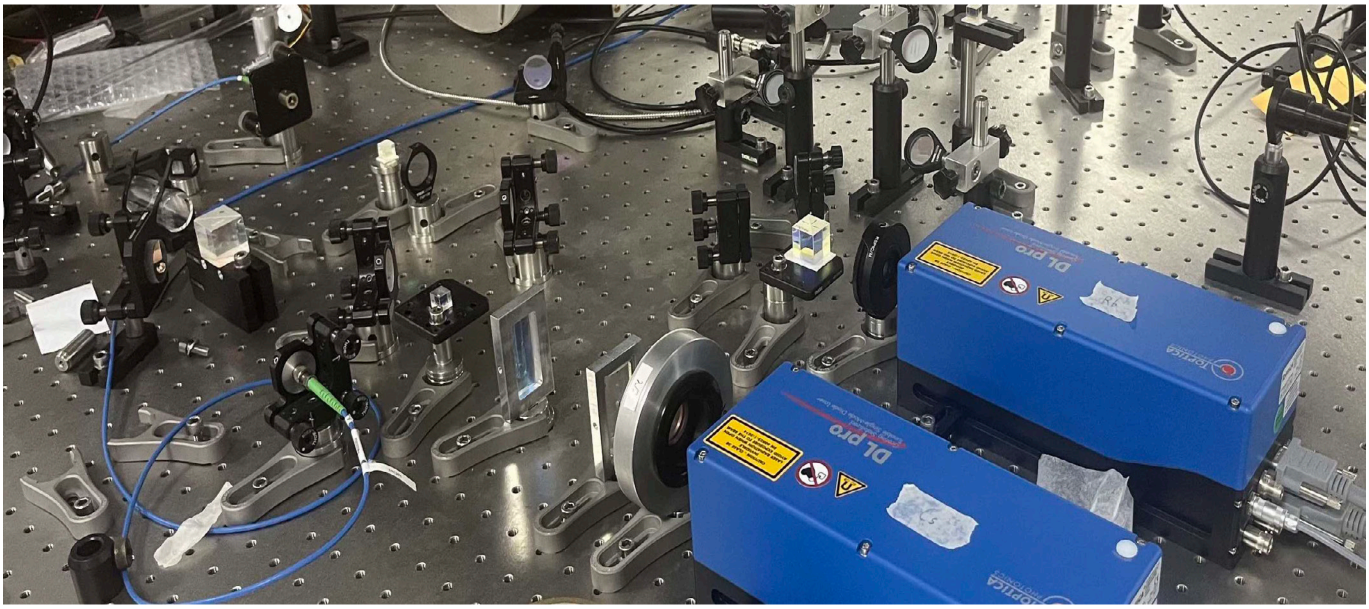
Quantum Sensing with Hot Atomic Vapors

The exquisite control of the atomic degrees of freedom by laser light has allowed a number of quantum technologies. One of the most prominent is quantum sensing. Hot atomic vapors have in recent decades become a paradigm system for quantum sensing, in particular the detection of very weak magnetic fields by hot vapor atomic magnetometers. Sensitive magnetometry has already found applications in medical imaging (magnetoencephalograhy) and low-field NMR and MRI.

The fundamental quantum limits of atomic magnetometers are critically dependent on spin noise, a manifestation of Heisenberg's uncertainty relation when measuring the spin of the atoms. After my involvement with atomic magnetometers in the group of Prof. Mike Romalis, my group focused on understanding the physics of spin noise in hot vapors. Related to spin noise is spin squeezing, the possibility to beat the standard quantum noise limits and increase the sensitivity of the magtnetometer, in particular boost its scaling with atom number.

In our lab we have studied spin noise in hot vapors experimentally and theoretically, addressing unappreciated details of the physics of spin noise generation. We have discussed the quantum nature of spin noise, and in recent years we increased the complexity of such measurements by introducing two interacting atomic species, studying the effect of spin-noise exchange. These studies led to unraveling of spin correlations that spontaneously build up by binary spin-exchange collisions. We have found that unperturbed vapors might not be uncorrelated as previously assumed. These studies also open interesting possibilities for using correlations in spin-polarized vapors in order to suppress noise and enhance performance.

In general, our work led to a deeper understanding of the rich physics of spin dynamics driven by spin-exchange collisions, which will further advance the quantum-technology applications of such systems.

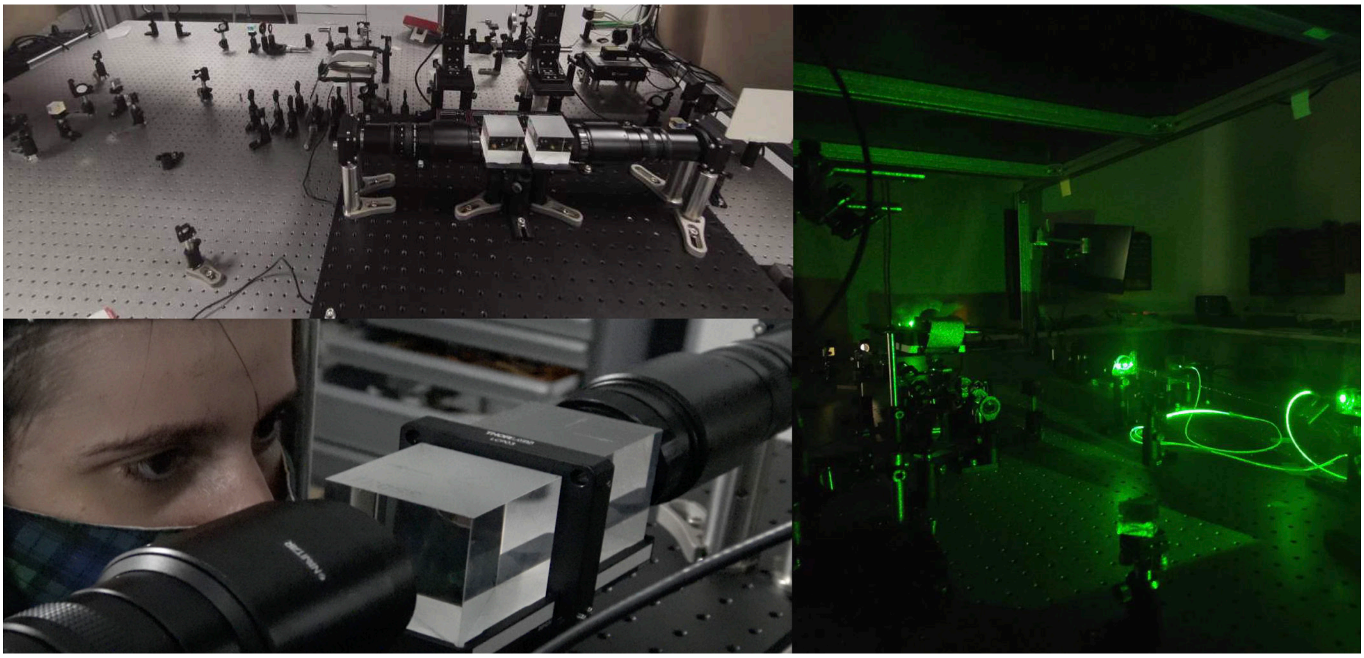


Quantum Vision

Quantum vision is a relatively recent research program aiming at synthesizing quantum optics with the physiology of human vision. We started this program in 2017, when we proposed a new methodology to authenticate human subjects based on the way they perceive very weak light. This methodology was termed quantum biometrics, as it takes advantage of the human visual system's ability to perform photon counting.

To realize the new biometric methodology, we developed a novel laser light source, which can stimulate the retina with spatial selectivity and with precisely known photon number, limited by photon statistics. Having this source, we realized that we can perform a novel measurement of the pupil light reflex, which is about changes of the pupil's diameter upon illumination.

While commercial pupillometers illuminate the whole retina with broad LED light, our apparatus can illuminate specified spots on the retina, and thus we can record several pupil reflex responses instead of just one provided by standard pupillometers.



The goal of our pupillometry work is to devise new ways to perform early diagnosis of diseases of the visual and nervous system. Indeed, any disease affecting the neural pathway of the pupil reflex, which starts from the cornea, reaches the retina, and then the mid brain, and back to the iris muscles, will have a signature on the measured pupil diameter changes.

Quantum Optics in Attosecond Science

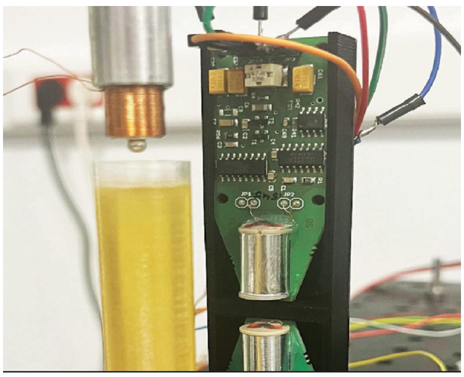
This work was led by my attosecond-science colleague Dr. Tzallas, who studies light-matter interactions at the femtosecond/attosecond time scale. These studies involve high-power ultrafast laser pulses inducing nonlinear phenomena in their interaction with matter. Quantum optics and strong-field physics haven been largely decoupled over the past decades, the former dealing mostly with non-classical few-photon states, while the latter with states having large photon numbers and resembling classical fields.

The new insight of our "attosecond" colleagues was that the interaction of the infrared light with matter leading to nonlinear processes, like high-harmonic generation, must somehow leave its footprint on the state of the infrared light. Until now, the treatment of high-harmonic generation was semi-classical, i.e. matter was treated quantum mechanically but light was taken to be a classical electromagnetic field, suffering no backaction from the light-matter matter interaction. In quantum optics the opposite is the case, since all partners of an interaction are affected and leave their footprint on one another.

By quantizing the infrared light field and including it in a quantum optical description of the process, we have shown that information on the high-harmonic generation is indeed imprinted in the quantum state of the infrared light. Experimentally, the high-harmonic spectrum was measured through the photon number distribution of the infrared light. This work will pave the way for new non-classical light sources working in the strong-field ultrafast regime, and novel XUV spectroscopy.

Magnetic Viscometry

Recently we embarked in an applied physics direction, namely we took advantage of our know-how with magnetic measurements and developed a new viscometer. We were inspired by the falling-sphere viscometer, which exists commercially, and is also one of the experiments taught in our undergraduate mechanics lab. We replaced the metal sphere falling through the fluid with a magnetic sphere, and next to the fluid we placed two fluxgate magnetometers. They measure the magnetic field generated by the falling sphere. By fitting theory to data, we can extract viscosity using a very small fluid volume around 10 mL, and with a very cheap apparatus with cost around 200 euros.



POSTDOC MENTORING

Dr. Ioanna Demeridou (PhD in Physics, 2021)

PHD STUDENT SUPERVISION

Kostas Mouloudakis, PhD in Physics, 2021
Spin noise correlations in multispecies hot atomic vapors

Nikos Tsatrafyllis (co-supervised with P. Tzallas), PhD in Physics, 2018
Quantum optical description of high-harmonic generation: quantum spectrometer in the XUV spectral range

Kyriacos Vitalis, PhD in Physics, 2017
Quantum metrology in biochemical magnetometers

Argyris Dellis, PhD in Physics, 2013
Quantum measurements of spin in alkali atoms and biomolecules

Giorgos Katsoprinakis, PhD in Physics, 2010
Spin noise, decoherence and magnetic effects in alkali atoms and biomolecules

MASTERS STUDENT SUPERVISION

Grigoris Magkos, Masters in Physics, 2018
Biometrics through retina detection of non-classical light

Manolis Petrakakis, Masters in Physics, 2017
Study of quantum coherence in multi-nuclear-spin radical-pairs by use of a parallel supercomputer

Kostas Mouloudakis, Masters in Physics 2016.
Entropy and quantum information in the biochemical reactions of the magnetic compass

Kostas Tsampourakis, Masters in Physics 2016
Quantum trajectories in photosynthetic radical-pair reactions

Michalis Kritsotakis, Masters in Physics 2014
Quantum trajectories and master equation of radical-pair reactions

Hrysanthi Sygelaki, Masters in Physics, 2011
Towards a new navigation cue of the avian magnetic compass

Argyris Dellis, Masters in Physics, 2008
Construction of a cesium magneti-optical trap and non-destructive temperature measurement using spin-polarization fluctuations

Giorgos Katsoprinakis, Masters in Physics, 2006
A proposal for a new high-bandwidth, EIT-enhanced pump-probe atomic magnetometer

UNDERGRADUATE STUDENT SUPERVISION

Christoforos Thalassinakis
Measurement of the parameters of the feedback control system for the pupillary reflex
Foivos Vouzinas
Spin noise correlations in hot atomic vapors
Zacharias Tzitzikas
Upgrade of experimental setup for pupillometry and biometrics
Apostolos Banoutsos
Review of quantum random number generators
Giorgos Stylianou
Nonlinear crystals for generating single photons
Antonis Margaritakis
Laser light source for biometrics and pupillometry
Danai Pantazopoulou
Electrophysiological recordings of single rod cell photoresponse
Dimitris Dolapsakis
Electrophysiological recordings of single rod cell photoresponse
Giouli Anyfantaki
Measurement of photon statistics with active control of laser intensity
Giorgos Garidis
Isolation of rod cells towards measuring the rod photoresponse magnetic sensitivity
Dimitris Giarikanis
Spin noise correlations in multispecies hot atomic vapors
Petros Ximerakis
Development of phosphor materials for construction applications
Kostas Mouloudakis
Pulsed photoexcitation may reveal the magnetoreception mechanism of the avian compass
Theodoros Ilias
Nuclear spin entanglement in the radical-pair mechanism
Christos Lymperopoulos
Computational tools for analyzing the response of neurons
Vassiliki Bolpasi
High precision laser wavelength measurement
Michalis Polis
Quantum random number generator based on alkali vapor spin noise
Giorgos Zouraris
Saturated absortpion spectroscopy
Giorgos Rizos
Review of operating principles of photovoltaic cells

POSITION OF FORMER GROUP MEMBERS AFTER LEAVING GROUP

Name	While in group	After leaving group
Demeridou	Postdoc	Research Assistant, FORTH
Mouloudakis	PhD	Postdoc, group of Prof. Mitchell at ICFO
Vitalis	PhD	Postdoc, group of Prof. Nicolaides at University of Cyprus
Dellis	PhD	Postdoc, group of Dr. Kitching at NIST
Katsoprinakis	PhD	Postdoc, group of Prof. Rakitzis at UoC & FORTH-IESL
Gratsea	Postgraduate	PhD, group of Prof. Lewenstein at ICFO
Petrakakis	MS	PhD, group of Dr. Stratakis at FORTH-IESL
Kritsotakis	MS	PhD, group of Prof. Dunningham at the University of Sussex
Tsampourakis	MS	PhD, Washington State University
Thalassinakis	Undergraduate	Research Scientist at Quantum Biometronics
Vouzinas	Undergraduate	Quantum Engineering Masters program, ETH
Tzitzikas	Undergraduate	Engineering Physics Masters, Royal Institute of Technology Stockholm
Stylianou	Undergraduate	Applied Physics Masters, Technical University of Delft
Pantazopoulou	Undergraduate	Brain & Mind Masters, University of Crete Medical School
Dolapsakis	Undergraduate	Photonics & Nanoelectronics Masters, UoC Physics Department
Margaritakis	Undergraduate	PhD, University of Southern California
Anyfantaki	Undergraduate	Physics Masters, University of Copenhagen
Garidis	Undergraduate	Computational Physics Masters, University of Copenhagen
Giarikanis	Undergraduate	Electronic Physics Masters, Aristotle University of Thessaloniki
Ilias	Undergraduate	PhD, group of Prof. Plenio at Ulm University
Tavernarakis	Undergraduate	PhD, group of Prof. Heidmann at Ecole Normale Superieure
Bolpasi	Undergraduate	Photonics & Nanoelectronics Masters program, UoC Physics Department

TEACHING

General Physics I
One- and two-dimensional motion, Newton's laws, energy and work, momentum, collisions, rotational motion, angular momentum, gravitation, oscillations and waves, resonance, thermodynamics.

