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Manipulating matter with the light

A Nobel cause: public engagement and outreach

Extreme Light Infrastructure Nuclear Physics (ELI-NP)

Physics, lasers and the Nobel Prize

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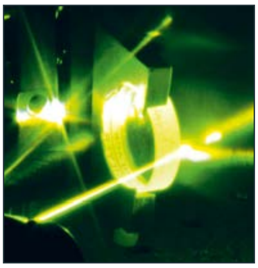
Cover picture: Special issue on lasers. See p.11 to 28. Image courtesy ©iStockPhoto



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SPECIAL ISSUE ON LASERS

The Editors are pleased to announce that, for this special issue on Lasers, **Antigone Marino** was willing to act as Guest Editor. In this capacity she organised and edited the Features on p. 11 through 28. The amount of work and time involved should not be underestimated. The Editors are extremely grateful to her for producing such an interesting issue.

[EDITORIAL]

Crackdown on academic freedom

Reform plans of the Hungarian government pose massive threats to the Academy of Sciences.

Since its landslide victory in the 2018 parliamentary election, the government of Hungary has embarked on sweeping reforms of the nation's academic institutions, and not for the better. The facts have been widely covered by the media, and they are well known. In a first step, public universities were placed under the authority of a chancellor, a state-appointed administrator. Next, the well-established, private Central European University was forced to leave the country, and relocated its seat and most of its activities to Vienna. More recently, the Hungarian Academy of Sciences (HAS) has become the victim of the government's tightening grip on the research system: a decree hastily approved by parliament in July paved the road for massive structural reforms, which would effectively transfer to the government all control over the research institutions which today are overseen by the Academy. They would reduce the role of HAS to an academic club with little influence on Hungary's science agenda. To make things worse, the newly appointed minister for innovation and technology, László Palkovics, announced in January that all academy institutes will need to apply to his ministry, through a competitive tendering process, for their entire budget – including basic funding which is urgently needed to pay for their running costs. It seems unclear who will evaluate the applications, what the criteria will be, and when funds will be released.

The government claims that the reorganization of the research system is a necessary move to improve efficiency and promote innovation. Whereas this is a laudable objective when taken at face value, there can be little doubt that – in the context of the present political climate in Hungary –it conceals, in the words of the HAS staff forum, a "crackdown on academic freedom". From the post-communist democratic transition, the venerable Academy – it was established in 1825 – emerged as a strong institution of international reputation which, for the past thirty years, has forcefully defended its independence and political neutrality. A well-thought-out and successful reform, conducted in 2011-2012 under the leadership of former HAS President József Pálinkás, restructured the Academy institutes into fifteen research centres and modernized management and funding structures, enhancing further its reputation and international competitivity. More recently, the ambitious "Momentum" programme has helped to retain the best scientific talent in Hungary, and to bring others back from abroad.

Against this background, the plans of the government raise widespread, legitimate concern that they will have serious consequences, and cause irrevocable damage far beyond financial imponderabilia. Institutes and research disciplines which do not conform to the visions of Prime Minister Viktor Orbán and his ultra-nationalist Fidesz party are likely to suffer most, notably in the humanities and social sciences. But it is no secret that basic research in the natural sciences is not popular with the government either. The climate of financial insecurity, and of massive threat to academic freedom and diversity, will unavoidably cause a new brain drain and a massive loss of talent for Hungary.

HAS President László Lovász, the Presidium and the academic staff are fighting hard to defend the independence of the Academy and to protect the excellence of Hungary's research landscape. They are to be commended on their steadfastness, and they deserve the respect and unreserved solidarity of the international scientific community.

Once again, we are challenged to defend the most fundamental values on which the scientific enterprise is built.

A worrying aspect of the Hungarian government's plans is that they serve as a blueprint for nationalist and populist movements which are on the rise in other European countries (and beyond). Moreover, opinion polls predict a significant gain in votes for populist parties at the forthcoming elections to the European Parliament, with consequences for European research institutions and future Framework Programmes. When the Berlin Wall came down in 1989 – with help from Hungary, ironically – we were all optimistic that we were entering an era where freedom of science and freedom of scientists could be taken for granted indefinitely. We were proven wrong. Once again, we are challenged to defend the most fundamental values on which the scientific enterprise is built.

This is the last contribution to *europhysics news* which I write during my term as EPS President, and I find it sad to end my series of editorials on a pessimistic note. By the time you read this, I will have passed the baton to my successor Petra Rudolf. Under Petra's leadership, the European Physical Society will be in safe and capable hands – and I hope that she will find better news and more positive developments to write about. Good luck, Petra! ■

Rüdiger Voss,
EPS President

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Emmy Noether Prize

Chiara Mariotti [Figure 1], a researcher at CERN and at the INFN, University of Turin, has been awarded the prestigious Emmy Noether Distinction of the European Physical Society for her exceptional contributions in the field of high energy and particle physics that include the creation of the LHC Cross-Section Working group and a prominent role on analyses leading to the discovery of the Higgs (H) boson, as well as decisive mentoring role for many young women physicists.

Born in Turin, Chiara joined the INFN in 1993 and then CERN from 1996 to 2002. She became a senior researcher at the INFN-Torino in 2002. She has been residing with her family in Thoiry on the French border near CERN for the past 20 years. Upon arrival at CERN, she quickly became a leading physicist in the DELPHI experiment at CERN LEP e^+e^- collider, in charge of various analysis groups until she became the overall Physics Coordinator in 1999. She remained the DEPLHI physics coordinator for almost a decade, responsible for the steering between the various analyses searching for new particles (especially the H boson), ensuring fast feed-back and preparing results for the LEP-Committee meetings and the conferences, as well as establishing the strategy for publications as chair of the DELPHI steering panel which comprised all physics group conveners of the experiment. In parallel to her DELPHI activities, she joined the CMS experiment at the LHC pp collider and became deputy leader of the Torino-CMS group. She supervised several PhD students sharing activities between the construction and commissioning of the barrel drift tubes muon detector. Many of the young people she

▲ **FIG. 1:** Chiara Mariotti as a mentor of many young physicists. Here explaining the H boson production from gluon-gluon and WW fusion in pp collision at CERN.©Niklas Elmehed

mentored have advanced since then to become key actors of the physics analysis in CMS. Chiara has played a pivotal role as a model in particular for many young women physicists who admired her enthusiasm, clarity and vision.

Chiara played a major role in the preparation for the H boson analysis and became co-convener of the CMS Higgs Physics Analysis group for a 2 years mandate starting in 2008. I had the pleasure to share one year of mandate with Chiara during that period and could vividly appreciate her exceptional skills in bringing the numerous groups and physicists coherently together to prepare the H boson discovery. Always a step ahead, Chiara was a founder and co-ordinator in 2010 of the LHC Higgs Cross Section Working Group that helped to produce LHC-wide agreements on cross sections, branching ratios and pseudo-observables relevant to SM and MSSM Higgs boson(s), a crucial work for future comparison and combination of results. She then became successively co-convener of the CMS "H to ZZ analysis sub-group" and of the CMS "Higgs Combination and properties" sub-group during the key discovery and H boson characterization period from 2011 to 2013 [Figure 2], providing measurements of the H boson mass, coupling strengths and spin-parity. Chiara herself was the leading co-editor of an extended version of the CMS H boson discovery paper published in 2013. She further convened the LHC Higgs Combination Group which made possible the first combination of ATLAS and CMS H boson results.

Besides her exceptional contributions to science, Chiara Mariotti has always been concerned with outreach activities. In the aftermath of the H boson discovery, after intense years of research in physics at CERN, Chiara finally found the time to indulge her passion for music. She dusted off her concert flute, followed her two boys at the Thoiry Musical School, got support from a teacher at the Geneva Conservatory, and swiftly rediscovered her sensations with the musical instrument. As an accomplished musician, she was then able to inspire us in 2014 at the occasion of CERN 60th birthday, collaborating with the physicist-musician composer Domenico Vicinanza on a sonification of physics. The sonification consists of applying a fixed algorithm to reinterpret a measured distribution, say that of the reconstructed invariant mass of individual H event candidates, and compose a complete musical score around this. Since then, Chiara has deployed her musical talent in a number of concerts in France, Switzerland and Croatia, and contributed to original video movies for the sonification of the H boson discovery at CERN [Figure 3].

With her contribution to leading research in science which she managed to enchant with music, Chiara successfully brought together two of the most creative areas of human activities. It is a great scientific and musical adventure for an exemplary women career which has been highlighted by the 2018 Emmy Noether Distinction. ■

Yves Sirois

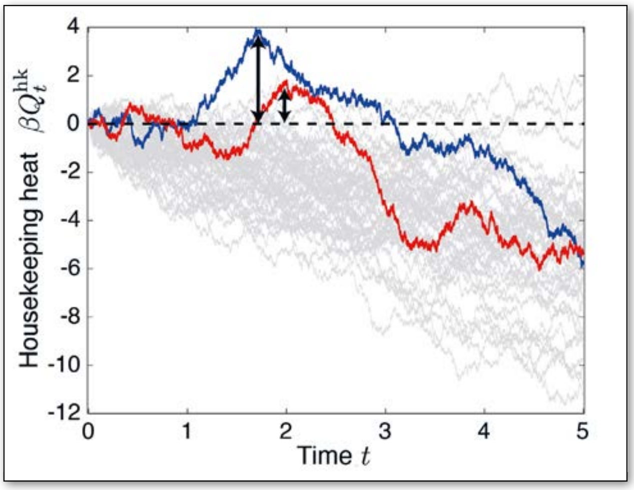
▲ **FIG. 2:** Just one of these legendary physics parties at Chiara's place in Thoiry. Here with her kids and part of the happy CMS H boson team on the 15th of June 2012 at the occasion of the H boson discovery.

▼ **FIG. 3:** Chiara Mariotti playing the H boson discovery on the concert flute in the CMS Cavern.

Highlights from European journals

STATISTICAL PHYSICS

Martingale theory for housekeeping heat



▲ Traces of fluctuating housekeeping heat (grey lines) behave like downtrend stocks. Our work investigates statistics of extrema (black arrows) against the average tendency.

Which universal thermodynamic properties emerge in a nonequilibrium process, in isothermal conditions at temperature T, that result from the violation of detailed balance, and how may they be quantified? The housekeeping heat is the fluctuating heat exchanged between a mesoscopic system and its environment due to the violation of detailed balance. Using the framework of martingale theory widely used in probability theory and finance, we derive a number of universal equalities and inequalities for extreme-value and stopping-time statistics of the housekeeping heat. Our theory provides a quantitative link between minimal models of gambling and financial markets (martingales) and heat fluctuations. The housekeeping heat behaves like a gambler's fortune in a casino: its expected value in the future is always smaller or equal regardless of its past values. The super-martingale structure of the housekeeping heat implies that certain statistical properties of the housekeeping heat are system-independent, *i.e.* universal. A particular result of our theory is that the average value of the maximum housekeeping heat that a system absorbs from its environment cannot exceed $k_B T$, with k_B Boltzmann's constant. ■

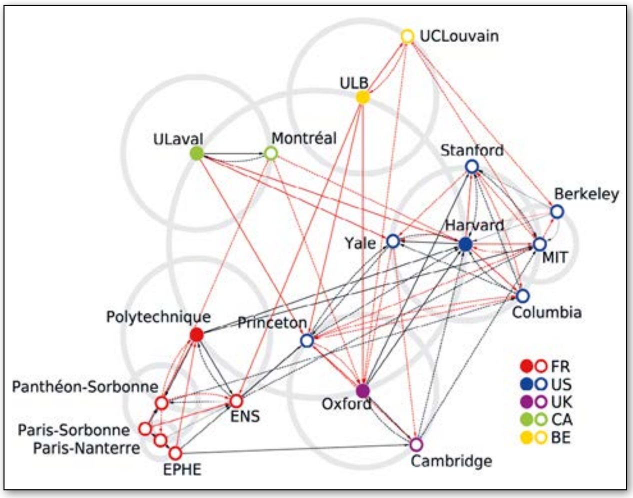
▮ **R. Chétrite**, **S. Gupta**, **I. Neri** and **E. Roldán**, 'Martingale theory for housekeeping heat', *EPL* **124**, 60006 (2018)

COMPLEX SYSTEMS

New university **ranking system includes the cultural perspective**

A new study proposes a new way of ranking universities, using a more balanced cultural view and based on 24 international editions of Wikipedia

Scientists in France have developed a new way of generating a ranking of the world's universities that places more emphasis on the cultural perspective. In a study published recently, the authors perform an analysis of Wikipedia editions in 24 languages, collected in May 2017—previous studies pursuing a similar approach focused on data from 2013. Employing well-known ranking algorithms, they establish a Wikipedia Ranking of World Universities based on the relative cultural views of each of the 24 language-specific Wikipedia editions. Thus, they provide a more balanced view that reflects the standpoints of different cultures. Specifically, the authors use (for the first time for this purpose) a new tool for the analysis of online networks, which is based on the PageRank algorithm and known as reduced Google Matrix analysis. In this study, they determine the interactions between leading universities on a scale of ten centuries, which provides insights into the relative influence of specific universities in each country. ■



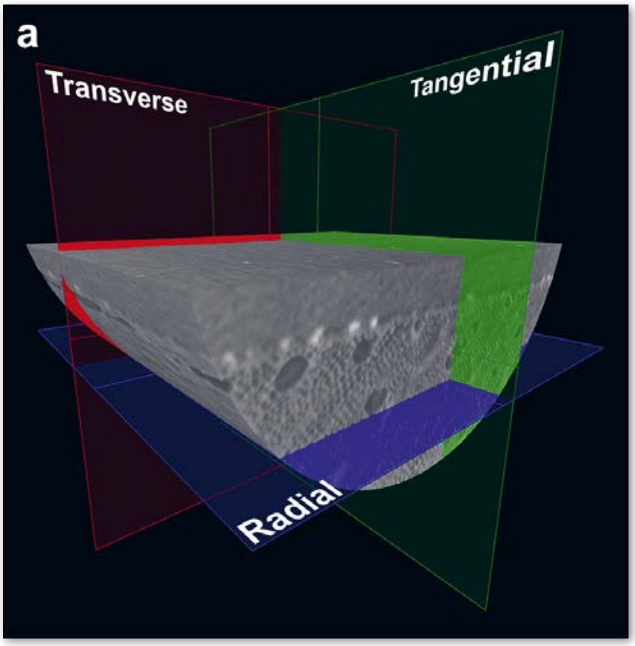
▲ Network of friends of top 20 PageRank universities from the French Wikipedia edition.

▮ **C.Coquidé**, **J.Lages**, and **D. L. Shepelyansky**, 'World influence and interactions of universities from Wikipedia networks', *Eur. Phys. J. B* **92**, 3 (2019)

APPLIED PHYSICS

3D virtual slicing of an antique violin reveals ancient **varnishing methods**

Physicists and chemists use 3D scanning to unlock the forgotten secrets of the multi-layered coating methods that give violins their exceptional tone and look



▲ Volume rendering of the wood with the coating system on it.

