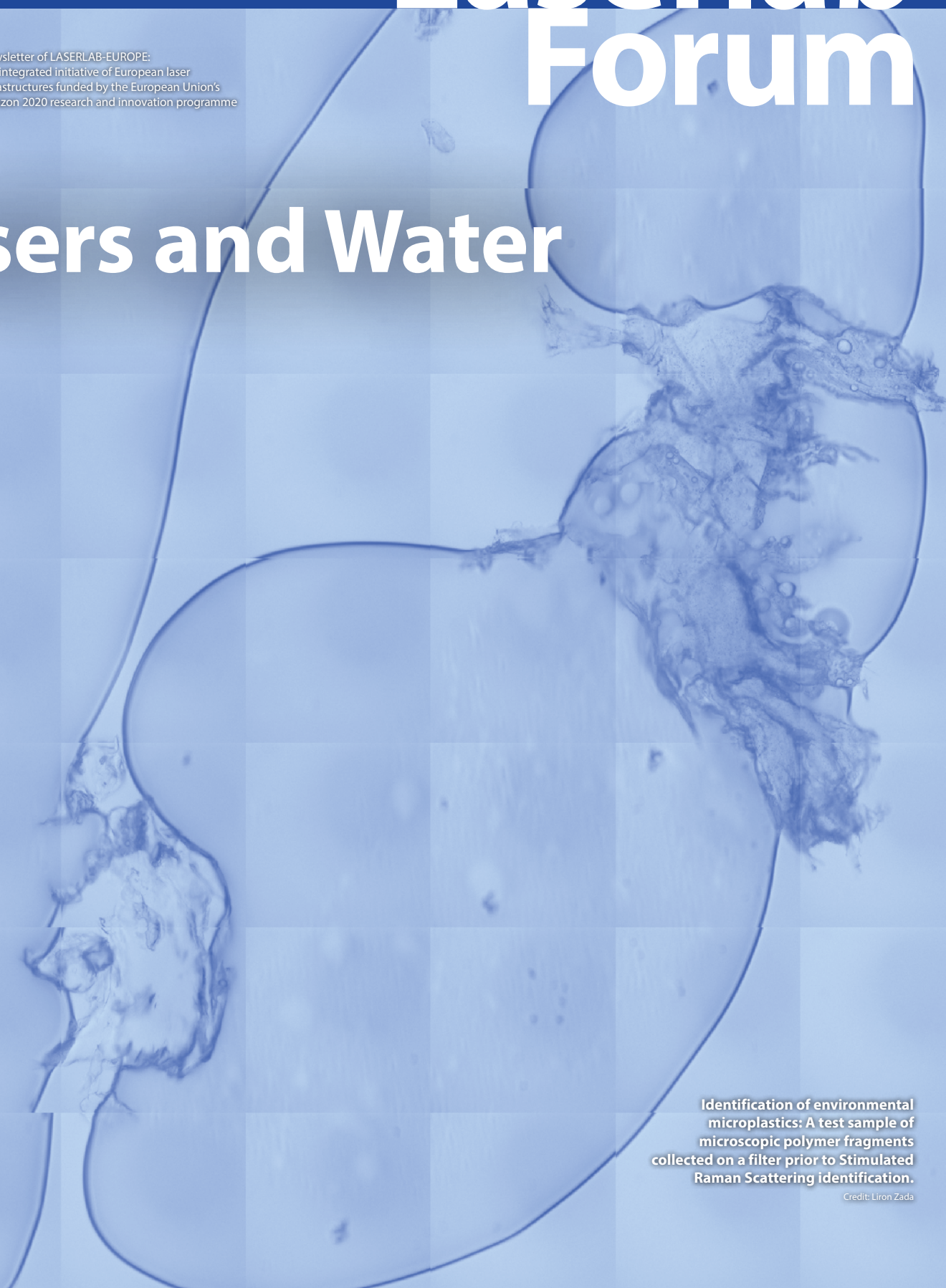


Laserlab Forum



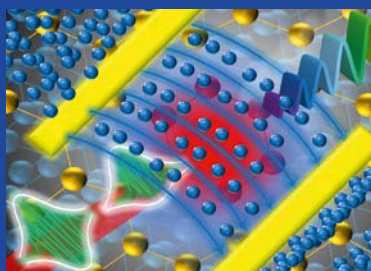
Newsletter of LASERLAB-EUROPE:
the integrated initiative of European laser
infrastructures funded by the European Union's
Horizon 2020 research and innovation programme

Lasers and Water



**Identification of environmental
microplastics: A test sample of
microscopic polymer fragments
collected on a filter prior to Stimulated
Raman Scattering identification.**

Credit: Liron Zada



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Editorial



Tom Jeltes

As much as 71 percent of the Earth's surface is covered with water, and of our own bodies 60 percent consists of H₂O. These facts alone make water a rather prominent substance, and it should therefore not come as a surprise that this 'liquid of life' is also studied extensively within Laserlab-Europe. This issue's focus section shows that the phrase 'Lasers and Water' can be understood to cover quite many pretty different types of water-related research. As Nature's preferred solvent, water and its detailed properties are evidently of huge importance to those who study life at the cellular and even molecular level, and because it makes up such a large fraction of our natural environment, being able to monitor water quality is important even for our own health. In all of these matters, and even regarding the question what role water has

played in the possible (extra-terrestrial) origin of life, lasers are indispensable instruments.

This issue's access highlight is easily linked to our focus theme, as it describes a new laser technique to study the shells of molluscs. The remnants of these marine creatures are found in large quantities at archaeological sites, and potentially provide a lot of information about the climatological conditions and ocean circulation through the ages.

Elsewhere in this issue, one can read that Laserlab-Europe's most prominent researchers have again been successful in securing prestigious ERC Advanced Grants – one eminent theorist, Maciej Lewenstein, even for the third time! In addition, we chose to highlight a few start-up companies that have their origins in different ERC projects, and have been set up using dedicated ERC Proof of Concept grants.

Tom Jeltes

News

Graphene gives boost to future terahertz cameras

A team led by researchers from Laserlab-Europe partner ICFO (Barcelona) has developed a graphene-enabled detector for terahertz light that is faster and more sensitive than existing room-temperature technologies. The work has been published in *Nano Letters* (19: 2765, 2019).

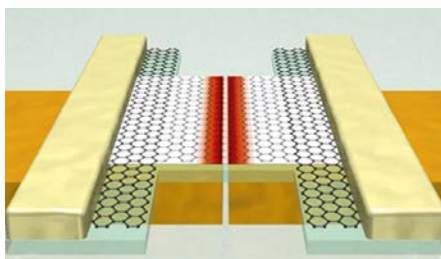
Detecting terahertz (THz) light is extremely useful because THz technology is becoming a key element in applications regarding, for example, security (such as airport scanners), wireless data communication, and quality control. However, current THz detectors have shown strong limitations in terms of simultaneously meeting the requirements for sensitivity, speed, spectral range, and operating conditions.

The advantage of graphene as a light detector lies in the fact that it can be used to detect very low-energy radiation, such as terahertz light. Nonetheless, no graphene-based detectors could so far beat commercially available detectors in terms of speed and sensitivity. Integrating a dipole antenna into the detector to concentrate the incident THz light around the antenna gap region, the team has now for the first time been able to create a very high sensitivity, high speed response detector based on graphene, with a wide dynamic range and a broad spectral coverage.

Thin films analysed with laser-induced breakdown spectroscopy

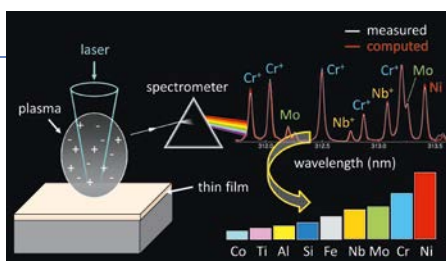
A recent Laserlab collaboration, carried out at LP3 in Marseille with a team from Laserlab-Europe partner INFLPR (Bucharest), has demonstrated that plasmas generated by laser ablation can be used to analyse thin films at the nanoscale in a fast and accurate way, employing calibration-free laser-induced breakdown spectroscopy.

