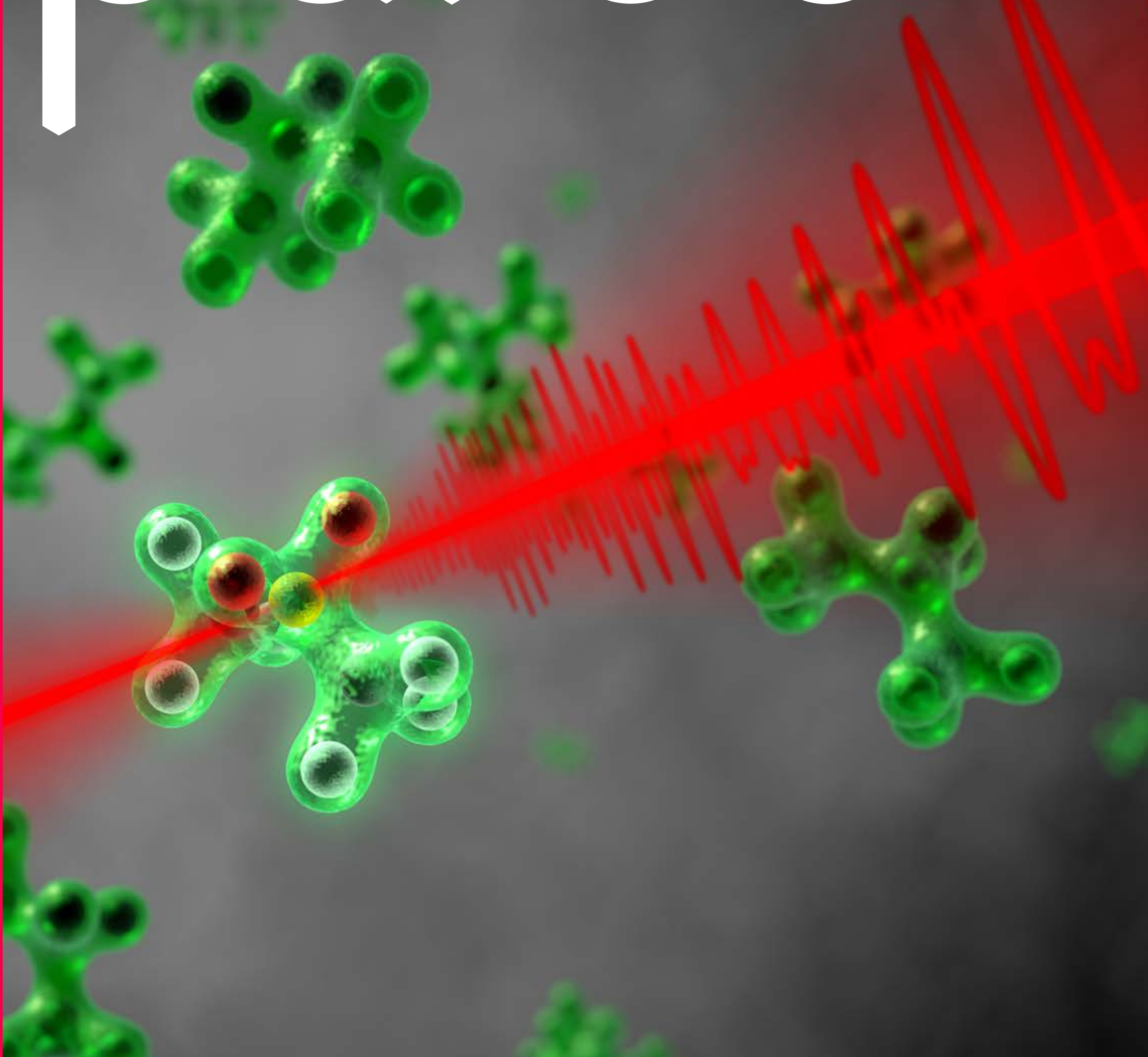
the newsletter of attoworld

volume 1 (2020)

pulse



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LMU

welcome to the first issue of our newsletter "pulse"!

When the MAP Cluster of Excellence – and its popular staff magazine "Am Puls" – came to an end, we decided to publish an English-language successor in a slightly different form, and under a slightly different title. In its new guise, "pulse" will feature stories about all kinds of activities at Attoworld, uniting teams of and events relating to our Attoworld 'family' which now unites the teams of the Laboratory for Attosecond Physics of the Max Planck Institute of Quantum Optics, of the LMU Chair of Experimental Physics – Laser Physics, and of the LMU Centre for Advanced Laser Applications (CALA). Our 'family' also closely collaborates with researchers from the Center for Molecular Fingerprinting (CMF, see article on page 10), clinics of the LMU and the Helmholtz Zentrum München in the Lasers 4 Life (L4L) collaboration.

In these pages readers will find reports and invited contributions on advances in the field of ultrafast phenomena in physics, together with features that focus on the lives and experiences of members of our current attoworld 'family', as well as the laboratory's many alumni around the world. We have always been an international team, and many former members who worked with us in Garching have moved on to positions elsewhere. Indeed, one of the aims of this new publication is to maintain contact with these far-flung colleagues and provide them with a forum that enables to keep us up to date on their research and their professional careers.

A magazine such as this is highly dependent on the commitment of the editorial team and on active feedback from its readers. We would be delighted to hear of any suggestions or information you may have, not only in relation to the field of laser physics, but also to newsworthy items concerning the doings of Attoworld members outside of the laboratory. We hope that – true to its title – "pulse" will become a vibrant source of information that provides a lively and engaging chronicle of the whole spectrum of Attoworld's activities.

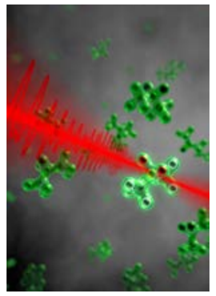
We hope you enjoy what we have to offer in this first issue.

Prof. Ferenc Krausz
Director MPQ
Chair of Experimental Physics LMU

Thorsten Naeser
Head of Public Relations

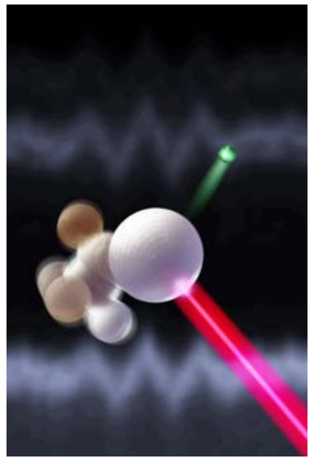
content

showroom



6 research@attoworld
capturing molecules at a new level

Researchers of the Attoworld team have developed a laser-based system that is capable of detecting minimal variations in the chemical make-up of biological fluids across the whole spectrum of molecular species.



10 research@attoworld
quantum brakes in molecules

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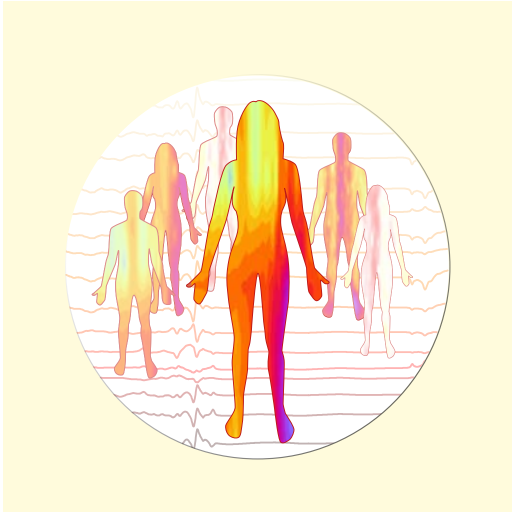

12 feature
a new watchman guarding our health?

Scientific developments at Attoworld have led to spawning a new research institution. In 2019, the Hungarian Ministry of Innovation and Technology approved financial support for a national project to propel health monitoring based on new laser technology. For this purpose, the Center for Molecular Fingerprinting (CMF) was founded in Budapest.

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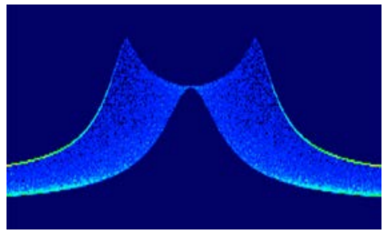
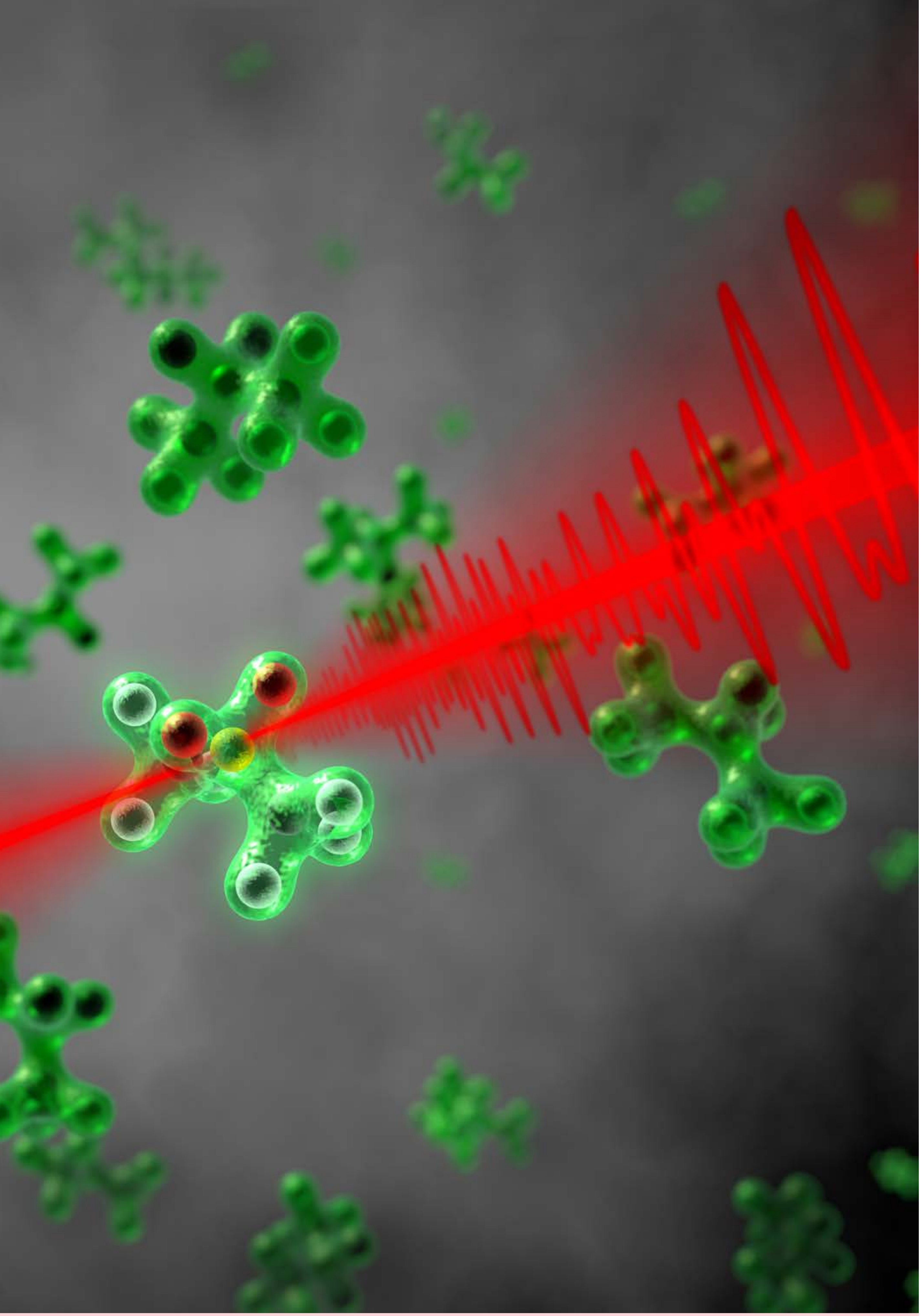
in darkness deep

Even when they are illuminated, some species of deep-sea fish remain essentially invisible to potential predators. This makes life more difficult for their would-be foes – and for photographers, who must dig deep into their box of tricks to image them.



30 art and science
mandalas of laser research

Let's look like young stargazers at images from the nanocosmos beyond the factual from a purely aesthetic and creative point of view. Science can become art here.



