the newsletter of attoworld

volume 2 (2021)

pulse

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

We have all come up against them – the challenges that test us to the limit – where success seems highly unlikely, if not wholly unattainable. But instead of throwing in the towel in such situations, it's a good idea to step back and take stock. For centuries, humanity's desire to know has proven again and again that what at first seemed impossible is in fact feasible. The essence of science is its ability to find ways of extending the limits of the possible.

A willingness to set ambitious goals, explore unorthodox ideas and ignore conventions can serve as a powerful motivator. It can open up unexpected routes to new insights, even when the final outcome remains in doubt. The history of the Natural Sciences has repeatedly demonstrated that obstacles can be overcome, provided one has the required tenacity and open mindedness.

Whether one regards a given task as 'impossible' or 'perhaps feasible' is often a matter of imagination. If one opts for the latter alternative, it helps to think outside the box, question accepted models, reconsider the fundamentals and seek unconventional solutions that no one else has hit upon.

We take pride in the fact that, as members of the ATTOWORLD team, we have the opportunity to probe the limits of the possible. How can we control the behaviour of light with even greater precision? How far can we push the limits of ultrashort-pulse spectroscopy in practice? What sorts of applications might such advances make possible – which may now seem illusory, but might well have a significant impact on our future? In their contribution to this issue of PULSE, Ioachim Pupeza, Alexander Weigel and Kafai Mak provide insights into their work at the forefront of laser physics.

In this spirit, we urge you to nurture your sense of wonder and thirst for knowledge. Have the daring to make a difference in your quest to discover what lies beyond the current frontiers of laser physics, and help to shape our common future.

Prof. Ferenc Krausz
Director MPQ
Chair of Experimental Physics LMU

Thorsten Naeser
Head of Public Relations

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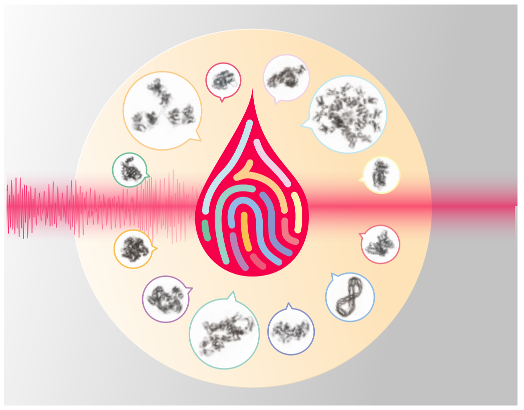
Researchers at Attoworld are exploring novel routes to reach the ultimate limits of broadband infrared spectroscopy. These developments grant deeper insight into light-matter interactions, advancing our understanding of fundamental processes in nature, and spawn spectroscopic technologies that expedite the early detection of diseases via quantitative, multivariate molecular probing of biological samples.



research@attoworld

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Thousands of researchers are seeking ways to capture human health within a simple probe. Why? Every person is unique – in the personality as well as in terms of health.

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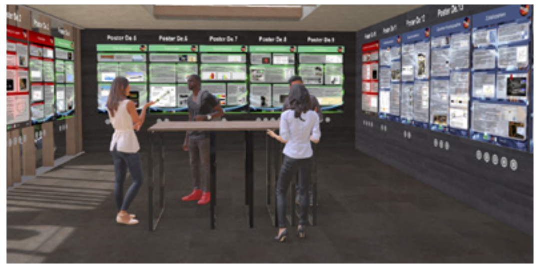
Meet the members of the Lasers4Life study team @ the LMU medical center.

photonworld.de

36 generating oxygen on mars

An instrument on board NASA's Mars rover "Perseverance" has, for the first time, used atmospheric carbon dioxide to synthesize molecular oxygen on the Red Planet. This represents a significant step on the way to interplanetary travel.



PhotonLab

38 the new world of learning

In the not-so-distant future, learning in a Student Lab is likely to include a mixture of interactive digital content and table-top experiments at home.

"we will see many devices based on attosecond technology"

[André Staudte]

july 05, 2020 // Thorsten Naeser

The attoworld team has a long-standing successful collaboration with the physicists from the Joint Attosecond Science Lab of the National Research Council of Canada (NRC) and the University of Ottawa (Canada). At the very beginning there was the production of the first isolated attosecond light flash in the team of Prof. Ferenc Krausz in a collaboration with Prof. Paul Corkum from the NRC in 2001. Now the next generation of ultrafast physicists is waiting with exciting research in attosecond physics. One of them is Dr. André Staudte, who works closely with Prof. Matthias Kling at Ludwig-Maximilians-Universität München (LMU Munich). André received his PhD in physics from Goethe University Frankfurt am Main in 2005. He is now head of the Attoscience group at NRC at an adjunct professor at the Department of Physics at the University of Ottawa. In this interview, he talks about his work, what excites him most about the world of attoscience, and what life is like in Canada.

Could you give us a brief overview of the research in your group?

In a nutshell our group does fundamental research on how matter interacts with intense, ultra-short light pulses. Matter in this context means atoms, molecules and condensed matter. We aim to find new ways to manipulate, image, and detect the constituents of matter. For this purpose we use all the tools that attoscience has to offer, from reaction microscopy, to transient absorption and high harmonic generation to new and custom-designed optical fields. The custom design of intense laser fields is a research topic in itself which we also pursue.

While we do primarily fundamental research, which has an application horizon of ten years or longer, we are also always looking for immediate applications. One of these applications is the imaging of electric fields in a silicon chip. Others are femtosecond laser-based imaging mass spectrometry, femtosecond pulse characterization techniques, and efficient solid-state high harmonic generation, with the aim of integrated XUV optics.

What phenomena excite you most in ultrafast physics?

Today we have incredible control over the optical fields created by lasers, both in time and in space. We can control the color, polarization and duration of laser pulses. We can combine nearly arbitrary frequencies and pulse durations. We can control the spatial properties of the light within the laser beam. For example we can create beams with a hole in the middle, beams with a spatially varying polarization vector, or beams whose wave front looks like a corkscrew in space.

Where do you see attosecond physics in ten years?

Over the past 20 years, attosecond physics has created a lot of technology. Attosecond technology, which sometimes does and sometimes does not provide actual attosecond time resolution. While measuring processes with attosecond resolution continues to be the pinnacle of the technological development, I believe attosecond physics will also continue to radiate into neighboring areas of research, such as chemistry, condensed matter physics, metrology, and even biology through its technology. In view of the explosion of solid state attosecond science in the last five years, I believe that in ten years we will see many more devices based on attosecond technology. On the fundamental side things move slower, but it is probably not too bold to assume that in ten years the transition to optical and UV atomic clocks will have been completed. In ten years also X-ray

free-electron-lasers could be available.

Are there opportunities for graduates to do a PhD thesis or work as a postdoc with you?

Thank you for asking. Yes, I am always looking for students or postdoctoral researchers from Germany. German universities produce some of the best young researchers, and therefore they are highly in demand. We have many interesting projects to work on and we encourage our students and postdocs to branch out and collaborate with internal and external teams.

You are originally from Frankfurt. What brought you to Canada?

I came with my young family to Ottawa as postdoc. After graduating we had looked for a postdoctoral position. In the end my wife and I decided to accept an offer in Ottawa at the National Research Council of Canada (NRC) with Paul Corkum, since we wanted to go abroad for a few years. The plan was always to return to Germany, but after 4 years as a postdoc I was offered a permanent position at the NRC, and we decided to stay.

What is life like in Canada?

Life in Ottawa is different to Frankfurt but not dramatically. In my experience, here life is a little more relaxed than in Germany. Although a relatively big city by the number of its inhabitants it feels much smaller. Part of this is, that Ottawa is relatively isolated from the other large urban centres. But another part is, that we just have more space. The stranger on the street is generally much friendlier in Ottawa than, say, Frankfurt. Mind you, I have often heard other Canadians speaking of Ottawans as uptight and unfriendly.

We can get many if not most of the things we are missing from home. There a butchers, bakers, and specialty stores that carry many ingredients we know from Germany. Ottawa even has a German language school on Saturdays, from kindergarten to high school, and really is a meeting point for the German-speaking community.

The weather, of course I have to mention the weather. The weather is special here. The winter is cold, white and bright. The ground is covered with snow without a break from December to March, sometimes April. We have great cross country skiing starting inside the city. Downhill skiing is not as great as the Alps, and it is also much colder on the hill. The summers are hot and humid, and the city is visibly empty since people spend the summer at their cottages by the countless lakes. For a North-American city, Ottawa also has a very well developed network of recreational bike paths of several 100km.

More informations about André Staudte:
science.uottawa.ca/physics/people/staudte-andre

“we will see an enormous impact of short-pulse technology”

[Elisabeth Bothschafter]

june 8, 2021 // Thorsten Naeser

After having completed her PhD, our former colleague Elisabeth Bothschafter left the attoworld team for Switzerland, where she worked for two years as a postdoc at the Paul Scherrer Institute. Now she's back in Munich and has moved to industry. Here she reviews her experiences over the past few years.

After completing your doctorate at the TU Munich and as a member of the attoworld team, you spent two years at the Paul Scherrer Institute in Switzerland. What were the factors that influenced this decision?

I joined the PSI as a PSI Fellow funded by the European Commission's Marie-Curie Actions programme because it was a great opportunity to further advance my knowledge of the behaviour of materials on ultrashort time scales, and it gave me the chance to work in larger international research teams. Joining Urs Staub's group at the PSI also permitted me to participate in and conduct unique experiments at other large-scale facilities that provide ultrashort X-ray pulses, such as BESSY in Berlin, the LCLS in Stanford, USA, the SACLA in Osaka, Japan, and the Diamond Light Source in Didcot in the UK.

Which area did you focus on in your research at PSI?

Using a combination of strong femtosecond laser pulses and femtosecond X-ray pulses, I studied the exciting dynamics of strongly correlated electron and lattice dynamics. I focused on the investigation of a multiferroic material, $TbMnO_3$, where I studied the dynamics of the melting of magnetic order. Another very exciting experiment I was involved in, together with a team from the ETH Zurich, PSI and the LCLS, was an investigation of the ultrafast Einstein-de Haas effect, in which the effect of demagnetization was revealed by the transfer of angular momentum from the spin system to the lattice within less than a picosecond.

How was life in Switzerland?

I travelled a lot during my time at PSI, both for work as well as privately, because my husband was working in the Netherlands while I was working in Switzerland. So I went back and forth about twice a month. But generally speaking, I really liked living in Switzerland. The scenery is beautiful and the food is great. The regular cheese fondue with the team, with a big pot of cheese melted over an open fire in the middle of the woods, was a real highlight. I lived in a small village close to PSI but regularly visited Baden and Zurich, which are close by. The people were very welcoming and relaxed, even at the local tax office. – And I learned that things can be done even more thoroughly and in a more organized fashion than in Germany – starting with the local recycling area, where cardboard is only accepted when folded neatly into A4 shape, up to the professional cleaning of the underside of your car before the mandatory technical inspection.

Now you're back in Munich and working in industry at Instrument Systems Optische Messtechnik GmbH. Why did you switch from research to industry?

After my postdoc stay at PSI I came back to Germany with our first son, and after my maternity leave, I was looking for new opportunities. I had discovered during my time as a project coordinator at MPQ/LMU, and while working with different teams at PSI, that I really enjoy working with people and leading teams with a technical focus. So the position as Head of Metrology in the R&D department at Instrument Systems was the perfect combination of technical challenge and opportunity for personal growth. I could still do research in an industrial setting, but also learned more about managing a group and fulfilling internal as well as external expectations. In comparison to an academic job, there is more external motivation, aka clients, and for me personally it is more rewarding and diversified.

What are your main tasks at Instrument Systems?

I'm a group leader in the R&D department, which means that I'm responsible for about 10-12 people, both engineers and project leaders. Together with the project leaders, I manage the tasks of my team in the different development projects, and align the project goals with those of the company in terms of resources and client expectations. Together with my fellow group leaders and product management, I coordinate the development of new measurement solutions for our clients and the market. Recently I switched from metrology, which involved the development of calibration and measurement solutions to measure light with the highest accuracy, to developing solutions for camera-based display testing. Leading a new team and now developing the real measurement hardware are formidable new challenges.

As a female physicist, you're working in a male-dominated industry. Would you encourage other young women to do the same?

I think everyone, no matter which gender or identity, should find something motivating, inspiring and challenging to pursue as a career. I truly believe that humans need positive challenges in their lives, in order to thrive and make the best of what is in them. And ideally they should do so in constant interaction with other people, asking questions and not being satisfied with the status quo. I found this in physics and in my current job.