The researchers first showed that plasmas generated by laser ablation may have unique properties, e.g. they combine spatial uniform-



© ICFO

Schematic representation of the central part of the graphene-based THz photodetector device.



Calibration-free laser-induced breakdown spectroscopy (published in *Anal. Chem.* 91: 2544, 2019)

ity with local thermodynamic equilibrium and present therefore an ideal radiation source. Next, they demonstrated that calibration-free laser-induced breakdown spectroscopy enabled quantitative analyses of multi-elemental, 150 nm thin films better than those obtained with other techniques.

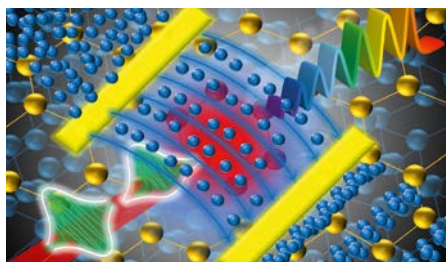
The research effort involved the groups of Jörg Hermann (as LP3 host) and Emanuel Axente and Valentin Craciun (INFLPR) and has been published in the journals *Physical Review E* and *Analytical Chemistry*. In addition, a further paper from the same collaboration has been selected as the best publication in *Spectrochimica Acta* of last year.

FET Open projects on fibre lasers and ultrafast electronics

Two new FET Open projects will be led by researchers from the Laserlab-Europe community. The PETACom project, which intends to use lasers for ultrafast electronics, is coordinated by Hamed Merdji from French partner LIDYL (Saclay) and also involves partner ICFO (Barcelona) and associate partner Wigner RCP (Budapest). NCLas ('Nanocrystals in Fiber Lasers') will be led by Matthias Jaeger from associate partner Leibniz IPHT in Jena, Germany.

While the terahertz regime in electronics is now just accessible, the partners in the PETACom project are already looking into solutions for the petahertz frequency range. The idea is to use electron currents in the conduction band of semiconductors controlled by the optical cycle of intense femtosecond laser fields.

The NCLas project aims at developing fibre lasers with new wavelengths for applications in medicine and telecommunications. By incorporating nanocrystals in a fibre, the scientists hope to produce light in the spectral range in which tissue is very transparent so that even deep layers become visible. And the more wavelengths a laser produces, the more chan-



Artist's impression by Maria Kholodtsova (LIDYL, Saclay)

What is Laserlab-Europe?

Laserlab-Europe, the Integrated Initiative of European Laser Research Infrastructures, understands itself as the central place in Europe where new developments in laser research take place in a flexible and co-ordinated fashion beyond the potential of a national scale. The Consortium currently brings together 33 leading organisations in laser-based inter-disciplinary research from 16 countries. Its main objectives are to maintain a sustainable inter-disciplinary network of European national laboratories; to strengthen the European leading role in laser research through Joint Research Activities; and to offer access to state-of-the-art laser research facilities to researchers from all fields of science and from any laboratory in order to perform world-class research.

nels are available for transmission of digital data through optical fibres for telecommunication.

FET Open (Future and Emerging Technologies) is an EU-funded programme which supports early-stage research and innovation around new ideas that could lead to radically new future technologies. As many as 375 proposals were submitted for this call, 38 of which were selected.

Radiation from the quantum vacuum

According to a new study by researchers at Laserlab-Europe partner University of Strathclyde, particles travelling through empty space can emit bright flashes of gamma rays by interacting with the quantum vacuum. The research has been published as an Editors' Suggestion in *Physical Review Letters* (122: 161601, 2019).

It has long been known that charged particles emit radiation when their speeds exceed that of photons in the surrounding medium. According to Einstein's theory of relativity, this so-called Cherenkov radiation should not occur in a vacuum as nothing can travel faster than light in empty space.

Physicists from Strathclyde have now found, however, that in extreme conditions, such as found at the focus of the world's most powerful lasers and the huge magnetic fields around neutron stars, virtual quantum particles can slow down gamma rays just enough for Cherenkov emission to occur. This means that the highest energy cosmic rays passing through the magnetic fields surrounding pulsars should predominantly emit Cherenkov radiation.

According to project leader Dino Jaroszynski, this new prediction could provide answers to basic questions concerning the origin of gamma ray glow at the centre of galaxies. The study was part of the international Lab in a Bubble project in which researchers aim to use high-powered lasers to conduct experiments in plasma bubbles so small that their diameters are equivalent to one tenth of the cross-section of a human hair.

Accelerator ring for matter waves

An international team of scientists at Greek Laserlab-Europe partner IESL-FORTH (Crete) has demonstrated the first coherent acceleration and transport of matter waves in atomtronic waveguides. This result, published in *Nature* (570: 205, 2019), is an important step towards small-sized super-sensitive sensors based on waves of ultracold matter.

In the emerging field of coherent atomtronics, atoms are manipulated in the form of matter waves originating from Bose-Einstein condensates: a state of matter where all the atoms lose their individual identity and become one single quantum state with all the atoms being everywhere in the condensate at the same time. The atoms in these matter waves behave much more like waves rather than individual particles. These matter waves can be brought to interfere in order to measure incredibly small forces or tiny rotations.

The breakthrough of the scientists at IESL-FORTH, led by Wolf von Klitzing, is that they used a combination of magnetic fields at different frequencies to produce so-called time-averaged adiabatic potentials (TAAP). In order to prove that these matter wave guides are perfectly smooth, they constructed a mm-sized accelerator ring for neutral matter waves, much like the km-sized CERN accelerator for charged particles.

The matter waves reached hypersonic speeds exceeding the speed of sound by a factor of 16, and guided the matter waves for more than 40 cm — an improvement of more than a factor of 1000 compared to the previous record.

In the near future, the team plans to construct a mm-sized atomtronic gyroscope and gravity sensor based on the ring.

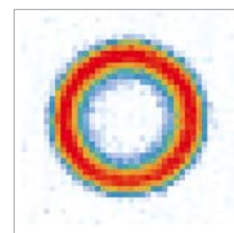


Photo of a Bose-Einstein condensate in a ring-shaped matter wave guide

© IESL-FORTH

ERC Advanced Grants

Another five experienced scientists working at Laserlab-Europe partners have been awarded Advanced Grants of 2.5 million euros each by the European Research Council. Here, their new projects are briefly described.

Maciej Lewenstein (ICFO): New applications of quantum simulators



© E. Blanco

Quantum simulators are experimental systems mimicking complex models of, for example, condensed matter and high-energy physics. Such quantum simulators can be realised on various platforms, ranging from ultracold atoms and ions to Josephson junctions or superconducting qubits.

Maciej Lewenstein's third ERC Advanced Grant project, NOQIA, aims at introducing quantum simulators to two novel areas: physics of ultrafast phenomena and attoscience on one side, and quantum machine learning and neural networks on the other. The project will, for example, address the question whether intense laser physics may serve as a tool to detect topological effects in solid state and strongly correlated systems (such as graphene), and whether ultracold atoms can mimic such phenomena. In addition, the aim is to design and analyse quantum neural network devices that will employ topology in order to achieve robust quantum memory or robust quantum information processing.

Thomas Elsaesser (MBI): Probing DNA and RNA charge dynamics



© R. Guenther

Biological macromolecules exist in an environment of water molecules and solvated ions, where electric water dipoles and charged ions exert electric forces on the biomolecules and, thus, strongly influence their structure and biological function. Understanding such interactions at the molecular level is a major scientific challenge;

presently, their strengths, spatial range and interplay with other non-covalent interactions are barely known.

