Laserlab
Europe

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Laserlab Forum

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the integrated initiative of European laser
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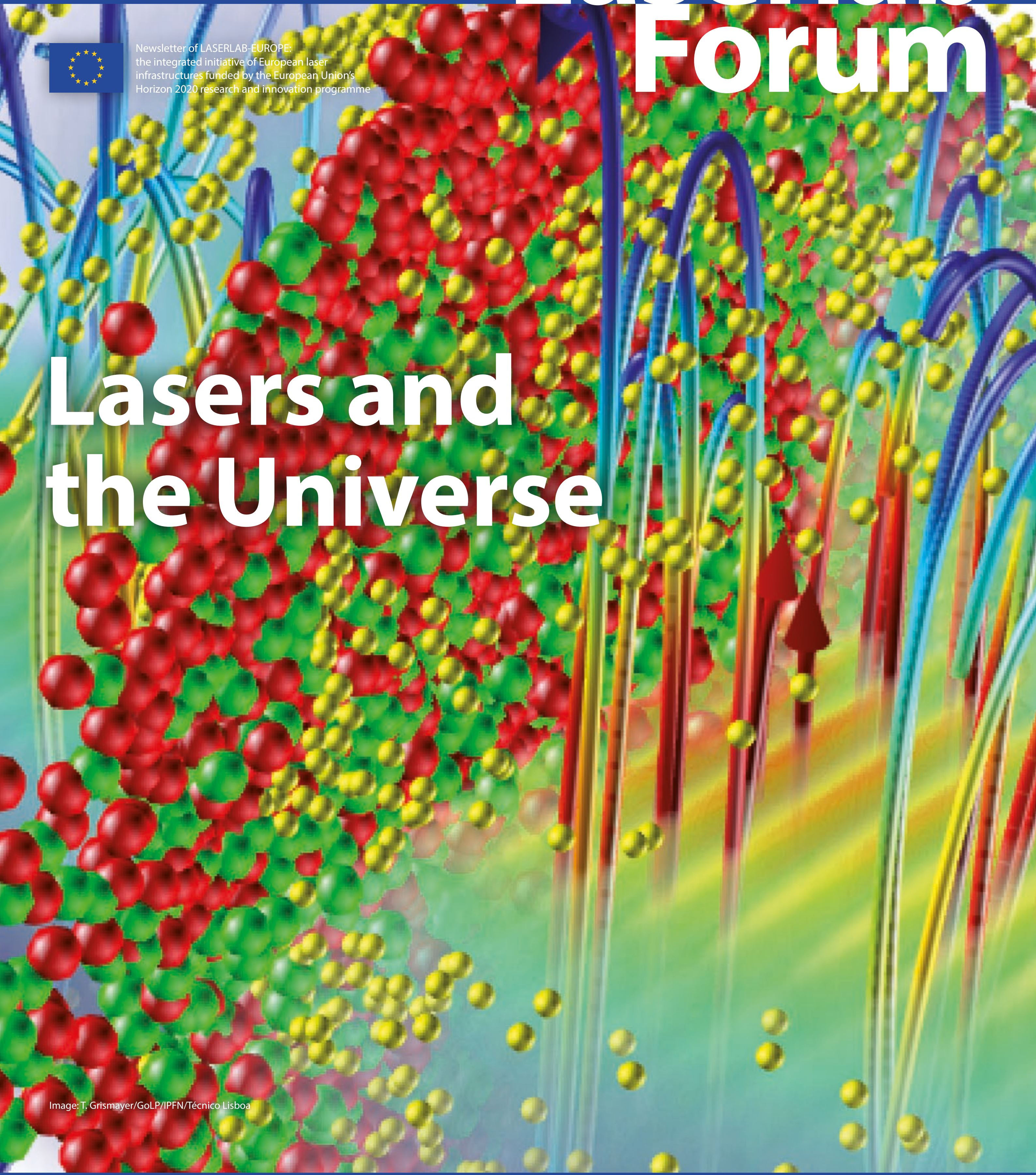

Lasers and the Universe

Image: T. Grismayer/GoLP/IPFN/Técnico Lisboa

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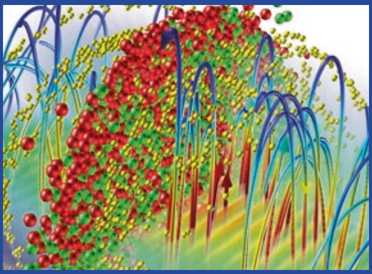
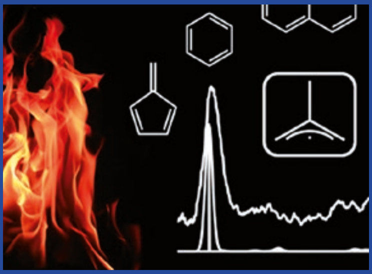




Editorial

Sylvie Jacquemot

The Laserlab-Europe newsletter is a major communication tool for our community; in addition to news from our consortium and access highlights, it regularly presents a set of articles dedicated to a hot topic where the laser contribution is invaluable. This issue is focused on the laser-driven exploration of the Universe.

Lasers are indeed very unique tools to explore the Universe, either in space or in the lab. In the first case, the LISA mission, which aims to observe gravitational waves in space using three satellites connected by laser beams, was recently marked as feasible and entered its final design phase. In the second case, laboratory astrophysics is key to analyse astronomical observations and deepen our knowledge of the chemical and physical processes underlying them. It implies access to a series of instruments, from high performance computers to laser research infrastructures, and covers a large variety of scientific fields, from astrochemistry and materials science to plasma physics and quantum electrodynamics, as shown in this newsletter.

Enjoy reading.
Sylvie Jacquemot

News

Twisted nanophotonic technology for integrated chiroptical sensing of drugs on a chip

TwistedNano

Financed by the Pathfinder Open 2021 Call of the European Innovation Council, the project TwistedNano aims at developing an innovative platform to measure tiny amounts of chiral drugs. The consortium consists of six European academic institutions, including the Laserlab-Europe partner ICFO, as well as a global player in pharmaceutics and a young start-up.

TwistedNano will develop a set of new-generation ultrasensitive LOC-integrable photonic sensors of chiral drugs. The optical technologies of the consortium, capable of measuring AC and enantiomeric purity, will revolutionise at source the technological toolbox for drug discovery and nanomedicine. The envisioned devices will provide radically new and advanced capabilities for remote and distributed analysis, reduced sample consumption, cost reduction, parallelisation, increased speed and sensitivity, crucial for fast clinical trials.

https://www.twistednano-horizon.eu

Anne L'Huillier, Paul Corkum and Ferenc Krausz awarded with Wolf Prize in Physics 2022

© Erika Weiland

Anne L'Huillier

The 2022 Wolf Prize in Physics was awarded to Paul Corkum, Anne L'Huillier and Ferenc Krausz for pioneering and novel work in the fields of ultrafast laser science and attosecond physics and for demonstrating time-resolved imaging of electron motion in atoms, molecules, and solids. Each of them made crucial contributions, both to the technical development of attosecond physics and to its application to fundamental physics studies.

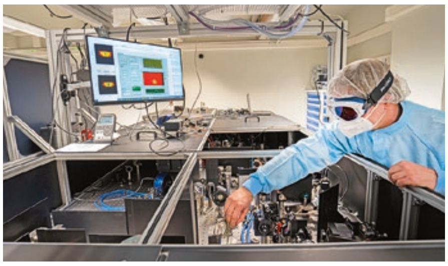
© Peter Seidel/MPQ

Ferenc Krausz

The international Wolf Prizes are awarded to outstanding scientists and artists from around the world, for achievements in the interest of mankind and friendly relations amongst peoples. The scientific categories of the prize include Medicine, Agriculture, Mathematics, Chemistry and Physics.