Laser technology is thought to have enormous potential. You studied and did your doctorate in ultrashort laser-pulse physics. What do you think will be possible with these techniques in about ten years?

I think both in communications and in sensing, we will see an enormous impact of short-pulse technology. With the miniaturization and power of pulsed, vertical surface-emitting lasers (VCSELS) at various wavelengths, we will see numerous new inventions and applications, be it in self-driving cars or holographic video conferencing. Solid-state short-pulse systems will enable further gains in communication bandwidth and new applications in our everyday lives.

“laser shine brighter than ever before”

[Tom Metzger]

march 19, 2021 // Thorsten Naeser

Our former colleague Tom Metzger has been appointed managing director of TRUMPF Scientific Lasers in Unterföring, near Munich. From 2002 to 2012 he was a PhD student and postdoc in the attoworld-team. Then he was drawn to the economy. There he started as Chief Technology Officer. In the interview, he gives information about his career, what fascinates him in physics and where laser technology will look in the future.

How did you get into laser physics? And what fascinates you about this discipline?

Light has always been fascinating to me. The large variety of light in nature from sparkling stars until Alpine glow is almost magic. The main subject laser material processing of my mechanical engineering study dragged me right into laser development. An internship in a laser company in the US confirmed my decision to keep on working in the field of laser development.

You went from research to business in 2012. What made you do it?

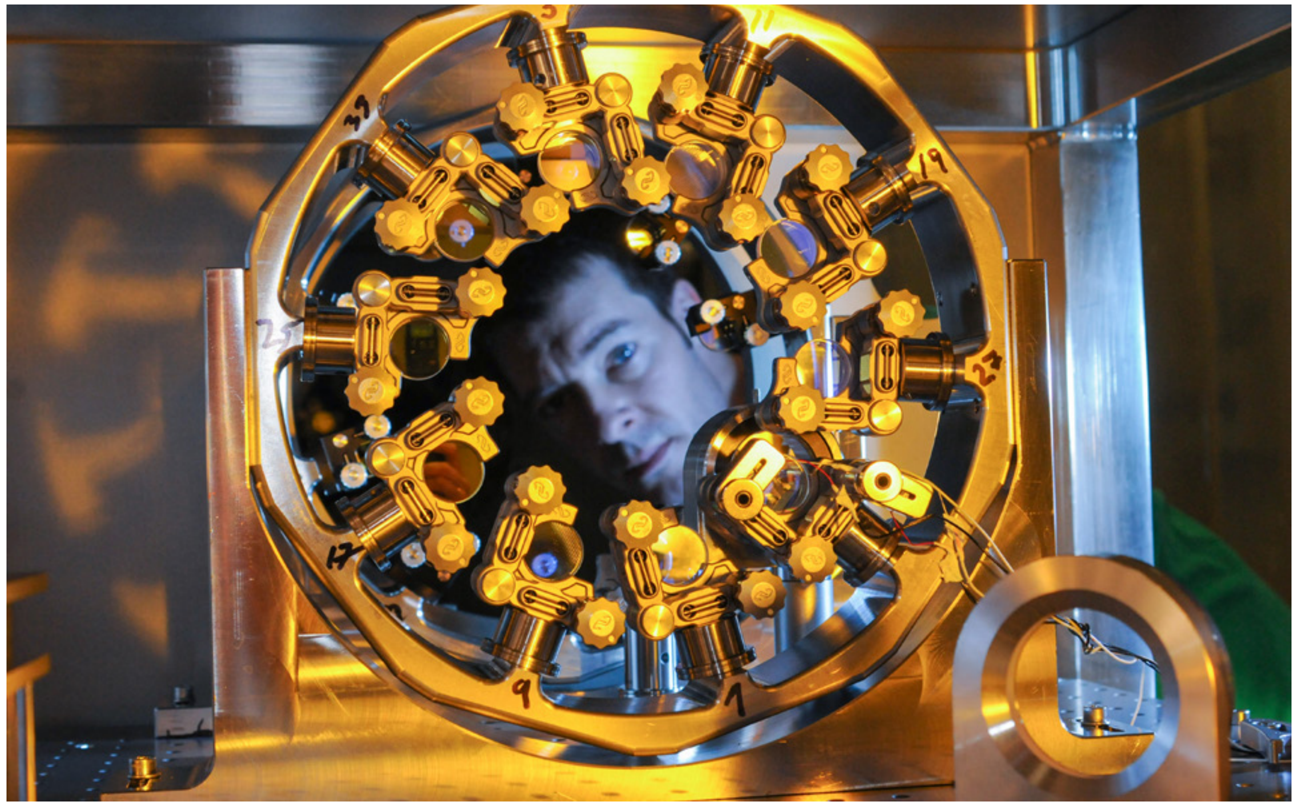
During my time in the laboratory for attosecond physics I had already a long and very productive cooperation with TRUMPF Laser GmbH and was in the lucky situation to use industrial thin-disk laser components for building my laser amplifiers. In 2012 I had the unique opportunity to start in the new incorporated subsidiary TRUMPF Scientific Lasers as Chief Technology Officer. It was like a dream come true, founding a company based on your research and being able to shape it to your ideas and wishes was a great opportunity I had to jump at.

You are currently responsible for the development of thin-disk lasers. What do disc lasers have that others don’t?

At TRUMPF Scientific Lasers I am responsible for the development of a very special type of thin-disk lasers: Ultrafast amplifiers with high pulse energies up to the Joule level and high average powers in the multi-kW regime at the same time. Thin-disk lasers are just great: The efficient one-dimensional heat removal and the small longitudinal extension of the gain medium allow the thin-disk geometry exceptional scaling performance both in terms of energy and average power. Additionally, thin-disk lasers are nowadays commodity, have reached by far than others an incredible degree of industrialization, robustness, stability and repeatability and allow us to develop at TRUMPF Scientific Lasers beautiful lasers with highest stability and reliability.

You worked on disk lasers while you were on the attoworld-team. How have they developed since 2012?

Within the lab team we were a few great and enthusiastic colleagues working on thin-disk lasers, everything we tried was new to us. Today with more than 15 years of experience in this field and a large team working and concentrating only on ultrafast thin-disk amplifiers, the development and progress is tremendous. It's amazing to see what the team is doing and achieves. I couldn't have imagined in my wildest dreams that we would make progress so quickly. In a few years we were able to increase the pulse energy and the average power of this lasers by almost two orders of magnitude.



Where do you see the best areas of application for disc lasers?

Thin-disk laser technology is very versatile. Thin-disk laser systems cover an extremely large bandwidth of parameters and it would be presumptuous by me to say that they have a “best area of application”. From drilling the finest holes no wider than a hair, to welding panels in ship building the variety of their applications is just incredibly large. I hope we see thin-disk lasers soon also in the field of secondary sources such as EUV generation, X-ray beams and maybe even neutron sources discovering new fields of applications.

What is the difference between your work today and when you were a young researcher?

As a young researcher I spent most of the time in the lab working in a very small team or even alone on a laser. Today I see the lab only occasionally. The strategic and operational responsibility for TRUMPF Scientific Lasers with a team of 20 researchers working on various customer projects shifted the focus clearly towards administrative activities.

What does your current job look like and what appeals to you about it?

If you are a hands-on experimentalist, the description of an administrative job sounds probably shockingly boring. But in fact, at TRUMPF Scientific Lasers, it is not, and the range of different tasks really thrills me every day. Working with the amazing team at TRUMPF Scientific Lasers on new lasers and developments is fascinating and a great honor. The direct and close contact to our customers brings us together with fascinating researchers and their exciting experiments and challenges us everyday to find working solutions.

If you look at the development of laser technology, could you make a prediction for us what lasers can do in 10 years?

Lasers will certainly conquer many other fields of application and I am probably not allowed to tell you much about what we will be working on in the future. But one thing is for sure, they will shine brighter than ever before.

feature

approaching the ultimate limits of infrared spectroscopy

november 15, 2020 // Dr. Ioachim Pupeza, Dr. Alexander Weigel & Dr. Kafai Mak

Researchers at Attoworld are exploring novel routes to reach the ultimate limits of broadband infrared spectroscopy. These developments grant deeper insight into light-matter interactions, advancing our understanding of fundamental processes in nature, and spawn spectroscopic technologies that expedite the early detection of diseases via quantitative, multivariate molecular probing of biological samples.

Attoworld scientists preparing the 1st-generation FRS instrument for measurements.
Picture: Thorsten Naeser

The origins of the term *spectroscopy* can be traced back to the second half of the 17th century, when Sir Isaac Newton observed that a prism can disperse sunrays into a *spectrum* of beams with different colors. The common perception that optical spectroscopy evaluates color- or (frequency-)specific *intensities* in a static (that is, time-averaged) manner, prevailed for three centuries – until several decades ago, when laser *modelocking* provided a new means of confining broad optical spectra to ultrashort flashes of light. Nowadays, modelocked oscillators routinely produce femtosecond pulses throughout the visible and near-infrared spectral ranges. Their brevity makes it possible to trace ultrafast phenomena in matter as they unfold on their native time scales, such as (bio-)chemical reactions or lattice dynamics in solids.

While the mechanisms of laser modelocking ensure a recurring *temporal intensity envelope* of ultrashort pulses, the most sophisticated degree of control over light came about in the 1990s with the additional ability to control the *timing of the individual oscillations* of the optical electric field with respect to its intensity envelope. This, in turn, allows the manipulation of dynamics in matter which are intimately linked to the electric field of light via (susceptible) local charge distribution. Thanks to their outstanding temporal coherence properties, femtosecond-laser architectures based on optical-phase-stabilized pulses derived from modelocked lasers have revolutionized our perception of *spectroscopy* and provide real-time access to the oscillatory nature of light.

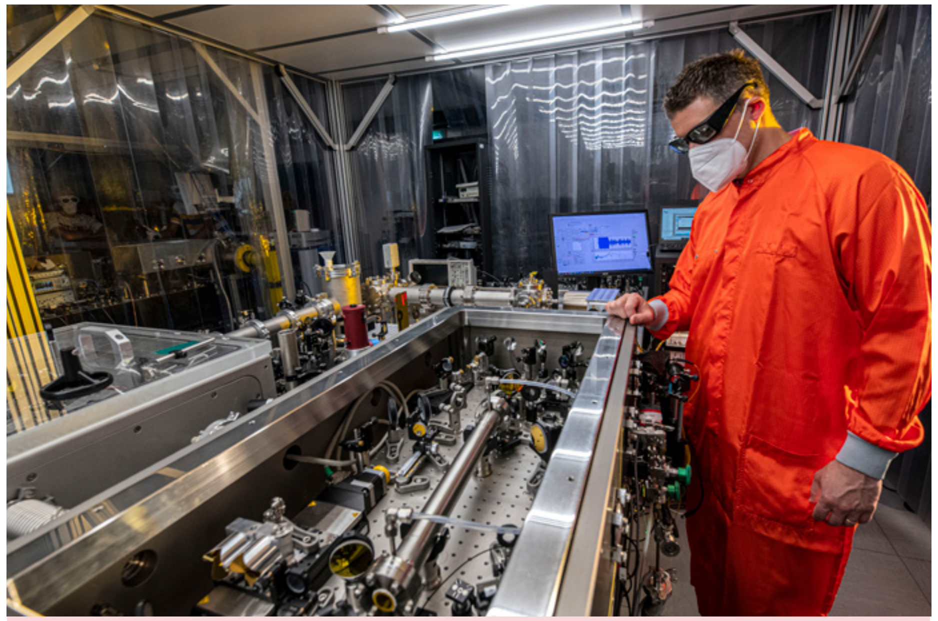
At Attoworld, the generation, measurement and application of intense optical pulses as short, or shorter than, a single oscillation of the electric field has a long tradition. In recent years, research has focused on high-sensitivity electric-field-resolved spectroscopy (FRS) in the *infrared (IR) spectral region.* In biological molecules – which constitute the building blocks of life – the interaction with light in this spectral range induces characteristic internal vibrations with a particularly high efficiency. In contrast to other analytical techniques, broadband vibrational spectroscopy delivers a signal consisting of coherent contributions from *all* constituent molecular vibrations, thus forming a sample *fingerprint* that is highly specific and sensitive to minuscule changes of the sample composition.

Teams affiliated with three institutions forming the Attoworld are closely working together to develop IR spectroscopy toward the fundamental limitations set by the nature of light. These emerging spectroscopic tools are advancing our understanding of fundamental physical processes, as well as the realization of the vision of establishing molecular vibrational fingerprinting as a standard, high-throughput screening technique for health monitoring and early disease diagnostics.