In his second ERC Advanced Grant project, Thomas Elsaesser will try to map these molecular forces on sub-nanometer length scales and at terahertz frequencies. He will do this by measuring the vibrational response of the biomolecules DNA and RNA to the charge dynamics and local electric fields, using multidimensional vibrational spectroscopy on a femtosecond timescale. As a groundbreaking open problem, the role of magnesium and other ions in DNA and RNA structure definition and folding will be addressed. Beyond RNA research, the present approach holds potential for fundamental insight in transmembrane ion and water channels.

Theo Kitsopoulos (IESL-FORTH): Slice imaging to understand catalysis



© Max Planck Institute for Biophysical Chemistry

Catalysis and catalytic processes account, directly or indirectly, for 20-30 % of world gross domestic product. In order to optimise these important chemical processes, knowledge of elementary chemical reaction mechanisms in heterogeneous catalysis (where molecules in different states of aggregation interact with each other)

is needed to construct comprehensive kinetic models.

In his ERC Advanced Grant project, Theo Kitsopoulos will use the slice imaging technique developed at IESL-FORTH to measure catalytic rates for site-specific elementary reactions. Originally, this slice imaging technique, was developed to study gas phase processes such as laser photodissociation or crossed-beam reactive scattering. In collaboration with the Max Planck Institute of Biophysical Chemistry, Kitsopoulos' methodology was extended to measurements of the kinetics of catalysis in the microsecond regime, at industrially relevant temperatures of 200 to 1000 Kelvin. His intention is to focus on elementary reactions involving carbon, hydrogen, oxygen, and nitrogen, as these are important in many key industrial processes.

Antonio Acín (ICFO): Certification of quantum information systems



© ICFO

Currently, complex many-body quantum systems are prepared in many labs worldwide, and quantum information technologies are making the transition to real applications. The concept of quantum certification covers the questions of ensuring entanglement, randomness, and security of these quantum information systems, as

well as whether the performed quantum calculations are indeed correct.

Antonio Acín's ERC Advanced Grant project aims at bringing quantum certification to the next level, focussing on tools to identify quantum properties of many-body quantum systems; characterising networks in the quantum regime, and constructing cryptography protocols offering certified security. Expected outcomes of this project include new protocols to benchmark quantum simulators and annealers, first methods to characterise quantum causality, and new protocols exploiting simple network geometries.

Jens Limpert (HIJ): Compact lasers as alternative to synchrotron facilities



© Leistungszentrum Photonik Jena

At the moment, large-scale research facilities

High-quality radiation in the terahertz and mid-infrared spectral range can, for example, be used for non-destructive investigation of complex materials and detection of diseases in the human body, respectively. However, the radiation provided by current laser-based sources is not yet of sufficiently high quality for these practical

ties such as synchrotrons are still needed for this kind of research.

With his ERC Advanced Grant, Jens Limpert intends to develop a high-performance fibre laser system to generate coherent laser pulses in the infrared, terahertz and soft X-ray range. Since direct emission of coherent radiation with the wavelength agility and performance of a synchrotron is not possible with conventional lasers, Limpert and his team in Jena are adopting a different approach. They first generate laser pulses of a different frequency and focus them through a non-linear medium, which shifts the frequency into the desired range. In order to achieve significantly longer wavelengths, they will – among other things – use thulium-doped ultrafast fibre lasers.



Laserlab ERC start-ups

One of the ways to allow society to benefit from scientific research is to develop and market a specific product based on the researchers' findings. In order to support this process, the European Research Council has installed the Proof of Concept funding scheme for ERC Grant holders, comprising of up to 150.000 euros, allowing them to turn their research outputs into a commercial or socially valuable proposition. Here, we highlight a few start-up companies which are the result of earlier ERC grant projects of researchers at Laserlab institutions.

Quside Technologies: Quantum random number generators for data security (ICFO)

Quside Technologies was established in Barcelona in September 2017. The company's technology was partially funded and pushed towards the market through two ERC Proof of Concept projects, which both involved ICFO researchers Antonio Acín, Morgan Mitchell, and Valerio Pruneri: MAMBO (2012) and ERIDIAN (2016). These projects led to the development of a market-ready quantum random number generator for next-generation cybersecurity technologies.

Quside's proprietary technology permits the generation of fully unpredictable random digits at high rates and in a chip-size form factor, thereby satisfying key requirements for next generation security technologies as well as high-performance computing platforms.

The start-up, which currently employs 10 people, is led by Carlos Abellan, who obtained his PhD at ICFO working on the quantum technology now marketed by Quside. "Understanding the quantum world and finding efficient ways to use these concepts to tackle industry problems was an exciting research and development programme that combined fundamental physics and engineering", he says. "From here, hand in hand with the Knowledge and Technology Transfer unit at ICFO, we are now tremendously excited to be able to bring quantum technologies from the lab to people."

www.quside.com



NIREOS: Interferometric spectroscopy as an analytic tool (POLIMI)

NIREOS is a spin-off company from Politecnico di Milano (POLIMI) located in Milan, Italy, which has grown out of two consecutive Proof of Concept projects of POLIMI researcher Dario Polli, called CHIMERA (2017-2018) and FLUO (started 2018). CHIMERA's aim was to develop a device to identify the chirality of molecules; FLUO is an ongoing project that is bringing to the market a device to spectrally and temporally resolve fluorescence, which combines low costs, reduced footprint, and exceptional stability as well as high acquisition speed and sensitivity.

Both Proof of Concept projects are based on a patented interferometer. Based on this device, NIREOS offers a series of products for spectroscopy, in particular the ultra-broadband spectrometer SPECTRE (with a range of 0.8 – 4.2 micron), the ultra-stable interferometer GEMINI (providing 1 attosecond stability between two replicas of light) and is now launching the ultra-sensitive global-imaging hyperspectral camera HERA.

NIREOS, which was established in 2018 and has a team of seven people, aims at customers from scientific research labs as well as R&D and quality control departments of companies that use spectroscopic analysis to monitor the quality of their processes and the properties of their products.

www.nireos.com



Sphere Ultrafast Photonics: Solutions for ultrafast pulsed lasers (LLC, with University of Porto)

Sphere Ultrafast Photonics was founded in September 2013 by a team involving people from Lund Laser Centre (LLC) and the University of Porto, Portugal. The company, based in Porto, was directly involved in a Proof of Concept (PoC) project led by LLC's Anne L'Huillier which started in that same year.

The PoC project allowed the company to build and market a device for characterization and control of femtosecond pulses, called 'd-scan'. The d-scan technique was invented by Miguel Miranda and co-workers in Lund and Porto while working towards his joint PhD degree from both universities, co-supervised by Anne L'Huillier, Cord Arnold (Lund) and Helder Crespo (Porto).

Recently, a second PoC project was proposed and accepted (2018), and is ongoing at the moment. It aims at developing single-shot d-scan setups able to characterize both few- and many-cycle laser pulses on a shot-to-shot basis.

