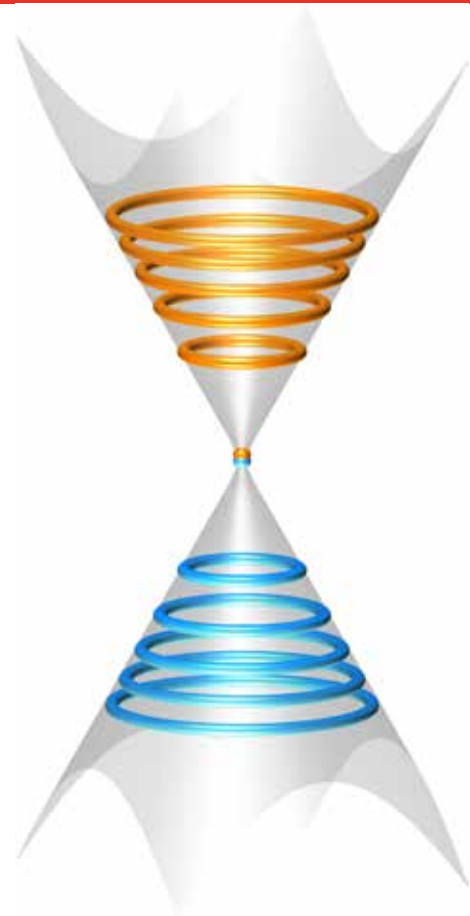


SPG Mitteilungen

Communications de la SSP



“Bernoulli’s Law”

• Assumptions:

• “stationary”:

$$\partial_t \vec{v} = 0$$

• forces from potential:

$$\vec{f} = -\nabla \Psi$$

• isentropic:

$$\nabla s = 0$$

⇒ from thermodynamics:

$$\nabla h = T \nabla s + \frac{\nabla P}{\rho} \quad (h: \text{specific enthalpy})$$

• apply to Euler equation

$$\partial_t v + (\vec{v} \cdot \nabla) \vec{v} = -\frac{\nabla P}{\rho} + \vec{f}$$

vector identity:

$$\nabla \left(\frac{1}{2} v^2 \right) = \vec{v} \times (\nabla \times \vec{v}) + (\vec{v} \cdot \nabla) \vec{v}$$

$$\Rightarrow \vec{v} \times (\nabla \times \vec{v}) = \nabla \left(\frac{v^2}{2} + h + \Psi \right) \quad \Big| \vec{v} \cdot$$

$$0 = \vec{v} \cdot \nabla \mathcal{B} \quad \text{with} \quad \mathcal{B} \equiv \frac{v^2}{2} + h + \Psi$$



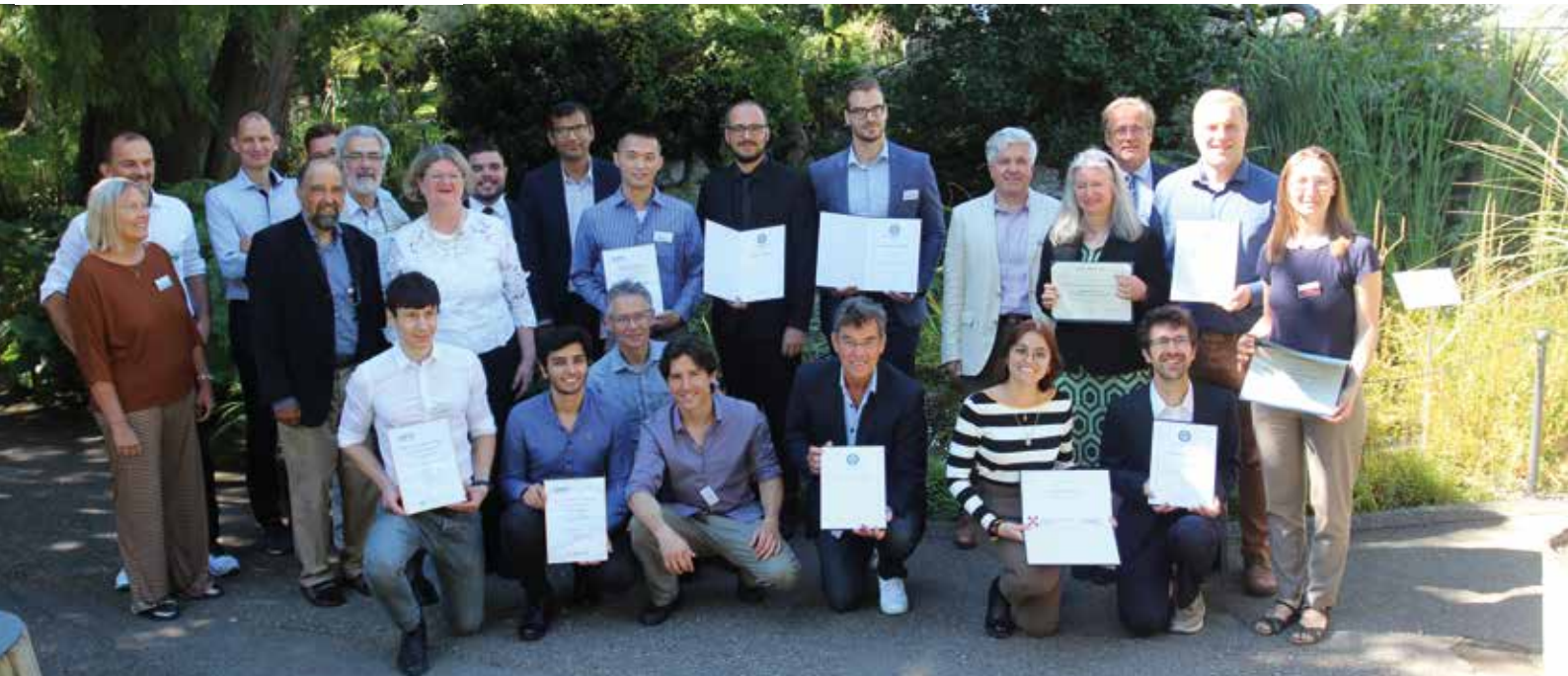
Daniel Bernoulli
1700 - 1782

12

New EPS Historic Site: The inauguration of Daniel Bernoulli's research environment "Stachelschützenhaus" in Basel included also talks on his scientific research. A biographical summary and review of the inauguration can be found on p. 54.

A strong magnetic field applied to a crystalline solid creates a set of discrete cyclotron orbits, called Landau levels. Read the full article on p. 35.

At our Joint Annual Meeting many colleagues were pleased to receive the top-class awards from SPS, ÖPG, SGN and EPS. The picture shows the winners and representatives of the sponsoring companies and societies. See p. 4 and 10 for details.



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member of the



Editorial

Next-Future Plans for the SPS

Teresa Montaruli, SPS President

After one year as vice-president of the SPS I started my mandate as president in Basel during our recent Joint Annual Meeting (see review on p. 8).

The next Joint ÖPG-SPG Annual Meeting is planned to take place in Vienna in 2025. It will be a special one, as it will be happening during the International Year of Quantum Science and Technology (IYQ2025), proclaimed by UNESCO to "celebrate the profound impacts of quantum science on technology, culture, and our understanding of the natural world". It should also emphasize the cross-cutting role of this scientific field for the critical societal challenges highlighted by the UN's 2030 Sustainable Development Goals, including climate, energy, food safety and security, and clean water. As a country on the frontline in this field, Switzerland is starting coordinated activities by the Swiss Quantum Commission of SCNAT¹, chaired by Prof. Nicolas Gisin. The SPS has very proactively defined an initial program of activities:

- Two historical symposia will be held at the SPS Annual Meetings: in 2024 on De Broglie, to celebrate his thesis on the theory of wave/particle duality concluded in 1924, and in 2025 on Pauli and Heisenberg, to commemorate the first formulation of the "Pauli principle" for electrons in 1925, and the mathematical formulation of quantum mechanics in a seminal paper published in 1925 by Heisenberg.
- Another initiative is an exhibition at the libraries of UZH/ETHZ in Zürich, a town which played a relevant historical role in the history of Quantum Science. The PGZ archive of the ETHZ library is currently scanning the minutes of meetings and public seminars from the period 1921-1927 in which Schrödinger was a professor at UZH, where his famous equation was published in 1926. This could be a subject for another historical symposium. These symposia have now become a tradition for SPS.
- The next issue of the **SPS Focus**, entitled "*The Role of Physics in Computing. Increasing Efficiency while Minimizing Energy Consumption*" is in preparation. The exponentially increasing digitization of society is a challenge where physicists in fundamental and applied research are asked for solutions.

The SPS is composed of 10 sections, for which various chairs must be renewed at the Annual Meeting 2024. Additionally, the Board decided to redefine the section "*Earth, Atmosphere & Environmental Physics*" to cover sustainability in physics research and energy science. The section was, besides numerous subjects related to geophysics and climate physics, already implicitly concerned with energy topics, but by reshaping and renaming it, the Board wishes to put the accent on energy as well as sustainability in physics research and applied science.

A roundtable on Sustainable Physics Research (see p. 16) indicated, i.e., the interest on defining strategies at physics departments, laboratories and experiments for CO₂ emission reduction.

Another relevant proposal to be discussed in the Board is the establishment of a commission on "*Equal Opportunity and Diversity*" (EOD), along the lines of our neighbour societies. Rather than a section, this would have a horizontal connection through sections. The scope of the commission is also to institutionalize in the SPS the organization of the *Women in Physics Career Symposium*, started by Marc Janoschek, which was successfully held at this year's Annual Meeting for the second time. The organizing committee has set up a mentoring program for female physics researchers.

The SPS EOD would also connect to other similar initiatives of neighbour societies. The EPS, i.e., has an Equal Opportunities Committee, which organises the *Emmy Noether Distinction* for Women in Physics². Several researchers in Switzerland obtained this prestigious award already, i.e. in 2015 Prof. Anna Fontcuberta i Morral (EPFL) and this year Prof. Ilaria Zardo (Uni Basel, see p. 10).

The German Physical Society (DPG)³ has a similar "Arbeitskreis Chancengleichheit", which organizes many activities, as the Lise-Meitner Lectures initiative, and the German Conference of Female Physicists. Relevantly, Switzerland is now represented by Christine Klauser in the ICWIP conference, which happened in July 2023 and to be repeated every 3 years organized by the WG5 of IUPAP on Women in Physics. A similar commission has been recently activated also by ÖPG. The EOD would also connect to other national activities, e.g. the SATW Tech Ladies and SCNAT Women in Science Portraits.

The General Assembly has accepted the increase of the membership fees, as announced in the last *SPG Mitteilungen*, thus helping to stabilize our finances and to continue our support for various initiatives.

The current trend regarding membership numbers is still unclear, we must consider this carefully by becoming more effective in our communication, and trying to become more evenly spread in the Swiss confederation. We recently opened a LinkedIn channel and set up a team for delivering news and monthly newsletters. It also includes PhD students who are interested in learning about science communication with experts like Margherita Boselli, responsible for the *SPS Newsletter*. A new web page is planned to become active soon. All these challenges lie ahead of me during my mandate.

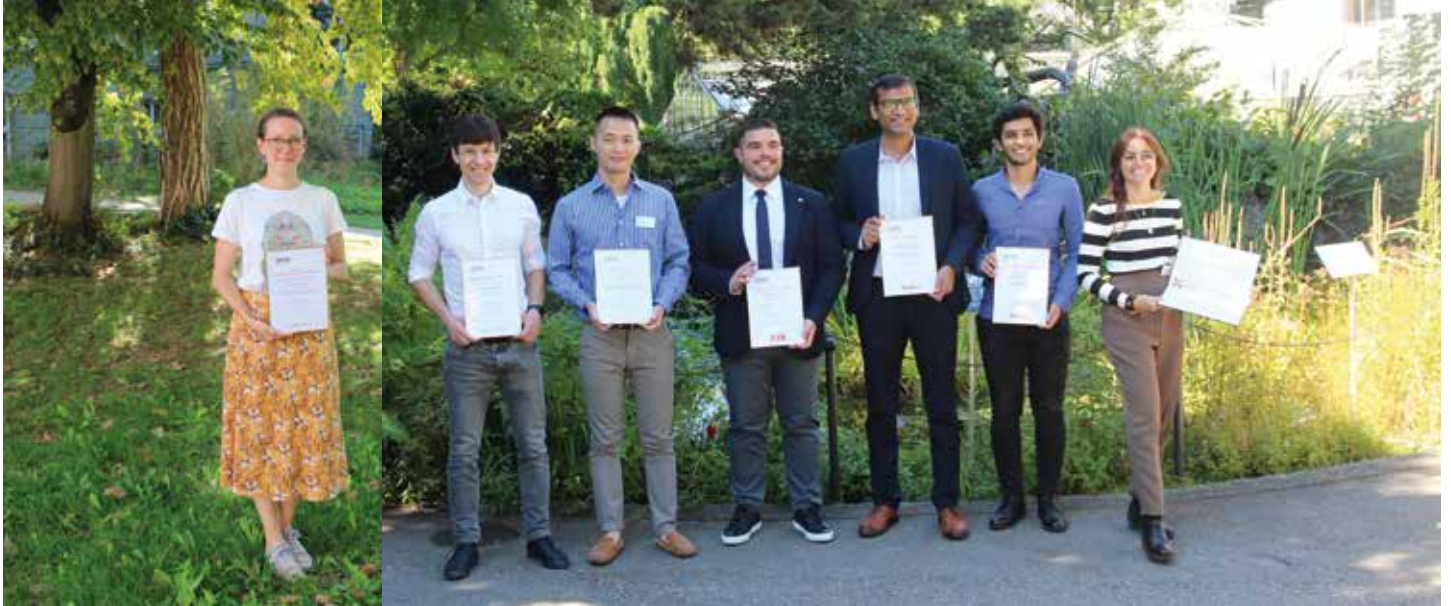
² https://www.eps.org/page/distinction_prize_en

³ <https://www.dpg-physik.de/>

¹ <https://quantum.scnat.ch/de/commission>

The winners of the SPS Awards 2023

The SPS Award committee, chaired by Prof. Hugo Zbinden, selected the winners for 2023 out of many submissions. The winners presented their work at the Joint Annual Meeting in Basel. Below are the laudationes (written by the representatives of the sponsors in the award committee) and brief summaries directly provided by the winners.



From left to right: Katharina Kaiser, Michele Simoncelli, Shih-Chi Yang, Simone Gargiulo, Vivek Maradia, Mohammad J. Beryhi (SPS Awards) and Elisabetta Nocerino (SGN Award).

SPS Award in all Physics Domains, sponsored by ABB Schweiz AG

This year, the General Physics prize goes to **Simone Gargiulo** for his work on the control of nuclear excitations by electron capture. This work is the content of his PhD thesis and has been already featured in respectable physics journals. Gargiulo's work shows that by controlling electron screening in excited ions, the probability of nuclear excitation by electron capture can be increased by three orders of magnitude, in comparison to the standardly computed ground state cross sections. He also found that engineering the electron wave function into a vortex can enhance the

cross-section for electron capture (and therefore creation of nuclei isomers) up to six orders of magnitude. Following this theoretical breakthrough, Gargiulo has engaged in the construction of an experimental table-top set up, to simulate astrophysical conditions for nuclear excitations. This is achieved by employing optical laser generated plasma. Gargiulo's work is greatly innovative, and interdisciplinary and his findings may have an impact in future energy harvesting technologies.

Electromagnetic processes of nuclear excitation

Since their discovery in 1921, long-lived nuclear excited states, known as nuclear isomers, have had impact on diverse domains, ranging from fundamental research to practical applications such as astrophysics and medicine, with also prospective potentials for nuclear clocks and energy harvesting. In this latter context, isomers have held for more than four decades the promise of delivering high-density compact energy storage due to their ability to remain in these metastable states for millions of years and beyond, even surpassing the age of the Universe in the case of $^{180\text{m}}\text{Ta}$. Unfortunately, our current ability to control the activation and depletion of these states is still far from being energetically viable. The main challenge lies in the fact that most processes that could enable the control of the isomer population demand strict conditions to occur and generally possess small cross-sections.

In recent years, my co-authors and I have explored and proposed novel mechanisms to enhance these cross-sections. We have performed theoretical and experimental investigations on several electromagnetic processes of nuclear excitation, including direct photoexcitation in a laser-plasma scenario, nuclear excitation by electron capture (NEEC) [1], and nuclear excitation by free muon capture (NE μ C) [2]. Our research shows that a significant increase in the cross-section by several orders of magnitude can be obtained in certain scenario. These studies offer alternative ways to populate the isomer from the ground states or to manipulate their decay, which might bring us a few steps closer to the long-sought dream of releasing the energy stored in isomers on demand.

[1] Simone Gargiulo, Ivan Madan, and Fabrizio Carbone. "Nuclear excitation by electron capture in excited ions." *Physical Review Letters* 128.21 (2022): 212502.

[2] Simone Gargiulo, Ming Feng Gu, Fabrizio Carbone, and Ivan Madan. "Nuclear Excitation by Free Muon Capture." *Physical Review Letters* 129.14 (2022): 142501.

SPS Award in Condensed Matter Physics, sponsored by IBM

The SPS 2023 Prize in Condensed Matter Physics, sponsored by IBM, is awarded to **Katharina Kaiser**, for synthesizing the carbon allotrope cyclo[18]carbon by means of atom manipulation and for revealing its structure by high resolution atomic force microscopy. The new carbon molecule C_{18} , whose structure was highly debated, was realized starting from a more stable precursor by scanning tunne-

ling microscope and atomic force microscope technique on an ultrathin NaCl layer on Cu. After the molecule was synthesized, Katharina Kaiser revealed its structure using high-resolution AFM with functionalized tips. Her achievements constitute a major milestone in the study of carbon allotropes and synthesis of molecules using scanning probe techniques.

Creation of the elusive carbon allotrope cyclo[18]carbon; a cyclic carbon molecule

Cyclo[n]carbons, ring-shaped purely sp-hybridized carbon allotropes, have been predicted for decades to exist [1] but their high reactivity has prevented them from being stably isolated and characterized. A distinctive feature is their two perpendicular π -systems, which can stabilize a perfectly n-fold symmetric ring-shaped structure. However, depending on the size of the ring, distortions in this geometry are more or less likely, making it difficult to theoretically predict a ground state structure. As a result, the structures of cyclo[n]carbon remained unknown.

Meanwhile, high-resolution atomic force microscopy (AFM) with functionalized tips has seen tremendous progress. For small tip-sample distances, AFM facilitates the imaging of atoms and covalent bonds within single molecules with atomic precision and bond-order resolution. In addition, using the tip as a local trigger to induce on-surface chemical reactions allows forming and investigating novel structures within the inert environment of the microscope – structures that may not be stable under ambient conditions.

Following this approach, we aimed to form and image cyclo[18]carbon (C_{18}) using atom manipulation and AFM. To this end, we used different precursors to C_{18} (one of which is shown in Fig. 1a) that we deposited onto thin NaCl islands on a metal surface. By positioning the tip close to the precursors and applying bias voltage pulses between the tip and the sample, we could trigger bond breaking reactions, leading to the formation of various reaction intermediates (Fig. 1b, c) and finally to the formation of C_{18} [2]

Figure 1 shows the molecular structures and bond-resolved AFM images of one of the precursors, as well as the structures that were formed on the surface by atom manipulation. Comparison of AFM images of C_{18} with simulated AFM images of different possible ground state structures indicates the presence of alternating single and triple bonds. The high exposed electron density of the triple bonds leads to a characteristic bright contrast in constant-height AFM images at large tip-sample distances, which is also visible in Fig. 1h. Thus, our experimental results show that the ground state structure of cyclo[18]carbon adsorbed on bilayer NaCl is polyynic.

[1] von Helden, G. et al. *Nature* **363**, 60–63 (1993)

[2] Kaiser, K., Scriven, L. M. et al. *Science* **365**, 1299–1301 (2019)

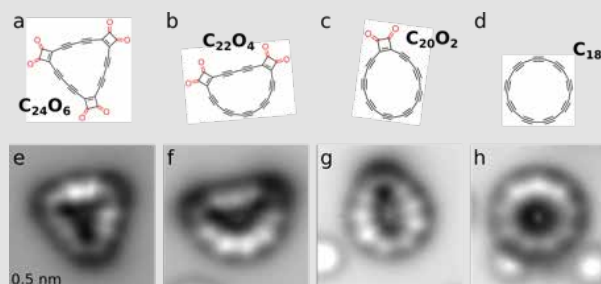


Figure 1: (a-d) Chemical structure of the utilized precursor, intermediate reaction products, and cyclo[18]carbon. (e-h) Constant-height AFM images of the precursor molecule (e), the reaction intermediates (f, g) and cyclo[18]carbon (h).

SPS Award in Applied Physics, sponsored by Oerlikon Surface Solutions AG

The SPS 2023 Prize in Applied Physics, sponsored by Oerlikon, is awarded to Dr. **Vivek Maradia** for his impressive work on the optimization of proton therapy for cancer treatment. In his PhD Thesis Vivek Marek described several new ways to improve the beam optics and other beam-line elements of a cyclotron. These optimizations enable beams of higher intensity at the isocenter, significantly reducing treatment time. For often weak-breathing lung cancer patients, this means holding their breath for only seconds instead of

a minute. The improvements also increase the number of patients that can benefit from proton therapy and enable concepts for ultra-compact, low cost and high-performance proton therapy facilities.

His research work has already resulted in three patent applications, six peer-reviewed journal publications and a Recognition Award from the Swiss Society of Radiation Biology and Medical Physics

Ultra-fast treatment delivery to enhance the potential of proton therapy for cancer treatment

Proton therapy has gained credibility as a treatment option for specific cancers, particularly through spot scanning or pencil beam scanning (PBS) due to its enhanced dose conformity. However, the effectiveness of PBS is limited for tumors affect-

ed by anatomical changes and motion. Motion mitigation techniques like rescanning and gating prolongs the treatment time and reduce patient comfort.