Impulsively exciting molecular vibrations

The temporal confinement of broadband IR radiation to pulses comprising merely a few oscillations of the electric field of light lends itself to the impulsive excitation of molecular vibrations in complex samples, see also Fig. 1. For the brief time span of the excitation pulse, the oscillating electric field of light modulates the inter-atomic distances in the sample by acting on the molecular electric dipole moments. In the wake of the few-cycle excitation, the molecular vibrations continue, each vibrating dipole emitting radiation at its specific frequency. The contributions of molecular vibrations of the same type add up coherently, forming a highly-specific sample response to the ultrashort excitation. Exciting the molecular vibrations with a short pulse allows to separate the coherently emitted long-living sample response from the excitation. This differs from time-integrating spectroscopies, such as Fourier-transform spectroscopy, in that the excitation impinges on the detectors only during a comparatively ultrashort portion of the sample response. Important advantages of FRS regarding robustness against excitation noise (filtered out by the aforementioned temporal separation) and an increased range of detectable concentrations were recently demonstrated with our 1st-generation instrument (Pupeza et al., ***Nature*** 2020). The requirement of an ultrashort, fast-decaying excitation is tantamount to a broad bandwidth of the excitation. In turn, the latter provides access to a wide range of molecular vibrations. Thus, both the time-domain and the frequency-domain aspects of FRS set the course for developing waveform-stable IR sources with as broadband and short pulses as possible. While the 1st-generation instrument covered only ~10% of the IR spectral region relevant for vibrational fingerprinting, recent developments at Attoworld, employing 2-µm femtosecond frontends, have demonstrated the feasibility of covering the entire spectral range of interest with single-cycle pulses.

The time-domain character of molecular fingerprinting with FRS both requires and affords a new perspective on the concept of molecular fingerprints. Scientists at Attoworld are currently developing standardized protocols for recording *impulsively-interrogated electric-field molecular fingerprints* (EMFs), based on the basic concept of causality (invited paper, in preparation for Nature Protocols).



FRS in the gas phase. The excellent sensitivity of FRS enabled limits of detection in the ppb range at an interaction length of only 45 cm. The gas cell is the metal tube visible on the picture.
Picture: Thorsten Naeser

Optical waveforms with zeptosecond reproducibility

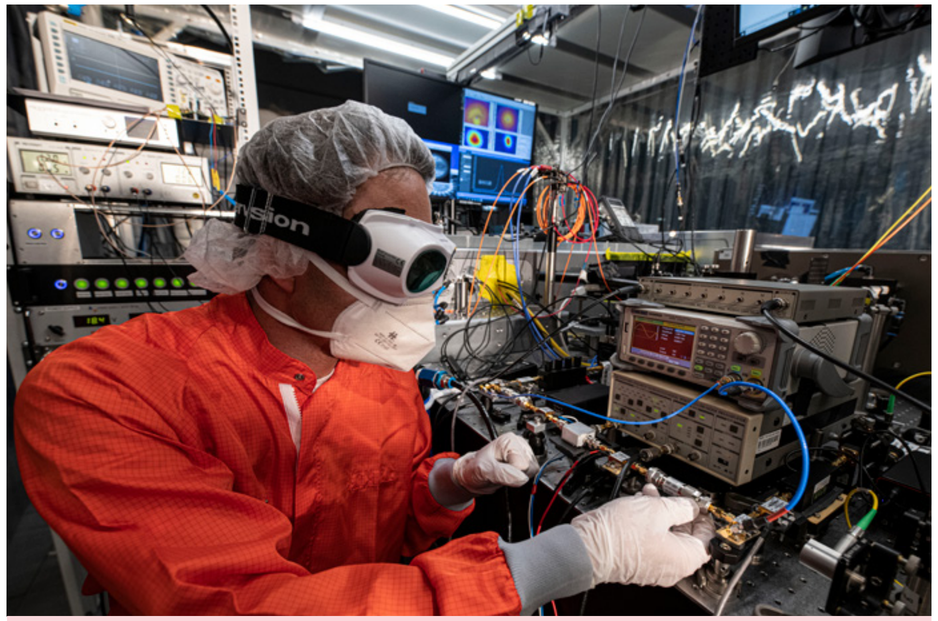
The first key ingredient for recording high-quality EMFs of (complex) molecular samples is the reproducibility of the optical waveform exciting the molecular vibrations. Employing lowest-order (that is, most efficient) nonlinear processes both for the generation of optical-phase-stable IR pulses and for the detection of their fields, our team has recently demonstrated optical waveforms with world-record reproducibility. In a measurement time of ~1 minute, the individual zero crossings of these waveforms can be located in time with a precision of roughly 100 zeptoseconds, see also Fig. 1. For comparison, this is more than a thousand times less than the 150 attoseconds

it takes for an electron to orbit around a proton according to Bohr's model of the hydrogen atom.

Numerical modeling performed in our team traced this residual jitter back to the technical noise of our 1st-generation modelocked laser. Recent developments of our 2nd-generation femtosecond frontends, based on Cr:ZnS 2-µm modelocked oscillators, have provided output pulses exhibiting tantalizingly low noise. If this can be further lowered towards the shot-noise limit inherent to the photon nature of light, it could improve IR waveform stability toward the fundamental physical limit and enable FRS with single-digit-zeptosecond precision.

Careful listening to molecular vibrations

The electric field of light emanating from a molecular sample upon a waveform-stable, impulsive excitation, entails the full macroscopic information content acquirable via linear optical spectroscopy. However, its detection on the level of the individual electric-field oscillations is challenging because IR light oscillates about a thousand times faster (~10 femtoseconds) than the fastest electronics (~10 picoseconds). Sampling these optical waves fundamentally requires a shorter event, constituting a temporal *gate*, through which only a fraction of the stream of photons making up the entire EMF can enter toward the detector, see blue pulse in Fig. 1.



Precision time-domain measurements require advanced optical and electronic techniques. With those, we performed – for the first time – IR spectroscopy with two separate modelocked oscillators, with sub-attosecond precision. Picture: Thorsten Naeser

Once more, the confinement of light to very short flashes provides the key ingredient. The gating mechanism we employ relies on an optical nonlinear mixing process in which the IR wave to be sampled interacts with the gate flash within a nonlinear crystal. Such nonlinear effects inherently bring about a bandwidth-versus-efficiency trade-off, and require high intensities. The latter, in turn, are limited by damage in the nonlinear medium.

In collaborations with Prof. Alfred Leitenstorfer at the University of Konstanz and Prof. Jens Limpert at the University of Jena, world-leading experts in fiber lasers, we have devised a new regime for optical-field sampling, employing short-wave mid-IR pulses as short as 10 fs to sample octave-spanning EMF waves with an efficiency exceeding 1% of all the photons. Expressed in terms of molecular concentration – which scales with the electric field strength – the demonstrated detection sensitivity is merely 10 times away from the ultimate quantum limit.

feature

This sensitivity exceeds by far that of previous optical-field sampling techniques and, together with the record average powers of our 2nd-generation IR sources, they provide quantitative access to unprecedently large molecular concentration ranges.

Molecular fingerprinting with unprecedented sensitivity and detectable range of concentrations

In a first proof-of-principle with a 2nd-generation FRS instrument benefitting from record-high excitation powers and electric-field detection efficiency, we have recently demonstrated the capability of quantitatively recording EMFs from multi-species gas-phase samples spanning a concentration range of close to 8 orders of magnitude. Notably, this performance was achieved with a broadband IR coverage of more than an octave, and at a sample interaction pathlength of only 45 cm. With pathlength enhancement technologies such as multi-pass cells or enhancement cavities, the detection of concentrations spanning 10 orders of magnitude seems within reach.
In terms of detection sensitivity and accessible concentration range, these performance parameters vastly exceed the capabilities of other devices – such as time-integrating optical spectrometers and gas chromatography-mass spectrometry – for the simultaneous detection of multiple species. In addition, they point to the capability of FRS to – in principle – record molecular signals over the entire physiologically-relevant concentration range of molecules in biological samples.

While these proofs of principle attest to the conceptual feasibility of IR spectroscopy with FRS close to the ultimate limits set by the quantum nature of light, our prototypical instruments are rather bulky and expensive. Scientists in the CMF team are working on the next generation of FRS instruments based on the Cr:ZnS femtosecond technology developed at Attoworld, with the aim of combining the spectral coverage of the entire molecular fingerprint region with close-to quantum-limited EMF detection sensitivity, in compact, robust and cost-efficient instruments.

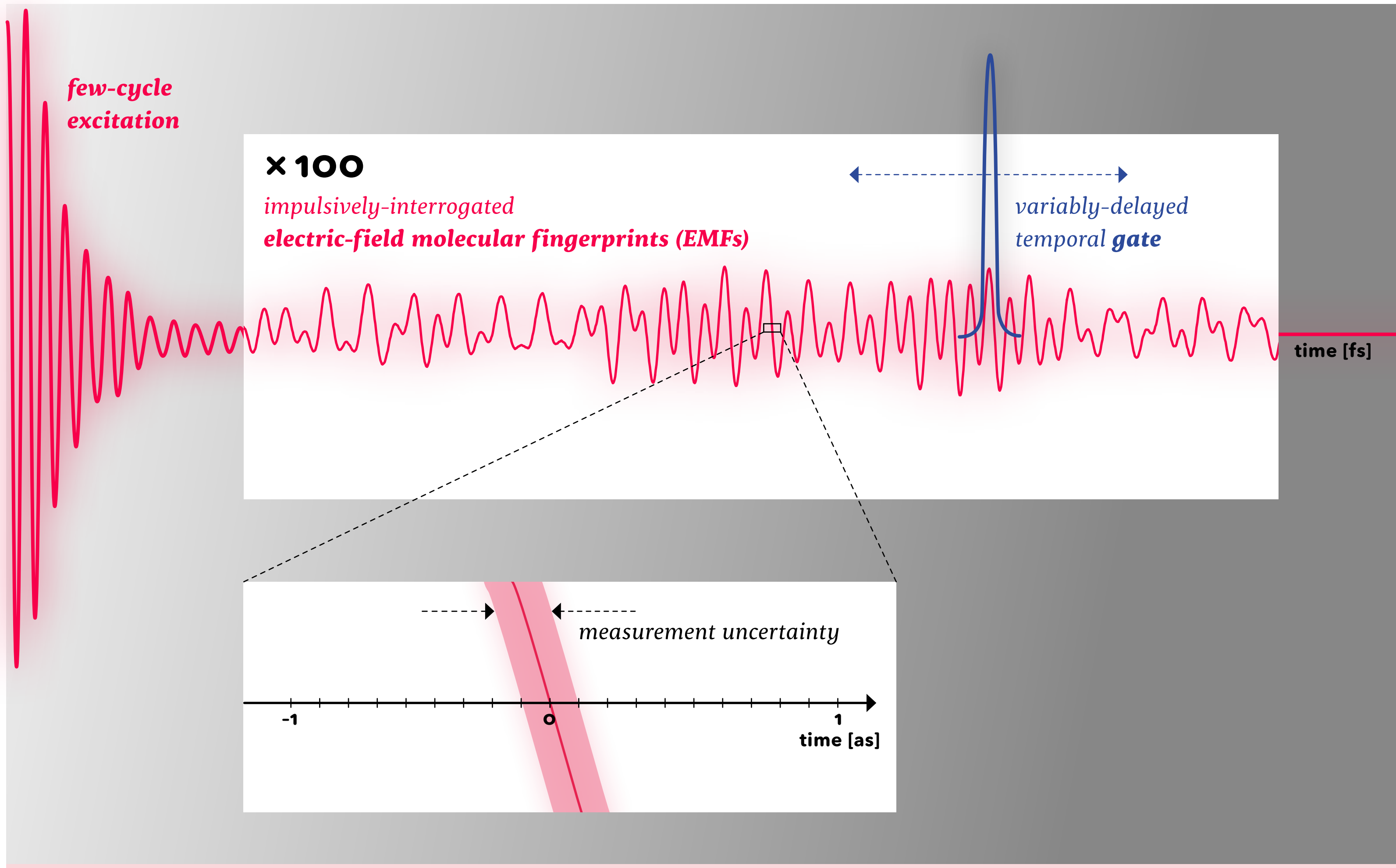


Figure 1: A few-cycle IR pulse excites molecular oscillations in a sample. Upon excitation, these emit a sample-specific response, the "EMF". This signal is recorded via nonlinear mixing of the EMF with a 10-fs-scale gate pulse. The inset illustrates our current measurement uncertainty for individual zero crossings of the EMF, which is on the order of 100 zeptoseconds.
Graphic: Dennis J. K. H. Luck