Sphere Ultrafast Photonics is led by Rosa Romero, a member of the Laserlab-Europe Industrial Advisory Committee. The company offers compact, inline d-scan devices for the simultaneous measurement and compression of ultrafast pulses down to single-cycle durations, the CEP-tag system for measuring the carrier envelope phase offset in single-shot operation, as well as custom solutions for few-cycle pulse control in various ultrafast applications.

www.sphere-photonics.com



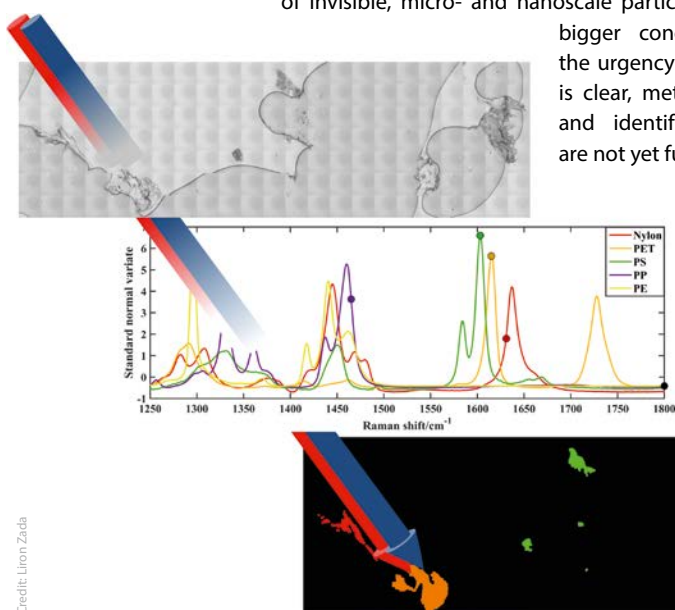
Lasers and Water

In this focus section a sample can be found of laser research within Laserlab-Europe related to water in the broadest sense. As is shown on the following pages, lasers can be used to try to understand the peculiar behaviour of water as a liquid (there seem to be two 'types' of water), and water can be an object of detailed study concerning its electrical properties. Even the most basic interactions between water and light – what happens when a beam of light hits the water surface? – are still under study. How water interacts with acids under 'stardust conditions' sheds light on primordial molecular evolution in outer space. And last, but not least, laser-based techniques to study microbial water quality or to detect microplastics in water can contribute greatly to protection of our natural environment, as well as to our own safety and health.

Lasers and water pollution: detecting environmental microplastics (LaserLaB Amsterdam, The Netherlands)

The growing amount of plastic micro- and nanoscale particles in canals, lakes, rivers and oceans presents a serious environmental concern. Researchers at Laserlab-Europe partner LaserLaB Amsterdam have built a setup for stimulated Raman scattering microscopy, which can be used to quickly identify the five major types of polymer particles collected on a filter.

In recent years there has been a growing concern regarding environmental microplastics. These polymer particles can have many different chemical compositions, sizes and shapes. They are either added deliberately to certain products such as cosmetics, or can result from plastic waste fragmented by mechanical or photochemical degradation. A large fraction enters our rivers and canals (also because sewage treatment plants do not remove them very efficiently) and ultimately ends up in the marine environment. Large concentrations of floating plastic garbage are known as "plastic soup", but the much larger numbers of invisible, micro- and nanoscale particles are an even bigger concern. Although the urgency of the problem is clear, methods to detect and identify microplastics are not yet fully developed.



Credit: Liron Zada

A test sample of microscopic polymer fragments collected on a filter (top). For SRS, the sample is irradiated with two overlapping picosecond laser beams, of which the photon energy difference matches a vibration of the target polymer (selected from the conventional Raman spectra of five common plastics; middle). The images recorded at six different wavenumber settings are combined using a multiplexing algorithm to identify the different polymer types (bottom).

LaserLaB Amsterdam has been involved in several projects related to microplastics and aquatic pollution. Raman spectroscopy is very suitable for the chemical characterization of polymers: when irradiating a sample with a laser and detecting the (very weak) fraction of inelastically scattered light, we obtain a fingerprint spectrum showing the vibrational modes of the molecules in the sample. Different polymer types give very different Raman spectra. The figure shows the Raman spectrum of a white microplastic particle collected from the effluent of a wastewater treatment plant. Comparison with reference spectra clearly identifies the polymer as polyethylene.

We are currently looking with a drinking water research facility at the effectiveness of the various purification steps. Raman spectroscopy plays an indispensable role in such projects, but unfortunately the classical mapping approach is quite time-consuming. As a new development, we have therefore built a setup for stimulated Raman scattering (SRS) microscopy, which can speed up the identification of polymer particles collected on a filter by 3-4 orders of magnitude.

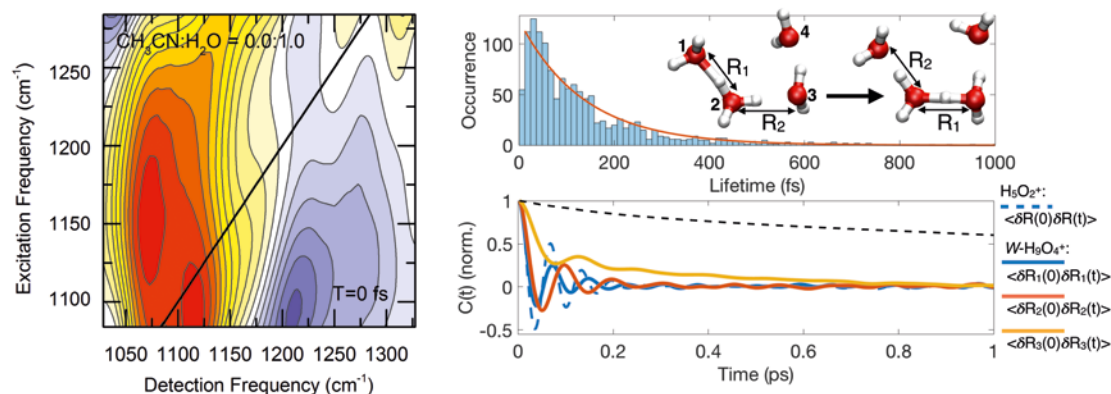
For SRS, the sample is irradiated with two (picosecond) laser beams, of which the difference in photon energy matches a vibration of the target molecule. As a result, a signal integration time of the order of microseconds per pixel is sufficient, compared with seconds in the case of conventional Raman spectroscopy. By repeating the SRS image with six different wavenumber settings, the five major polymer types can be distinguished at the fastest mapping speed for environmental samples to date. As a proof-of-principle, we demonstrated this approach for microplastic particles identification in sediment from the Rotterdam harbour area.

Liron Zada & Freck Ariese (LaserLaB Amsterdam)

L. Zada et al., J. Raman Spectroscopy 49: 1136, 2018

Solvation structure and ultrafast motions of hydrated excess protons (MBI, Germany)

Understanding the solvation shell of hydrated protons is a long-standing open question that is key to proton transport via the Grotthuss mechanism – also known as 'proton jumping'. Novel experiments at Laserlab-Europe partner MBI shed light on proton solvation structure and dynamics on the ultrafast timescale.



Left: two-dimensional infrared spectrum of excess protons solvated in neat water with ground state bleach. Stimulated emission components shown in red and excited state components shown in blue. Right: timescale of interconversion of the H₃O₂⁺ Zundel-motif (marked by R₁) within the H₃O₂⁺ unit obtained from ab-initio molecular dynamics simulations.

The solvation structure of excess protons in aqueous surrounding is highly relevant to electric properties and for understanding proton transport in liquids and membranes. Despite such overarching importance, the microscopic details of the solvation shell constitute a long-standing unresolved question. Commonly, solvation of an excess proton H⁺ is discussed within two limiting structures: in the Eigen complex (H₉O₄⁺) a central hydronium ion (H₃O⁺) harbours the proton and is surrounded by three water molecules, while in the Zundel cation (H₅O₂⁺) the proton is part of a strong hydrogen bond between two flanking water molecules. In particular the lack of suitable non-invasive experimental observables, as well as structural fluctuations of the solvent molecules on a multitude of timescales, have prevented an unequivocal assignment of the abundance of different solvation structures.