One potential solution is single breath-hold treatment, but it requires ultra-fast delivery within a timeframe of 5-15 seconds. Treatment delivery time in PBS proton therapy depends on

beam-on time and the dead time (time required to change energy layers and/or lateral position). To reduce beam-on time, several approaches have been proposed. These include using asymmetric collimators or scattering foil to transport maximum acceptable emittance and an energy selection system (ESS) with a wedge to reduce beam momentum spread. Simulations have demonstrated significantly increased low-energy beam transmission, allowing beam-on time to be limited to less than a second [1].

Optimizing spot-reduced plans has helped reduce lateral scanning time while maintaining treatment quality. This advancement has enabled the delivery of a single field within a breath-hold

for lung cancer cases. Efforts to decrease energy change time have led to the development of a universal and dynamic ridge filter that broadens the Bragg peak, further reducing treatment time [2].

In summary, by improving beam-on time, reducing dead time PBS proton therapy can be effectively delivered within a breath-hold. These advancements hold promise for treating moving targets and expanding the applications of proton therapy, all while reducing costs.

[1] V. Maradia et al., *Nature Physics* (2023); *Medical Physics* (2022); *Frontiers in Physics* (2022); *Medical Physics* (2021).

[2] V. Maradia et al., *Radiotherapy and Oncology* (2022); *Physics in Medicine & Biology* (2022).

SPS Award related to Metrology, sponsored by METAS

The SPS prize related to Metrology is awarded to **Mohammad J. Breyhi** for his outstanding PhD on quantum nano-optomechanical systems. Mohammad used structural hierarchy for the design of a novel kind of silicon nitride nanomechanical resonators improving substantially their mechanical quality factor. This work has been published in

Nature Communications [1] and the method presented has democratized the access to such high quality factor resonators.

Mohammad's research opens thus the way for new applications in various fields like sensing, quantum optomechanics and metrology.

Ultra-low quantum decoherence nano-optomechanical systems

Thermal motion of a room-temperature mechanical resonator typically dominates the quantum backaction of its position measurement. This is a longstanding barrier for exploring cavity optomechanics at room temperature.

In this work, we present the design, fabrication, and characterization of three different classes of nanomechanical resonators: clamp-tapered, fractal-like [1], and polygon resonators [2], which support perimeter modes, with Q factors exceeding 3 billion at room temperature and their optical readout using an integrated nearfield nano-optomechanical transducer using high stress silicon nitride. Our transducer features a one-dimensional Fabry-Perot optical cavity integrated with a high-Q nanomechanical resonator. The Fabry-Perot optical cavity is formed by patterning two photonic crystal reflectors on a silicon nitride waveguide designed for high-Q optical modes. Our approach allows indi-

vidual optimization of optical and mechanical resonators, while maintaining a high optomechanical coupling rate due to large optomechanical mode overlap. Our best performing devices show on-chip optomechanical transducers with single photon cooperativities as high as 123 with mechanical quality factor of 120 million at room temperature.

The developed system enables new possibilities in optomechanics, metrology and sensing. In quantum optomechanics, it will serve as a platform for quantum feedback control of the nanomechanical resonators to achieve motional ground state of a macroscopic resonator and generation of squeezed light at room temperature. Owing to their record value mechanical quality factors, the room temperature force sensitivity of our highest Q perimeter modes is on par with atomic force microscopy cantilevers at millikelvin temperature.

[1] M. Breyhi et al. 'Hierarchical tensile structures with ultralow mechanical dissipation', *Nature Communications* (2022)

[2] M. Breyhi et al. 'Perimeter Modes of Nanomechanical Resonators Exhibit Quality Factors Exceeding 10^9 at Room Temperature', *Physical Review X* (2022)

SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS 2023 Prize in Computational Physics, sponsored by COMSOL, is awarded to **Michele Simoncelli**, for his contributions to unifying the existing fundamentally different heat conduction theories in crystals and glasses. The two novel viscous heat equations cover, on the same footing, both the Fourier and hydrodynamic limits and all intermediate regimes. With his work at the junction of theoretical condensed matter physics and computational material science, he has achieved a milestone in solving the long-standing

problem of accurately predicting the thermal properties of crystals with ultralow or glass-like thermal conductivity, and explaining conduction minima in minerals, as observed in experiments. While the computations for the development of the theory are based on electronic-structure calculations and materials modeling at the nanoscale (density-functional theory), the new equations will also impact computational schemes for larger structures.

Modern theory of thermal transport in solids

Crystals and glasses exhibit fundamentally different heat conduction mechanisms. The periodicity of crystals allows for the excitation of vibrational wavepackets, which carry heat by diffusing particlelike, as first discussed by Peierls. In glasses, instead, the lack of periodicity breaks Peierls's picture and heat is mainly carried by wavelike tunneling between vibrational eigenstates, often described by a harmonic theory introduced by Allen and Feldman. Here, we show that these two established conduction mechanisms emerge from a unified Wigner transport equation, which encompasses the Peierls-Boltzmann and Allen-Feldman formulations as special cases and, most importantly, overcomes their failures in the intermediate regime where both particlelike and wavelike conduction mechanisms are relevant. We shed light on how the relative strength of particlelike and wavelike transport can be regulated by varying the degree of compositional, topological, or geometrical disorder in the atomistic structure of a solid, practically allowing us to engineer the magnitude and temperature dependence of its thermal conductivity. We demonstrate that this unified approach solves the long-standing problem of understanding and accurately predicting from first principles the ultralow thermal conductivity typical of excellent thermoelectrics, thermal barrier coatings, and nanoporous materials [1]. Next, we focus on crystalline heat conductors, where the Wigner formulation reduces to the Peierls-Boltzmann equation (PBE), and

exploits PBE's microscopic symmetries and conservation laws to rationalize the conditions under which heat transport macroscopically behaves fluid-like, deviating from Fourier's diffusive law. Specifically, we first show that the solution of the microscopic PBE can be decomposed into odd-parity and even-parity parts, and these affect heat transfer in a complementary way: the well-known odd-parity part determines the thermal conductivity; the hitherto neglected even-parity part determines another quantity—thermal viscosity—which becomes especially relevant in the 'hydrodynamic' regime, where most of the collisions between vibrational wavepackets (phonons) conserve energy and crystal momentum, akin to interparticle collisions in classical fluids. We demonstrate that thermal conductivity and viscosity parametrize a set of "viscous heat equations"—two coupled equations for the temperature and phonon drift-velocity fields—which generalize Fourier's law, describing not only diffusion but also heat hydrodynamics. These findings are showcased combining first-principles and finite-elements calculations in devices made of graphite, rationalizing the experimental finding of fluid-like behavior for heat in this material [2]. Finally, we employ this theoretical-computational approach to devise strategies to amplify and control heat hydrodynamics, paving the way for its exploitation in next-generation electronic and phononic devices.

[1] Simoncelli, Marzari, & Mauri. *Phys. Rev. X* **12**, 041011 (2022)

[2] Simoncelli, Marzari, & Cepellotti. *Phys. Rev. X* **10**, 011019 (2020)

SPS Award with relation to Energy Technology, sponsored by Hitachi Energy Switzerland AG

Shih-Chi Yang obtains the Swiss Physical Society Award with relation to Energy Technologies sponsored by Hitachi Energy Switzerland for his outstanding PhD thesis on bi-facial thin-film Copper-Indium-Gallium-Di-Selenide (CIGS) flexible solar cells. Among another highlight, namely, the development of the first bi-facial perovskite-CIGS tandem solar cell, his most remarkable result concerns the achievement of a world record efficiency. After systematic funda-

mental experimental studies and in-depth characterizations of structural, optical, and electronic properties of CIGS, Dr. Yang was able with a silver-assisted process to reduce the substrate temperature for film deposition to below 400°C, which was a reduction by more than 100°C and eventually allowed to boost the efficiencies from 9.0 % to 19.8 % for front illumination and from 7.1 % to 10.9 % for rear illumination.

High performance bifacial Cu(In,Ga)Se₂ solar cells with silver promoted low-temperature process

Bifacial photovoltaic (PV) systems have shown great promise in generating higher annual energy yields compared to conventional monofacial-based PV systems. They offer advantages in building-integrated PVs, vertically mounted bifacial PVs, and agrivoltaics, with low-carbon emissions and a cost-effective leveled cost of electricity.

However, bifacial thin-film solar cells, specifically bifacial Cu(In,Ga)Se₂ (CIGS) cells, have not kept pace with their monofacial counterparts. The efficiencies of bifacial CIGS cells remain low, hindering their adoption in various applications. Challenges such as the detrimental GaO_x interlayer formation at the CIGS/TCO (transparent conductive oxide) interface during high-temperature deposition have degraded device performance, leading to stagnation in the development of TCO-based CIGS devices. To overcome these limitations, a groundbreaking study introduced an Ag-promoted low-temperature CIGS deposition process [1]. This innovative approach enabled high-quality CIGS

growth at lower temperatures, preventing oxidation reactions at the CIGS/TCO interface. It resulted in higher Ga gradings, enhancing carrier collection under rear illumination. Optimizing the substrate temperature achieved a record bifacial CIGS solar cell with efficiencies of 19.77 % (front) and 10.89 % (rear) under one-sun illumination, independently certified by Fraunhofer ISE.

Additionally, the study directly fabricated bifacial CIGS solar cells on flexible substrates without lift-off process, offering scalability and cost reduction for larger-scale production. Furthermore, the demonstration of the first-ever bifacial perovskite/CIGS tandem solar cell in a 4-terminal configuration achieved a power generation density of 28.0 mW/cm² BiFi300, opening possibilities for various device architectures. These advancements hold great potential for the photovoltaic community, offering high performance and expanding the range of clean and sustainable energy applications.

[1] Yang, Shih-Chi, et al. "Silver-Promoted High-Performance (Ag,Cu)(In,Ga)Se₂ Thin-Film Solar Cells Grown at Very Low Temperature." *Solar RRL* **5**, no.5 (2021): 2100108

[2] Yang, Shih-Chi, et al. "Efficiency boost of bifacial Cu(In,Ga)Se₂ thin-film solar cells for flexible and tandem applications with silver-assisted low-temperature process." *Nature Energy* (2022): 1-12

Review of the Joint Annual Meeting 2023 in Basel

Our recent joint annual meeting took place in the Kollegienhaus (main building) of the University of Basel. Besides the Austrian Physical Society (ÖPG), we had again a few partners contributing to the program, namely the *Swiss Institute of Particle Physics* (CHIPP), the NCCR SPIN and the *Swiss Neutron Science Society* (SGN/SSSN).

The conference was again very well attended, despite, as is nowadays almost impossible to avoid, competing conferences having taken place at the same time as ours. Nevertheless, more than 520 participants attended, more than 310 oral and 63 poster presentations have been given and 10 exhibitors showed the latest lab equipments, measuring tools, books and more. Besides the usual ingredients like the general assembly, award ceremony and conference dinner, for the second time the satellite event *Women in Physics Career Symposium* has been organised, and with the celebration of the 400th birthday of Blaise Pascal we integrated our yearly historical symposium as an "opening" into the annual meeting.

Special thanks go to the house service and technicians for their help and support with the local organisation, as well as the helpers at the registration desk and in the lecture rooms. We heard a lot of positive comments about the meeting and would like to thank all participants who made with either their contributions or just as audience the conference a success.

In the following, we report as usual on selected topical sessions, present the winners of the Best Poster Awards (p. 17), and print the extended abstracts of those plenary talks which the speakers have kindly provided (p. 19 ff).

Physics Funding in Switzerland

After the successful session on Physics Funding at the Annual Meeting 2022, a similar session was held again this year. **Bernd Gotsmann** (IBM Rueschlikon and since 2020 president of Div. 2 of the Swiss National Science Foundation (SNSF)) presented with "Trends and developments in funding by the SNSF" recently established remarkable changes in the funding policy. We summarise them here as they are relevant to many scientists:

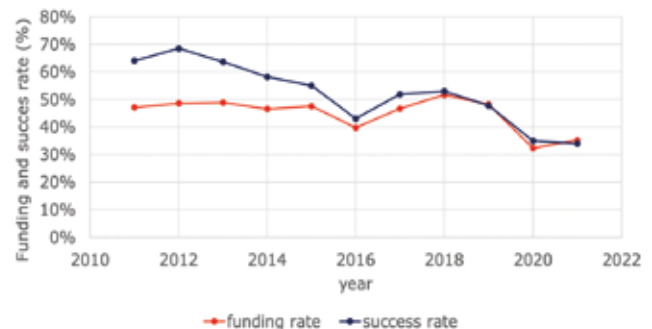
1) The current *Sinergia* program is now fully integrated into the project funding. Interdisciplinary projects that in the past



Philipp Treutlein, Bernd Gotsmann and Ben Kilminster.

would fit *Sinergia*, can be still submitted to the project funding requesting a dedicated evaluation panel for interdisciplinary projects. Collaborative projects or more applicants including 1 applicant from abroad are possible and coordination costs are eligible for 3 or more applicants. As a rule, hierarchical dependencies between applicants are not permitted.

2) A new limit of funding per project at 250 kCHF/year/PI is introduced in 4-year project grants and the maximum is 1 MCHF. Additionally, a PI has the possibility to have a maximum of 3 ongoing projects at the same time during the duration of a project funding grant if at least one of them is a Lead Agency/Weave project, International Co-investigator scheme, a European consortium agreement for a Joint Transnational Call (JTC) organized by an ERA-Net or European Partnership. Bernd presented statistics of various SNF funding programs, dissected into natural, medical and humanistic sciences. Most trends were very similar to what was presented at the funding session held in 2022. A key point is that an increasing funding demand has led to an



Funding rate = approved budget / requested budget

Success rate = number of approved proposals / submitted proposals



The plenary speakers in Basel: Anna Sfyrla, Felix Mayer, Markus Valtiner, Louise Harra, ...

overall lower success rate. This generates the disruptive funding environment and the negative impacts explained by Ben and Philipp afterwards.

Ben Kilminster (University of Zürich and CHIPP chair) presented the point of view of the particle and astro-particle physics communities. He explained the need for sustaining long-term projects for large experiments for all kind of research, either to answer fundamental questions or to create the necessary infrastructures and the tools to make them work. He considered that the success rate of fundamental physics science projects has decreased (see figure shown by BG at the 2022 session). As possible solutions, among others, he envisaged that SNSF could consider that relevant Swiss investments and commitments in large infrastructures cannot be nulled suddenly but continuation needs to be ensured. Possibly, cutting partially projects according to referee statements but not entirely as it used to be done in the past, or adding a criterium on relevance of national commitments can sustain projects in the longer term. Additionally, the *FLARE* program could allow hiring postdocs and not only engineers. He proposed to consult experts from other countries in funding physics on recent SNSF funding choices and to make a critical evaluation if changes are effective or not.

Finally, **Philipp Treutlein** (Chair of the Physics Department of the University of Basel) brought the point of view of the cantonal universities and pointed out that the project funding is surely the one with the highest potential and should be strengthened by ensuring a high success rate beyond 50 %. Cantonal universities have only these means for research and success rates as low as 20 % may challenge the system from being efficient and healthy. Additionally, the cancelled program *R'Equip* was a vital program for professors to make their laboratories more competitive and innovative and for the starting professors to establish their experimental activity.

Teresa Montaruli, Université de Genève

Pascal Symposium

The Pascal Symposium at the beginning of the SPS Annual Meeting on 4 September 2023 can be remembered as a success. Nearly 120 listeners including many students followed the presentations about person and work of Blaise Pascal from a historical as well as from a contemporary point of view in four exciting lectures. A short review has already been published by SCNAT at <https://map.scnat.ch/de/id/sZcwu?embed=HZk77>.



The speakers and chairpersons of the Pascal Symposium: Bernhard Braunecker*, Thomas Schulthess, Teresa Montaruli*, Dominique Descotes, Helena van Swygenhoven and Michael Korey in front of the newly inaugurated EPS Historic Site "Stachelschützenhaus" (see the article on p. 54)*

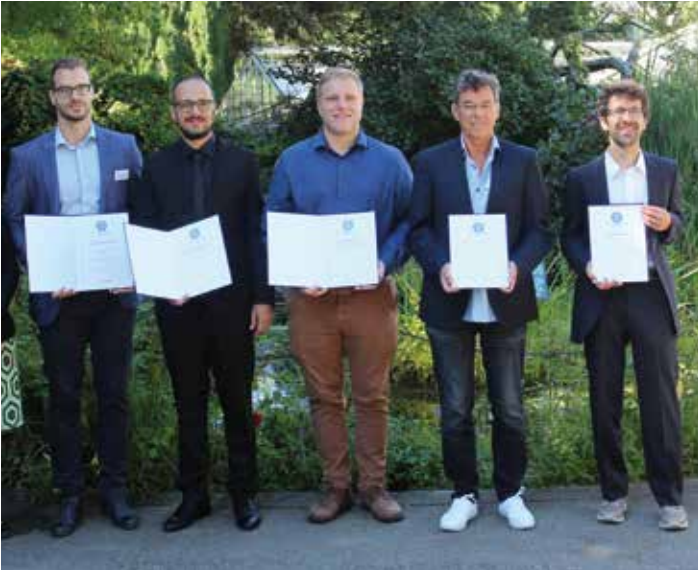
- If you want to know more about the contents of the lecture of Dominique Descotes, you may refer to some of his books <https://www.fnac.com/a1607882/Dominique-Descotes-Treize-etudes-sur-Blaise-Pascal> or also <http://ihrim.ens-lyon.fr/recherche/breve/dominique-descotes-savoir-demeurer-en-repos-chez-soi-avec-blaise-pascal>.
- The slides of the presentations of Helena van Swygenhoven and Thomas Schulthess can be downloaded from <https://indico.cern.ch/event/1252545/sessions/497418/#20230904>
- We hope to receive from the author of the 3rd talk, Michael Korey, for one of the next issues of the *SPG Mitteilungen* an article about the time before Pascal, the exciting phase of the beginning of precision mechanics for clocks, but also computing machines as the Pascaline.

We plan to continue our series of historical symposia at the annual meeting 2024, taking place at ETH Zürich with the topic: "Louis de Broglie: 100 years of wave / particle dualism". More information will appear in the next *SPG Mitteilungen*.

Bernhard Braunecker



... Bodo Wilts, Peter Puschnig, Christian Wüthrich, ...



The ÖPG winners: Nicola Opačak (Boltzmann Award), Igor Sokolovic, Josef Leutgeb (Thesis awards), Franz Embacher (Sexl Award), Bernd Aichner (Thesis Award).

Award Ceremony

In addition to the usual awards of the organising societies SPS (see also p. 4) and ÖPG, this year the *Emmy Noether distinction* of the European Physical Society (EPS) dedicated to female physicists has been given.

Prof. Petra Rudolf, chair of the EPS Equal Opportunities Committee and former president of the society, handed over the EPS Emmy Noether Distinction 2022 to Prof. **Monika Ritsch-Marte** (full career) and to Prof. **Ilaria Zardo** (mid-career).



Petra Rudolf, Ilaria Zardo, Charpak-Ritz Award winner Bruno Mansoulié and Monika Ritsch-Marte

Monika Ritsch-Marte, from the Institute of Biomedical Physics, Dept. of Physiology & Medical Physics, Medical University of Innsbruck, Austria, was awarded "for exceptional contributions to optical microscopy and manipulation methods and for the promotion of women's careers in physics."

Ilaria Zardo, researcher at the Department of Physics of the University of Basel, Switzerland, was awarded "for her contributions in the methodology of characterizing nanoscale materials and the consequent discovery of their new functional properties."

The ceremony was followed by an interview of both EPS laureates by Prof. Rudolf and a group photo with laureates of all the presented prizes in the beautiful botanical garden of the university.

Gina Gunaratnam, Communication coordinator, EPS

Accelerator Science and Technology

The Accelerator Science and Technology session (as special part of the Applied Physics session), reflected a wide range of accelerator related research activities in Switzerland.

The majority of the contributions dealt with research towards the next proposed future CERN project FCC. These have been undertaken within the Swiss Accelerator Research and Technology collaboration CHART at CERN, EPFL, ETHZ, PSI and University of Geneva.

The development of high field magnets (HFM), using both low (LTS) and high (HTS) temperature superconducting materials, was covered in a number of presentations. Remarkable results presented pointed out not only very encouraging steps toward the HFM magnets, but also a number of synergies with the needs for such magnet technology in applications ranging from lowering the power consumption of the future accelerators to the use in light sources, neutron scattering and medical applications. A positron source for a collider, to be tested at PSI and utilizing a strong HTS magnet, will reach high conversion efficiency.

Studies of LHC electron clouds, which affect the beam stability and cryogenic load in the LHC, provide an opportunity



... Nobel Laureate 2022 Anton Zeilinger, Karina Morgenstern and Sascha Schmeling.



At this year's General Assembly Dr. Bernhard Braunecker and Prof. Dr. Ruth Durrer have been elected as Honorary members. The presentations and laudationes have been printed in the last issue of the SPG Mitteilungen.

to understand the constraints imposed by this effect on future colliders such as the FCC.

Muon beam cooling experimentally tested at PSI is promising 8 orders of magnitude reduction of phase space.

The session finished with a review of advanced ideas for proton and ion beams for radiation therapy that are being implemented in several studies undertaken by accelerator specialists in Switzerland.