Italian violin-making masters of the 17th and 18th century developed varnishing techniques that lent their instruments both an excellent musical tone and impressive appearance. Few records from this era have survived, as techniques were most often passed down orally to apprentices; only scarce information is available on the original methods used for finishing the instruments. In a new study published recently, the authors use the YRMEP beamline at the Elettra Synchrotron facility in Trieste to develop a non-invasive 3D-scanning approach, using the Synchrotron Radiation micro-Computed Tomography (SR-micro-CT), that yields insights into the main morphological features of the overlapping finishing layers used on violins. In turn, the morphological images can be used to suggest the chemical nature of the materials involved in the finishing process. This newly developed method could help scientists rediscover the procedures and materials used, and reproduce the multi-layered coating methods of the ancient masters.

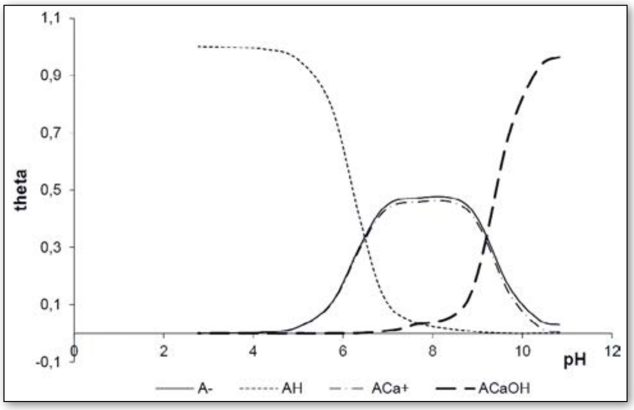
They first use the X-ray beam to scan two sets of mock-ups, prepared in their lab to mimic the finishing layers on the historical instruments. Using the mock-ups, they then optimise the 3D scanning settings, boost the spatial resolution and define the parameters required for 3D reconstruction. They then focus on a large fragment removed from a damaged cello made by the 17th-century Italian luthier Andrea Guarneri. Lastly, they compare their findings with those produced by micro-invasive analyses of the varnish to evaluate the merits of the reconstructed volumes and virtual slicing in terms of investigating such layered, complex structures. ■

▮ **G. Fiocco**, **T. Rovetta**, **M. Malagodi**, **M. Licchelli**, **M. Gulmini**, **G. Lanzafame**, **F. Zanini**, **A. Lo Giudice** and **A. Re**,
'Synchrotron radiation micro-computed tomography for the investigation of finishing treatments in historical bowed string instruments: issues and perspectives',
Eur. Phys. J. Plus **133**, 525 (2018)

BIOPHYSICS

How ion adsorption affects biological membranes' functions

A new study presents new models describing how the adsorption of calcium, barium and strontium ions onto biological membranes may affect the functions of cells



▲ Coverage of the lipid bilayer membrane surface with ions, as a function of pH.

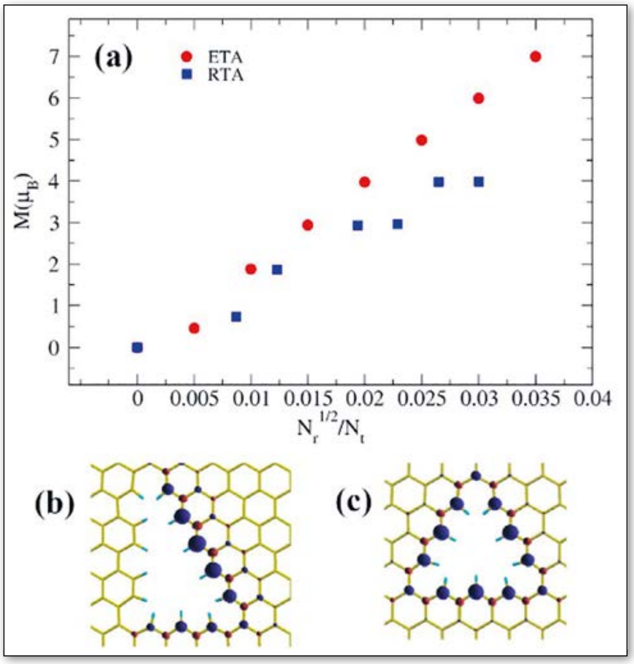
Ions with two positive electrical charges, such as calcium ions, play a key role in biological cell membranes. The adsorption of ions in solution onto the membrane surface is so significant that it affects the structural and functional properties of the biological cells. Specifically, ions interact with surface molecules such as a double layer of lipids, or liposomes, formed from phosphatidylcholines (PC). In a new study published recently, the author develops a mathematical model describing the electrical properties of biological membranes when ions such as calcium, barium and strontium adsorb onto them at different pH levels. Her work helps shed light on how ion adsorption reduces the effective surface concentration of add-on molecules with a specific function that can take part in biochemical reactions. These factors need to be taken into account when studying the diverse phenomena that occur at the lipid membrane in living cells, such as ion transport mechanisms. ■

■ **I. Dobrzyńska,**
'Association equilibria of divalent ions on the surface of liposomes formed from phosphatidylcholines', *Eur. Phys. J. E* **42**, 3 (2019)

CONDENSED MATTER

Holey graphene as Holy Grail alternative to silicon chips

Novel spintronics applications could stem from introducing holes into graphene to form triangular antidot lattices, granting the material new magnetic properties



▲ Total magnetic moments of triangular holes in graphene.

Graphene, in its regular form, does not offer an alternative to silicon chips for applications in nanoelectronics. It is known for its energy band structure, which leaves no energy gap and no magnetic effects. Graphene antidot lattices, however, are a new type of graphene device that contain a periodic array of holes-- missing several atoms in the otherwise regular single layer of carbon atoms. This causes an energy band gap to open up around the baseline energy level of the material, effectively turning graphene into a semiconductor. In a new study published recently, Iranian physicists investigate the effect of antidot size on the electronic structure and magnetic properties of triangular antidots in graphene. The authors have confirmed the existence of a band gap opening in such antidot graphene lattices, which depends on the electron's spin degree of freedom, and which could be exploited for applications like spin transistors. ■

■ **Z. Talebi Esfahani**, **A. Saffarzadeh**, and **A. Akhound**,
'A DFT study on the electronic and magnetic properties of triangular graphene antidot lattices', *Eur. Phys. J. B* **91**, 308 (2018)

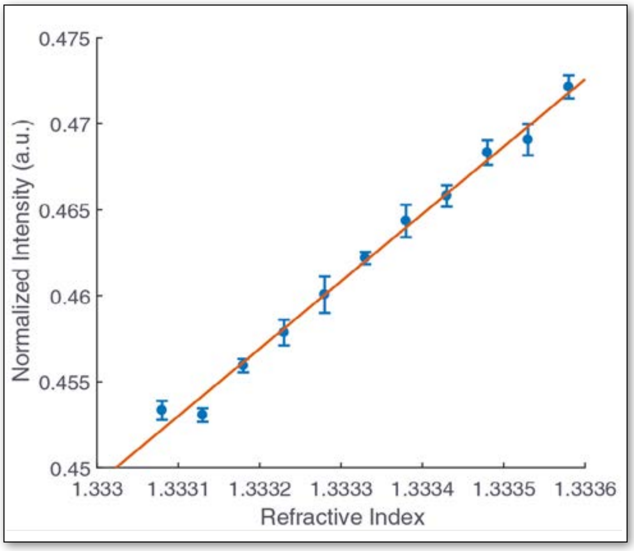
APPLIED PHYSICS

Multimodal microscope enables structural and functional cellular imaging

Answering cell physiology and pharmacology research questions often requires structural and functional information to be obtained from a network of cells. The authors have developed a multi-modal imaging system based on surface plasmon resonance (SPR) that combines several additional imaging modalities including bright-field, epi-fluorescence, total internal reflection microscopy and SPR fluorescence microscopy. The microscope features a wide field of view that can study ~40 cells simultaneously with subcellular resolution.

SPR is the collective oscillation of free electrons in a metal excited by polarized light. The resonance condition is highly dependent upon the refractive index of the media. Exploiting this allows the detection of both spatial and temporal variations in refractive index (RI) label-free.

▼ The sensitivity of the SPR imaging system.



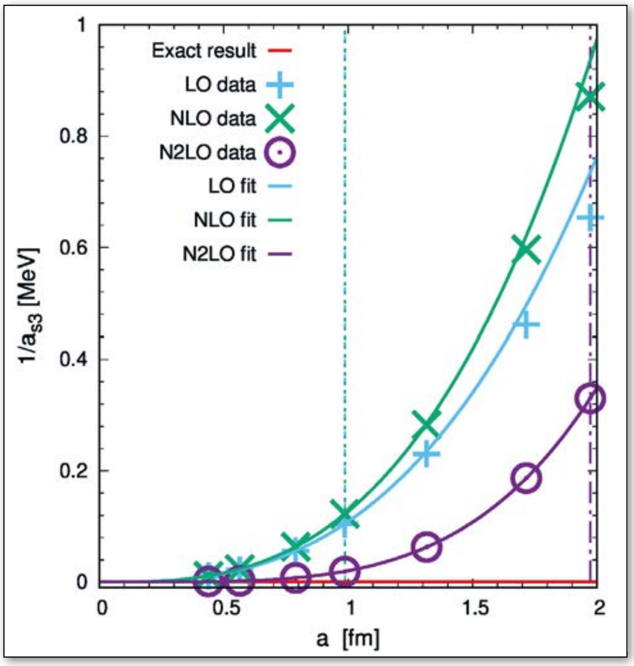
In this work the authors describe a detailed design of the microscopy platform including standard tests for characterization of spatial resolution and sensitivity. Using SPR for imaging requires that the cell of interest is closely adhered to the surface. The spatial variation of refractive index was shown to be reasonably homogenous from a cultured neuron. Finally, a prototypical functional imaging experiment is reported where spatiotemporal cellular functions of stem cell-derived cardiomyocytes have been realised by detecting localized contractions. ■

■ **C. L. Howe**, **K. F. Webb**, **S.A. Abayzeed**, **D. J. Anderson**, **C. Denning** and **N. A. Russell**,
'Surface plasmon resonance imaging of excitable cells',
J. Phys. D: Appl. Phys. **52**, 104001 (2019)

THEORETICAL PHYSICS

Lattice Improvement **in Lattice Effective Field Theory**

Lattice calculations using the framework of effective field theory have been applied to a wide range of few-body and many-body systems. One of the challenges of these calculations is to remove systematic errors arising from the nonzero lattice spacing. While the lattice improvement program pioneered by Symanzik provides a formalism for doing this and has already been utilized in lattice effective field theory calculations, the effectiveness of the improvement program has not been systematically benchmarked.



▲ The dimer-boson inverse scattering length $1/a{3}$ versus lattice spacing at LO, NLO, and N2LO. The vertical lines give the upper limits of the fit range.

In this work lattice improvement is used to remove lattice errors for a one-dimensional system of bosons with zero-range interactions. To this aim the improved lattice action up to next-to-next-to-leading order is constructed and it is verified that the remaining errors scale as the fourth power of the lattice spacing for observables involving as many as five particles. These results provide a guide for increasing the accuracy of future calculations in lattice effective field theory with improved lattice actions.■

■ **N. Klein**, **D. Lee** and **U.-G. Meißner**,
'Lattice improvement in lattice effective field theory',
Eur. Phys. J. A **54**, 233 (2018)

QUANTUM PHYSICS

Quantifying how much **quantum information can be eavesdropped**

New study yields more precise characterisation of monogamous and polygamous entanglement of quantum information units

▲ Eavesdropping. Photo by Dmitry Ratushny on Unsplash.

Encrypted communication is achieved by sending quantum information in basic units called quantum bits, or qubits. The most basic type of quantum information processing is quantum entanglement. However, this process remains poorly understood. Better controlling quantum entanglement could help to improve quantum teleportation, the development of quantum computers, and quantum cryptography. Now, the authors have focused on finding ways to enhance the reliability of quantum secret sharing. In a new study published recently, they provide a much finer characterisation of the distributions of entanglement in multi-qubit systems than previously available. In the context of quantum cryptography, these findings can be used to estimate the quantity of information an eavesdropper can capture regarding the secret encryption key. ■

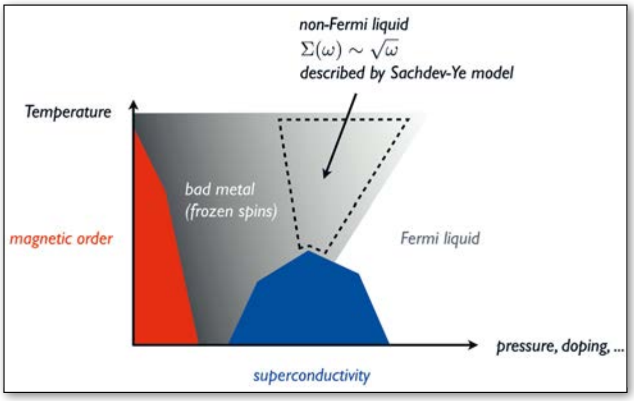
■ **Z. Zhang**, **Y. Luo**, and **Y. Li**,
'Tighter monogamy and polygamy relations in multiqubit systems', *Eur. Phys. J. D* **73**, 13 (2019)

CONDENSED MATTER

Spin freezing **and the Sachdev-Ye model**

The infinite-range, random-exchange Heisenberg spin model introduced in 1993 by Sachdev and Ye describes a non-Fermi liquid metal without quasi-particles, which resembles the bad-metal state of unconventional superconductors. Because of the somewhat artificial nature of the model, it is however not obvious how to connect this result to phenomena observed in strongly correlated materials. The latter are typically described by the Hubbard model and its multi-orbital extensions. Interestingly, the same non-Fermi liquid exponents as in the Sachdev-Ye model are generically observed in the correlated metallic phase of multi-orbital Hubbard models with Hund coupling. Our analysis suggests that the Sachdev-Ye model can be regarded as an effective description of a spin-freezing crossover regime with fluctuating local moments and that the variance of the random coupling in the Sachdev-Ye model is related to the Hund coupling. This analogy provides new insights into the nature of non-Fermi liquid metals, and into the close connection between spin freezing and unconventional superconductivity. ■

▼ Generic phase diagram of unconventional superconductors showing a bad metal phase with frozen magnetic moments crossing over into Fermi liquid metal. The crossover regime with fluctuating moments is effectively described by the Sachdev-Ye model.