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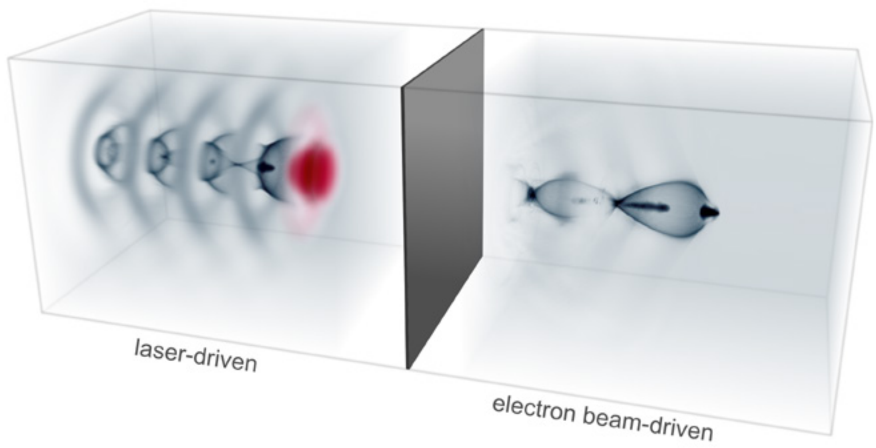
two-stage particle-beam booster

june 6, 2021 // Thorsten Naeser

Particle accelerators have made crucial contributions to some of the most spectacular scientific discoveries of modern times, and greatly augmented our knowledge of the structure of matter. Now a team of laser physicists led by Prof. Stefan Karsch at the Ludwig-Maximilians-Universität München (LMU Munich) and the Max Planck Institute of Quantum Optics (MPQ), in cooperation with scientists based at the Helmholtz Centre in Dresden-Rossendorf (HZDR), the Laboratoire d'Optique Appliquée in Paris (LOA), Strathclyde University in Glasgow and the DESY Electron Synchrotron in Hamburg, have now achieved a significant breakthrough in accelerator miniaturization. They have built the first compact two-stage plasma-based accelerator in which particles in a plasma wave initiated by a powerful laser are used to accelerate a beam of electrons.



Left panel: Schematic depiction of a laser-driven accelerator (LWFA) with the propagating laser beam shown in red on the left. Right panel: Electrons accelerated by the LWFA are used to drive the second-stage particle accelerator (PWFA).
Picture: Thomas Heinemann & Alberto Martinez de la Ossa

Particle accelerators have become an indispensable tool for studies of the structure of matter at sub-atomic scales, and have important applications in biology and medicine. Most of these systems make use of powerful radio-frequency waves to bring particles up to the desired energy. One drawback of this approach, which has been the standard methodology in the field for decades, lies in the risk of electrical breakdown when very high levels of electrical power at radio frequencies are coupled into the accelerator. This potential risk effectively limits the field strengths attainable, and is one of the reasons why these accelerator systems are typically many kilometers long. Physicists have therefore been exploring ways of reducing their size by exploiting the fact that a plasma can sustain much higher acceleration fields. In this case, the electric field generated by a powerful laser or a particle beam is used to strip electrons from the atoms in a gas and to create a wake similar to the one produced by a speedboat on water, Electrons surfing on that wake can get accelerated to nearly the speed of light within a distance of only a few millimeters.

Studies on plasma-based acceleration with the aid of lasers, i.e. Laser Wakefield Acceleration (LWFA), are now in progress in many research institutions around the world. In contrast, work with accelerators based on particle beams – a field which is known as Plasma Wakefield Acceleration (PWFA) – has so far been possible only in large-scale accelerator facilities (e.g. CERN, DESY and SLAC), although it offers a number of advantages over LWFA. For example, particle beams do not heat the plasma as much as laser beams and allow to use a longer accelerating distance. This in turn promises to improve the quality of the beam and increase its energy, parameters that are a very important in terms of the technique's potential range of applications.

In their experiments, the authors of the new study were able, for the first time, to build and successfully test a practical and compact particle-based plasma accelerator. The essential breakthrough lies in the fact that the PWFA, which accelerates the final electron beam, is driven by a particle beam from an LWFA. The latter is itself highly compact, so that the hybrid plasma accelerator is only a few centimeters long. Moreover, simulations indicate that the acceleration fields are more than three orders of magnitude higher than that attainable in conventional accelerators. Another promising result of the study is that the data obtained at LMU are confirmed by complementary tests performed with the DRACO laser at the HZDR.

Dr. Andreas Döpp, a member of the Munich group led by Prof. Stefan Karsch, points out that "only a few years ago, the practical realization of such a combination would have been unthinkable. The hybrid accelerator was made possible by subsequent developments in the design of laser-based accelerators, which have led to tremendous improvements in the stability of the beam and in other vital parameters." Much of this progress has been made at LMU, following the installation in the Centre for Advanced Laser Applications (CALA) of the ATLAS laser, which is one of the most powerful of its kind in Germany.

The successful demonstration of the hybrid plasma accelerator represents the latest advance ahead. "We had already shown that our compact plasma accelerator behaves very similarly to its conventional and far larger conventional cousins. So we are confident that we will be able to generate extremely bright electron beams with this set-up in the near future," says Stefan Karsch.

original publication:

demonstration of a compact plasma accelerator powered by laser-accelerated electron beams
AUTHORS: T. Kurz, T. Heinemann, M. Gilljohann, Y. Y. Chang, J. P. Couperus Cabadağ, A. D. Debus, O. Kononenko, R. Pausch, S. Schöbel, W. Assmann, M. Bussmann, H. Ding, J. Götzfried, A. Köhler, G. Raj, S. Schindler, K. Steiniger, O. Zarini, S. Corde, A. Döpp, B. Hidding, S. Karsch, U. Schramm, A. Martinez de la Ossa, A. Irman
JOURNAL: ***Nature Communications* 12,** 2895 (2021)

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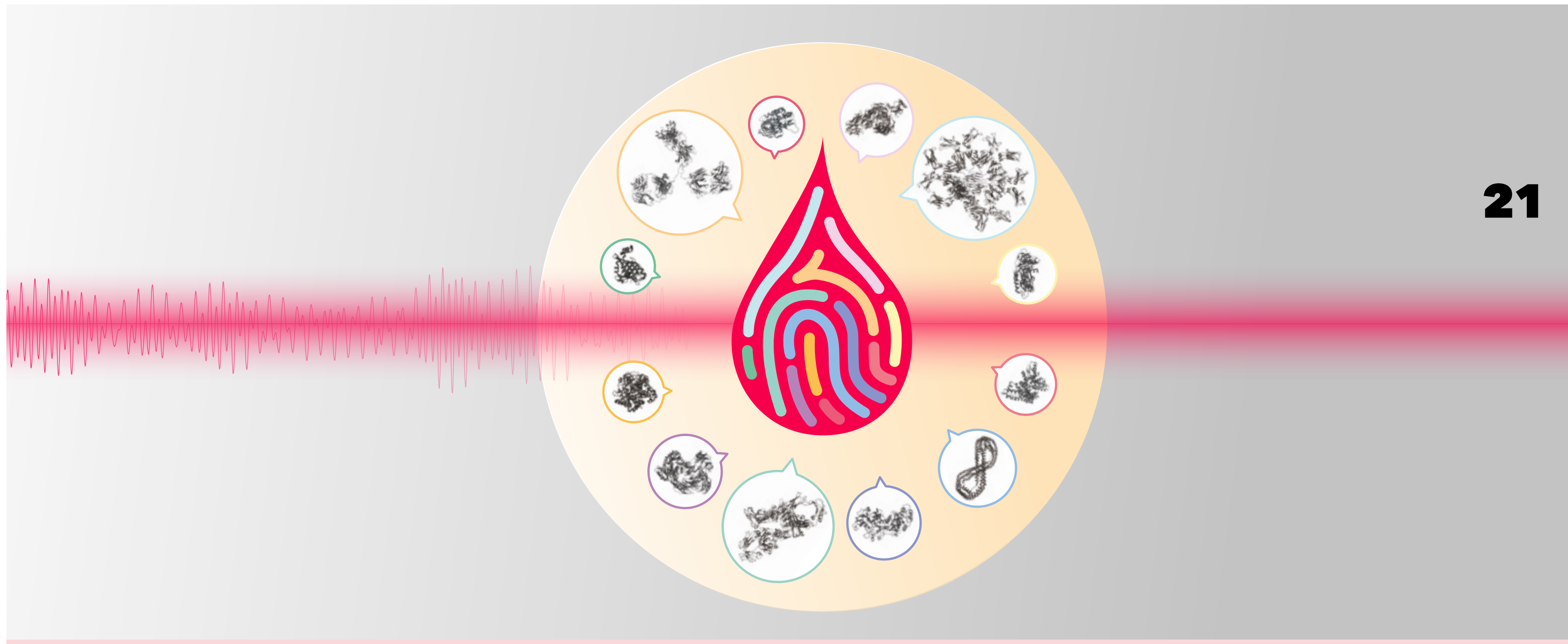
a drop in the ocean

june 10, 2021 // Mihaela Žigman

Thousands of researchers are seeking ways to capture human health within a simple probe. Why? Every person is unique – in the personality as well as in terms of health. And the task of defining the healthy state at a populational level is just colossal. In the face of this, it is crucial to detect aberrations in health as soon as only possible, raising the alarm that a disease is sneaking into one's body. Many diseases could be better coped with if we were alarmed earlier, as they only start developing. Especially cancer. This is where less invasive ways of disease detection come into play.

Cover image: In this study we use three experimental methods that serve different goals: proteomics looks closely into the blood constituents, biochemical fractionation reduces the chemical complexity of blood serum by taking apart groups of molecules, while infrared spectroscopy provides a snapshot of all blood components.
Image: Liudmila Voronina (Construction), Thorsten Naeser (Photo) & Dennis J.K.H.Luck (Artwork)

In a very inter-disciplinary team at the laser physics department of the LMU Munich, we believe to have made a step in this direction: We analyzed a fluid that connects all the organs – blood. The idea is familiar to anyone from medical check-ups, and it has recently been used for profiling with modern omics techniques. In our case, however, we exposed tiny amounts of blood to infrared light and captured the vibrations originating from the soluble biomolecules. In collaborative work with medical doctors from the LMU Comprehensive Pneumology Center, we set up a proof-of-principle clinical study to collect blood of individuals that were definitely known to have lung cancer, and in parallel from generally healthy, comparable individuals. We measured their blood samples with infrared spectroscopy. And finally – with quite high certainty – we succeeded to tell apart whether a person had lung cancer or not. From a mere drop of blood.



Each proteins contributes its own unique signature to the overall infrared molecular fingerprint of blood serum.
Graphic: Dennis J.K.H.Luck

Eureka? Well, we want to go even further. While infrared fingerprints may distinguish lung cancer, they do not yet inform us about the individual blood components that make up the difference. Nevertheless, it would be good to know their identity to be able to further improve the method. This is what we demonstrated in a new study just published in Angewandte Chemie (DOI: 10.1002/anie.202103272). It is all about a combination of two techniques that are usually applied separately: mass spectrometry and infrared spectroscopy. The aim was to decode the actual chemical changes behind the previously "black box" infrared fingerprints of lung cancer. Now, with mass spectrometry of blood samples performed at the Max Planck Institute of Biochemistry in Munich, we identified a set of 12 proteins that account for the spectral signature of lung cancer, where early diagnostic markers are currently missing. All of these proteins were known since a long time. Now – like old dogs playing new tricks – the combinatorial protein signature that we defined turns a new page in diagnostic efforts. And this signature can be measured in a matter of minutes using infrared light!

So are we now one step closer to capturing disease and defining health? Certainly so. Especially as laser scientists at our department are engineering new ways of delivering ever shorter and more precise pulses of light for spectroscopic investigations. Metaphorically, this is like a magnifying lens that allows us to inspect the molecular zoo in our blood at once – in a snapshot. Finally, the results are of broader relevance for many disciplines, as one may generalize our findings to detection of other diseases that leave their traces in blood.