Anne L'Huillier, LLC, Sweden, and Ferenc Krausz, MPQ, Germany, have received prestigious ERC grants during past years.

MPQ: New High-Power CEP-Stable Mid-IR Laser System for XUV spectroscopy


© Thorsten Naeser/MPQ

At the Max Planck Institute of Quantum Optics (MPQ), the new high-power ultrafast laser system HORUS (High-power OPCPA system for high Repetition rate Ultrafast Spectroscopy) has taken a major step towards completion.

This system, combining high-power thin-disk technology with an Optical Parametric Chirped Pulse Amplification (OPCPA) scheme, will provide the CEP stable mid-IR (2 µm) driver pulses for the HORUS attosecond/XUV beamline system which currently is under construction as well.

The thin-disk laser system and two OPA stages have been commissioned and are now fully operational, delivering up to 7 W of CEP-stable 2 µm pulses at 10 kHz repetition rate with a pulse duration of 18 fs. Implementation of the final OPA stage for an envisaged output power of more than 20 W as well as the dedicated HORUS attosecond beamline is being worked on with completion expected by mid-2023.

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 35 leading organisations in laser-based inter-disciplinary research from 18 countries. Additional partners and countries join in the activities through the association Laserlab-Europe AISBL. 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.

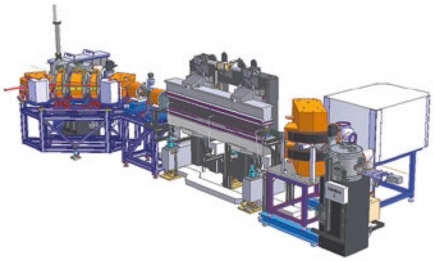
FELIX free electron laser: extension of the wavelength range realized


© HFML-FELIX

The technical team at FELIX-2.

In May, a brand-new undulator produced its first light at HFML-FELIX, thereby extending the tuning range of the FELIX-2 beamline to 3 µm.

The free electron lasers at Radboud University in Nijmegen, the Netherlands, provide high-intensity, widely tunable and ultrashort pulse radiation in the infrared and terahertz spectral range. Until now, the suite of four free electron lasers covered a wavelength range from 5 to 1500 µm. Pulse duration and micropulse energy vary with wavelength but range typically between 1-50 ps and 5-50 µJ.



Overview technical drawing of the novel FELIX-2 laser undulator and resonator.

After a period of design and construction in collaboration with colleagues at the Fritz Haber Institute in Berlin, during a six-week reconstruction period the FELIX technology team has installed and commissioned the undulator and renewed the FEL laser cavity. With the new FELIX-2 undulator, the wavelength coverage is extended to 3 µm and an increase in stability is realised by the novel cavity design. This significant upgrade allows further exploitation of FELIX by expanding its spectroscopic capability.

NIREOS receives 1.5m euros grant from the European Innovation Council (EIC)

NIREOS

The Italian start-up NIREOS receives support for its project HYPERIA "High-throughput hyperspectral imaging across the VIS-SWIR spectrum in a single device" from the EIC. With this grant, NIREOS will develop an innovative hyperspectral imaging camera covering a huge spectral range (400-1700 nm), with a single device and a single measurement. The system will measure the colour of objects as well as the entire light spectrum for each pixel of the two-dimensional field of view, with a hitherto inaccessible level of sensitivity even in low-light illumination conditions, covering a dramatically wider wavelength range from the visible to the short-wavelength infrared.

The HYPERIA project aims at targeting different applications, both in the scientific and in the industrial field, spanning from plastics sorting to cultural heritage, from remote sensing to microbiology, and many others.

In memoriam Professor Algis Petras Piskarskas

Laserlab-Europe is sad to announce that Professor Algis Petras Piskarskas passed away on 11 June 2022.


© VULRC

Algis Piskarskas, one of the most renowned Lithuanian physicists, made pioneering developments in non-linear optics, notably the first implementation of Optical Parametric Chirped-Pulse Amplification (OPCPA), a technique widely used worldwide today. He contributed thus to building the laser community in Lithuania, far beyond the academic circles. In 2004, under his leadership, the Vilnius University Laser Research Centre became a founding member of Laserlab-Europe and has been an active partner since then.

The Laserlab-Europe community will miss his expertise and his great humanity.

ERC Grants

The European Research Council (ERC) promotes frontier research by awarding prestigious grants to outstanding researchers for projects of ground-breaking nature. Laserlab-Europe researchers have again been successful in the ERC's highly competitive selection process. Congratulations to the four scientists who were recently awarded ERC grants, two receiving Advanced Grants, one receiving a Consolidator Grant, and one receiving a Starting Grant.

Nathalie Picqué (MPQ): Precision measurements in molecules with frequency combs

© Max Planck Institute of Quantum Optics

With her ERC Advanced Grant, Nathalie Picqué explores a new concept of precision measurements with frequency combs. A revolutionary spectrometer will simultaneously achieve broad spectral coverage, Doppler-free resolution and extreme accuracy for precise studies of small molecules. The unprecedented degree of control of frequency combs achieved in this way could also open up new experimental possibilities for the study of highly non-linear phenomena in strong-field and attosecond physics.

For more than ten years, Nathalie Picqué has developed pioneering methods using frequency combs in high-resolution molecular spectroscopy. These provide essential information about the structure and dynamics of molecules and open numerous new applications in chemistry, biology and environmental sciences, but also in fundamental physics, for example for precision measurements of fundamental constants.

Olga Smirnova (MBI): Ultrafast molecular chirality: twisting light to twist electrons on ultrafast time scale

© Misha Ivanov

Chiral molecules exist in pairs of non-superimposable "mirror twins" called enantiomers. The specific stereo arrangements of their nuclei underlie their key functions in chemistry and biology. Yet, little is known about chiral molecular interactions at the level of electrons, occurring on ultrafast time scales. Developing extremely enantio-sensitive, ultrafast and all-optical approaches to track electronic dynamics is an important unsolved challenge.

The ERC Advanced Grant supports the multidisciplinary project ULISSES. It aims to address this challenge by taking advantage of chiral electronic currents that arise naturally when chiral molecules interact with sufficiently intense light.

The project applies light with polarisation structured both in space and in time, endowing such light with local chiral and global topological properties. It aims to induce new optical effects being orders of magnitude more enantio-sensitive than the traditional optical techniques, gaining access to the ultrafast electron dynamics and physical mechanisms underlying chiral functions.

Frederico Fiúza (IST): Extreme particle acceleration in shocks: from the laboratory to astrophysics

Astrophysical shocks, generated by violent interactions of supersonic plasmas, are among the most powerful particle accelerators in the Universe. The underlying physics of particle acceleration in astrophysical shocks is not yet well understood, nor fully explored in the laboratory.

But this is about to change. Advances in computational power and fully-kinetic plasma simulations are making it possible to conduct new research. New machine learning tools enable the development of models that can capture the interplay between the plasma microphysics and the global dynamics of these distant systems. Such advances are complemented by developments in high-power lasers, intense particle beams, and plasma diagnostics. Using his ERC Consolidator Grant, Frederico Fiúza takes advantage of the opportunities these new developments provide to probe plasma physics processes and particle acceleration mechanisms in well-controlled laboratory experiments.