Mechanics Laboratory
Linear motion, physical pendulum, free fall, harmonic oscillation, thermodynamics.

General Physics II
Electric field and potential, Gauss law, conductors, capacitors, current, resistance, Kirchoff's law, circuits, magnetic field, charge motion in magnetic field, laws of Biot-Savart, Faraday and Ampere, geometric optics, laws of Snell, Young's experiment.

Advanced Physics Laboratory
Vacuum technology, ferromagnetic hysterisis, Hall effect, Franck-Hertz experiment, photoelectric effect, Zeeman effect, molecular spectroscopy, radiation detectors.

Optics Laboratory
Geometric optics, index of refraction, cavities, polarization, gratings, diffraction, optical activity, microwaves, optical spectroscopy.

Advanced Electromagnetism
Electromagnetic wave propagation in vacuum, dispersion, reflection refraction and dissipation, dipole radiation, antennas, radar systems, waveguides, cavities, introduction to accelerators, scattering, classical theory of coherence.

Physics for Biologists taught to 1st year students of the Department of Biology

Linear motion, momentum and energy conservation, energy and power, drag forces, terminal velocity, hydrostatics, fluid dynamics, electrostatic forces, water and hydrogen bonding, surface tension, electric circuits, electric and magnetic fields, current and voltage, electromagnetic waves, photons, first and second law of thermodynamics, heat capacity, energy and entropy.

Graduate Quantum Mechanics

Pure and mixed states, separable and entangled states, entanglement measures, time evolution, quantum coherence and quantum beats, transitions between discrete levels, discrete level coupled to continuum, Fermi's golden rule, transitions induced by random perturbations, selection rules in atomic transitions, optical Bloch equations, optical pumping and double resonance, irreducible spherical tensor operators, hyperfine interactions, decoherence, Lindblad formalism.

Modern Physics Undergraduate Seminars

Lecture first-year undergraduate students on modern quantum science and technology

Introduction of Two New Courses in the Physics Curriculum

1. In the fall semester of 2017 I introduced the course Molecular Biophysics, the first such course in the Department of Physics of the University of Crete. The goal of the course is to provide students with a first outlook of the vast field of biophysics, and show them how the basic physics they learn in other courses can be used to explain the complex biological phenomena at the biomolecular scale. The course was very warmly welcomed by students, with about 80 students enrolling in each semester the course is taught. The syllabus includes an introduction to the complexity of biological systems (multitude of spatial and temporal scales, nonlinear processes, feedback processes, open and evolving systems etc), a chapter on feedback control and examples of its application in biological regulation, a chapter on biomolecular interactions and biomolecular structure (covalent bonding, hydrogen bonding, van der Waals forces, DNA and protein structure), a chapter on biological thermodynamics (entropy and its manifestation in biological processes, protein folding etc), a chapter on experimental methods (mostlyNMR and X-ray diffraction), and a chapter on neurobiology (up to the introduction of Hodgkin-Huxley theory).

2. In the fall semester of 2022 I introduced the course Introduction to Quantum Computers, the first such course in the Department of Physics of the University of Crete. The goal of the course is to introduce the students to the rapidly growing field of modern quantum technology, providing them with a systematic conceptual introduction to a language required to understand modern developments. The syllabus includes quantum states of a single qubit, Bloch sphere and quantum coherence, quantum states of two or more qubits, entanglement, quantum measurements and decoherence, classical and quantum information, quantum gates, basic principles of quantum computers, quantum algorithms, physical realization of quantum computers, quantum cryptography and communications, quantum sensing, quantum artificial intelligence.

TEACHING AND MENTORING STYLE

For the members of my group I strive to adapt projects to their interests and special skills, and give them the freedom to grow, mature and eventually become independent. In my class teaching I place particular emphasis on conveying the basic ideas of physics, and connect them with the evolution of physics, the connection of physics with other sciences, the technology and even the martket place. Even in undergraduate teaching I attempt to make connections with research, and quickly veer off the attitude of solving problems defined by others, pushing instead the attitude of asking the right questions and then designing the optimal way to find the answers.

With students I am absolutely open to all sorts of questions without ever being judgmental, therefore students feel free to consult me not only about their studies but also their career options within or outside academia. I try to instill to students the joy of doing science, but also the dedication and hard work required to do so competitively and professionally. I stress that physics education is not only about doing science, but also about being trained to think in ways that are useful in many different career paths. There are in fact numerous examples where I helped students define such a career path either within or outside science, based on how they outline their interests and how I gauge their skills and potential. In too many cases I am happy to learn several years later that those students (not only my group members) indeed formed a successful career either at home or abroad.

RESEARCH PRESENTATIONS

Dec	2023	Center for New Technologies, Warsaw
Dec	2023	Workshop on Continuously Monitored Quantum Systems, Warsaw
Nov	2023	School of Physics, Westlake University, Hangzhou
Nov	2023	Department of Physics, Hangzhou Dianzi University, Hangzhou
Nov	2023	International Magnetobiology Frontier Research Center, Hefei
Nov	2023	Department of Precision Machinery and Precision Instrumentation, USTC, Hefei
Nov	2023	Department of Physics, Huazhong University of Science and Technology, Wuhan
Nov	2023	School of Chemistry, Peking University, Beijing
Nov	2023	Beijing Computational Science Research Center
Nov	2023	Institute of Mathematics, Chinese Academy of Science, Beijing
Nov	2023	School of Physics, Beijing Normal University
Oct	2023	School of Physics, Peking University, Beijing
Oct	2023	Institute of Physics, Chinese Academy of Science, Beijing
Oct	2023	Department of Physics, Khalifa University, Abu Dhabi
Oct	2023	Quantum Center, Technology Innovation Institute, Abu Dhabi
Sep	2023	Quantum2023 Workshop, Torino
June	2023	Austrian Academy of Sciences, Institute of Quantum Optics and Quantum Information, Vienna
June	2023	Department of Physics, Czech Technical University in Prague
June	2023	2nd International Forum on Neural Engineering and Brain Technologies, Berlin
Dec	2022	Quantum Days, University of Crete, Heraklion
Nov	2022	Stereodynamics 2022, Rethymno
Oct	2022	Surrey Quantum Biology Doctoral Training Center Seminars, online
June	2022	Workshop on Quantum Effects in Biological Systems, Heraklion
Apr	2022	FORTH Quantum Technologies Workshop, Heraklion
Sep	2021	UCLA Quantum Biology Square Table, online
Nov	2020	Seminar at the Institute of Electronic Structure and Laser, FORTH, online
May	2020	Quantum Optics and Information Meeting 4, Izmir Institute of Technology, online
Oct	2019	28th Meeting of the Hellenic Society for Neuroscience, FORTH, Heraklion
Aug	2019	Heraeus Workshop on Quantum Sensing and Magnetometry, Bad Honnef
June	2019	Autoimmune Research Group Meeting, Heraklion
Nov	2018	Workshop on Quantum Biology and Quantum Processes in Biology, NSF, Virginia
Nov	2018	Institute of Physics 3, University of Stuttgart
Nov	2018	Department of Physics, Koc University, Istanbul
Oct	2018	Department of Chemistry, University of Crete, Heraklion
June	2018	Greek Quantum Technologies Meeting, FORTH, Heraklion
May	2018	Workshop on Hot Atomic Vapors, University of Stuttgart
May	2017	Department of Physics, University of Crete, Heraklion
May	2017	Workshop on New Trends in Complex Quantum System Dynamics, Cartagena
Mar	2017	German Physical Society Meeting, Mainz
Mar	2017	Workshop on Quantum Effects in Biological Systems, Jerusalem
Nov	2016	International Quantum Science Symposium, University of Cambridge
Nov	2016	Exploratory workshop on EU flagship program on quantum technologies, Berlin
Oct	2016	ICFO, Barcelona
May	2016	5th International Conference on Mathematical Modeling in Physical Sciences, Athens
Apr	2016	Department of Materials Science & Technology, University of Crete
Sep	2015	Laboratory Kastler Brossel, Ecole Normale Superieure, Paris
Sep	2015	Laboratory of Chemical Physics, University Paris Sud
Sep	2015	Laboratory of Laser Physics, University Paris 13

Jul	2015	Workshop on Quantum Effects in Biological Systems, Florence
Jun	2015	Department of Physics, University of Konstanz
Jun	2015	Department of Analytical Chemistry, Leipzig University
Jan	2015	ESF Forward Look Meeting on Quantum Biology, Brussels
Jan	2015	45th Winter Colloquium on the Physics of Quantum Electronics, Snowbird Utah
May	2014	Laboratory Kastler Brossel, Ecole Normale Superieure, Paris
Apr	2014	Laboratory of Laser Physics, University Paris 13
Mar	2014	APS March Meeting, Denver
Nov	2012	International Quantum Science Symposium, University of Cambridge
Oct	2012	Department of Physics, University of Crete
Sep	2012	Workshop on Quantum Biology, University of Surrey
Jun	2012	National Institute of Standards and Technology, Boulder
Jun	2012	Workshop on Quantum Effects in Biological Systems, Berkeley
May	2012	Department of Physics, Stevens Institute of Technology, New York
Apr	2012	Beckman Institute, University of Illinois at Urbana-Champaign
Mar	2012	Department of Physics, University of Massachusetts Boston
Mar	2012	Department of Physics, Stevens Institute of Technology, New York
Feb	2012	Department of Chemistry, Columbia University, New York
Feb	2012	Department of Physics, Princeton University
May	2011	Spin Chemistry Meeting, Noordwijk
Mar	2011	APS March Meeting, Dallas
Mar	2010	Workshop on Quantum Measurement and Chemical Spin Dynamics, Leiden
Oct	2009	Department of Physics, University of Crete, Heraklion
Aug	2009	Spin Chemistry Meeting, St. Catharines Ontario
Jul	2009	International Conference on Quantum Foundation and Technology, Shanghai
Jul	2009	Workshop on Quantum Effects in Biological Systems, Lisbon
Jun	2009	Max Planck Institute for Quantum Optics, Garching
Jun	2009	Vienna Symposium on the Foundations of Modern Physics
Oct	2008	Department of Chemistry, University of Fribourg
Oct	2008	Department of Physics, University of Fribourg
Apr	2008	Department of Physics, University of Crete, Heraklion
Jun	2007	Institute of Physics, Jagiellonian University
May	2007	Research Center for Astronomy and Applied Mathematics, Academy of Athens
May	2007	ECAMP 9, Heraklion
Apr	2007	Cold Matter Group Seminar, Imperial College, London
Nov	2003	Institute Laue-Langevin, Grenoble
May	2003	DAMOP Conference, Boulder
Oct	2002	Department of Physics, University of Crete, Heraklion
Jul	2002	International Conference on Atomic Physics, Boston
Jun	2000	GDH-Workshop, Mainz
May	1998	DAMOP Conference, Santa Fe

PROFESSIONAL SERVICE

- Reviewer for funding agencies

European Research Council · MacArthur Foundation · DFG Deutsche Forschungsgemeinschaft · European Science Foundation · anr agence nationale de la recherche · FNSNF Fonds national suisse de la recherche scientifique

- Reviewer for journals

APS physics: PHYSICAL REVIEW A · PHYSICAL REVIEW E · PHYSICAL REVIEW RESEARCH · PHYSICAL REVIEW LETTERS · PHYSICAL REVIEW APPLIED · PRX QUANTUM

AIP American Institute of Physics: APPLIED PHYSICS LETTERS · JOURNAL OF APPLIED PHYSICS

nature portfolio: nature communications · nature materials · scientific reports

AAAS: Science Advances

BioSystems · IEEE Sensors Council · The Science of Nature Naturwissenschaften · entropy

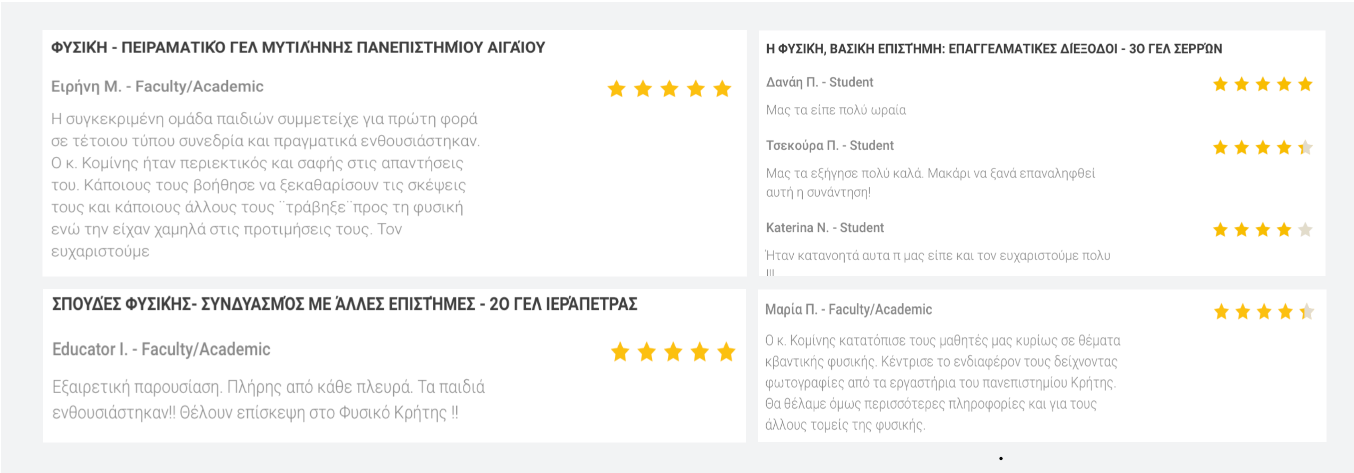
IOP Publishing: New Journal of Physics — The open access journal at the forefront of physics