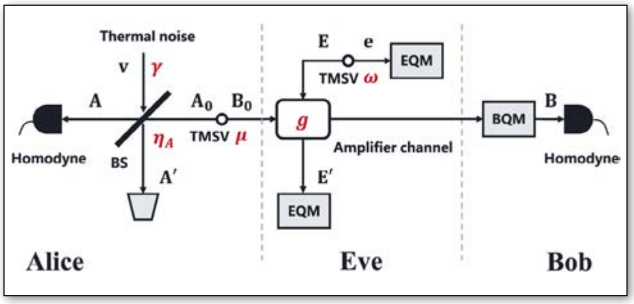


■ **Ph. Werner**, **A.J. Kim** and **Sh. Hoshino**,
'Spin freezing and the Sachdev-Ye model', *EPL* **124**, 57002 (2018)

QUANTUM PHYSICS

Better safeguards for sensitive information

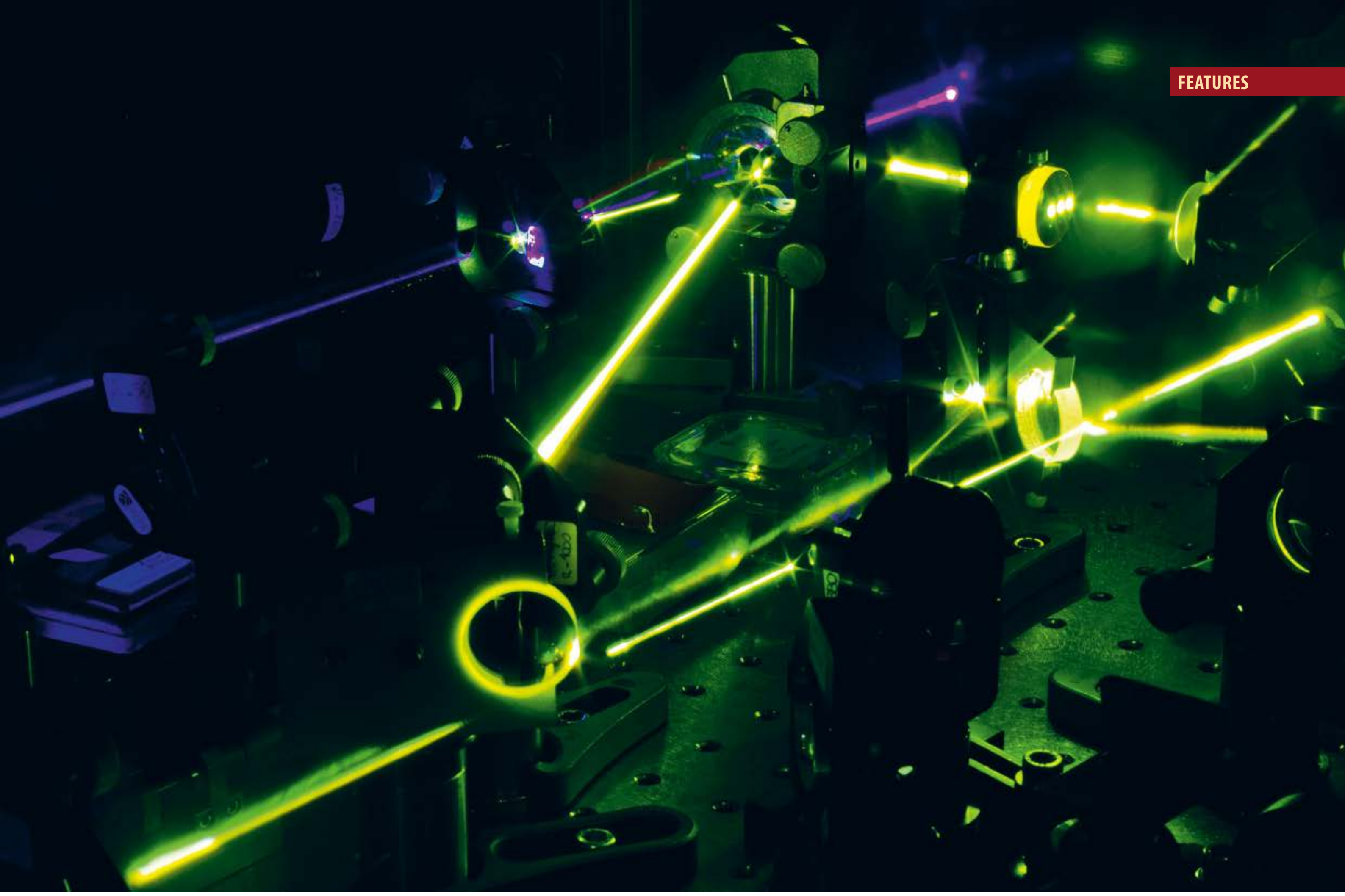
Study improves the lower boundary and secret key capacity of an encryption channel



▲ Schema of the encryption channel.

The secure encryption of information units based on a method called quantum key distribution (QKD) involves distributing secret keys between two parties—namely, Alice, the sender, and Bob, the receiver—by using quantum systems as information carriers. However, the most advanced quantum technology, QKD, is currently limited by the channel's capacity to send or share secret bits. In a recent study the authors show how to better approach the secret key capacity by improving the channel's lower boundary. They focus on a particular type of channel, called the noisy thermal amplifier channel, where the input signals are amplified together with noise induced by the thermal environment. The authors calculate the highest-known amount of secret information units, or bits, that Alice and Bob can share via such a channel. This is done by injecting controlled noise—made up of well-defined thermal agitation—into the detection apparatuses. By optimising over this noise, they improve the lower boundary of the capacity in the amplifier channel. The authors also confirm that the distribution of secret keys over this channel may occur at higher rates than the transmission of quantum information itself. ■

■ **G. Wang, C. Ottaviani, H. Guo,** and **S. Pirandola,**
'Improving the lower bound to the secret-key capacity of the thermal amplifier channel', *Eur. Phys. J. D* **73**, 17 (2019)



ULTRAFAST LASERS: FROM FEMTOSECONDS TO ATTOSECONDS

Giulio Cerullo and Mauro Nisoli – DOI: https://doi.org/10.1051/epn/2019201
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We review the capability of lasers to generate light pulses of incredibly short duration, from a few femtoseconds (1 fs = 10^{-15} s) in the visible down to a few tens of attoseconds (1 as = 10^{-18} s) in the extreme-ultraviolet, reaching peak powers up to several petawatts (1 PW = 10^{15} W).

Ultrashort laser pulses

One of the properties of lasers is the capability of generating a coherent monochromatic light beam, as opposed to incoherent, natural light, which is typically polychromatic, being emitted over a broad spectrum of frequencies. Soon after the advent of lasers, however, it was discovered that they can also produce broadband light in the form of trains of pulses, with duration ranging from the nanosecond down to the femtosecond temporal domain. The most widely used technique for the generation of short light pulses, in the picosecond and femtosecond range, is known as *mode-locking*, since the laser cavity modes are made to oscillate with some definite relation among their phases [1]. The light emitted from a mode-locked laser thus consists of the coherent superposition of many sine waves of different frequencies, corresponding to the longitudinal modes, which interfere destructively except at the times when they are all in phase. This interference

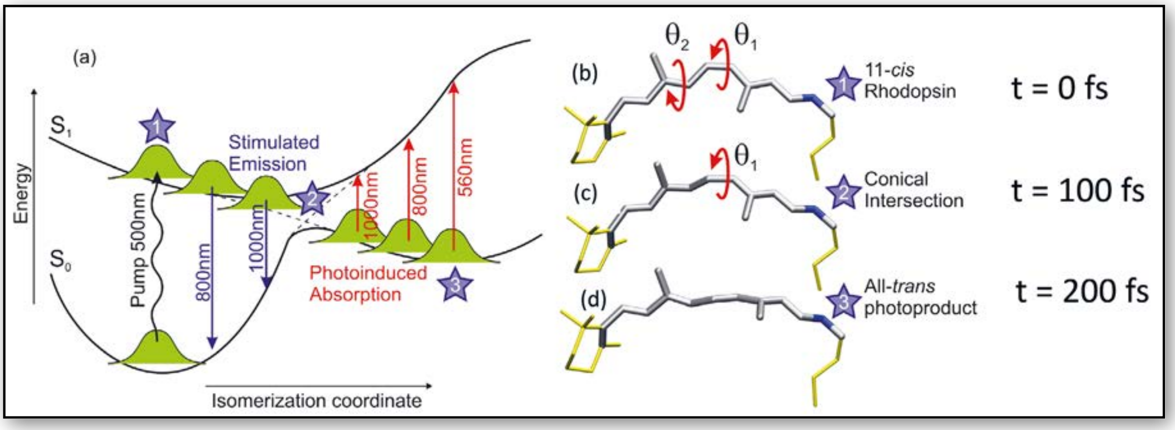


FIG. 1: Molecular movie of isomerization of rhodopsin. (a) wavepacket motion from the excited state potential energy surface of the reactant (with stimulated emission) to the ground state potential energy surface of the product (with photoinduced absorption). (b)-(d) calculated snapshots of the structure of retinal during the process at the initial 11-*cis* (b, $\theta_1 = -12.8°$, $\theta_2 = 173.9°$), conical intersection (c, $\theta_1 = -87.8°$, $\theta_2 = -144.6°$) and final *all-trans* (d, $\theta_1 = -141°$, $\theta_2 = -142°$) configurations [8].

pattern results in the emission of a train of ultrashort light pulses, spaced by the cavity roundtrip time, which is the time it takes for light to travel back and forth between the cavity mirrors. Each of these pulses has an ultrashort duration which, according to the Fourier transform theorem, is inversely proportional to the number of locked modes and therefore to the width of the frequency spectrum emitted by the laser. Already in 1965, after the discovery of laser mode-locking by DeMaria and co-workers [2], it was possible to generate light pulses with a duration of 10 ps, which is three orders of magnitude shorter than the shortest pulses of incoherent light, obtained with the electro-optic Kerr shutter. In the two following decades, there was an intense race to shorten the pulse duration, exploiting liquid dyes as optical amplification media because of their broad gain bandwidth. The pulse duration dropped by three additional orders of magnitude [3], to the femtosecond regime, until the milestone result by Shank and coworkers, who generated in 1986 visible pulses with 6-fs duration by using a post-compression technique based on the nonlinear optical process of self-phase modulation in an optical fibre [4]. **This is a remarkable achievement because such pulses contain just a few cycles of oscillation of the carrier light wave (for visible light at $\lambda = 600$ nm the oscillation period is $T = 2$ fs) and are thus close to the ultimate limit of pulse duration in the visible range**.

Applications of femtosecond pulses

In the following decades, important technical advances were introduced which greatly improved the reliability and the accessibility of femtosecond laser technology. Liquid gain media were replaced with solid-state ones, such as Ti:sapphire crystals and Yb:doped crystals and fibers, greatly increasing long-term stability and average power of the laser sources [5]. Second- and third-order nonlinear optical effects, such as self-phase-modulation and optical parametric amplification, were used to further broaden the spectrum of the pulses and to tune their frequency, enabling to cover an extremely broad range from the mid-infrared to the ultraviolet [6]. Exploiting this tunability, femtosecond pulses have become invaluable tools for physicists, chemists and biologists in order to investigate the ultrafast non-equilibrium processes occurring in atoms, molecules and solids, using a variety of spectroscopic techniques [7]. Femtosecond laser pulses can be used to shoot "slow-motion movies" of key photoinduced processes in bio-molecules, such a photosynthesis and vision, as well as to get insight into the non-equilibrium charge carrier dynamics underlying the operation of (opto)-electronic devices. As an example, Figure 1 shows a schematic sketch of the primary event of vision, which is *cis-trans* isomerization (*i.e.* structural rearrangement) of retinal ($C_{20}H_{28}O$), which is the visible light-absorbing chromophore covalently bound within rhodopsin , the light-sensitive receptor protein involved in visual phototransduction in humans and many vertebrates. A wavepacket, created in the excited state of the 11-*cis* reactant, slides on its potential energy surface until it reaches, within 200 fs, the ground state of the all-*trans* photoproduct (Fig. 1a). Ultrafast laser spectroscopy with 10-fs time resolution allows to record the characteristic signals of the isomerization [8] and, combined with ab-initio numerical simulations, to derive the structural dynamics of the retinal molecule during the process (Figs. 1b-d).

Increasing the pulse energy

Mode-locked lasers produce pulses with relatively low energy, of the order of a few nanojoules (1 nJ = 10^{-9} J), which cannot be directly amplified due to damage occurring in the optical gain medium when the intensity exceeds a certain threshold. This problem was elegantly solved by the invention of the Chirped Pulse Amplification (CPA) technique [9]. In CPA laser systems the ultrashort pulses are first temporally stretched, by sending them to an optical system in which their frequency components travel with different speeds and become temporally separated, resulting in a pulse-width lengthening by several orders of magnitude. The stretched pulses are then safely amplified without damaging the optical amplifier material and finally sent to a pulse compressor, which is an optical system where the relative delays of the different frequency components are reversed, thus restoring the original pulse duration. **The CPA technique, for which Donna Strickland and Gerard Mourou were honored with the Physics Nobel Prize in 2018, allowed to increase the energy of ultrashort pulses by over 10 orders of magnitude, resulting in peak powers reaching the petawatt regime.** Such incredibly high instantaneous powers, which exceed by more than two orders of magnitude the combined power of all the world electrical grids, enable completely new regimes of light-matter interaction, where electrons and ions can be accelerated by the laser light to relativistic speeds. Besides their huge scientific impact, ultrashort light pulses are finding more and more real-world applications in materials processing, as they allow depositing energy in the irradiated volume in a very short time, avoiding heat diffusion and resulting in clean ablation without collateral damage. High intensity femtosecond lasers are used for drilling holes in metals, such as in the injectors of diesel engines or the stents used in vascular surgery. They find also medical applications in refractive eye surgery, using the laser-assisted in situ keratomileusis (LASIK) procedure (where keratomileusis means surgical reshaping of the cornea) to correct myopia and astigmatism. It is worth mentioning that in the last few years the European Commission funded the Extreme Light Infrastructure (ELI), a pan-European infrastructure completely devoted to the generation and application of ultra-intense laser sources.

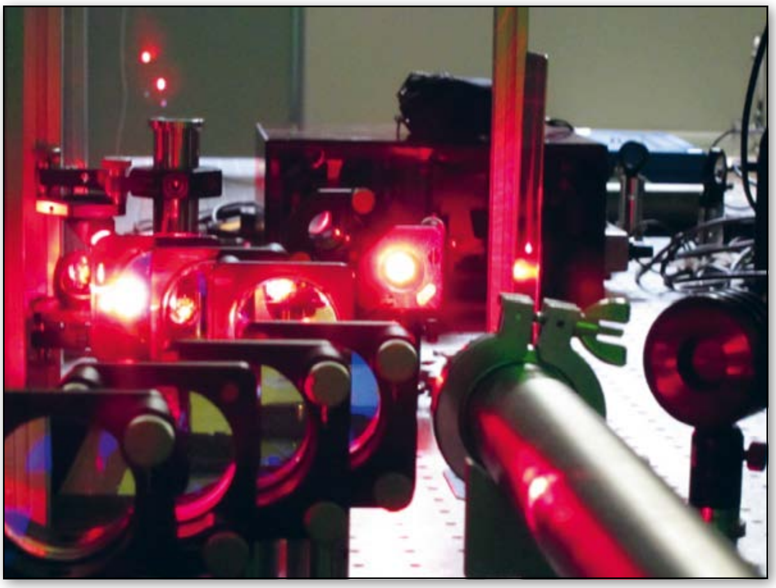
Attosecond pulses

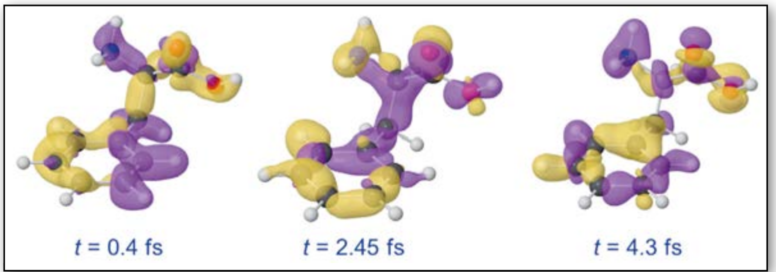
A further conceptual breakthrough in ultrafast optics was achieved with the discovery of high-harmonic generation (HHG) from noble gas atoms illuminated by ultrashort light pulses with a peak intensity of the order of 10^{13}-10^{15} W/cm^2. The process of HHG can be intuitively understood in terms of the so-called "three-step model" [10-11]. When the electric field of the driving light pulse is intense enough, an outer-shell electron is tunnel ionized from the atom into the continuum (first step). The freed electron is then accelerated by the light electric field, gaining kinetic energy (second step); when the electric field of light points in the opposite direction in the course of an oscillation cycle, the electron is accelerated back to the parent ion and, with a small probability, recollides with it. If the recolliding electron recombines with the parent ion, the kinetic energy acquired during its motion in the continuum can be released in the form of a burst of high-energy photons with attosecond temporal duration (third step). Since this process is periodically repeated every half optical cycle of the fundamental radiation, a train of attosecond pulses is generated, separated by half the optical cycle of the driving field. If the harmonic generation process is confined to a single event, by using few-cycle driving pulses with controlled electric field and employing suitable gating techniques, isolated attosecond pulses can be generated: this is important for a number of applications. Typically, sub-5-fs pulses with energy in the millijoule range are generated by using a post-compression technique based on spectral broadening in a gas-filled hollow-core fibre [12]. Figure 2 shows the spectrally-broadened beam at the output of a hollow fibre, which is reflected by a few chirped mirrors used for ultrabroadband dispersion compensation.