By combining nonlinear two-dimensional infrared spectroscopy in the mid-infrared molecular fingerprint region (~ 8 μm) with ab-initio molecular dynamics simulations, we have tracked the genuine proton degrees of freedom in varying acetonitrile/water mixtures, including neat water. The strategy of building the water environment step-by-step provides a benchmark of aqueous solvation geometries via a spectroscopic comparison to excess protons selectively prepared with only a few water molecules in neat acetonitrile. As such, it was demonstrated that for all investigated mixing ratios, excess protons are confined within a low barrier double-minimum potential and are subject to large amplitude displacements due to the fluctuating electric field imposed by the structural fluctuations of the solvent shell. The results thus demonstrate that excess protons in water are predominantly solvated within dimeric water structures, i.e., within a H₅O₂⁺ Zundel-motif.

The accompanying simulations reveal how the dimeric water solvation structure interacts with its closest water neighbour in an H₇O₃⁺ unit without persistent localization of the excess proton in a single H₃O⁺ unit. The results suggest that a rearrangement of the hierarchical hydrogen bond structure, accompanied by translocation of the dimeric solvation geometry, is a key element in the microscopic mechanism of proton translocation in aqueous solution. Our investigations thus shed light on the elementary steps of proton translocation in aqueous solution via the Grothuss mechanism of structural diffusion.

Benjamin P. Fingerhut (MBI)

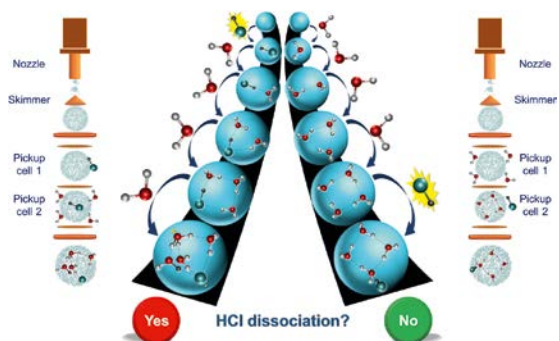
A. Kundu et al., *J. Phys. Chem. Lett.* 10: 2287, 2019

Chemistry in ultracold interstellar space: complex behaviour of acids (FELIX, The Netherlands)

Because primordial molecular evolution occurs on icy mantles of dust nanoparticles or on ultracold water clusters in dense interstellar clouds, chemical reactions at ultralow temperatures are of fundamental importance to this process. Using spectroscopic analyses and computer simulations, a team of researchers from Ruhr University Bochum and Laserlab-Europe partner FELIX Laboratory in Nijmegen discovered that at extremely low temperatures proton release from hydrochloric acid (HCl) depends on the order in which water and hydrochloric acid molecules are brought together.

A fundamental question concerning primordial molecular evolution is whether acid/base chemistry, such as discovered in stratospheric clouds, could already be triggered at ultracold 'stardust conditions' by dissociation of acids, e.g., HCl, in the absence of thermal and photoinduced activation.

Solvated acids tend to release a proton, and at room temperature hydrochloric acid (HCl) immediately dissociates when it comes into contact with water molecules. It releases its proton (H⁺) and one chloride ion (Cl⁻) remains. However, under 'stardust conditions' they display a more complex behaviour. Studying reactions in a stepwise manner in ultracold helium nanodroplets by mass-selective infrared (IR) spectroscopy provides an avenue to mimic these 'stardust conditions' in the laboratory.



Two different pathways for the aggregation of HCl(H₂O)_n clusters depending on the pick-up order in helium droplets, depicting that acid formation at ultracold temperatures follows a unique pathway.

In a joint experimental and theoretical study, involving researchers from the Cluster of Excellence RESOLVE at Ruhr University Bochum and FELIX Laboratory, H₂O molecules have been successively added to HCl, disclosing a unique IR fingerprint at 1337 cm⁻¹ using the FELIX free electron laser. The IR signature signals hydronium (H₃O⁺) formation and, thus, acid dissociation generating solvated protons. In stark contrast, no reaction is observed when reversing the sequence by allowing HCl to interact with preformed small embryonic ice-like clusters.

Ab initio simulations demonstrate that not only reaction stoichiometry but also the reaction sequence needs to be explicitly considered to rationalise ultracold chemistry. One may expect that the results can also be applied to other acids and as such represent a basic principle of chemistry under ultracold conditions.

Britta Redlich (FELIX)

D. Mani et al.: Science Advances 5: eaav8179, 2019

When light meets water: a splash rather than a dip (CLL, Portugal)

What happens when light crosses the interface between air and water? Countless experimental attempts to see either a splash or a dip had given contradictory results, but the controversy now seems to have been solved at Laserlab-Europe partner Coimbra Laser Lab (CLL). An experiment involving pulsed light illumination of the air/water interface, under conditions where thermal effects are avoided, clearly shows that the light causes a splash rather than a dip.

Every second, 10³⁵ photons cross the air/water interface at the surface of the Earth, change velocity and transfer momentum to that interface. Two competing theories, proposed by Hermann Minkowski and Max Abraham, have been used for over one century to describe what happens

when light crosses the air/water interface and slows down. Minkowski proposed a momentum transfer that pushes the water interface up to the air – a splash – whereas Abraham deduced that the momentum transfer pushes the interface inwards to the water – a dip.

These conflicting theories have motivated many experiments and interpretations, but measurements of the momentum transferred at the air/medium interface remained elusive. A major experimental difficulty has been the separation of the very minute effect expected for momentum transfer from other possible effects, such as thermal effects due to light absorption.

The work at the Coimbra Laser Lab eliminated thermal effects by taking advantage of a remarkable property of water: the thermal expansion coefficient of water is zero at 3.9 °C. Based on three decades of experience in photoacoustic calorimetry, researchers at CLL used pulsed laser excitation of air/water interfaces at 3.9 °C to measure photoacoustic waves exclusively generated by volume changes at the air/water interface.

The experiments employed the total reflection angle of light to water/air surface, which maximizes the photoacoustic signal generated by photon momentum transfer at the interface. The optical radiation pressure pushes the water/air interface outwards to air and the angular dependence of the photoacoustic waves follows the predictions of Minkowski. There is a splash when the photons hit the water/air interface!

Fabio A Schaberle, Carlos Serpa and Luís G Arnaut (CLL)

F. A. Schaberle et al., New Journal of Physics 21: 033013, 2019.

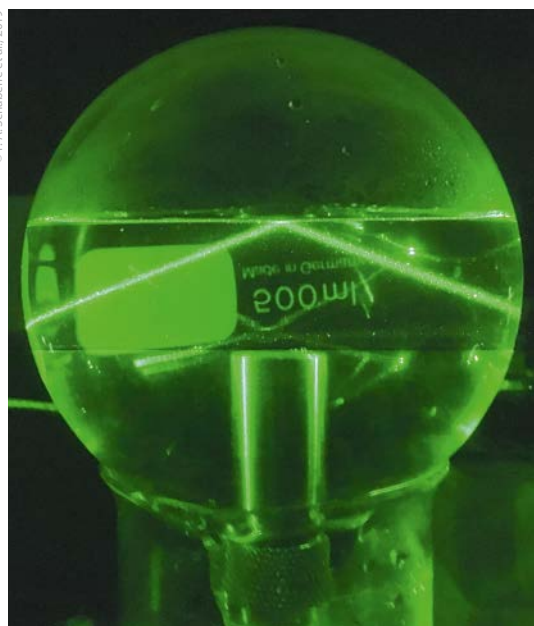
Monitoring water quality using endogenous fluorescence of algae (ILC, Slovakia)

Photosynthetic pigments in algae are sensitive to changes in their environment, thus acting as natural biosensors that reflect changes in water quality. At Laserlab-Europe partner International Laser Center (ILC) confocal microscopy and time-resolved fluorescence imaging are employed to study the reaction of algae to various kinds of stress. The research should lead to new methods for monitoring water quality.