- Reviewer for book publishers — Routledge Taylor & Francis Group

- Invited Chairman in the PhD Examination Committee of Vito G. Lucivero at ICFO, Barcelona, October 2016
- Institute of Physics Trusted Reviewer

UNIVERSITY OF CRETE PHYSICS DEPARTMENT SERVICE

- Member of Scientific Committee, 2nd Crete Physics Conference, https://sfkritis2023.wordpress.com
- 1st Quantum Technology Summer School, Department of Physics, University of Crete, September 2022 https://www.physics.uoc.gr/sites/files/physics/QuantumSummerSchool_2022.pdf
- Physics Department presentation to visiting high school students
- Organization of AMO Seminars 2017-2021, 30 talks
- Organization of Physics Collaboration Exploratory Visit at the University of Crete by Representatives of the National Tsing Hua University in Taiwan, October 2019
- Participation in the 100Mentors platform, 7 completed sessions, 75 participants
- Organization of Physics Department Colloquium, 2012-2015, 80 talks



CONFERENCE ORGANIZATION

- 12th Workshop on "Quantum Effects in Biological Systems", Heraklion, June 2022, www.quebs.gr
- Science Day, School of Natural Sciences, University of Crete, December 2021
- Workshop on "Quantum phononics: from transport and optomechanics to quantum biology", Heraklion, May 2015
- European Conference on Atoms Molecules & Photons IX (ECAMP 9), Heraklion, May 2007

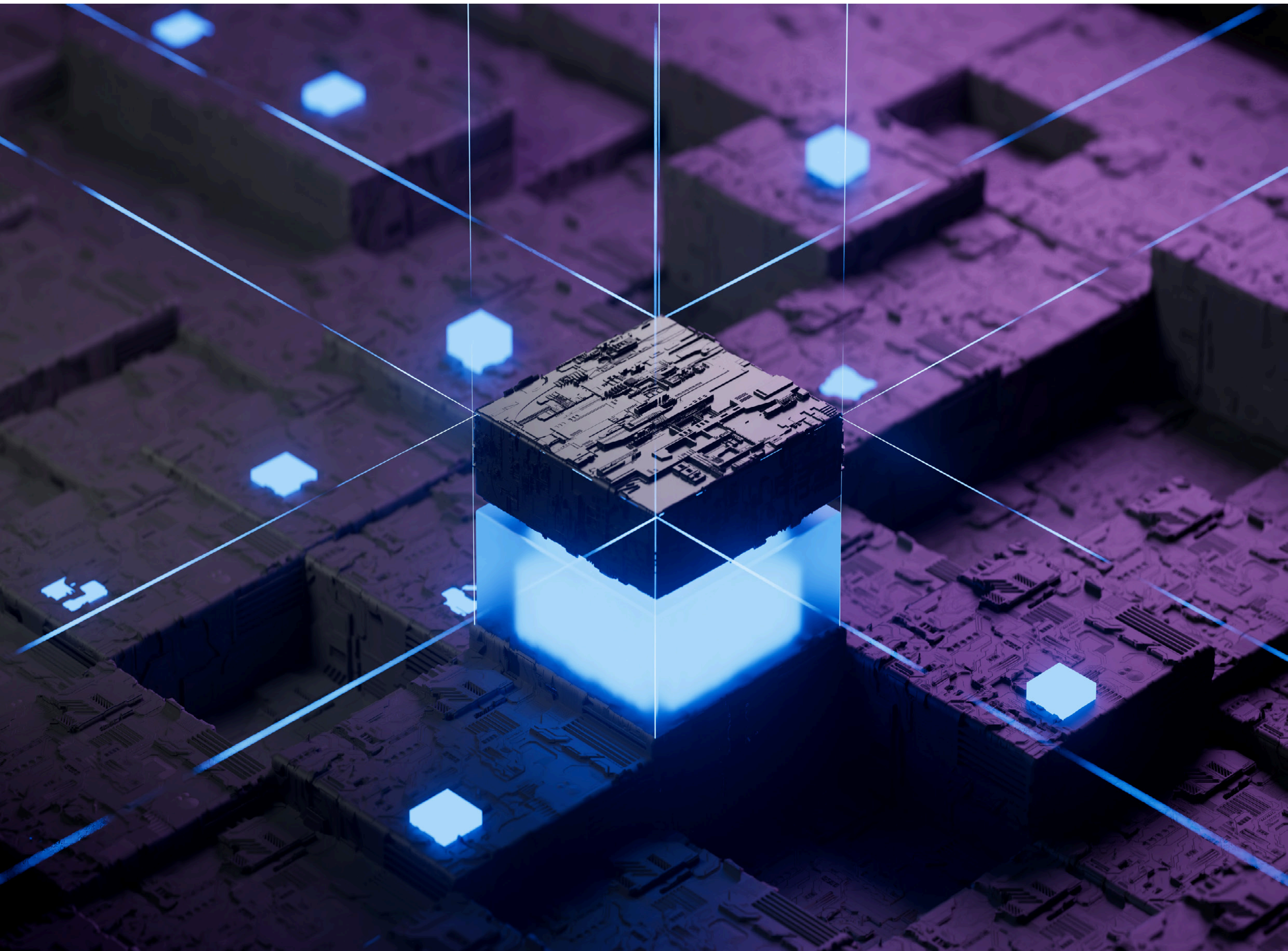
RESEARCH FUNDING

- Marie Curie International Reintegration Grant, €80k, 2004.
- FORTH-IESL Special Actions, €150k, 2005-2007.
- Heraklitos program of the Greek Secretariat for Research and Technology, €45k, 2010-2012
- John Latsis Public Foundation Award 2010, €12k.
- Thales Program of the Greek Secretariat for Research and Technology, €40k, 2012-2014
- Regional Potential-Departmental EU Funding, €170k, 2013-2016.
- Small Research Programs of the University of Crete, €6k, 2014-2018.
- University of Crete public investment funds, €42k, 2018.
- Research-Create-Innovate program, €230k, 2018-2020.
- Region of Crete RIS3Crete program, €450k, 2020-2023.

Laboratory for Quantum Physics and Quantum Biology

DETAILED RESEARCH DESCRIPTION

Citations in the following description refer to publications found in pages 26-29



What is Quantum Biology ?

Quantum biology is a new and genuinely interdisciplinary field synthesizing modern quantum science and technology with physical chemistry, biochemistry and biology, with the goal to study the fundamental nature of various biological systems and processes at the quantum level. Quantum biology is not about the quantum mechanical analysis of biomolecular structure, which is a mature and always relevant field. In contrast, quantum biology is about studying whether the most counter-intuitive quantum mechanical effects related to quantum coherence and entanglement underlie any biological processes.

The intriguing aspect of this question is that only during the last two decades did physicists manage to experimentally demonstrate such effects, with the goal to develop a number of quantum technologies, like quantum computers, quantum sensors etc. The central difficulty in this quest is the environment interacting with the very fragile quantum systems, and unavoidably destroying quantum coherent effects, rendering the dynamical phenomena "classical", that is, forcing them to abolish their underlying quantum character. This is why modern quantum technology requires exquisite experimental control of the quantum systems, in order to optimally decouple them from their decohering environment.

This paradigm naturally led to the question whether Nature herself has managed to develop quantum technology during her 4-billion-year-long "research-and-development" program. In other words, did Nature find ways to establish an operational advantage relying on genuinely quantum dynamics? The intuitive answer to this question was negative, exactly because the biological environment is "warm, wet and messy", nothing like a well-controlled apparatus used in modern quantum science experiments.

Yet it now appears that Nature has found ways to use quantum effects to her benefit in several biological processes. This is exactly the premise of quantum biology. In particular, it is now known that there are biological processes, like the ones we address in our work, where quantum coherence survives long enough to become pertinent to the workings of these processes.

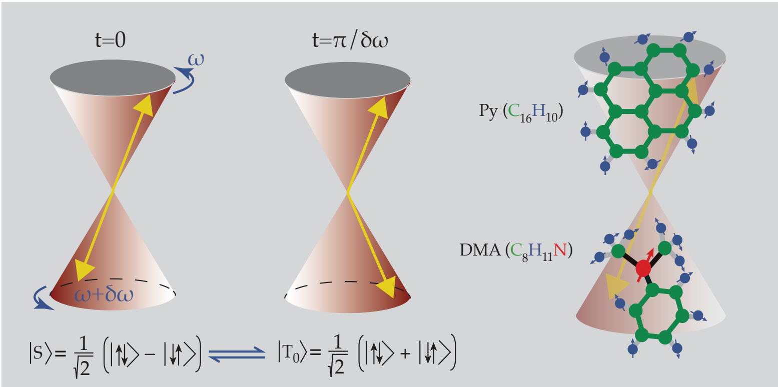
Another way to define quantum biology is to first realize that Nature is fundamentally quantum at all distance scales. However, the wave nature of particles, the tunneling effect, quantum coherence and entanglement, are effects limited to the microcosm, whereas the macrocosm, the theater of biology and life, appears to be adequately described classically. Thus there appears to be a boundary separating the two worlds, called the quantum-to-classical transition, beyond which all quantum effects die out and classical physics becomes an excellent approximation of physical reality. What the recent findings of quantum biology suggest is that certain biological processes operate much closer to this boundary, or even unfold right on top of the boundary crossing into the quantum world, whereas we used to think that they were confined well inside the classical macrocosm.

The scientific and technological potential of quantum biology is rather evident. The synthesis of two monumental, yet until now disjoint fields, quantum science & technology with life sciences and biotechnology has the potential to produce unimaginable scientific insights for life at the quantum level, and correspondingly novel technology aimed at understanding, controlling and mitigating disease at the quantum level.

Quantum Foundations of the Radical-Pair Mechanism

A solid paradigm for quantum biology

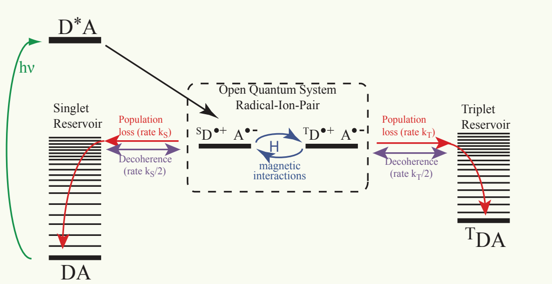
Until now, quantum coherence effects were associated with precision experiments in quantum physics laboratories, where quantum systems are carefully isolated from their environment in order to sustain quantum coherence. That such effects are found to exist in biological nature is a tremendous paradigm shift in our understanding of quantum physics and molecular biology.



One system making a strong case for quantum biology are the spin-dependent biochemical reactions studied in spin chemistry, radical-ion-pair reactions. These reactions are present in the photosynthetic reaction center and have been studied with NMR in order to elucidate the structure of reaction centers, and the dynamics of charge and spin transport therein. Furthermore, there is now ample evidence supporting Schulten's 1970s conjecture that radical-pair reactions underlie the avian magnetic compass.

The foundational theory of spin chemistry is a master equation, dating to 1976, and accounting for the time evolution of the radical-pair's spin state density matrix. We have shown that the old theory scrambles the inherent quantum nature of radical-pair reactions. We demonstrated that in order to establish a physically sound foundation of spin chemistry we had to introduce several concepts of quantum information science, like quantum measurements, measurement-induced decoherence, quantifiers of quantum coherence, quantum trajectories, the quantum Zeno effect, the concept of quantum retrodiction, even fundamental entropy bounds on the information extraction by a quantum measurement.

Interestingly, we retrieve the old theory by forcing our quantum coherence quantifier to be zero at all times, meaning that the old theory treats radical-pairs as completely incoherent, whereas in reality they are partially coherent [37,40,44,46,47,48].



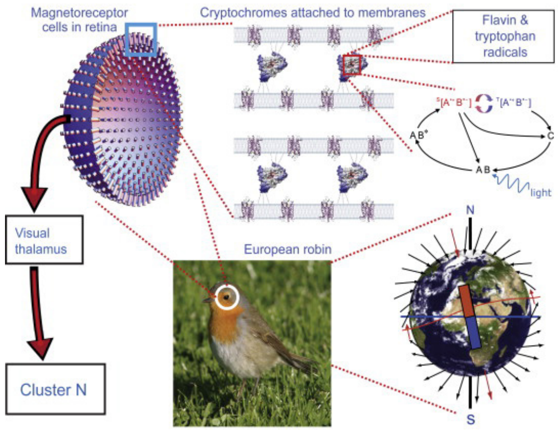
MASTER EQUATION FOR FUNDAMENTAL QUANTUM DYNAMICS OF SPIN-SELECTIVE RADICAL-PAIR REACTIONS

$$\frac{d\rho}{dt} = -i[H,\rho] - \frac{k_S + k_T}{2}\left(\rho Q_S + Q_S\rho - 2Q_S\rho Q_S\right) - (1 - p_{coh})\left(k_S Q_S\rho Q_S + k_T Q_T\rho Q_T\right) - \frac{k_S \mathrm{Tr}\{Q_S\rho\} + k_T \mathrm{Tr}\{Q_T\rho\}}{\mathrm{Tr}\{\rho\}} - \left(p_{coh} Q_S\rho Q_S + p_{coh} Q_T\rho Q_T + Q_S\rho Q_T + Q_T\rho Q_S\right)$$

The insight produced by this discovery is that there is already a biological process, the radical-pair reaction, working much like a quantum computer. That is, Nature has, not surprisingly, invented quantum technology before humans. Since we now know that this is possible, we have more reasons to search for more quantum effects in biology, and perhaps discover a whole new quantum world underneath life.