Applications of attosecond pulses

Since the first experimental demonstration of the generation of attosecond pulses in 2001 [13-14], such pulses have been used in time-resolved spectroscopy with extreme temporal resolution. **The main target of attosecond science is to get direct access to the electronic dynamics in atoms, molecules, nanostructures and solids, and the possibility to directly control such ultrafast processes.** A number of spectacular applications of attosecond pulses has been reported in the last 18 years, ranging from atomic physics to solid-state physics. The application of attosecond techniques to atomic physics has proven to be crucial for example for the measurement of the delay in photoemission and for the analysis of the process of tunnel ionization. Application of attosecond pulses in molecular physics has been pioneered in 2010, with the investigation of the charge localization process in hydrogen molecules initiated by isolated attosecond pulses (see Ref. [15] for a recent review on the application of attosecond pulses to the investigation of ultrafast dynamics in molecules). Attosecond pulses have been used more recently to investigate the process of charge migration in aminoacids [16]. Theoretical studies have pointed out that very efficient charge dynamics can be driven by purely electronic effects, which precede any rearrangement of the nuclear skeleton and which can evolve on a temporal scale ranging from few femtoseconds down to tens of attoseconds. This ultrafast charge dynamics, essentially driven by electron correlations, has been referred to as charge migration. The first experimental measurement

▾ FIG. 2: Spectrally-broadened beam at the output of a gas-filled hollow fibre, reflected by a set of chirped mirrors.





▲ FIG. 3: Charge dynamics calculated in phenylalanine after excitation by an isolated attosecond pulse at $t = 0$ [16]. Dark gray spheres represent carbon atoms, light gray spheres hydrogen atoms, blue sphere nitrogen and red spheres oxygen.

of charge migration in the α-amino acid phenylalanine ($C_9H_{11}NO_2$), after attosecond excitation was reported in 2014 [16]. An α-amino acid consists of a central carbon atom (α carbon), linked to an amine (-NH_2) group, a carboxyl acid (-COOH) group, a hydrogen atom and a side chain, which is specific to each amino acid. In particular, we investigated the aromatic amino acid phenylalanine, where the side chain is a methylene (-CH_2-) group terminated by a phenyl ring. The molecular structure of the most abundant conformer of phenylalanine is shown in Figure 3. Phenylalanine plays a key role in the biosynthesis of other amino acids and is important in the structure and function of many proteins and enzymes. Figure 3 shows the calculated evolution of the charge density in phenylalanine after prompt ionization induced by an attosecond pulse: a notable rearrangement of the charge is already visible 2 femtosecond after the excitation. The application of attosecond technology to the investigation of electron dynamics in biologically relevant molecules represents a multidisciplinary work, which can open new research frontiers: those in which few-femtosecond and even sub-femtosecond electron processes determine the fate of bio-molecules.

The extension of attosecond methods to solid-state physics is still limited, but important results have been already achieved. The experimental results reported so far demonstrate that the application of attosecond techniques to solids offers the possibility to investigate important physical processes, not accessible by using longer temporal resolution. The measured delays in photoemission from various solids are of the order of a few tens of attoseconds [17]; the intra-band motion of charges leading to the Franz-Keldysh effect in dielectrics evolves on the attosecond time scale [18]; the measured upper limit for the carrier-induced band-gap reduction and the electron-electron scattering time in the conduction band of silicon is of the order of a few hundreds of attoseconds [19]. These results clearly demonstrate the advantages offered by the application of attosecond techniques.

Finally, we mention that an alternative way for generating intense ultrashort pulses in the VUV/X-ray energy region is provided by X-ray free-electron lasers (FELs): several techniques have been proposed in the last years to generate high-energy attosecond pulses with these lasers. ■

About the authors

Giulio Cerullo is Full Professor of Physics at the Politecnico di Milano. His research activity deals with the generation of tunable few-optical-cycle light pulses and their application to the study of photoinduced processes in biomolecules and nanostructured materials. He is Chair of the Quantum Electronics and Optics Division of the European Physical Society.

Mauro Nisoli is currently Full Professor with the Department of Physics at Politecnico di Milano. His research interests include attosecond science, ultrashort-pulse laser technology, control and real-time observation of electronic motion in atoms, molecules and nanoparticles. He is author of about 200 research papers in international journals.

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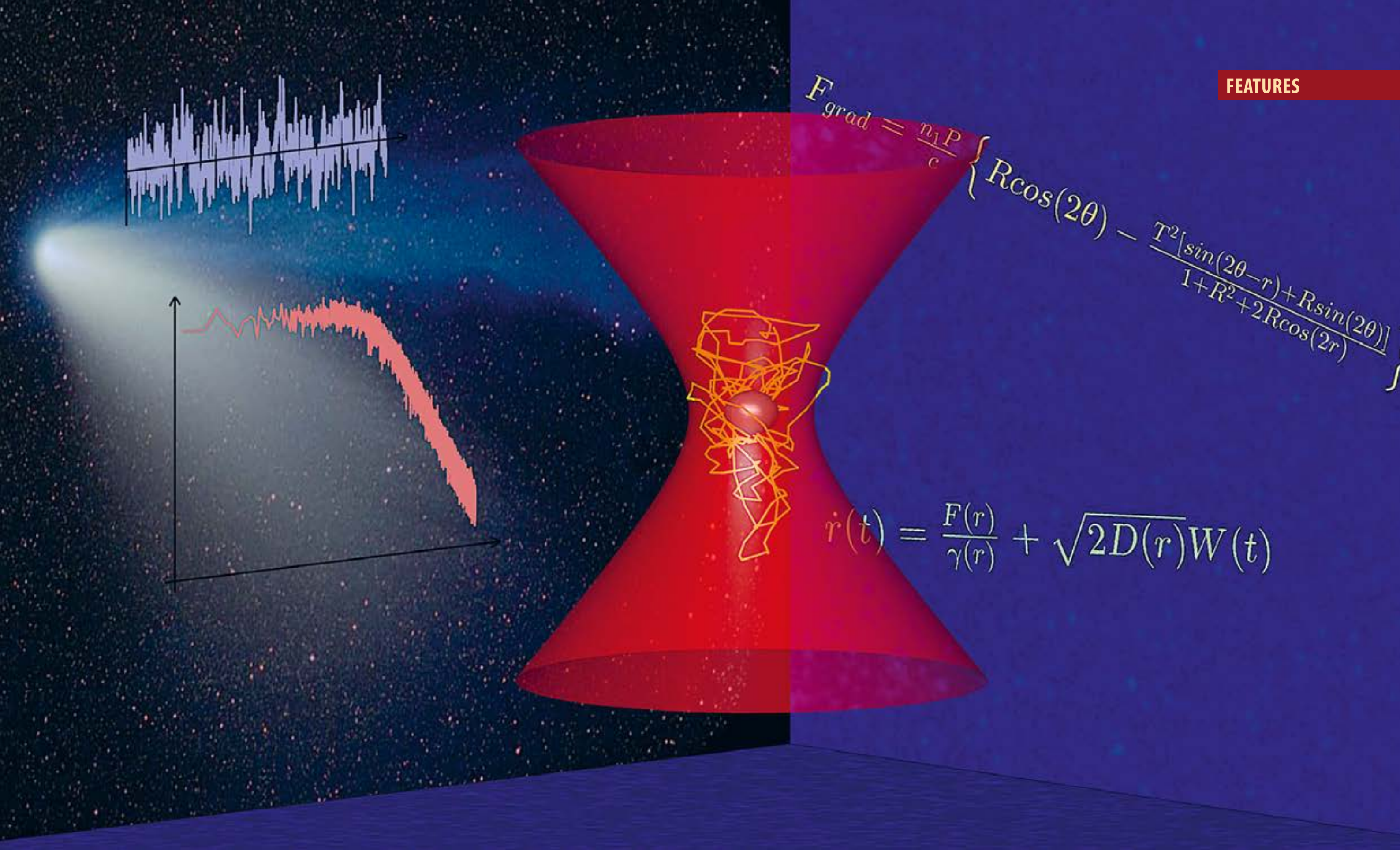

MANIPULATING MATTER WITH LIGHT

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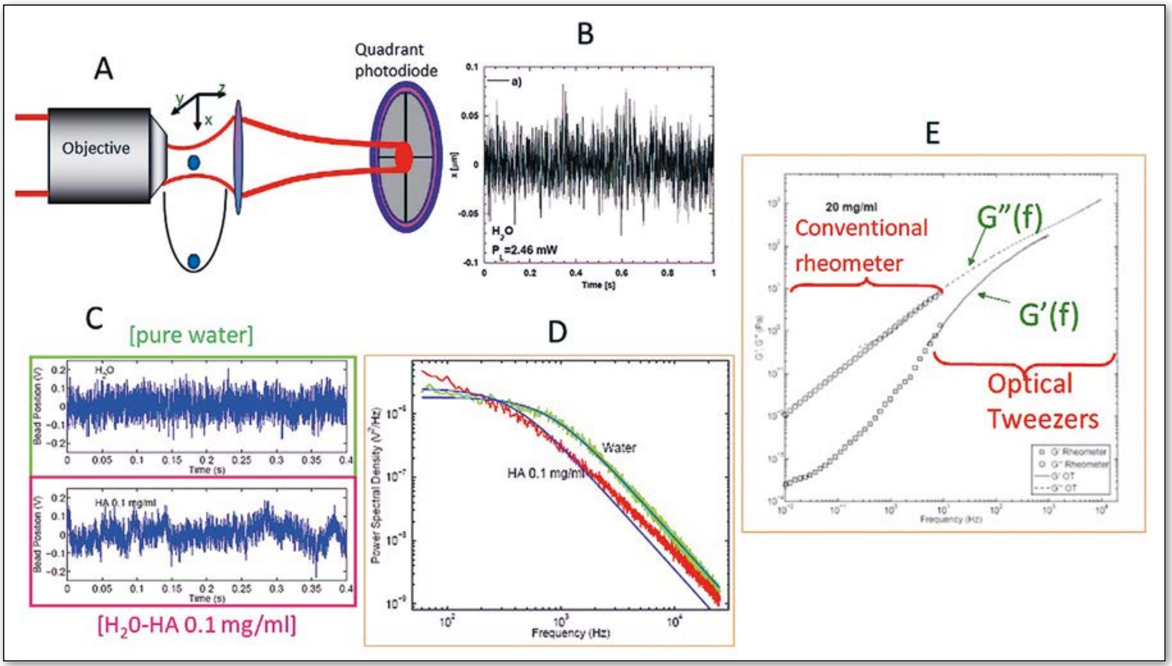
Arthur Ashkin, with his discovery of the optical tweezers, has made possible the dream of science fiction to manipulate matter with light. The optical tweezers have opened up an extremely interesting field of science, not yet exhausted, where questions of fundamental physics intertwine with intriguing investigations of biological systems at level of single macromolecule or cell.

Arthur Ashkin, with his discovery of the optical tweezers, has opened up an interesting research topic where fundamental physics intertwines with intriguing investigations in the biological field.

While the energetic effects of light are rather known being close to our daily life, the mechanical ones, *i.e.* the ability of light to exert forces and torques on the matter, are less know but much more intriguing.

The advent of the laser has made possible to use such effects for manipulating not only atoms but even objects of microscopic size. This has produced very relevant discoveries in the field of physics as proved by the numerous Nobel prizes awarded in the last two decades for laser cooling techniques and Bose-Einstein condensates. The last Nobel Prize awarded in 2018 to Arthur Ashkin *"for the optical tweezers and their application to biological systems"* represents a particular feature of this physics at the frontier with other scientific disciplines such as biology and medicine.

Following back the steps of this long journey quickly, it was the astronomer J. Kepler (1571-1631) to advance the first proposal of the mechanical properties of light ascribing the comets' tails formation to the "solar wind".



▸ **FIG. 1:** A micrometric bead is confined in the harmonic potential well of the trap **(A)** and its stochastic trajectory is acquired by a quadrant photodiode with accuracy of few nm **(B)**. The stochastic traces are altered from the passage from a Newtonian fluid to a complex one, as shown in **(C)** and **(D)**. Losses and elastic moduli versus the frequency as determined with conventional rheology and OT-based microrheology (E).

J.C. Maxwell, with his electromagnetic theory, interpreted the solar wind in terms of radiation pressure. Later on, the quantum theory introduced the concept of momentum carried per single photon.

The phenomena related to the experimental verification of the mechanical effects of light by Lebedev and Nichols and Hull (1901) using conventional lamps were certainly important but they had no follow-up for many years until the laser was invented (Maiman, 1960).

Optical manipulation, as we intend it today, is certainly due to the pioneering work of Arthur Ashkin who, using weakly focused laser beams, was able to drive and accelerate dielectric microparticles in water (1970) or to hold them suspended by balancing gravity (optical levitation). In those years he also hypothesized the possibility of rotating particles and to apply these techniques to atoms.

In 1986, Ashkin and his colleagues Dziedzic, Bjorkholm and Chu [1] realized at the Bell Labs the first optical trap or optical tweezers (OT) based on tightly focused laser beam by high-numerical aperture microscope objectives. The gradient force was so great as to overcome the radiation pressure which, instead, tends to push the particles in the direction of propagation of the laser beam. The gradient force can be approximated by F_g=-kΔx, *i.e.* it acts as a spring. Since sizes of trapped particles can range from tens of nanometers up to some tens of micrometers and considering that the involved optical forces can vary from nN to fN, it was immediately evident the huge potentiality to extend OT to contactless manipulation of biological particles, as virus or cell (1987). Handling of biological particles, however, requires keeping as low as possible optical absorption to avoid thermal and photochemical damages.