Lenny Rivkin, PSI Villigen

Applied Physics and Plasma Physics

Ten contributions were presented in the Applied Physics and Plasma Physics topical group session. Two posters covering, in the first instance, parallel computing applied to plasma physics and in the second addressing the application of neural networks to the solution of some of the fundamental equations of physics. Eight talks were given, with one on applied physics and seven on plasma physics. The applied physics talk addressed ultra-sonic testing of materials. The plasma physics talks covered topics from tokamak physics and fundamental plasma physics addressing subjects as broad as fast ion transport to machine learning applied to inverse problems. This year's applied physics and plasma physics topical section provided a very rich and interesting collection of presentations. Thank you all.

Laurie Porte, EPFL

Nuclear, Particle and Astrophysics

The particle, astrophysics and nuclear physics session was organized jointly between the TASK ("Teilchen-, Astro- und Kernphysik") section of the SPS and the corresponding FAKT ("Fachausschuss für Kern- und Teilchenphysik") section of the Austrian Physical Society, and with the support of CHIPP, the Swiss Institute for Particle Physics.

In the first talk of the plenary session Anna Sfyrla (UniGe) introduced the Large Hadron Collider (LHC) with its large experiments and newly added smaller detectors, providing an overview of achievements and giving an outlook towards the new data-taking period and expected results (p. 19, <https://indico.cern.ch/event/1252545/contributions/5534708>).

Later in the session, Bruno Mansoulie (Université Paris-Saclay), this year's recipient of the Charpak-Ritz prize awarded jointly by the Swiss and French Physical Societies, told a story of his scientific life – about how the standard model of particle physics was built thanks to experiments at hadron colliders (<https://indico.cern.ch/event/1252545/contributions/5534710>).

Parallel sessions were split in six topical blocks dedicated to the physics from the LHC experiments and theory, precision experiments with muons, low-energy experiments and antimatter studies, detectors and algorithms, collider dark sector and neutrinos, and dark matter searching experiments. These subjects were covered in 48 oral presentations and 6 posters, and they were lively discussed in the audience, which brought together particle physicists from various sub-fields. Most contributions presented at the TASK/FAKT session are available in the indico page of the event (<https://indico.cern.ch/event/1252545/sessions/497620/#all>).

History and Philosophy of Physics

The history session was quite well attended and interesting questions popped up after the different contributions.

Reinhard Folk scored, as so often in the past, with profound research, clarity of the slides and very good explanation concerning the Irish scientist Richard Kirwan (1733 – 1812) and his contributions to theory of ferromagnetism. Franz Sachslehner was able to demonstrate his penchant for physics experiments in a presentation about selected objects from the historical physics collection at the University of Vienna. He also used multimedia presentations to show its practical use in classroom experiments. Bruno Besser (and Nora Pärri) illustrated the construction and instrumental equipment of various astronomical observatories in the Austrian-Hungarian Empire in the second half of the 18th century by means of descriptions from the travelogues of Johann III Bernoulli (1744 - 1807). Last but not least, Martin C. E. Huber (and co-workers) introduced the audience to some local historical facts about Daniel Bernoulli (1700 - 1782) and his experiments and col-



Martin C. E. Huber during his talk.

lection of instruments in the Physics Cabinet at the Basel “Stachelschützenhaus”, which was assigned as an EPS Historic Site later in September 2023 (see p. 54).

The plenary lecture by Prof. Christian Wüthrich (p. 31) was in a class of its own, talking about the future promises for quantum gravity and the consequences for our understanding of physical processes in general. His contribution made many in the audience think about where the journey in an important field of physics could or has to proceed in future. Hints about the consequences of different ideas and/or approaches, or even a radical change in our way of thinking, could or would have, concluded his philosophical contribution.

Bruno Besser, Österreichische Akademie der Wissenschaften

Atomic Physics and Quantum Optics

In the Atomic Physics and Quantum Optics session this year we had 16 talks. Controlling, understanding and leveraging light-matter interaction was the common theme, covering a very wide range of systems and applications. This was exemplified by many presentations covering the study of nano-mechanical oscillators, including in particular the presentation Mohammad Bereyhi, laureate of the SPS METAS PhD prize (see p. 6), as well as ultra-cold atoms or biological systems. The quantum aspects have been strongly emphasized this year, with the important role it plays in the Austrian community as well. The applications described range also towards ultra-fast switches of direct relevance to future electronic devices.

On the fundamental physics side, quantum optics and atomic physics proved again a valuable field to search for the origin of the classical-quantum boundary, both from the conceptual point of view and for searching for quantum advantages in performing certain tasks. Notably, a presentation demonstrated potential application of atomic physics spectroscopy methods in the particle physics context, in the investigation of the matter-antimatter differences.



Anton Zeilinger at the end of his talk, answering questions from the audience.

The plenary presentation of Anton Zeilinger, Nobel laureate in 2022 for his work on quantum entanglement, in front a fully packed auditorium was a major highlight and demonstrated the spectacular evolution of the field from fundamental

interrogations on quantum mechanics to future technological applications.

Jean-Philippe Brantut, EPFL

Condensed Matter (KOND)

The Condensed Matter session consisted of 7 blocks scheduled from Tuesday to Friday. We report here on 4 of them. In addition, reports from several special sessions dealing with related topics can be found further below.

The first block focused on electronic and thermal properties of 2D systems and it was attended by about 50 people, ranging from PhD students to senior PIs. It started with Michele Simoncelli, the recipient of the SPS Award in Computational Physics (see p. 6), who presented his unified formulation of thermal transport and the effect of geometrical and topological disorder on the thermal properties of materials. The discussion continued with the presentation of experimental observation of thermodynamic fingerprints in twisted monolayer-bilayer graphene, electronic Poiseuille flow in hexagonal Boron Nitride encapsulated graphene FETs. Several contributions reported on the properties of van der Waals heterostructures, superconductors and twisted multilayers graphene explored with different experimental techniques, ranging from ARPES to electronic transport experiments. In between talks, lively discussions triggered by questions took place.

The third block on devices and applications facilitated discussions that delved into the exciting realm where fundamental physics converged with practical applications. Throughout the session, the audience actively participated by asking questions and engaging in lively discussions.

The session opened with the invited talk by the winner of the SPS Award in Energy Technology, Shih-Chi Yang (p. 7), whose novel work on High-Performance Bifacial Cu(In,Ga)Se₂ Solar Cells opened new horizons in the realm of clean and sustainable energy sources. Yang's presentation resonated with the session's overarching theme of transformative applications. Following this talk, the session continued with four contributed presentations, each spanning a diverse spectrum of subjects. These talks showcased the session's remarkable versatility, weaving together both experimental and theoretical research. They delved into captivating topics such as thermal rectification in nanowires, tannin-furanic foams, ultrafast photoinduced phase transitions, and innovative fabrication techniques for magnonic conduits. This session served as a testament to the multifaceted nature of condensed matter physics, where scientific exploration intersects with the practical realm to create tangible advancements with profound real life applications.

The Varia block on Wednesday was attended at the beginning by about 30 participants, and towards the end by about 20 participants. All the 9 talks were about 15 minutes long, 6 talks dealing with theoretical and simulation aspects and 3 talks dealing with experimental aspects presented for different kind of materials (superconductors, metal oxides, ferroelectric materials, ferromagnetic materials, antiferromagnetic materials). After each talk at least one or two questions were asked, contributing to the discussion of the 9 presentations, all the presenters keeping the time assigned.



Coffee breaks, poster sessions and vendor exhibition were all located on the first floor of the Kollegienhaus, allowing for excellent interaction and vivid discussions.

The last block on Friday was attended by 20 - 30 participants and it focused on X-Ray Scattering and inelastic light scattering experiments to probe the crystal structure and collective excitations of different type of materials, nanocrystals and heterostructures. Furthermore, femtosecond transient absorption microscopy experiments were presented.

Ilaria Zardo, Aswathi Kanjampurath Sivan, Universität Basel, Maurizio Musso, Universität Salzburg

New prospects in ARPES for quantum materials

The special session “New prospects in ARPES for quantum materials” highlighted the importance of various forms of angle-resolved photoemission spectroscopy (ARPES) for the discovery and investigation of novel quantum phenomena in condensed matter. In 2023, it took place for the second

time within the SPS annual meeting, and more than 30 scientists were attending the afternoon session that gathered 15 different oral presentations, including 3 invited ones. There were also two contributions as posters. This year, a recurring theme was related to the measurement of tiny two-dimensional samples made of monolayers and heterostructures of van der Waals materials, which is very timely in the hard condensed matter community. Another highlight was about the use of circular dichroism in the photoemission process to extract information about the wave function of electrons in solids. Finally, the audience could also learn about the latest developments in orbital tomography in the time domain, a method to reconstruct the real space orbital shape of molecules, and soon crystals, on the femtosecond time scale. The high quality of the talks and posters, highlights the breadth and depth of the ARPES community in Switzerland and Austria.

Claude Monney, Université de Fribourg

Magnetic fields for materials research

The EU project ISABEL (“Improving the sustainability of the European Magnetic Field Laboratory”) aims, with its “Community building and membership enlargement” work-package, to expand the users community of the High Magnetic Field Laboratory (HMFL) from the different European countries, strengthening therefore its position as an essential facility for the scientific research. The mutual benefits of this collaboration should be the object of a contract between the HMFL and each country, allowing a sustainability of the HMFL over long term and providing a financial support to the infrastructure.

Switzerland benefits from the access to HMFL performing several experiments every year at the different locations of the facility: although this magnet time constitutes a small percentage of the total magnet time, it enables several Swiss experimental groups to perform research at the forefront of the science. This has been the framework leading to the organization of a special session at the joint annual meeting of SPS and ÖPG. This annual gathering has been selected for its large number of participants to showcase the remarkable impact of the HMFL on the Swiss and Austrian condensed matter research.

Charles Simon, current director of the HMFL, has reviewed the capabilities of the laboratory and its development plans: one side side, the laboratory aims to reach higher magnetic field values and, on the other side, to become more sustainable, in particular with respect to its actual use of electric power. The advantages of accessing large magnetic fields have been illustrated in the scientific talks of Ana Akrap (University of Fribourg) and Matija Čulo (University of Zagreb). The two speakers have discussed magneto-optics and magneto-transport experiments respectively performed at different HMFL locations in order to unveil the electronic band structure of 2D semi-metals and superconductors. In the last invited talk, Alexander Steppke (PSI and University of Zurich) has presented the progress of a collaboration with the HMFL to provide pulsed magnetic fields at the Cristallina end-station of the Swiss Free Electron Laser (SwissFEL) for wide-angle X-ray scattering: the aim is to reach magnetic field up to 40 T within a repetition rate of minutes. The session, chaired by the Swiss representative of the ISABEL

project, Stefano Gariglio (University of Geneva), has been attended by an audience of ~40 people and sparked several discussions, both on the physics of the 2D systems and on the future of the HMFL. The SPS greatly acknowledges the financial support received from ISABEL for hosting this special invited session. A possible integration of the HMFL Swiss research in the program of the SPS annual meeting will be discussed after the success of this first event.

Stefano Gariglio, Université de Genève

Spintronics and Magnetism at the Nanoscale

Mesoscopic Systems (ETH Zürich / Paul Scherrer Institut) is pleased to have organized several Spintronics and Magnetism at the Nanoscale sessions at the 2023 Joint Meeting of the Swiss and Austrian Physical Societies. The audience was treated to eighteen talks from researchers representing nine research institutes during the presentation sessions. Topics ranged from quantum computing using spins, antiferromagnetic dynamics, topological magnetic textures, three-dimensional magnetic imaging, and the burgeoning field of magnonics. Professor Hans Hug (Empa / Uni Basel) and Dr. Santa Pile (Johannes Kepler University) were invited speakers. In addition to the wonderful presentations, fourteen researchers presented their work as part of the conference-wide poster sessions.

Jeffrey Brock, PSI Villigen & ETH Zürich

Neutron Science

The 'Neutron Science' session at the Swiss and Austrian Physical Society meeting built on the success of its last year's first edition. The session impressively showed how versatile the elemental particle can be used to investigate solid state materials, study the fundamental principle of particle physics and research on applied materials. This was also reflected by the two prize talks of the *Swiss Neutron Science Society*, highlighting the power of neutron scattering to probe the various degrees of freedom in complex materials and to test predictions beyond the standard model.



Elisabetta Nocerino, one of the winners of the Young Scientist Prize of the Swiss Neutron Science Society, sponsored by SwissNeutronics.

The first part of the general neutron session was dedicated to the cutting-edge research on complex magnetic materials. Particular focus was given to magnetically frustrated materials, revealing strong electronic fluctuations that trigger novel quantum states. The second part of the session commented on novel approaches in modeling magnetic interactions in artificial spin structures, ideas how to reach higher external magnetic fields at future neutron sources, recent progress in magnetic domain imaging, the current state of a future neutron beta-decay experiments, and recent research on nuclear storage materials.

The lively discussion during the session and poster session testifies the high quality of the presentations, and the deep interest the scientists follow their research activities. The combined session between neutron scattering, imaging and particle physics also allowed for a mutual understanding between the various research activities neutrons can be used for.

Daniel Mazzone, PSI Villigen

Biophysics, Soft matter and Medical Physics

This year's sessions on Biophysics, Soft matter and Medical Physics covered a broad range of subjects, indicated by the two invited talks. Here Suliana Manley from EPFL showed how Physics and imaging-based approaches can give us important insights into the division machinery of mitochondria and Vivek Maradia from PSI described how the proton therapy beamline at PSI can be used even for more dynamic tissues, such as the lung, due to vast increases in the delivery time of the dosage (see also p. 5). Thus, while showcasing very different areas of Bio- and Medical Physics, both of the talks highlighted the importance of technological developments in the field of imaging and radiation therapy.

In addition to these two invited talks, there were 19 contributed talks. These spanned the entire field, and we learned how curved surfaces as well as random light fields influence soft matter aggregates, where experimentally bacterial colonies or tissue cultures were studied and theoretical modelling of colloid-light interaction as well as the topology of nematics on curved surfaces was performed. On the other hand, we saw how random light fields can be used in the form of wave-front shaping to enhance deep-tissue imaging. In other presentations, the soft matter aggregates consisted of biological tissues going through morphogenesis and shaping tissues, such as the vein patterns in the drosophila wing, where detailed regulatory networks are at play that can be modelled to describe both the wild type process as well as mutant phenotypes. These regulatory mechanisms also need error correction mechanisms that another presentation has studied in terms of their importance in pattern formation. Finally, the behaviour of entire organisms, like *C. elegans* and *S. Cerevisiae* formed the basis of several presentations as models of decision making and the study of neuronal networks.

With their breadth the three sessions illustrated the field of soft matter, bio- and medical physics very well and showed how basic physics concepts, such as topological defects, fluid flow, liquid crystals, Casimir forces, randomness and pattern formation can be used to understand biological systems or be useful in a medical context.

Christof Aegerter, Universität Zürich

Theory

As for the past annual meetings of the SPS the theory talks were embedded in their respective topical sessions, which is well appreciated. At the last joint SPS and ÖPG meeting in Basel there were many theoretical talks distributed among the different sections. In the TASK sessions were only 3 theory related presentations on a total of about 50

talks, which covered topics including dark matter and QCD aspects. In the ARPES session were 5 theory talks out of 15, whereas in the the session on quantum computing 6 of the 17 talks were on theory aspects. In Atomic Physics and Quantum Optics 5 out of 16 talks and in the session on Spintronics and Magnetism at the Nanoscale 2 out of 18 were on theory aspects. In the KONND sessions about a third of the presentations were on theoretical topics. The number of theory talks, as expected, varied significantly among the various sessions, but constituted in general a sizeable fraction ($\sim 10 - 30 \%$) of all contributions.

For the first time a new session on **Gravitational Waves** has been organized. It took place on Tuesday afternoon and comprised 10 talks mostly on theoretical and data analysis aspects both for LISA, the planned gravitational wave detector in space, and for the Earth bounded detectors LIGO/Virgo, which have already detected more than 100 events since they became operational in 2015. The session was well attended and appreciated. We shall thus organize it also in the forthcoming meetings.

Philippe Jetzer, Universität Zürich

Nanotechnology – From Hype to Application

This session organized by the SPS/ÖPG sections “Physics in Industry” focused on how nanotechnologies have matured over the decades from an (over-) hyped topic to an enabling technology for a broad, diverse set of fields and industries. Probably the most widespread applications are in thin film coatings, ranging from nanocomposites for scratch-resistant furniture (P. Fankhauser, Senoplast) over PVD coatings for wear reduction in engines and cutting tools (A. Müller, Oerlikon Balzers) and components for LCD and OLED displays (D. Pires, Rolic) to UV-nanoimprinting for antibacterial, antireflective, light-diffusive or even air-drag reducing surfaces (B. Stadlober, Joanneum Research). Measuring at the nanoscale requires ever more powerful tools, be it sophisticated self-driving atomic force microscopes (D. Ziegler, Nanosurf), fast and efficient X-ray detectors for protein crystallography (S. Traut, Dectris), scanning large wafers for nanoscale defects by picosecond cathodoluminescence (S. Sonderegger, Attolight) or even detecting cancer cells with nanomechanical sensing (P. Oertle, Artidis). Recent advances in micro-/nanofabrication were presented, ranging from applying femtosecond laser pulses to pattern glass for the watch industry or for producing flexible, hollow glass needles (C. Alferi, Femtoprint) all the way to nanoscale “sculpting” with a heated atomic force microscope tip that is used as a chisel for closed-loop grayscale litho-



graphy (F. Könemann, Heidelberg Instruments Nano). Two presentations demonstrated vividly the virtues of nanofabricated optics where nanopatterned zone plates enable to focus X-rays more tightly (A. Kubec, XRnanotech) or for integrated, efficient optical data communication components (T. Kornher, Lumiphase).

Peter Korczak, ÖPG; Christian Teissl, Werkstätte Wattens; Andreas Fuhrer, Thilo Stöferle, IBM Rorschlikon

Quantum Computing

The Quantum Computing session took place in 3 blocks on Thursday and Friday afternoon, consisting of a mixture of talks reporting on both experiments and theory, from both Austria and Switzerland. The talks described recent scientific advances on various aspects of quantum computing covering both hardware and software. The session was opened with a brief introduction by Dominik Zumbühl (NCCR SPIN, Basel), and featured 17 talks. 6 of them were from theory, including two invited talks (Daniel Egger, IBM, and Zoë Holmes, EPFL). 11 talks were about experiments, with 3 invited speakers (Andrea Hofmann, Basel, Georgios Katsaros, IST Austria, and Ben Lanyon, Innsbruck). Finally, there was also an external invited talk from a pioneer of the field (Lieven Vandersypen, TU Delft). The session was organized by the *NCCR SPIN: Spin qubits in Silicon* (<https://nccr-spin.ch/>), bringing together the quantum computing communities from Austria and Switzerland.

Dominik Zumbühl, Universität Basel

Sustainable Research in Physics

A panel discussion on Sustainable Physics Research was held on the last day of the Annual Meeting, organised by Hugo Zbinden. Philipp Treutlein (Chair of the Physics Department in Basel), Anna Soter (DPHYS, ETHZ), Mike Seidel (PSI Villigen) and Tomoko Muranaka (EPFL) illustrated strategies respectively at the Physics Departments of the University of Basel and of ETHZ and at EPFL to incorporate good practice in Physics Research and adaptation of laboratories and building infrastructure for energy savings. D-PHYS produced recently a document listing a number of possible actions to assess and reduce CO₂ emissions, starting with online conferences to reduce travel not strictly necessary. The target at ETHZ is to reduce CO₂ emission by about 40 % in 2030. Travel represents the main contributor



From left to right: Philipp Treutlein, Hugo Zbinden, Tomoko Muranaka, Mike Seidel, Anna Soter.

to CO₂ emission. In the roundtable, it was discussed that a more conscious travel policy should be adopted in institutes where most of the meetings could be held also online and in person only when strictly necessary. Educating the future generations for sustainability, optimised use of resources, and carbon-free energy production was also felt as part of our mandate as physics teachers.

Teresa Montaruli, Université de Genève

2nd Women in Physics Career Symposium

Building on the success of the inaugural “Women in Physics Career Symposium” carried out at the annual SPS meeting 2022, the goal of the 2nd symposium is to continue to boost women in the early career stage from undergraduate to postdoctoral studies and to consolidate the associated professional and mentoring network in physics. In addition, this year the scope was extended to include speakers pursuing successful careers both in and outside academia. The event was organized with the financial support of the University of Zurich, the Paul Scherrer Institute, and the Swiss Physical Society, Swiss Academy of Natural Sciences (SCNAT) and Zurich Instruments. Notably, mentees selected for the mentoring network associated with the event received a small travel stipend to facilitate their travel to Basel, which was kindly sponsored by Zurich Instruments.

The symposium was chaired by Philipp Schmidt-Wellenburg (PSI, Chair of Committee for Equal Opportunities) and was kicked off by two keynote talks given by **Jamie Gloor** (Diversity and Leadership Expert, CCDI, HSG) who presented on techniques of “Careering while Female” and **Tomas Brage** (Lund University) who discussed how “Bias ruins everything!”. The keynotes were followed by career talks given by **Mitali Banerjee** (EPFL), **Ruth Durrer** (UniGe), **Heidi Potts** (Zurich Instruments), **Zoë Holmes** (EPFL), **Andrea Biedermann** (Career Center, PSI) and **Tracy Northup** (Universität Innsbruck). All speakers provided in-depth insights into their careers and gave advice to the mentees and participants. The program also included a presentation

by **Barbara Stäuble** from Women-in-Tech Switzerland (<https://women-in-tech.org/ch>) — a world leading organization for Inclusion, Diversity & Equity in the STEM field working on educating, equipping and empowering women and girls with the necessary skills and confidence to succeed in STEM careers. Finally, a podium discussion moderated by **Anna Fontcuberta i Morral** (EPFL) that allowed participants to ask questions completed the event. This supportive atmosphere spurred conversation



The participants of the Women in Physics Career Symposium.