Romain Géneaux (LIDYL): Controlling spin angular momentum with the field of light

In his recently awarded ERC Starting Grant, Romain Géneaux will study the interaction between light and the spin of electrons, an intrinsic quantum property directly responsible for macroscopic properties of materials, such as magnetism. The goal is to answer a fundamental question: are there direct and coherent interactions between the electronic spins of a solid and the electric field of light?

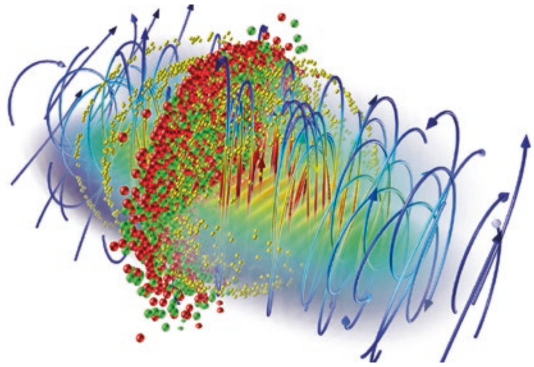
This problem, which involves concepts from relativistic quantum electrodynamics or many-body quantum physics, is yet unsolved because answering it requires capturing spin dynamics at ultrashort timescales, with great precision. With the help of attosecond science and state-of-the-art instrumentation available at the ATTOLab facility, Romain Géneaux hopes to finally bring these field-spin interactions into light. The results could give rise to new ways of using lasers to control the magnetisation or topology of materials, which are key properties to develop future generations of electronic devices.

Lasers and the Universe

Laserlab-Europe – bringing together all the required instruments and related expertise – is a unique place to investigate our Universe. Lasers are indeed exceptional tools to explore phenomena occurring in space. Data from laser-based spectroscopy endstations can help researchers to decipher meteorite composition or determine the formation processes of complex molecules under severe interstellar or circumstellar conditions, while high-energy-density laser facilities can recreate deep planet interiors or violent astrophysical events in the lab. Advances in terms of laser intensities, towards 10^{24} W/cm^2, finally open new routes for extreme quantum astrophysics.

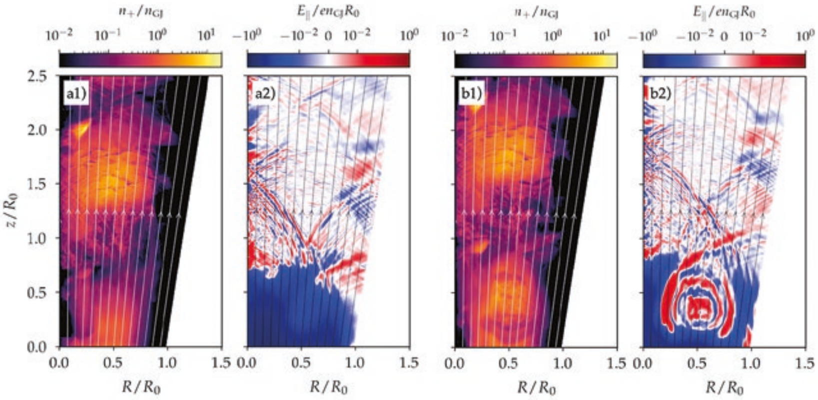
From in silico laser-driven QED cascades to neutron star pair plasmas (IST, Portugal)

Laser intensities approaching 10^{24} W/cm^2 have already been achieved, and facilities worldwide aim to achieve even higher intensities in the future. At these intensities, novel effects driven by quantum electrodynamics (QED) start to be important. Many scientists, including several Laserlab-Europe partners, are working to determine the optimal conditions for producing pair plasmas or gamma rays, and exploring laser configurations that can trigger QED processes (for instance, conversion of gamma-ray photons into cascades of electron-positron pairs). Besides addressing fundamental questions at the interface of laser physics, QED, and plasma physics, these secondary sources have highly relevant applications in materials science, biology, and medicine. The scientific pursuit of these extreme regimes has triggered fundamental advances in the theory of ultra-high-intensity laser physics, and in the development of novel kinetic models that exploit high-performance computing to capture the multi-dimensional, many-body physics, strong field QED, collective plasma dynamics, and radiation (Figure 1).



Courtesy: T. Grismayer/GoLP/IPFN/Técnico Lisboa

Figure 1: 3D particle-in-cell simulation snapshot of QED cascades in a rotating electric laser field generated by two counter-propagating laser pulses. The laser pulses are shown through isocontours of the electromagnetic energy. The electrons, positrons and photons are represented in red, green and yellow, respectively.



Courtesy: F. Cruz/GoLP/IPFN/Técnico Lisboa

Figure 2: Two-dimensional simulation of a pulsar polar cap, showing the self-consistent excitation of plasma waves during a QED cascade. The panels show (1) the plasma density and (2) the electric field at times just before (a) and during (b) a QED cascade. The horizontal axis (R/R_0) is aligned with the star radius, while the vertical axis (z/R_0) is aligned with the axis of rotation of the pulsar.

Delivering the focused intensities required to drive QED cascades in the laboratory will allow the complex interplay between QED and plasma physics to be probed. This interplay is pervasive in some of the most extreme events in the Universe, for example in the polar caps of neutron stars. Electrons that are strongly accelerated in vacuum gaps can radiate in the ultra-strong magnetic fields and generate gamma rays, which in turn generate more electrons (and positrons), thus driving cascades of electron–positron pairs. Scientists at Instituto Superior Tecnico, Lisbon, Portugal, supported by the European Research Council, have been exploring these astrophysical scenarios, using the same tools that have been used to explore high-intensity laser-plasma interactions, and leveraging what has been learned from such interactions. Their *ab initio* simulations, conducted in collaboration with researchers at Princeton University, have recently been published in the Astrophysical Journal Letters [1], and demonstrate how coherent radiation (in the radio regime) can be generated by the cyclic production of pair plasmas in QED cascades. Many of the relevant physical processes share the same underlying physics as laser-matter interactions in the QED regime, and scientists are now exploring the possibility of mimicking these extreme scenarios in the laboratory with lasers, particles beams, or a combination of the two.

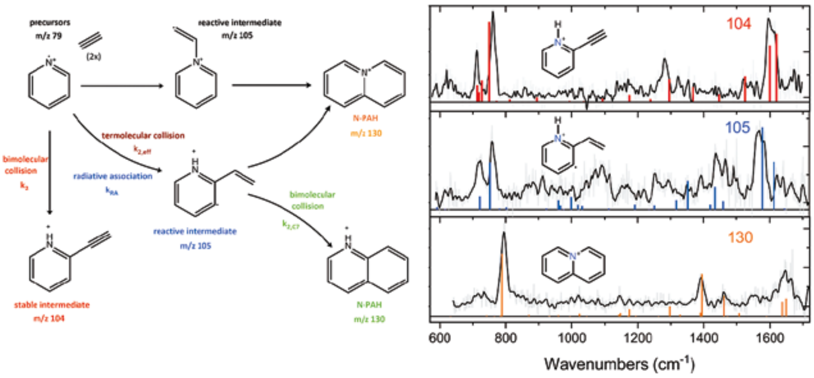
Luis Oliveira e Silva, Fábio Cruz,
Thomas Grismayer (GoLP/IPFN, IST)

[1] F. Cruz et al., The Astrophysical Journal Letters, 919: L4 (2021)

Infrared spectroscopy sheds light on the formation of complex organics in space (FELIX, the Netherlands)

Polycyclic aromatic hydrocarbons (PAHs) – in principle large molecules made up from fused benzenoid rings – are produced as toxic pollutants on Earth in combustion processes. In space, they are amongst the most complex organic molecules detected, representing a major reservoir for cosmic carbon, and yet their formation pathways in cold environments of the Universe remain elusive. Recent astronomical detections show that current astrochemical models drastically underestimate the abundance of aromatic molecules in cold molecular clouds. These molecular clouds are the birthplaces of new stars and planets, and the detailed study of their chemistry will provide astronomers with a better understanding of the process of star and planet formation.