Yet, while we are working on new advances in capturing human health by shining light through drops of blood, we are bearing in mind the notion of Isaak Newton: "What we know is a drop, what we don't know is an ocean.".

original publication:

molecular origin of blood-based infrared spectroscopic fingerprints

AUTHORS: L. Voronina, C. Leonardo, J. Mueller-Reif, P. Geyer, M. Huber, M. Trubetskov, K. Kepesidis, J. Behr, M. Mann, F. Krausz, M. Žigman

JOURNAL: ***Angewandte Chemie 60,*** 2 (2021)

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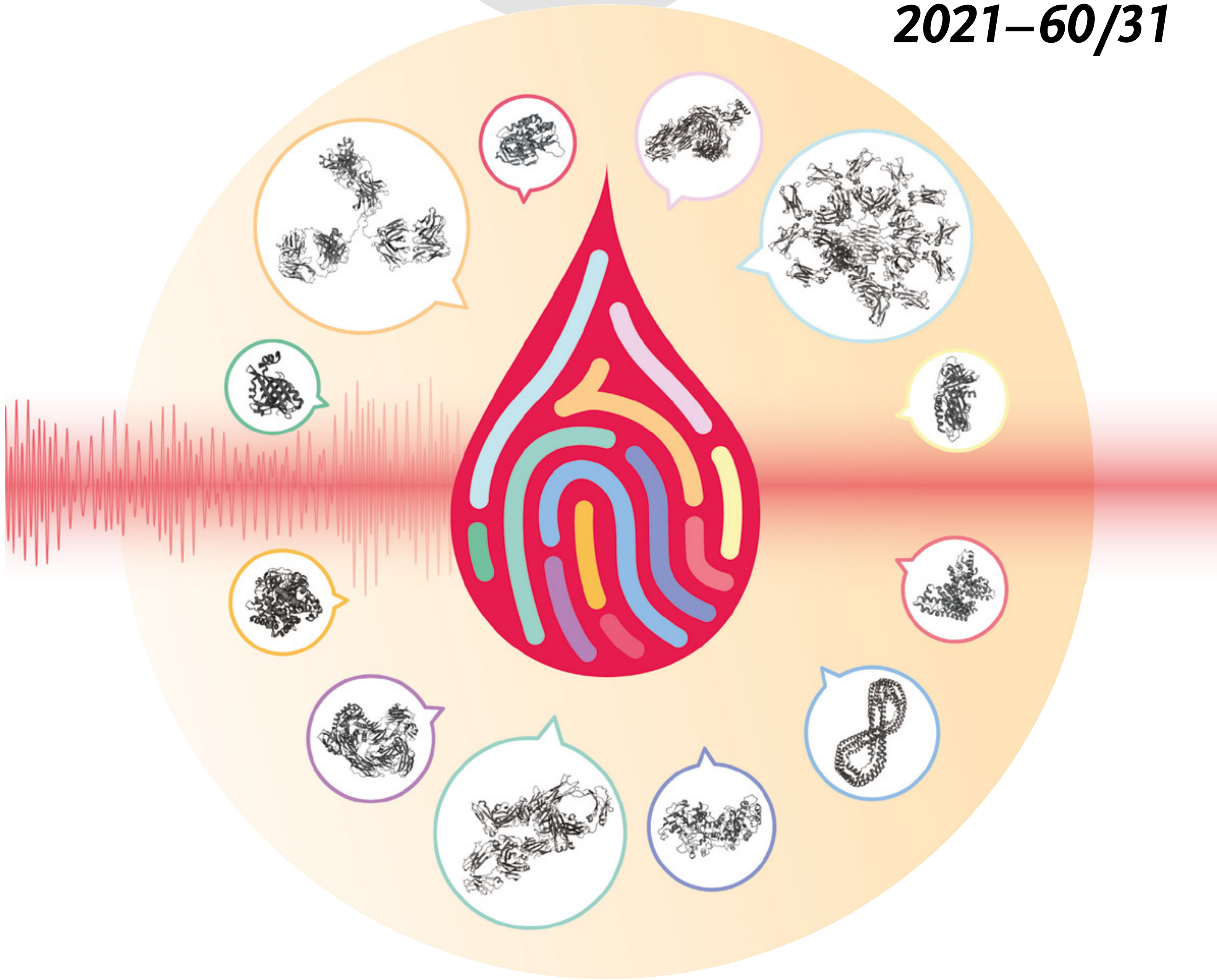
2021–60/31



A snapshot of blood serum composition …

… reflects the health state of an individual. It can be obtained using infrared spectroscopy in a simple and inexpensive manner, but the molecular nature of the disease-related changes therein remains poorly understood. In their Research Article on page 17060, Liudmila Voronina, Mihaela Žigman et al. used proteomics to reveal a set of proteins that contribute the most to infrared absorption of blood serum and show that they create a distinct signature of lung cancer.

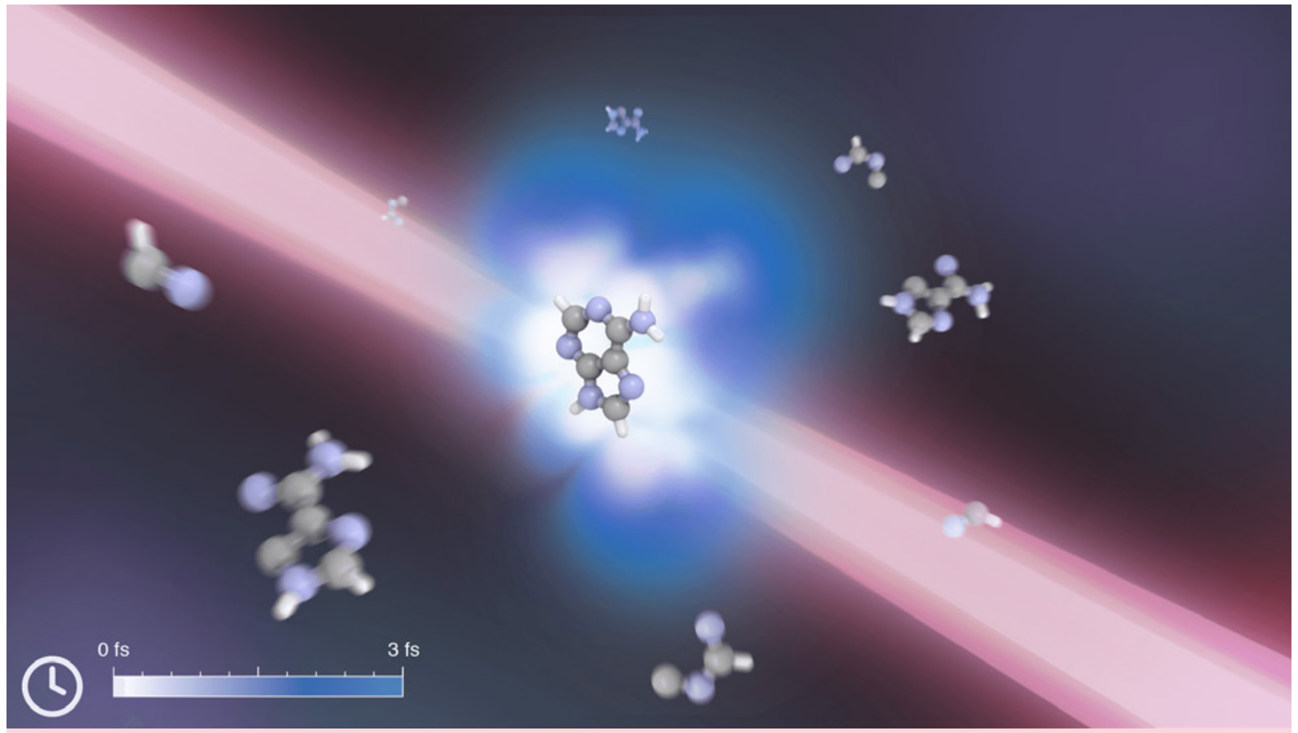
WILEY-VCH

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.

light protecting from light

may 20, 2021 // Thorsten Naeser

Ultra-short laser pulses can protect DNA components from damage from vacuum ultra-violet (VUV) radiation. That is the result of a study conducted by an international research team led by Professor Francesca Calegari from the Center for Free-Electron Laser Sciences (CFEL), operated by Deutsches Elektronen-Synchotron (DESY), the University of Hamburg and the Max-Planck-Society. The researchers discovered that infrared flashes can stop the destruction of the Adenin molecule re-stabilizing it if the particle is hit by a strong ultraviolet laser flash attoseconds later.



When the adenine molecule is ionized by VUV radiation, splitting occurs. However, by properly timing a second infrared laser pulse and exploiting charge migration, the molecule can be stabilized by a second ionization.
Graphic: Umberto De Giovannini, MPSD

High-energy radiation can cause irreparable damage to biological molecules such as the DNA, leading to mutations or cell death. The damages often start molecule ionisation. Protecting cells from damage through radiation is difficult since the light-induced fission process previously could not be stopped. However, in their ultra-short-time experiments, Francesca Calegari's research group found out that it is indeed possible to protect the molecules.

In their experiments, the researchers exposed molecules of the Adenine DNA-component for an interval of a few attoseconds to ultraviolet flashes. When they radiated the molecules femtoseconds later with infrared light, they noticed that the molecules had stabilized and their degradation was stopped by ejecting an electron. Doubly ionised but intact adenine-molecules remained. The group was able to save around 1 percent of the molecules from destruction. The team identified the electron charge as the mechanism responsible for the stabilisation: a purely electronic process that hinges on the ultrafast charge migration away from the molecule.

The findings are an important step toward the understanding of the fast mechanisms that are activated by the interaction between biomolecules and light, and its roles in the protection from destruction from light. "The proof of an ultrafast stabilising process for a DNA-component could considerably improve our possibilities regarding the control of ionisation damages – with interesting perspectives for the protection of molecules from light," Calegari explains.

original publication:

real-time observation of a correlation-driven sub 3 fs charge migration in ionised adenine
Erik P. Månsson, Simone Latini, Fabio Covito, Vincent Wanie, Mara Galli, Enrico Perfetto, Gianluca Stefanucci, Hannes Hübener, Umberto De Giovannini, Mattea C. Castrovilli, Andrea Trabattoni, Fabio Frassetto, Luca Poletto, Jason B. Greenwood, François Légaré, Mauro Nisoli, Angel Rubio & Francesca Calegari
***Nature Communications Chemistry* 4,** 73 (2021)

welcome!

august 30, 2021 // broadband infrared diagnostics

Meet the members of the Lasers4Life study team @ the LMU Medical Center.

Members of the Lasers4Life clinical study team in their office in the LMU Medical Center in Großhadern, Munich. From left: Sabine Witzens, Carola Spindler & Jacqueline Hermann. Pictures: Thorsten Naeser

We may have passed each other in the corridors of the LMU Medical Center in Großhadern at one time or another. And right here we would like to introduce ourselves!

We are members of the interdisciplinary research team Lasers4Life (L4L). The L4L team is led by Dr. Mihaela Žigman and affiliated with the LMU and the Max Planck Institute of Quantum Optics. And we are all members of the attoworld community (attoworld.de). The aim of L4L is to develop a method for the detection of cancers and other diseases at the earliest possible stage, with the aid of a unique technology based on the generation of ultrashort pulses of laser light. Such a light source can in principle be used to analyze the molecular composition of blood samples.

So can pulsed laser light tell whether or not a person has cancer? – Not yet. But this is the ultimate goal of the L4L project, in which international researchers including laser physicists, mathematicians, physicians and molecular biologists are collaborating. The goal that they all share is to develop, test and validate a procedure that can do just that. In addition to scientists and medical experts, such an ambitious project requires a team that organizes the collection of samples with which the analytical method can be tested and standardized. – That is our task. We maintain contact with both patients and healthy blood donors, collect and document the required samples, and make them available to the researchers for analysis.

team news

Who are we?

Jacqueline Hermann, a molecular biotechnologist, is the leader of the team. Jacqueline is our project manager, and is also responsible for liaison between the research team and the clinicians at the LMU Medical Center. In addition to these managerial tasks, she is involved in coordinating the work of the national and international research groups engaged in the project.

Jacqueline is not alone. Without the support of Sabine Witzens, her job would be impossible. – Sabine is our medical lab technician, and has years of clinical experience.