An infrared laser pulse hits a dymethylsulfone molecule and stimulates it to vibrate. After the passage of the pulse, the vibrating molecules emit coherent light at highly characteristic wavelengths or, equivalently, oscillation frequencies.
Image: Dennis J.K.H.Luck & Alexander Gelin

capturing molecules at a new level

january 2, 2020 // Thorsten Naeser

The combination of molecules found in body fluids such as blood plasma is unique to each individual, and the composition of this 'brew' can provide information on an organism's state of health. The problem lies in learning to decipher the information it contains. Complete molecular characterization has been impossible up to now, because our instruments are not sensitive enough to identify and quantify the entire range of chemical compounds present. But this goal has now moved a step closer to realization. Researchers of the Attoworld team in cooperation with scientists of the King Saud University have developed a laser-based system – the first of its kind in the world – that is capable of detecting minimal variations in the chemical make-up of biological fluids across the whole spectrum of molecular species.

At the biochemical level, organisms can be thought of as complex collections of different species of molecules. In the course of their metabolism, biological cells synthesize chemical compounds, and modify them in multifarious ways. Many of these products are released into the intercellular medium and accumulate in body fluids like the blood. One major aim of biomedical research is to understand what these immensely complex mixtures of molecules can tell us about the state of the organism concerned. All differentiated cell types contribute to this 'soup'. But precancerous and malignant cells add their own specific molecular markers – and these provide the first indications of the presence of tumour cells in the body. So far, however, very few of these indicator molecules have been identified, and those that are known appear in minuscule amounts in biological samples. This makes them extremely difficult to detect. It is assumed that many of the most informative molecular signatures comprise combinations of compounds that belong to all the various types of molecules found in cells – proteins, sugars, fats and their diverse derivatives. In order to define them, a single analytical method that is versatile and sensitive enough to detect and measure the levels of all of them is needed.

The interdisciplinary team has now built a new laser-based system that is specifically designed for this purpose. This system enables one to obtain chemical fingerprints in the form of spectra of infrared light, which reveal the molecular compositions of samples of all sorts, including samples of biological origin. The technique offers unprecedented sensitivity and can be used for all known classes of biomolecules.

The new laser spectrometer builds on technologies that were originally developed for the production of ultrashort laser pulses, which are used to study the ultrafast dynamics of subatomic systems. The instrument, which was built by Dr. Ioachim Pupeza and his colleagues, is designed to emit trains of extremely powerful pulses of laser light

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that cover a broad segment of the spectrum in the infrared wavelength. Each of these pulses lasts for a few femtoseconds (in scientific notation 1 fs = 10^{-15}s, one millionth of a billionth of a second). These extremely brief flashes of infrared light cause the bonds that link atoms together to vibrate. The effect is analogous to that of striking a tuning fork. After the passage of the pulse, the vibrating molecules emit coherent light at highly characteristic wavelengths or, equivalently, oscillation frequencies. The new technology makes it possible to capture the complete ensemble of wavelengths emitted. Since every distinct compound

Ioachim Pupeza (left) and Marinus Huber (right) are working on the new laser system. Picture: Thorsten Naeser

in the sample vibrates at a specific set of frequencies, it contributes its own well defined ‘subspectrum’ to the emission. No molecular species has anywhere to hide.

“With this laser, we can cover a wide range of infrared wavelengths – from 6 to 12 micrometers – that stimulate vibrations in molecules,” says Marinus Huber, joint first author of the study and a member of biologist Dr. Mihaela Žigman’s group, which was also involved in the experiments carried out in the Attoworld family. “Unlike mass spectroscopy, this method provides access to all the types of molecules found in biological samples,” she explains.

Each of the ultrashort laser pulses used to excite the molecules consists of only a few oscillations of the optical field. Moreover, the spectral brightness of the pulse (i.e. its photon density) is up to twice as high as those generated by conventional synchrotrons, which have hitherto served as radiation sources for comparable approaches to molecular spectroscopy. In addition, the infrared radiation is both spatially and temporally coherent. All of these physical parameters together account for the new laser system’s extremely high sensitivity, enabling molecules present in very low concentrations to be detected and high-precision molecular fingerprints to be produced. Not only that, samples of living tissue up to 0.1 mm thick can, for the first time, be illuminated with infrared light and analyzed with unparalleled sensitivity. In initial experiments, the team has applied the technique to leaves and other living cells, as well as blood samples.

original publication:

field-resolved infrared spectroscopy of biological systems

AUTHORS: Ioachim Pupeza, Marinus Huber, Michael Trubetskov, Wolfgang Schweinberger, Syed A. Hussain, Christina Hofer, Kilian Fritsch, Markus Poetzlberger, Lenard Vamos, Ernst Fill, Tatiana Amotchkina, Kosmas V. Kepesidis, Alexander Apolonski, Nicholas Karpowicz, Vladimir Pervak, Oleg Pronin, Frank Fleischmann, Abdallah Azzeer, Mihaela Žigman & Ferenc Krausz
JOURNAL: ***Nature 577,*** 52 (2020)

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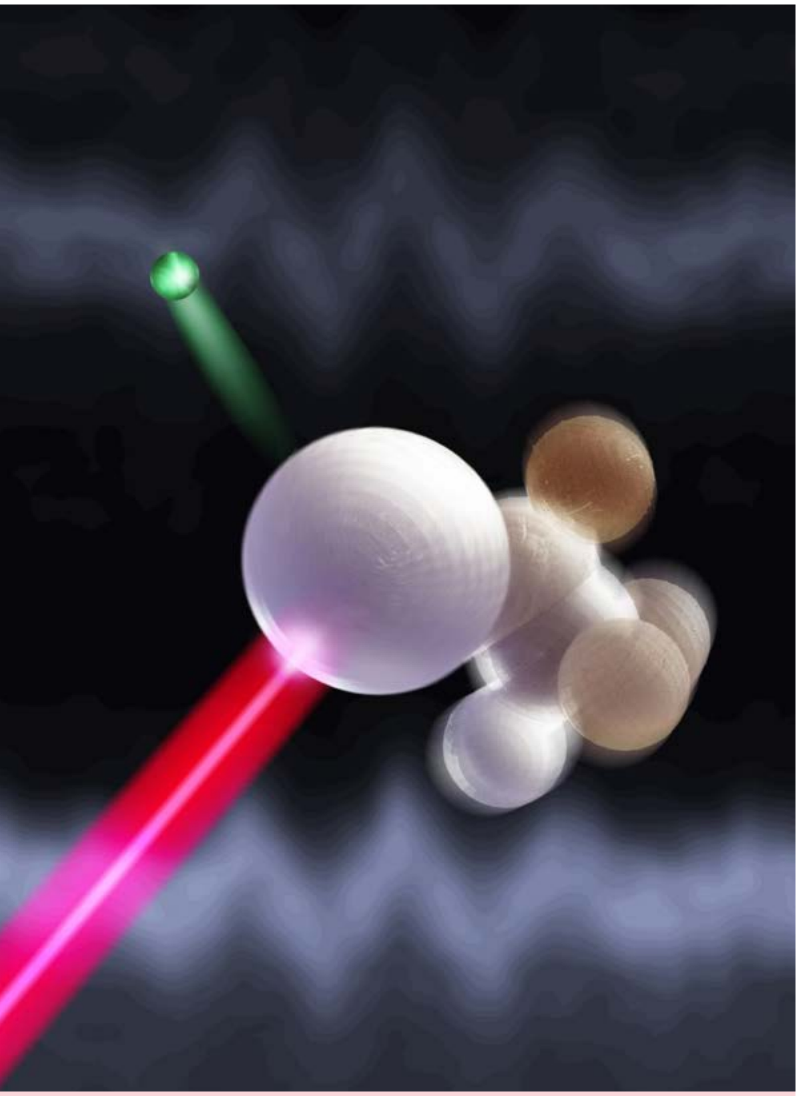
quantum brakes in molecules

may 14, 2020 // Thorsten Naeser

One of the most fundamental processes in the microcosm is photoemission, in which photoexcitation by light results in the release of electrons. The kinetic energy of these electrons is characteristic for an atom and depends on the wavelength of the light. But how fast is an electron emitted from an atom? And does its journey always take the same amount of time, no matter if it comes from an individual atom or from an atom as part of a molecule? An international team of researchers led by Attoworld laser physicists has studied the influence of the molecule on photoemission time.



An ultrashort x-ray laser pulse (in violet) removes an inner-shell electron from the iodine atom in ethyl iodide. The experiment times the propagation of the electron with attosecond precision, and measures how much the released electron is decelerated or accelerated by intramolecular forces.
Image: Thorsten Naeser & Dennis J.K.H.Luck

The theoretical description of photoemission in 1905 by Albert Einstein marked a breakthrough in quantum physics, which is still drawing much attention in the world of science and beyond. How much such an elementary quantum particle, the electron, is slowed down or accelerated in a molecule, is an important question that promises a deeper understanding about the quantum process of photoemission and the involved forces that hold molecules together.

The Attoworld team has now, in close collaboration with researchers from the King-Saud University (KSU) in Riyadh and additional international partners, investigated just how long it takes electrons to be photoemitted from a specific atom within a molecule (here iodine within ethyl iodide). The measured times were in the range of tens of attoseconds. One attosecond is a billionth of a billionth of a second.

The researchers, who conducted the experiments at the Laboratory for Attosecond Science in Riyadhh in Saudi Arabia, used different excitation pulses in the x-ray region to control the initial conditions for the small quantum particles. The use of machine learning helped to improve the accuracy in the experimental data analysis and enabled improved comparison to theoretical predictions. “The comparison of the experimental data with theoretical simulations finally shows the molecular influence on the time that electrons need for the photoemission process”, explains Prof. Matthias Kling, head of the research group “Ultrafast Imaging and Nanophotonics” within the Attoword team. It was found that the time delay from the molecular environment was the larger, the smaller the energy of the light flashes, and therefore the initial energy of the electrons was.

The observations may be compared with exploring a landscape. When flying over it, many details at the ground remain unnoticed. When walking, every single bump is clearly felt. It is similar for the electrons. When they leave the molecule slowly, they experience more of the forces that hold the molecule together.

“Our observations indicate that experiments tracing photoemission time permit to learn about the forces within the molecules”, explains Prof. Abdallah Azzeer, head of the Laboratory for Attosecond Physics at KSU in Riyadhh. “These studies could improve our understanding of quantum effects in molecules and chemical reactions”, adds Prof. Alexandra Landsman from the Ohio-State University in the US, who leads the group that conducted the majority of the theoretical work.

original publication:

probing molecular environment through photoemission delays
AUTHORS: Shubhadeep Biswas, Benjamin Förg, Lisa Ortmann, Johannes Schötz, Wolfgang Schweinberger, Tomáš Zimmermann, Liangwen Pi, Denitsa Baykusheva, Hafiz A. Masood, Ioannis Liontos, Amgad M. Kamal, Nora G. Kling, Abdullah F. Alharbi, Meshaal Alharbi, Abdallah M. Azzeer, Gregor Hartmann, Hans J. Wörner, Alexandra S. Landsman & Matthias F. Kling
JOURNAL: ***Nature Physics* 16,** 778 (2020)