Quantum Foundations of the Radical-Pair Mechanism

A solid paradigm for quantum biology

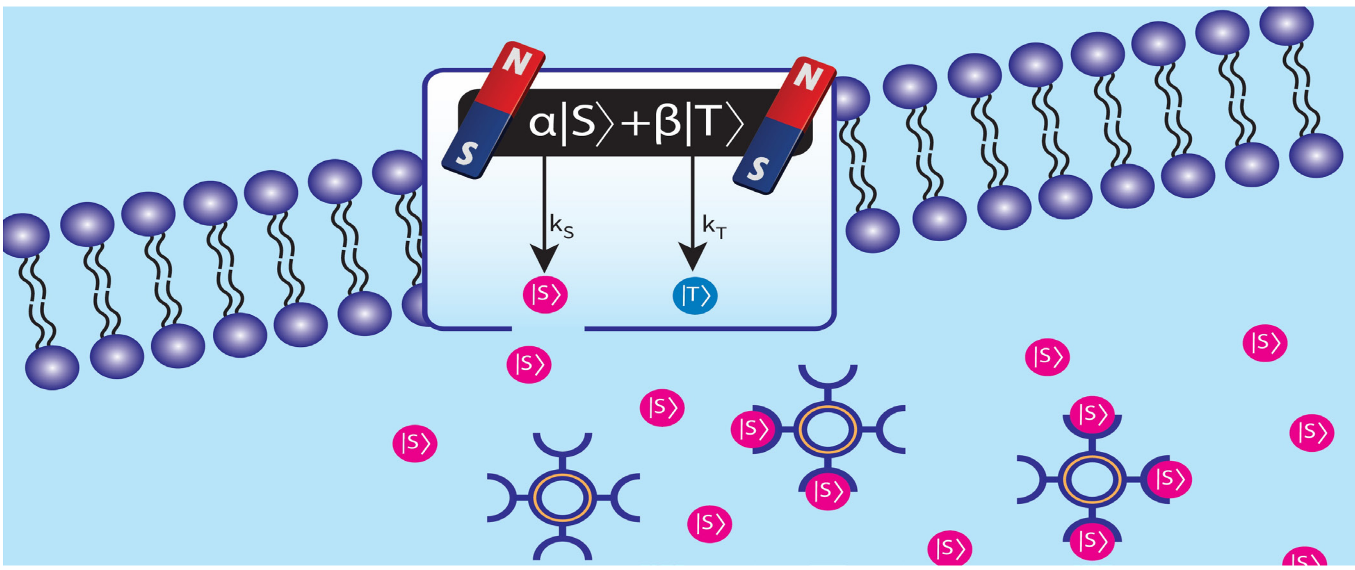


A major application of the radical-pair mechanism is in avian magnetoreception. We have studied this topic from several directions, always adding in our quantum perspective of the reaction dynamics. An interesting finding in this direction has been that in the quantum Zeno regime of the reactions, their magnetic sensitivity is rather insensitive on molecular structure details. This is a vivid example where a quantum effect provides an operational advantage to the biological mechanism, rendering it robust [41].

We stress that the avian compass and the understanding of its workings are only one aspect of our work, which is about the fundamental quantum dynamics of spin-dependent biochemical reactions. As noted in the following section on photosynthesis, these reactions are at the core of several experiments. Thus this work is directly relevant to experiments, aside its very captivating connection with animal navigation.

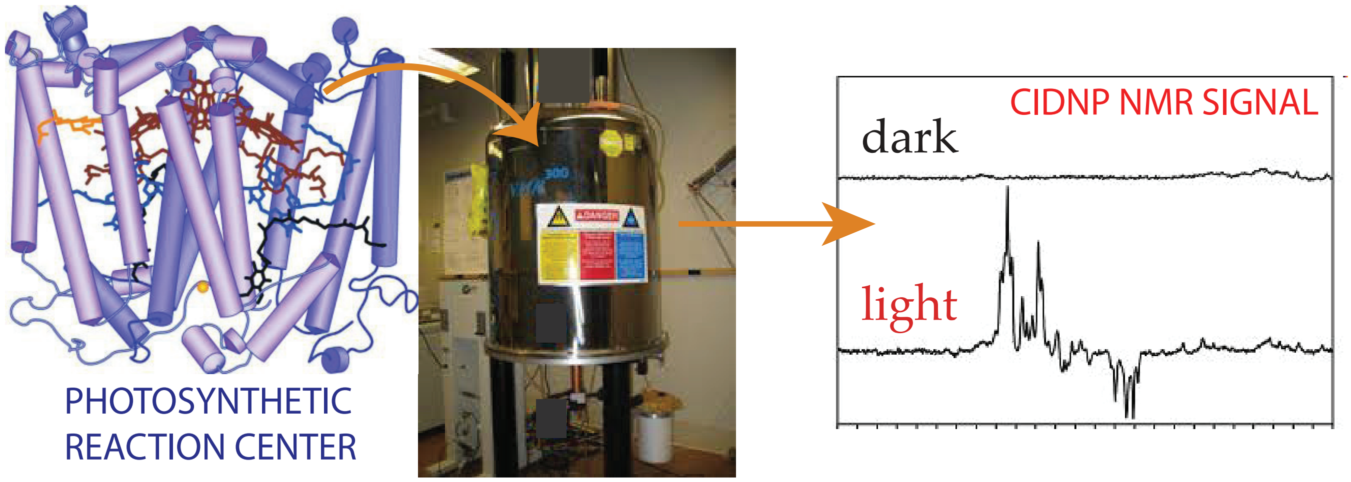
We also introduced further quantum information for radical-pair reactions [51], and also a quantum circuit description [52]. More recently, we were the first to introduce a formal quantifier of singlet-triplet coherence [53], which has a central role in reaction dynamics, based on quantum relative entropy. Using this quantifier, we demonstrated for the first time the concrete quantum advantage provided by coherence to the compass function.

A most recent advance [54] is the the introduction of a new measure of singlet-triplet coherence based on the Wigner-Yanase information. This measure allows us to search for quantum biological effects in the cellular environment. This is because for the first time we establish a connection between the coherence of reactants with fluctuations in the concentration of reaction products.

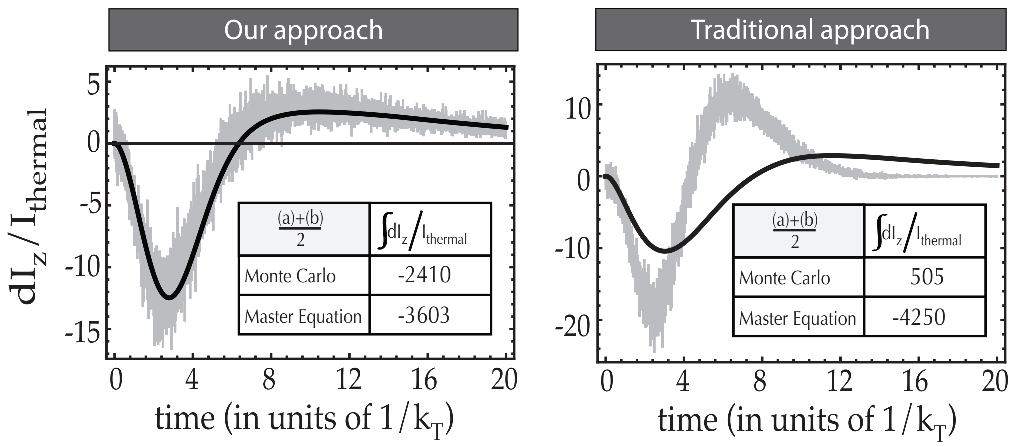


Quantum Dynamics of Spin Transport in Photosynthetic Reaction Centers

Understanding Nature's ability to harness sunlight



Charge and spin transport in photosynthetic reaction centers [45,47] produces large non-equilibrium nuclear spin polarizations. These are seen as strong NMR peaks when lighting up the reaction centers inside the NMR magnet. The effect is called Chemically Induced Dynamic Nuclear Polarization (CIDNP). Our description of the fundamental quantum dynamics of radical-pair reactions is complete, in the sense that we can produce quantum trajectories describing the dynamics at the single-molecule level. Our trajectory average is consistent with our master equation (bottom left fig). In contrast, the only way one could imagine introducing trajectories in the traditional theory leads to severe inconsistencies with the traditional master equation (bottom right figure).



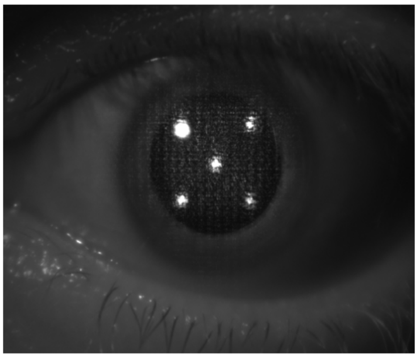
The inconsistency can reach the level of 500%, hence the same level of discrepancy exists in attempting to theoretically interpret CIDNP data and exctract useful structural information for the reaction centers. This is one reason that a precise **quantitative** agreement between the longstanding traditional theory of radical-pair reactions and experimental CIDNP spectra has so far not been demonstrated, a problem we hope to address in the future.

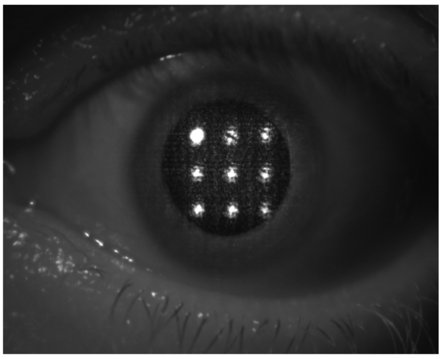
Quantum Pupillometry

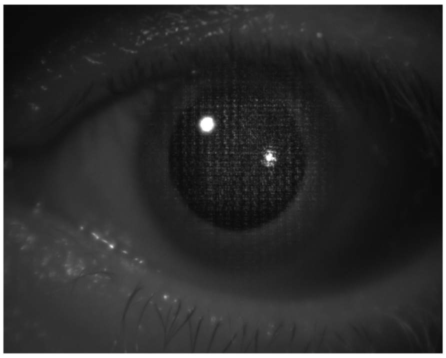
A new window to the human brain

Pupillometry is a window to the brain. When illuminated with light, the pupil's reflex circuits emanating from the retina, going through the mid-brain, and returning to the pupil's control muscles reduce the pupil's diameter. At the end of illumination, the pupil redilates.

The dynamics of the pupil diameter changes reflect brain function and have been correlated with several diseases of the visual and nervous system. Current pupillometers use light-emitting diodes to indiscriminately illuminate the whole pupil and thus stimulate the whole retina. In constrast, we can "surgically" stimulate individual spots on the retina and obtain a wealth of information inaccessible until now.

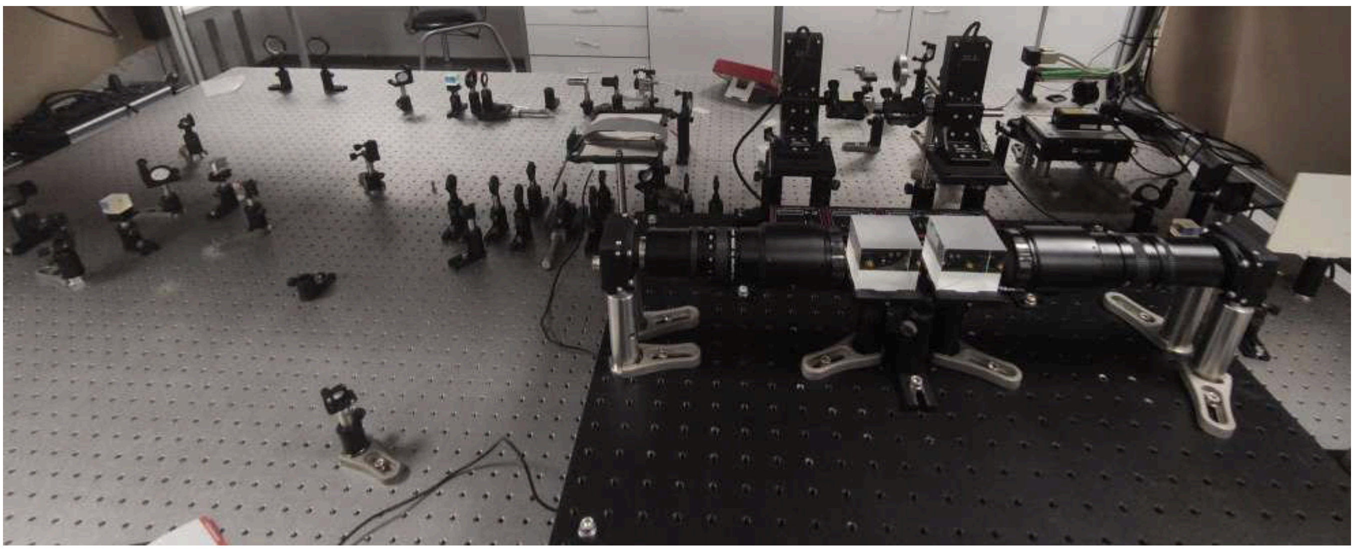






We have developed a light stimulus source that can advance pupillometry to a much higher level of control and precision, as current pupillometers lack spatial selectivity in illumination. The developed light source is based on a laser light beam having a cross section consisting of discrete pixels, allowing for an arbitrary pattern of illuminated pixels. Both the illumination pattern and the photon number per pixel per unit time are computer controlled, offering simple and unsupervised scanning of these parameters. Moreover, infrared light exactly superimposed on the stimulus pattern can be used for acquiring exact information on the illumination geometry on the pupil.

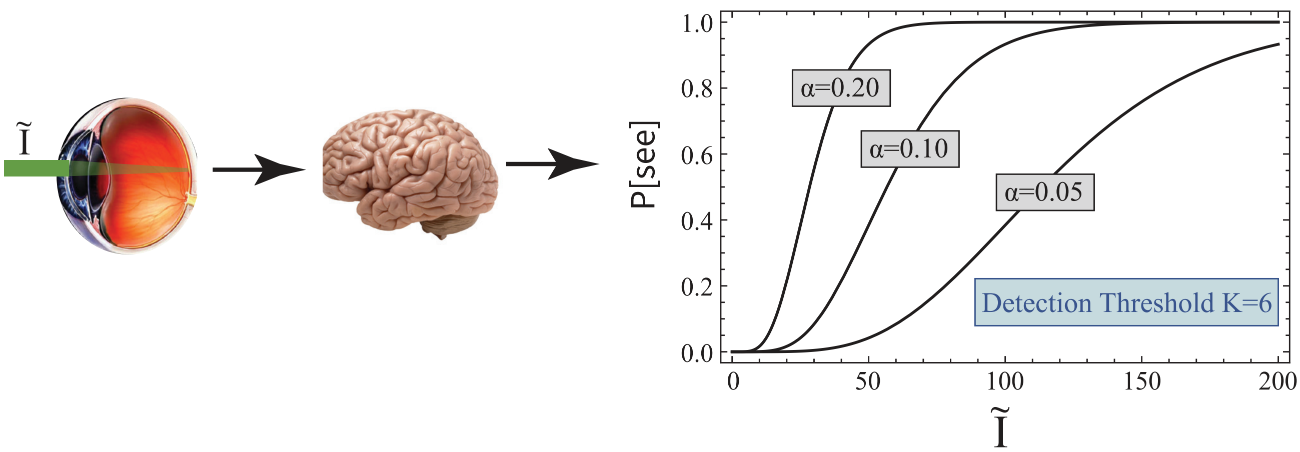
We demonstrate repeatability of the pupil diameter dynamics when we surgically illuminate nearby points on the pupil, and hence stimulate nearby points on the retina. Interestingly, we also demonstrate a wealth of pupil responses when we illuminate different points. They carry rich information on brain function, yet to be interpreted and used for medical diagnosis [20].