From 1985 to today the number of publications based on OT has grown impressively with applications in various fields of physics and bio-medicine. In these years, the development of exotic laser beams (Bessel, Airy and Mathieu beams) based on diffractive optics and holography has led to optical lattices for multiparticle trapping for new experiments in microscopic science (particle sorting, optical binding, *etc.*). Shaping phase and amplitude of laser beams optical vortex have been set up for transferring orbital angular momentum. Moreover, combination of plasmonic with optical trapping has opened new possibility for bioscience at nanometric scale.

For exhaustive reviews on OT see the textbooks [2-4].

In this short article we will touch only few of the many application based on OT performed at the Department of Physics of Naples.

Exploring mechanical properties of complex fluids at mesoscopic scale

An optical trap can be approximated by a harmonic potential and a bead confined in it behaves as a sort of extremely sensitive dynamometer suitable for exploring, on a mesoscopic scale, very soft forces exchanged with environment. In water, a purely viscous medium, the confined particle is animated by Brownian motion governed by the overdamped regime Langevin equation:

$$\dot{x}(t) = -\Gamma\frac{dU}{dx}+f_{ther}(t) \qquad (1)$$

where $1/\Gamma=6\pi\eta\alpha$, being η the fluid viscosity and α the particle radius), $U=1/2kx^2$ is the trap potential (with k the *trap stiffness*), $f_{ther}(t)=(2\Gamma k_B T)^{1/2}\delta(t\text{-}t')$ represents the random thermal forces. A characteristic time of the system is t, the ratio between the hydrodynamic factor and the trap stiffness ($\tau=1/\Gamma k$) which is of the order of 0.03 s. A solution of Eq.(1) can be given in terms of the mean square displacement (MSD) or the power spectral density (PSD) or the autocorrelation function (ACF). Therefore, once calibrated the traps, analyzing one of these functions the local viscosity around the particle can be estimated. This sort of micro-viscosimeter can also be made by revisiting the well-known Beth's experiment (1936), *i.e.* using spin or orbital angular momentum of the light to rotate microspheres. Balancing optical and dragging torques the particle achieves a limit angular velocity depending on the viscosity of the medium.

More intriguing is the case of complex fluids, characterized by the coexistence of viscous and elastic character. Usually such properties are measured by means of rheometers, whose main limits lie in mechanical inertia of the instruments. Moreover, even if the quantities of fluid that are needed are quite small (centiliters), in some cases, as for example for rare biological substances, there is an objective limit of their applicability. On the contrary, an OT needs only a few femtoliters and can explore viscoelasticity of environments not accessible to a conventional rheometer, even the inner part of living cell (microrheology), so allowing to study cytoplasm transformations due to external stimuli.

A spherical probe embedded in a complex fluid experiences a stochastic force F_x and its displacement x is linearly related: $x(f)=\alpha(f)F_x(f)$, where $\alpha(f)$ is the complex response of the material related to the complex shear modulus G^* through the generalized Stokes-Einstein equation and the fluctuation-dissipation theorem.

In Fig. 1 is shown the essential scheme of an OT. The stochastic traces of pure water (Newtonian) and of hyaluronic-water mixtures (complex fluid) are compared in terms of the relative PSD. Only for Newtonian fluids the PSD is represented by a Lorentzian curve showing a power law $1/f^2$ (panel D). The elastic $G'(f)$ and viscous $G''(f)$ moduli estimated by OT well match with traditional rheometer but cover a wider frequency range [5].

Molecular motors and "apparent" thermodynamics violation

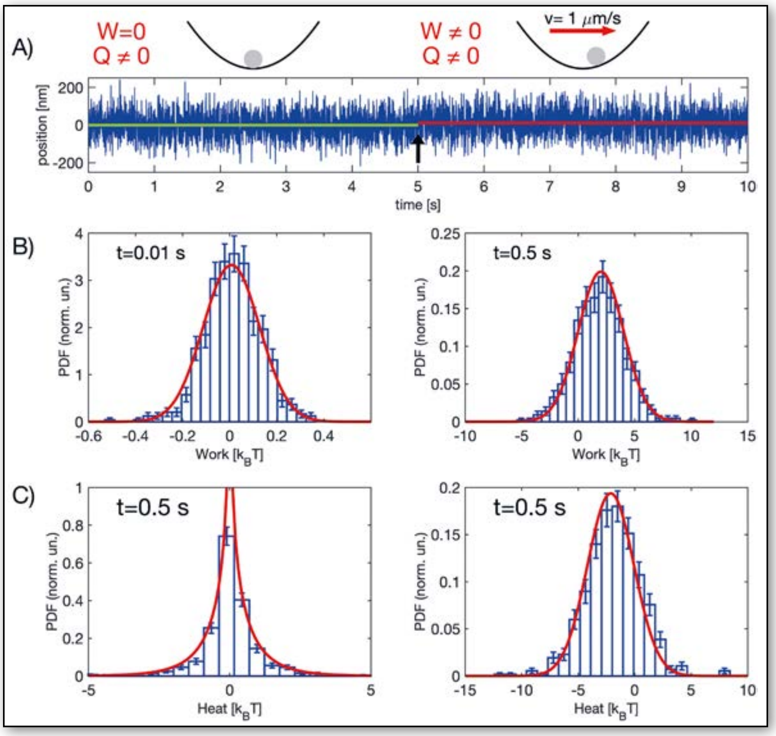
Among the many application in biology, OT have made many contributions to our understanding of the mechanochemistry of molecular motors. In 1993 Svoboda *et al.* [6] have studied the mechanisms which govern linear motors, as kinesin-actin, in which the energy of ATP hydrolysis in converted into mechanical work finding the characteristic steps and forces involved.

From a thermodynamics point of view, an OT behaves as a microsystem where the fluctuations of work and heat that it exchanges with the surrounding environment are comparable with thermal energy k_BT. Hence, it is not surprising having transient violation of the second principle of thermodynamics.

Let us consider a bead dragged through water with a certain velocity X'(t). The potential energy difference ΔU between the initial and final state is ΔU=W+Q, being W and Q the thermodynamical work done on the particle and Q the heat exchanged by the particle with the thermal bath. The Langevin Eq. (1) can be modified by replacing the static potential U(x) into a time-dependent potential $U(x, X(t))=1/2k(x-X(t))^2$, with X(t)=v·t. Therefore, the work done on the particle and the heat exchanged with the environment are:

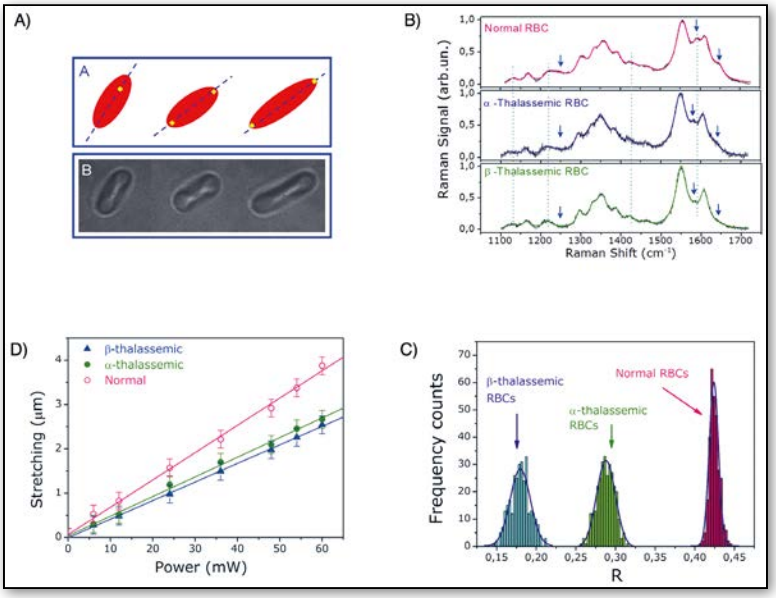
$$W=\int dX\,\frac{\partial U}{\partial X} \qquad Q=\int dx\,\frac{\partial U}{\partial X} \qquad (2)$$

Since x is a stochastic variable, also the integrals of Eq.(2) are stochastic, *i.e.* they have to be considered in terms of probability distribution function (PDF). In our experiment [7], the work and heat done and exchanged during a single trajectory was measured by dragging the microscope stage for 5 s with a velocity of 1 µm/s repeating the procedure for 600 trajectories. In Fig.2 it is shown the trajectory when the stage was at rest (used for trap calibration) and the successive trajectory during the motion. The estimated trapping and dragging forces were ~12 and ~9 fN, respectively, hence the work done on the particle resulted actually comparable with k_BT. The histograms and the expected PDF from theory of W are plotted in Fig.2 for times shorter (t=0.01 s) and longer (t=0.5 s) than the characteristic time τ =0.026 s. For W both distributions are Gaussian:



▼**FIG. 2: (A)** Stochastic trace of a trapped bead at rest and dragged at a velocity of 1 µm/s. **(B)** Histograms of the work exerted on the particle by the optical trap for *t*=0.01 s and *t*=0.5 s. **(C)** Histograms of the heat exchanged by the colloidal particle with the environment, with optical trap at rest *v*=0 and with *v*=1µm/s. The lines corresponds to the expected PDF as given by theory [7] with no adjustable parameter.

for t<<τ (entropy consumption regime) the distribution is centered around zero while the peak moves to positive values as t increases. The exchanged heat Q was instead measured: i) with the stage at rest and ii) moving the trap with v=1 µm/s. For both cases the histograms agree with the expected theoretical PDFs; in particular the tails of the distribution were found to be exponential for the first



▲ **FIG. 3:** Typical images of stretched RBC **(A)**. Raman spectra of healthy and thalassemic erythrocytes; the two peaks highlighted by the arrows represent vibrational modes sensitive to oxy/deoxy states **(B)**. Histograms of the ratio R obtained analysing three volunteers groups **(C)**. Response to applied stretching for normal and abnormal RBCs **(D)**.

case while the distribution resulted Gaussian for moving trap (in agreement with theory). It can also be seen that the mean values of the work and of the heat are the negative of each other, as expected in the longtime range.

Manipulation and spectroscopy of single cell

Another significant achievement based on OT concerns their application to biological studies at the single-cell level.

By using an OT, it is possible to catch a single cell and to stretch it by trapping directly two of its ends or two bonded beads used as handles (optical stretcher).

An optical stretcher can also be realized with microfluidic systems (lab-on-a-chip) in which cells pass one at a time between two opposed, non-focused laser beams, emitted from optical fibers. These experiments allow us to study the mechanical response of a cell, a very important parameter to distinguish cells at different phase of their development, or, more importantly, healthy from diseased cells.

Optical manipulation has been also combined with Raman spectroscopy (Raman Tweezers). Raman spectroscopy is in fact able to provide a sort of digital fingerprint of the cell allowing an imaging reconstruction in terms of the cellular constituents (lipids, proteins, DNA, etc).

Red blood cells (RBCs) have been extensively investigated for this type of activity, both for the ease of finding this type of cells and for the relevance associated with many blood disorders.

For instance, one significant question is to better understand the oxy/deoxy transition of hemoglobin (Hb) during the stretching which occurs when erythrocytes pass through microcapillaries (Hb is packaged in a smaller volume facilitating its interaction with the cell membrane in contact with the vessels). Nevertheless, alterations of oxy/deoxy states can also reflect blood diseases, including thalassemia, a genetic defect which reduces the synthesis of one of the globin chains α and β of Hb. The ratio $R = I\nu_{37}/I\nu_{11}$ between two Hb bands sensitive to iron spin-state in the heme-group, enables to distinguish quite well normal from α and β thalassemic volunteers (see Fig.3).

It is interesting to note that, in addition to a reduced oxygenation capacity of the thalassemic red blood cells, the stiffness of such abnormal erythrocytes is also higher, affecting the release of oxygen during the stretching in microvessels (panel D of Fig.3) [8].

We can conclude by saying that the continued improvements of optical manipulation techniques will certainly enable many fascinating discoveries in the field of physics and biophotonics. ■

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Our group has been working with OT since 2000 dealing with many aspects related to them: force measurements, microrheology of polymeric systems and cells, applications to statistical mechanics, mechanical properties of cells. Another aspect taken care of concerns the combination of optical trapping with single cell Raman spectroscopy. More recently, the group is focused on development of Surface and Tip Enhanced Raman Spectroscopy-based systems (SERS and TERS) for the study of cell membranes.

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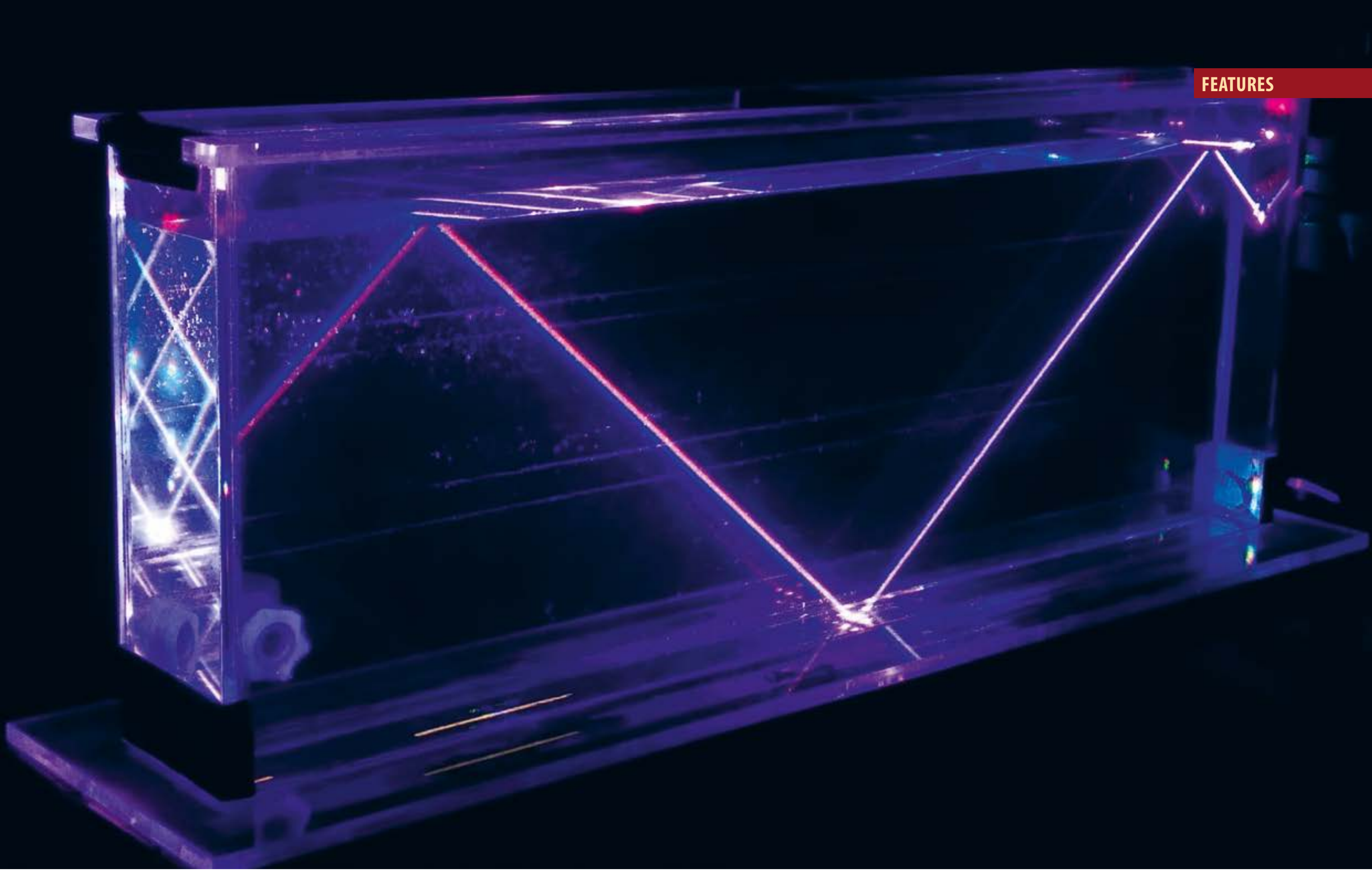

A NOBEL CAUSE: PUBLIC ENGAGEMENT AND OUTREACH

Christopher Holmes, Pearl John and Callum Stirling – DOI: https://doi.org/10.1051/epn/2019203

Showcasing cutting edge physics research to school children and the general public humanizes 'the scientist'. This can help towards removing stereotypes and enabling greater diversity in physics. Here we share some of the lessons learnt and activities conducted at the University of Southampton to achieve this goal.