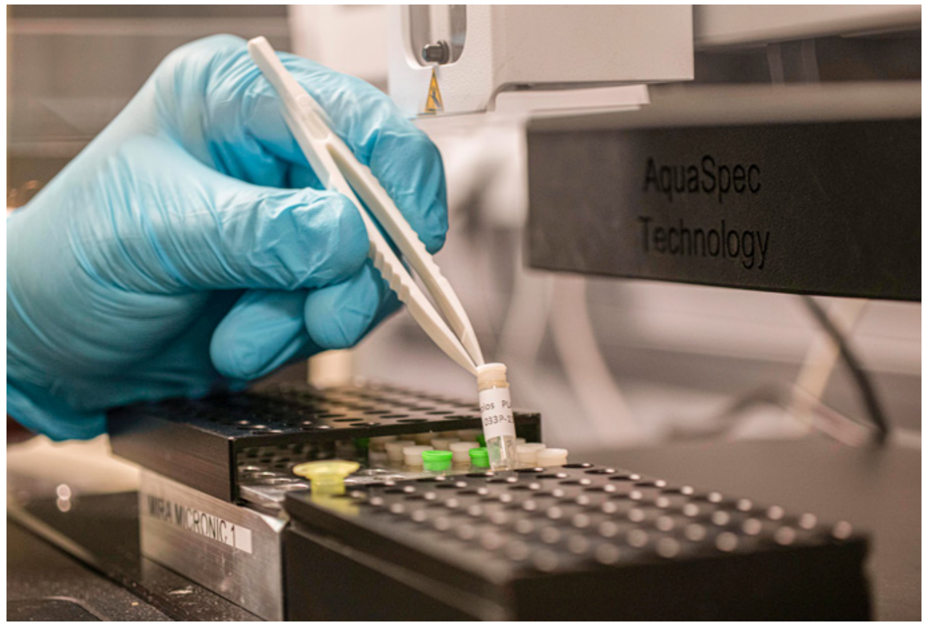
The third member of the L4L team is Carola Spindler, who provides support in the management of the project and the study data. Carola has a Master's degree in Business Psychology, but she decided to branch out into a different field. – And her particular point of view demonstrates the advantages of transdisciplinary collaboration every day.

Where do we work?

We are based in the Department of Urology at the LMU Medical Center, which is headed by Prof. Dr. Christian Stief. Sabine and Carola are mainly involved with patients. They outline the nature of the project, and ask patients whether they would be willing to support it by donating a blood sample. They take the samples, document and process them, and enter the data into the project's database.

Our search for sample donors

The collection of blood samples requires great care and meticulous planning. Our working day begins with the search for suitable subjects for our study. Potential donors must fulfil certain specific criteria – e.g. in relation to age and clinical history. We then explain the rationale and the aim of the clinical study.



Persons who agree to take part in the study then donate a blood sample. We draw between 5 and 10 ml of blood, which is immediately centrifuged to separate the liquid from the cellular constituents. Each fraction is then divided into 0.5-ml 'aliquots', little tubes that get to be stored in a

The blood samples are first processed in the laboratory at the LMU Medical Center in Großhadern.

freezer at −80°C, and subsequently transported to LMU's Laboratory for Extreme Photonics (LEX) in Garching for laser analysis.

What do we do with the blood samples?

At temperatures of −80°C, samples can be safely stored for years. Furthermore, in the laboratory at LMU, samples can be frozen in liquid nitrogen at −180°C, which ensures that they will remain unchanged for decades.

The researchers need to analyze as many physiological states as possible, so they need access to a large and highly diverse collection of blood samples. Like a person's fingerprints, the biochemical composition of the blood is unique to each individual. To investigate these fingerprints in detail, the data obtained from laser analyses with ultrashort light pulses will be processed with the aid of methods drawn from artificial intelligence (AI). This approach enables computers to detect subtle patterns in the infrared spectral data, which in turn makes it possible to reliably connect specific features of blood chemistry with underlying disorders.

The blood samples are stored at −80°C prior to being transferred to the laser lab in Garching.

The use of liquid nitrogen for sample storage has one very important advantage. Science and technology do not stand still – thus long-term storage ensures that researchers and medical professionals can probe the same blood samples with ever more refined analytical methods and diagnostic procedures, thus gaining new insights from these samples for decades to come.

Why we are excited by this innovative research project

"It's a very varied job, with a range of responsibilities, and it presents new challenges every day. What appeals to me most is having the opportunity to work in a forward-looking and very interesting environment," says Carola. – And Sabine adds "I enjoy working with people, and it's encouraging to see that a very large proportion of those we speak to are ready to take part in our study. The participants are also interested in the scientific background of the project, and put lots of questions to us."

Would you like to know more? If so, do get in touch with us in person: We welcome everyone who wishes to help shape the future of medical probing aided by ultrafast metrology!

The study has been registered with the German Registry for Clinical Studies (DRKS) and has been assigned the number: **DRKS00013217.**

Recruitment of individuals and the collection of blood samples are performed at cancer centers within the Munich area (LMU Clinic in Munich and Asklepios Lung Center in Gauting) in close collaboration with our **clinical partners:**

- Department of Urology, LMU Medical Centre
- Department of Gynecology, LMU Medical Centre
- Department of General Medicine V, LMU Medical Center
- Department of Radiology, LMU Medical Centre
- Department of Otolaryngology, LMU Medical Centre
- Department of General Medicine II and III, LMU Medical Centre
- The Comprehensive Pneumology Center
- Asklepios Lung Clinic in Gauting

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team news

an important milestone for CMF

august 16, 2021 // CMF research group

July 27th, 2021 marked an important milestone for the research activities of our colleagues at the **Center for Molecular Fingerprinting (CMF)** in Hungary. Following a two-year preparation period, the large-scale, longitudinal populational study **Health for Hungary – Hungary for Health (H4H)** has been kicked off with the recruitment of the first volunteers donating their blood for advancing medicine. The H4H study is aimed to establish infrared fingerprinting for health monitoring. The doors for this nation-wide research program just opened at Székesfehérvár, near Budapest, being the initial site in a series of further ones to be joining soon.

What is this research and study good for? CMF's goal is to develop new laser-based tools for monitoring human health in a new way, not possible before. How? By analyzing blood samples in an innovative process using ultrashort laser flashes. This unique and complex technique originates from our research at attoworld and is now being applied to probing human health and further developed in collaboration with CMF.

The goal of the H4H program is to recruit individuals as volunteers from broad segments of the Hungarian population – to facilitate the development of this research and to finally develop a new possibility to track and monitor development of diseases.

The study is designed for a period of 5 years, over which 10,000+ healthy individuals at numerous sites across Hungary will repeatedly donate their blood for establishing person-specific "normal ranges" of their respective blood-based infrared molecular fingerprints. Once established, the individualized infrared fingerprints will allow early detection of deviations, such as diseases. If successful, the approach may offer a new avenue for the future of preventive medicine.

team news

invited by the Optical Society

august 13, 2021 // advanced multilayer optics

Dr. Vladmir Pervak is invited by the Optical Society to give a half-day short course at the 15th Topical Meeting on Optical Interference Coatings in the area of: Phase Properties of Optical Coatings.

The 2022 Conference will follow the tradition of the previous OIC conferences and will focus on the major topics and advances of optical interference coatings, including coating design, manufacturing, characterization and applications that range from the X-rays to FIR spectral regions.

The OIC 2022 conference will be held on June 19-24, 2022 at the Whistler Convention Center, Whistler, British Columbia, Canada. More detailed information about the conference can be found at the conference website: ***www.osa.org***

a warm welcome to Matthias Stadter

august 4, 2021 // high-repetition-rate femtosecond sources

The attoworld-team welcomes Matthias Stadter, the new mechanical engineer in the group of Kafai Mak. Having studied at TU Munich, he will contribute his expertise in terms of design, cooling and vibrations to help constructing femtosecond lasers with the highest stability.

a warm welcome to Pushpa!

july 29, 2021 // broadband infrared diagnostics

We are happy to announce that very recently micro-/nano-fabrication specialist, Pushparani Micheal Raj, has joined our team!

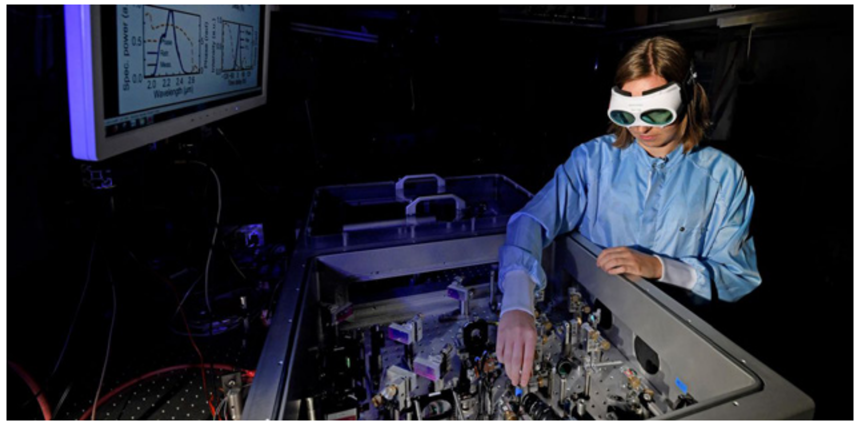
Coming all the way from the Lund University, Pushpa came over to strengthen the CMF and the BIRD team to facilitate the marriage between two disciplines – microfluidics and electric-field infrared spectroscopy. She is working on developing automated platform for rapid, uniform and reproducible fluid micro-channels and sample management. Pushpa is devising ways to probe most tiny sample volumes at greatest efficiently.

goodbye, Martin!

july 20, 2021 // high-field lasers and applications

Martin Kaumanns (in the middle of the picture) says "Goodbye" to the attoworld team. "The last seven years were quite a journey with a lot of new experiences and more lasers than I could have ever imagined", he says. "Something unique in this group that I do not expect to find anywhere else and that I am certainly going to miss is the possibility to read into a completely new topic, collect some questions and then be able to essentially visit your colleague next door to get those questions answered. And this colleague is not only proficient in this topic but is typically one of the leading experts in this field. So much world class knowledge covering so many topics concentrated in a single place will be difficult to find again."

Martin will move to Oberkochen. There he will take up a position with the Zeiss company as a scientific assistant in the field of lithography.



physicist of the week

june 29, 2021 // high-repetition-rate femtosecond sources

Our colleague Dr. Nathalie Nagl was "Physicist of the Week" of the German Physical Society (DPG). Since January 2018, the Equal Opportunities Working Group of the DPG has been presenting a female physicist in a short portrait every week. Of course, we would like to encourage all female colleagues to participate in this campaign as well.

electrons for life going live in Vienna

june 01, 2021 // attoworld

After a very long pause due to the pandemic, the chance to listen to a lecture and talk to Ferenc Krausz in person took place just on May 28th in Vienna. It was a special occasion. In a city special for attoscience. The Austrian Academy of Sciences (ÖAW) held its Ceremonial Congress of 2021, welcoming Ferenc Krausz as the keynote speaker.

Anyone that would like to watch the ceremonial presentation and has missed the live stream has the chance to see the video: ***youtu.be/4dQn4fe33hc***

In a wake of this impulsive lecture, the main Austrian broadcasting house (ORF) held an interview with Ferenc Krausz. And right here you have the chance to listen and read on the interview with journalist Robert Czepel and learn about what happened in the cellar laboratory of the TU Vienna about two decades ago: ***science.orf.at/stories/3206849/***

PhD hat by Dr. Nathalie Nagl. Picture: Nathalie Nagl

congratulations to Dr. Cristina Leonardo

july 22, 2021 // broadband infrared diagnostics

Cristina Leonardo has defended her doctoral thesis titled: **“Infrared spectroscopy of blood-based biofluids: Towards populational probing of common phenotypes”**.

congratulations to Dr. Enrico Ridente

july 20, 2021 // attosecond metrology 2.0

Enrico Ridente has defended his doctoral thesis titled: **“Few-cycle optical waveforms for transient molecular fingerprinting”**.

congratulations to Dr. Christina Hofer

july 13, 2021 // field-resolved infrared metrology

Christina Hofer has defended her doctoral thesis titled: **“Detection Efficiency and Bandwidth Optimized Electro-Optic Sampling of Mid-Infrared Waves”.**

congratulations to Dr. Sonja Tauchert

july 7, 2021 // atomic & electronic motion in 4d

Sonja Tauchert has defended her doctoral thesis titled: **“Chiral phonons as the carriers of angular momentum in the ultrafast demagnetization of Nickel”.**

congratulations to Dr. Dmitrii Kormin

march 18, 2021 // high-field lasers and applications

Dmitrii Kormin has defended his doctoral thesis titled: **“Development of high power pump laser for future sources of isolated attosecond pulses”**.

congratulations to Dr. Markus Pötzlberger

april 12, 2021 // high-repetition-rate femtosecond sources

Markus Pötzlberger has defended his doctoral thesis titled: **“High-power Femtosecond Laser Sources for Mid-Infrared Generation”.**

congratulations to Dr. Theresa Buberl

march 3, 2021 // field-resolved infrared metrology

Theresa Buberl has defended her doctoral thesis titled: **“Towards next-generation molecular fingerprinting”.**

congratulations to Dr. Ali Hussain

february 3, 2021 // field-resolved infrared metrology & cmf research group

Ali Hussain has defended his doctoral thesis titled: **“Field resolving spectrometer for mid-infrared molecular spectroscopy”**.

congratulations to Dr. Nathalie Nagl

january 21, 2021 // high-repetition-rate femtosecond sources

Congratulations to Dr. Nathalie Nagl on her successful PhD defense about: **“A New Generation of Ultrafast Oscillators for Mid-Infrared Applications”.**

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.

generating oxygen on mars

april 30, 2021 // Thorsten Naeser

An instrument on board NASA's Mars rover "Perseverance" has, for the first time, used atmospheric carbon dioxide to synthesize molecular oxygen on the Red Planet. This represents a significant step on the way to interplanetary travel.