The conference dinner took place in the restaurant "Ayledo", situated close to the university in a nice "Naturgarten", which was ideally suited for the apéro.

ÖPG president Christian Teichert, SPS vice-president Teresa Montaruli and SPS president Johan Chang during their after-dinner-speech.

among participants who had the opportunity to learn from their peers how to navigate a career in physics at different stages, ask questions, share career advice, gain information, and expand their network. Interactions and moments throughout the event were captured by Visual Artist and Designer **Nathaniel Miller**, who created live sketches and drawings of the event in real-time.

Marc Janoschek, PSI Villigen und Universität Zürich

New SPS Committee Members

Dr. Valeria Bragaglia (Section Physics in Industry)

Valeria Bragaglia holds a bachelor's and a master's degree in Physics from the "Tor Vergata" University in Rome, Italy.

In 2017, she obtained her Ph.D. in Experimental Physics at the Humboldt University in Berlin, working at the Paul-Drude Institute and Helmholtz-Centrum Berlin for Materials and Energy. As the understanding and engineering of materials' properties are the base for advancing a vast number of technologies based on electron devices, she specialized in condensed matter physics, with a focus on material development. Epitaxial growth of crystals, conventional spectroscopic and structural characterization techniques, as well as more advanced synchrotron-based characterization ones, are part of her scientific portfolio. She worked on epitaxially grown chalcogenide materials: Ge-Te-Sb alloys and heterostructures of GeTe/Sb₂Te₃ for memory applications.

In 2018, she joined IBM Research Europe – Zurich as Staff Research Scientist working in the field of *Neuromorphic Devices and Systems*. Her focus is on developing materials and tuning their physical properties to build new performing devices and circuit architectures for electrical cognitive computing. She leads the Resistive – Random Access Memory (ReRAM) effort but also works on Phase Change Memory (PCM) and Ferroelectric – RAM technologies.

Valeria is an IBM Research Outreach Ambassador and is involved in several mentoring programs aiming at promoting MINT and STEM careers to young students.



"I am honored to join the SPS as it is a great community actively promoting physics in the different layers of society. As co-lead of the *Physics in Industry* section I look forward to contributing toward bridging the academic and industrial world to foster a fertile ground for innovation and disruptive ideas".

Dr. Gian Salis (Section Physics in Industry)

Gian Salis studied experimental physics at the ETH in Zurich, where he received a PhD degree in 1999 for his research on electron transport in semiconductor quantum structures. His thesis was awarded with the ETH silver medal. From 1999 to 2001, he worked as a post-doc at the University of California in Santa Barbara, investigating electron spin dynamics in semiconductors with ultra-short laser pulses. He became a research staff member at the Zurich Lab of IBM Research in 2001. In his career he has worked on both applied and exploratory research topics, including optimizing CMOS-based gas-flow sensors, developing a planar optical waveguide technology and investigating spintronic concepts in semiconductor/ferromagnetic devices. He is an expert in the physics of spins in semiconductors and in quantum computing with solid-state qubits. His current research focuses on building a scalable spin qubit platform based on silicon and Ge/SiGe heterostructures.

From his engagement in the *Physics in Industry* section of the SPS, he expects to further foster close links between physics students, academic researchers and physicists working in industry.

Best Poster Award 2023

The three best posters presented at the Joint Annual Meeting at the University of Basel have been honored with the Best Poster Award, each doted with CHF 200.-. A total of 38 posters competed for the award from which the poster jury selected the works of **Sergey Ermakov**, **Jessica Richter**, and **Alina Weiser** as the final winners in a two-step evaluation procedure.

The winners conveyed the essence of their work in a brief 1-slide presentation during the poster award ceremony on the last day of the meeting. We thank the participants for the high quality of their contributions and express our gratitude to all members of the poster jury for their hard work during the evaluation of the posters. Namely, the jury members were: Lukas Gallmann, Thilo Stöferle, Roland Resel and Benjamin Klebel-Knobloch.



Jessica Richter, Sergey Ermakov, Alina Weiser

COMSOL Simulations of the Active Magnetic Shielding of the n2EDM Experiment

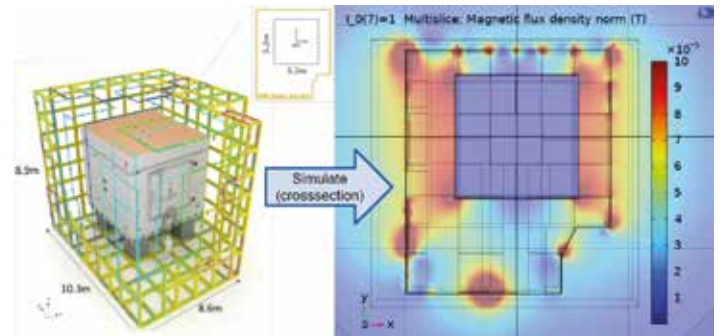
Sergey Ermakov, Vira Bondar, Klaus Stefan Kirch, Patrick Mullan, Nathalie Ziehl, ETH Zürich

The n2EDM experiment searches for the neutron electric dipole moment (nEDM), which could help understand the baryon asymmetry of the universe. High precision measurements of the nEDM requires a magnetically stable volume, such that the experimental apparatus is placed within a magnetically shielded room (MSR) surrounded by an active magnetic shield (AMS). The AMS dynamically compensates external fields by minimising the fields measured by 8 magnetometers placed around the MSR.

The system is simulated in COMSOL to study how the MSR influences the performance of the AMS. The performance

of the AMS field-compensation depends on the position and number of magnetometers used. This optimization problem is solved by applying a genetic algorithm.

Read more on: <https://arxiv.org/abs/2307.07588>

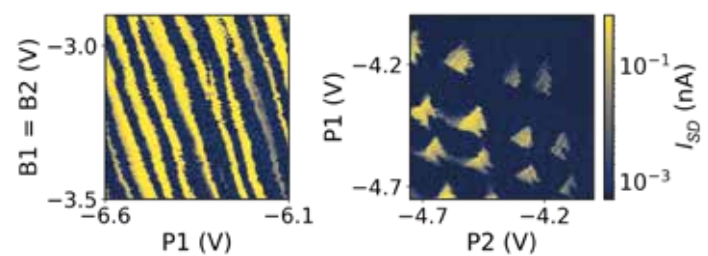


Impact of screening gates on reproducible quantum dot formation

Jessica Richter, Felix Schupp, Lisa Sommer, Stephan Paredes, Michael Stiefel, Gian Salis, Patrick Harvey-Collard, Andreas Fuhrer, Matthias Mergenthaler, IBM Research Europe – Zurich

Hole spin qubits can be realized in semiconductor quantum dots (QDs) by accumulating holes, i.e., confining them geometrically or by applying voltages to nanoscale gate electrodes. The fin field effect transistor (finFET) naturally exhibits such a wire like confinement defined by the fin cross section. While the finFET should accumulate holes only at the tip of the fin, spurious hole accumulation under the gates outside the fin is frequently observed. To mitigate this problem, we implement a planar MOSFET platform with

screening gates to constrict the channel. We perform DC transport measurements and capacitive charge sensing to investigate the properties of these devices and explore the impact of the screening gates on QD accumulation, shape, and geometry.



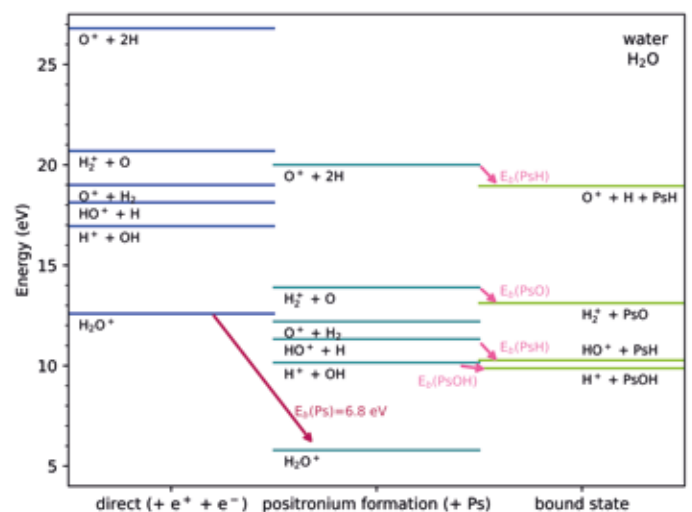
Transport measurement of a planar MOSFET device tuned to a single and double quantum dot.

A positron trap for observing molecules containing positronium

Alina Weiser and Daniel J. Murtagh, Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences

A positron trap is a powerful and adaptable tool for performing experiments with positrons and positronium. These devices use a strong magnetic field, a stepped potential well and nitrogen and SF₆ buffer gas. This type of positron trap can typically produce $\sim 10^5$ e⁺/s in bunches with a diameter of 1-2 mm and an energy spread of approximately 50 meV.

We aim to use the positron pulses from such a trap to observe molecules containing positronium, such as PsH and PsO via collisions in gases like methane and carbon dioxide. By using a high mass resolution ion spectrometer to detect fragments from dissociation, a precise measurement of their binding energy will be performed.



Fragments from the dissociation of water and their appearance energies after positron impact.

For more information please visit: <https://www.oeaw.ac.at/smi/research/precision-experiments/positrons>

Plenary Talks

Meanwhile a well accepted service for our members: after the annual meeting we ask the speakers of the plenary talks to summarize their presentation as an extended abstract. You will find the articles from those speakers willing to contribute below, they are later also collected as an own series on our webpage (<https://www.sps.ch/en/articles/plenary-talks/>).

(Note: For editorial reasons the order of the articles does not reflect the order in which the talks were held at the conference.)

Looking forward to new physics with the LHC

PT 01/2023

Anna Sfyrla, University of Geneva

The Large Hadron Collider (LHC) stands as one of the most remarkable achievements in the realm of particle physics. Situated 100 m beneath the Swiss-French border, LHC experiments are collecting massive volumes of data to scrutinize the Standard Model, the reigning theoretical framework that describes the fundamental particles of matter and their interactions. The Standard Model has been confirmed by numerous experiments, showcasing its remarkable accuracy. However, it still leaves essential questions unanswered.

Among the prominent enigmas is the low mass of the Higgs boson and the quest to identify and understand dark matter, required to explain century-old astronomical observations. More subtle puzzles include the neutron electric dipole moment measured to be close to zero. These and other mysteries collectively inspire physicists to venture beyond the Standard Model.

The quest for new physics beyond the Standard Model is far from straightforward. The absence of signals thus far suggests that any new phenomena are rare, necessitating vast data quantities to gain sensitivity. Yet, the search resembles finding needles in a haystack, demanding sophisticated techniques to distinguish potential signals from the Standard Model processes. To enable detailed measurements and searches, LHC experiments demand unprecedented precision, resulting in their substantial size and stringent requirements, including fast and radiation-resistant sensors, structural stability and accuracy, rapid readout systems for low-latency processing, and robust computing infrastructure for handling large data volumes.

The LHC has been accelerating beams since 2010, with the two general-purpose experiments, ATLAS [1] and CMS [2], collecting data from proton-proton collisions at various center-of-mass energies. While specialized experiments such as LHCb [3] and ALICE [4] have made substantial contributions to the knowledge gained from the LHC, this article won't delve into these experiments. After the current data-taking phase, Run-3, the LHC will be transformed into a 'high-luminosity' machine, capable of generating data at unprecedented rates. By the end of Run-3, the ATLAS and CMS experiments will have accumulated only around 10 - 15 % of the data expected throughout the entire lifetime of the LHC. As the accelerator undergoes enhancements to prepare for the high-luminosity data-taking phase, the ATLAS and CMS detectors are also being upgraded.

These upgrades include the integration of state-of-the-art radiation-hard sensor technologies, extremely fast trigger and readout systems, as well as novel computing infrastructures. These advancements represent the culmination of intensive research and development efforts over the last decade.

Searches for new physics at ATLAS and CMS.

At the large general-purpose LHC experiments, the quest for new physics takes two primary approaches: indirect exploration through precision measurements that probe challenging regions of the Standard Model's phase space, and direct investigation via searches for new particles inspired by various theories and models [5, 6].

The precision measurements span about 14 orders of magnitude in production cross-section rates, which represent the probability that a physics process occurs, such as the production of W , Z , or Higgs bosons. The study of the Higgs boson, discovered in 2012, holds a special place in the physics program of the experiments. It represents a new opportunity, and our understanding of this particle remains incomplete. For instance, both experiments currently lack sensitivity to the simultaneous production of two Higgs bosons, as this process is exceptionally rare according to the Standard Model predictions. Deviations from these predictions in production rates could signal the presence of new physics.

Direct searches for new physics typically align with theoretical models proposing final states with specific characteristics, such as large particle multiplicity, the presence of high-energy particles, distinctive kinematic properties, and particles with varying lifetimes, ranging from prompt decays to particles that travel long distances before they decay. Despite the richness of these searches and the occasional tantalizing excesses of data above the Standard Model predictions that could be indicative of new physics, conclusive evidence of such effects at the LHC remains elusive. And while the breadth of searches is large, the explorations mainly focus on new particles that generally couple strongly to the known Standard Model particles and are produced at high transverse momentum, as our experiments do not yet have large enough datasets to probe rare low-mass weakly-interacting new particles, leaving them largely unexplored.

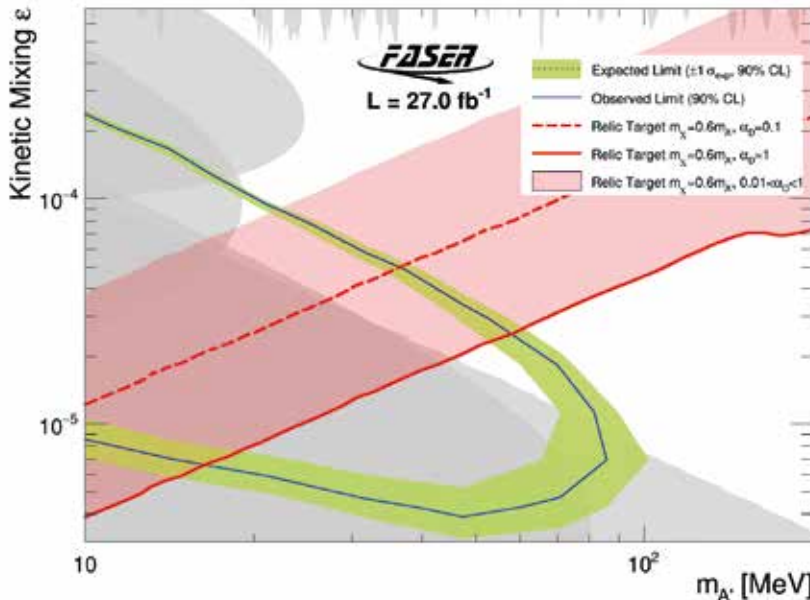


Figure 1: The 90 % confidence level exclusion contour in the dark photon parameter space. Regions excluded by previous experiments are shown in grey. The light red shading indicates the area favoured by dark matter relic density constraints, which lead to a viable parameter space that lies above the solid red line. The result explores parameter space uncharted in experiments since the 1990s. Figure from [11].

New forward experiments at the LHC.

Large rates of high-energy light new particles with masses in the MeV to GeV range could be produced at low transverse momentum at the LHC, in decays of light mesons such as pions and kaons, abundantly present in proton-proton collisions, primarily at a small angle to the beam collision axis. These high-energy low-mass particles would be long lived and thus travel a long distance before decaying. It is estimated that particles with energies in the TeV range will only spread out by 10 cm to 1 m in the transverse plane about 500 m downstream from the collision point. It is 480 m downstream of the ATLAS interaction point (IP) where a small new detector, FASER (ForwArD Search ExpeRiment at the LHC) [7], is strategically placed, providing sensitivity to particles that would be completely out of reach in the general-purpose LHC experiments. The FASER detector was approved by the CERN research board in 2019, and was constructed with cost-effectiveness in mind, partly by re-purposing unused detector components from the larger LHC experiments, ATLAS and LHCb. Besides innovative searches for new physics, the FASER experiment also aims at directly studying for the first time collider neutrinos produced in enormous numbers at the ATLAS IP marking the highest energies ever achieved for these particles at a laboratory. A second experiment with similar objectives, SND@LHC (Scattering and Neutrino Detector at the LHC) [8], was approved in 2020 to be placed symmetrically to FASER with respect to the ATLAS IP.

Both experiments were fully constructed, installed and commissioned, ready to take data in 2022 with the start of Run-3. The collaborations produced their first results in spring 2023 [9, 10]. They reported the first direct observation of collider neutrinos, with FASER achieving a remarkable 16σ significance and SND@LHC reaching 7σ . The FASER

collaboration also announced the observation of the highest-energy human-made electron neutrino, surpassing 1.5 TeV of energy. Additionally, FASER published the first search results for dark photons, delivering insights into parameter space that had remained unexplored since the 1990s and disproving previously viable models associated with dark matter, as shown in figure 1.

Future prospects.

In alignment with the consensus reached by both the European and the United States particle physics communities, which advocates for the full utilization of the LHC's potential throughout its operational lifetime, an innovative Forward Physics Facility (FPF) [12] is proposed to be constructed at CERN on a timeline similar to the start of the LHC's high-luminosity phase. Its primary mission is to conduct in-depth investigations into the forward production of particles at the ATLAS IP. The proposed FPF is envisioned to host multiple experiments, each designed to offer unique insights. These experiments will play a pivotal role in both the quest for new, weakly interacting particles and the exploration of Quantum Chromodynamics (QCD) phenomena through the detailed study of neutrino production and interactions.

Looking beyond the LHC towards large scale infrastructures, future collider projects will play a crucial role in advancing the human knowledge of particle physics. The Future Circular Collider (FCC) project [13], being studied by the international high-energy physics community, will operate in two phases: first as a lepton collider, pushing the intensity frontier by providing unprecedented statistics on the production of particles such as the Z boson, and subsequently as a very-high-energy hadron collider, pushing the energy frontier. The FCC offers a solid and diverse physics program that ranges from measurements of ultimate statistical precision to searches for new physics of unprecedented reach. It promises to advance boundaries in the search for light, weakly interacting particles and explore new avenues in our quest to comprehensively understand the universe.

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A journey to the Sun: why, how and what is being discovered PT 02/2023

Louise Harra, *Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center (PMOD/WRC), Dorfstrasse 33, CH-7260 Davos Dorf & ETH Zürich*

In February 2020, an ESA/NASA space mission Solar Orbiter was launched from Cape Canaveral on a United Launch Alliance Atlas V 411 rocket. This was the culmination of work over 20 years to design a mission that can orbit close to the Sun. The reason why this was one key goal is that the solar wind that emanates from the Sun measured at Earth has already had time to evolve. To understand the source(s) of the solar wind it is necessary to get in close to measure 'pristine' solar wind. Not only do you need to measure the solar wind close to the Sun with in-situ instruments, but you also need to 'see' the Sun to determine the sources of the wind. This requires remote sensing instruments that can operate in this challenging environment. Different technologies were required to achieve this orbit – this included a new development of a heat shield to protect the instrument from the intense heat (see Figure 1).

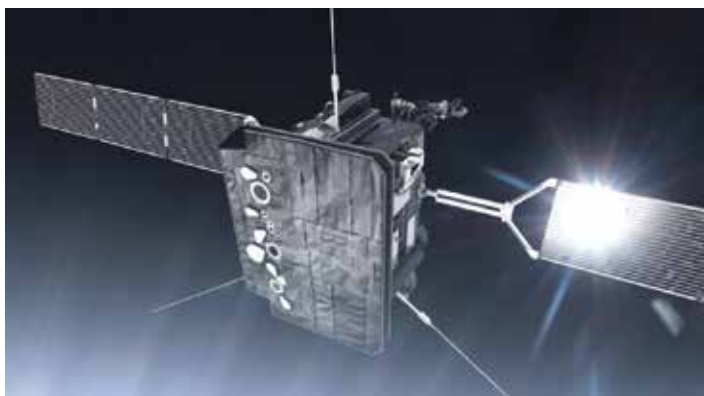


Figure 1: The Solar Orbiter spacecraft from the front view showing the heat shield. The apertures for the remote sensing instruments are shown with their doors. The solar panels also tilt to reduce the heat load when close to the Sun.

The orbit of the mission takes the spacecraft to 0.28 au. To achieve this orbit, a series of Earth and Venus fly-bys are carried out. This not only allows the mission to get close to the Sun, but the energy gained from the fly-by allows the spacecraft to slowly move outside of the ecliptic plane. This is another key aspect from the mission – providing the first view of the polar regions. The poles have been observed with the Ulysses mission but only with in-situ data and from further away. This will be the first ever view of the poles. The poles are of interest as they are not well observed from the Earth view restricting our insight into the magnetic field and activity there. This gap in knowledge makes it difficult to constrain the models of the solar cycle accurately to allow for consistent predictions.

The main overarching science goal of the mission is:

“How does the Sun create and control the heliosphere – and why does solar activity change with time?”

The mission's instruments were designed to measure the solar wind plasma, fields, waves and energetic particles as close as 0.28 au with the in-situ instruments. The Remote-sensing instruments observe the entire Sun in visible light, UV, X-rays, including its uncharted polar regions. There is simultaneous high-resolution imaging and spectroscopy

which probe the characteristics of the solar plasma. Measurements of vector magnetic field of solar photosphere are made to characterise the magnetic field which is the driver of all solar activity. This activity can then be tracked through the heliosphere by imaging.

The mission is well underway and has orbits with perihelia down to 0.28 au and aphelia close to 0.9 au. Three 'science' perihelia have been successfully completed when all the instruments are operational. The fourth perihelion will take place on 7 October 2023 at 0.29 au. The in-situ instruments are operating continuously, and the remote sensing instruments operate for 3 'windows' which are ten days long around perihelia.



