15.2.2019
IAP DAY

14:00 – Jean-Philippe Brantut, EPFL
“From atom traps to quantum simulators”

15:00 – Adrian Cavalieri, University of Bern
“Timing”

16:00 – Poster teasers

16:30 – Poster session and apero

Venue
Hörsaal A6
Institute of Applied Physics
Sidlerstrasse 5
CH-3012 Bern
www.iap.unibe.ch

Organizing committee
H. Günhan Akarçay
Klemens Hocke
Michael Jaeger
André Stefanov
Over the last decade, the level of control over trapped gases has improved, from the first observations of Bose-Einstein condensation, to the point that atoms can now be used to simulate the behaviour of electrons in realistic materials. These progresses rely on optical manipulation and detection methods developed since the beginning of the 80s. I will review their principles, and illustrate the state of the art with the realization of mesoscopic structures simulating the physics of nano-electronic devices. I will then present a few perspectives for future developments, such as the manipulation with quantized light fields.
It is my pleasure to have the opportunity to introduce myself on this annual IAP-day. I will describe my research in developing and applying new light sources to study dynamical processes in materials with highest possible time resolution. Ultimately, our goal is to coherently control these materials with light. I will present early work performed at the Sub-Picosecond Pulse Source at the SLAC National Accelerator Laboratory. SPPS was a precursor to the first X-ray free-electron laser where we studied coherent lattice dynamics by femtosecond time-resolved X-ray diffraction. Following these activities, I moved to the Max Planck Institute of Quantum Optics in Munich. Here, we developed attosecond techniques to observe electronic dynamics in real time, for example clocking the photoelectric effect in metals. Upon moving to the University of Hamburg and the Max Planck Institute for the Structure and Dynamics of Matter, I have worked to extend the tools of attosecond spectroscopy to X-ray free-electron laser facilities. We characterized the X-ray pulse structure and timing with femtosecond precision, which allows us to explore advanced X-ray pulse shaping and compression. At the Institute for Applied Physics here in Bern, we plan to develop new phase-stabilized infrared sources to control materials. While these dynamics can be accessed indirectly by optical spectroscopy, X-rays from the newly commissioned SwissFEL would also allow for microscopic observations. Building on our past work in instrumentation, we will also contribute to a larger effort to deliver temporally coherent attosecond X-rays at SwissFEL. This unique capability would allow for new experimental approaches in nonlinear X-ray science.
Soft-prior regularization for improved speed-of-sound imaging in CUTE

P. Stähli, M. Kuriakose, M. Frenz, M. Jaeger

Institute for Applied Physics, University of Bern

Computed ultrasound tomography in echo mode (CUTE) complements conventional ultrasound by imaging the tissue's spatial distribution of speed-of-sound (SoS) using a single handheld device, with promise for diagnosing e.g. liver disease. CUTE is based on analyzing the phase-shift of echoes when detected under varying transmit and receive steering angles. The problem of deriving the spatial distribution of SoS from the spatial distribution of echo phase-shift is ill-posed, and thus requires regularization.

In previous studies, we used Tikhonov regularization of the spatial gradient of the SoS (SG), and demonstrated quantitative SoS imaging in layered phantoms mimicking the abdomen. In-vivo, however, the SG regularization turned out to be of limited use: With the substantial phase noise due to clutter and aberrations, SoS contrast resolution is obtained at the cost of a low spatial resolution. As a result, sub-resolution features of superficial tissue structures result in distortion of quantitative SoS values inside deeper tissue layers.

To solve this shortcoming, we propose a soft-prior (SP) regularization. This approach allows to encode spatial information derived from B-mode US, so that regularization takes place within pre-defined regions but not across boundaries where SoS is a-priori known to vary on a short spatial scale.

In-vivo results of imaging the abdomen underline the potential of soft-prior regularization for improved quantitative CUTE (see Fig. 1): The conventional B-mode US shows the anatomy and allows segmentation of the different tissue types (a). In (b) the B-mode
image is fused with a SoS image based on SG regularization. Due to the low resolution imposed by SG, the spatial distribution of reconstructed SoS deviates from the anatomy (mostly in the thin part of the muscle), and unrealistic axial variations of SoS are observed inside the liver. In contrast, SP regularization based on the segmentation in (a) leads to a strongly improved SoS image that agrees with the anatomy and shows nearly constant SoS within each segment (c).