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feature

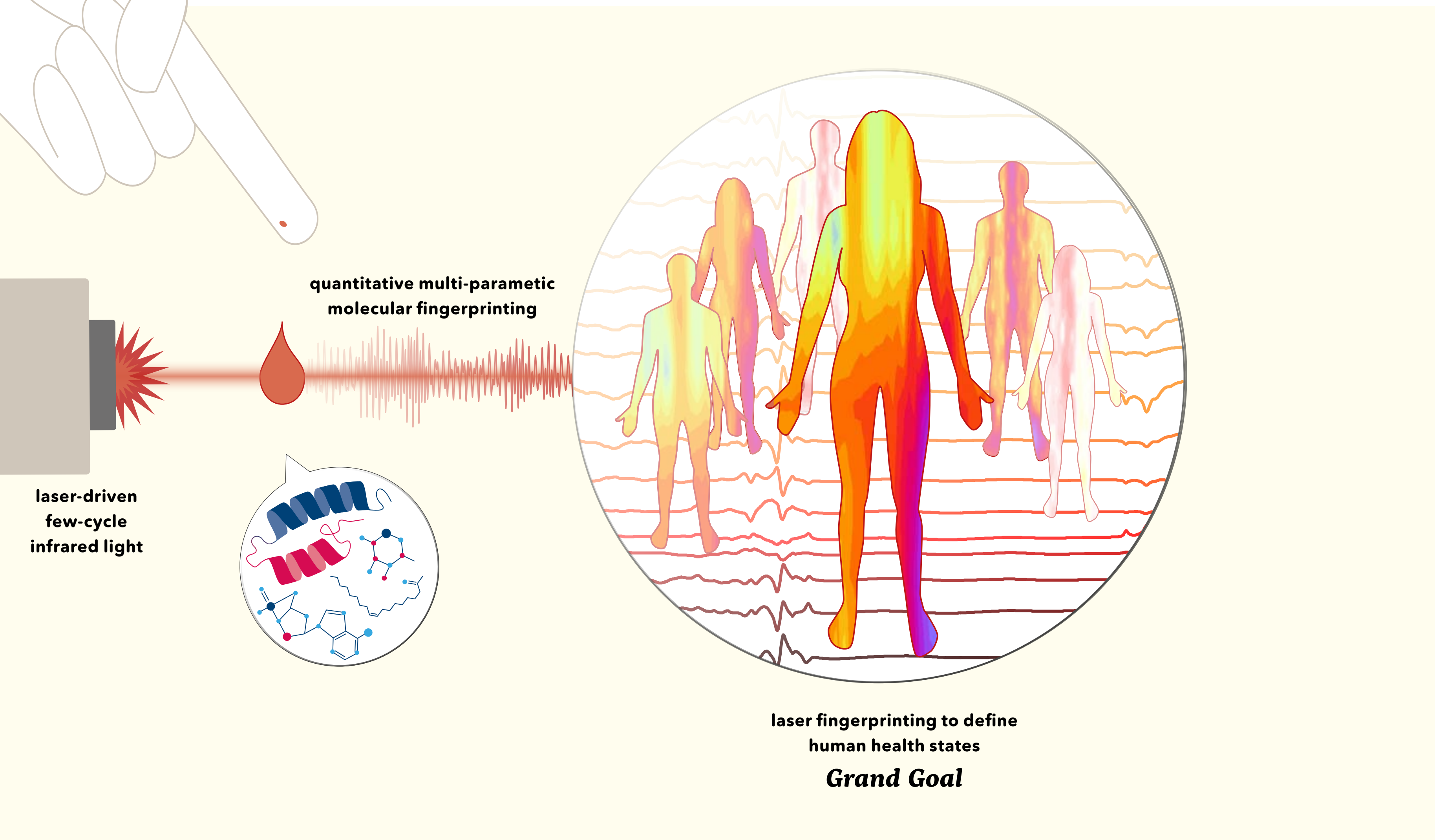
a new watchman guarding our health?

november 15, 2020 // Dr. Mihaela Žigman

Scientific developments at Attoworld have led to spawning a new research institution.In 2019, the Hungarian Ministry of Innovation and Technology approved financial support for a national project to propel health monitoring based on new laser technology. For this purpose, the Center for Molecular Fingerprinting (CMF) was founded in Budapest. Although still a very young institution, the CMF is about to acquire a status of being one of the National Laboratories in Hungary and is relevant to the research efforts at the LMU.

In the springtime of its evolution, what are the main aims of CMF?

It has been known that a few molecules in our blood can be regarded as reporters which are beneficial to track if we suffer from specific diseases. But is there more to that?



Quantitative multi-parametric molecular fingerprinting of human blood, based on few-cycle infrared excitation combined with highly sensitive electro-optic sampling (Pupeza et al., ***Nature* 577**, 52, 2020), ***aims at new avenues to assess human health and disease.***
Graphics: Dennis J. K. H. Luck

Can one imagine the day when a doctor will tell us with confidence whether we are still fully healthy, simply by analysing as little as a drop of our blood? In other words: Could looking at signals from all the different circulating molecules together – most of which are unknown to date or still impossible to quantify – in a combined pattern be accounted for comprehensive monitoring of human "healthiness" without the need of physically examining each and every organ by different, sometimes invasive or even noxious interventions? Unfortunately, major health problems in their preliminary stage run under the radar of current detection techniques too often, as the improvement of early disease markers is tedious and slow.

Suffice to say that we have started to pave the path towards this long anticipated goal! Scientists of the CMF-LAP collaboration are challenged to devise a pioneer blood-based diagnostic assay for health monitoring in a fast and accurate manner, further advancing recently developed mid-infrared laser technology (Pupeza et al., ***Nature* 577**, 52, 2020). Our laser scientist are working on electric-field resolved laser spectrometry that is capable of sensing the minuscule changes in the full molecular composition of blood, which herald a disease already before it manifests physical symptoms.

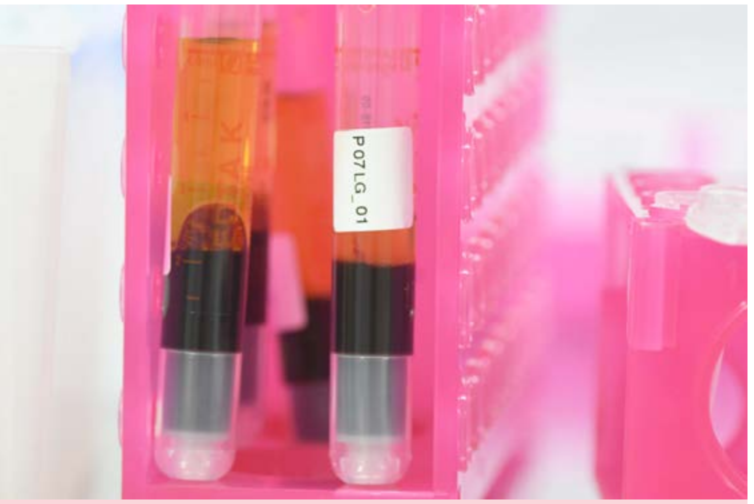
How could one possibly detect minor deviations from health by analysing a drop of blood?

The idea we pursue is to use the newly available technology to attribute the health status of a person to the information embedded in the molecular composition of a blood sample. Blood not only nurtures our cells and tissues, but it also interconnects each segment of the human body and carries soluble molecules released by organs, which are often indicative of their function. Thus, when a local anomaly emerges within our body, say in the liver for example, a severe liver disease could possibly be prevented if having a routine method at hand that quickly analyses the overall molecular content of blood during a regular health-check. In this case the key to detecting e.g. liver disease is that the analysis needs to be sensitive and broadband enough to cover a wide range of molecular substances (or classes of molecules) – to reflect the early pathophysiological changes of the liver. There are immense efforts exerted by basic biomedical researchers and the pharmaceutical industry to tap on the footprints of diseases in the blood. Although these endeavours have resulted in an ever-increasing number of diagnostic tests being used in daily practise, the number of tests, which actually make it from the research bench to the market, is surprisingly small, and the pace of developing new tests is erratic.

A late diagnosis of a serious health condition often leads to a much worse outcome. In fact, we are still often faced with way too late disease detection! So, it is pivotal to switch paradigm and opt for a sensitive pan-molecular detection of diseases, and even pre-disease states, to better guard our health. It has become clear that such interventions must be performed in a personalized manner since every individual's blood constitution is different at the molecular level. Equally, even every person's healthy state is a little bit different. Practically speaking, following-up a person's current health status by our proposed assay regularly might become paramount for timely-detecting relevant deviations.

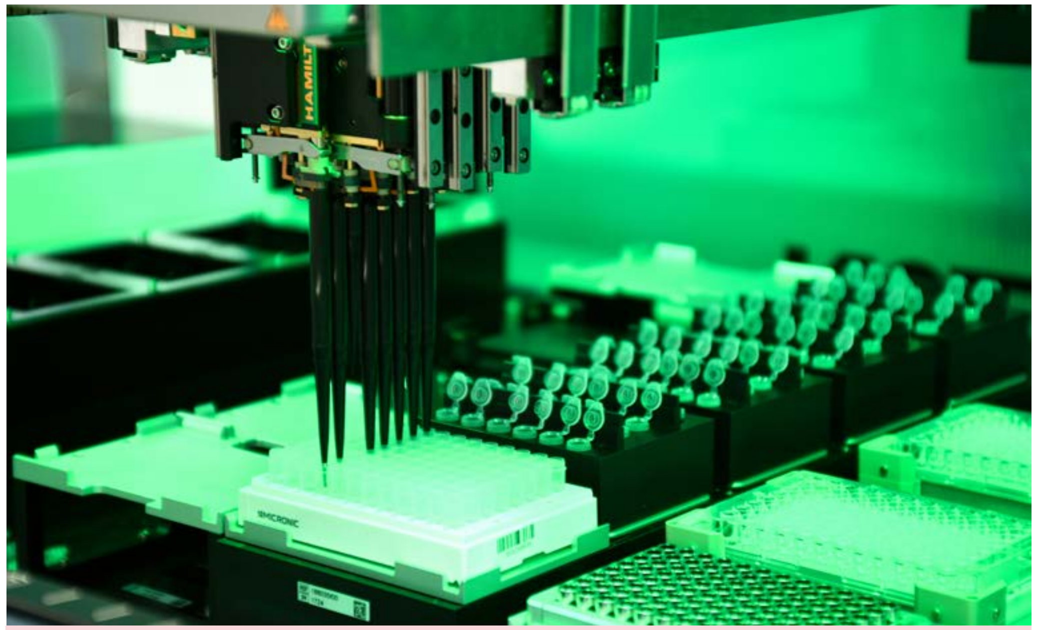
There are ways to sensitively capture blood composition by detecting a diversity of molecules at once

Besides variations in the constitution, it is understood that the quantity of certain molecules in the blood vary within a healthy reference range. We often get the heat going through our veins when we look at our blood test results and notice that a particular value is out of the indicated reference range, or near the thresholds. Often this is ahead of our notion of being actually ill. It has been increasingly accepted that one single molecular biomarker can hardly be used for accurate prognosis of any complex disease (apart from a few very specific cases of microbial infections or specific metabolic disorders of the kidneys or the liver). Instead, molecular profiling has been growing recent attention in important fields, like the most common diseases as cardiovascular diseases and cancers. While looking at a bigger picture, such blood analysis can be interpreted as putting a perplexing puzzle together – where we do not even have a clear idea of how the final picture looks like or sometimes, how a single piece should appear. Ideally, we would have a complete "quantitative blood-based molecular landscape" which identifies all biomarkers and estimates their concentration. In reality, we are speaking of several tens of thousands of circulating molecules that have currently been associated to have an instructive role in medical diagnostics. Yet, there is no such technology to screen all types of molecules at once, or which is sensitive enough to detect all the important ones in the complex mixture of blood.



Human blood samples to be processed for infrared spectroscopy.
Picture: Thorsten Naeser

The scientists at LAP have recently demonstrated the first generation of such a technology that allows for higher sensitivity in reporting on the nature of the entire complexity of molecules in liquid water-based samples (Pupeza et al., ***Nature* 577**, 52, 2020). Our paradigm relies on new ultrashort laser-pulsed field-resolved infrared spectroscopy measuring the molecular fingerprint that the sample leaves in the infrared, characteristic of both the nature and the quantity of the constituting molecules. We went on and devised new ways how to derive such infrared molecular fingerprints of human blood, after the blood and immune cells swimming therein are removed. In this sense, field-resolved infrared molecular fingerprints capture signals dependent on chemical bonds within all circulating molecules, independently of the higher-order structure of molecules in



High-thoruput blood serum/plasma handling using automated liquid sampling system.
Picture: Thorsten Naeser

the sample – thus probing complex human samples in a pan-molecular manner that has not been imaginable with other technologies. Human biofluids will now be efficiently characterized by this new approach, with molecular fingerprinting on a new level of sensitivity combined with molecular coverage.

Is that sufficient, and could we now go on and apply infrared molecular fingerprinting to capture diseases or characterize and monitor different states of human health?

The technology, while being extremely promising, is still in its early state and has been awaiting the clinical applicability. Nevertheless, it is prime time to get the feet wet and test our assay on real-world settings, which is the monitoring of healthy individuals. In collaboration with different clinics at the LMU in Munich, LAP scientists have already shown that every person has a unique infrared fingerprint. Importantly, our scientists could already provide evidence that these blood-based infrared fingerprints are stable over time and robust to daily perturbations. The existing data suggest that the infrared molecular fingerprints are, in principle, applicable to monitoring the deviations from a healthy state. Only if robust signal patterns can be derived out of further large-scale independent studies, can we make sure that one day we will be able to distinguish between healthy and disease electric-field molecular fingerprints which will be our entry pass to clinical practice.