Quantum Biometrics

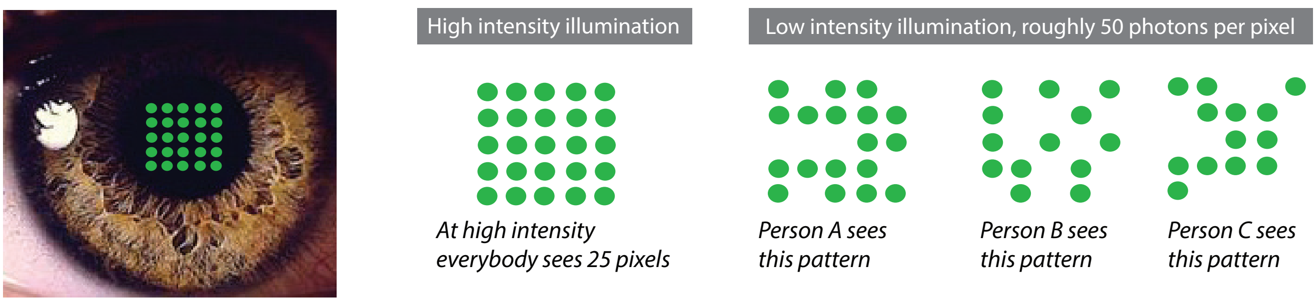
Uncompromising authentication security

Quantum biometrics is for biometric authentication what quantum cryptography is for communications. While all current biometric methodologies, such as iris scan or the traditional fingerprint, can be foiled by an impostor, our approach cannot, even in principle. It is because we probe the visual center of the brain with a small number of photons, and the relevant "fingerprint", residing in the eye, retina and the brain, cannot be accessed in any way.



The idea is simple enough. We illuminate the human eye with a flash of light containing a small number of photons, that is, we work around the visual perception threshold. In this regime, the probability of seeing a flash of light is strongly dependent on the optical losses, which light suffers along its path from cornea to retina. The optical loss parameter differs among people, and depends on the particular optical path towards the retina. Our biometric quantifier is an a-map distinctive for each human.

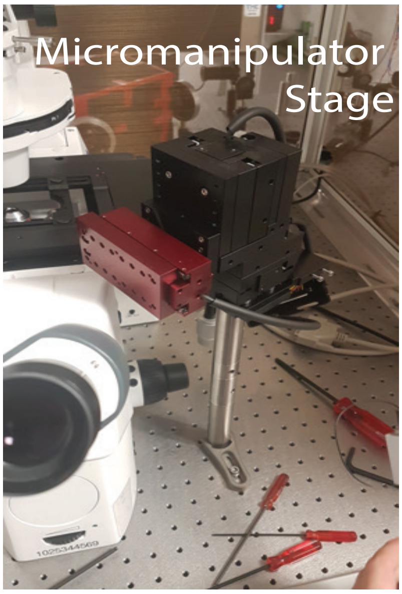
To illustrate the workings of our quantum biometric methodology, suppose we illuminate the eye with an array of 25 pixels of light. At high intensity everyone will see 25 pixels. But at low enough intensity every person will see a different pattern, because of the different a-values for different individuals. Thus we can address the visual perception of individuals, i.e. shine patterns of low-photon number that can be perceived only by a particular individual [19,22].

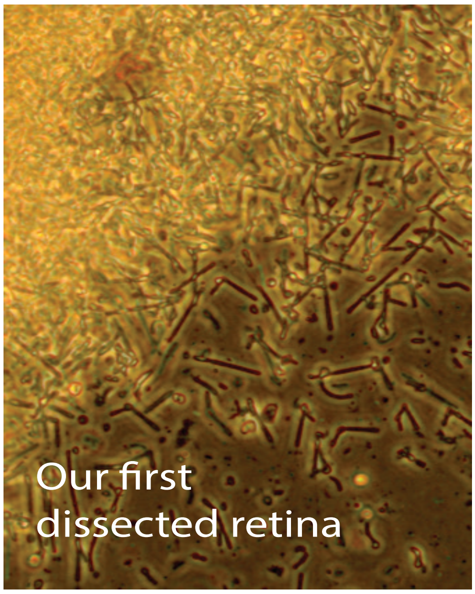


In more recent work [21] we discussed what sort of quantum advantage may result for the authentication protocol if one uses quantum light source to stimulate the visual system, in particular a single photon source. This way the noise of the stimulus (photon statistics) will be suppressed. Due to optical losses degrading the photon statistics of non-classical light, we show that the advantage is small but not negligible.

Probing Vision with Quantum Light

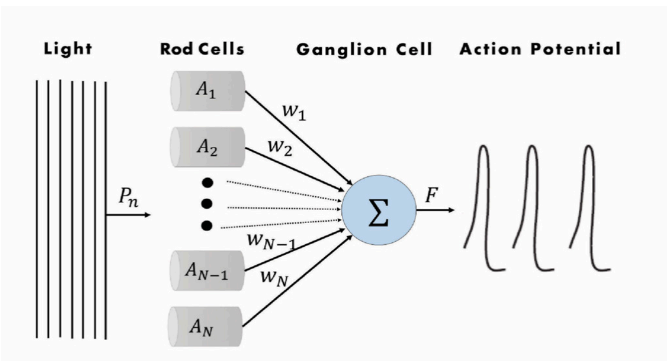
Unraveling the quantum foundations of vision at the cellular level

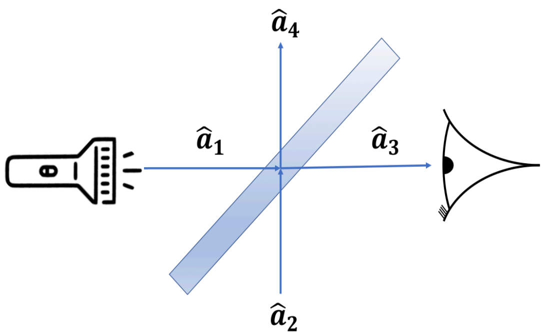




We have developed an experimental apparatus able to perform precision measurements of the electric current response of single rod cells. The apparatus consists of an inverted microscope, a sensitive electronic amplifier able to detect pA currents, a laser-based pipette puller to make glass pipettes holding the rod cells, and a set of micro-manipulators able to precisely position the pipette in the cell-containing sample. Our immediate goal is to reproduce rod-cell responses that have already been presented in the literature and then explore various quantum optical methodologies for the stimulus light.

This program fits well into our general research program on quantum vision, which consists of synthesizing quantum optics with the physiology of human vision. While we approach this with human subjects along the previously mentioned directions of pupillometry and biometrics, here we will study quantum vision in vitro. Alongside, we have done theoretical work studying the possible merits of studying vision and the relevant neural networks with quantum light [23], in particular, looking at the photon transduction at the level of rod and ganglion cells from the perspective of quantum parameter estimation.

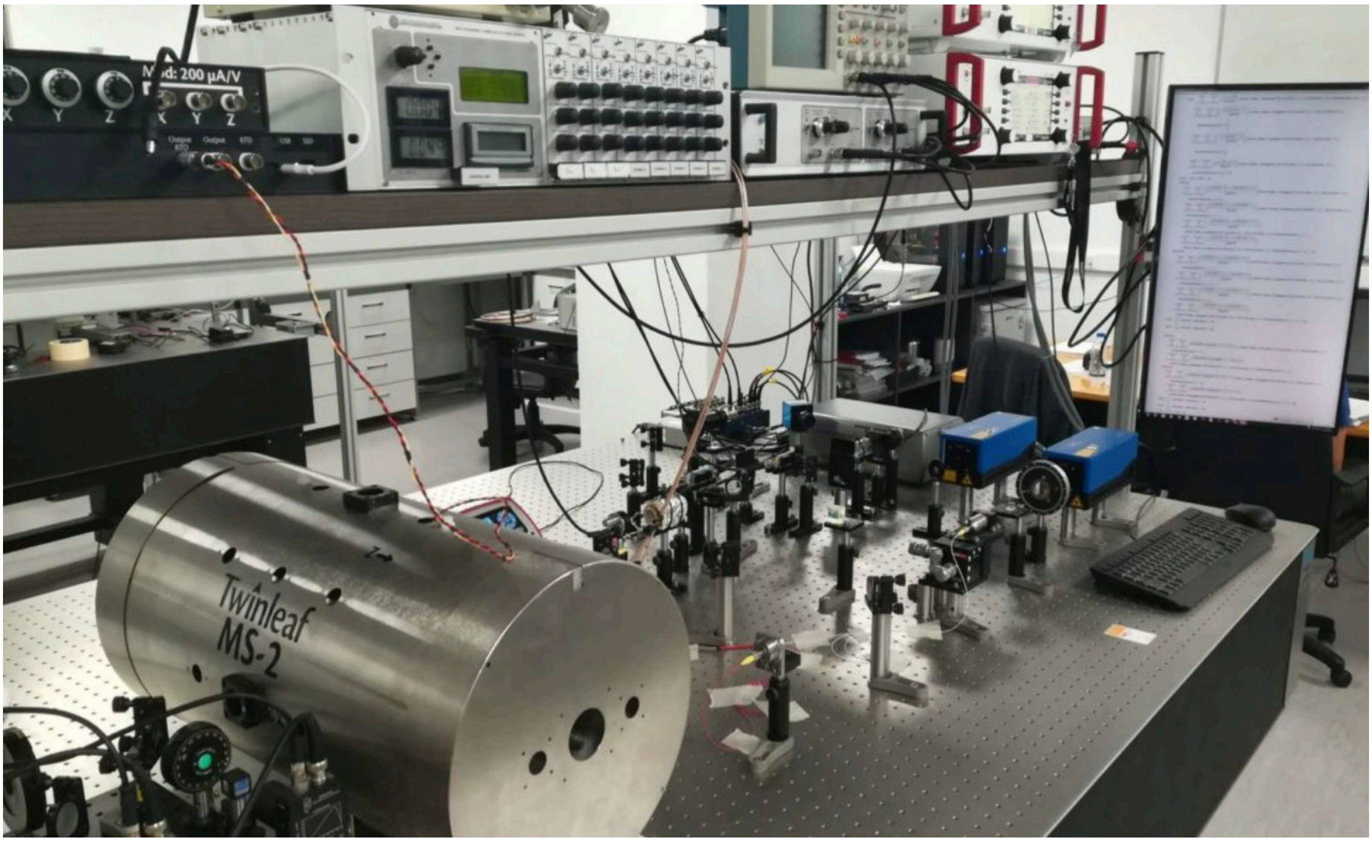




Spin Noise Spectroscopy with Hot Atomic Vapors

Producing novel quantum sensor technology

Atomic magnetometers have revolutionized the technology of quantum sensing of magnetic fields, surpassing in sensitivity superconducting devices, and offering a simple means to detect magnetic fields at the fT level. Such ability finds several applications, the most prominent being the detection of the spontaneous magnetic activity of the human brain. Atomic magnetometers operate with spin-carrying atoms in the form of a hot vapor, which interacts with laser light so that the atomic quantum state becomes magnetic-field sensitive. One of the major obstacles towards the ultimate magnetic sensitivity of these devices is spin noise, the spontaneous quantum fluctuations of the collective atomic spin produced by quantum measurement and never-ending atomic collisions.



In our lab we have studied several aspects of spin noise, and continue to do so with measurements of increasing complexity. In our early studies [29] we demonstrated that spin noise is not just some unwanted disturbance, but carries useful information on the relaxation properties of the atomic vapor. It can even be used as a quantum random number generator [31]. In recent studies we observed a peculiar effect [32] when studying spin noise in multispecies vapors, that is, vapors containing at least two different kinds of atoms. When left completely unperturbed, the two atomic species spontaneously build up noise correlations at low magnetic fields. We explained these correlations by introducing the quantum trajectory picture of spin-exchange collisions [33], that is, study the quantum evolution of atomic collisions atom by atom.

Most recently we have extended such studies of correlations. We have shown that spin-exchange collisions can build up quantum correlations lasting for significant time [34]. We have further analyzed the physics of spin-noise correlations in single and dual species vapors [35,36], essentially showing that what we consider as an unperturbed vapor of uncorrelated atoms might not be so in many cases. These studies can further advance the metrological capabilities of atomic magnetometers, since correlations potentially imply noise suppression.

Publications

PUBLICATION TOPICS

QUANTUM BIOLOGY
QUANTUM SENSING WITH HOT ATOMIC VAPORS
QUANTUM VISION
QUANTUM OPTICS IN ATTOSECOND SCIENCE
QUANTUM THERMODYNAMICS
APPLIED PHYSICS
MEDIUM ENERGY NUCLEAR SPIN PHYSICS

GOOGLE SCHOLAR PUBLICATION METRICS

TOTAL PUBLICATIONS=66
JOURNAL PUBLICATIONS=54
CITATIONS=5274
H=24

QUANTUM BIOLOGY

Invited article at the AQT special issue on “Quantum Sensing”

54. Physiological search for quantum-biological sensing effects based on the Wigner-Yanase connection between coherence and uncertainty
IK Kominis
Advanced Quantum Technologies 2300292 (2023)

53. Quantum relative entropy shows singlet-triplet coherence is a resource in the radical-pair mechanism of biological magnetic sensing
IK Kominis
Physical Review Research 2, 023206 (2020)

52. Quantum-limited biochemical magnetometers designed using the Fisher information and quantum reaction control
KM Vitalis, IK Kominis
Physical Review A 95, 032129 (2017)

51. Quantum information processing in the radical-pair mechanism: Haberkorn's theory violates the Ozawa entropy bound
K Mouloudakis, IK Kominis
Physical Review E 95, 022413 (2017)

50. Revealing the properties of the radical-pair magnetoreceptor using pulsed photo-excitation timed with pulsed rf
K Mouloudakis, IK Kominis
Biosystems 147, 35 (2016)

49. Reply to the Comment on "Quantum trajectory tests of radical-pair quantum dynamics in CIDNP measurements of photosynthetic reaction centers" by G. Jeschke
IK Kominis
Chemical Physics Letters 648, 204 (2016)

Invited review article

48. The radical-pair mechanism as a paradigm for the emerging science of quantum biology
IK Kominis
Modern Physics Letters B 29, 1530013 (2015)

47. Quantum trajectory tests of radical-pair quantum dynamics in CIDNP measurements of photosynthetic reaction centers
K Tsampourakis, IK Kominis
Chemical Physics Letters 640, 40 (2015)

46. Retrodictive derivation of the radical-ion-pair master equation and Monte Carlo simulation with single-molecule quantum trajectories
M Kritsotakis, IK Kominis
Physical Review E 90, 042719 (2014)