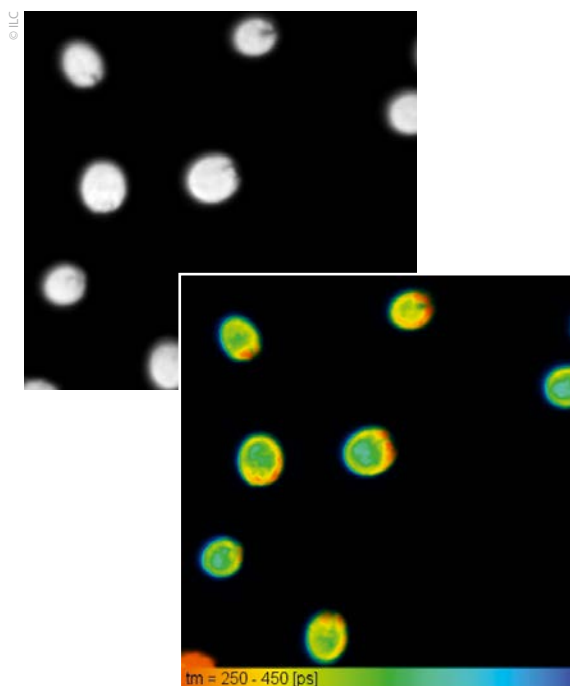
Acidification of the aquatic environment presents an important environmental stress factor, as under the influence of industrial pollution acid rain can reach a pH of below 5, severely impacting mainly coastal water. Pollution by heavy metals constitutes a hazard to aquatic organisms as well.

Algae play a crucial role in aquatic ecology, producing oxygen and serving as the food base for almost all aquatic life. We evaluate responses of the endogenous fluorescence related to chlorophylls, as well as other pigments, such as flavonoids and carotenoids, in algae. Pigments of various algae, namely seawater algae *Dunaliella* and fresh water algae *Chlorella sp.*, as well as phototropic *Euglenas* are studied by advanced spectroscopy and microscopy methods in their natural environments, but also in response to environmental changes, namely pH modification, or presence of heavy metals – more specifically cadmium.

Employing advanced spectrally-resolved confocal microscopy and time-resolved fluorescence imaging, we study the fast (in terms of minutes), as well as the long-term (in terms of weeks) responsiveness under stress conditions of the algae, but this approach can also be used to monitor changes in water moss, or higher plants. Deep understanding of algal cell response to stressors will be helpful for monitoring water quality, and can become essential in biosensing and thus predicting how ecosystems may be affected by water pollution, climate change and other human activities.



Experimental setup with water and incident light at total reflection angle, showing also the 10 MHz immersion transducer used to detect the ultrasound waves.



Fluorescence lifetime imaging (FLIM) of endogenous fluorescence in marine algae *Dunaliella*, following excitation by a 475 nm picosecond laser, recorded by a TCSPC system. Intensity image (left); lifetime distribution image (right), shown in the range 250-450 ps, demonstrates the presence of at least 2 fluorescence lifetimes in control conditions.

In more detail, fluorescence lifetime (FLIM) autofluorescence images are recorded using the time-correlated single photon counting (TCSPC) technique following excitation with a 475 nm picosecond laser diode. The laser beam is reflected to the sample through an epifluorescence path of a laser scanning confocal microscope. The emitted fluorescence is separated from laser excitation using a long pass filter 500 nm and detected by a photomultiplier array.

This work is done in the common lab of biophotonic technologies of the International Laser Center and the University of Ss. Cyril and Methodius in Trnava, Slovakia, in collaboration with Ruder Boskovic Institute in Zagreb, Croatia.

Alzbeta Marcek Chorvatova
(ILC and University of Ss. Cyril and Methodius)

N. Ivosevic DeNardis et. al., European Biophysics Journal 48: 231, 2019

Two types of water revealed by ultrafast spectroscopy (LENS, Italy)

Water might actually come in two distinct forms, which could explain its peculiar behaviour compared with other liquids. Experiments using ultrafast laser spectroscopy, performed at Laserlab-Europe partner LENS, provide evidence of the coexistence of two local structural configurations of water molecules, which supports the hypothesis of high-density and low-density forms of water.

Water can remain liquid below its freezing point, entering into a metastable phase known as “supercooled wa-

ter”. In this water phase, a series of physical characteristics show anomalous behaviours that distinguish it from other liquids (e.g. the density has a maximum at 4°C). Despite the relative simplicity of water molecules, its liquid phase remains an open problem for liquid physics; the strong network of hydrogen bonds formed by the molecules support extended and collective interactions, which are very hard to describe by physical models.

One of the most credited models assumes that water is actually made up of two different types of liquid: low-density water and high-density water. The former is characterized by tetrahedral local intermolecular structures, very similar to those found in ice, and the latter by less ordered and more compact structures. According to this model, at low temperatures these two water forms are distinct and separated by a phase transition, while at higher temperatures they interpenetrate and continually exchange in extremely rapid timeframes, typically 10^{-12} seconds.

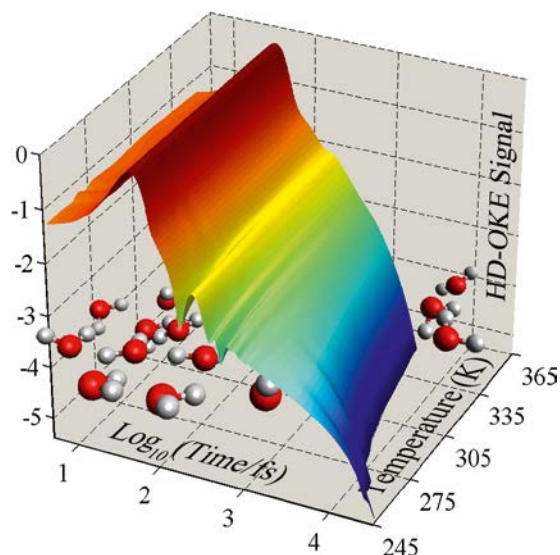
Experimental detection of these two water forms is made particularly difficult precisely by the speed and frequency of the rearrangements of the local liquid structures. To date there is still no definitive proof of the existence of these two water forms. However, in an ongoing campaign, a group of researchers at the European Laboratory for Non-Linear Spectroscopy (LENS, University of Florence) is undertaking a series of experimental studies using ultrafast spectroscopy techniques based on femtosecond laser sources.

Measuring the dynamics of liquid water at temperatures down to -28 °C, these studies show that vibrational and structural dynamics of the water molecules reveal the presence of two major molecular organizations: one characterized by a high order of tetrahedral hydrogen bonds, while the other presents strong local distortions of the lattice. These two types of local organization of water molecules can be interpreted as evidence of the existence of water of low and high density.

Renato Torre (LENS)

A. Taschin et al., submitted, 2019

A. Taschin et al., Nat. Commun. 4: 2401, 2013



Heterodyne Detected – Optical Kerr Effect data of liquid water at different temperatures.

Micro-LIBS imaging of mollusc shells: a window to the past

In a recent article in *Scientific Reports*^[1], resulting from a Laserlab-Europe transnational access project, scientists at IESL-FORTH, collaborating with the Max Planck Institute for the Science of Human History and the School of Geography, University of Melbourne, have shown that LIBS microscopy enables extensive elemental mapping of mollusc shells, providing an insight into the rich environmental archives contained in such specimens. This is a major step forward for the exploitation of mollusc archives to study climate in a range of applications, including ocean circulation, glacial/interglacial climates, and anthropogenic climate change.

Shellfish have played a significant role in the diet of pre-historic coastal populations, providing valuable nutrients. They are a common find at archaeological sites all over the world, usually in huge numbers, and researchers have long explored how they could be used to make inferences about the environments that humans experienced at those locations in the past. However, although techniques have been developed to extract valuable climate-related information from shells, it has been too expensive to obtain data on a scale beyond individual and isolated records. The current study presents a technique to use rapid laser imaging to increase the number of analysed shell records to previously unknown scales, and thereby greatly expand the time periods and accuracy of the reconstructed records.