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Frequency-domain reconstruction in optoacoustic microscopy and the ominous coherence factor

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Computed Ultrasound Tomography in Echo mode (CUTE) was developed to image the speed-of-sound (SoS) inside tissue using echo ultrasound, based on measuring the phase shift of reconstructed echoes when insonifying the tissue under varying transmit (tx) angles. One promising target of CUTE is the diagnosis of atherosclerotic plaque inside the carotid artery. However, substantial blood motion during the acquisition of a typically required number of tx angles leads to decorrelation of echoes, and has so far inhibited successful results. To solve this problem, we propose receive (rx) steering as opposed to tx steering: Only few tx angles are used, but for each tx angle, echoes are reconstructed for a variety of different rx angles. The data corresponding to different rx angles can thus be obtained from a single acquisition, enabling robust echo phase tracking across different view angles without the influence of blood motion. In a phantom study, we have demonstrated that rx steering is equivalent to tx steering in terms of the resulting echo phase shift and reconstructed SoS images.
Quantitative optoacoustic imaging with multiple-irradiation sensing (MIS): *in-vivo* proof of principle


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Quantitative optoacoustic (OA) imaging is on the verge of becoming a preeminent modality for the assessment of oxygen saturation levels (SO$_2$) in vessels. Main challenges include: (i) evaluating the light fluence at the position of the imaged vessels for the spectral correction of the OA signals and (ii) quantifying the uncertainty of the calculated SO$_2$ values. We have previously developed models to face these challenges, based on the non-invasive MIS probing technique. This technique uses the vessels as intrinsic fluence detectors so that the tissue is probed from within. A point-like light source scans the tissue surface to sample a large number of source-detector paths. Our semi-empirical light propagation model states that among all sampled paths, there exist paths where the light diffusion approximation is applicable. This enables the retrieval of the optical attenuation coefficient(s) of the probed tissue by making use of the statistics provided by the OA signals emanating from the vessels, combined with the statistics collected over the probed paths. This optical characterization then allows for the spectral correction of the OA signals and the SO$_2$ calculation by spectral fitting. To quantify the error in the SO$_2$ determination, we have introduced a metric that has been identified by exploiting the features of blood spectra. We have already ascertained the viability of our methods with numerical simulations and phantom experiments. Here, we present *in vivo* results obtained from measurements on a volunteer’s forearm. This study opens new doors not only for quantitative OA, but also for *in vivo* optical characterization of tissues.
Unmanned Aerial Vehicles (UAVs) are a significant and growing security and safety concern: both through their use by malevolent actors, and through inadvertent misuse near airports or in other areas where they pose a danger to the public. It is therefore increasingly important to be able to detect and monitor such devices. A wide range of different technologies can be used to do this, but radar is often a critical part. Therefore, the radar cross sections (RCSs) and the (micro-) Doppler signatures of UAVs is critical. In small numbers of cases, these can be measured, but to truly cover the huge variety of UAVs available, simulation is very important. The problem with simulation is that, for complex targets like UAVs, it is only ever approximate. In this poster, we look at how detailed RCS simulations need to be adequately approximate measured results, and to produce good-enough micro-Doppler signatures for classification purposes. To that end, we compare hexacopter and simple and complex quadcopter simulation results against anechoic chamber measurements, as well as making comparisons between simple and complex octocopter simulations. We also show the extent to which a simple analytic approximation to the scattering from a rotor can be used to classify full-wave UAV micro-Doppler simulations by number of rotors.
Stratospheric ozone profiles from the GROMOS microwave radiometer at Bern: intercomparison, trends and their uncertainties

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Stratospheric ozone depletion has been a focus of attention for the last few decades. After a continuous ozone decline, first signs of an ozone recovery in the stratosphere were observed starting in 1997. Recent studies have confirmed that ozone is increasing in the upper stratosphere at mid- and low-latitudes, but different trend profiles are not always consistent. To improve trend estimations of stratospheric ozone profiles, continuous and stable time series are crucial and trend uncertainties need to be addressed.