How will CMF efforts contribute to health monitoring?

CMF realizes that turning the vision into reality requires continued dedicated technological development along with well-controlled populational studies at the forefront of the scientific research. It starts from the development of new mid-infrared laser sources via advancing sample handling and detection technologies and goes towards finding optimal data acquisition and processing strategies. Over the last couple of months, a new team has formed at CMF with the particular goal to tackle these technical and scientific challenges. In close collaboration, the CMF laser development and technology team at the Garching research center is joining forces with LMU laser scientists to combine all technological advances in a one of a kind prototype device for molecular fingerprinting of blood.

Viola Zóka at the LEX laboratory preparing blood-based samples for cryogenic storage. Picture: Thorsten Naeser

How is CMF planning to collect, store and analyze populational studies?

CMF has currently been setting up large-scale populational studies to register blood-based infrared molecular fingerprints from individuals over time. A network of collaborations across Hungary is being built, serving the aim of collecting several tens of thousands of blood samples and corresponding clinical information from every participant, with a first visit to collect a baseline and with several follow-up visits. This entails following the participants when their regular medical check-up is due for many years to come. Why the follow-up visits? As noted above, although molecules of blood trail differ from person to person, infrared molecular fingerprints of a particular person stay rather stable over time with the premise that no disease is being developed. To be in a position to figure out most precisely whether a healthy person is indeed healthy, it is paramount to compare a person's most recent fingerprint with his/her own earlier fingerprints. CMF will create a framework to recruit volunteers that will donate blood samples twice yearly, followed-up over several years.

A further advantage of blood-based human sample analysis is that samples can be stored deep-frozen. What is more, if stored under cryogenic conditions at –185°C, they can be securely preserved for decades. For this goal to achieve, a new fully automatic liquid nitrogen-based biorepository will be built at CMF, which will store hundreds of thousands of little tubes filled with blood samples (with no cells present). This resource will fuel the development of molecular fingerprinting and allow to evaluate its clinical utility in years and decades to come.

Additionally, CMF is planning to build new laboratories in Budapest – to be in the position to collect, prepare, store, measure and analyze samples at the same time, under the same roof. Once the laser laboratories of CMF will open their gates, the field-resolved infrared molecular fingerprinting will be fundamental to devise and evaluate high-throughput approaches for monitoring human health. Moreover, the corresponding infrared molecular fingerprints will be analyzed together with medical data using several emerging artificial intelligence techniques.

What is the perspective in seeing deeper without the need of looking deeper?

Although almost two centuries have passed since Dr. Elisabeth Blackwell, the first US female doctor, spotlighted the value of monitoring human health "we are not tinkers who merely patch and mend what is broken… we must be watchmen, guardians of the life and health of our generation, so that stronger and more able generations may come after …". Ever since the unmet medical needs remained the same, but the diagnostic approach is now driven by laser technology that can detect individual chemical bonds – thus letting us see through to the bottom of the molecular zoo in our blood! The transfer from basic scientific understanding about blood-based infrared molecular fingerprints to the applied question of what these fingerprints will tell us about diseases and conditions will probably take several more years to come. In the meantime, the CMF team, with its headquarters office at Budapest and scientific teams at Garching and Budapest, is further strengthening and extending the research efforts, that have already taken a deep dive into the depths of field-resolved molecular fingerprinting.

The CMF team in Budapest is working hand in hand with their colleagues in Munich (Nov. 4th 2020, Budapest). Picture: Károly Dobrosi

congratulations on your 80th birthday

november 23, 2020 // broadband infrared diagnostics

Congratulations to Dr. Ernst Fill. He has just celebrated his 80th birthday with his family. A surprise visit from the BIRD team came to his front door. The team brought a very special gift. A homemade cake. Its top side was decorated with an enhancement cavity with a thin taut foil as coupler, which is applied at a 45 degree angle. This arrangement was developed by Ernst Fill a few years ago. His invention is now not only very useful in infrared spectroscopy, but even a a culinary delicacy.

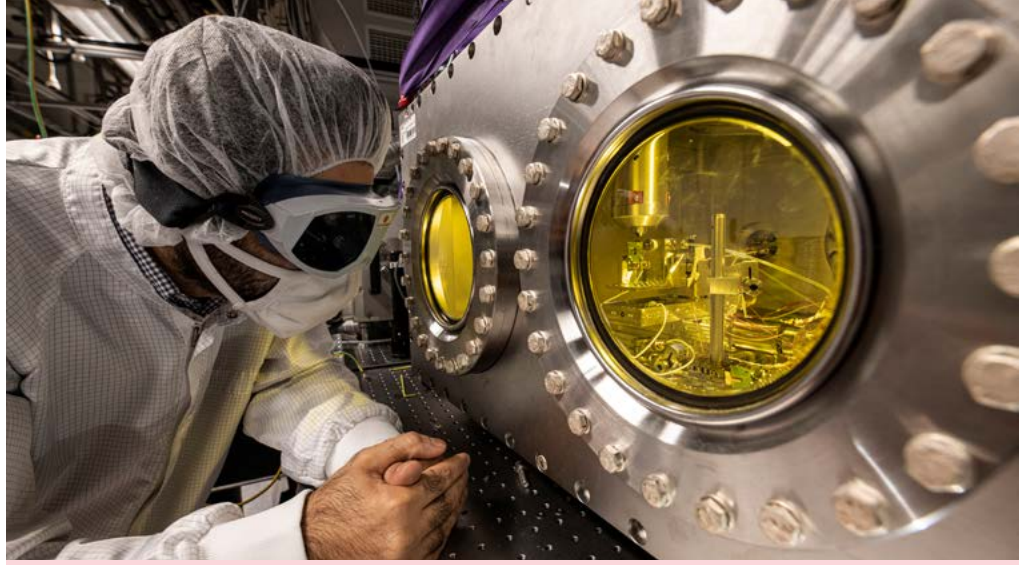
how to get cooler!

october 9, 2020 // broadband infrared diagnostics

Picture: Thorsten Naeser

The new liquid-nitrogen cooling system at the Centre for Advanced Laser Applications (CALA) fulfills all prerequisites for secure long-term storage of blood donated to the Lasers4Life project. In the Biobank, the samples are maintained under cryogenic conditions, i.e. at less than -150°C in the gaseous phase over liquid nitrogen. The 11-tier system can accommodate approximately 60,000 (0.5-ml) samples of plasma or serum. Storage and retrival of samples is carried out by an integrated robotic system. The latter steps are performed at a temperature of -100°C, so that the whole operation takes place without interruption of the refrigeration chain.

In terms of both storage and handling, the new system has marked advantages over the previous procedure, in which samples were manually stored at -80°C. Most importantly, thanks to the use of ultracold liquid nitrogen, samples remain at the set temperature even in the unlikely event of a power cut lasting for several days. They can also be stored for at least 10 years without any alteration or loss. This means that samples can always be (re-)analysed with the latest generation of lasers available, in order to extract still more information than could previously be obtained.

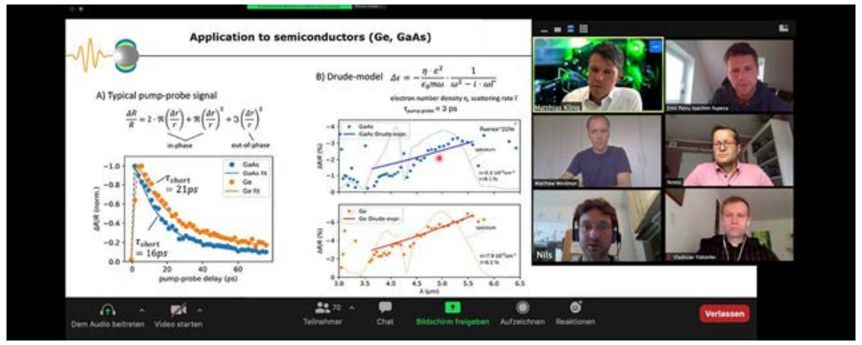


Picture: Thorsten Naeser

watching photoelectrons

october 5, 2020 // attosecond metrology 2.0

Towards the advancement of attosecond metrology, Keyhan Golyari prepares the AS2000 beamline for the next experimental campaign. In the next set of experiments, the team around Matt Weidman and Vladislav Yakovlev intends to better understand the interaction of a laser light with photoelectrons in the vicinity of a metal electrode. Outcomes of these experiments should further improve the measurement technique where the electric current flowing from the electrode through an external circuit enables precise and fast measurements of electric fields oscillating at optical frequencies.



attoworld annual retreat via zoom

september 23, 2020 // attoworld

Unfortunately, the COVID-19 also has an influence on our attoworld annual retreat this year. While last year we were able to meet together in a cozy atmosphere in South Tyrol, we now unfortunately had to postpone to a three-day zoom conference. Until tomorrow, the group leaders of the individual teams will present their current research results. Each team member has the opportunity to give a short presentation as well. We very much hope to meet again next year in person in front of the mountain scenery of South Tyrol.

watching metamaterials via time-resolved electron diffraction

november 24, 2020 // atomic & electronic motion in 4d

A team of physicists from the Ludwig-Maximilians-Universität München (LMU Munich), the University of Regensburg and the University of Konstanz has successfully demonstrated that electron pulses experience a quantum mechanical phase shift through their interaction with light waves in nanophotonic materials. Equipped with ultrashort electron pulses that are compressed in time by means of terahertz radiation, the researchers were able to resolve the oscillations of the electromagnetic near-fields at the optically-excited nanostructures via pump-probe electron diffraction. Ultrafast electron holography and diffraction can therefore resolve the functionality of nanophotonic materials and metamaterials in space and time. The corresponding study has now been published in the latest issue of "Science Advances".

original publication:

ultrafast electron diffraction from nanophotonic waveforms via dynamical aharonov-bohm phases

K. Mohler, D. Ehberger, I. Gronwald, C. Lange, R. Huber, P. Baum

***Science Advances* 6,** eabc8804 (2020)

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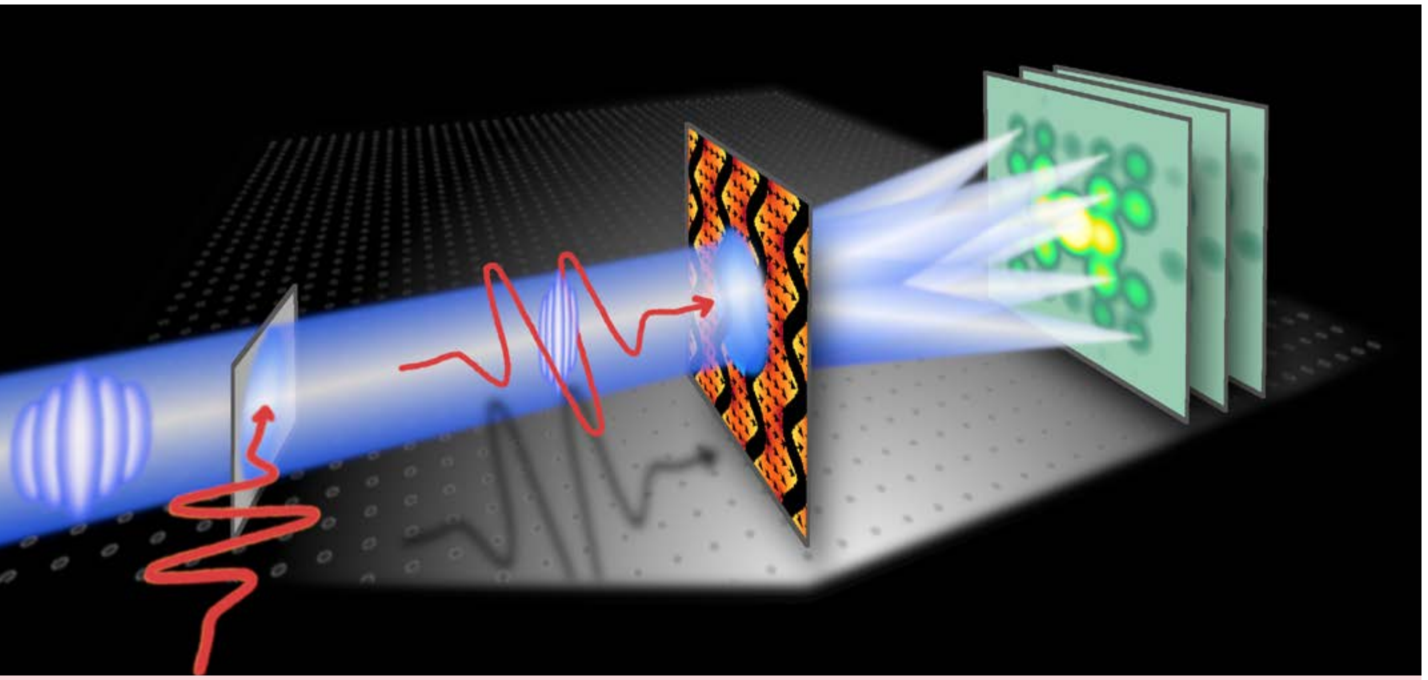