The effort was led by Niklas Hausmann at IESL-FORTH in the framework of his Marie Skłodowska Curie fellowship project ACCELERATE (www.accelerate-project.com). He joined the research group of Demetrios Anglos (University of Crete and IESL-FORTH) and collaborated with Panagiotis Siozos, senior researcher, and Andreas Lemonis, automation and programming expert, developing an automated scanning micro-LIBS (laser-induced breakdown spectroscopy) apparatus that enabled mapping of large numbers of shells of the course of the project.

It is important to note that this research emerged from a Laserlab-Europe access project. It was in December 2013 that Hausmann, then a PhD student at the University of York, UK, approached Costas Fotakis and Demetrios Anglos at the Ultraviolet Laser Facility-FORTH inquiring on

the possibility to use their laser for carrying out oxygen isotope analysis on shells. After an access proposal was approved, Niklas Hausmann visited ULF-FORTH and carried out a series of exploratory experiments in April-May 2014.

Following two weeks of hard work, Hausmann and his co-workers were able to obtain the first LIBS images showing variations of the magnesium to calcium (Mg/Ca) concentration on sections of mollusc shells^[2, 3]. These variations, traced along the shell growth lines, were consistent with seasonal temperature variations, showing the potential of micro-LIBS as a new tool for obtaining high-resolution elemental images of shell surfaces.

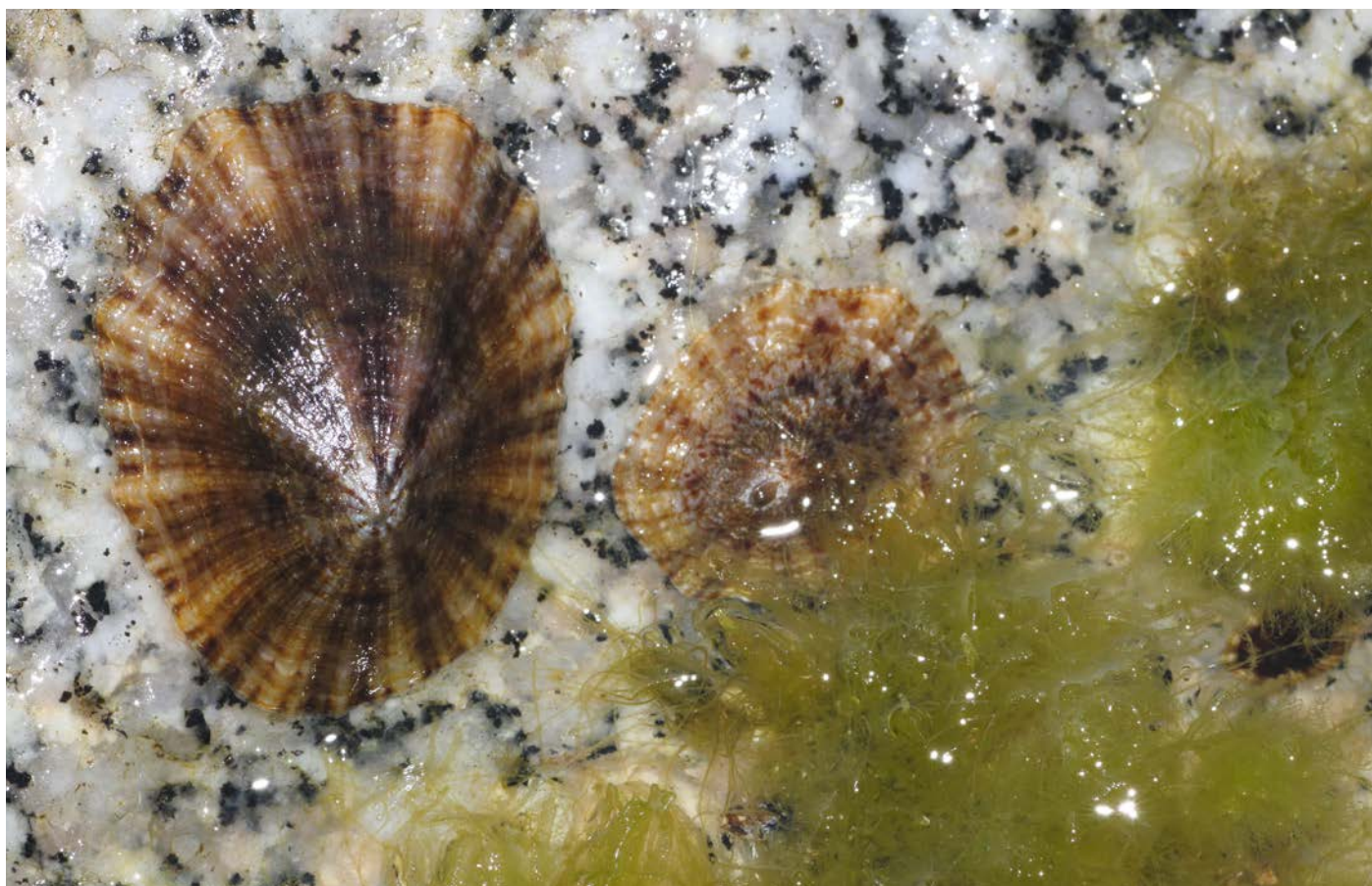
This success was enough to spark a more consistent effort to investigate LIBS mapping in detail, and led to the ACCELERATE project. Within this project, mollusc shells from a range of countries and archaeological sites were analysed, covering 20 countries on all continents and ranging back into past time periods with shells collected by Neanderthals. Most shells, however, dated to modern periods, where the elemental composition could be compared to readings from instrumental data, as was the case for the study in *Scientific Reports*[1]. Here LIBS allowed to analyse quickly and at low cost shells from across the Mediterranean in a wide and multi-regional study that compared different localities, rather than only one, resolving major concerns in the field regarding the improvement of rapid and low-cost climate proxies such as Mg/Ca ratios in shells.

So far, it had been hard to link such elemental ratios of shell carbonate to sea surface temperatures because the interpretation of the measurements was hampered by variations in study location as well as vital or physiological effects between and within individual mollusc specimens. Having identified the Mediterranean limpet *Patella caerulea* as an ideal species to assess elemental variations through LIBS, elemental maps and line scans of 19 shell specimens from 9 sites were produced for the study.

The Mg/Ca ratio maps of almost all specimens show repeating bands of high and low intensity throughout the entire length of growth increments, corresponding to the seasonal changes in sea surface temperature known from satellite measurements. Only two shells – the ones that had grown for less than a year – lacked these bands. As many as 8 out of the 19 specimens, however, showed additional Mg/Ca patterns unrelated to sea surface temperature, and in two of those specimens this prevented reliable temperature reconstruction. Such problematic specimens would skew the sea surface temperature record if measured without being recognised.



Map of sample locations that were analysed in the Mediterranean study.