This study helps to explain inconsistencies in recent trend profiles of stratospheric ozone at northern mid-latitudes by comparing ground-based ozone time-series and assessing their trends and uncertainties. We present an updated and improved 22-years time series of stratospheric ozone from the GROMOS (GROund-based Millimeter-wave Ozone Spectrometer) microwave radiometer located at Bern, Switzerland. We compared the GROMOS data with data from other ground-based instruments in central Europe from the Network for the Detection of Atmospheric Composition Change (NDACC), namely lidars, ozonesondes and microwave radiometers. We found a good agreement in the middle and upper stratosphere with relative differences of 3 to 10% and identified some biased periods possibly due to instrumental issues.

Stratospheric ozone trends based on the different instruments were estimated with a multilinear trend model, which can handle uncertainties in a flexible way. We assessed how instrumental uncertainties contribute to the trend estimates by adapting uncertainties of the underlying ozone time series in the trend model. Furthermore, we show how different sampling rates and period lengths influence the resulting trends. The GROMOS data are well suited to investigate such factors thanks to the long and complete time series and the high temporal resolution.

Time series of zonal and meridional wind speeds in the stratosphere and lower mesosphere measured by passive Doppler microwave radiometry

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Institute of Applied Physics, University of Bern

The microwave radiometers WIRA and WIRA-C and GROMOS-C are capable of measuring horizontal wind speeds between 30 and 70 km altitude. They observe the
142 GHz ozone rotational emission line and exploit the Doppler shift introduced by the moving air as well as the pressure broadening effect to retrieve altitude resolved wind profiles. Passive microwave instruments work independent of daylight and clouds and operate autonomously, which makes them especially suitable for continuous observations. All instruments have provided continuous time-series from campaigns at tropical, arctic and mid-latitudes (La Réunion Island, 21 °S; Andøya, 69 °N; Bern, 46 °N, Ny-Ålesund, 78 °N). These continuous wind measurements have proven to coincide well with models and Doppler-Lidar measurements. Due to receiver noise, the time resolution for these instruments is typically limited to 12 to 24 hours, which is well-suited to observe seasonal cycles and extreme events like sudden stratospheric warmings. We give an overview on the time-series of zonal and meridional wind speed measurements acquired so far from the different campaigns and instruments.

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Long-term measurements of middle atmospheric water vapor at the Zimmerwald observatory

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Atmospheric water vapor is a major field of research at the Institute of Applied Physics (IAP) at the University of Bern. Water vapor plays a key role in the earth's radiative budget and is the most important greenhouse gas in the atmosphere. In the middle atmosphere (30-80 km) water vapor is the major source of the OH (hydroxyl) radical which is involved in the destruction of the ozone layer. Mechanisms that control the long term variability of stratospheric and mesospheric water vapor are not well understood. Therefore, long-term high quality measurements of middle atmospheric water vapor are very important. With the MIAWARA radiometer more than a decade of continuous observations are achieved now.

Fig. 1 The observatory for water vapor at Zimmerwald and the Middle Atmospheric Water Vapor Radiometer (MIAWARA).
Middle-atmospheric H$_2$O and O$_3$ measurements by ground-based microwave radiometry in the Arctic

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Water vapour and ozone profiles in the Arctic middle atmosphere have been measured with the two ground-based microwave radiometers MIAWARA-C and GROMOS-C for 3 years. The instruments have been located at the AWIPEV research base at Ny-Ålesund, Svalbard (79° N, 12° E) since September 2015 and the measurements are ongoing. We present the 3-year long and almost continuous datasets of water vapour and ozone which are characterised by a high time resolution. A thorough intercomparison of these datasets with models and with satellite, ground-based and in-situ measurements was performed. During these first three years of the measurement campaign we observed dynamical events which are typical for the Arctic middle atmosphere. The descent rate of mesospheric water vapour inside the polar vortex in fall was found to be 435 m/day on average. In early 2017 distinct increases in mesospheric water vapour of about 2 ppm were observed when the polar vortex was displaced and midlatitude air was brought to Ny-Ålesund. Two major sudden stratospheric warmings took place in March 2016 and February 2018 where stratospheric ozone enhancements of up to 4 ppm were observed. The zonal wind reversals accompanying a major SSW were captured in the GROMOS-C wind profiles which are retrieved from the ozone spectra. After the SSW in 2018 the polar vortex reestablished and the water vapour descent rate in the mesosphere was 355 m/day.
Integration of a high-flux energy-time entangled photon source into the Zimmerwald Laser and Astronomy Telescope