Ultrafast electron diffraction of optically-excited metamaterials. Image: Kathrin Mohler, LMU Munich

a 'picoscope' for elementary particles

july 21, 2020 // attoelectronics

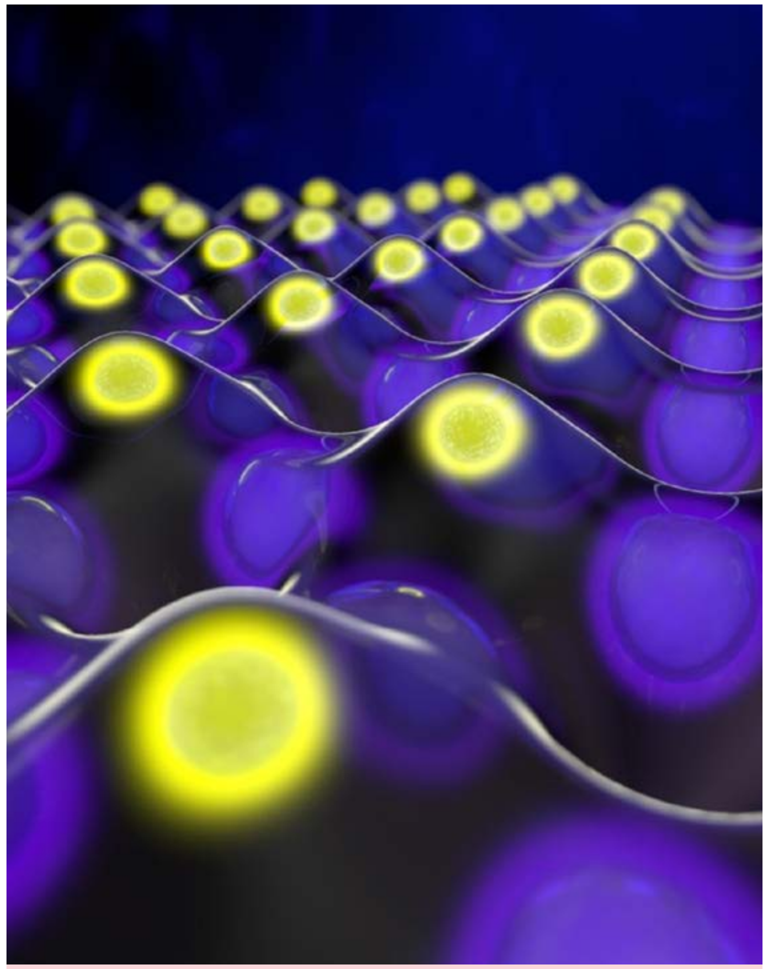

Image: Dr. Christian Hackenberger

A research team led by laser physicist Eleftherios Goulielmakis at Rostock University has developed a new technology, which makes it possible to image free electrons in crystalline materials.

Microscopes of visible light allow us to see tiny objects such living cells and their interior. Yet, they cannot discern how electrons are distributed among atoms in solids. Now researchers around Prof. Eleftherios Goulielmakis of the Extreme Photonics Labs at the University of Rostock and the Max Planck Institute of Quantum Optics in Garching, Germany, along with coworkers of the Institute of Physics of the Chinese Academy of Sciences in Beijing, developed a new type of a light microscope, the Picoscope, that allows overcoming this limitation. The researchers used powerful laser flashes to irradiate thin, films of crystalline materials. These laser pulses drove crystal electrons into a fast wiggling motion. As the electrons bounced off with the surrounding electrons, they emitted radiation in the extreme ultraviolet part of the spectrum. By analyzing the properties of this radiation, the researchers composed pictures that illustrate how the electron cloud is distributed among atoms in the crystal lattice of solids with a resolution of a few tens of picometers which is a billionth of a millimeter. The experiments pave the way towards developing a new class of laser-based microscopes that could allow physicists, chemists, and material scientists to peer into the details of the microcosm with unprecedented resolution and to deeply understand and eventually control the chemical and the electronic properties of materials.

original publication:

laser picoscopy of valence electrons in solids

H. Lakhotia, H. Y. Kim, M. Zhan, S. Hu, S. Meng, E. Goulielmakis

***Nature* 583,** 55 (2020)

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"Sydney is going to be my home for a much longer time than originally expected" [Alexander Fürbach]

september 11, 2020 // Thorsten Naeser

When Prof. Krausz and his Vienna-team produced the first attosecond flashes of light in 2001, Alexander Fürbach was a doctoral student in the group led by Ferenc Krausz at the University of Vienna. At that time he was involved in the development of femtosecond lasers. After working at "Femtolasers", he planned to go to Australia for two years. It has now been almost 20 years. He is now a professor at the Department of Physics and Astronomy at Macquarie University in Sydney. Here he tells about his passion for femtosecond lasers and what it's like to live and work in Australia.

As a young doctoral student in the Attoworld team, you dealt with the development of femtolasers in Vienna. What was the goal of the work at that time?

At the time I did my PhD, the use of femtosecond lasers was very much limited to scientific applications in a controlled laboratory environment. The main aim of my work was the development of novel ultrafast laser sources for micromaching applications, with the ultimate goal of realizing laser systems that could also be used in industry or medicine, for example as a replacement for the dreaded mechanical dental drill. One particular approach that our team pioneered back then was the concept of a chirped-pulse oscillator (CPO) for the generation of high-power femtosecond pulses without external amplification. This new technology was eventually translated into a commercial product by Femtolasers GmbH and enabled us for example to demonstrate the possibility of selectively analyse individual oil-inclusions in quartz crystals for petrochemical applications. To come full circle, one of these laser systems is now the workhorse of many of my research projects here at Macquarie University in Sydney.

You were also there when the team produced the first attosecond flashes of light. How did you experience this event?

I not only remember the event itself, but also the long and difficult road to get there. While I was not directly involved in this work, it was on multiple occasions that I would come to the lab early morning to greet some very tired colleagues of mine after yet another round of all-night measurements. We knew that other groups were also working on the generation of attosecond pulses and the pressure was enormous. For me the main reasons that our group eventually succeeded were the comprehensive scientific expertise that existed within the team and maybe even more so, Ferenc's very unique leadership skills. He always managed to motivate all his students and coworkers and create a fantastic team-spirit that made us all feel proud of being part of something very special. And when eventually the first "atto-flash" was then finally confirmed, everyone was ecstatic that all the hard work eventually paid off. It was a great time.

Today you are still dealing with femtosecond laser technology. What is the focus of your research team today?

The main focus of my research activities is the use of ultrafast lasers for the inscription of photonic structures into transparent dielectric materials. When an ultrashort laser pulse is tightly focused into a transparent material, a highly localized change in the refractive index can be induced and this provides the basis for the so-called femtosecond laser direct-write technique. While the same principle can be used in application fields as diverse as astro-photonics or quantum-information, my team and I are currently focusing on the development of hybrid waveguide-fibre sources for the mid-infrared spectral region, in particular ultrafast and ultrabroadband laser systems. This specific part of the electromagnetic spectrum has long attracted much scientific and technological interest due to the fact that virtually all molecules have their rotational-vibrational absorption lines in this range. For this reason, the mid-infrared is often referred to as the "molecular fingerprint" region. Owing to the high-impact applications that result from the strong molecule-photon interaction, such as trace molecular detection for airport security screening and non-invasive breath analysis, mid-IR photonics has become a hot topic in modern optics research.

Why did you end up in Australia?

After having spent the first 30 years of my life in Vienna, and after having fallen in love with Australia during a long camping holiday, I decided that I would like to take the opportunity to work as a Post-Doc at the University of Sydney for two years, to use this time to experience the city and the country, and then to move back to Austria. Then came an early-career fellowship and a tenure-track position at Macquarie University and now, almost 20 years later, I am still in Sydney. In the meantime, I became dual Austrian-Australian citizen and I find it still hard to believe that my daughter is already in year 3 at school and that my little boy is about to start school next year. Looks like Sydney is going to be my home for a much longer time than originally expected.

You are a professor at Macquarie University in Sydney. What is life and work like in Sydney?

When I came to Australia in 2004 I was amazed by how laid-back the country was compared to Vienna. While "no worries" is still a phrase that can be heard very often, life in Sydney has also become more and more fast-paced over the years. Houses are ridiculously expensive, traffic is bad and having a mortgage the size of a small country (something I would have never even considered when I was still living in Europe) has become something that is just normal. Academic life is highly competitive as everywhere in the world with the usual and constant pressure to publish and to attract funding. Still, a short drive to a stunning beach on a sunny 20°C winter day reminds me that Sydney is a beautiful city. The suburb that I live in, called Wollstonecraft, features some amazing parkland with breathtaking views of the city skyline with its famous opera house, even on a hot summer's day there is always a nice ocean breeze and the Blue mountains, a paradise for rock-climbing and hiking (called "bushwalking"s) are only an hour's drive away. I guess overall, I can't complain about life and work in Sydney.

If you imagine laser technology in 20 years. What does it look like?

Laser technology is already ubiquitous, and I think that this trend will continue in the next 20 years. With respect to my own research activities into mid-infrared laser systems my hope is that in 2040 we will have access to compact and field-deployable spectroscopy systems that are capable of analyzing the molecular composition of gases, liquids and solids with unprecedented selectivity and sensitivity. This will enable for example the early detection of various forms of cancer just from the exhaled breath of a person or the precise measurement of the concentration of various trace-gases that are present in the atmospheres for constant air-quality monitoring. My prediction is that in 20 years, these systems will be so small that they can be integrated into miniature drones so that they can be employed even in remote and unsafe locations. Only time will tell if I am right but my group and I are doing our best to make this vision a reality one day.

life within attoworld

“biomolecules will become of interest”

[Marcus Seidel]

october 30, 2020 // Thorsten Naeser

Since November 2019, our former colleague Marcus Seidel has been working at the Deutsches Elektronen Synchrotron (DESY) in Hamburg. Currently, a major upgrade for the Free Electron Laser FLASH is in progress. In this context Marcus is also involved in the development of laser systems. In this interview he talks about his work and what the future of Free Electron Lasers could look like.

Why did you move so far north from Munich?

I was actually not afraid to go “so far north” since I had already been studying in Rostock for several years. But I would not say that going north was really on purpose. After spending two years abroad my family and I had the desire to move back to Germany. We checked several sites and at the end Hamburg suited us best. I believe that Hamburg is a great place to continue my scientific career. Although I would claim that Munich is still the “science capital” of Germany, I feel like science has been really boosted here over the past years. We have got many new buildings of DESY, Max Planck and the university on our campus which is even supposed to grow to a “Science City” over the next decades.

How does life in Hamburg differ from life in Munich?

Well, I have changed my fast food preference from “Leberkäsemmel” to “Fischbrötchen“. A deeper answer to this question is actually quite hard at present. I have spent most of the time here under all these corona restrictions, and thus cannot tell up to now how life in Hamburg is in normal times. Nevertheless, under the given circumstances, a great advantage of the city has turned out during the past summer: The beaches of the Baltic and the North Sea are only a good hour drive away from our home.

Your specialty is Free Electron Lasers. Can you give us an overview of your work at DESY?

Although I am working at FLASH, I am not too much into the Free Electron Laser itself. Close to 90 % of the experiments carried out at the FLASH facility are excite-probe experiments where conventional lasers excite the sample under test to a specific state. The Free Electron Laser is then probing the state dynamics. With “conventional” I mean that these lasers are actually based on the process of stimulated emission and are very compact compared to the large scale Free Electron Laser which is based on wiggling of electron bunches. In short, I am mainly developing ultrafast lasers for these excite-probe experiments, and thus I am staying close to my research field at MPQ. We have just completed the development of a new laser system for user experiments. Last week we handed it over to our operations team. In two weeks first external users will work with it. It is the first laser at FLASH which is based on pulse compression instead of parametric amplification. We try to pick up current trends of the scientific community, do our own research on it and adapt these trends to the very specific laser specs we need. Since this new laser system is ready now, I can spend at present more time on an own independent research project and on student supervision.