Figure 2: This is an image of the corona is made up of 25 high resolution images in a mosaic to cover the whole solar disc. The images were taken on 7 March 2022, when the spacecraft was crossing directly between the Earth and Sun. This is the highest resolution image of the Sun taken in the corona (https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter/Zooming_into_the_Sun_with_Solar_Orbiter).

The results from the first perihelion are published in a special A&A edition (<https://www.aanda.org/component/toc/?task=topic&id=1717>) in 2022. The results are wide ranging and look towards big steps forward in heliophysics in the next years. We can now observe the smallest features in the solar corona ever seen (see Figure 2). These can produce jets of plasma that can feed into the solar wind. The solar wind measurements close in are indicating that the size scales of these small brightenings and jets can feed into the solar wind. The small-scale features can lead to the large-scale structures that slow through our solar system. The energy release mechanisms for these small brightenings have been shown through models to come from energy dissipation in nonpotential coronal magnetic fields. The Sun's activity level is increasing and will likely reach a max-

- Development of product groups such as CO₂ and particulate matter (PM2.5)
- Handover of the CEO function after 18 years from Moritz Lechner and Felix Mayer as Co-CEOs to Marc von Waldkirch, who is also a physicist
- Initial public offering of the shares at the Swiss Stock Exchange in 2018
- Development of many more environmental sensors

Besides the internal development many external impacts influenced the company. Here a few chances and challenges triggered by external factors highlighted at the presentation:

- Challenge: The September 11 attacks, commonly known as 9/11: This event led to Sensirion losing the external engineering orders and having to adapt its strategy to fully focus on its own products in a very early phase of the company.
- Challenge: Currency crisis: The exchange rate €/CHF went from 1.6 to first 1.2 and later to 1.0 or less. Having the expenses in Switzerland and exporting 99% is a continuous challenge.
- Chance and challenge: The iPhone as the first smart phone appeared on the market in 2007. Soon, people wanted to integrate sensors in the new smartphones. A huge market potential, but also a challenge. Sensirion managed to place a sensor in the Galaxy S4 from Samsung and sold more than 100 million sensors only for this phone. Unfortunately, the humidity sensor was no longer included in the following phone models for various reasons.
- Chance and challenge: The COVID-19 pandemic was a difficult time for many companies. Sensirion, as a main supplier for sensors for medical ventilators, was challenged by a huge demand which was more than 10 times higher than before the pandemic. We managed to meet the demand despite the difficult situation in the supply chain.



2. Sensirion Today

Sensirion is a pure-play sensor company at the forefront of sensor innovation and has demonstrated a strong track record of developing and manufacturing sophisticated and cost-effective environmental and flow sensor solutions for the automotive, medical, industrial and consumer markets. Sensirion has more than 25 years of experience in creating best-in-class sensor solutions for a variety of demanding customer applications, including those in which the sensors perform mission-critical functions. In 2022 Sensirion sold

more than 150 million sensors and generated a revenue of over 320 million CHF.

Sensirion re-invests around 20 % of its revenue into research and development (R&D). Innovation and R&D are critical for us to bring breakthrough technologies and innovations to the market. Customer feedback and the latest technological advances are therefore a key element of how we create economic and environmental value for our company and stakeholders. As a high-tech company, our success is defined by our ability to bring new, innovative products to the market that address real-life problems and add value for customers. While our R&D team leads innovation, we also have a dedicated business development team that includes our founders, who act as Co-Chairmen of the board and actively participate in identifying innovative products and solutions. We think long-term, behave entrepreneurially and work hard, always putting people at the center of our solutions.

3. Physicists as Part of the Story

Around 100 of the over 1200 employees are physicists (and many others also have a scientific background in electrical engineering, material science, computer science, chemistry, biology, mechanical engineering and more). The two founders are physicists as well, and the actual CEO is also a physicist and started his career at Sensirion just after his PhD.

To give you an insight into the daily work of physicists at Sensirion, here are four typical examples:

Mareike Weiss



Studied *Physics at University of Bayreuth, DE*

- Master Thesis focus on optical properties of organic solar cells

Personal Interests

- Family: engaged
- Hobbies: trail running, hiking, building furniture, sewing clothes

Joined Sensirion fresh from University in 2021, stations within Sensirion:

- 6-month Internship in R&D Humidity and Temperature Sensors
- Field Application Engineer with market focus on HVAC and Appliances
- Currently: Project Leader in R&D Humidity and Temperature Sensors with focus on automotive and second sourcing

As a project leader for humidity sensors, Mareike is responsible for many aspects of the next generation of our sensors. Not only for the sensing part itself, but also for the whole product. Some examples of the tasks are:

- Developing new sensor features on smallest scales
- Close cooperation with technology groups in realization of project goals
- Developing new measurement principles
- Supporting running production

Lukas Mahler

Studied *Physics at ETH Zürich* from 2000 to 2005

- PhD at Scuola Normale Superiore di Pisa 2006 to 2009 (“Photonic Structures for THz Quantum Cascade Lasers”)
- Interests in Physics
- Photonics, Semiconductors



Personal Interests

- Family: 3 kids of 16, 14 and 11 years
- Hobbies: Outdoor activities, preferably in the mountains

Since 2009 with Sensirion, in various positions:

- 2009-2011: Project Leader R&D Liquid Flow Sensors
- 2011-2019: Director R&D Liquid Flow Sensors
- 2015-2019: Director R&D Technologies (concurrently)
- Since 2019: *Director R&D Gas Sensors*

After having led projects for liquid flow sensors, Lukas was responsible for our technology groups. Today he is director of R&D for gas sensors. Here his role is:

- Leading a large product development team of ~40 scientists and engineers, developing gas sensors based on optical, electro chemical, metal oxide and thermal conductivity sensing mechanisms.
- Responsible for ~20 development projects, which are supported by ~100 FTEs in total, from various R&D teams (ASIC, MEMS, HW, SW, etc.)
- Focusing on organizing autonomous teams for faster and better decision making, as well as on the interplay of organizational and employee development
- Setting up infrastructure and procedures to systematically accelerate sensor development in an explorative environment

Martin Winger

Studied *Physics at ETH Zürich* from 2000 to 2005

- PhD in Quantum Optics at ETH Zürich in 2009
- Postdoc at California Institute of Technology from 2010 through 2012



Interests in Physics:

- Photonics, lasers, spectroscopy, integrated photonics
- MEMS, sensors, semiconductors

Personal Interests

- Family: married, 2 children (5 & 7 years)
- Hobbies: Piano, music, cooking, skiing, water sports

Since 11 years with Sensirion, stations within Sensirion:

- 2012-2016: R&D Engineer MEMS Technology
- 2016-2018: Project Leader Gas Sensor Development
- Since 2018: Sensor Innovation; *Lead of Photonics Cluster*

Martin started his career at Sensirion as a MEMS engineer. With his background in photonics, he then initiated some of our first products based on optical sensing, such as our CO₂ sensor. Later, he sparked the development of laser-spectroscopy based trace-gas monitor to detect methane (CH₄) leakages in the oil & gas industry. Today, Martin is a scout for

applications and technologies in photonics. His tasks are:

- Observing trends and activities in photonics industry and research
- Fostering and supporting collaborations with universities and research institutes
- Visiting international conferences and workshops
- Keeping intra-Sensirion photonics activities together
- Technical lead of a team of 5 PhD-level engineers / scientists

Susanne Pianezzi

Studied *Physics at University of Heidelberg, DE*

- Diploma in Particle Physics at Deutsches Elektronen Synchrotron (DESY), Hamburg, DE (“Development of new detector technologies”)



Interests in Physics

- Nuclear astrophysics
- Experimental particle physics

Personal Interests

- Family: married, 2 little kids
- Hobbies: Horseback riding (dressage and jumping), sailing

Since almost 8 years with Sensirion, stations within Sensirion:

- *Product and Key Account Manager* for Liquid Flow Products focusing on medical and diagnostic applications
- *Business Development Manager* at Sensor Innovation
- Currently: *Global Sales Director Emissions Monitoring*, Sensirion Connected Solutions AG (international team of ~10)

Susanne started as a product and key account manager from 2015 to 2020. For Sensirion, it is important that our technical sales team, that is daily in contact with customers, has a deep understanding of the technology behind our products. Our customers are typically scientists or engineers too, and thus it is important that we “speak the same language”. As a business development manager of the Sensor Innovation team, Susanne explored in 2021 a new business field for Sensirion: Methane emissions monitoring.

What is the problem with methane:

- Methane is a powerful greenhouse gas. Over a 20-year period, it is 84 times more potent than CO₂.
- High loss of methane throughout the oil and gas value chain is a well-known issue, but one that is solvable. There are ~1 million oil & gas wells in the US alone.
- Reliable leak detection and rapid repair is crucial. Yet, manual leak detection is rarely performed and labor intensive.

Sensirion decided to enter this field in 2021 and started to develop an end-to-end IoT solution. By investing heavily in new sensor technologies, and in parallel into data analytics and IoT platforms, we continuously monitor critical oil & gas sites across North America and Europe today to protect the environment from unwanted methane emissions.

As the global sales director for emissions monitoring, Susanne is responsible for building the new business on the customer side.

Photoemission orbital tomography: imaging molecular orbitals at intrinsic length and time scales

PT 04/2023

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The frontier orbitals of molecules, i.e., quantum mechanical single-electron wave functions $\varphi(\mathbf{r})$ of the highest occupied and lowest unoccupied states, are the prime determinants of molecules' chemical, optical, and electronic properties. Already in 1977, the later Nobel prize laureate Kenichi Fukui noted that "If we could experimentally obtain any knowledge of orbital patterns, chemistry would be profoundly affected" [1]. It took until the early 2000s until the first experiments have reported the observation of orbital densities of molecules, i.e., the absolute value of $|\varphi|$, employing diverse techniques ranging from electron momentum spectroscopy [2], tomographic imaging using intense femto-second laser pulses [3], and scanning probe microscopy [4]. While the former two techniques could only be applied to comparably small molecules, such as NH_3 or N_2 in the gas phase, the latter has found wide-spread applications for larger π -conjugated molecules, such as the organic semiconducting molecule pentacene ($\text{C}_{22}\text{H}_{14}$), adsorbed on weakly interacting surfaces. However, imaging of orbital densities with STM comes also with certain limitations, including the need for decoupling layers, the use of cryogenic temperatures, and a sensitivity of the orbital images on the configuration of the tip.

This article concentrates on another powerful technique, photoemission orbital tomography (POT) [5,6], that is based on angle-resolved photoemission spectroscopy and has been shown to yield orbital densities of molecules adsorbed on more strongly interacting substrates while at the same time being applicable at elevated temperatures. It has led to a wide variety of applications, ranging from the reconstruction of molecular orbitals in two and three dimensions [7,8], the identification of surface reaction products [9], to the tracing of orbital images on a femtosecond time scale [10].

In POT, measured photoemission angular distributions from oriented films of organic molecules are connected with the molecular orbitals from which the electrons have been emitted. As illustrated in Fig. 1, the observed angular dependence can be visualized as a hemispherical cut through the three-dimensional Fourier transform of the initial state orbital. This finding is based on a Fermi's golden expression which is at the heart of the one-step model of photoemission

$$W_{i \rightarrow f} \propto |\langle \Psi_{i,j,k}^N | \mathbf{A} \cdot \mathbf{P} | \Psi_{i,0}^N \rangle|^2 \cdot \delta(\hbar\omega + E_i^N - E_f^N) \quad (1)$$

It describes the transition probability between an initial N -electron ground state $\Psi_{i,0}^N$ with energy E_i^N to the final state, consisting of $N - 1$ electrons in some bound state j and the one liberated electron with momentum \mathbf{k} , with energy E_f^N triggered by the light field with frequency ω and vector potential \mathbf{A} . Under certain assumptions, including the sudden and the plane-wave final state approximations [11], and discussed elsewhere in more detail [5,6,12], the transition matrix element can be simplified to

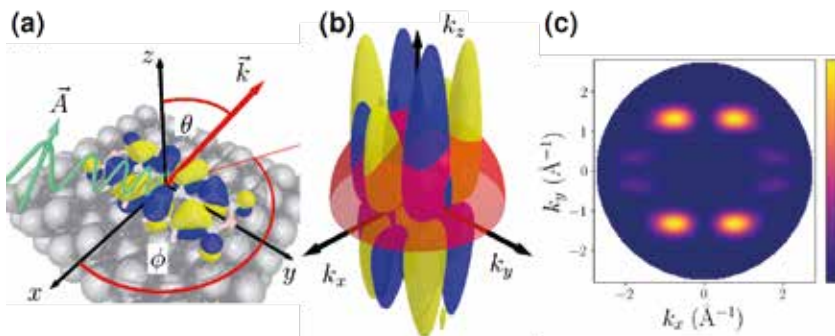


FIG. 1. Illustration of photoemission orbital tomography. (a) Light in the extreme ultraviolet regime illuminates an oriented molecular film leading to the emission of electrons with momentum \mathbf{k} . The photoelectron angular distribution is described by a hemispherical cut through the momentum space orbital (b) leading to the momentum map depicted in (c).

$$\langle \Psi_{i,j,k}^N | \mathbf{A} \cdot \mathbf{P} | \Psi_{i,0}^N \rangle \approx (\mathbf{A} \cdot \mathbf{k}) \mathcal{F}[D_j](\mathbf{k}) \quad (2)$$

This relation shows that the photoelectron angular distribution is proportional to the Fourier transform of the Dyson orbital $D_j(\mathbf{r})$, defined by the overlap of the N and $(N - 1)$ -electron wave functions [13], modulated by the weekly angle-dependent polarization factor $\mathbf{A} \cdot \mathbf{k}$. Often, these Dyson orbitals can be replaced by readily available Kohn-Sham orbitals $\psi_j(\mathbf{r})$ and, using this approximation, Eq. 2 has found many interesting applications [6].

Here, we concentrate on two examples. In the first, it is demonstrated how measured momentum maps, i.e., photoemission angular distribution maps which – according to Eq. 2 – are proportional to the orbital density in momentum space $|\mathcal{F}[\psi_j](k_x, k_y)|^2$ can be transformed to real-space orbitals via an iterative procedure which also retrieves the lost phase information. This has first been demonstrated for monolayers of the organic dye molecule perylene-tetracarboxylic dianhydride (PTCDA) and the organic semiconducting molecule pentacene, respectively, adsorbed on a Ag(110) surface and has led to two-dimensional images of the molecular orbitals [7]. Fig. 2 summarizes how this method has also been extended to yield truly three-dimensional orbital images reconstructed from experimental photoemission data [8].

To this end, so-called photoemission initial state scans are performed, where a series of momentum maps for a selected initial state energy is recorded by varying the photon energy, where a careful calibration of the photon flux is essential. As illustrated in the top row of Fig. 2 for the HOMO and LUMO of PTCDA, this leads to the orbital density in momentum space data on hemispheres of increasing radii $k = \frac{2m}{\hbar^2} \sqrt{\hbar\omega - |E_i| - \Phi}$. In the next step (middle panel), the phase information is retrieved using a numerical procedure that only demands $\psi(\mathbf{r})$ to be spatially confined, for instance, to a region defined by the van der Waals size of the molecules. Indeed, this turns out to be sufficient to yield a stable solution for the iteratively recovered phase information. Finally, imposing π -symmetry of the orbital and extending the

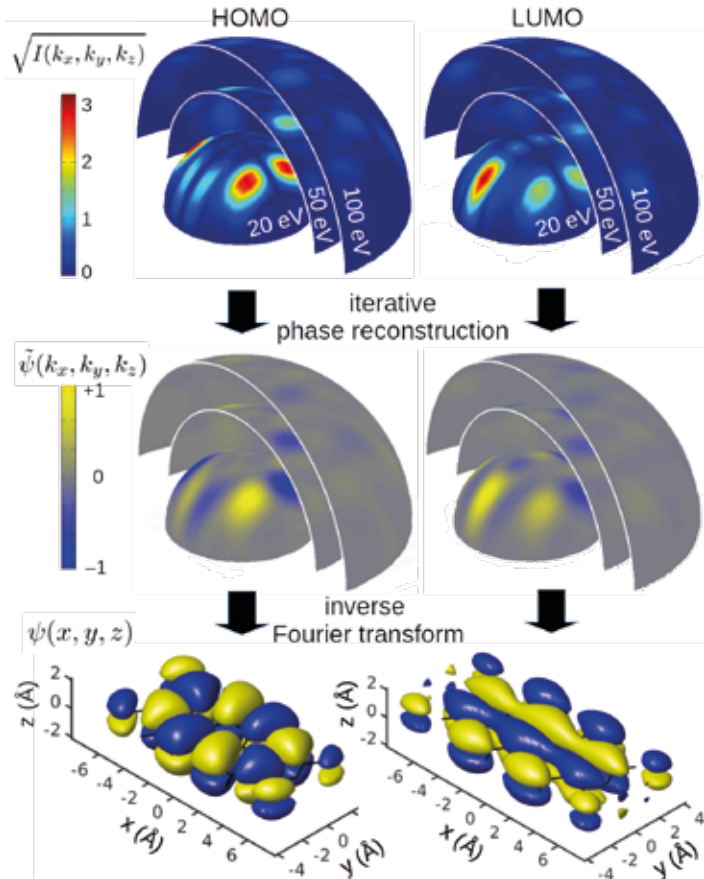


FIG. 2. Illustration of the reconstruction of molecular orbital in three dimensions [8]. Experimental momentum maps for the highest occupied molecular orbitals (HOMO) and the lowest unoccupied molecular orbital (LUMO) of the molecule perylenetetracarboxylic dianhydride (PTCDA) are recorded for a series of different photon energies (top). After recovering the phase information employing an iterative, numerical scheme (middle) [7], an inverse Fourier transform leads to three-dimensional orbital images (bottom) reconstructed from experimental data.

data to the negative k_z direction accordingly, an inverse Fourier transform yields the reconstructed orbitals in real space which are depicted in the bottom panel of Fig. 2. While the so-obtained orbital images compare well with computed orbital images from quantum chemical calculations, it should also be noted that a closer inspection of the photon-energy dependent data reveals systematic deviations from the ex-

pectations based on a plane wave final state that have been studied in more detail in a recent publication [14].

The second example portrays the recent extension of POT to the time domain. By combining time-resolved photoemission using high laser harmonics and a momentum microscope, the full momentum-space distribution of transiently excited electrons has been measured leading to tomographic imaging of excited state orbitals on a femto-second time scale [10]. In this proof-of-principle experiment, PTCDA molecules are deposited on an oxygen-covered Cu(100) surface, thereby forming a well-ordered monolayer structure with two perpendicularly oriented molecules in the surface unit cell (Fig. 3a). It is important to note that the oxygen-coverage passivates the metal substrate and thereby decouples the molecules electronically from the underlying substrate. This is essential since it increases the life time of the optically excited state that is populated by the pump laser which is tuned to excite a transition from the HOMO to the LUMO in the PTCDA molecule. The pump pulse is followed by a probe pulse of 21.7 eV, obtained through laser high-harmonic generation, leading to the emission of electrons, which are detected in a time-of-flight momentum microscope resulting in a four-dimensional data cube $I(E_i, k_x, k_y, t_p)$. In addition to dependencies of the measured intensity I on the initial state energy E_i and parallel momenta components k_x and k_y , respectively, the data also depends on the time delay t_p between pump and probe pulses.

Experimental momentum maps for selected time delays are depicted in Figs. 3b and 3c for initial energies of $E_i = +0.45$ eV and $E_i = -2.18$ eV as measured relative to the Fermi edge. The state below the Fermi edge shows virtually no dependence t_p and can be explained by emissions from the HOMO as evidenced by the simulated momentum maps depicted in Fig. 3e. On the other hand, the emissions originating from 0.45 eV above the Fermi are characteristic of the LUMO of PTCDA as verified by the corresponding simulations in Fig. 3d. The data clearly shows the transient population of the LUMO, i.e., no signal for negative delay times, a rise of the intensity according to the pump intensity followed by an exponential decay after the pump pulse with a life time of ≈ 250 fs. The data clearly showcases the capability of time-resolved POT in identifying excitation

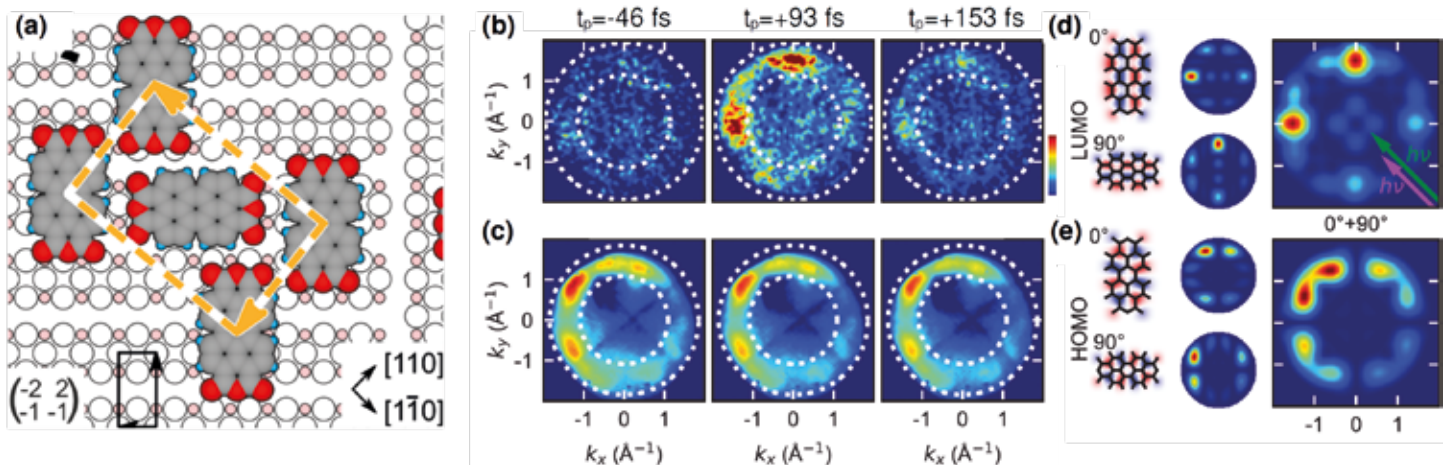


FIG. 3. (a) Monolayer structure of PTCDA on an oxygen-passivated Cu(100) surface. (b) Experimental momentum maps obtained at selected delay times t_p and at $E_i = +0.45$ eV above the Fermi edge. (c) Same as for (b) but at $E_i = -2.18$ eV, i.e., below the Fermi edge (intensity reduced by a factor 1850). (d) Two-dimensional

cuts through the Kohn-Sham LUMO of gas-phase PTCDA (left) and corresponding theoretical momentum maps including polarization factor plotted for two orientations 0° and 90° (middle) and their sum (right). (e) Same as for (d) but for the HOMO.

mechanisms by tracing electrons not only in time but also in (momentum) space. We expect that future experiments of this type will enable studies of molecular electron transfer processes at surfaces and interfaces with unprecedented detail. Moreover, an extension to attosecond time resolution seems feasible. The availability of momentum-space information relaxes pertinent requirements on energy resolution, allowing in turn for an increase in time resolution. In this way, the temporal and spatial evolution of electronically excited states should become resolvable by photoemission tomography even before the nuclei start to move.