Here may come a time when Mars does not seem as forbidding to us as it does now. Indeed, thanks to an instrument carried by NASA's latest Mars rover "Perseverance" hopes that this will prove to be so have now received a boost. The reaction vessel concerned, which is about the size of a toaster and is familiarly known as MOXIE ("Mars Oxygen In-Situ Resource Utilization Experiment"), has enabled researchers at NASA to extract oxygen from the Red Planet's thin, carbon-dioxide-rich atmosphere. This is a remarkable achievement. Never before have humans succeeded in remotely generating oxygen so far from home.

Carbon dioxide accounts for no less than 96% of the Martian atmosphere. MOXIE is capable of stripping oxygen atoms from molecules of the gas, converting it into carbon monoxide, which is returned to the atmosphere.

The process requires temperatures of around 800°C, which explains why MOXIE is made from heat-resistant materials. These include 3D-printed components made of a nickel alloy that serves to both heat and cool the gas during and after the reaction, and a light-weight aerogel which acts an insulator. The outer surface of the reactor is plated with a thin layer of gold, which reflects the infrared radiation generated during the heating step, and thus prevents it from propagating outward and possibly damaging parts of the rover itself.

MOXIE's first production run yielded about 5 grams of molecular oxygen, enough to supply the needs of an astronaut for about 10 minutes. MOXIE is designed to synthesize up to 10 grams of oxygen per hour. According to current plans, over the course of the Martian year (equivalent to nearly 2 Earth years), the device is scheduled to carry out nine more experiments of this type under a variety of conditions.

If all goes well after this promising start, MOXIE could turn a trope of science fiction into reality. The ultimate goal is to generate, collect and store large quantities of oxygen on Mars for use as a propellant for rockets that are powerful enough to enable teams of astronauts to

lift off the surface of the planet. But of course, such facilities could also provide breathable air for astronauts on the surface.

"This is a critical first step at converting carbon dioxide into oxygen on Mars," said Jim Reuter, principal investigator on the MOXIE project.

With the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), researchers from the U.S. space agency NASA have succeeded in extracting oxygen from the thin, carbon dioxide-rich atmosphere of the Red Planet. Photo: NASA/JPL-Caltech

"The results are full of promise, as we move toward our goal of one day seeing humans on Mars."

Bringing astronauts back from any future mission to the surface of Mars will require approximately 7 tons metric tons of rocket fuel and 25 metric tons of oxygen. However, once a permanent base has been established, astronauts living on Mars would need far less of the gas – on the order of 1 metric ton per year, the team reckons.

Getting 25 tons of oxygen from here to Mars is a challenging logistical proposition. It would make much more sense to dispatch to the Red Plant a 1-ton converter capable of producing the same amount of the gas in situ. If and when that becomes possible, that facility will be a direct descendant of the pioneering MOXIE.

Since 2011, the PhotonLab — built up by MPQ, LMU and MCQST — has been a focal point for all those who want to learn about light. About 2000 students visit the PhotonLab annually.

the new world of learning

april 30, 2021 // Thorsten Naeser

In the not-so-distant future, learning in a Student Lab is likely to include a mixture of interactive digital content and table-top experiments at home. Laboratory work in settings like the PhotonLab at the Max Planck Institute of Quantum Optics can then be devoted to the discussion, extension and consolidation of the knowledge acquired.

PhotonLab Digital: 3D setting with posters and videos. Images: Munich Center for Quantum Science & Technology (MCQST)

Although it's impossible to foresee whether we will encounter anything like the pandemic again, we would be well advised to be better prepared for the next crisis. So let's take a look in our crystal ball, shall we? The coronavirus pandemic is now years behind us, but it triggered an unprecedented wave of digitalization, which has transformed the practice of education. Individualized learning concepts have now been widely adopted in education and training, and the importance of new scientific discoveries and technological innovations for the optimal exploitation of dwindling natural resources has been fully recognized. Photonics continues to play a leading role in the quest for new solutions. The field has now led to a range of devices based on quantum technologies, lasers have not only revolutionized medical research and diagnostics, they have become the favored mode of propulsion for small spaceships.

In this new world, student labs affiliated with, and managed by research institutes play a central role in the training of the next generation of specialists. The rapid rise of the flipped-classroom concept really began during the pandemic itself, and it was employed at that time in PhotonLab, the Student Lab set up by the Max Planck Institute of Quantum Optics. The basic idea is that students study the basic concepts required to perform and interpret a specific experiment in photonics – one involving interferometry, let's say – at home. Then they perform the experiment in the PhotonLab, under the supervision of specialists. The combination of self-instruction, hands-on experience and expert know-how markedly enhances retention of knowledge and experimental technique.

"I believe the teacher's task is to actively support the learning process, and in this way the motivation provided by the laboratory setting can be translated into the classroom," says Dr. Andreas Kratzer, who is responsible for the Student Labs at the Technical University of Munich. "This mode of learning gives students more independence and promotes a culture of self-assessment," Kratzer adds, "and if self-motivated learning can become an established feature of education, it could also lead to a completely new approach to the use of space in schools."

Moreover, the model could be further enriched using the resources provided by research in the areas of machine learning (AI) and virtual reality, which enable students to investigate artificial environments either online or with the aid of smart glasses. "I imagine that it should be possible, with the aid of Augmented Reality (AR) glasses, to visualise experimental phenomena that are not directly accessible," says Linda Qerimi. Qerimi has just completed her training as a secondary-school teacher of physics, and is now engaged in the further development of the curriculum of experiments at the PhotonLab. "One example of such a visualisation would demonstrate how the polarization of light is altered by changing the orientation of a wave-plate," she suggests.

PhotonLab

“The resulting rotation of the polarization of the incident light, which is not visible to the unaided eye, can be mimicked by the glasses.” Qerimi is confident that this approach can also be applied to experiments involving quantum-mechanical phenomena, many of which – such as the superposition of quantum states – are non-intuitive. Mathematical formulae could also be presented as soon as they become relevant for

the experiment. “So the students come into the laboratory and put on AR glasses for particular experiments,” she says. “This should intensify their engagement with the experiments, and boost the learning experience.”

Prof. Jochen Kuhn, Head of the Research Group on the Didactics of Physics at the Technical University of Kaiserslautern, also believes that smart glasses have a future in education. “The real world is already entangled with the digital sphere,” he says. “And it can be assumed that we will be provided with much more digital information by wearable computers such as smart glasses.” These wearables are equipped with sensors that are able to track one‘s position (GPS) and direction of gaze (eye trackers), as well as monitoring physiological parameters, and can display this information, in real time, in the wearer’s field of vision.

Kuhn envisages a significant role for these devices as “reinforcements’ in education. For example, if a student who has already exhibited an interest in lasers is standing in line in a supermarket, his smart glasses could automatically show a video illustrating the function of the laser scanner, while an audio feed explains how the scanner works. In this way, students could receive supplementary information that reflects their interests and levels of competence. If the system can tell that further information would be welcome, based on the student’s engagement with this information, it could supply tips on related experiments (such as those available from the PhotonLab) and instructions on how to set them up, with the aid of a 3-D printer and a laser pointer.

Since these systems can access other digital media stored by the student in the Cloud, and draw on the toolbox provided by neural networks, a personalized learning profile can be constructed for the user. “Each student then has an individual electronic compendium of information about lasers, which can be continuously broadened and deepened,” says Kuhn.

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from dawn till dusk: Claude Monet's series of works of Rouen Cathedral

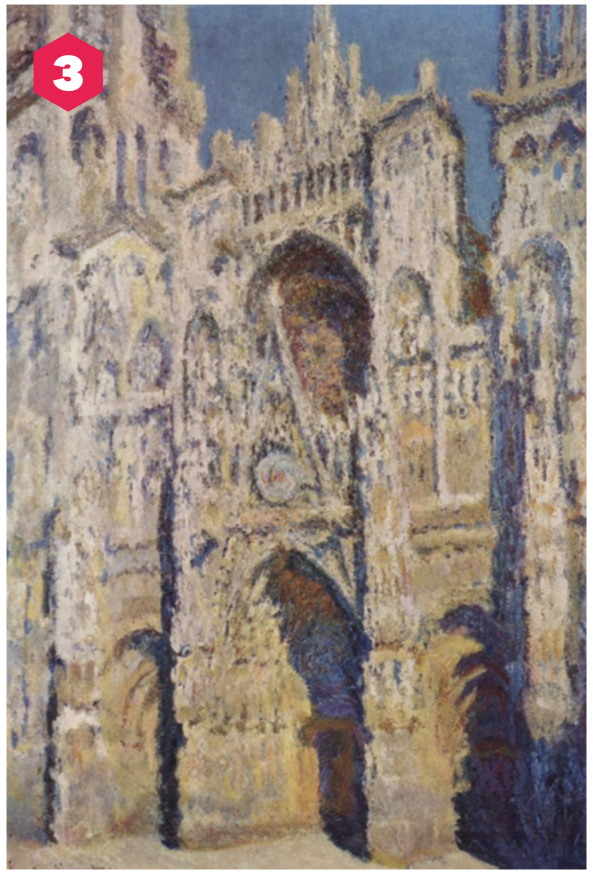
july 15, 2021 // Dr. Veit Ziegelmaier

The depiction of light and its atmospheric ambiences has always been a central theme in the visual arts. From the implementation of mythological ideas of antiquity to the sophisticated, technically demanding lighting of the Old Masters to contemporary art, where real light sources are increasingly being used: the aim is to literally put motifs, sceneries and places in the right light. In Impressionism, a stylistic era of the late 19th century, the facetted rendering of light reached a peak in the course of the endeavor of capturing the peculiarity and the atmosphere of a special moment on canvas. And so it happened that the world-famous painter Claude Monet (1840–1926), at the height of his creative powers, was eager to dedicate an entire series of 33 paintings to Rouen Cathedral in the light of different times of day.

art and science

Claude Monet is considered one of the main representatives of "Impressionism" and pioneer of modernism, known also for his impressive series of paintings of water lilies. At the end of the 19th century, painters left their studios to capture directly on location the atmosphere and the splendor of a light setting. This required a brisk and simultaneous painting method, which is therefore called "wet-on-wet" painting. Rather than elaborating precise details, the impasto and dynamic application of paint in the paintings of this period convey a vividly shimmering impression of the scenery, as if in the blurring of contours the permanent changes in the play of wind, light and shadow can be picked up.

Monet's series of works of Rouen Cathedral was created in 1892–94, initially renting a small apartment with a direct view of the church's west portal during his first stay, and later painting directly on site. He was not primarily concerned with the precise reproduction of the magnificent 13th-century architecture, but with the impression of the sensation of how the light played around the forms of the façade at different times of the day. This is also evident in the almost identically chosen image details with only a few perspective deviations. Monet even went so far as to have his preliminary drawing printed on canvas so that he could concentrate entirely on the special and fleeting moment of the prevailing light conditions. He tirelessly rendered the cathedral sometimes in a milky morning mist that obscured its outlines, or in the blue-orange tones of the rising morning sun. At other times in the shimmering, glistening midday light or even in the rich glow of the evening sun. He also picked up on different weather conditions.



While painting, he placed small patches of varying colors directly next to each other, sometimes in nuanced gradations, sometimes in contrasting colors. Only with some distance the sum of these color parts mixes in the eye of the viewer to an overall impression of an intense light and shadow play.

In the end, far more than 33 pictures were created, none of which can claim general validity due to the constant changes in lighting conditions. But Monet struggled with himself and was plagued by doubts whether he could succeed in a suitable representation at all and destroyed several versions himself. Today, as then, these paintings are considered masterpieces and among the most important creations of the era. And they are an essential step in the development of modern art.

The Russian painter Kazimir Malevich (1878–1935), a pioneer of 20th century abstraction, wrote with admiration about Monet's Rouen Cathedral: "[This is] painting in the true sense, movement and endless growth of colored spots, no one has ever seen that. [...] His central goal was not light and shadow [...] It's not about the cathedral, it's about painting."

image 1: ***The Portal of Rouen Cathedral in morning light, 1894***
Oil on canvas
100 × 65 cm
J. Paul Getty Museum, Los Angeles

image 2: ***Rouen Cathedral, the portal in morning sun, harmony in blue, 1893***
Oil on canvas
91 x 63 cm
Musée d'Orsay, Paris

image 3: ***Rouen Cathedral, the portal and the Staint-Romain tower in bright sunlight, harmony in blue and gold, 1893***
Oil on canvas
107 x 73,5 cm
Musée d'Orsay, Paris

image 4: ***Rouen Cathedral, sunset, 1892***
Oil on canvas,
104 x 65 cm
Pola Museum of Art, Hakone

maybe it was a marker buoy ... ?