Invited article at the EPJ-Plus Topical Issue “Quantum Information and Complexity”

45. Lamb shift in radical-ion pairs produces a singlet-triplet energy splitting in photosynthetic reaction centers
KM Vitalis, IK Kominis
European Physical Journal Plus 129, 187 (2014)

44. Reactant-product quantum coherence in electron-transfer reactions
IK Kominis
Physical Review E 86, 026111 (2012)

43. Magnetic sensitivity and entanglement dynamics of the chemical compass
IK Kominis
Chemical Physics Letters 542, 143 (2012)

42. Photon statistics as an experimental test discriminating between theories of spin-selective radical-ion-pair reactions
AT Dellis, IK Kominis
Chemical Physics Letters 543, 170 (2012)

41. The quantum Zeno effect immunizes the avian compass against the deleterious effects of exchange and dipolar interactions
AT Dellis, IK Kominis
Biosystems 107, 153 (2012)

40. Radical-ion-pair reactions are the biochemical equivalent of the optical double slit experiment
IK Kominis
Physical Review E 83, 056118 (2011)

39. Comment on "Spin-selective reactions of radical pairs act as quantum measurements"
IK Kominis
Chemical Physics Letters 508, 182 (2011)

Invited article at the NJP Focus Issue "Quantum Effects and Noise in Biomolecules"
38. Coherent triplet excitation suppresses the heading error of the avian compass
GE Katsoprinakis, AT Dellis, IK Kominis
New Journal of Physics 12, 085016 (2010)

Commentary by New Scientist, APS Quantum Times
Triggered Lorentz Center Workshop
First paper on the quantum foundations of spin chemistry
37. Quantum Zeno effect explains magnetic-sensitive radical-ion-pair reactions
IK Kominis
Physical Review E 80, 056115 (2009)

QUANTUM SENSING WITH HOT ATOMIC VAPORS

36. Inter-species spin-noise correlations in hot atomic vapors
K Mouloudakis, F Vouzinas, A Margaritakis, A Koutsimpela, G Mouloudakis, V Koutrouli, M Skotiniotis, GP Tsironis, M Loulakis, MW Mitchell, G Vasilakis, IK Kominis
Physical Review A 108, 052822 (2023)

35. Effects of spin-exchange collisions on the fluctuation spectra of hot alkali vapors
K Mouloudakis, G Vasilakis, VG Lucivero, J Kong, IK Kominis, MW Mitchell
Physical Review A 106, 023112 (2022)

34. Spin-exchange collisions in hot vapors creating and sustaining bipartite entanglement
K Mouloudakis, IK Kominis
Physical Review A Letter 103, L010401 (2021)

33. Quantum trajectories in spin-exchange collisions reveal the nature of spin-noise correlations in multi-species alkali vapors
K Mouloudakis, M Loulakis, IK Kominis
Physical Review Research 1, 033017 (2019)

32. Spin-noise correlations and spin-noise exchange driven by low-field spin-exchange collisions
AT Dellis, M Loulakis, IK Kominis
Physical Review A 90, 032705 (2014)

31. Quantum random number generator based on spin noise
GE Katsoprinakis, M Polis, A Tavernarakis, AT Dellis, IK Kominis
Physical Review A 77, 054101 (2008)

30. Sub-shot-noise magnetometry with a correlated spin-relaxation dominated alkali-metal vapor
IK Kominis
Physical Review Letters 100, 073002 (2008)

29. Measurement of transverse spin-relaxation rates in a rubidium vapor by use of spin-noise spectroscopy
GE Katsoprinakis, AT Dellis, IK Kominis
Physical Review A 75, 042502 (2007)

28. Collision kernels from velocity-selective optical pumping with magnetic depolarization
T Bahmre, R Marsland, IK Kominis, BH McGuyer, W Happer
Physical Review A 87, 043412 (2013)

27. Quantum Zeno effect in atomic spin-exchange collisions
IK Kominis
Physics Letters A 372, 4877 (2008)

26. High frequency atomic magnetometer by use of electromagnetically induced transparency
GE Katsoprinakis, D Petrosyan, IK Kominis
Physical Review Letters 97, 230801 (2006)

25. A sub-femtotesla multichannel atomic magnetometer
IK Kominis, TW Kornack, JC Allred, MV Romalis
Nature 422, 596 (2003)

24. Sol-gel coated glass cells for spin-exchange polarized 3He
MF Hsu, GD Cates, IK Kominis, IA Aksay, DM Dabbs
Applied Physics Letters 77, 2069 (2000)

QUANTUM VISION

23. Using quantum states of light to probe the retinal network
A Pedram, ÖE Müstecaplıoglu, IK Kominis
Physical Review Research 4, 033060 (2022)

Invited Chapter for “Recent Advances in Biomtetrics”
22. Quantum biometrics
IK Kominis, ÖE Müstecaplıoglu, M Loulakis
IntechOpen, DOI: 10.5772/intechopen.103752

21. Quantum advantage in biometric authentication with single photons
IK Kominis, M Loulakis
Journal of Applied Physics 131, 084401 (2022)

20. Spatially-selective and quantum-statistics-limited light stimulus for retina biometrics and pupillometry
A Margaritakis, G Anyfantaki, K Mouloudakis, A Gratsea, IK Kominis
Applied Physics B 126, 99 (2020)

qubiom
United States Patent US 11,867,173
System and methiod for biometrics identification and pupillometry

Editor's Suggestion, Commentary by MIT Tech Review & PhysicsWorld
19. Quantum biometrics with retinal photon counting
M Loulakis, G Blatsios, CS Vrettou, IK Kominis
Physical Review Applied 8, 044012 (2017)

qubiom
United States Patent US 11,275,937
Quantum biometric identification of ultrahigh security based on the quantum statistics of photodetection by the human retina

QUANTUM OPTICS IN ATTOSECOND SCIENCE

18. High-order harmonics measured by the photon statistics of the infrared driving-field exiting the atomic medium
N Tsatrafyllis, IK Kominis, IA Gonoskov, P Tzallas
Nature Communications 8, 15170 (2017)

17. Quantum optical signatures in strong-field laser physics: Infrared photon counting in high-order-harmonic generation
IA Gonoskov, N Tsatrafyllis, IK Kominis, P Tzallas
Scientific Reports 6, 32821 (2016)

16. Quantum-optical nature of the recollision process in high-order-harmonic generation
IK Kominis, G Kolliopoulos, D Charalambidis, P Tzallas
Physical Review A 89, 063827 (2014)

QUANTUM THERMODYNAMICS

15. Algorithmic quantum heat engines
E Kose, S Cakmak, A Gencten, IK Kominis, ÖE Müstecaplıoglu
Physical Review E 100, 012109 (2019)

APPLIED PHYSICS

Editor's Featured Paper, Cover for JAP Volume 134 ISSUE 16, Featured at AIP KUDOS Publishing Showcase
14. A magnetic falling-sphere viscometer
C Patramanis-Thalassinakis, PS Karavelas, IK Kominis
Journal of Applied Physics 134, 164701 (2023)

MEDIUM ENERGY NUCLEAR SPIN PHYSICS

13. ^{3}He spin-dependent cross sections and sum rules
K Slifer et al
Physical Review Letters 101, 022303 (2008)

12. Extraction of the neutron magnetic form factor from quasielastic ^{3}He(e,e') at Q^2=0.1-0.6 (GeV/c)2
B Anderson et al
Physical Review C 75, 034003 (2007)

11. RETrap – a cryogenic Penning ion trap system
S Toleikis, R Maruyama, DA Church, D Schneider, SJ Freedman, IK Kominis, PA Vetter
Nuclear Instruments and Methods In Physics Research B 235, 479 (2005)

10. Detecting shake-off electron-ion coincidences to measure beta-decay correlations in laser-trapped ^{21}Na
ND Scielzo, SJ Freedman, BK Fujikawa, IK Kominis, R Maruyama, PA Vetter, JR Vieregg
Nuclear Physics A 746, 677c (2004)

9. Measurement of the generalized forward spin polarizabilities of the neutron
M Amarian et al
Physical Review Letters 93, 152301 (2004)

8. Parity-violating electroweak asymmetry in e-p scattering
KA Aniol et al
Physical Review C 69, 065501 (2004)

7. Basic instrumentation for Hall A at Jefferson Lab
J Alcorn et al
Nuclear Instruments and Methods In Physics Research A 522, 294 (2004)

6. Q^2 Evolution of the neutron spin structure moments using a ^{3}He target
M Amarian et al
Physical Review Letters 92, 022301 (2004)

5. Plane-wave impulse approximation extraction of the neutron magnetic form factor from quasielastic ^{3}He (e,e') at Q^2=0.3 to 0.6 (GeV/c)^2
W Xu et al
Physical Review C 67, 012201 (2003)

4. The Q^2 evolution of the generalized GDH integral for the neutron using a ^{3}He target
M Amarian et al
Physical Review Letters 89, 242301 (2002)

3. Precision measurement of the spin-dependent asymmetry in the threshold region of ^{3}He (e,e')
F Xiong et al
Physical Review Letters 87, 242501 (2001)

2. New measurement for parity violation in elastic electron-proton scattering and implications for strange form factors
KA Aniol et al
Physics Letters B 509, 211 (2001)

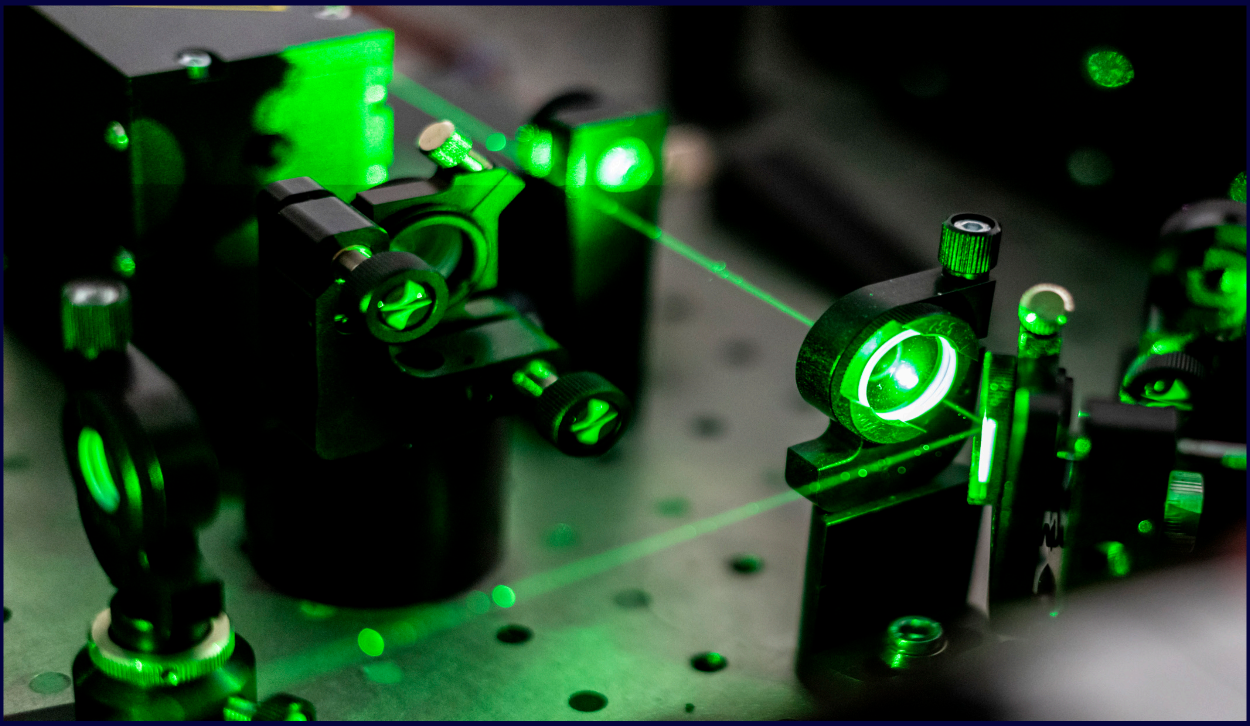
1. The transverse asymmetry AT' from quasi-elastic ^{3}He (e,e') process and the neutron magnetic form factor
W Xu et al
Physical Review Letters 85, 2900 (2000)

Quantum Biometronics

about qubiom

Quantum Biometronics is a spin-off company of the University of Crete, aspiring to commercialize cutting-edge technology at the niche interface of quantum science & technology with life sciences & biotechnology.

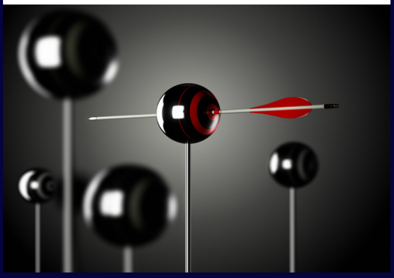
We firmly believe in the long-term scientific and commercial potential of quantum+bio, and we are positioning to take advantage of the niche synthesis of two monumental, yet until now disjoint technologies and markets, quantum technology and biotechnology.



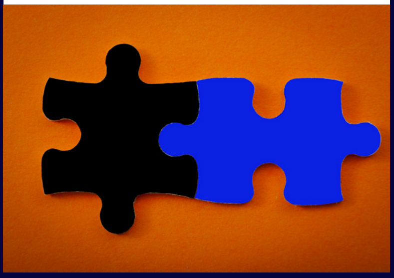
We are driven by the limitless possibilities of producing disruptive technologies using the spectacular tools of quantum technology, having them work synergistically within complex environments, and offering fundamentally new and unanticipated insights. By bolstering quality, precision and synergy, our grand vision is to develop deep-tech products of uncompromising performance with the goal to advance the quality of life.

Quality

Precision

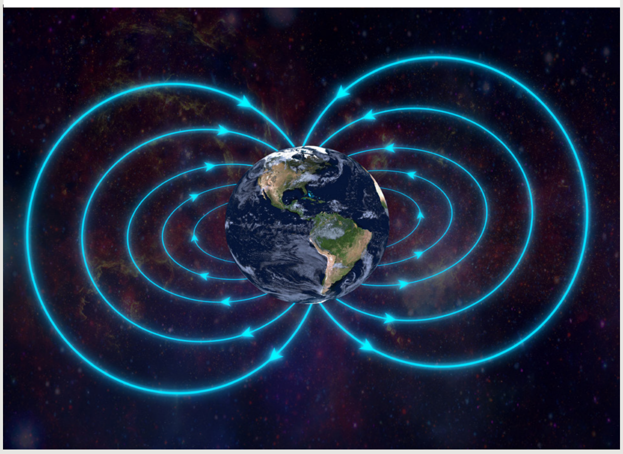


Synergy



We are developing products in three different directions: (a) Quantum Geomagnetics, (b) Precision Viscometry, and (c) Quantum Pupillometry. In all three cases our technology offers significant advances in the precision of the respective measurements, along with several other unique figures of merit to be presented in the following pages.