Physics can often be challenging to communicate to a general audience, in part because the concepts can be abstract and far removed from the layperson's everyday experience. The 2018 Nobel Prize in Physics is a prime example of this challenge, as the uses of squeezed light and optical tweezers are not immediately obvious to a non-specialist. Despite this, effective communication of such non-intuitive concepts to the general public is increasingly being identified as a social obligation by research funding bodies [1].

The recent Nobel Prize also highlighted the limited diversity in Physics, as Professor Donna Strickland was the first female Physics laureate for 55 years. Promoting physics to a broad range of people will help ensure that there is a range of talent driving new ideas and innovation [2,3]. Outreach and public engagement offer useful routes to communicate with diverse audiences and can begin to change the perceived stereotypes of physicists, making career paths in physics more accessible to all.

▲ Light Express Total Internal Reflection Demonstration (Credit photograph: Dr Sam Berry)

Over the last two decades the University of Southampton has operated a dedicated programme of optics and photonics Outreach and Public Engagement (OPE). The programme, run by a team of volunteers and dedicated staff, reaches approximately 5,000 members of the public, pupils and teachers, annually. Stakeholders are both internal to the University and external organisations, all of whom provide leadership, event funding and partnership opportunities. In this article we discuss some of our initiatives, outline lessons we have learned, benefits received and the importance of evaluation.

The development of any new outreach workshop or public engagement event by our programme team starts by us asking one question: "what are we trying to achieve with this event?" Determining where the motivation for the activity lies directs our approach in planning an activity.

The design of an OPE event is dictated by the type of audience. Targeting audiences from under-served groups is important to increase both the number of people in physics and the diversity of backgrounds, but reaching a new audience can often be challenging. Several of our OPE initiatives are designed in partnership with the University of Southampton's Widening Participation team, who work to increase the number of students at university from schools with low levels of progression to higher education. Approaching schools can be often difficult due to the numerous pressures on the time and resources of school staff, but this is often even more pronounced in schools in disadvantaged socioeconomic areas. The Widening Participation team at Southampton conducts multiple engagements with the same audience, which is important in raising the "science capital" of the participants. This concept has been introduced to provide a valuable insight into why and how some people participate and engage with science and why some do not [4]. Familiarising people with science and raising their science capital through multiple OPE engagements has been demonstrated as being the one of most effective ways of making a career in science more accessible [5].

In general we, at Southampton, provide a broad range of activities, including interactive lectures for large audiences, smaller-scale hands-on activities for schools and resources and photonics training events for teachers. Examples of our activities include:

The Light Express Roadshow [6], which is an interactive lecture series on photonics, pictured in Figure 1. Light Express is used primarily as a photonics public engagement activity, allowing demonstrators to explain the basic physics behind their research during the show;

The Lightwave Roadshow [7], a set of hands-on experiments and demonstrations delivered primarily to school classes for outreach purposes;

Photonics Explorer kits [8], an outreach activity with school teachers, providing them with training and resources to teach photonics with a kit for an accompanying optics workshop. Each kit can provide materials to teach 200 students (from primary to college age), pictured in Figure 2;

The Photon Shop for the 'Light Up Poole' art festival [9]. This places a team of researchers in an empty shop for three nights, to reach new audiences, through hands-on public engagement activities with photonics, physics and astronomy demonstrations, supported by the Institute of Physics (IOP) [10].

The activities we deliver for outreach events are inherently one-directional and are more akin to an informal teaching session about physics and photonics in general. Ideally, we include demonstrations that are

▸ **FIG. 1:** A Light Express audience engaging with temporal exposure imaging. Credit: Photograph Rob Luckins both illustrative and can capture the imagination of the audience; activities that "show" rather than "tell" are better received. For workshops, this does not restrict the activities from being interactive. A good example is the 'Guess the Gas' workshop [11], designed by the Outreach team of the South East Physics Network (SEPnet), which allows students to explore the concepts of spectroscopy by constructing the experimental equipment needed.

Good demonstrations can extend known concepts in a way that they would have not previously have been taught. For example, a common topic for a primary Lightwave activity is for the workshop to begin with a demonstration of a simple reflection from a mirror, perhaps in the context of an Infinity Mirror (shown in Figure 3), then to progress to an explanation of how optical fibres work by many reflections inside a core, and end with a description of how the Internet depends on both reflection and optical fibres. We find that a strong narrative, from observation to theory or from problem to solution, is essential for explaining the relevance and context to audiences. Further examples of inspiring activities can be found from STEM Learning [12] or the Physics Education journal [13].

Public engagement events are approached differently with an objective of having a two-way conversation with an audience. Best practice in Public Engagement would be citizen science projects, such as Aurora Zoo, Southampton's project (currently under review) on the Zooniverse citizen science platform [14]. Zooniverse is a research platform covering many disciplines in which "anyone can contribute to real academic research on their own computer at their own convenience" [15]. Alternatively, Public Engagement activities can provide opportunities for the general public to interact with scientists in an informal environment, such as in our 2018 International Day of Light celebration [11] or during the Pint of Science festival talks which includes discussion about research in pubs and cafes [16].

It is important to note, that not only do the public and schools benefit from OPE. Those delivering activities, whom at Southampton are predominately postgraduate students, benefit greatly from the skills and experience they aquire through the interaction. This experience is invaluable when it comes to job applications and interviews. When interviewed for this article former Lightwave Director Dr Hannah Collins said, *"I have often been asked about public engagement at job interviews, and relied on that experience to demonstrate important transferrable skills."* These skills can include leadership and team management, event planning, marketing, budgeting and video production, none of which are taught by a typical Physics undergraduate or postgraduate programme.

An obvious benefit to the demonstrator is the development of their communication skills. Every scientist needs to be able to communicate their research effectively. For OPE however, we cannot assume any background knowledge or even interest on the part of the audience. Demonstrators are challenged to be both succinct and clear in their descriptions of science in ways they would not be through ordinary academic presentations. If researchers leave academia for industry, this particular style of communication is very useful, for example in effectively describing an innovation to a non-technical stakeholder.

▲ **FIG. 2:** Postgraduates demonstrating the Photonics Explorer kit to Teachers, (from EYEst) – demonstrating diffraction gratings, Light Emitting Diodes and polarisation principles. Credit: Jon Banfield

Furthermore, student-led OPE activities can provide a valuable opportunity for the students to gain experience in writing grant applications, an essential skill for any career academic, much earlier than they otherwise would in their career path. As part of our activities, students have applied for outreach grants through student chapters of the Optical Society, SPIE and IEEE Photonics Society, as well as through the Institute of Physics and the Royal Academy of Engineering.

The impact of our all our activities is measured in reach (the numbers we have engaged with) and significance for the audience. To determine significance effective evaluation is necessary. Our learning outcomes are based on 'Generic Learning Outcomes' designed for informal education settings [10]. We evaluate to determine participant's enjoyment of activities, whether they have gained any knowledge, and whether we have changed their views or behaviours. It is important to refer back to learning outcomes, to ensure the questions you ask are appropriate in determining whether these outcomes have been fulfilled.

The method of evaluation can vary greatly depending on the type of activity and its delivery. Most evaluation methods consist of completing a form, with perhaps a short knowledge quiz and additional questions on enjoyment and levels of interest in science. The design of the form should be appropriately designed for the audience, for example, to avoid young children becoming bored. Other ideas for evaluation include:

Snowballing: an engaging method to receive feedback. The concept being that instead of long evaluation forms, an audience can be asked to write ratings (out of 10) along with the favourite (or least favourite) part of the show onto a piece of paper, which will be screwed up and thrown to the front of the room. This is a suitable method to determine if activities need to be changed to appeal to the age-group.

Social media is also a powerful tool for evaluation for mature audiences; asking an audience to Tweet, can give a clear idea of which parts of an event are capturing the imagination of the public and also provide recognition of the activity for a much wider audience.

Electronic quiz software, such as KAHOOT, enables real time data collection, and makes the evaluation process more time effective.

Running focus groups and interviewing participants can help determine the following; their enjoyment of the activity and whether there has been a change in their knowledge and/or behaviour. Our methods have also included gathering before/after drawings of what a scientist looks like to determine whether scientist stereotypes have been successfully challenged.

There is a strong motivation for university researchers to engage with public audiences, partially promoted through their funding bodies. Such activities have clear benefits for the demonstrators involved, schools and members of the public. Showcasing the cutting edge research to schools and the general public humanizes 'the scientist'. This can help towards perception of science, working towards greater diversity in the range of people entering physics. Through OPE, researchers not only share what they know, but can also learn from the public and bring that learning into research, design and decision-making. It is important moving forward that we not only assess which resources and techniques work well, but to then share these ideas so that the quality and effectiveness of our efforts can be maximised. Help us work towards this goal by contributing to the discussion through Twitter: #ANobelCause. ■

▸ FIG. 3: The 'Infinity Mirror', part of the Lightwave Roadshow, used to illustrate how light is guided inside an optical fibre by multiple reflections inside the core. (Credit photograph – Krzysztof Herdzik)

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EXTREME LIGHT INFRASTRUCTURE NUCLEAR PHYSICS (ELI-NP)

V. Zamfir, K. Tanaka, C. Ur – DOI: https://doi.org/10.1051/epn/2019204

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ELI - Extreme Light Infrastructure, a project to build an international research infrastructure "dedicated to the investigation and applications of laser matter interaction at the highest intensity level" is one of the 35 projects in the first Roadmap, in 2006, of the European Strategy Forum on Research Infrastructures (ESFRI) [1]. "ELI will comprise three branches: ultra high field science that will explore laser matter interaction up to the nonlinear QED limit including the investigation of pair creation and vacuum structure; attosecond laser science designed to conduct temporal investigation at the attosecond scale of electron dynamics in atoms, molecules, plasmas, and solids; lastly, the highenergy beam facility devoted to the development of dedicated beam lines of ultra short pulses of high energy radiation and particles up to 100GeV for users."

The project was initiated by the European laser community lead by Gerard Mourou, the co-inventor, back in 1985, of the Chirp Pulse Amplification (CPA) method to generate ultrashort optical pulses. In 2018, Mourou and Donna Strickland were awarded Nobel Prize in Physics for this accomplishment.

Supported by the European Commission through a DG-Research Preparatory Phase Project (2008-2010) [2],the construction of the distributed facility among three European countries (the Czech Republic - secondary sources, Hungary – attosecond pulses and Romania – nuclear physics) is funded by European Commission through Structural Funds.

The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility [3] is being built near Bucharest, at the Magurele Physics research campus. Following Mourou's vision, ELI-NP will enable the exploration of a novel field of science at the frontier between laser, plasma, and nuclear physics. At ELI–NP, two well–established scientific communities, high-power lasers and nuclear physics, have joined their efforts to build a new interdisciplinary facility and to define its research program.

The implementation of the ELI-NP project, valued at 311 MEuro, is financed by Structural Funds and the Romanian national budget. The project began in January 2013 and the new facility will be operational by the end of 2019. The construction, finished in 2016, consists of innovative buildings assuring stability in temperature, humidity, pressure, and against floor vibration, covering a total area 33,000 m^2 and with a Geothermal system providing 6 MW.

The main equipment is a high-power laser system consisting of two 10 PW ultra-short pulse lasers based on CPA method. The center will also have a brilliant energy tunable gamma-ray beam machine. The ELI-NP high-power laser system was constructed by an association between Thales Optronique SA France and Thales Romania. It consists of two parallel Chirped Pulse Amplification systems at about 820 nm central wavelength, with a dual front-end architecture, designed to minimize down-time for the laser facility. Each of the two parallel chains includes Ti:Sapphire amplifiers to bring the final output energy to the level of a few hundreds of Joule. Subsequently, the pulses are compressed to around a 20 fs pulse duration that implies a peak power of 10 PW at a repetition rate of 1 shot per min for each of the two arms. Along the two amplification chains, additional outputs with corresponding optical compressors have been installed. Their corresponding power levels are 0.1 PW and 1 PW at repetition rates of 10 Hz and 1 Hz, respectively.

The commissioning of this equipment is under way, and with 10 PW power level recently achieved, is the most powerful laser in the world.

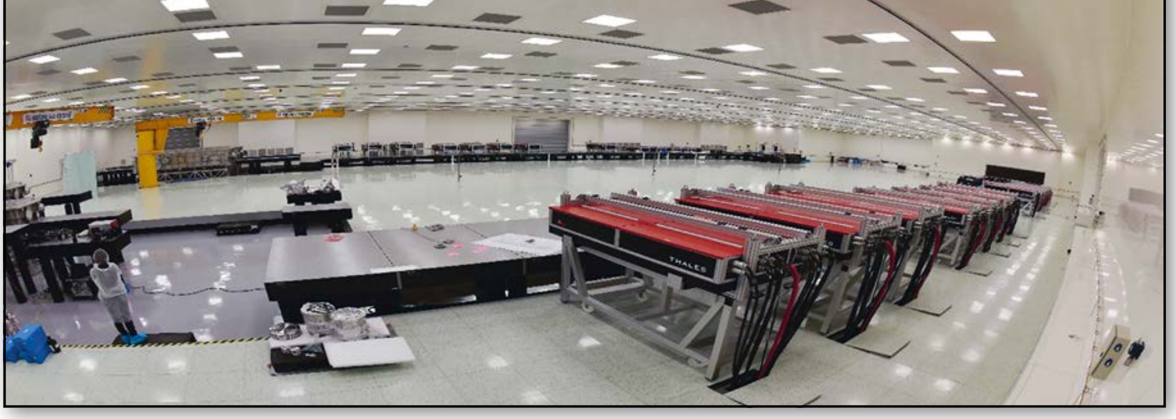
The mission of the ELI-NP center covers scientific research involving laser-matter interaction experiments related to nuclear physics and strong-field quantum electrodynamics. The main research topics are:

Investigation of the high-power laser-matter interactions using nuclear physics methods in order to study the possibilities of obtaining electron, proton, and heavy ion accelerated beams using lasers.