Thorsten Naeser

In a new book, astrophysicist Avi Loeb speculates on the nature and possible origin of the interstellar object 'Oumuamua.

In 2017, a very strange object paid a short visit to our Solar System. Indeed, it was unlike anything astronomers had ever seen before. The observers on Hawaii who first discovered it named it 'Oumuamua (meaning "messenger from the remote past"), as its brief encounter with our neighbourhood prompted associations with a scouting mission. Since then puzzlement has reigned with respect to both its origin and significance. For a start, 'Oumuamua was unusually bright – far brighter than typical asteroids. With an aspect ratio of about 10:1 and a radius of around 100 m, its shape was reminiscent of a squashed cigar. Even though its unusual trajectory suggested the presence of a non-gravitational component of motion such as that provided by a classical gaseous comet tail, no such activity could be detected. So it's not surprising that the search for a convincing scientific explanation of its unprecedented features continues.

However, one theorist – Avi Loeb – has now come up with a startling hypothesis. Loeb, who heads the Department of Astronomy at Harvard University, is an established and highly regarded astrophysicist, and within the scientific community he has a reputation for thinking outside the box. He has now published a book, entitled "Extraterrestrial", in which sets out his own ideas on the form and origin of 'Oumuamua. In his view, 'Oumuamua might indeed be a visitor from the remote past – a messenger from an alien civilization. He suggests that the object could represent a piece of space junk, or even a small spaceship like the two Voyagers launched from Earth in 1977, which have now left the Solar System.

Avi Loeb is certainly not a fantasist. His scientific contributions are well founded and his arguments are always reasoned and comprehensible. In addition to his professorial duties at Harvard, he serves as Chairman of the Advisory Committee for the Breakthrough Starshot Initiative. – Its goal is to use the radiation pressure exerted by powerful lasers as a mode of propulsion to send miniature, ultralight satellites to the solar system next door to ours. This visionary project is symptomatic for the thrust of many of Loeb's speculations regarding 'Oumuamua. Thus, he argues that 'Oumuamua's peculiar trajectory through the Solar System could be accounted for by the pressure exerted by the Sun on a satellite designed to make use of this very effect. That is undoubtedly a daring hypothesis but, as Loeb says in his book, it is no more exotic than many other proposals that have been advanced to explain the remarkable path traced by 'Oumuamua on its brief encounter with our neck of the woods.

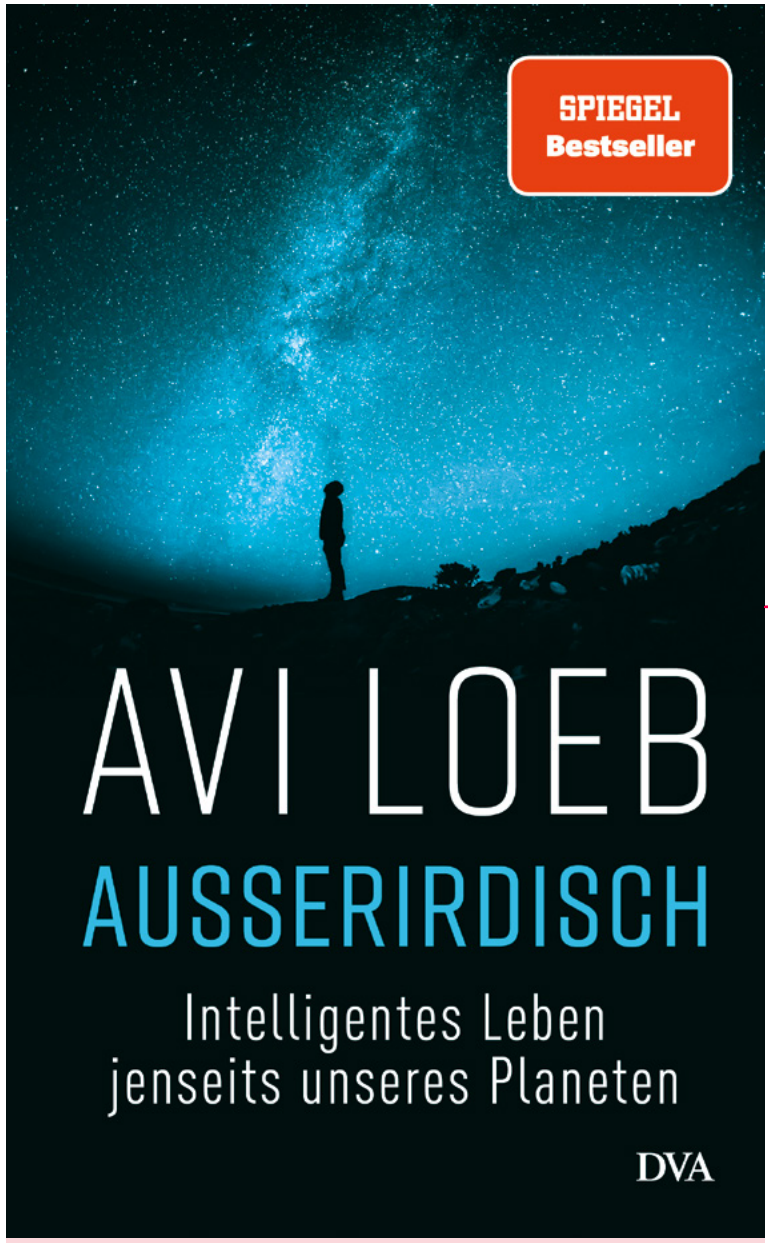
His second conjecture takes a different tack: 'Oumuamua might once – long, long ago – have been a piece of technical equipment that was constructed for a specific purpose by an extraterrestrial civilization. Loeb suggests that it might have served as a marker buoy, remaining virtually at rest as the Solar System surges past at high speed. Why would extraterrestrials bother to build such an object, one might ask? Maybe it was intended as a navigational beacon, like a lighthouse, or as an alarm or early warning system, Loeb writes – and if that were the case, only one conclusion is possible: 'Oumuamua is of extraterrestrial origin, and we are not the only form of intelligent life in the vast expanses of space.

Indeed, this conclusion is at the core of the book. Loeb is convinced that life exists elsewhere in the Universe. He argues that we need to seriously pursue a new field of science – devoted to what he calls space archaeology. Just as Earth-bound archaeologists dig up and study the material remains of past civilizations, astronomers should actively search for signs of other technological civilizations – in other words, engage in 'space excavations'.

In this context, Loeb sharply criticizes the entrenched structures that characterize the study of outer space in its widest sense, in which speculations of this sort provoke wry smiles at most. Young researchers who decide to specialize in exotic or highly speculative topics, such as the search for extraterrestrial life, are likely to damage their future career prospects, he writes, and this explains why most choose areas that are already overpopulated. As far as Loeb is concerned, if humanity is to make real progress in its efforts to understand the Universe, it is imperative to leave the beaten track and explore unconventional ideas.

Loeb's new book is based on well attested astronomical findings and insights. It tells the story of the discovery of 'Oumuamua and it objectively describes the observations made by astronomers around the world. But – as is perfectly legitimate between the covers of a book – he also indulges in speculation, and formulates controversial and visionary ideas. Nevertheless, his arguments are always coherent and plausible, as one would expect from an author who is led by empirical facts.

Loeb concludes his book with a piece of advice. If and when we come across an extraterrestrial civilization that is superior to us, we should defer to its pre-eminence – for it might well have the answers to many questions that we have been unable to resolve.



Avi Loeb
Außerirdisch: Intelligentes Leben jenseits unseres Planeten
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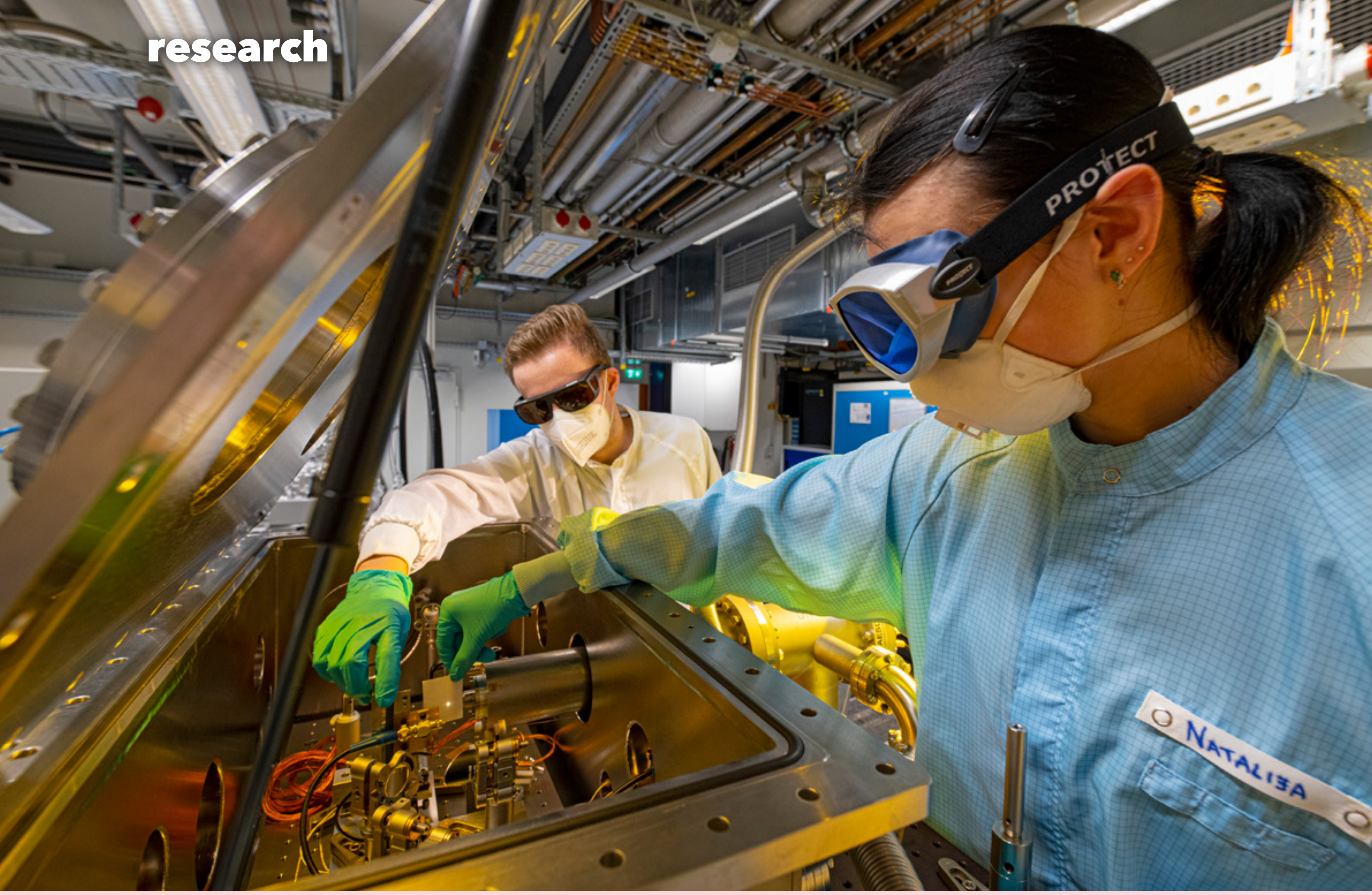
ATTOWORLD is a home for synergies across institutions and borders. By uniting the teams of the MPQ Laboratory for Attosecond Physics, the LMU Chair of Experimental Physics – Laser Physics, and of the Centre for Advanced Laser Applications (CALA) and closely collaborating with researchers from the LMU 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

ultrafast currents

march 29, 2020 // field-resolved nano spectroscopy

The ultrafast current sampling setup is being built up in the new HORUS Experimental Area. Employing frequency broadened and compressed laser pulses from a Ti:Sa-laser system, the students Natalija Schreiber und Johannes Blöchl investigate the interactions of nanostructures with optical fields. Therefore, laser-induced currents are measured in time-domain in order to gain the full information of amplitude and phase of the electric fields modified by the nano-sample. However, not only the effect of the latter on the electric field can be measured, instead, nanostructures themselves are also used for direct field-sampling of light.