Acknowledgments

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Tailoring the environment to steer laser-driven reactions at surfaces: Solvation, confinement, and more

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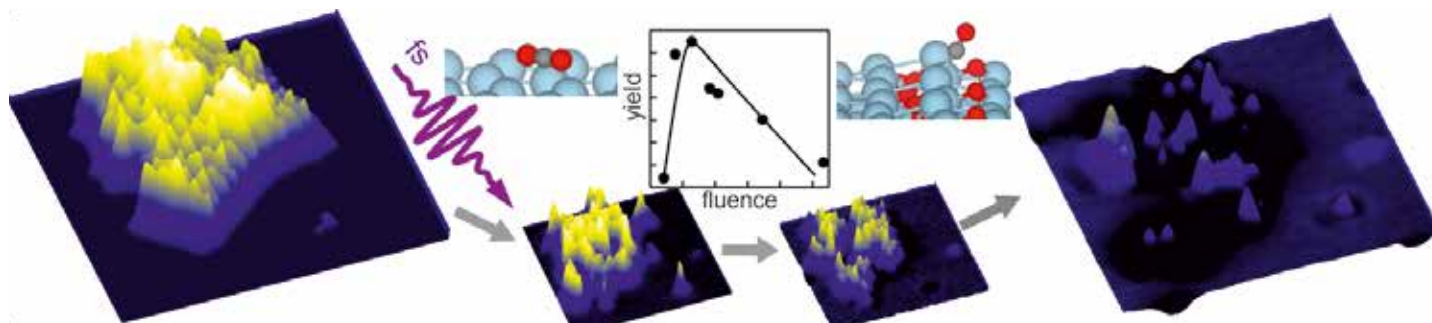


Figure 1: Laser-induced dissociation of CO_2 within clusters on $\text{Ag}(100)$, left, [1] to atomic oxygen and CO , right, tunnelling parameters: 100 mV, 6.5 pA, illumination at 400 nm with 50 fs laser pulses with an accumulated fluence of 0.1 mJ/cm^2 ; STM images on false-colour scale displaying the surface in dark blue, CO_2 in yellow and the products in blueish; The dissociation barrier of the CO_2 molecules modelled by DFT (left scheme) increases from being smaller to being larger than the laser excitation energy by co-adsorption of the dissociation product oxygen (right scheme) for details see [2].

Laser pulses are an intriguing tool for driving non-adiabatic processes at surfaces. Amongst others, they may be utilized for tailoring adsorbed molecules or the surfaces themselves with the aim of custom-made properties that cannot be achieved under equilibrium conditions. We advance the microscopic understanding of the fundamental steps involved in laser-molecule or laser-matter interaction and the details of the dynamics induced by fs-lasers on specific surface sites by a real-space analysis of the resulting products and structures on the sub-nanometer scale, combining short-pulse lasers with low-temperature scanning tunnelling microscopes.

Following individual molecules and their changing environment during fs-laser-induced dissociation reveals the importance of local changes during a reaction on its efficiency [2].

We reveal with single-molecule resolution how the surroundings of the reactants evolve with progressing ultra-short laser illumination and with it their propensity for dissociation. Counteracting processes lead to a volcano-like reactivity in the laser-induced dissociation of CO_2 on $\text{Ag}(100)$ (Fig. 1, middle). The first process is an increased laser-induced disorder within the CO_2 islands, suppressing energy redistribution to neighbouring molecules, thus enhancing reactivity. The second process is a poisoning of the surface by one of the products, the oxygen atoms, that increase the dissociation barrier of adjacent CO_2 molecules, thus suppressing reactivity. The microscopic view on individual molecules before and after their photoinduced reaction enhances the understanding of the influence of changes in the reactant's environment on photochemical reactions.

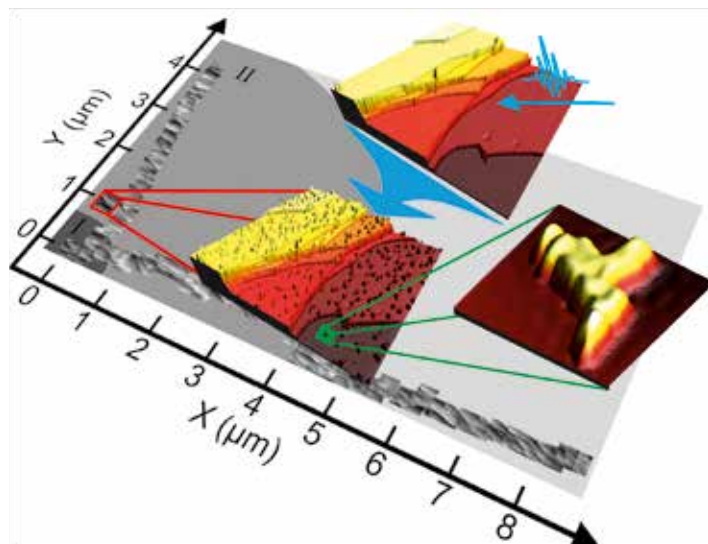


Figure 2: Laser-induced changes to a Cu(111) surface upon illumination with 400 nm-50 fs pulses at a fluence of 7.5 mJ/cm² at different parts of the laser spot; tunneling parameters: 228 mV, 100 pA; STM images on false-colour scale from red to yellow; for details see [4,5].

Such reactions of metal-adsorbed molecules are mostly initiated by energy transfer through the metal [3] because the used laser light is off-resonance the optical transitions within the molecule. The laser photons are absorbed by metal electrons, which either heat molecular vibrations directly or excite metal phonons that subsequently transfer their energy to the molecules to initiate a reaction. The energy thus flows through the metal, where it may excite the atoms. Indeed, the metal is altered at higher fluences, forming qualitatively different structures in dependence of local fluence, a fluence that varies largely across the Gaussian profile of a laser plot (Fig. 2). Such changes, described in more detail in [4,5], are only observable by real-space high-resolution methods.

It reveals that the surface can often not be assumed to be static during a femtochemical surface reaction or only below threshold fluences as employed for the example presented in Fig. 1.

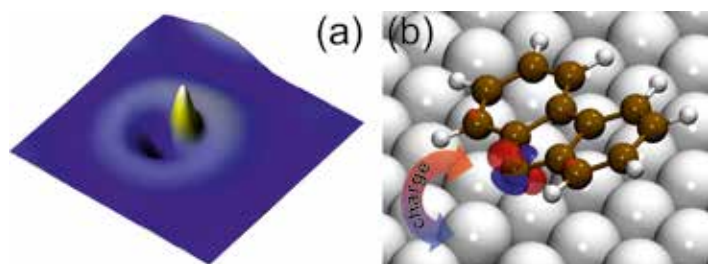


Figure 3: Fluorenylidene on Ag(111): (a) three-dimensional STM image on false-colour scale after dissociation of diazofluorene by 365-nm illumination, displaying fluorenylidene in yellow with the charge transfer to the molecule visible as a dark blue hole surrounded by a light-yellow charge screening ring; blue represents the surface, tunnelling parameters: 100 mV, 8 pA (b) calculated adsorption geometry with charge transfer; from [7].

On the other hand, it is impossible to address specific bonds within a molecule, if the laser light is adsorbed by the metal because the electrons redistribute their energy shortly after their excitation, leading to a broad range of electron energies [3]. It impedes controlling a complex reaction. To demonstrate that specific bonds of adsorbed molecules are

accessible, we utilised a tunable ps-laser. For instance, the C-N bond of a diazo-protected carbene molecule, diazofluorene, was successfully dissociated on Ag(100) at the same wave length as successful in cryogenic materials [6]. Dissociation leads to a major charge transfer from the metal to the carbene without water (Fig. 3) [7], but to fluoreneol in the presence of water [8].

Other molecules that were successfully dissociated were dibromobiphenyl, leading to a product that is inaccessible in the liquid phase [8] and chlorobenzene (Fig. 4) [9]. The latter was adsorbed on amorphous ice structures, making it a model system for atmospheric chemistry. Investigating the chloride formation by light on the nanoscale questioned classical models of these processes.

Our studies line out how to steer selectivity and yield beyond equilibrium on surfaces by tailored excitation sources. The microscale understanding of the influence of the immediate environment on laser-driven processes, may be used to tailor it for a desired outcome.

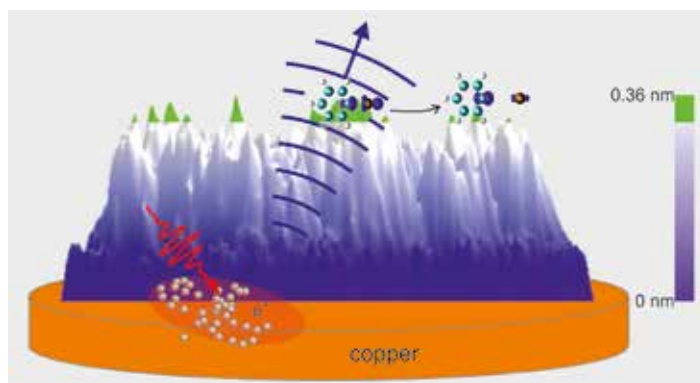


Fig. 4: Model system for atmospheric chemistry: Electron attachment to dissociative orbital of chlorobenzene resulting from *ab initio* calculations superimposed on STM image of chlorobenzene colored in green on amorphous ice in blue (3D representation, color scale on right-hand side, 100 mV, 7.3 pA); from [9].

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Science Education in an International Context

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This article is based on a keynote given at the joint annual meeting of the Austrian and Swiss Physical Societies. It gives an overview of science education programmes and the research thereon at CERN, as well as some more personal thoughts on modern science education in an international context.



CERN and its Mission ¹

The European Organization for Nuclear Research was founded in 1954 by 12 European countries, among them Switzerland; Austria joined five years later. The core of the Organization is the Council, which also gave it the name: Conseil Européen pour la Recherche Nucléaire – *CERN*.

Four missions were given to the new organisation, performing fundamental research at the frontier of human knowledge – especially in particle physics, development of innovative technologies to pursue fundamental research, international collaboration for the good of humanity, and education and inspiration for the future generations of scientists, engineers, and the public at large. The latter mission is at the core of this article and also rhymes well with goal 4 “Quality Education” of the UN’s Sustainable Development Goals (*SDG*) ².

Outreach and Training Programmes at CERN

CERN is well known for outreach and training, the former mainly through the experiments performed at CERN and the outreach networks between the countries performing particle physics research, the latter through a variety of programmes for students and graduates.

Outreach, which is also done by several entities at CERN, seeks to inform the public about the activities of the lab and the connected institutes. Part of this is done through publications and exhibitions, but there are also educational programmes, most notably the International Masterclasses ³ run by IPPOG ⁴.

Training resp. professional development programmes vary from internships, studentships, fellow placements, a large catalogue of specific training programmes on technology, safety, and leadership, to world-renowned graduate schools, e.g. the CERN Accelerator School, the CERN School of Computing, and several CERN Physics and Instrumentation Schools ⁵.

Science Education

The question about what is “science education” has probably more answers than the number of science educators in

Europe, nevertheless a basic principle can be seen as the basis: “Nature of Science” (*NoS*). The first definition of this I found by Ernst Mach: “I have no doubt that if, somewhere in the universe a creature organized like ourselves could make observations it would perceive a universe working similarly to that we ourselves describe.” ⁶ So, NoS is the scientific method itself, without which we could not formulate science correctly, reproducibly, and understandably. Teaching NoS as the basis and conveying scientific results as examples seems to me to be the best method of inspiring learners, young and old, for science and technology at large. The path to reaching everyone, which is the final goal, can be followed differently. CERN’s approach(es) are listed here below.

CERN’s Education Approaches

Fulfilling its mission, CERN strives to reach everyone with its education programmes ⁷. The basis being the short programmes on-site, educational introductions to various topics, combined with visit programmes to where research happens, guided by scientists and engineers, and hands-on and minds-on experience in the education lab. The new CERN Science Gateway, which will open its doors to the public in October, offers exhibitions, large education labs, as well as educational science shows for an audience from 3 years of age onwards.



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For those coming for longer stays, CERN offers own internship programmes ⁸, e.g. the High-School Students Internship Programme (*HSSIP*), but also enables programmes together with partners, e.g. Netzwerk Teilchenwelt ⁹ in Germany. In addition to these programmes for individual students, CERN successfully runs programmes for schoolteachers ¹⁰

⁶ formulated 1886, quoted from Mach E., “The Guiding Principles of My Scientific Theory of Knowledge and Its Reception by My Contemporaries”, 1910

⁷ <http://education.cern>

⁸ <http://cern.ch/internship-portal>

⁹ <http://www.teilchenwelt.de>

¹⁰ <http://teachers.cern>

¹ cf. <https://home.cern/about/who-we-are/our-mission>

² <http://sdgs.un.org/org>

³ <https://physicsmasterclasses.org/>

⁴ <https://ippog.org/>

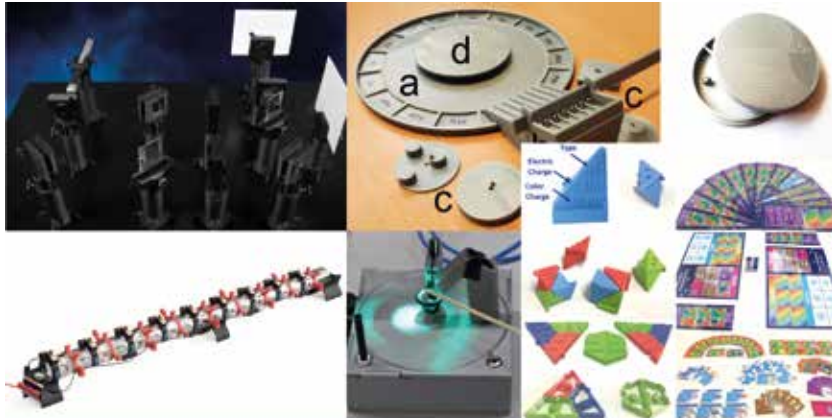
⁵ <https://indico.cern.ch/category/4147/>

since 1998: international programmes in English as well as programmes in various national languages. Currently, we welcome in total around 1000 teachers each year in two international programmes as well as up to 35 national ones.



Activating far more school students is the Beamline for Schools Competition (BL4S)¹¹ with more than 300 teams of high-school students participating each year and three winning teams that get to perform their own experiments at

CERN or DESY beamlines for two weeks each year. Every year, more than 3000 people are activated to work on experiments.



Examples for low-cost education material developed at CERN

Still, only a fraction of the potential audience can come to CERN, so the education team provides various resources for teachers, school students, and the general public. These resources range from virtual educational science shows and online courses, via the presence at science fairs, to teaching material for everyone. This low-cost material is designed to convey modern physics through hands-on experience. All programmes and material can be found at <http://education.cern>.

Science Education Research

All programmes at CERN are developed resp. followed-up scientifically in the education research team. Numerous publications in national and international journals have been published on a variety of subjects. This is made possible by the significant contributions of doctoral students, that make up much of the team, and the collaborations stemming from the cooperation with universities in CERN's Member States, where the doctoral students have their scientific alma mater.

Material, labs, and learning activities are designed based on research; key traits such as motivation and curiosity of our audiences are researched together with our impact on them; large-scale studies of curricula and expectations are performed. An overview can be found on CERN's PER site¹². In addition, CERN is publisher for the multilingual international journal "Progress in Science Education" (PriSE)¹³.

Collaboration

A significant reach to fulfil the education mission is achieved by collaborating with different associations, facilities, networks, and publications, on national as well as on international scales.

Notably in Switzerland, we collaborate with the Swiss Science Education Association (*DiNat*)¹⁴, Schülerlabore Schweiz, and the ScienScope¹⁵ of the University of Geneva. On an international scale, partners include the European Physical Society (*EPS*)¹⁶, EIROForum with "Science in School"¹⁷, and the International Research Group on Physics Teaching (*GIREP*)¹⁸.

Personal Remarks on Science Education

Following the request of the conference organisers, please find here some personal remarks on science education. Those do not represent CERN's position nor this of the Physics Education Division of EPS, that I have the pleasure to chair.

To me, scientific education for the public at large, starting from young learners is key to the future of humanity on this planet, which is part of a universe we seek and need to understand. Making this education more impactful using education research seems to be the most promising approach. A frequently asked question in this respect is what to educate. One answer to that you can find above,

the scientific method, i.e. "nature of science", but this answer should be complemented two-fold:

1. We need to teach competencies these days, not so much skills as before, and even less pure knowledge as at the time when I went to school. The former brings a society forward, while the latter two are too vast now to be taught exclusively.
2. The subjects, that in my mind are key in science education today are
 - Education for Sustainable Development – nearly old already, but still not consistently present throughout curricula,
 - Quantum Physics and its Applications – especially the application part is not (yet) present in schools,
 - Radiation – at least trying to bust the myths persisting around it, in order to have a clear understanding and not unfounded fear, and
 - Artificial Intelligence – not as a replacement of natural intelligence but giving the world a founded understanding of potentials and risks.

Education is key to sustainability, it is key to society, so let's all work together. My team and myself are open to your proposals!

¹⁴ <http://dinat.ch>

¹⁵ <http://scienscope.unige.ch>

¹⁶ <http://www.eps.org>

¹⁷ <http://scienceinschool.org>

¹⁸ <http://girep.org>

¹¹ <http://cern.ch/bl4s>

¹² <http://cern.ch/PER>

¹³ <https://e-publishing.cern.ch/index.php/prise/index>

A World not in Spacetime?

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General relativity (GR) conceives of gravity as an expression of a non-trivial geometry of spacetime. Studying this geometry has led to the prediction of the existence of black holes and gravitational waves. The detections of both of these phenomena have been awarded with Nobel Prizes, signalling their widespread acceptance in physics. Apart from these spectacular successes, GR is indispensable in mundane tasks such as ordinary navigation on which millions of users routinely rely. In short, GR is as firmly confirmed as a theory of gravity (and thus of spacetime) as ever.

However, GR assumes that the matter-energy content of the universe is purely classical. If there is any grand lesson the history of 20th-century physics teaches us, then it is of course that matter is fundamentally quantum. Although GR is an excellent approximation to gravitational physics in situations in which the quantum nature of matter does not show, we thus need a theory, which can combine (classical or quantum) gravity with quantum matter. This is the project of *quantum gravity*. One can reasonably expect that such a theory will be necessary to understand the physics of black holes and of the very early universe in particular, i.e., domains in which strong gravitational fields meet quantum behaviour of matter or energy. To date, as empirical constraints remain weak, theorizing in quantum gravity has produced a number of research programmes based on rather different principles, methods, and techniques. Most prominent is string theory [6], but there are also loop quantum gravity [7] and causal set theory [9], to name just three examples.

GR has revolutionized our conceptions of space and time, but quantum gravity may well turn out to have much more radical implications here. This is perhaps what one would expect, given that quantum gravity fuses insights from quantum physics with those of GR. As it turns out, many approaches to quantum gravity either presuppose or entail that space and time disappear from the fundamental description of the world [4]. Just as hydrodynamics describes the motion of fluids emerging from a fundamental reality of elementary particles, which by themselves are in no meaningful sense ‘fluids’, GR becomes an effective theory describing a spacetime emerging from a fundamental reality, which in itself is not directly spatiotemporal. And just as elementary particles interact to form molecules, which may collectively behave like a liquid governed by the Navier-Stokes equations under favourable circumstances, the fundamental degrees of freedom postulated in quantum gravity may collectively, and in serendipitous cases, give rise to a spacetime satisfying Einstein’s field equation.

In string theory—which extrapolates principles and methods honed on high-energy particle physics—, we have a framework of various theories, some of which are related by so-called ‘dualities’. A duality is a relation between two theories that establishes that the two theories are in some sense physically equivalent. For example, T-duality establishes the equivalence between the physics of a closed string of radius R with one of radius $1/R$, and the AdS/CFT correspondence suggests the equivalence between the d -dimensional ‘bulk’ spacetime of anti-de Sitter geometry and the conformal field

theory on its $(d-1)$ -dimensional boundary. Given that in the first case, equivalent theories disagree over spatial distances, and in the second case over the dimensionality of spacetime, we may not want to consider distances or dimensions as ‘real’, i.e., as actually being present in the physical situation [2]. This suggests that physical space itself is not fundamentally real, or at least not all its standard properties.