- The extremely high intensity of the laser beam will allow the study of fundamental physics phenomena anticipated by theory, such as vacuum birefringence, dark matter,and pair creation in intense electric fields.
- Investigation of nuclear structure and reactions cross sections of interest for astrophysics using photonuclear reactions.
- New methods of identification and remote characterisation of nuclear materials with application for homeland security and nuclear material management.
- New ways of producing more efficiently radioisotopes currently used in medicine and the producing of newly proposed ones.

At full power, the ELI-NP lasers will reach intensities at the 10^{23} W/cm^2 level, never obtained before, allowing for the exploration of ion acceleration regimes with key features, such as quasi monoenergetic distribution or solid state density (~10^{22} ions/cm^3), many orders of magnitude higher than the ion bunches provided by "classical" accelerators. Such very intense laser pulses will radically change the paradigm of particle acceleration and will lead to an extreme shrinking of the dimensions of particle accelerators.

▸ FIG. 1: ELI–NP experimental building.



◂FIG. 2: The 40m × 70 m clean room for ELI-NP High Power Laser System.

ELI-NP is a world-leading research infrastructure in the newly emerging field of science, Nuclear Photonics. Nuclear Photonics is a cross-disciplinary field where nuclear physics, laser physics, material science, accelerator science, andlife sciences are converging to establish new directions of fundamental and applied research and to develop unique societal benefits.

A broad biomedical research program, anchored in the unique ELI-NP capabilities, is currently being developed at ELI–NP and addresses topicsuch as: production of radiotherapy relevant nuclear beams, radiobiological effects of laser and gamma nuclear beams, medical imaging research with laser X-ray sources and medical isotope production research with laser nuclear beams. Research efforts aim to enhance the spatial resolution of medical imaging by using laser driven X-ray sources as well as improving the biological effectiveness of charged particle therapy by using ultra–short/ultra–intense laser accelerated charge particle pulses. Production of radioisotopes with medical relevance via nuclear reactions driven by laser and gamma beams is also considered.

Highly-penetrating gamma beams of high energy, with very small energy dispersion, are the perfect tools for active interrogation of special nuclear materials, industrial radiography and tomography and cultural heritage studies. Nuclear resonance fluorescence (NRF) can be combined with computed tomography (CT) to yield 2D/3D maps of elemental/isotopic distributions in a large variety of objects. CT–NRF mapping done with quasi–monoenergetic gamma beams can be successfully employed in the detection of special nuclear material, assay of spent fuel or elemental analysis of work of arts.

ELI-NP will perform innovative research in the field of materials behavior in extreme environments and radiobiology, with direct application in the development of accelerator components, new materials for next generation fusion and fission reactors, shielding solutions for equipment and human crew in long term space missions, and new biomedical technologies.

Benefiting from the collaborations of more than 100 scientists from 30 countries, the ELI-NP facility is on track with the implementation of the Technical Design Reports [4] and construction of the experimental set-ups and their commissioning will start in 2019.

ELI–NP is going to be the most advanced research infrastructure in the world focusing on photonuclear physics studies and applications. As the first large-scale European research facility in Romania, the project is likely to become the flagship of the national scientific research, covering frontier fundamental physics, new nuclear physics and astrophysics, as well as applications in nuclear materials management, materials science and life sciences. ■

About the Author

Victor Zamfir is Scientific Researcher in Experimental Nuclear Physics, co-author of more than 300 articles in ISI journals with more than 6500 citations (Hirsch index 40), member of the Romanian Academy. He is Director General of the "Horia Hulubei" National Institute for Physics and Nuclear Engineering (IFIN-HH), Bucharest-Magurele, Romania and Director of the ELI-NP Project. He was member of Nuclear Physics European Committee (NuPECC) of European Science Foundation (2005-2008) and member of Nuclear Physics Board of EPS (2007-2013, 2012-2013 Chairman). Since 2016 is a member of the Executive Committee of EPS.

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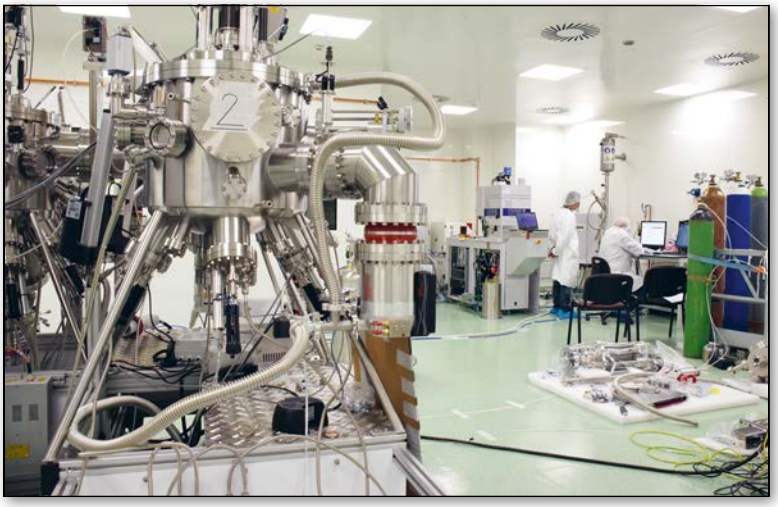
▾FIG. 3: ELI-NP Target Laboratory.



PHYSICS, LASERS AND THE NOBEL PRIZE

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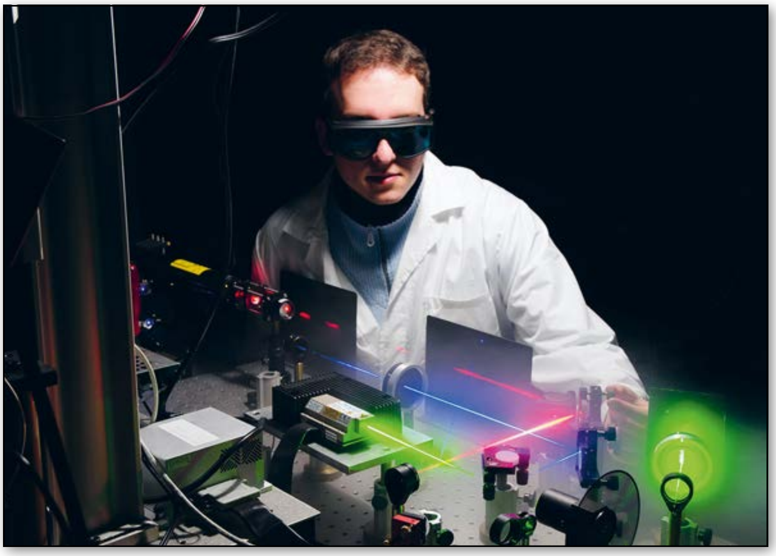
Like every year, we have been waiting for the announcement of the most important award for natural sciences, the Nobel Prize in Physics. Perhaps it is since 2013, the year in which the award was given for the discovery of the Higgs boson, that the Nobel Prize has great media visibility. The public, scientific or otherwise, is waiting to know who will be awarded.

We also know that, following the announcements, social media will be responsible for making the general public understand who and especially which discovery has been rewarded. The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems" [1], the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses" [2]. Since 1964, when Charles Hard Townes, Nicolay Gennadiyevich Basov and Aleksandr Mikhailovich Prokhorov were awarded "for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle" [3], many Nobel prizes in physics have seen the laser as a best actor or supporting actor. Even this year what seems to have been awarded is not only the excellent work of three scientists, but also the human enterprise of science. Making a quick overview of the physics Nobel Prizes history, we can find the laser in 1971 with Dennis Gabor "for his invention and development of the holographic method" [4]. In 1981 with Nicolaas Bloembergen and Arthur Leonard Schawlow "for their contribution to the development of laser spectroscopy" [5], together with Kai M. Siegbahn "for his contribution to the development of high-resolution electron spectroscopy" [6]. In 1997 Steven Chu, Claude Cohen-Tannoudji and William D. Phillips were awarded "for development of methods to cool and trap atoms with laser light" [7]. In 2005 Roy J. Glauber won "for his contribution to the quantum theory of optical coherence" [8] together with John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique" [9]. Even the 2017 prize, that will be remembered as the gravitational waves award, it actually went to Rainer Weiss, Barry C. Barish and Kip S. Thorne "for decisive contributions to the LIGO detector and the observation of gravitational waves" [10], one of the biggest laser based facility in the word. Surely from this excursus I may have left out some years, some Nobel Prizes, perhaps not in physics but in chemistry or medicine, who have had the laser as an actor. However, the mentioned awards already give a measure of how much laser technology has been treading the stage of science for more than 50 years.

And if in science they rode the stage of success, in every day life they went among the people. Just think of the countless laser applications such as medical ones, eye surgery, cancer treatment, or industrial applications such as laser etching, welding and drilling. Even the barcode readers, CD players, car distance sensors. This list could last for the full length of the article, it is sure.

The way a laser works is easy to understand. When the electrons in atoms in special glasses, crystals, or gases absorb energy they become excited. The excited electrons move from a lower-energy orbit to a higher-energy orbit. When they return to the ground state, the electrons emit photons. Laser light is different from normal light for two reasons: these emitted photons are all at the same wavelength, which means that the generated light is coherent (figure on p. 26); the latter is that laser light is directional. Whereas a laser generates a very tight beam, a flashlight produces light that is diffuse.



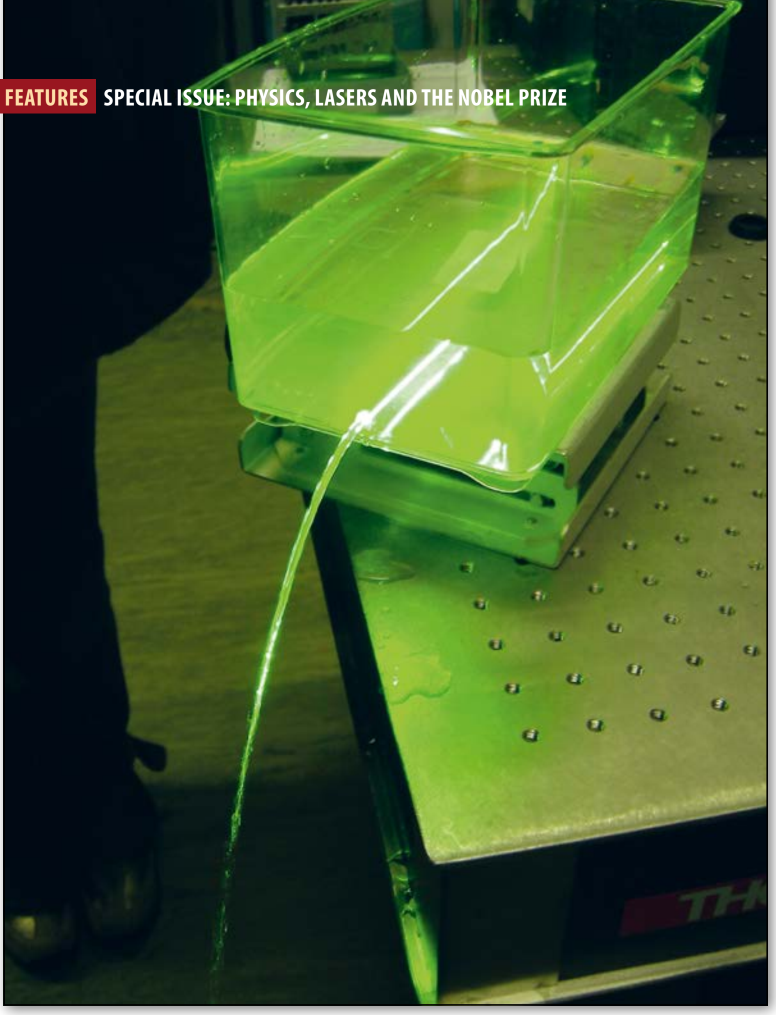
▲ **FIG. 1:** Force sensing and optical tweezers realized probing different wavelength, © Sebastiano Vasi

There are many ways to control laser light. For instance, using different materials which leads to different electron transitions, thus different energies and wavelengths. Otherwise one can act on the collimation design, or different amplification systems in order to create more powerful lasers. Having control of the laser properties opens up new possibilities for probing and manipulating matter. That is how optical tweezers have been developed, allowing Arthur Ashkin to win the Nobel Prize for 2018.

Optical tweezers use a highly focused laser beam to provide an attractive or repulsive force to physically hold and move microscopic objects (figure 1). The greater the laser power control is, the better the control in the manipulation of objects is. In 1986, Ashkin used the optical tweezers technique to trap living bacteria just illuminating them with lasers. In this EPN special issue we asked Antonio Sasso and his group to show us the last discoveries in the field of optical tweezers since this technique's invention.

Sometimes, what is needed is to have not only the laser power control, but also its pulse frequency. In some extreme cases what we might want is to have a single short burst. This was a very difficult task for scientists. The creation of a short and ultra-powerful impulse was not easy, often it involved the destruction of the material used to amplify the light and generate the laser light itself. This problem was solved by Gérard Mourou and Donna Strickland in 1985. They proposed a four steps setup: first, they created standard laser pulses; then, they stretched

◄ **P26:** Laser light is coherent, all emitted photons are all at the same wavelength, thus same colour.



▲ **FIG. 2:** Laser light travelling through a stream of water flowing from a pipe (the John Tyndall's experiment) © Antigone Marino

the pulses in time, which reduces their peak power and makes them less destructive; next, they amplified the time-stretched, reduced-power pulses; and finally, they compressed the now-amplified pulses in time. The new technique, named chirped pulse amplification, became a standard for high-intensity lasers. In this EPN issue we asked Giulio Cerullo and his research group to review the capability of lasers to generate light pulses of incredibly short duration, from a few femtoseconds down to a few tens of attoseconds.

▼ **FIG. 3:** Donna Strickland receiving the Nobel Prize in Stockholm. Picture by Alexander Mahmoud © Nobel Media AB 2018

The purpose of this EuroPhysics News's special issue on lasers is to celebrate the scientific work of this year's Nobel Prize in physics winners and their collaborators. Morover, we wish to celebrate also the journey of laser technology from the 50s to nowadays. We have seen and we will see lasers applications in many fields of science and daily life. In the coming decades we will see a growing request and development of large facilities based on laser light, like the European X-Ray Free-Electron Laser Facility (European XFEL) in Germany or the Extreme Light Infrastructure (ELI) in the Czech Republic, in Hungary and in Romania. That's why we invited Victor Zamfir to write a feature on ELI, the laser facility that aims to host the most intense beamline system worldwide.

The scientific research produced by lasers is terrific. As a scientist in love with outreach activities, let me also mention the faces of the public when I show Tyndall's experiment (figure 2), how the laser light gets trapped in a gush of water acting as an optical fiber, or the fun of children when playing in a laser maze that even Lupin III could not escape. And that's why we have invited Christopher Holmes and his colleagues from the Southampton Optoelectronics Research Centre to introduce us to their famous light show.

The 2018 Nobel Prize in Physics has a strong historic importance because of Donna Strickland becoming the first woman to win a physics Nobel Prize in more than 50 years (figure 3). This issue ends with a beautiful opinion by Elizabeth Rogan, CEO of the Optical Society, who carefully describes the importance of this event not for women in science, but for science.

We hope that the reading of this issue will enlighten you, of coherent light, laser light! ■

About the Author

Antigone Marino is researcher at the Institute of Applied Sciences and Intelligent Systems of the Italian National Research Council in Naples, Italy. Her research activities are concentrated on the study of soft matter optics. She is in the OSA Foundation Board of Directors, topical editor of the Journal of the Optical Society of America A, of Euro Physics News and of Giornale di Fisica.