Researchers at HFML-FELIX have provided novel experimental evidence for alternative formation routes of PAHs in cold environments of the Universe. The team set out to study a specific class of reactions, those between a cationic and a neutral molecule. In a pathfinder study, they investigated the reaction of the monocyclic pyridine cation with neutral acetylene (C_2H_2). A cold ion-trap instrument, stationed at one of the FELIX end stations and developed in collaboration with Prof. S. Schlemmer, University of Cologne, was used to mimic the cold and dilute conditions of molecular clouds. Mass-spectrometry studies showed that larger molecules, with masses corresponding to two added acetylene units, were indeed efficiently formed. However, by only detecting the mass of a certain molecule, no information on its structure could be obtained, to prove that the product was indeed a PAH, and not just a pyridine with some dangling acetylene units.



Schematic reaction scheme from monocyclic pyridine radical cation to the polycyclic quinolizinium (left), as elucidated by FELIX infrared spectroscopy of the reaction intermediates and the final product (right).

By combining their low-temperature kinetic studies with *in situ* infrared spectroscopic probing, using the FELIX free-electron laser, the team obtained unambiguous experimental proof of the formation of the polycyclic quinolizinium from a monocyclic precursor. Furthermore, spectroscopic identification of reaction intermediates allowed competing formation pathways to be disentangled, providing information beyond purely mass-spectrometry and computational studies. The observed quinolizinium belongs to an astronomically interesting, but experimentally little studied, class of PAHs. The spectroscopic data obtained can thus act as a basis for future astronomical observations aimed at unravelling the formation of PAHs in space, for example with the recently launched James Webb Space Telescope.

Daniël B. Rap, Johanna G.M. Schrauwen,
Aravindh N. Marimuthu, Britta Redlich,
Sandra Brünken

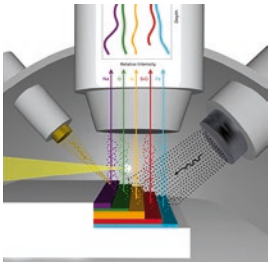
D.B. Rap et al., Nature Astronomy 6: 1059–1067 (2022)

Boosting meteorite mass spectrometry with lasers (ILC, Slovakia)

Combining advanced surface characterisation techniques with state-of-the-art laser technology lies at the forefront of current research in areas such as material science and condensed matter physics. The International Laser Centre in Bratislava successfully integrated a secondary ion mass spectrometer with a femtosecond laser to achieve adaptive control post-ionisation, delivering significantly enhanced capabilities for the characterisation of meteorites/micrometeorites.

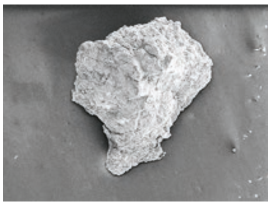
Secondary ion mass spectrometry is a well-established analytical technique. A pulsed ion gun produces bunches of primary ions that sputter the sample surface, creating a phenomenon called collision cascade. The uppermost layers of the sample are thereby ionised, extracted and analysed in a high resolution mass spectrometer. The technique shows very high sensitivity (ppb), high mass resolution (m/Δm ~10^4), and, in principle, high spatial resolution (down to nm). As such, it is very suitable for a broad range of applications throughout material science, analytical chemistry, the semiconductor industry, and the life sciences. However, the technique is non-quantitative. The ion yield during the collision cascade is sensitive to the chemical environment of the sample surface, resulting in different secondary ion yields due to the so-called matrix effect. Moreover, the secondary ion yield is generally low, with less than 1% of the sputtered species being in an ionised form.

Yield can be improved by applying “post-ionisation,” i.e. externally delivering energy to the desorbed species and removing (ideally one) outer electron thereby turning the neutral atoms and molecules into ions. In the research part LaPoM2et, sponsored by the European Space Agency’s Plan for European Cooperating States, a commercially available time-of-flight secondary ion mass spectrometry (TOF-SIMS) apparatus (ION-TOF IV, Munster, Germany) was combined with a custom-built femtosecond Cr:forsterite laser system. Ultrashort pulses (120 fs duration, 4 mJ energy) were focused inside the SIMS chamber to produce a beam waist approximately 250 µm above the sample surface. Here the desorbed, mostly neutral, species undergoes post-ionisation, and the ionised atoms/molecules are subsequently extracted by means of external bias for analysis by a TOF mass analyser.



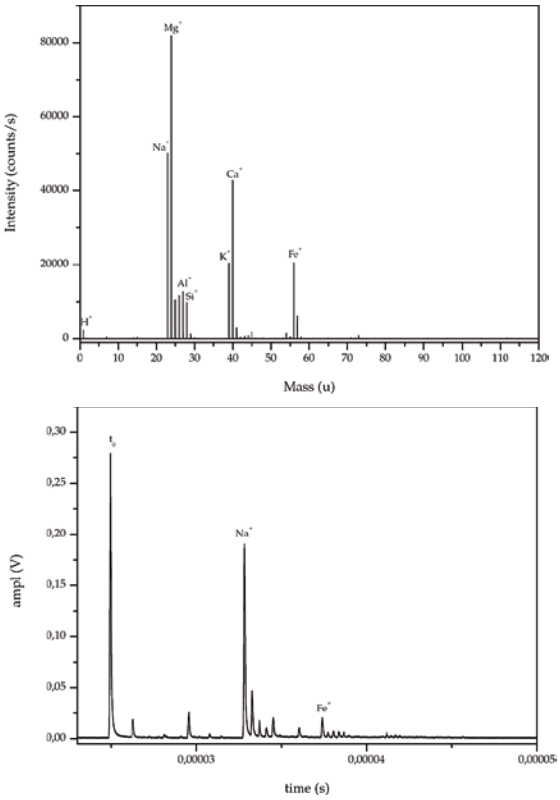
Schematic of the experimental set-up, showing post-ionisation above the sample surface

Sample mass spectra were derived for an ordinary class H5 chondrite metoerite, the parent body of which entered the atmosphere on 28 October 2010 near the town of Kosice in Eastern Slovakia.



Small fragment of the Kosice meteorite

Besides the usual terrestrial contaminants C_xH_y, the standard SIMS spectrum shows characteristic elemental features (Mg, Ca, Si) that correspond to the composition of expected minerals, such as forsterite, enstatite, diopside, augite, etc. The post-ionised mass spectrum shows a simpler structure and lower mass resolution, but the peak intensities correspond to the relative abundance of elements within the sample, providing quantitative results. Future work will focus on improving post-ionisation mass analysis by the application of machine learning methods.



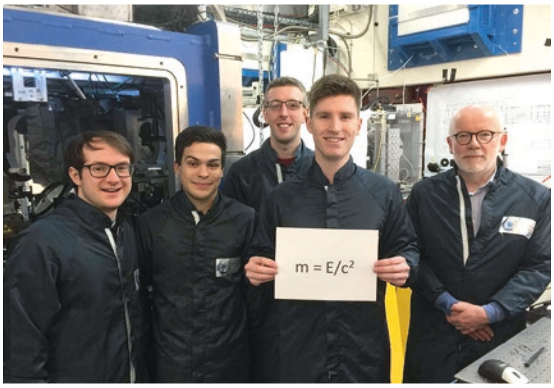
Standard (top) and post-ionised (bottom) mass spectra of the Kosice meteorite

Justina Novakova, Eva Noskovicova, Monika Jerigova, Dusan Lorenc and Dusan Velic (ILC)

Turning light into matter (CLF, United Kingdom)

A team led by Imperial College, London, and with strong participation from European Institutes and Universities, carried out an experiment in the Gemini facility at the Central Laser Facility at the STFC Rutherford Appleton Laboratory, in an attempt to prove an 88-year-old theory.