Quantum Geomagnetics

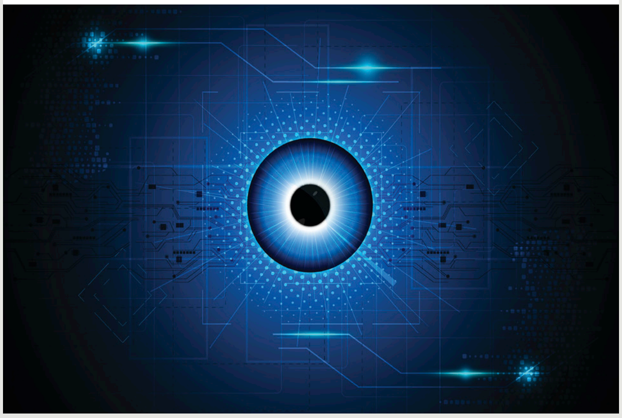


The magnetic field, in particular the magnetic field of the earth, carries a lot of information. We are developing a synchronized network of ultra-precise magnetometers to operate in the field and detect tiny changes of the geomagnetic field. Potential applications involve monitoring urban environmental dynamics, prospecting for natural resources, and military applications related to submarine detection.

Precision Viscometry

Viscosity is a central property of fluids quantifying the ease with which they flow. For example, honey is more viscous than oil. We developed a precise method for measuring the viscosity of fluids, requiring very small sample volume, and taking only a few seconds. Our viscometer can find numerous applications in petroleum, food, biotech and cosmetics industries.

Quantum Pupillometry

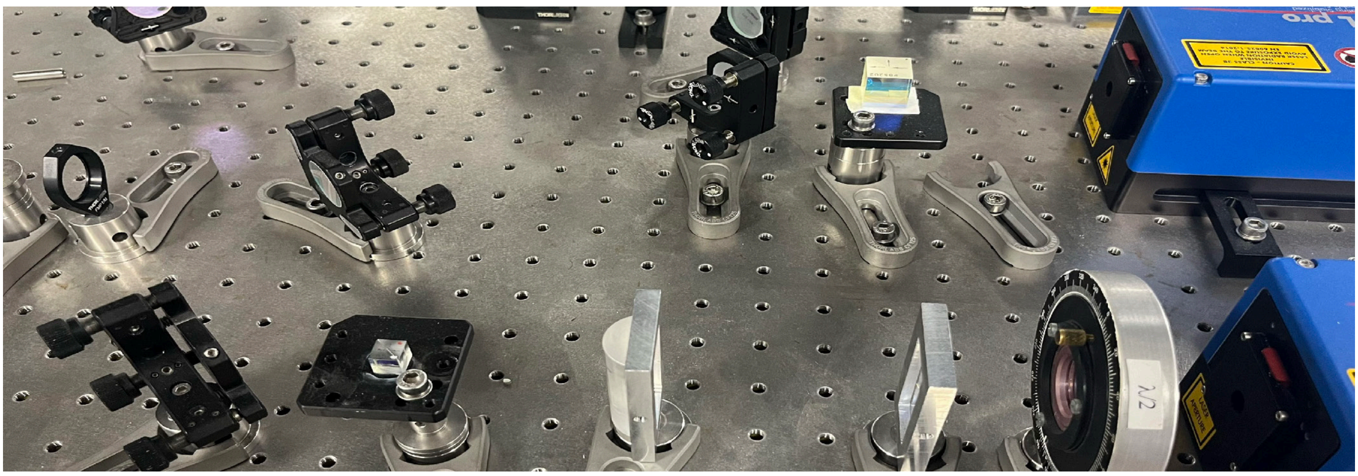


Pupillometers measure the pupil's light reflex, which is a time-dependent change of the pupil's radius upon illuminating the eye. We developed the first laser pupillometer in the world, offering spatially selective stimulation of the retina. By precisely stimulating and monitoring the pupil's light reflex we envision ealy-diagnosis capability of a number of pathologies of the eye and the nervous system.

quantum geomagnetics market

In collaboration with the Institute of Theoretical and Computational Physics of the University of Crete, and with the support of the Regional Government of Crete, we are developing a synchronised magnetometer network to monitor in real time the geomagnetic field variations due to all urban activities having a magnetic footprint. The initial network will feature four nodes, one at the University of Crete campus, and another three in the city of Heraklion.

This work is an application of quantum technology in a complex environment, which can involve different spatial scales, ranging from a major infrastructure, to urban and suburban scales. It also involves big data exquisitely rich in information. In the context of smart cities, the geomagnetic field carries a wealth of information reflecting urban dynamics, like energy consumption and transport dynamics. In suburban scales it can convey information about seismological or meteorological activity.



quantum geomagnetics market

By 2030 five billion people will be living in cities. The population and city-size distribution is about 40 cities with population larger than 10 million, 66 cities with population between 5 and 10 million, 597 cities with population between 1 and 5 million, and 710 cities with population between 0.5 and 1 million. In total, about 1400 "large" cities. In the complex socioeconomic and technological environment, cities will be required to become "smart".

Smart cities need to understand and manage huge amounts of complex information in order to be able to cope with the citizens' demands in an economically sustainable way. Such information includes energy (management of all types of energy resources consumed by nunicipal buildings, vehicles, and public areas), traffic (understanding in real time traffic conditions in roadways, bike ways and pedestrian paths), lighting (smart lighting to reduce the city's energy footprint).

In all of the above, magnetometers can provide unique real-time information which can be used by municipal governements in order to optimize their services and minimizing their costs. By 2025 we will be able to provide citys with integrated packages comprising a number of magnetometric sensor nodes (5-20, depending on pupulation) wirelessly transmitting information to a server, and a big-data analysis software unraveling critical aspects of urban dynamics.

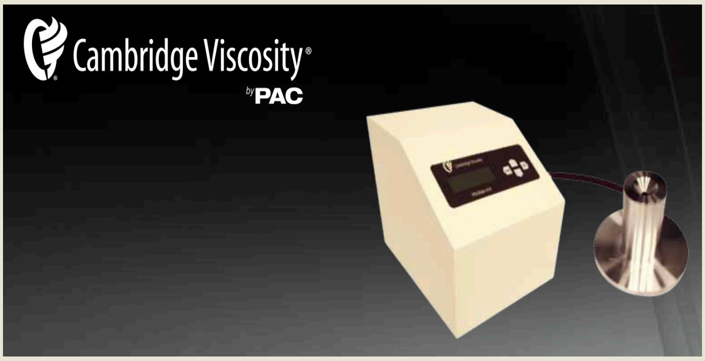
The market for such technology is estimated to be at least $1b, given the cost savings that can be achieved by smart use of subtle information provided by the geomagnetic field.

precision viscometry market

Characterizing the flow of fluids is crucial for several applications and useful for standardizing several processes. A central physicochemical quantity describing fluid flow is the viscosity. For example, engine oil must have precisely prescribed viscosity values over a range of temperatures relevant to engine operation. The viscosity of edible fluids, like olive oil, milk etc is also determined regularly as part of the production process. Similarly, the viscosity of cosmetic products like cremes and oils, and the viscosity of paints/inks is a standard measurement taken into account in the relevant quality tests. Finally, the pharmaceutical industry is also a major user of viscometers.

The current market size of viscometers is about $500M, with tens of companies producing such devices. There are in-line viscometers continuously used in production processes, and there are laboratory (benchtop) viscometers measuring sample by sample.

Typical prices of currently existing devices start from $400 for rotational viscometers requiring large sample volumes and a time-consuming measurement, up to $10k. In particular, there is a gap in the market at the price range between $400 and $3k.



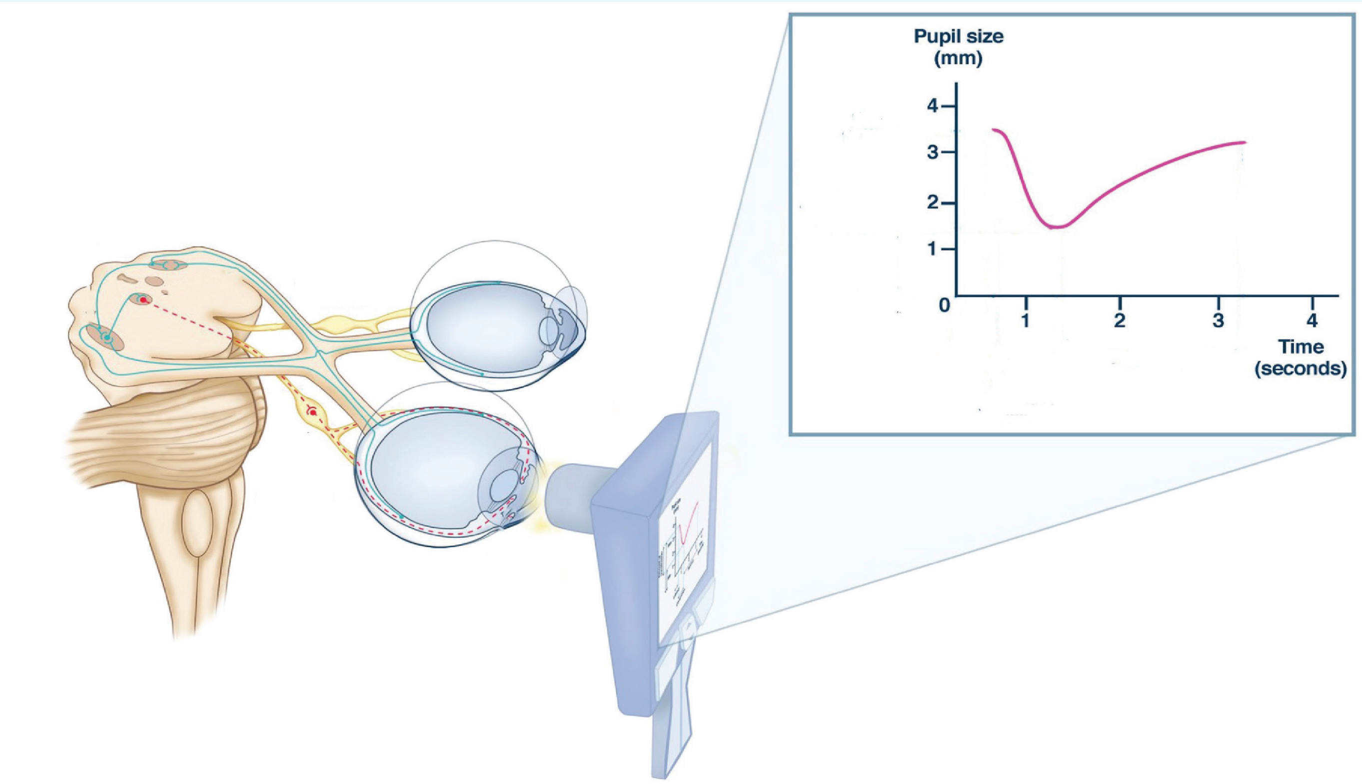
We have developed a viscometer that provides competitive performance while filling this market gap. Our viscometer is (i) **compact**, measuring in size about 10cm x 5 cm x 5 cm, (ii) **fast**, delivering a measurement in a few seconds, (iii) **precise and accurate at the level of 2%**, (iv) requires **minimal sample volume**, currently 15 mL, and design underway with just 1 mL sample volume, (v) **competitive in price**, with production cost about $200/piece, and (vi) **very user friendly**, requiring minimal effort by the user. Patent is pending.

Our viscometer features a small magnetic sphere falling in the fluid under test, and sensitive magnetometers tracking the sphere's trajectory. From the magnetometers' signals the fluid's viscosity can be readily extracted. Our viscometer can be produced at our facilities. It requires (i) a 3d-printed enclosure, (ii) a few electronic components and (iii) in-house assembly. We plan to commence production and sales end 2023-mid 2024.

Target market are companies producing cosmetics like oils or essential oils, where the small sample volume is important. Another target market are biotech companies doing blood analyses.

quantum pupillometry market

Pupillometry is a diagnostic technique measuring the constriction of the pupil under illumination, and its subsequent redilation after terminating the illumination. The dynamics of the pupil diameter changes are regulated by neural circuits emanating from the retina and reaching the mid-brain before returing to the pupil's muscles. Pupillometry data contain a wealth of information that could be useful for the diagnosis of a number of pathologies of the eye/retina/brain.



Dynamic pupillometers existing in the market are produced by Neuroptics (US), Metrovision (France), Ivis Technologies (Italy), Adaptica (Italy), IdMed (France), Nidek (Japan).

They are all based on the same core technology, with minor differences on data processing and display. The core technology is based on illumination with a broad flash of LED light illimunating the whole eye. Such pupillometers provide ***one response curve per eye.*** Based on the published clinical measurements, they have limited diagnostic capability. The main clinical use of currently existing pupillometers is to objectify measurements of the pupil light reflex, which previously were done empirically with their gross interpretation based on the practitioner's experience.

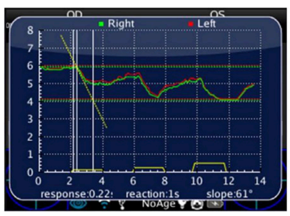
We next present the current pupillometry market. Then we introduce our technology, which brings about a significant advancement in pupillometry technology, and we elaborate on use cases and business opportunities which open up in the "quantum pupillometry market".

quantum pupillometry market

Publicized pupillometry market figures are not easy to find, however, some figures exist which can be used to infer the current pupillometry market. Neuroptics is dedicated to pupillometers, whereas Metrovision, IVIS, IDEK, Adaptica, NIDEK produce several ophthalmologic devices.

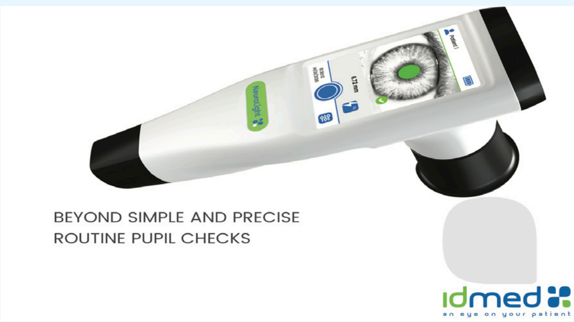
Neuroptics is supposed to have about 60 employees. For a small size US tech company we estimate a revenue per employee on the order of $300k. With an average US salary of $80k, salary costs run at about $5M/y and revenues at about $20M/y. The Neuroptics pupillometer sells for about $5k. We estimate its cost at $1k, hence the company sells about 5,000 devices/y and sees a net profit of $10M. Part of the company's business model are the sales of consumables even after the client acquires the pupillometer, which are used to store and retrieve single-patient data.