How does your work differ from that at MPQ?

The main difference is that DESY is a user facility. Therefore, our first priority is safety and the second is to serve our users. Our own research results are certainly important for providing our users cutting-edge tools but they are ranked lower in our priority list. For instance, the lasers we develop do not have to provide record-breaking parameters but must be extremely reliable. Our users plan their Free Electron Laser experiment many months in advance and have only a very limited beam time of one week to make it work. They cannot afford to have one of our lasers not running properly. For that reason all researchers of our laser group got on-call duty twice a year, i.e. they may have to get up in the middle of the night to fix laser issues at FLASH. Fortunately, that has not yet happened to me.

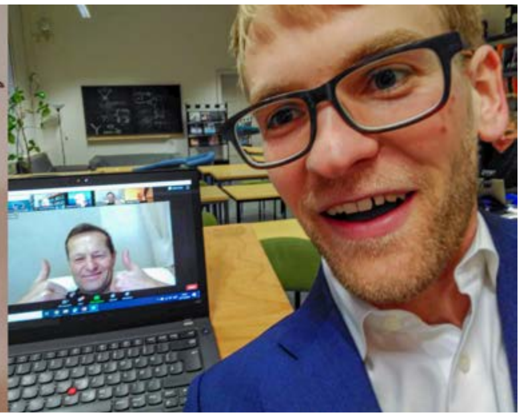
Where do you see Free Electron Lasers technologically in 10 years?

At present, FLASH is the only Free Electron Laser worldwide that provides more than 1000 pulses per second. That will change in the near future as new facilities in the US and China will open for user operation. Hence, I can claim that the FEL developments are somehow driven by the same motivation that I had when I did my PhD at MPQ: increasing repetition rate increases data rate and grants access to photon-hungry applications, for example in solid-state physics. Another important trend, which is also at the heart of the currently starting FLASH 2020+ upgrade, is seeding of Free Electron Lasers. The FEL radiation is at present initiated by a spontaneous emission process which leads to uncertainties in the arrival time and the spectral width of the pulses. “Seeding” means that this spontaneous process is suppressed by the injection of photons with precise timing and wavelength control. I would say that the attosecond physics community and the FEL community will approach each other in the upcoming years. FELs are doing excellent in pulse energy and wavelength tunability but only processes in the 10s of femtosecond range can be tracked. Attosecond pulses on the other hand could benefit a lot by becoming more energetic but the temporal resolution they provide is fantastic. Seeding of FLASH will be an important milestone towards reaching the attosecond frontier also with Free Electron Lasers.

And what will we be able to explore with FELs?

Just recently, I was very impressed again by the powerfulness and the versatility of high brightness light sources. Our colleagues from the synchrotron Petra III investigated how different drugs interact with a corona dummy virus. The brightness of Free Electron Lasers is even higher than that of synchrotrons. The applications are manifold. We divide them into four categories. First, in experiments with atoms and molecules a better understanding of high-field ionization dynamics will be developed, charge-transfer processes will get a closer look and chemical reactions in space will be mimicked and examined. Time and space resolved studies of chemical reaction pathways are the second main field of applications. Here, the scientific interest reaches from fundamental aspects like the understanding of dynamics at conical intersections to applied research, for instance on carrier dynamics in photovoltaics. Third, the condensed matter community typically gets a significant amount of beam time at our FLASH facility. Photoelectron spectroscopy is a heavily used tool in solid state physics and high repetition rate FELs provide outstanding parameters for such experiments. In particular, we are looking forward to gaining better understanding of quantum effects that trigger highly application relevant phenomena like high temperature superconductivity, colossal magnetoresistance or metal-insulator phase transitions. Last but not least, the extraordinarily high brightness and the short wavelengths of FEL sources result in unique imaging capabilities. Whereas our European XFEL colleagues can resolve structures down to the atomic level, the wavelengths we provide at FLASH are well-suited for resolving nanometer-size objects. Especially large biomolecules will become of interest after our upgrade. However, there are two calls per year for experiment proposals at FLASH. So, we are looking forward to exciting suggestions that our external users come up with.

PhD hat by Dr. Mikhail Mamaikin. Picture: Mikhail Mamaikin

Dr. Marinus Huber

november 27, 2020 // broadband infrared diagnostics

Marinus Huber has defended his doctoral thesis titled: **"Field-Resolved Infrared Spectroscopy From Fundamentals towards Medical Applications".** We congratulate warmly on passing successfully the exam.

graduations

Dr. Haochuan Wang

october 15, 2020 // field-resolved Raman micro-spectroscopy

Congratulations to Haochuan Wang on his successful PhD defense about: **"High-Energy and High-Power Multi-Octave Pulse Generation".**

Dr. Mikhail Mamaikin

july 7, 2020 // attosecond metrology 2.0

Congratulations to Mikhail Mamaikin on his successful PhD defense about: **"Time-Resolved Microscopy of Near-Infrared to Visible Waveforms".**

Dr. Lauryna Lötscher

may 8, 2020 // attoworld

Congratulations to Lauryna Lötscher on his successful PhD defense about: **"High Power Ultrafast Light Generation from 1ps to 70 fs, 5 mJ to µJ Pulses and Low Harmonic at High Repetition Rates".** In the time of Corona, the doctoral examination took place online for the first time.

Dr. Martin Kaumanns

march 2, 2020 // thin-disk laser technology

Congratulations to Martin Kaumanns on his successful PhD defense about: **"Generation of Energetic Femtosecond Pulses at High Average Power".**

Dr. Florian Siegrist

february 6, 2020 // attosecond metrology 2.0

Congratulations to Florian Siegrist on his successful PhD defense about: **"Light-Field Driven Charge and Spin Transfer".**

Dr. Ayman Alismail

february 5, 2020 // field-resolved Raman micro-spectroscopy

Congratulations to Ayman Alismail on his successful PhD defense about: **"Multi-Octave, CEP-Stable Source for High-Energy Field Synthesis".**

A look beyond the horizon is obtained by entering the search term "attoseconds" in the online science portal of the Information Service Science (idw). Here are some exciting new findings in the world of Attosecond Physics from our European colleagues.

electron movements in liquid measured in super-slow motion

august 21, 2020

For the first time, scientists around Prof. Hans Jakob Wörner of the Laboratory of Physical Chemistry at ETH Zurich have succeeded in studying the first few dozen attoseconds of electron movement in a liquid. The researchers made use of photoemission in water: they irradiated water molecules with light, causing them to emit electrons that the scientists could then measure. "We chose to use this process for our investigation because it is possible to start it with high temporal precision using laser pulses," Wörner says.

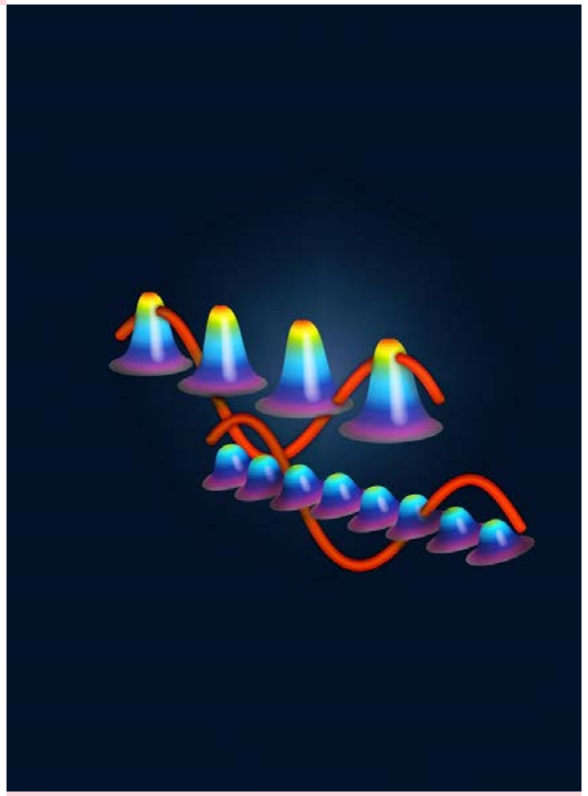
The new measurements also took place in high vacuum. Wörner and his team injected a 25-micrometre-thin water microjet into the measuring chamber. This allowed them to discover that electrons are emitted from water molecules in liquid form 50–70 attoseconds later than from water molecules in gaseous form. The time difference is due to the fact that the molecules in liquid form are surrounded by other water molecules, which has a measurable delay effect on individual molecules.

original publication:
attosecond spectroscopy of liquid water
I. Jordan, M. Huppert, D. Rattenbacher, M. Peper, D. Jelovina, C. Perry, A. von Conta, A. Schild, H.J. Wörner,
***Science* 369,** 974 (2020)

shaping the electric field of an attosecond pulse

february 13, 2020

A team led by Prof. Dr. Giuseppe Sansone from the Institute of Physics at the University of Freiburg shows in the scientific journal Nature how they were able to completely shape the waveform of an attosecond pulse. The team carried out the experiment at the Free Electron Laser (FEL) FERMI in Trieste/Italy. This laser is the only one which offers the unique capability to synthesize radiation with different wavelengths in the extreme ultraviolet spectral range with fully controllable relative phases.



Researchers were able to shape the electric field of an attosecond pulse.
Image: Jürgen Oschwald & Carlo Callegari

The attosecond pulse results from the temporal overlap of laser harmonics. The scientists generated groups of four laser harmonics of a fundamental wavelength using the undulators available at FERMI. One of the main challenges of the experiment was the measurement of these relative phases, which were characterized by acquiring the photoelectrons released from neon atoms by the combination of the attosecond pulses and an infrared field. This leads to additional structures in the electron spectra, usually referred to as sidebands. The scientists measured the correlation between the different sidebands generated for each laser shot. This finally enabled them to fully characterize the attosecond pulse train.

"Our results indicate not only that FELs can produce attosecond pulses", says Sansone, "but, due to the approach implemented for the waveform generation, such pulses are fully controllable and attain high peak intensities. These two aspects represent key advantages of our approach. The results will also influence the planning and design of new Free Electron Lasers worldwide."

original publication:
attosecond pulse shaping using a seeded Free Electron Laser
P.K. Maroju et al., G. Sansone
***Nature* 578,** 386 (2020)

a laser clock with a quantum hand

january 1, 2020

What happens when a molecule breaks apart? A phenomenon like this can be investigated with short laser pulses. But there is a problem: one has to deal with very different time scales simultaneously. The electrons move so fast that they have to be studied on an attosecond time scale. The heavier particles in the molecule, on the other hand, hardly move at all within an attosecond.

A method has now been developed at TU Wien that makes both time scales accessible simultaneously. The method uses an elliptically polarized laser pulse. The duration of the laser pulse is long enough to probe the comparatively slow break-up of the molecule, but the rotation of the electric field is fast enough to serve as a time reference for the ultrafast dynamics of the electrons. Both kinds of motion are closely related.

"In our experiment, we shoot a laser pulse at a hydrogen molecule," says Markus Kitzler-Zeiler from the Institute of Photonics at the

TU Wien. The molecule consists of two hydrogen atoms – two protons and two electrons. The electric field of the laser rips off an electron. Within attoseconds the electron leaves the molecule and flies away. As soon as an electron is missing, the bond between the remaining particles of the molecule changes, too. The distance between the two protons increases. If later during the pulse the second electron is also removed by the laser field, the two protons repel each other and the molecule disintegrates completely.

As each proton is about two thousand times heavier than an electron, the protons move much more slowly. The motion of the atoms as they are drifting apart is measured in femtoseconds or even picoseconds. The difference to the ultrafast dynamics of the electrons is so large that it is very difficult to find a suitable clock that can measure both the rapid motion of the electrons and the slower break-up of the atomic bonds.