Loop quantum gravity attempts a canonical quantization of GR and thus belongs to the family of canonical quantum gravity. This procedure demands that GR be cast as a Hamiltonian system. In order for Hamiltonian GR to be equivalent to standard GR with Einstein’s field equation, constraint equations must be imposed on the Hamiltonian system. It turns out that the Hamiltonian itself acts as such a constraint (at the classical and the quantum level), and that only quantum states $|\psi\rangle$ set to zero by the action of the Hamiltonian, i.e., $\hat{H}|\psi\rangle=0$, satisfy the constraint and are in this sense physical [1]. Naturally, a theory like that does not have an interesting dynamics — it is completely frozen! Not only appears there to be no dynamical evolution, but neither \hat{H} nor $|\psi\rangle$ contain a reference to time t , in any of the different formulations within canonical quantum gravity. This suggests that temporal and dynamical aspects of our world are not fundamental and must indirectly emerge from fundamental physics, in which there is no time.

Generally speaking, and although the absence comes in degrees, and varies from approach to approach, quantum gravity suggests that physics at the scale of quantum gravity is in some significant ways not spatiotemporal. Quantum gravity thus promises to have deep implications for the philosophical study of the nature of space and time. Unsurprisingly, philosophers have taken up the study of quantum gravity.

When I took up my research twenty years ago in what is now the field of philosophy of quantum gravity (which did not yet exist back then), many philosophers considered the idea that our physical world may not be fundamentally spatiotemporal outrageous, even incoherent, and obviously false [8]. No doubt it runs against our intuitive conception of the physical world we inhabit, but so have other results in science. Nick Huggett and I tried to formulate a more interesting argument against the possibility of a fundamental physical theory in which spacetime is absent.

Here is our best attempt [3]. Confirmation in the empirical sciences requires measuring or observing some quantity or state of affairs. The forms in which the data are collected, organized, and represented are all in some way spatiotemporal: we are observing a localized something, situated in spacetime. It seems as if a theory denying the fundamental existence of spacetime were true, then there could not be such localized something and we would have no means to empirically confirm the theory. Thus, such a theory would be *empirically incoherent* in that its truth would undermine any empirical justification we may have for accepting it as true.

It would indeed be a problem if our most fundamental theories in physics were empirically incoherent in this way. However, there is an obvious way around the problem: any physical theory ought to be consistent with the conditions for its empirical confirmation. And there is no reason to think that theories of quantum gravity could not be consistent in this way, as long as we can establish the emergence of spacetime in their context: for every such theory, it must be shown how relativistic spacetime emerges as an approximation at the relevant scales.

Quantum gravity must thus offer an explanation of how spacetime emerges, in order to circumvent the problem of empirical incoherence. But also for a more general reason: any theory, which succeeds another one, should explain its predecessor's successes (and failures). Since it is hard to imagine that such an explanation could take a form other than showing how relativistic spacetimes are an excellent approximation at the scales at which GR has been successfully tested, a quantum theory of gravity must admit the emergence of spacetime.

What does it take to establish the emergence of spacetime? For this, it has been proposed [5] that the following two steps are necessary and jointly sufficient:

- (1) Spacetime and its relevant properties are reduced to their functional roles, such as spacetime localization, spatial dimensions and distance, temporal duration, and so on.
- (2) It is then shown how the quantum gravity degrees of freedom jointly act such as to fulfil these functional roles; i.e., it is shown how spatial distance can arise from the fundamental structure, and so on.

To work out the details is the programme of *spacetime functionalism*, a recent and exciting development in the philosophy of quantum gravity. Emphatically, it does not include deriving or otherwise establishing the 'metaphysical nature' of spacetime, but only recovering its physically relevant functions.

In sum, the philosophy of quantum gravity exemplifies a profound interaction between insights gained from fundamental physics and the application of principles and strategies developed in philosophy, naturally seasoned with a hearty dose of formal and mathematical methods.

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Kurzmitteilungen - Short Communications

Pre-announcement: SPS Annual Meeting 2024

The next annual meeting, will take place at the **ETH Zürich** in the week of **9 - 13 September 2024**.

The well established tradition of collaborating with CHIPP will be continued, and collaboration with further partners is also planned.

Save the date !

It is **your** conference, so we welcome contributions from all topical fields. In addition to the regular conference it is also planned to include a historical symposium (similar to this year's Pascal Symposium) with the topic: "*Louis de Broglie: 100 years of wave / particle dualism*".

The detailed announcement will be published in the next *SPG Mitteilungen*, available in early 2024, as well as on our website.

Obituary for Dionys Baeriswyl



Dionys 2012 on a hike near Zermatt.

Dionys Baeriswyl (23 June 1944 – 9 August 2023) was an Emeritus Full Professor from the University of Fribourg, Switzerland, who worked on condensed matter theory. Baeriswyl is known primarily for his contributions to the theory of strongly correlated electron systems. In particular, he has conducted fundamental work on conjugated polymers and other quasi-one-dimensional electronic systems, emphasizing early on the importance of electronic correlations in these systems. In addition, Baeriswyl is known for his work on variational-wave-function approaches to one- and two-dimensional correlated

electron systems, applying them to the Peierls and the Mott transitions as well as to superconductivity in high- T_c cuprates. In the course of this work, he introduced the variational wave function now known as the “Baeriswyl wave function,” which can be viewed as the strong-coupling complement to the Gutzwiller wavefunction. While the Gutzwiller wavefunction incorporates correlation effects into the free-electron state, the Baeriswyl wavefunction incorporates itinerant electron movement into a localized, strongly correlated insulating state.

Dionys Baeriswyl attended gymnasium at the benedictine college in Sarnen where he discovered his passions for natural science, foreign languages and music, especially the piano and organ. He concluded his studies in physics in 1969 at the University of Basel with a diploma in theoretical nuclear physics. In 1973 he earned his PhD at the University of Geneva with a thesis on the theory of elementary excitations in superfluid helium. In 1979 he obtained the teaching diploma of higher education of the Canton of Zurich. In 1985 he was given his *Venia Legendi* at the ETH Zurich with a habilitation thesis on theoretical aspects of conducting polymers.

Baeriswyl led the Institute of Theoretical Physics at the University of Fribourg from 1989 until 2000, served as the Dean of the Faculty of Science between 2002 and 2004, and became the President of the Department of Physics from 2007 - 2009. His administrative roles were marked by his humanist and transparent style, with a profound respect for his students, colleagues, and co-workers.

During his tenure as Dean of the Faculty of Science at the University of Fribourg, Dionys Baeriswyl encountered Swiss Entrepreneur Adolphe Merkle to discuss the granting of the

honorary doctorate at the *Dies Academicus* on 15 November 2003. Merkle donated in 2006, among others through Baeriswyl's facilitation, 100 million Swiss Francs to the University of Fribourg for the foundation of a new scientific institute for nanomaterials (FriMat), later called Adolphe Merkle Institute.

Baeriswyl organized numerous conferences and actively participated in establishing new series of events and meetings. Notable examples are the series of meetings at Gwatt (Switzerland), at the ISI Foundation (Turin, Italy) and at Évora (Portugal).

In addition, Baeriswyl served on the International Advisory Council (IAC) of the International Institute of Physics (IIP) in Natal, Brazil, for six years beginning with its creation in 2009. The IAC provides the academic leadership of the IIP, guiding all the academic programs, new hirings of research leaders, and the development of new research areas. At the IIP, Baeriswyl was also directly involved in the organization of several memorable scientific meetings in condensed matter physics and related topics. After leaving the board, he became an IIP Distinguished Professor and is well known to several generations of students and postdoctoral associates for his inspiring talks and numerous contributions to their research seminars. The many months he stayed in Natal were cherished by all thanks to his high spirits, his critical views of physics and life in general, and his never ending optimism and generosity.

The open, friendly, and transparent style exhibited during Baeriswyl's tenure as Dean of Faculty of Science at Fribourg has been characteristic of his entire career. For example, Baeriswyl resigned a permanent position as a staff member in the RCA Laboratories in 1982 to allow a colleague with a young family to assume that position. As a consequence, Baeriswyl became a “free-lance physicist” between the years of 1982 and 1989. During this period he visited many institutions in Germany, Denmark, United States, Switzerland, and Italy, spreading his influence and ideas widely throughout the physics community.

Among his co-authors on work on conjugated polymers, other one-dimensional systems, and the Hubbard Model are Alan Bishop, David Kelly Campbell, Kazumi Maki, Sumit Mazumdar, José Manuel Pereira Carmelo, and many others, who can be found on his google scholar entry, https://scholar.google.com/scholar?hl=en&as_sdt=0%2C22&q=dionys+baeriswyl&oq=dionys+ba. A list of his most important publications can be found there, too.

Dionys was a member of the Swiss Physical Society for almost 50 years and served in the SPS committee from 2009 - 2012.

He has been an exceptional colleague, mentor, and friend to all of us. He left a beautiful legacy about how to create a better world. He will always remain alive in our heart!

Florian Gebhard, Reinhard Noack, David Campbell, Jose Carmelo, Alvaro Ferraz, and Cristiane Morais Smith

Nobel Prize in Physics 2023 Awarded to Pioneers of Experimental Attosecond Science

Lukas Gallmann, ETH Zürich

This year's edition of the Nobel Prize in physics has been awarded in equal parts to **Pierre Agostini** (Ohio State University, USA), **Ferenc Krausz** (Max Planck Institute of Quantum Optics, Garching and Ludwig-Maximilians-University, Munich, Germany) and **Anne L'Huillier** (Lund University, Sweden). The official quotation for the award is “*for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter*”. The latter lead many journalists to call the three new nobelists ‘particle-researchers’. However, their true background lies in atomic and ultrafast laser physics.



The winners of the 2023 Nobel Prize in Physics. Image credit: Royal Swedish Academy of Sciences.

Anne L'Huillier studied the interaction of intense ultrashort laser pulses with rare gas atoms. She discovered that sufficiently intense pulses will trigger the emission of a high number of coherent odd-order harmonics of the original laser frequency, converting the fundamental infrared light into the extreme ultraviolet domain [1]. It could be shown, that the underlying process is non-perturbative in nature – very much in contrast to frequency conversion in traditional nonlinear optics.

Early on it was suspected that the coherent nature and broad spectral coverage of the emitted harmonics should permit the formation of light pulses with attosecond (10^{-18} s)

duration in the time domain, motivated by the fact that the duration of the shortest pulses that can be formed is inversely proportional to the available spectral bandwidth. While the high-order harmonics have been observed already in 1987, it took significant technological advancements until the formation of attosecond pulses could be demonstrated for the first time in 2001.

In that year, it was not only Pierre Agostini and co-workers who reported the generation of trains of attosecond pulses from a single fundamental infrared pulse [2]. A collaboration lead by Ferenc Krausz, on the other hand, achieved the generation of a single, isolated attosecond pulse from a single input pulse [3]. For a long time it was thought that the latter was a prerequisite for the pulses to be useful for studying ultrafast dynamics. However, time since then has shown that both approaches contribute equally to the advancement of the field – a fact that has been recognized by the Nobel Prize Committee in awarding the prize to both in equal share.

The ground-state vibration period of a hydrogen molecule, which is formed by the lightest of all nuclei, amounts to about 8 fs ($8 \cdot 10^{-15}$ s). As a result, amongst the ‘normal’ constituents of matter, only electrons are light enough (i.e., possess sufficiently low inertia) to exhibit significant motion on sub-femtosecond time scales. Thus, the field of attosecond science, pioneered by the three awardees, studies fast electronic processes in matter. Originally, it focused on atomic systems in gas phase. Today, attosecond science expanded towards large molecular or condensed phase systems, often devoted to revealing the first glimpse of how photons interact with matter and the complex cascade of processes they may initiate.

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Nobel Prize in Chemistry 2023

This year's Nobel Prize in Chemistry goes to **Moungi Bawendi**, **Louis Brus** and **Alexei Ekimov** for the discovery and development of so-called quantum dots. The three scientists, who work in the U.S., have performed fundamental work for this area of nanotechnology with their research, the committee said in explaining its choice. Quantum dots are used in screens and displays, but also have many other applications.

The Nobel award reflects the fact that technologies based on quantum physics will shape our lives in the future.



Progress in Physics (99)

Landau level spectroscopy

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Introduction

When a strong magnetic field is applied to a crystalline solid, the laws of quantum mechanics confine the motion of band electrons into a set of discrete or quasi-discrete cyclotron orbits. This regime is usually referred to as the Landau quantization and the distinct cyclotron orbits are called Landau levels. Using light, one can then excite charge carriers from one Landau level into another. Tracing such excitations experimentally is known as Landau level spectroscopy and provides us with indispensable insights in the material's band structure. Since the early experiments in the 1950s, this technique has been widely employed as an extremely sensitive probe of semimetal and semiconductor band structures. The technique can also help assess the materials' quality. For example, one can obtain the scattering time or the carrier mobility, as well as the carrier density.

History of Landau level spectroscopy

Magneto-optical spectroscopy has a long history, intimately tied with important discoveries in solid state physics. Classically, magneto-optics dates to Michael Faraday and his 1845 experiments on magneto-optical rotation, today known as Faraday effect. However, quantum physics fundamentally changed this technique, how we understand it, and what we can learn from it.

The starting point for modern magneto-optics and Landau level spectroscopy are the first cyclotron resonance experiments from the early fifties. Arthur Kip, Gene Dresselhaus and Charles Kittel were the first to observe the cyclotron resonance in crystals of germanium [1]. Cyclotron resonance itself is a classical effect, where a charged particle which moves in a magnetic field follows a helicoidal path. An electron (or a hole) in a semiconductor can complete many cyclotron orbits before being scattered. It absorbs energy resonantly at its cyclotron frequency $\omega_c = eB/m_c^*$, where m_c^* is the cyclotron effective mass. Measuring cyclotron resonance then allows to measure effective masses.

Observing the cyclotron resonance in germanium was a key achievement for the history of solid state physics. It helped to experimentally establish the quasiparticle concept [2]. The cyclotron resonance experiment provided a mapping of the dependence of the cyclotron effective mass as a function of the angle between the magnetic field and the various crystallographic directions.

The first experiments on germanium were quickly followed by a series of experiments in many other semiconductors. Studies on InSb [3] showed extremely small effective mass carriers, with a large effective g factor, $g \sim -50$. Because InSb lacks spatial inversion, and has a large spin-orbit interaction, it has been discovered that it has linear k terms in $E(k)$, near the Brillouin zone center, where the band extrema occur.

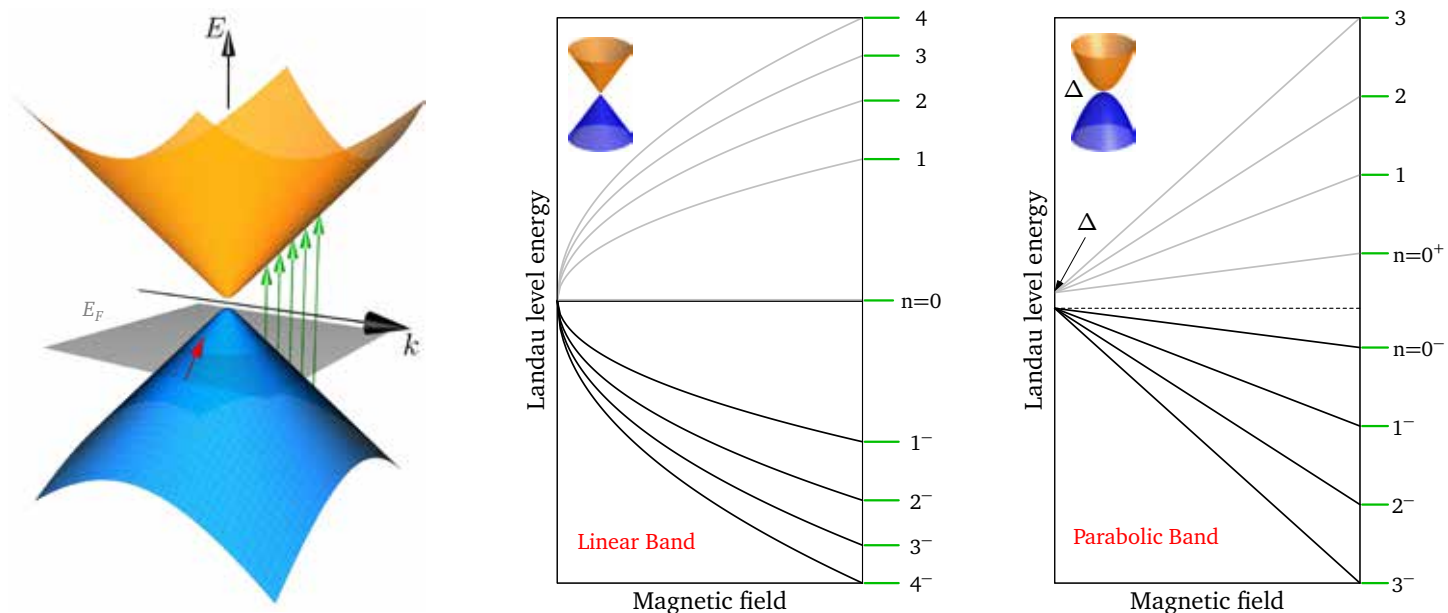


Figure 1. Left: Band structure described by a model of massive Dirac electrons. The Fermi level E_F is shown in gray. Short red arrow illustrates intraband excitations, while green arrows show interband optical excitations. Middle and right: Schematics of Landau levels for a conical band (e.g., in graphene) and two parabolic bands (e.g., in semiconductors). The field dependence of Landau levels differs profoundly. The \sqrt{B} dependence is a hallmark of conical bands, while the linear in B dependence is typical of systems with a parabolic dispersion. The zero-field extrapolation of optical excitations between Landau levels provides us with a useful estimate of the band gap.

Even though some Landau level spectroscopy experiments can be successfully interpreted using a simple picture of classical cyclotron resonance, usually a full quantum-mechanical treatment of the data is necessary. This may be illustrated on cyclotron resonance in germanium. While cyclotron resonance of electrons in germanium can be explained semi-classically, the interpretation of hole cyclotron-resonance data requires a detailed knowledge of the Landau level spectrum. This is due to a more complex structure of the valence bands in germanium, comprising two anisotropic dispersion branches (referred to as light and heavy holes).

In three-dimensional materials, Landau quantization splits the electronic bands into one dimensional sub-bands. These sub-bands show up very distinctly in optical data, as their density of states can exhibit sharp peaks under favourable experimental conditions. Soon after the pioneering experiments, it became clear that the interband optical absorption in high magnetic fields was a method which could reveal a wealth of band-structure information [4].

Landau level dispersion

To illustrate how Landau level spectroscopy works, let us consider a pair of bands, in our example defined by a massive Dirac dispersion and let us show processes induced an incident photon. If the Fermi level is placed within the valence band, two processes may occur at $B = 0$. The first one is an intraband excitation of electrons – so-called Drude absorption, characteristic of all systems with free charge carriers – illustrated by the red arrow in Figure 1(left). Here, carriers are excited just across the Fermi energy. The interband excitation is the second possible process. It brings

an electron from a partly occupied conduction band, across the band gap, into the empty conduction band. When a sufficiently strong magnetic field is applied, both type of processes are impacted by Landau quantization.

Here, we will consider two simple cases, see Fig. 1(middle-right). A band with a linear dispersion, $E(k)$, has the Landau level spectrum reading:

$$\varepsilon_n^\pm = \pm \hbar v \sqrt{k_z^2 + \frac{eB}{c} 2n} \quad (1),$$

where the individual levels are labelled by the integer Landau level index n , v is the velocity parameter describing the steepness of the conical band, and B stands for the magnetic field. In turn, a parabolic band gives the following sequence of Landau levels:

$$\varepsilon_n = \frac{\hbar^2 k_z^2}{2m} + \hbar \omega_c \left(n + \frac{1}{2} \right) \quad (2).$$

In both cases, the k_z is the momentum along the applied magnetic field that is not quantized by the applied magnetic field. Importantly, a detailed quantum-mechanical analysis – so-called selection rules – is needed to know the probability of different excitations of electrons in the Landau level spectrum. Most often, the rule is that the Landau level index has to change by 1 or -1.