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The essence of each society is communication. Communication can happen in a personal face-to-face interaction or remotely, where a potentially very long channel links the sender and receiver of a message. Nowadays, the physical exchange of information between two parties is mostly based on the laws of classical physics. On the other hand, the laws of quantum mechanics have proven to be of particular importance for communication once the information carrier is extended from a classical two-level system to a discrete superposition of two quantum states, the qubit. Quantum communication, for instance, allows for provably secure communication between two partners in contrast to actual encryption schemes [1]. Moreover, it has been shown that a secret key can be distributed with entangled states, even without trusting the devices generating and detecting the photons. The aim of a global quantum communication network therefore relies on the efficient distribution of entangled photon states over long distances [2, 3].

This preparatory project therefore aims at the first realization of an infrastructure for the distribution of entangled photons over free-space links in Switzerland. As a first step, it foresees the integration of a high-flux energy-time entangled photon source based on spontaneous parametric down-conversion into the Zimmerwald Laser and Astronomy Telescope ZIMLAT (Fig. 1). The latter is operated by the Astronomical Institute of the University of Bern and is primarily used for satellite laser ranging and tracking of space debris.

First experiments will exploit the telescope optics to emit the entangled photons to a nearby retroreflector (659m) and measure the received photons in coincidence. These experiments will help to establish a test-bed for future investigations incorporating adaptive optics and multiplexed detection schemes.

Unraveling emission mechanism and electron mobility in fluorescent carbon nanodots by mean of 1D and 2D ultrafast transient absorption spectroscopy in various solvents

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Carbon nanodots (CDs) are a novel family of optically-active carbon-based nanomaterials discovered only a few years ago. They are 1-10 nm nanoparticles endowed with a rather appealing combination of properties: first of all a tunable and strong fluorescence in the visible, excellent solubility in aqueous environments and bio-compatibility, sensitivity to perturbations like the presence of metal cations and the capability of behaving as efficient photo-activated acceptors or donors of electrons and protons. Understanding their optical properties at a fundamental level and especially the interplay between core and surface groups is crucial to provide tailored samples for applications in many fields as optoelectronics, bio-imaging, nanosensors and markers.
We carried out an extensive study with 1D and 2D DUV-to-Vis femtosecond transient absorption (TA) spectroscopy on N-rich CDs in various solvents and pump-probe configurations. This family of dots is particularly interesting because of its high emission QY up to 80%, the possibility to tune the nm core structure from crystalline to amorphous and the presence of dual emission with strong sensitivity to the environment. As the fundamental properties are subject of strong debate in literature, our TA studies allow to disentangle the dynamics of different bands contributing to the emission activity (Figure 1) and to address size-dependent effects on optical and physical properties. We also provide unanticipated insight on the photocycle of CDs, unravelling the relaxation steps upon photo-excitation with the characteristic timescales. Moreover anisotropy studies in different solvents as water, ethanol, DMF and deep eutectic solvents (DES) allowed us to study the rotational diffusion of the transition dipole moment on fast timescales (10s ps), much faster than the rotational diffusion of the entire nanoparticles (10s ns). This finding reveals a diffusional energy transfer occurring through surface electronic states of the nanodots assisted by solvent fluctuations. The extensive study in DES, newly studied bio-compatible solvents related to ionic liquids, allowed important findings on the nature of the emission efficiency thanks to the possibility of varying the amount of water in solution.

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Ultrafast photo-induced enhancement of oxidation catalysis at Mo(VI) centers of Ru(II)-Mo(VI) dyads

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As a part of our research activity aimed to investigate the photophysics of photo-catalyzers containing metal complexes, we are extending our study to hard X-ray domain with
femtosecond optical pump/X-ray probe at the European free electron laser (EU-FEL) [1]. The first step is to choose promising molecular systems and to characterize their photo-induced dynamics with ultrafast optical spectroscopy. Such a study is mandatory before to apply for beam time at EU-FEL.

In this contribution, first we briefly describe the different supramolecular systems under investigation and then we will mainly focus on a biomimetic molybdenum (Mo) complex [2]. This system consists of a Ru(II) photoactive unit, bridged to a Mo(VI) catalytic moiety, is designed to facilitate oxidation catalysis at the Mo(VI) group by photo-triggered electron transfer (PeT) towards the Ru center.