The solution was to link different timers. The fast timer is the rotation of the light field. “Just as you can add an additional hand to a wristwatch to measure shorter time intervals, we have added a quantum hand to the laser pulse”, says André Staudte. The direction of the electric field of the elliptically polarized laser light rotates, but at an extremely fast speed – once every 2.5 femtoseconds. This continuous change of direction can be used to investigate how the fast motion of the electrons is related to the slow motion of the protons. As the research team was able to show, the slower proton movement can be analyzed by looking at the energy of the protons after the molecule fracture.

original publication:
subfemtosecond tracing of molecular dynamics during strong-field interaction
V. Hanus et al.
***Physical Review Letters* 123,** 263201 (2019)

Light is the engine of life. It is a volatile medium. However, mankind understands better and better how to make use of the radiation. If you would like to inform yourself about current topics related to light, the photonworld.de homepage is the right place for you. Here, the Attoworld team reports in a generally understandable way about exciting findings and discoveries in physics, biology, chemistry or astronomy. The authors explain how to use light in technology and what visions are coming through the minds of researchers and engineers to make light the tool of the 21st century. Here we publish a sample in our newsletter.

in darkness deep

july 30, 2020 // Thorsten Naeser

Even when they are illuminated, some species of deep-sea fish remain essentially invisible to potential predators. This makes life more difficult for their would-be foes – and for photographers, who must dig deep into their box of tricks to image them.

The black dragonfish (Idiacanthus antrostomus), which is found in the Pacific Ocean at depths below 200 m, has a good claim to possess the most effective camouflage in the world. In its native habitat, it is to all intents (especially those of potential predators) and purposes, invisible. This is because its ultra-black skin absorbs more than 99.5% of the light that reaches its dimly lit home. This level of absorbance means that even species equipped with bioluminescent organs draw a blank.

The skin of the black Pacific dragonfish absorbs 99.5% of ambient light. At depths below 200 m, this makes the species virtually invisible to would-be predators.
Pictures: Karen Osborn

Their frustration can be easily imagined when one considers that most organisms reflect over 50% of the ambient light.

A group of researchers from Duke University in Durham (North Carolina), led by Alexander Davis, has now studied the phenomenon of near-total light absorption. In Monterey Bay of the coast of California and in the Gulf of Mexico, the marine biologists discovered no less than 16 different species of deep-sea fish whose skins are extremely black from depths on the order of 1500 meters.

They went on to show that the black dragonfish and its peers owe their ultra-dark colours to a very thin sheet of densely packed pigment cells located immediately below the outermost, epidermal layer of the skin. These cells possess specialised organelles called melanosomes, which are packed with light-absorbing molecules. In the course of evolution, a wide range of organizational patterns has been "discovered" for the storage of melanin, the major pigment synthesized in cells that contain melanosomes. Melanin is the pigment responsible for determining skin colour in most vertebrates, including humans.

The skin of very many species of fish is darkly pigmented. In most of them, however, the pigment cells do not form an unbroken layer, but are intermingled with non-pigmented cells. This arrangement allows significant proportions of the ambient light to be reflected. In contrast, according to Davis and his co-authors, the extremely dense packing of pigment cells found in ultra-black species such as the black dragonfish enables them to reduce the range of vision within which would-be predators can see them by a factor of more than six – relative to prey that reflect 2% of the incoming light.

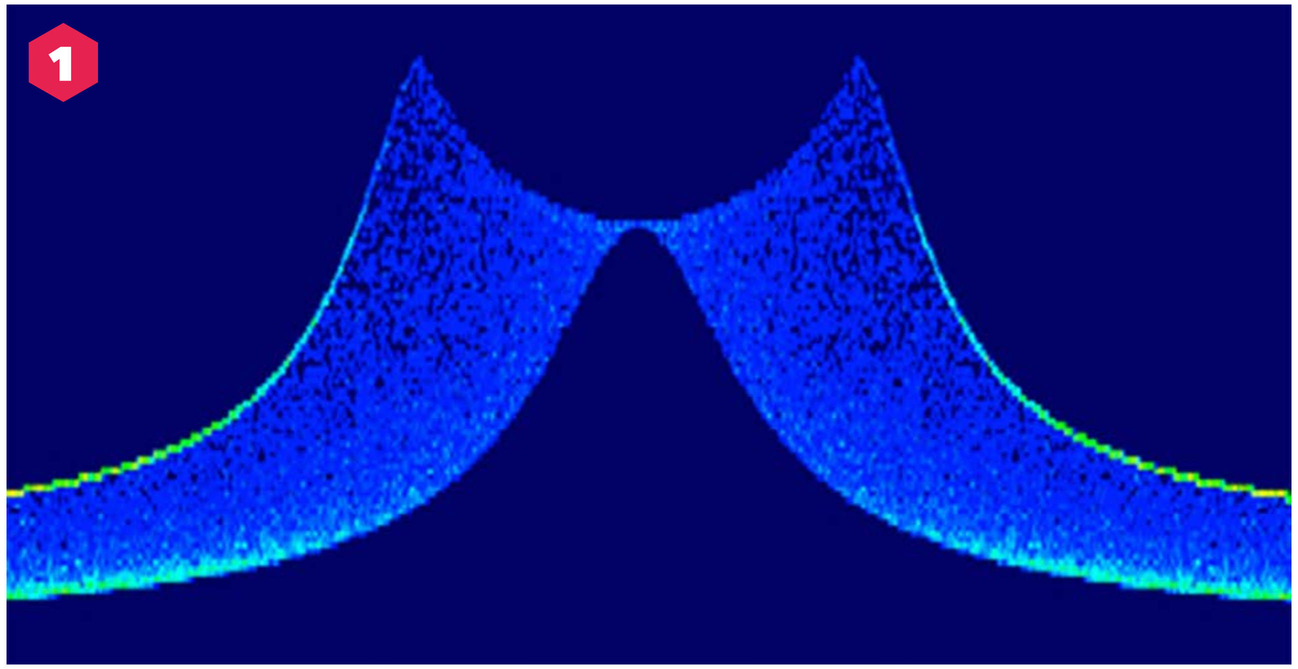
Needless to say, this unusual feature considerably complicates the task of photographing these fish. Without reflection, there can be no image. Nevertheless, marine biologist Karen Osborn, who is at the Smithsonian National Museum of Natural History in Washington DC, took up the challenge, and succeeded in obtaining impressive photographic portraits of the black dragonfish. "Much of my time is devoted to photographing deep-sea fish," she explains, as images are very useful for morphological and behavioural studies. But this time, no matter how I set up the cameras and the lighting, the fish absorbed virtually all of the light. I used four flash units for the pictures that appear in the report. Luckily, we were able to keep two specimens in an aquarium on board our research vessel, and this gave me the time to try out enough lighting configurations to allow me to capture morphological details of the animals."

Osborn used a Canon EOS 5DS R and a 65-mm macro-lens to photograph her uncooperative subjects. "In order to reveal details, you have to use lots of lights and experiment with many different angles and camera settings", she says. Post-processing was restricted to the use of a high-pass filter to reveal extremely fine detail. "It doesn't always work, but I got lucky with these two specimens."

The surface properties that make photographing ultra-black fish a nightmare for photographers could be of interest for technological applications. "In size and form, melanosomes are perfectly designed for maximal extinction of incoming light", says Alexander Davis. "Maybe we can someday make use of this astonishing feature of deep-sea fish for the development of ultra-black materials."

original publication:
Alexander L. Davis et al.
ultra-black camouflage in deep-sea fishes
***Current Biology* 30,** 3470 (2020)
doi.org/10.1016/j.cub.2020.06.044

The gaze into the stars is as old as mankind. Early on, people tried to interpret formations of stars as constellations, to name them after figures from mythology or to read the signs of the zodiac into them. But also the view into the subatomic area, which in the sum only makes up the whole, is fascinating and has become possible thanks to laser research. Let's look like young stargazers at images from the nanocosmos beyond the factual from a purely aesthetic and creative point of view. Science can become art here.

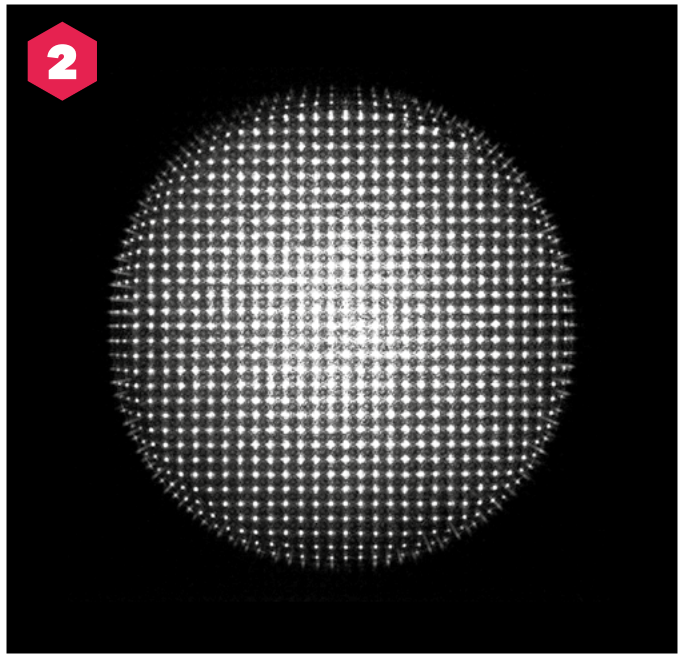


mandalas of laser research

november 16, 2020 // Dr. Veit Ziegelmaier

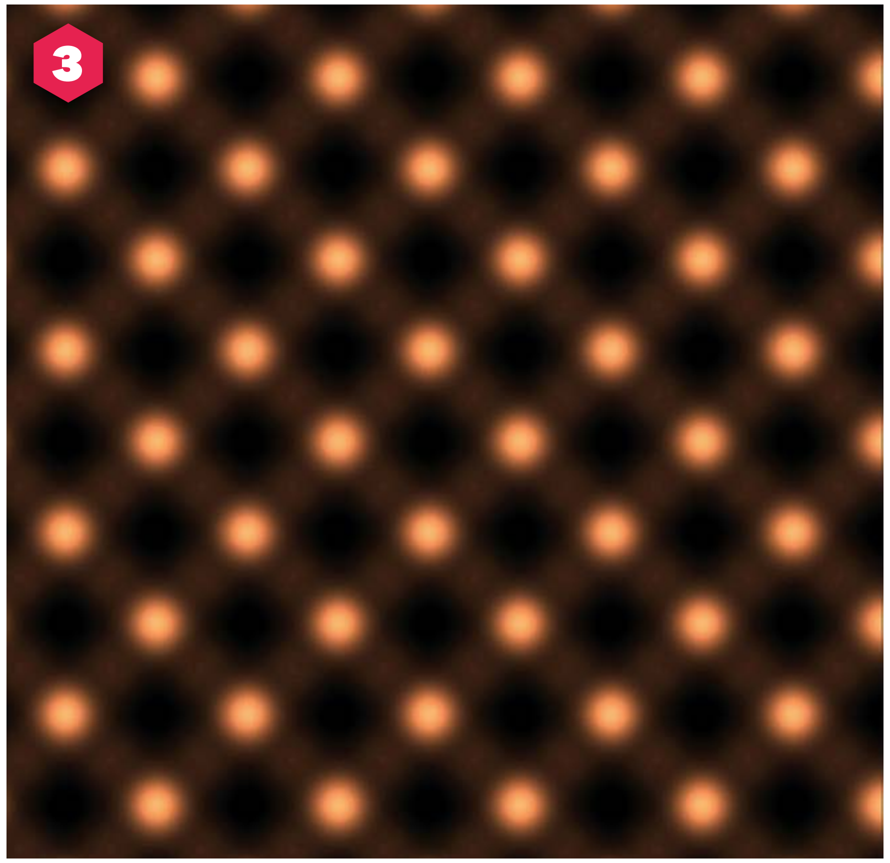
Against a blue-monochrome background, one of the images shows two cornucopia-like structures that are joined together as a pair of wings. The inward and outward swinging shapes consist of a coarse-grained structure that sometimes lets the background shimmer through, captured at the edges by pixels of bright green. The grainy texture may remind of Tibetan mandalas. These are elaborately designed geometric-ornamental patterns of colored grains of sand, which are swept together and deliberately destroyed after their meditative process of creation. In their ephemeral appearance mandalas express the fleetingness of an instantaneous state of existence, just as it is the case with measurements in research after lengthy preparation. Like a picture puzzle, the curves of the form simultaneously create negative forms in their recesses. Thus, below the two buildings, one sees a parabola-like conical section above which a semicircular structure hovers, like the schematic representation of a mountain over which the sun or the moon appear to be standing (image 1).