In 1934, using the then new theory of the interaction between light and matter known as quantum electrodynamics (QED), Gregory Breit and John Wheeler proposed a mechanism whereby light can be turned into matter under certain conditions. The Breit-Wheeler (BW) process involves smashing two photons together to create an electron and a positron. This process is widely believed to have been present during the first 100 seconds of the Universe and to be responsible for gamma-ray bursts, but has not been demonstrated experimentally, with past attempts requiring the addition of other high-energy particles.



© Imperial College

Experimentalists from Imperial College and the Friedrich Schiller University Jena

Prof. Steve Rose at Imperial College, London derived a method to demonstrate the process using only photons, which was tested in Gemini in 2018 by a team of physicists from Imperial College, Friedrich Schiller University Jena, and Queen's University Belfast. Whilst the team is still analysing the results, details of the experiment were published a few months ago [1].

Two of Gemini's high-power laser beams were used to create the photons of light to be smashed together. Photons from one beam contained about one thousand times the energy of photons that produce visible light, while those from the other beam contained some one billion times the energy. The beams were focused on two separate tiny targets inside a chamber that contained complex optics to focus the laser beams, and magnets to deflect the charged particles.

In the set-up used, a collimated beam of very high-energy photons was fired through the cloud of x-ray photons emitted by a hot plasma, and the positrons produced in the collision were captured using a highly specialised detector. These charged positrons will confirm if the process was a success.

The experiment characterised the photon and electron beams, and recorded the positrons from the interaction as well as background levels. Careful data analysis is being carried out to determine whether the positrons can be confirmed as originating from the BW process, and not from other background processes. The team hopes that the method used could pave the way to observing the BW process using only photons, and provide statistically significant proof of light being turned into matter.

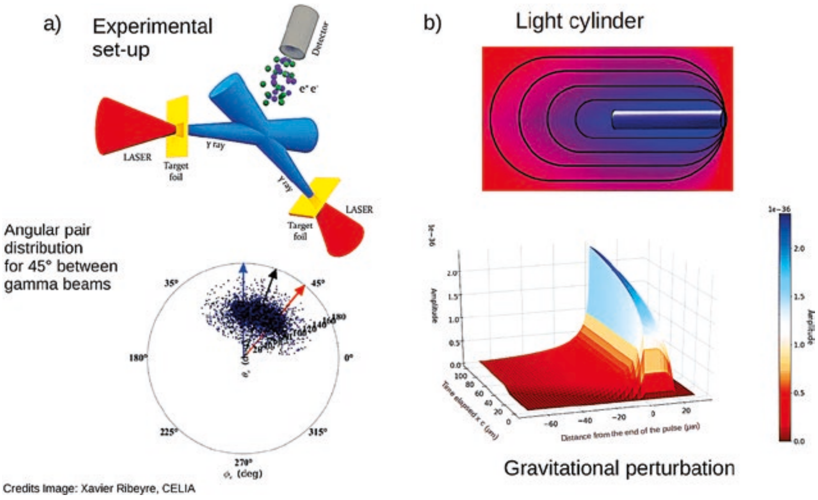
Rajeev Paramel Pattathil (CLF)

[1] B. Kettle et al., New J. Phys. 23: 115006 (2021)

Extreme laboratory astrophysics using high power lasers: from QED effects to gravitational waves (CELIA, France)

The advent of new multi-petawatt laser systems is opening up new pathways to extreme laboratory astrophysics.

The first study presented here concerns the direct production of electron-positron pairs in photon collisions, one of the basic processes in the Universe. The linear Breit-Wheeler (BW) pair creation process ($\gamma+\gamma'$ to $e^+ + e^-$) controls the energy release in Gamma Ray Bursts (GRBs) and Active



Credits Image: Xavier Ribeyre, CELIA

Galactic Nuclei. The BW process, with its important probability of matter creation, has never been clearly observed in the laboratory, because of the absence of the intense gamma ray sources. Recently, a team at CELIA [1] proposed a new experimental setup (Figure a, top) based on numerical simulations with QED effects (Figure a, bottom) to observe the process, involving the collision of two identical gamma photon beams in the MeV range. Colliding the beams in vacuum would enable production of a significant number of electron-positron pairs in a controllable way. A project (Turn Light Into Matter (TULIMA)), funded by the French National Research Agency ANR, is underway to optimise the gamma ray and electron-positron pair generation, with particular emphasis on the development of suitable detectors. Some 1 – 100 pairs per laser shot are predicted [2], making the experiment difficult, but high power lasers offer a unique way to observe and study the process in the laboratory.

The second study [3] is devoted to the influence of high power lasers on gravity. Gravitational waves, as first predicted by Einstein, have recently been detected on the LIGO-VIRGO interferometers and a new field of astronomy is emerging. The possibility of producing gravitational perturbations using high power laser beams is discussed, and a theoretically exact solution of general relativity for a light pulse modelled by a cylindrical shape (Figure b, top) is presented, with the solution for the perturbation provided (Figure b, bottom). The gravitational perturbation is small in the laboratory (of the order of ~10^{-36} amplitude for 1 PW), but several research groups have proposed new concepts for detecting such levels of perturbation, for example, by the delay induced on an atomic clock. Because general relativity concerns a lot of astrophysical phenomena, the theoretical results are also applied to GRBs. These phenomena produce very high energy and powerful gamma rays (10^{44} W), which deform the local space-time, and it may be possible to detect the perturbation during these extreme astrophysical events.

Xavier Ribeyre and
Emmanuel d'Humières (CELIA)

[1] X. Ribeyre et al. Phys. Rev. E, 90: 013201 (2016)
[2] L. Esnault et al. Plasma Phys. and Cont. Fusion 63: 125015 (2021)
[3] P. Lageyre et al., Phys. Rev. D 10: 104052 (2022)

New laser beamline for laboratory planetary science at GSI (Germany)

Warm dense matter – matter with a temperature and pressure in the 1–10 eV and 1–100 Mbar ranges, respectively – pervades the interior of many astrophysical objects, such as planets, and understanding its properties is essential for planet modelling. Creating such states of matter in the laboratory is possible, but requires powerful drivers. Nanosecond-laser-based drivers have delivered many new results in the last decade, although there are indications that material properties might be different under laser-driven shock experiments and static conditions. For instance, the melting temperature of iron, which is essential to modelling the magnetic field properties of the Earth, differs in laser-driven experiments and static ones. Using heavy-ion beams as drivers – such as those that are available at Laserlab-Europe member GSI and that will be available at the future accelerator facility FAIR – is a complementary approach that offers much more uniform experimental conditions, both spatially and temporally, and therefore has the potential to deliver highly accurate measurements closer to thermodynamic equilibrium.