One of the analysed species of molluscs, Mediterranean limpet *Patella caerulea*, in its natural environment.

photo: H. Krisp (<https://commons.wikimedia.org/wiki/File:Patella-caerulea.jpg>), „Patella-caerulea“, <https://creativecommons.org/licenses/by/3.0/legalcode>

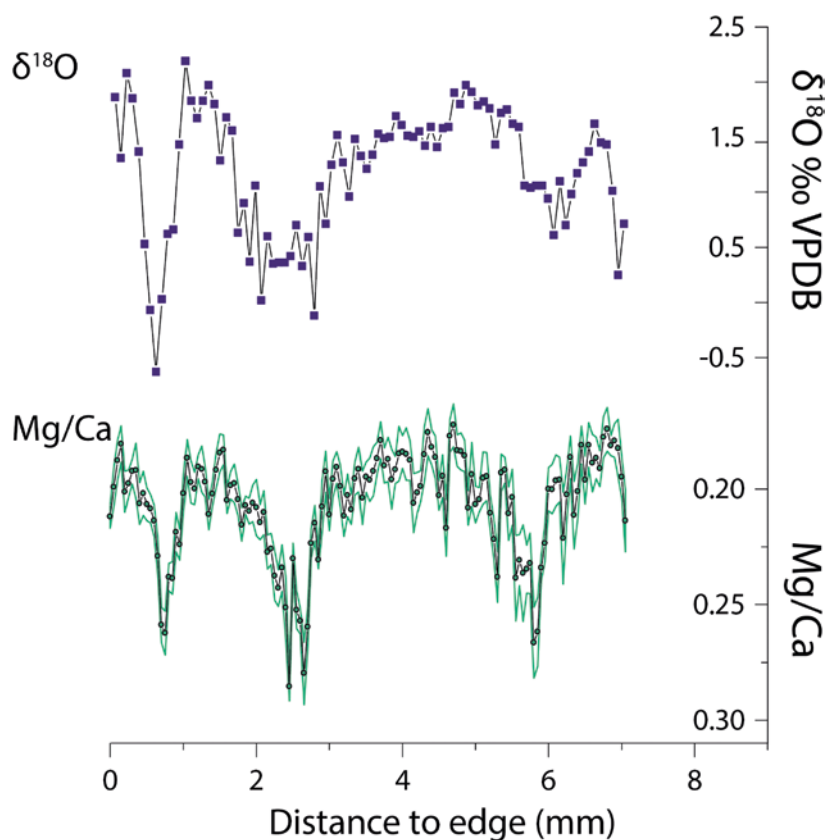
The observed seasonal changes in Mg/Ca ratios obtained by LIBS allow archaeologists to determine at relatively low costs in which season the specimen has been consumed, which is of importance for the study of past human and animal behaviour.

Hausmann is now seeking funding to set up a dedicated micro-LIBS facility for large-scale mollusc screening, based on the outcomes of the ACCELERATE project, which did not only find new ways of analysing temperature changes, but also to reveal growth structures within shells. These can be key to efficiently plan analyses using other geochemical proxies, such as oxygen isotope analysis or clumped isotope analysis, which are more expensive.

In addition to molluscs, there are other carbonate archives with their own interesting research trajectories that LIBS mapping can address. Stalagmite and corals have previously been shown to provide important elemental records of climate change and would benefit from rapid analysis or screening prior to more detailed geochemical studies. The team at FORTH investigates these potential applications.

**Niklas Hausman (University of York),
Panagiotis Siozos & Demetrios Anglos
(IESL-FORTH)**

1. N. Hausmann et al., *Scientific Reports* 9: 3698, 2019
2. N. Hausmann et al., *J. Anal. At. Spectrom.* 32: 1467, 2017
3. N. Hausmann et al., pp 725-740, in: N. Rasul, I. Stewart (eds), *Geological Setting, Palaeoenvironment and Archaeology of the Red Sea*, Springer, Cham, 2019



Records showing the good correlation of expensive oxygen isotope records (above) and rapid LIBS records.

Wayforlight: The Catalogue of European Light Sources

Thanks to the Horizon 2020 EUCALL project, the Wayforlight database, which previously only included synchrotron and free electron laser facilities, has now reached a broader scope and includes also optical laser sources that provide access to secondary sources in the XUV and X-ray range – among them the majority of Laserlab-Europe's facilities. Users can now browse more than 300 beamlines at 38 facilities, fine-tuning their search for the most suitable and complementary instruments for their future experiments.

Wayforlight.eu is a user-oriented web-portal offering a standardised database to retrieve up-to-date information on European light facilities, beamlines and their instrumentation. The new, augmented database was designed and realized at Elettra Sincrotrone Trieste. It offers a set of Advanced Programming Interfaces (APIs) allowing automatic synchronisation of the information provided by each fa-



The catalogue of European light sources

www.wayforlight.eu

ility. Current discussions on interoperability also involve the FELs of Europe association, the MERIL community and the CatRIS Horizon 2020 project.

Within the Horizon2020 CALIPSOplus project, Wayforlight has been enriched with two sections dedicated to academic and industrial users, respectively. Industry can easily find useful information in a multi-language section presenting the resources available at the various light sources, as well as direct contacts of their industrial liaison offices. In the future, facilities offering access also to lasers working in the visible range will be included.

First ions and first electrons accelerated at ELI Beamline

At ELI Beamlines near Prague, Czech Republic, plasma-based secondary sources have been generated for the first time by the L3-HAPLS laser system. Two short experimental campaigns on ion and electron acceleration, respectively, have been carried out at the TERESA (TEstbed for high-REpetition-rate Sources of laser-Accelerated particles) target area.

Although the laser energy on target was still only 100 mJ, the estimated intensity was well above 10^{18} W/cm². Those relativistic laser intensities have enabled the acceleration of protons and carbon ions from thin solid targets, as well as electrons from a gas target, thus demonstrating the focusability and compression of the HAPLS laser beam.

SYLOS 2A laser system inaugurated at ELI-ALPS

On 15 May 2019, the SYLOS 2A laser system officially started its operation at the ELI-ALPS facility in Szeged, Hungary. The system, which has been designed by the Lithuanian companies EKSPLA and Light Conversion and developed in collaboration with ELI-ALPS personnel over the past four years, will drive four of the twelve beamlines of ELI-ALPS.

The SYLOS laser system, emitting 4.5 Terawatt pulses with durations of a few femtoseconds at 1 kHz repetition frequency, will drive two gas-based and one solid surface based plasma generation station for coherent soft x-ray sources and associated detection stages, as well as an additional source for high peak intensity electron pulses.

Forthcoming events

Lasers in Medicine and Life Sciences – LAMELIS

4–12 July 2019, Szeged, Hungary

ELI Summer School – ELISS 2019

25–30 August 2019, Dolní Břežany/Prague, Czech Republic

Joint JRA Meeting and Laserlab Conference

9–11 October 2019, Florence, Italy

Laserlab User Meeting

27–29 October 2019, Coimbra, Portugal

To find out more about conferences and events, visit the Laserlab online conference calendar.

How to apply for access

Interested researchers are invited to contact the Laserlab-Europe website at www.laserlab-europe.eu/transnational-access, where they find relevant information about the participating facilities and local contact points as well as details about the submission procedure. Applicants are encouraged to contact any of the facilities directly to obtain additional information and assistance in preparing a proposal.

Proposal submission is done fully electronically, using the Laserlab-Europe Proposal Management System. Your proposal should contain a brief description of the scientific background and rationale of your project, of its objectives and of the added value of the expected results as well as the experimental set-up, methods and diagnostics that will be used.

Incoming proposals will be examined by the infrastructure you have indicated as host institution for formal compliance with the EU regulations, and then forwarded to the Access Selection Panel (ASP) of Laserlab-Europe. The ASP sends the proposal to external referees, who will judge the scientific content of the project and report their judgement to the ASP. The ASP will then take a final decision. In case the proposal is accepted the host institution will instruct the applicant about further procedures.

Laserlab Forum Contact

Professor Claes-Göran Wahlström
Coordinator – Laserlab-Europe
Email: Claes-Goran.Wahlstrom@fysik.lth.se
The Coordinator's Office
Daniela Stozno
Max Born Institute
Max-Born-Str. 2A | 12489 Berlin | Germany
Phone: +49 30 6392 1508
Email: stozno@mbi-berlin.de

Editorial Team:

Tom Jeltens (tomjeltens@gmail.com)
Julia Michel, Daniela Stozno
Layout: unicom Werbeagentur GmbH

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