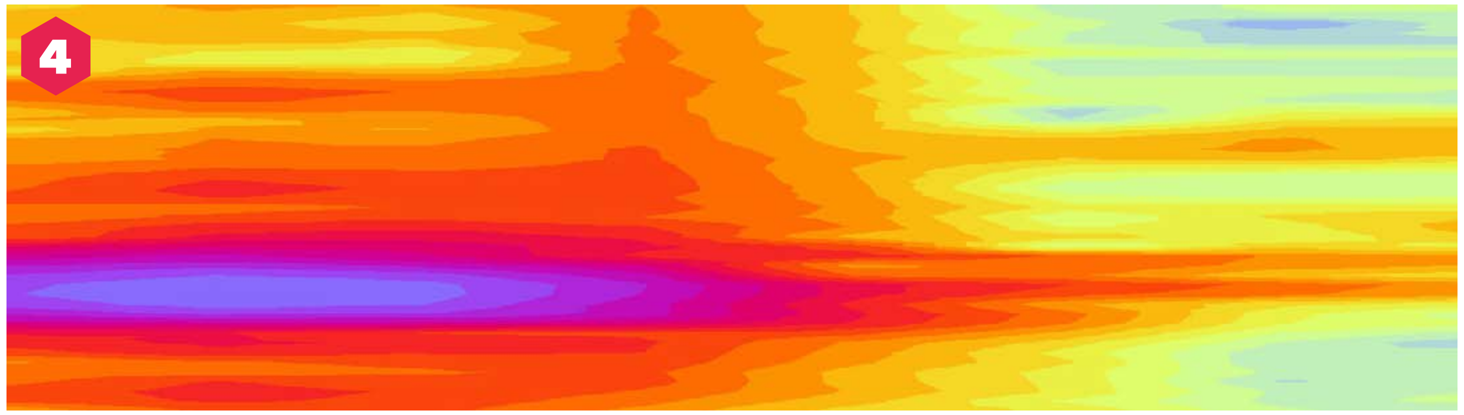
art and science



Another depiction shows a spherical body formed by numerous glittering dots against a black background, which looks like a nail sculpture by the German artist Günther Uecker. Illuminated by a central light source, from a distance the structure resembles a mirrored disco ball. Even in antiquity, the sphere was considered the perfect form, symbol of constant renewal and eternity, also or precisely because perfect symmetry does not prevail in visible nature (image 2).

Another graphic representation of a measurement is reminiscent of a deliberately veiled photograph of diagonally arranged bars with dimmed light bulbs. It shows only a section, because it is trimmed at the edges, and suggests a principally infinite continuation of this geometric pattern. The underlying ordered structure of x-shaped components and diamond-shaped hollow forms, which add up to and condense into ornamental patterns, results in a portrait of perfect harmony and meditative calm in interaction with the lighting mood created, while at the same time providing a mysterious insight into the beauty and nature of material structures (image 3).





A portrait of special abstract quality is the last example. In richly nuanced dissolving color gradients, which cover the visible color spectrum from violet to red, like the chromaticity of a rainbow, a picture emerges, which associatively evokes the pathos of an evening light mood over a vast desert landscape with a suggested water source. The abstract play of colors, which superficially celebrates the intrinsic value of colors detached from the actual object, is all the more impressive because it is the product of an imaging procedure that refers to states of electromagnetic wavelengths and thus, in the true sense of the word, represents concrete phenomena of nature (image 4).

image 1: ***In ultra-short time physics, simulations are an important tool to verify experimental results. This simulation shows what happens when particles, which are separated from a molecule by two time-delayed laser pulses, fly apart. The image shows their kinetic energy as a function of the time interval between the two pulses.***
Picture taken from the publication: K. Schnorr et al. Time-resolved study of ICD in Ne dimers using FEL radiation, Journal of Electron Spectroscopy and Related Phenomena, 30 July 2015

image 2: ***The picture shows a Shack-Hartmann wavefront sensor (consisting of a microlens array and a camera) illuminated by a round laser beam. The distortion around the edges indicates the presence of spherical aberrations.***
Picture: Leonard Doyle

image 3: ***The picture shows the structure of the crystal CaF_2 taken with the picoscopy technique of the team around Prof. Eleftherios Goulielmakis. The bright spots are calcium ions, the dark bridges are florine ions from one of the crystal planes.***
Picture: Goulielmakis-group

image 4: ***The picture shows a spectrogram of vibrating molecules emitting a coherent electric field after being excited by a few-cycle infrared laser pulse.***
Picture: Broadband infrared diagnostics

does James Bond defy physics?

Thorsten Naeser

If you find wrestling with the complexities of ultrafast physics insufficiently challenging, you might consider mulling over the physical plausibility of the stunts featured in James Bond movies. In a book entitled "Shaken, Not Stirred", physics professors Metin Tolan and Joachim Stolze have done just that, and they come to some very surprising conclusions.

It's pretty safe to assume that all of you have, at one time or other, seen a James Bond movie. As aficionados of physics, you have very probably wondered whether or not many of the hero's exploits – fantastic escapes, incredibly involved chases in every conceivable manner of contraptions and contexts, extraterrestrial excursions – are physically feasible.

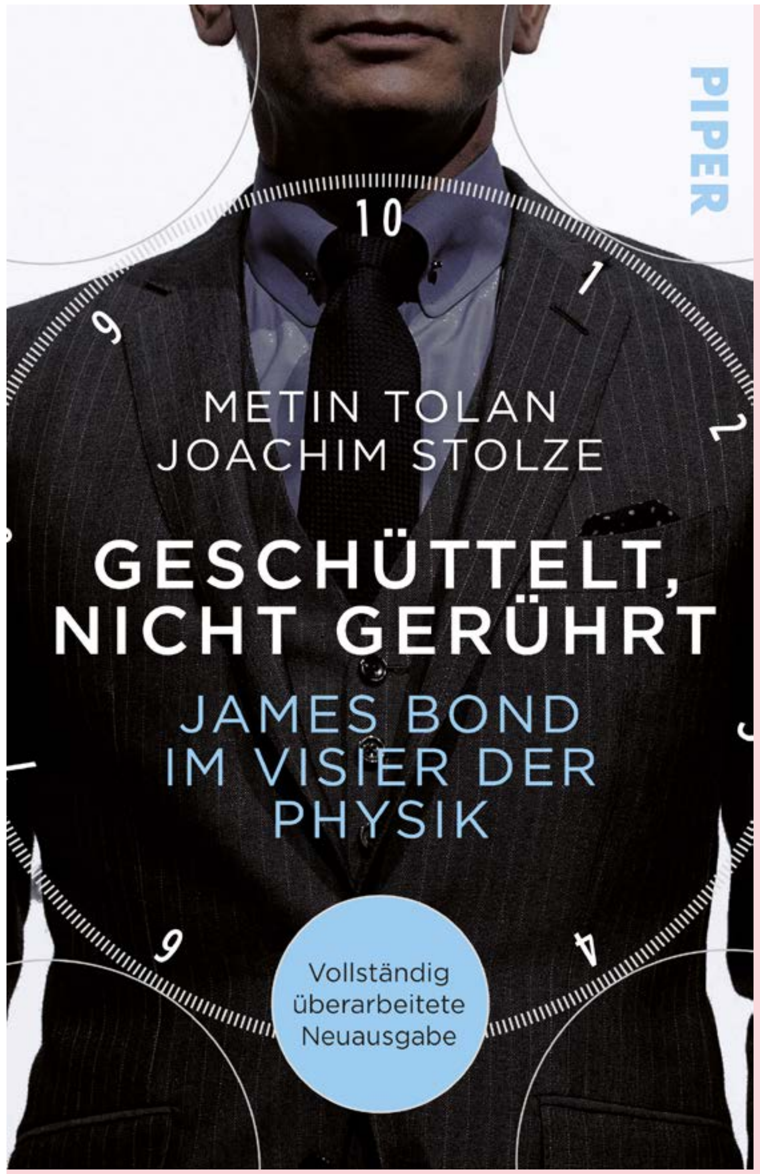
If problems like these have kept you awake at night, and your doodles, diagrams, formulae and calculations have yielded unsatisfactory results, the new edition of "Shaken, Not Stirred! James Bond in the Spotlight of Physics" by Metin Tolan and Joachim Stolze (see on page 34) should help you to sleep soundly in future. The authors have written an absorbing and witty book in which they assess, from a physical perspective, the feasibility of the most exciting scenes in the 25 films that currently make up 007's cinematic canon.

One of the most spectacular scenes in the series occurs in the film GoldenEye. As so often before, Bond is desperately fleeing from his pursuers. He reaches the cliff edge, and jumps off as a small plane (which happens to be pilotless) comes into view. After a free fall that lasts for 26 seconds, he is able to 'catch his flight', board the plane via the open door of the cockpit, take the controls, avert the imminent crash and live to fight another day. The episode raises several questions. Could Bond possibly catch up with the diving plane? According to Tolan und Stolze's calculations, the answer is 'in principle, yes' – provided that the cliff is at least 2600 meters high and Bond is able to drastically reduce his air resistance relative to that of the aeroplane. The snag here is that the scene is set in the vicinity of Archangelsk, and the sea-cliffs in the region are nowhere near high enough. But that's a minor detail in comparison to the next step – boarding the plane. The authors reckon that, in free fall, Bond is travelling at a speed of 85 km/h relative to the aircraft at this point. In other words, their cold-blooded calculations demonstrate that he could not survive physical contact with any part of the alleged escape vehicle.

Scenes from more recent films in the series, with Daniel Craig in the leading role, are also subjected to analysis. One such example is a sequence in Casino Royale in which Bond seems to possess indestructible shinbones. This time Bond is chasing the bad guy, Mollaka, on a building site in the fictitious State of Nambutu, and jumps from a height of around 6 meters. This implies that, upon impact, his body must absorb a force equivalent to 10,000 newtons, i.e. one tonne, within the space of one-tenth of a second.

This sounds like a very nasty crunch. But actually it shouldn't a big problem – for the shinbones at least. Physicists at the Massachusetts Institute of Technology in Cambridge have suggested that each shinbone can in principle absorb an instantaneous impact of up to 50,000 newtons without breaking. With 100,000 newtons to play with, these bones should readily withstand the impact of a 6-m jump. But Tolan und Stolze then spoil the party by pointing out that other, equally vital, body parts are considerably less resilient. The message is clear: Don't try this at home!

The authors also tackle the most important problem of all: Why does Bond insist that martinis should be shaken, never stirred? The answer is complex, both from the point of view of the 'nutritional value' of the concoction and in terms of the physics involved. According to the analysis presented in the book, Bond's preference suggests that he is either a health fanatic (his job is, after all, quite stressful) or a gourmet. But that still leaves lots of room for further speculation – which you may wish to indulge in with your colleagues during the next break for liquid refreshments in the laser lab.



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ATTOWORLD is a home for synergies across institutions and borders. By uniting the teams of the MPQ Laboratory for Attosecond Physics, the LMU Chair of Experimental Physics – Laser Physics, and of the Centre for Advanced Laser Applications (CALA) and closely collaborating with researchers from the LMU Center for Molecular Fingerprinting (CMF), clinics of the LMU and the Helmholtz Zentrum München in the Lasers for Life (L4L) Collaboration.

We pursue – supported by UltraFast Innovations (UFI) – transfer of our technological developments to interested research groups all over the world, exemplified by the creation of the Attosecond Science Laboratory at King Saud University, the first of its kind in the Arabic World. We feel obliged to disseminate the knowledge we acquire and are glad to share our findings, provide advice and technical assistance to researchers of any public institution of the world committed to advancing science, technology or medicine. Do get in touch if you are interested!

Our Logo displays the first light wave ever captured, in this case a few-cycle wave of red laser light. It was recorded with attosecond flashes of light, establishing attosecond metrology, the fastest metrology on Earth.

Picture: Thorsten Naeser

new laser source for attosecond experiments

july 16, 2020 // Thorsten Naeser

In the laboratories of the Max-Planck-Institute of Quantum Optics the team around Prof. Matthias Kling and Dr. Thomas Nubbemeyer has made the first steps towards a new high-power light source for few-cycle femtosecond pulses. Based on Optical Parametric Chirped Pulse Amplification (OPCPA) and on the well-established and highly reliable Thin-Disk Laser technology, the new laser system will provide CEP-stable light pulses in the visible as well as the mid-infrared spectral range with several millijoules of pulse energy.

Upon completion this laser system will be used for operating the Attosecond beamlines ATTO-1 and ATTO-2 with a significantly higher pulse repetition rate of 10.000 shots per second. Currently the main high-power laser amplifier is being set up by our scientists. This amplifier, as it builds upon the Thin-Disk laser principle, will be able to provide more than 1 Kilowatt of average output power which in turn is going to be be used for pumping the two OPCPA channels in the visible and mid-IR range.