The MonCV device by **Metrovision** does not only perform dynamic pupillometry, but several ocular tests like perimetry, electrophysiology, video oculography etc. It is thus difficult to assess the contribution of the pupillometry component to the company's revenues and the global market size, even more so because there are no public numbers whatsoever for this French company. The pMetrics pupillometer of **Ivis Technologies** performs dynamic pupillometry and is a desktop device ideally suited for ophthalmology practices.



Adaptica makes a refractometer, which also performs dynamic pupillometry, albeit with limited precision due to its imaging restrictions. **IDMED** makes a pupillometer of similar design and technology to the Neuroptics device. **Nidek** makes keratometer, which also provides functionality for dynamic pupillometry.

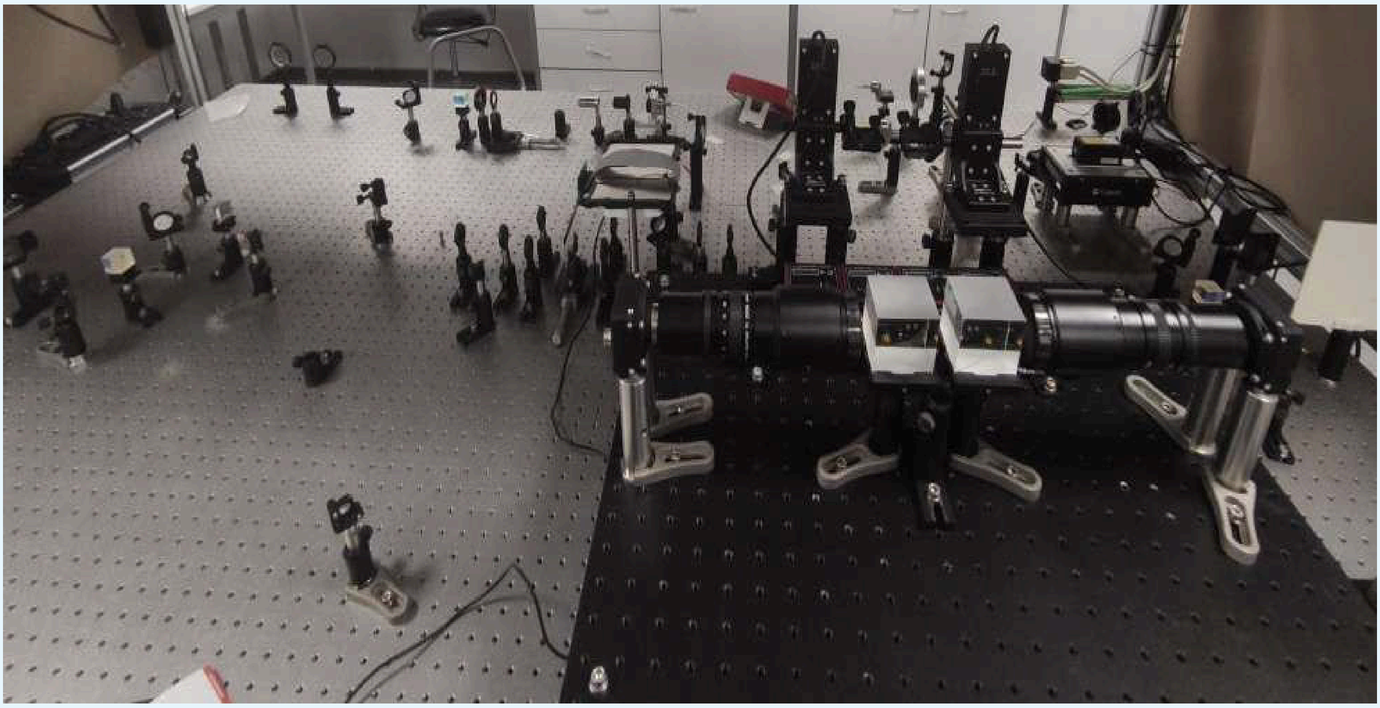
Based on all of the above, and assuming a market equaly split among all current players, a fair estimate of the current **global pupillometry market is at the level of $100M.** As we will elaborate next, the market size appears to be limited by the current technology, which puts severe limits to the diagnostic capabilities of pupillometry.



Our technology is the first introducing lasers to study the pupillary dynamics, significantly enhancing the precision of the method, and thus opening the possibility for a significant market expansion and the potential for a serious market share for qubiom.

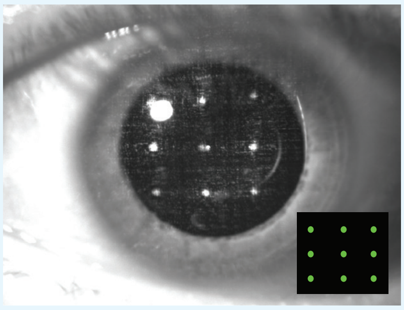
quantum pupillometry market

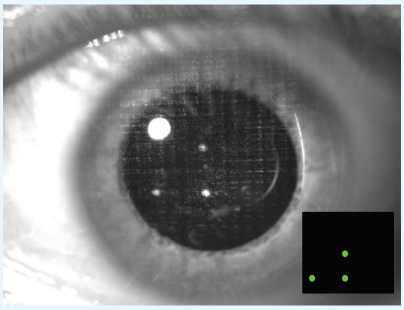
We have devised the first pupillometer in the world using laser light as a stimulus light source. The modern photonic technology we introduced allows us to stimulate the retina with *spatial selectivity*. In constrast, existing pupillometers stimulate the whole retina with a flash-lamp-type of light. In particular, we have developed a light stimulus source which can illuminate the eye with green laser light having a beam profile consisting of discrete pixels (25, in an array of 5 x 5).

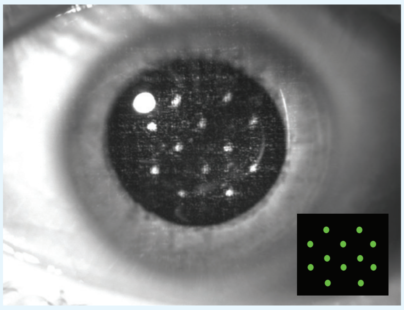


Our "surgical" light stimulus boosts the amount of information accessible by pupillometry *by a factor of 100*, opening a radically new window into brain function and medical diagnosis. Our light stimulus has the following *unique* properties:

- Any pixel arrangement can be illuminated by computer control.
- The photon number per unit time per illuminated pixel is precisely known and also computer controlled.
- Through reflection of infrared light (850 nm) exactly superimposed on the green stimulus light we obtain direct visual information of the illumination geometry on the pupil, shown in the figures below displaying examples of various illumination patterns.

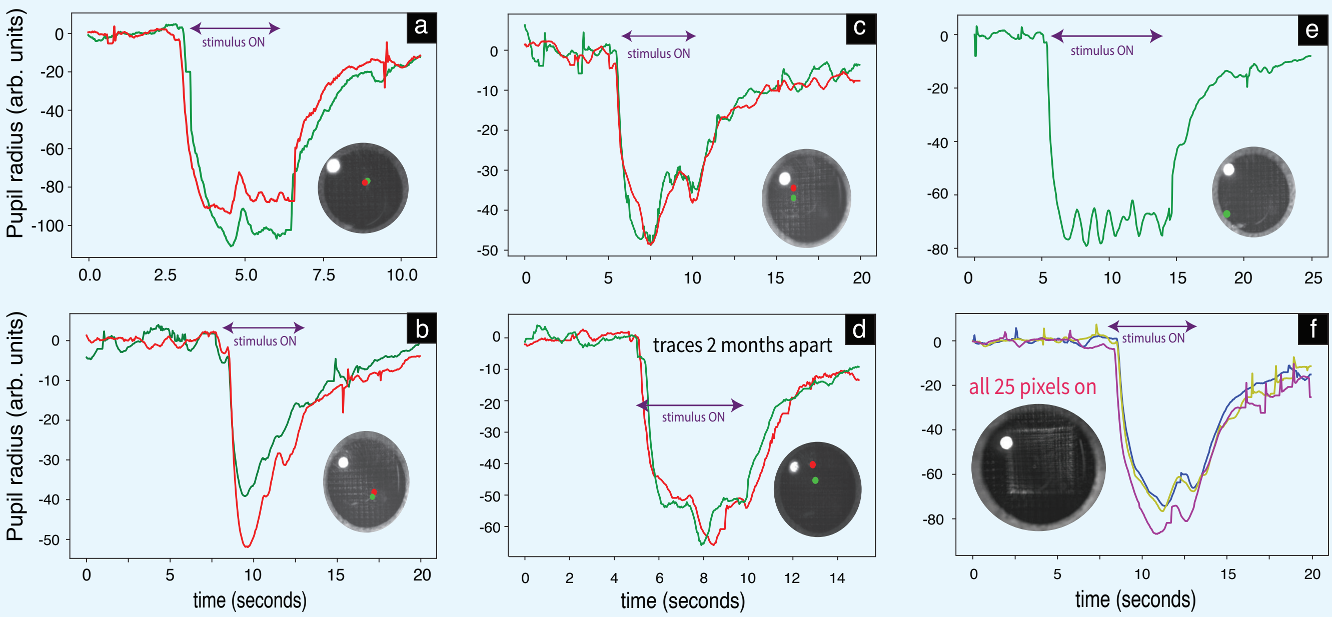






quantum pupillometry market

We clearly demostrate the wealth of neural information that for the first time becomes accessible by measuring the pupil light reflex for different illumination points on the pupil, hence different stimulation points on the retina. **We repeatably obtain wildly different responses** (figs. a-e below). We can also simulate current pupillometers by turning on all of the 25 pixels at our disposal (figure f below). This is **just a single response current pupillometers can offer.** **We offer tens of different responses.** The reason is that with our spatially-selective laser stimulus we selectively stimulate a specific spot on the retina, which then stimulates a specific neural pathway regulating the pupil reflex.



To give a financial analogy, existing pupillometers are the analogue of the stock-market index, while our technology provides the price for each individual stock comprising the index. Financial investors would clearly prefer the latter. Likewise, medical practitioners would clearly prefer to have access to more information than less.

United States Patent US 10,867,173

System and method for biometrics identification and pupillometry

United States Patent US 11,275,937

Quantum biometric identification of ultrahigh security based on the quantum statistics of photodetection by the human retina

quantum pupillometry market

Pupillometry can in principle address a large number of pathologies of the visual system and the nervous system. Below is a list of such pathologies or clinical situations, numbers refer to worldwide population, are estimated from US population scaled by a factor 10.

Table 1

Ophthalmological case

- Glaucoma (80M people)
- Diabetic retinopathy (100M people)
- Test for floppy iris syndrome prior to cataract operations (20 M/year)

Table 2

Neurological case

- Parkinson's disease (10M people, 600k cases/year)
- Alzheimer's disease
- Tramautic brain injury (30M cases/year)

Regarding use of pupillometers in clinical environments and medical practices, their most prevalent use is in Ophthalmology practices regarding ophthalmological cases, and in Neurology practices and Intensive Care Units regarding neurological cases. Psychiatric practices can also make use of pupillometry, but regarding our technology we do not forsee an adoption by psychiatric practices in the near term, although it cannot be excluded.

Table 3

- Intensive Care Units (100k ICUs, 1M ICU beds. For semi-continuous monitoring of ICU patients demand could reach one pupillometry device/ICU bed)
- Opthalmology practice (200k)
- Neurology practice (150k)
- Psychatric practice (500k)

The above potential use of pupillometry is not in par with the current market size. The basic issue hindering the wider clinical use of pupillometry and the respective market growth is the limited sensitivity and specificity. Our technology has the potential to address this issue for the first time after a long period of use of current pupillometers.

qubiom growth

Bootstrapping 100 keuros
Grant money 300 keuros
2 granted patents, 3 pending
Participating in InnoStars EIT-Health business accelerator (25 keuros award)
Participating in Eurobank's EGG bussiness accelerator
Member of the ELEVATE GREECE Greek Start-Up registry

European Union
European Regional Development Fund
EPAnEK 2014-2020
OPERATIONAL PROGRAMME
COMPETITIVENESS
ENTREPRENEURSHIP
INNOVATION
ΕΣΠΑ 2014-2020
Partnership Agreement 2014 - 2020
Operational Programme CRETE 2014 - 2020

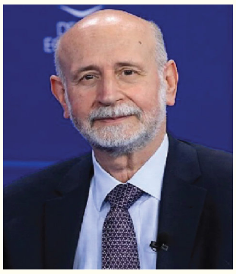
With the co-funding of Greece and the European Union

ELEVATE GREECE BETA
national startup point

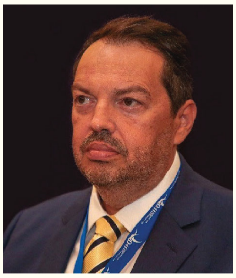
eit Health
Co-funded by the European Union

enter grow go
egg

Business Advisors



Athanasios Kefalas
Athanasios Kefalas is president of the Greek Mining Enterprises Association since June 2015. He is also Chairman of IMERYS Greece S.A. and IMERYS Bauxites Greece S.A. He has studied Mining Engineering-Metallurgy at the National Technical University of Athens and has completed an Executive MBA at INSEAD. He has held several leadership positions for more than three decades, initially starting on operations and gradually moving to more strategic roles with high international exposure. He has extensive background and experience in mineral exploration and evaluation as well as in design and implementation of mining projects mostly related in developing value chains based on minerals.



Minas Papadakis
Minas Papadakis received a diploma in Chemical Engineering from the Aristotle University of Thessaloniki in 1991, and an MBA from Imperial College in 1994. He has been a Member of the Board of Directors at Minoan Lines (2003-2009), Head of Private Clients at Eurobank Equities (2009-2013), Tied Agent at Eurobank Equities, 2013-present. Mr. Papadakis is the Managing Director of Heraklion Port Authority AE, since 2020.

René Reijtenbagh
René Reijtenbagh is CEO of Business Angels Connect and founder of Angel Funding Germany that is specialized in connecting Dutch growth companies to German investors. He has two decades of experience in helping companies funding their growth via business angels. He is Vice President of Business Angels Europe, the European confederatie of business angels networks. He has a track record in selecting, coaching and introducing promising companies to the business angel community. He was founder of the Business Angels network for Overijssel and Gelderland, Masters of the Future. For the Association of Business Angels Netwerken Nederland he was one of the founders. He has an education in Economic Geography and Business Administration.

CURRICULUM VITAE
IANNIS K. KOMINIS

Department of Physics
University of Crete
Heraklion 70013
Greece

ikominis@uoc.gr
www.quantumbiology.gr
ikominis@qubiom.com
www.qubiom.com