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SCIENCE AND LONG-TERM THINKING[1]

THE CLUB OF ROME, A CLUB OF LONG-TERM THINKERS

Ernst Ulrich von Weizsäcker – DOI: https://doi.org/10.1051/epn/2019206

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The Club of Rome, founded a few months before the European Physical Society, first addressed "the predicament of mankind". The founders, among them the Italian industrialist Aurelio Peccei and Alexander King, then the head of science at the OECD, were looking for methods of mathematically based forecasts for the future of humankind and of the life supporting systems on this planet.

[1] The article is based on an oral presentation using power-point pictures during the Festakt on 28 September celebrating the 50th Anniversary of the European Physical Society

◂ P.30:
Cover picture of Nature, Vol.527, 25 November, 2015. Paris Climate negotiations as an international puzzle. Picture by David Parkins.

The first – spectacular – result was the book The Limits to Growth[1]. The book became a world bestseller (ca 30 million copies sold in dozens of languages), and served as a shock. Figure 1 shows the pivotal picture, the "standard run" covering two centuries and depicting the assumed dwindling of natural resources, the peaking of industrial output, population, food (per capita), and pollution.

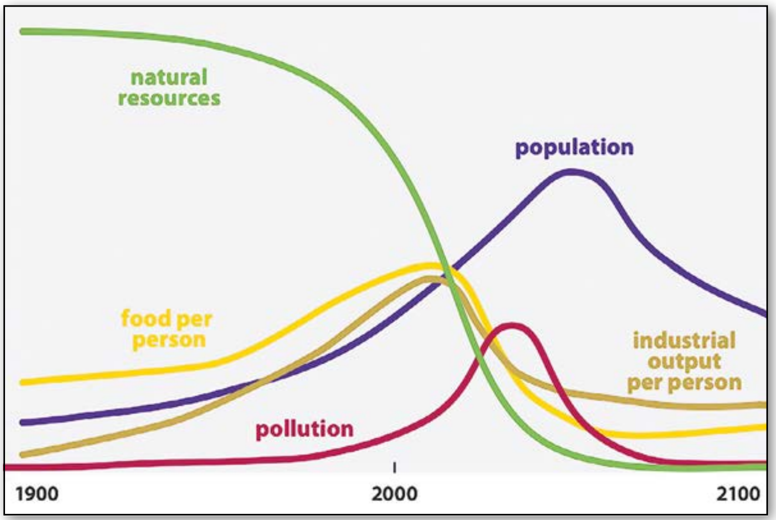
Fortunately for the world, there were two major mistakes in the model: "Resources" represented commercially available resources assuming that no progress would be achieved in exploration and exploitation. In reality, exploration and exploitation soared after the "oil crisis" of the 1970s causing a dramatic increase of resource prices, and hence of the profitability of exploitation. The second mistake was the assumption that pollution was strictly coupled with industrial output. Before 1972 that assumption was empirically reasonable, but soon came strict environmental laws in all industrialized countries, leading to much cleaner industrial production.

On the other hand, the 1972 study was far too optimistic regarding the two alarming world trends which entered the environmental agenda some fifteen years later: global warming and the rapid disappearance of animal and plant species. In the end, the basic message of The Limits to Growth remained correct and must be considered in our days.

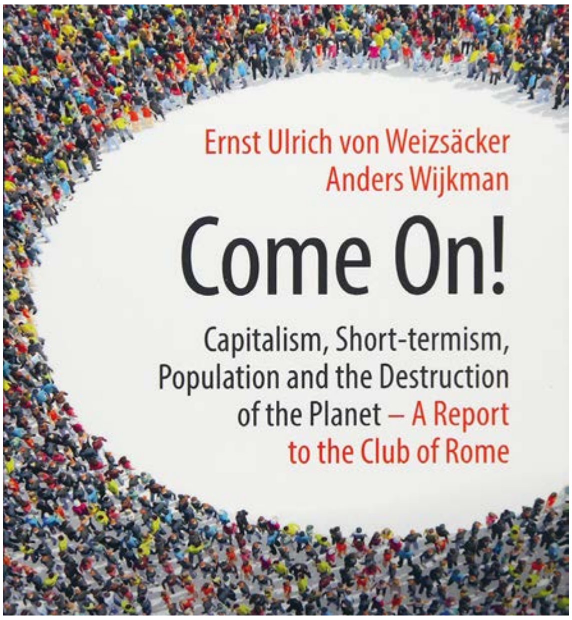
A new Club of Rome Report, called "Come On!"

Some 45 years after the publication of Limits, the Club of Rome undertook the writing of a new report addressing today's challenges and offering solutions. The new book is called "Come On!"[3] and contains three chapters differentiating the two diametrically differing meanings of Come On:

(1) C'mon! Don't tell me the current trends are sustainable!
(2) C'mon! Don't stick to outdated philosophies!
(3) Come On! Join us on an exciting journey towards a sustainable world!



▾ FIG. 1: The "standard run" of five parameters, according to The Limits to Growth (footnote 2). It assumes a collapse shortly after the year 2000 of food per person (yellow line), and ensuing population shrinking (blue line). The most conspicuous curve is the green line, assuming dwindling natural resources within less than a century.



The intellectual challenge is the evident but embarrassing distinction between the "empty world" and the "full world", according to Herman Daly[4]. Figure 2 offers a caricature picture of the difference.

Herman Daly, once chief economist of the World Bank, clearly says that an economy for the full world has to significantly differ from the economy of the empty world. Mining the environment was tolerable in the empty world but is dangerously unsustainable in the full world.

The full world is nowadays called the Anthropocene, the geological age in which one single living species, Homo sapiens, is dominating (and in many cases destroying) the rest of the world.

Talking about geological ages clearly signifies the need for thinking long term. What can be the future of humankind and of the natural base for humans and all the other living species? Addressing such questions cannot be done within the time frame of the quarterly reports of commercial companies, let alone of the daily needs and talks of families.

The Club of Rome provided 35 co-authors for Come On! – plus a few eminent non-Club members. The Executive Committee of the Club took ownership of the new report by writing a strategic Preface declaring the need for a bold new beginning "*The time has come, we believe, for a new Enlightenment or for otherwise overturning current habits of thought and action that only consider the short term* [5]." This is a quote from the Preface.

New Enlightenment

Thinking long term, then, appears to lead directly to the quest for a New Enlightenment. The book shows in detail that some of the heroes of modern economics were perfectly right for their situation of the empty world but would be miserably misinterpreted for the situation of the globalized full world.

For Adam Smith, it was perfectly clear that the geographical reach of the market (of the "invisible hand") was identical with the geographical reach of the Law. Under such conditions, individual selfishness is indeed helpful for the augmentation of the Wealth of Nations. But today, financial markets are global, and the Law remains mostly nation if not provincial. Financial markets, in search for maximized returns on investments, have begun to blackmail national parliaments and governments to change rules for the benefit of capital and the disbenefit of the poor and of nature.

For David Ricardo, capital remained geographically fixed and was not travelling over the borders. Today, capital is by far the most mobile production factor, ignoring comparative advantages according to Ricardo, and creating absolute advantages destroying the losers and boosting the wealth of the winners.

Modern Darwinism acknowledges that the "weak" genes typically survive being "invisible" in the phenotype and are thus enriched in the genepools of a species, and serving as options to master new challenges that can always occur. Modern economics, on the other hand, finds the extermination of weak options a virtue, not a loss. Social Darwinism according to Herbert Spencer should be seen as a huge misunderstanding from the perspective of modern Darwinism! [6]

The new Club of Rome report then takes up the challenge of the Preface of outlining a new Enlightenment that goes far beyond the simplistic rationalism and reductionism of materialistic analytical philosophy. We postulate the virtue of balance and of complementarity according to Niels Bohr and Werner Heisenberg. If you hear of a quarrel between two persons or camps, our typical reaction is that one side is right and the other wrong, and the search for truth means that the one who is right will beat or even eliminate the one who is right.

In Asian cultures, the same quarrel tends to trigger the reaction "Well, both are right in a sense, but you have to find a reasonable balance". This is the basic structure of the Yin and Yang philosophy.

We postulate that our civilization in the full world has to find suitable balances between

- Short term and long term;
- The Law and the markets;
- Humanity and Nature;
- Speed and stability;
- Women and men;
- Equity and awards for achievement;
- State (and Constitutions) and religion.

These are seven examples out of perhaps a hundred. But they have one thing in common: In each pair it appears evident that the total victory of one side not only means the defeat of the loser but also means the deterioration if not destruction of the entire system.

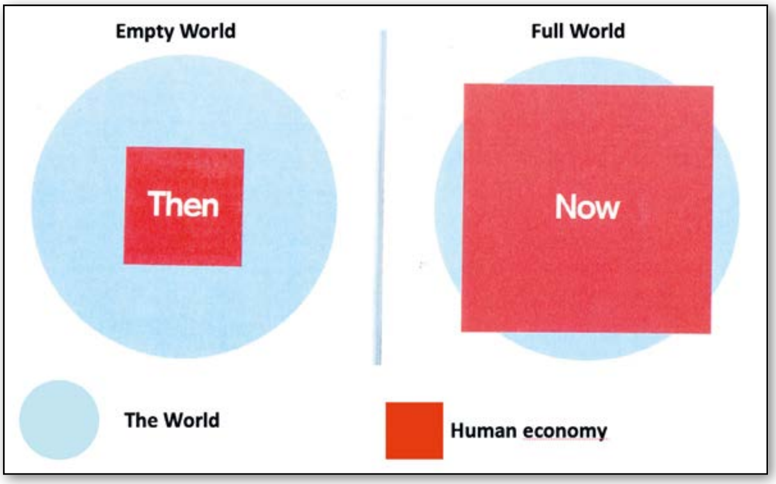
The Club of Rome is perfectly aware that the transition to a new Enlightenment will take decades. But nature and humanity cannot wait for decades until restoration and at least deceleration of destructive trends occur. Part Three of Come On! representing some 50% of the volume, is therefore devoted to options that can be built up right now and help the world onto a trajectory of sustainable development.

Part Three addresses regenerative agriculture, circular economy, climate-saving energy policies, re-regulation of the financial markets, options for international cooperation (instead of just rivalry). But summarizing all that would require a completely new article. ■

About the Author

Ernst Ulrich von Weizsäcker, Honorary President, The Club of Rome. Born 1939, 1972 professor of biology, 1975 university president, 1994 Director, Institute for European Environmental Policy, 1991 Founding President, Wuppertal Institute for Climate, Environment, Energy. 1998 – 2005 Member of Parliament, Germany, and Chair of the Environment Committee. 2006-2008 Dean, Bren School of Environmental Science and Management, U.C. Santa Barbara, California. Books: 1994 Earth Politics. 1997 Factor Four (w/ A & H Lovins). 2009, Factor Five (w/ Charlie Hargroves *et al.*), 2018 Come On! (w/ Anders Wijkman). Homepage www.ernst.weizsaecker.de

▼FIG. 2: In earlier times (actually until about 1950), humanity was small, and nature large and rich: the "empty world". But then began a steep rise into the "full world", with exploded population and human consumption and hardly any wild space left.



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[5] Quote from the Preface of Come On!, page vi.

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Opinion: by combatting bias, we can achieve parity for women in science awards

Elizabeth A. Rogan, CEO, The Optical Society (OSA)

A flurry of phone calls and text messages erupted at 6:00AM EST on 2 October 2018 at The Optical Society (OSA) as we learned that three OSA Fellows: Drs. Donna Strickland, Gérard Mourou, and Arthur Ashkin were the winners of the 2018 Nobel Prize in Physics. The society staff quickly provided content to the world media; photographs, biographies, published papers and video interviews to respond to requests about their discoveries, along with their personal and professional stories. Then the first of many comments and observations poured in. Donna Strickland was only the third woman to have won the Physics prize since it was first awarded in 1901. Questions as to why Donna did not have a Wikipedia page or why she was not a full professor at the University of Waterloo put the community on the defensive.

We were well aware of the historic importance of Dr. Strickland becoming the first woman Nobel Physics Prize winner in more than 50 years, a fact highlighted repeatedly in news coverage of the awards. This milestone celebration reinvigorated the charge to address the issue that women scientists remain vastly underrepresented among Nobel Laureates, major science awards and high-level positions across academia and industry. On average, women represent just 10 percent of all winners of major scientific awards for scholarly achievement.

The reasons why women scientists and their scholarly work continue to be overlooked are clear. Gender bias by members of award nominating committees—especially men who chair those committees—skews award recognition toward male colleagues, according to a 2012 U.S. National Science Foundation-funded study.

Equally troubling, women continue to suffer the consequences of sexual harassment that include prematurely abandoning scientific careers and unwillingness to participate in awards programs. Between 20 percent and 50 percent of women scientists, depending on discipline, suffer some form of sexual harassment according to a 2018 study by the U.S. National Academy of Sciences.

Like many scientific societies, the OSA Board took a hard look at our approach and impact in addressing gender parity. Despite many years of running inclusion programs, trainings, network events, writing about the challenges to our community, there was a serious lack of progress to increase inclusiveness and engagement for and with women. I naively believed that change would happen organically, due to the giving and appreciative nature in the science community. It is an expectation that the last five minutes of a scientific talk are spent thanking all of the many colleagues that supported the discoveries you are presenting. How often have we heard the line “stand on the shoulders of giants” in reference to the many achievements built on the discoveries of past generations? Despite many women adding value to the science eco-system, they somehow did not “qualify” for giant status.

To address the challenge, we had to make a case for support internally, to staff and volunteers. We turned the dial from “optional” to “required”, as new policy changes were implemented. It was clear that there were an abundance of qualified scientists and engineers including women who were not considered for key positions or speaking slots. That had to change.

We needed to set aggressive goals and metrics to reach gender parity within the organization, its governance and committees, including the awards committees, where important decisions were being made on nominee’s success, based on the lens of the specific member of that committee. We revised long established award criteria that unintentionally penalized candidates for taking breaks in their professional career.

OSA expanded its Diversity and Inclusion Advocacy Recognition program, raised the financial bar in offering travel funds, practical family care programs and grants, waived meeting registration fees, offered more speaker opportunities, hired dedicated staff and more. We’ve implemented and highlighted professional conduct policies during the registration step of attending an event, added public signage at events to communicate our goal to reduce harassment and bullying, and are offering a richer portfolio of training, including ally training. Partly due to the #Me Too movement, the current climate for acceptance that there is a parity problem is fueling the positive support by OSA’s industry partners that work to foster greater diversity and inclusivity.

Many international science and engineering organizations, including SPIE, IOP, AGU, APS, the IEEE, AIP, and the European Physical Society, have been developing policies and efforts similar to those at OSA.

The scientific community, with its collective knowledge and resources, has much to contribute to building a more-equitable society. The work begins with creating safe and diverse work environments of our own with inclusivity as an expected outcome.

We must do everything we can to combat bias against women in science, which includes sexual harassment, to ensure that their high-caliber scholarly work is recognized in addition to being the source of inspiration to new generations of scientists.

Donna has said, she sees herself as a scientist, not a woman in science. We do too. ■

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