The previously proposed model for the photo-induced oxidation-enhancing effect in Ru(II)-Mo(VI) complexes is described in three steps: (a) Photo-oxidation of the Ru(II) into Ru(III) and reduction of one of the Ru ligands (a bpy or a phen) upon formation of the Ru(III)-bpy/phen(-3) metal-to-ligand charge-transfer (MLCT) excited state, (b) neutralization of the charge on the ligand by means of an oxidizing agent and (c) finally, the activation of the Mo complex upon back-reduction of Ru(II/III). Since the second step is diffusion-limited, the last step, which corresponds to the production of a highly reactive one-electron oxidized Mo unit, occurs on μs time scales.

To verify this model and to shed new light on ultrafast photo-induced processes within the Ru(II)-Mo(VI) dyad relevant to the proposed intramolecular electron transfer mechanism, we carried out ultrafast transient absorption (TA) spectroscopic measurements of these complexes. We succeeded to track down the oxidation of the Mo unit and, surprisingly, we found multi-exponential dynamics spanning from 2 ps to 60 ps, with ca. half of the oxidation events happening within 2 ps. This result implies an intramolecular process which is in contrast with a diffusion-limited process. Based on this evidence, we propose a completely new explanation of the photo-induced oxidation-enhancing effect due to an electron transfer from Mo unit towards the bridging groups immediately after photo-oxidation of Ru(II) to Ru(III).

Time-resolved X-ray spectroscopy will be the ideal technique to definitively clarify the mechanism underneath this photo-induced oxidation enhancing effect.

Single cycle THz pulses for Stark Spectroscopy

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Energy shifts of molecular electronic transitions due to an external electric field, or Stark effects, are dominated by two molecular features; there exists a difference dipole moment over the transition and/or a difference in polarizability. Provided an isotropic distribution of molecules is maintained, these effects manifest spectrally as a broadening of the absorption peak in the case of the former or a shift in the case of the latter. By employing an intense THz single cycle pulse as external electric field source in a conventional femtosecond pump-probe setup, we can overcome many of the limitations of the conventional AC-electric field setup. By using a femtosecond supercontinuum as probe, we can study the evolution of Stark effects on ultrafast timescales. Future experiments are envisaged where, by first optically exciting the molecule, field effects can be studied during the photocycle.

Fig. 1 THz-induced Stark Spectroscopy.
Laser Cutting Parameters Optimization

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In this contribution we demonstrate an optimization procedure to determine optimal process parameters in reactive gas laser cutting of metals. The optimization scheme is based on a combination of a semi-analytical model for reactive gas laser cutting and the adaptive neuro-fuzzy inference system (ANFIS). The semi-analytical model was employed to generate training and testing data sets for ANFIS. Exemplarily, we show results for 10 mm thick DD11 steel plates. The system parameters consisted of two inputs: the cutting speed and the focal position of the laser with respect to the workpiece. The optimization was done with respect to the striation amplitudes. For each output a corresponding ANFIS-network was built. The optimal process parameters were extracted via a 3D surface or control plot of the generated fuzzy output for the striation amplitudes as a function of the two input parameters.

Extreme light generation in optical fibers

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In this contribution I present the vision and research questions that will be explored in my new group at the IAP, funded by an Eccellenza Fellowship of the Swiss National Science Foundation starting in July 2019. Understanding the interaction of intense ultra-short light pulses with plasmas is a key requirement to advance many ground-breaking strong-field physics applications like high harmonics generation, attoscience, and lightwave electronics. Gas-filled hollow-core photonic crystal fibers (HC-PCF) have emerged in recent years as an ideal platform for this purpose. The tight confinement of high intensity few-cycle laser pulses over long distances has made it possible to study the coherent nonlinear interactions between light and photo-ionised plasma in a well-controlled environment, and has led to the generation of light with extreme properties both in the temporal and the spectral domain.

In this project I will explore currently inaccessible regimes of light plasma interaction by combining advancements in the state-of-the-art of few-cycle laser pulse amplification with new concepts of plasma generation in HC-PCF. I expect to uncover new states of matter, novel nonlinear phenomena, and new technology for the development of in-fiber gas
lasers and extreme light sources from XUV to mid-IR with high potential impact on fundamental science, biology, healthcare, and sensing applications.

Fig. 1 Schematic of extreme light generation in optical fibers.