As part of the GSI infrastructure, the high-power laser PHELIX facilitates experiments combining the heavy-ion beam of the accelerator with high-energy laser pulses. PHELIX is a multi-100 J-class glass laser, operated as a Laserlab-Europe Access facility that has been open to the in-

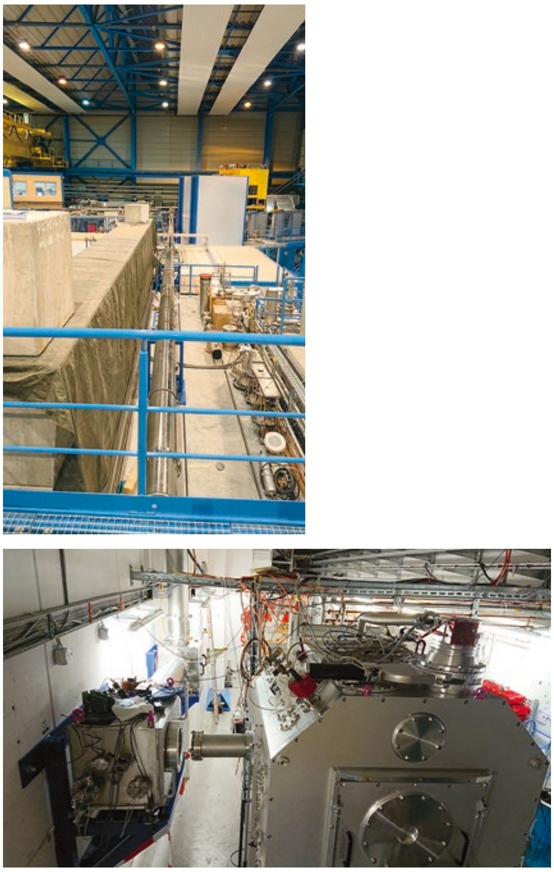

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Figure 1: The newly commissioned PHELIX-HHT beamline. Top: the vacuum beamline for laser-beam transport traversing the experimental hall covering a distance of approx. 65 m between the PHELIX building and the HHT experimental area. Bottom: laser-beam transport and target chamber at HHT.

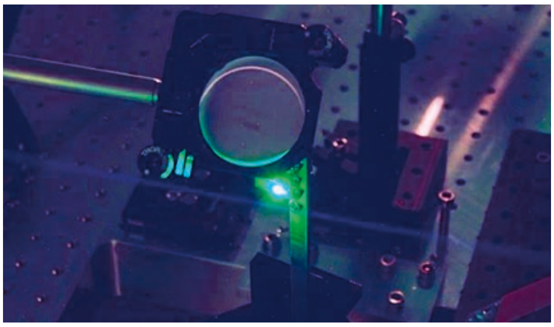

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Figure 2: The heavy-ion beam and the high-energy laser together in the HHT target chamber. The photograph shows the PHELIX laser pulse focused onto a PTFE target (green), and the ion-beam-induced fluorescence in Ar visualising the path of the focused Xe beam (purple).

ternational scientific community since 2008 for combined laser-ion experiments. A new high-energy laser beamline has recently been added to the infrastructure, guiding PHELIX's long-pulse beam to the HHT (high energy, high temperature) experimental area (Figure 1), downstream of the SIS-18 accelerator ring. High-energy laser pulses, with up to 200 J pulse energy at 1 ns pulse duration and 527 nm wavelength, are now available in the HHT area in addition to the high-intensity heavy-ion beam. In combined experiments, the heavy-ion beam acts as the driver and PHELIX as a powerful probe. The laser pulses are mostly used for driving x-ray sources that serve as diagnostic tools for warm dense matter generated by the ion beam. A series of commissioning experiments successfully demonstrated the temporal synchronisation of the laser and ion pulses in the HHT target chamber (Figure 2), and the use of the PHELIX pulse for x-ray-based diagnostics.

Experiments using this newly established experimental capability started this year, beginning with studies on iron and diamond under heavy-ion irradiation. This work paves the way for experiments in laboratory planetary science at FAIR, where ion beams of even higher intensity will be available, and will allow the HED@FAIR collaboration to fully realise its scientific programme.

Zsuzsanna Major and Vincent Bagnoud (GSI)

https://www.gsi.de/work/forschung/appamml/plasmaphysikphelix/hed_at_fair

Studying supernovae using high-power lasers (LULI, France)

Advances in laser technology have enabled the observation of new phenomena in plasma physics, including the investigation of astrophysical objects in the laboratory setting, via the use of appropriate scaling laws. Recent experiments on LULI2000 at the Laboratoire pour l'Utilisation des Lasers Intenses (LULI) have focused on the study of supernova remnants and their interaction with the surrounding medium. When a star runs out of fuel and dies, the subsequent explosion causes a blast wave, known as a supernova remnant, which spreads out for thousands of years across vast distances. This situation can be replicated in the laboratory by focusing a long-pulse laser onto a small cylindrical target inside a gas-filled vacuum chamber. The resulting blast wave can then be studied in detail with an array of diagnostics. Researchers at LULI performed three experimental campaigns, each centred on understanding a different part of this process.

In the first of these experiments, a strong magnetic field was applied to the whole system using a Helmholtz coil and pulsed power system. When this field was applied, the blast wave became elongated along one direction. Despite computational models predicting that these remnants ought to be spherically symmetric, many telescopic images exhibit an elliptical shape. Many hypotheses exist to explain these observations, but up until now, it has been difficult to test them. These results support the idea that a large-scale magnetic field is present around many observed supernova [1].

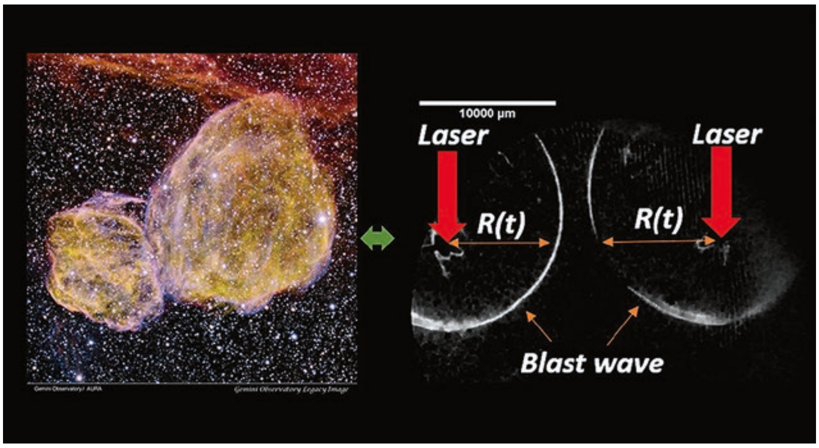
The second experiment studied the collision of two separate remnants (see figure). The team probed background gas properties, such as electron density and temperature, in the interaction region between the two waves. By observing changes in the spectral lines, researchers found that the interaction creates a high-temperature zone, up to 20% hotter than the single blast wave case. The region remains at the elevated temperature long after the start of the interaction, thus strongly affecting the dynamics of the background medium [2].

The final experiment investigated the interaction of a remnant with dense regions in the surrounding environment. Molecular clouds are collections of gas and dust in space. When left alone, these clouds remain in a state of peaceful equilibrium, but when triggered by some external agent, like a supernova remnant, shockwaves shoot through the gas and dust to create pockets of dense material. At a certain limit, that dense gas and dust collapses, and begins to form new stars. This process, known as triggered star formation, was replicated in the laboratory by placing a foam sphere of suitable density in the path of the expanding blast wave [3].

Future experiments are planned to reduce experimental error bars and thereby better constrain the astrophysical models, and to combine some of the themes explored and introduce new themes, such as the role of turbulence.

Paul Mabey (Freie Universität Berlin)

[1] P. Mabey et al., ApJ 896: 167 (2020)
[2] B. Albertazzi et al., Physics of Plasmas 27: 022111 (2020)
[3] B. Albertazzi et al., Matter and Radiation at Extremes 7: 036902 (2022)



© (photo left) P. Michaud, S. Fisher, and R. Carrasco from Gemini and T. Rector from the Univ. of Alaska at Anchorage/International Gemini Observatory © (graphic right) Bruno Albertazzi

The collision of two interacting Taylor Sedov blast waves. Left: Two supernova remnants located in the Large Magellanic Cloud captured by the Gemini South Multi-Object Spectograph (GMOS). Right: Schlieren images of analogue experiment carried out at the LULI laser facility.

Relevance of 2-methylallyl radicals in the formation of polycyclic aromatic hydrocarbons

Soot is generated as an unwanted by-product during incomplete combustion of hydrocarbon fuels. Due to its major impact on human health and on the environment, a fundamental understanding of the chemistry involved in its formation is of key importance in helping mitigate pollutant emissions. The most widely accepted class of molecules that act as building blocks for soot particles are polycyclic aromatic hydrocarbons (PAHs), some of which have been marked as priority pollutants due to their carcinogenic potential. Several studies agree on radical-based reactions (open-shell molecules with an unpaired electron) as a crucial step in rapid PAH growth. To gain a better understanding of these reactions, the group of Ingo Fischer and Anouk Rijs investigated the high-temperature chemistry of 2-methylallyl radicals using IR/UV ion dip spectroscopy at the FELIX free electron laser laboratory (Radboud University, Nijmegen, NL), one of the Laserlab-Europe partners. The results of this transnational access project were recently published in *Physical Chemistry Chemical Physics (PCCP)* and selected as a 2022 PCCP HOT article.

Understanding the formation of polycyclic aromatic hydrocarbons (PAHs) and soot remains a central topic in combustion research due to their environmentally harmful and carcinogenic potential, as highlighted by the recent discussion on diesel engines. Interestingly, a number of PAHs are also supposed to be present as IR absorbers in interstellar space. However, understanding their formation at both the high-temperature conditions of combustion processes and the cold temperature of interstellar space is still a challenging task. Almost all models agree on the importance of hydrocarbon radicals (open-shell molecules with an unpaired electron) in molecular growth. In particular, resonance-stabilised radicals (RSR) can accumulate in reactive environments, due to their lower reactivity towards oxygen, and therefore contribute to the formation of aromatic species via secondary reactions. To outline their chemistry, well-defined laboratory conditions are required to generate these molecules cleanly and at a sufficiently high number density. Unfortunately, real flames create a multitude of species, making it difficult to disentangle the chemistry of the selected intermediates. Here, high-temperature (pyrolysis) microreactors have been shown to generate radicals efficiently from suitable precursor molecules for gas-phase experiments. An illustration of such a microreactor is given in Figure 1 (top).

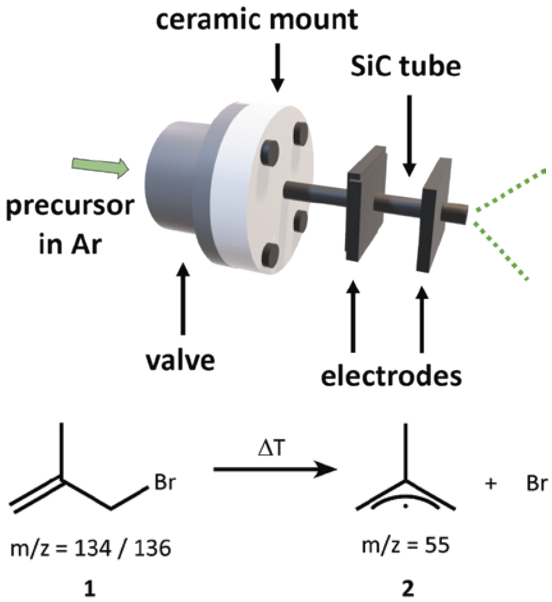


*Figure 1: Top: High-temperature pyrolysis microreactor (SiC tube) attached to a solenoid valve. Bottom: Generation of the 2-methylallyl radical **2** by pyrolysis of the corresponding bromide precursor. (Reproduced from Preitschopf et al. with permission from the PCCP Owner Societies.)*

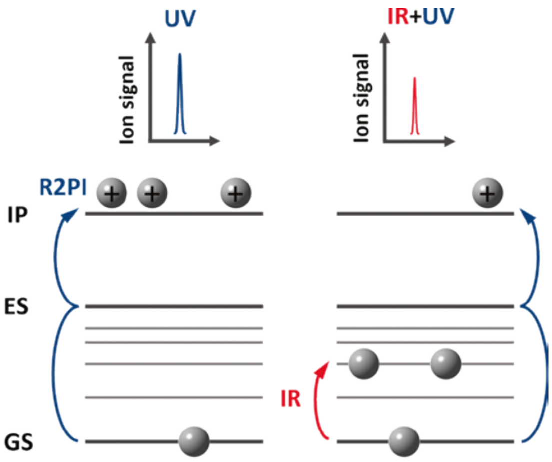


Figure 2: Mechanism of IR/UV ion dip spectroscopy. Molecules are ionised via [1+1] REMPI by a UV laser (20 Hz) and detected by TOF mass spectrometry (left). When the IR radiation provided by FELIX (10 Hz) is resonant with a vibrational mode, fewer molecules remain in the ground state and a depleted ion signal will be detected (right).

Flow microreactors also provide an environment that promotes secondary reactions of radicals, depending on the length of the heated region, pressure, temperature, and radical concentration, thereby facilitating investigation of the high-temperature products of radicals and derivation of a qualitative view of their chemistry. However, simple mass spectrometry is not appropriate for identifying the reaction products, due to the vast number of possible isomers that might be formed. Therefore, IR/UV ion dip spectroscopy is used (Figure 2), because it combines the mass selectivity of UV photoionisation with the structural sensitivity of IR radiation, allowing the IR spectra of each species present in the jet expansion to be measured in parallel. This method is based on the change of the vibrational population in the electronic ground state of a molecule by IR absorption, followed by [1+1]-multiphoton ionisation via intermediate electronically excited states by UV light (resonance enhanced multiphoton ionisation, REMPI). Resonant IR excitation leads to a decrease in the magnitude of the REMPI signal, resulting in species-selected IR spectra which can be used to assign a given mass signal to a specific isomer.

This technique is particularly well suited to aromatic molecules and PAHs that generally absorb in the UV. Here, well-resolved absorption spectra in the mid-IR fingerprint region (around 500-1800 cm^{-1}) are required for unambiguous identification of the reaction products. In addition, an intense IR light source is required to excite dilute samples in a molecular beam. One of the few sources that provides mid-IR radiation with a sufficiently high photon flux is the free electron laser, FELIX, at the Radboud University in Nijmegen, The Netherlands, one of the Laserlab-Europe partners. Consequently, research on the high-temperature chemistry of the resonance-stabilised 2-methylallyl radicals (2-MA) using IR/UV spectroscopy (Figure 3) was conducted in collaboration with the group of Anouk Rijs (previously: FELIX Laboratory, Radboud University; now: Vrije Universiteit Amsterdam).

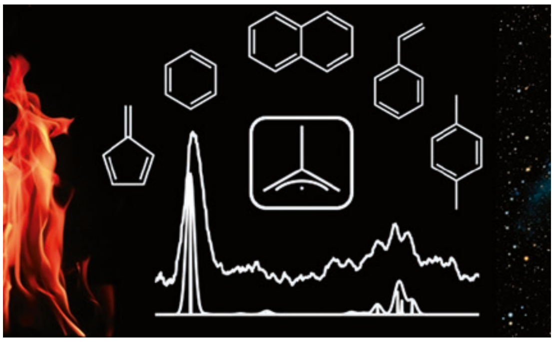


Figure 3: Mass-selected IR spectra of the various reaction products obtained in the high-temperature chemistry of the 2-methylallyl radical are recorded using mid-IR FEL radiation. (Reproduced from Preitschopf et al. with permission from the PCCP Owner Societies.)

2-MA (C_4H_7) (annotated **2**, bottom right in Figure 1) is an important intermediate in the ignition of isobutene and has been identified in the combustion of anti-knock additives like *tert*-butyl ethers. Furthermore, substituted allyl radicals are relevant in the decomposition of potential biofuels that often contain unsaturated fatty acid esters with C=C double bonds. At high temperature, the C-H bonds at the allylic sites will preferentially lose an H atom, forming intermediates that can be described as alkylated allyl radicals. Additionally, the reaction of the methylidyne radical CH with propene, C_3H_6, might be a source for C_4H_7 radicals in interstellar space, which potentially expands the relevance of 2-MA to astrochemistry.

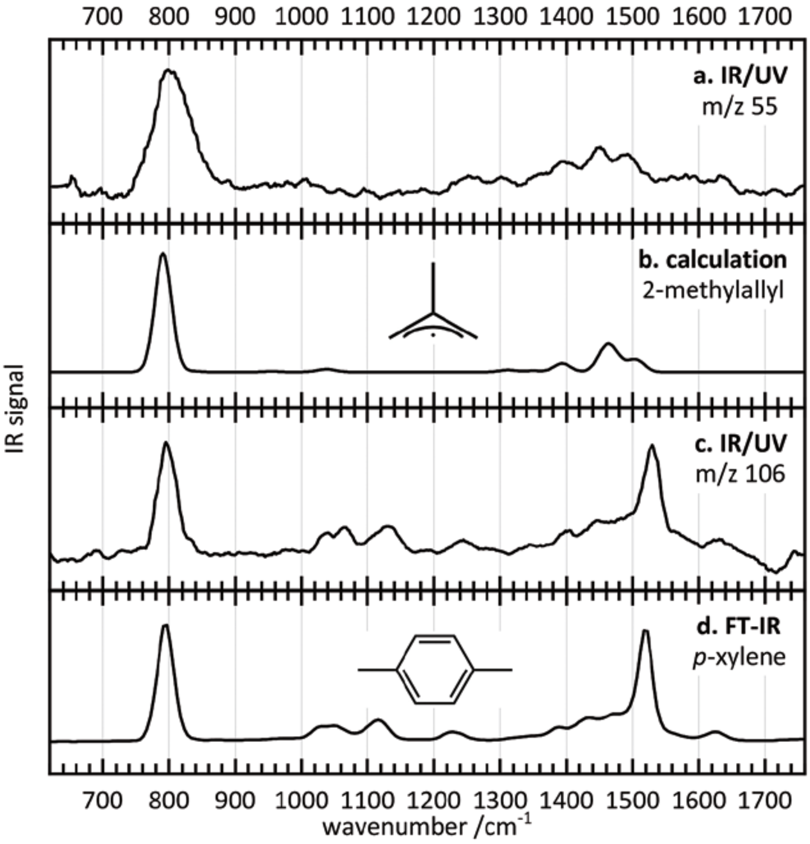


*Figure 4: IR/UV spectrum of m/z 55 (a), generated by pyrolysis of **1**, compared with a computed IR spectrum of 2-MA (b). The IR/UV spectrum of m/z 106 (c) is assigned to p-xylene by FT-IR spectroscopy (d). The observation of the latter demonstrates that secondary radical reactions occur in the microreactor.*

The bromide precursor **1**, seeded in a rare gas, was used to selectively generate 2-MA, as illustrated in the lower scheme of Figure 1. At a temperature of around 1000 K in the microreactor, 2-MA is efficiently formed and secondary radical reactions start to set in, as evident from the IR spectra of m/z 55 (trace a) and m/z 106 (trace c) presented in Figure 4. The IR spectrum of m/z 55 matches the computed IR spectrum of 2-MA (trace b), allowing for unambiguous identification of the radical. The spectrum of m/z 106 is assigned to *para*-xylene based on comparison with an experimental gas-phase FT-IR spectrum (trace d). The observation of the latter suggests the formation of the open chain radical-radical self-recombination product, followed by a very efficient conversion of 2-MA to the more stable condensed *para*-xylene via two sequential hydrogen loss processes, dehydrocyclisation ($-H_2$) and aromatisation ($-H_2$). Several more reaction products were identified in the study, among them fulvene, benzene, styrene, and naphthalene, as indicated in Figure 3. The latter indicates the relevance of 2-MA in the growth of PAHs in high-temperature processes. Interestingly, several reaction products are connected by addition of methyl groups, which suggests that methylation dominates in the formation of larger aromatics from 2-MA.

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T. Preitschopf et al., Phys. Chem. Chem. Phys. 24: 7682-7690 (2022)

Joint ELI user programme, integration progress and new Director of Science

In early June the first joint ELI call for user proposals was launched. This call is a crucial milestone for ELI, offering commissioned scientific equipment at both ELI ALPS and ELI Beamlines to the scientific user community for state-of-the-art experiments. The focus is on instruments with demonstrated readiness and reliability and most extensive operational experience. Proposals are accepted from worldwide and will be peer-reviewed. Access will be granted based on scientific excellence. All three of the ELI Facilities are included in this call, thanks to a close collaboration between ELI ERIC and the "Horia Hulubei" National Institute of Physics and Nuclear Engineering (IFIN-HH), and the support of the Horizon 2020 Project IMPULSE. The next call is expected to be launched in early 2023. The first Joint ELI ERIC User Meeting is planned for 3 November 2022 with facility-specific satellite events before and after the central plenary day.

Further key developments at ELI include the ongoing progress towards the integration of ELI Beamlines into ELI ERIC and the appointment of Andrew Harrison as the new Director of Science for ELI ERIC. During the complex integration process the responsibilities and liabilities for ELI Beamlines will be transferred to ELI ERIC from the Czech Institute of Physics (IOP) by January 2023. The integration of ELI ALPS is foreseen for 2024. Prof. Harrison, CEO of Diamond Light Source since 2014, will join the ELI ERIC in autumn 2022. He will lead the scientific programme as well as coordinate the ELI user programme.


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Alexandra Schmidli

ReMade@ARI: A recycling hub for materials research

According to the European Union's Circular Economy Action Plan, industry can determine up to 80 percent of a product's subsequent environmental impact at the design phase. However, the linear manufacturing pattern offers few incentives to make products more sustainable. The research infrastructure project ReMade@ARI, which deals with innovative materials for key components in various areas such as electronics, packaging and textiles, wants to change this. The goal is to develop new materials with high recyclability and at the same time competitive functionalities. To this end, the institutions involved want to harness the potential of more than 50 analytical research infrastructures throughout Europe.

The ReMade@ARI platform will be the central hub for all sectors and research areas in which new materials for a circular economy will be developed. "We provide scientists who are working on the design of new recyclable materials with analytical tools that enable them to explore the properties and the structure of their material in smallest details up to atomic resolution. This requires the exploitation of the most diverse analytical methods, involving appropriate combinations of photons, electrons, neutrons, ions, positrons and the highest magnetic fields," says Stefan Facsko, the project's scientific coordinator at HZDR. "Any scientist in academic or industrial research working on new recyclable materials should get in touch with us."

The project is funded for four years by the EU with a budget of 13.8 million euros. Ten Laserlab-Europe members are part of the consortium.

ReMade@ARI
A hub for materials research

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 technical feasibility and 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.

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