Landau level spectroscopy of topological materials

A number of topological materials have their band structures marked by low energy scales. Together with their low carrier densities and high carrier mobilities, this makes them well suited for experiments using infrared light and mag-

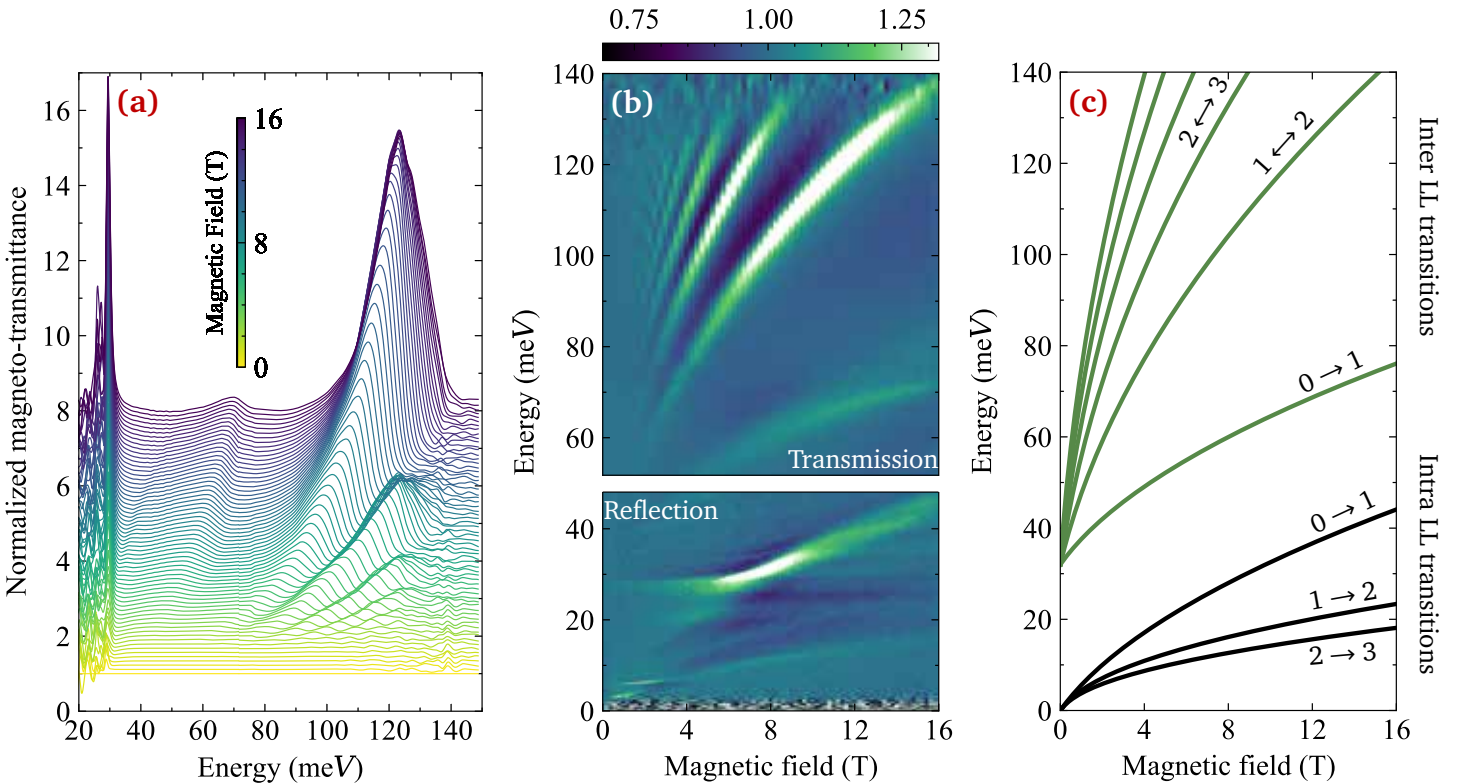


Figure 2. Magneto-optical spectra measured on a crystal of TlBiSSe. This material is a good illustration of a Dirac semimetal. (a) Stacked photon-energy-dependent spectra of relative magneto-transmission, measured up to 16 T. (b) Colorplot containing both magneto-transmission and magneto-reflection data. Lighter parts of the colorplot correspond to inter- and intra-Landau level transitions. (c) Using a massive Dirac model, we can assign the optical transitions to different combinations of Landau levels. The extrapolation of the $0 \rightarrow 1$ line into zero field gives us the value of the band gap.

netic field. In fact, many important insights on topological materials have been gleaned from Landau level spectroscopy. High-quality materials, where carriers can complete many cyclotron orbits before scattering, let us observe inter-Landau level transitions already at low magnetic fields. For example, in ZrTe_5 which has conduction and valence bands dispersing nearly linearly in two spatial directions, inter-Landau level transitions are observed, at low photon energies, at magnetic fields as low as a few milliteslas [5]. This allowed for a precise determination of a small band gap (5 meV) that increases monotonically with temperature [6].

Figure 2 shows another example of a topological material, TlBiSSe , which may be referred to as a “text-book Dirac semimetal” [7]. We show it here to illustrate the power of Landau level spectroscopy when applied to a topological semimetal. Through detailed measurements of magneto-transmission and magneto-reflection (Fig. 2(a)), one can construct a colormap (Fig. 2(b)) containing a series of transitions. Each of these lines is then attributed to a certain transition between a pair of Landau levels, such as shown in Fig. 2(c). This allows us to determine precisely the band structure parameters: the velocity parameters and also a small band gap, reaching in this case 4.0×10^5 m/s and 32 meV, respectively. Moreover, one may notice in Fig. 2(b) that there is an anti-crossing of the $0 \rightarrow 1$ line with an infrared-active phonon, suggesting an electron-phonon coupling.

Almost as a rule, Landau level spectroscopy provides deep and novel insight into any topological material it touches. Let us list a few relevant examples, in which authors of this text were involved. For the topological insulator Bi_2Se_3 , this technique showed that the conduction and valence bands are both parabolic-like, and firmly established the band gap value [8]. In the related topological insulator Bi_2Te_3 , Landau level spectroscopy shows that the fundamental band gap is not at the Γ point, contrary to popular belief [9]. As a first candidate of a Dirac semimetal, Cd_3As_2 incited a lot of excitement. However, magneto-optical experiments showed that the linear energy dispersion in this system is largely unrelated to its topological properties [10,11]. Weyl semimetals TaP and TaAs were also carefully studied using magneto-optical experiments. In TaP, one can obtain the exact scale of the band inversion, leading to Weyl nodes, and verify detailed theoretical models [12]. In TaAs, similar experiments showed that the number of Weyl nodes is smaller than previously believed [13]. In nodal line semimetals, Landau level spectroscopy uncovered a previously unseen relativistic-like effect, Lorentz boost, which can effectively mask the band gap [14].

Conclusions

Landau level spectroscopy is an established technique with a long and distinguished past. Presently it is employed by a handful of experimental solid-state physics groups around the world. Despite being much less represented than, for example, photoemission spectroscopy, this technique has provided us with a wealth of information about semiconductors and semimetals, be they topological or not, and will hopefully continue to do so in the years to come.

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Landau level spectroscopy is strongly tied to the high magnetic field technology development, and to our capabilities of generating sufficiently high magnetic fields. Until the 1950s, experiments were performed using electromagnets which could only reach about 2 T. In the early sixties, the available magnetic field range was extended to 15 – 20 T. These magnetic fields were achievable in several high magnetic-field facilities. In the late sixties, reasonably affordable superconducting coils made it possible to generate magnetic fields in the 10 T range and perform sophisticated magneto-optical experiments in one's own laboratory.

Modern experiments in high magnetic fields can be done in pulsed magnetic fields reaching several hundreds of Tesla. For the infrared experiments, however, we need static magnetic fields, which are limited to below 50 T. For example, at the Laboratoire National des Champs Magnétiques Intenses (LNCMI) in Grenoble, one can currently achieve magnetic fields up to 36 T using resistive magnets that are water-cooled and based on copper alloys. Their internal structures have special geometries to ensure very rapid thermal exchange with the cooling water, and to resist the Lorentz forces. Very soon, the static high field limit at LNCMI will be increased to 45 T in a hybrid magnet, combining a resistive insert magnet in a superconducting outer magnet.

Progress in Physics (100)

A journey in the topologically protected world

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One day, the little prince landed on the topologically protected planet.

The king invited him for coffee and poured the hot beverage into a weird-looking mug.

"I am sorry my prince, our topologically protected mugs acquired bizarre shapes over the years". The little prince was baffled, so the king explained that on his planet, besides the usual forces, a special thing called topological protection prevented objects from undergoing certain types of deformations.

Topology, he continued, is a branch of mathematics that studies the properties of space that are preserved under **continuous transformations**, such as stretching and bending. It focuses on the study of properties that do not depend on the exact geometrical shape, size, or orientation of objects. In other words, it captures the qualitative rather than quantitative aspects of geometry. For topology, a mug and a doughnut are the same objects because one can be transformed into the other continuously.

"What do you mean by continuously?" asked the prince. "Well, I mean without creating new holes (singularities) in the material forming the object, nor filling holes that already exist. For example, a sphere and a torus are not topologically equivalent as they do not have the same number of holes, zero for the sphere and one for the torus."

The king explained to the little prince that topology has revised their entire vision of physics as this new way of classifying objects has revealed novel phenomena which cannot be described by conventional geometrical aspects.

"The protection that exists on this planet - he continued - has a topological nature and prevents objects from undergoing deformations that form or eliminate holes as creating or removing holes is energetically costly. For this reason, when we drop a mug on the floor, its handle does not break like it happens on other planets. Instead, all the

energy of such a collision is used to create continuous deformations".

The king made a cartoon depicting the fate of a mug subjected to deforming forces, thermodynamic vibrations, collisions... on ordinary planets and on his own, to explain the prince why the mug he was drinking from had this special shape (Fig. 1).

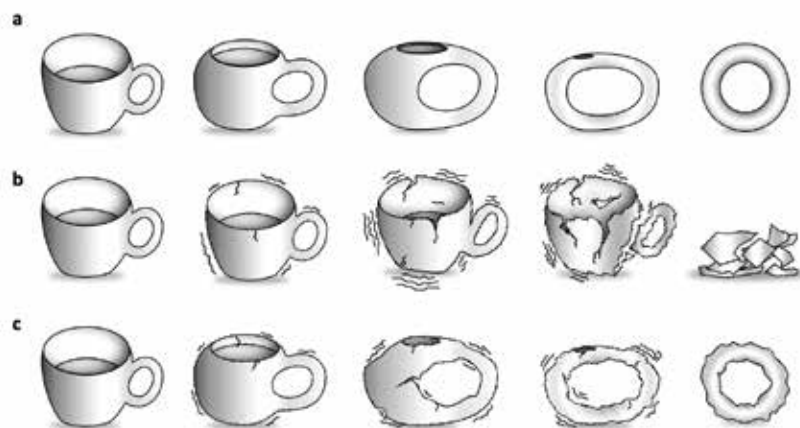


Figure 1. **a.** Illustration of the topological equivalence between a mug and a doughnut through a continuous deformation. The handle of the cup expands as the bottom of the cup fills it. **b.** If the deforming forces are too strong it can lead to the destruction of the mug. **c.** In this case where topological protection is strong enough, the mug survived to the excess of energy by undergoing a continuous transformation keeping the same topology.

The little prince also noticed a painting on the wall depicting three guys writing weird symbols on a blackboard. "Ah! - The king smiled - , those are Thouless, Haldane, and Kosterlitz, they understood the role of topology in materials and found a way to surround our planet with the topological field that protects our fragile objects. Sadly, all industries making glasses, mugs, windows, and fragile things like that went suddenly bankrupt. Those, and the drill industries in fact. Nobody has ever broken any of those objects since, nor has been able to make a hole easily on this planet after topological protection was activated".

Away from the weird topological protected planet, we wish to describe how manipulating topology in spatial distribution of spins can be achieved using out of equilibrium protocols. In our analogy, how to drill holes in mugs that are made of spins and that are topologically protected.

To understand this better, consider a simple example of a ferromagnetic material, such as iron, in which the spins of the individual atoms are aligned in the same direction, creating a uniform spin texture (see Fig. 2a). This spin distribution corresponds to the topological trivial case because it can be continuously deformed to a uniform spin texture in which spins align in any other direction without any topological change.

However, in certain materials the spin texture is not uniform, but rather contains defects such as skyrmions, which are whirlpool-like configurations of spins (see Fig. 2c), that are topological objects and have a nanometric size. Consequently, these defects have to be stable against conventional thermodynamic fluctuations (the equivalent of vibrations for the mug) and can be changed only by a topological transformation, which involves a change in the global topology of the spin texture.

These topologically non-trivial spin distributions have unique properties that make them interesting for various applications in electronics, spintronics, data storage, and quantum computing. For example, the topological defects in a spin texture could act as qubits, the basic units of quantum infor-

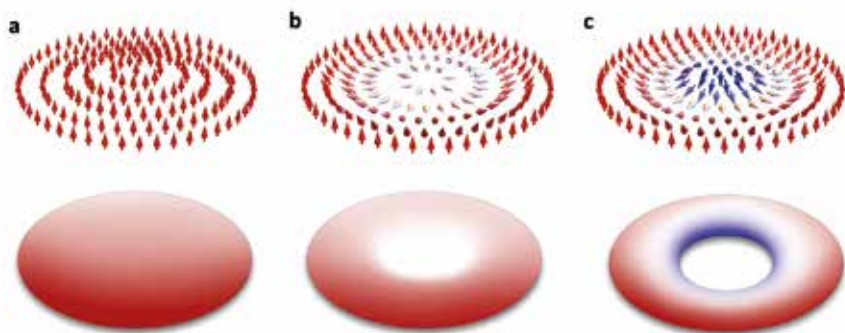


Figure 2. Illustration of the transformation between **a.** a trivial magnetic arrangement going through **b.** a non-uniform intermediate state reaching **c.** a non-trivial topological spin configuration, named Skyrmion, with their associated topological representation, respectively.

mation, and their stability and robustness make them promising candidates for building quantum computers at room temperature. However, to exploit the potential of such topological spin textures, one should find a way to manipulate them, create and erase topological defects, and even move them around at will.

Out of equilibrium protocols offer a unique opportunity in this respect because they allow to outrun thermodynamic fluctuations in a tunable fashion.

When a system is suddenly thrown out of equilibrium by an external perturbation, which can be a heat jump, a strong electric or magnetic field, or a light flash, its relaxation pathway can differ from those normally followed during a slow, adiabatic transformation. As an example, we can think of a ball falling down a stair bouncing off the steps (Fig. 3), where each step is a quasi-equilibrium thermodynamic intermediate state. In this scenario, it can even happen that an out-of-equilibrium protocol takes the system onto a different staircase, with different number of steps and height of the jumps which can even lead to a different equilibrium state that cannot be reached through the conventional

quasi-equilibrium process. Some people call this kind of state “hidden state” which can be short or long-lived. The idea is to exploit such a possibility to circumvent the topological protection and drive a material strongly out of equilibrium and see if it will land in different states, maybe some having different topological properties.

Such experiments were carried out at the Laboratory for Ultrafast Microscopy and Electron Scattering, LUMES, at the EPFL. Here, a customized Transmission Electron Microscope (TEM) has been developed that allows varying magnetic field and temperature on materials (conventional adiabatic processes) but that also allows perturbing the specimen with ultrafast light pulses (out of equilibrium protocol) while imaging its magnetization response in real space with nm resolution using Lorentz microscopy. This is a technique that uses the deflection of electrons by the magnetic fields present in a sample to map the in-plane magnetization [1].

Conventional (adiabatic) perturbations are typically slow on the scale of electronic and spin re-arrangements, and make a system evolve through a set of quasi-equilibrium states. Changing the temperature of a material for example, applying pressure to it, or an external magnetic field are the typical handles that are used to control the properties of solids. Lasers instead can produce flashes of light that are as fast or even faster than the characteristic times of electronic and spin rearrangements. Therefore, they can be used to suddenly shake up things in a material faster than topological protection can even realize and counteract, and by tuning the properties of such laser pulses one can even dose the balance between topological protection and other fluctuations, such as thermal for example, to obtain different magnetic textures and manipulate them.

The topological magnet of choice for these studies was the Mott Insulator Cu_2OSeO_3 , whose magnetic phase diagram is depicted in (Fig. 4a).

A 150 nm thick lamella of Cu_2OSeO_3 was inserted in the TEM and prepared in the low-temperature helical magnetic state. The ensuing magnetization was monitored with Lorentz TEM. By shining one single laser pulse at a time, varying its intensity, wavelength, and polarization it was found that above a certain fluence threshold skyrmions are generated (Fig. 4b).

Remarkably, laser pulses can generate skyrmions not only within the phase diagram regions where they are known to exist in equilibrium conditions, but also, they could be induced at very low magnetic fields where nobody ever observed skyrmions in Cu_2OSeO_3 (see [2]).

The explanation of this phenomenon is that indeed this material can host a variety of different topological phases, some of which however can only be reached through an out-of-equilibrium protocol that drives the system impulsively on a different relaxation path. LUMES researchers explained that light excitation was likely promoting the strong

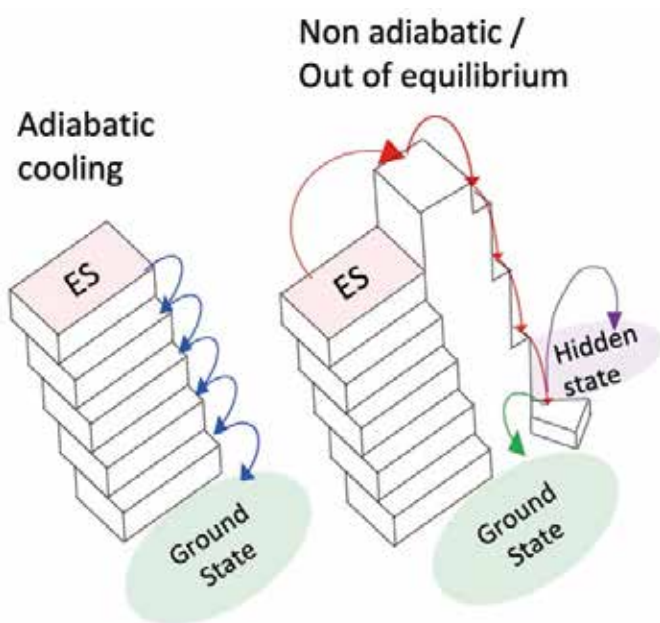


Figure 3. Left: Usual quasi-adiabatic relaxation pathway. Right: In the case that the excitation is faster than the system response timescale, the system can relax in an out-of-equilibrium fashion exploring other metastable states, and eventually reaching a hidden state.

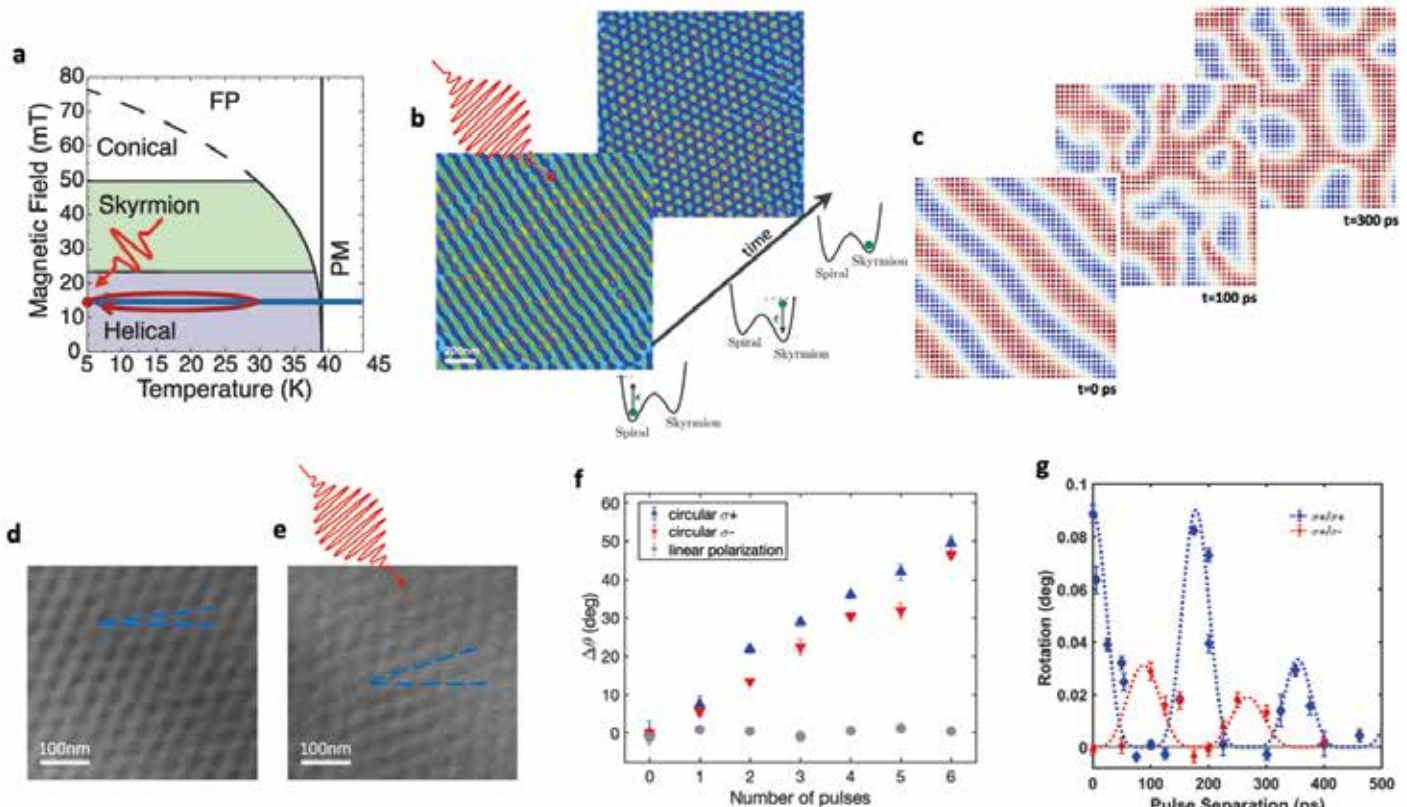


Figure 4. **a.** Typical magnetic phase diagram of a Cu_2OSeO_3 lamella using the field-cooled-cooling protocol. **b.** Real space LTEM image showing the topological transition from the helical state to the skyrmion state after single shot illumination. **c.** Atomistic spin simulation of the magnetization dynamics invoking the presence of a strong phonon-magnon coupling. Images **a-c** are adapted from [2] and **d-g** from [6].

magnetic state before and after photoexcitation with circularly polarized light, respectively. A clear skyrmion rotation is observed and is expressed in the graph **f**. **g.** Observation of oscillatory dynamics of the skyrmion rotation with a shift by half-period when the handedness of the second pulse is changed. Images **a-c** are adapted from [2] and **d-g** from [6].

coupling between phonons (collective distortions of the atomic lattice) and spin fluctuations (collective distortions of the spin arrangements), such that the impulsive lattice distortions eventually allowed for the formation of topological spin patterns. A theoretical simulation (Fig. 4c) confirmed that this was indeed a plausible explanation. Interestingly, the skyrmions hidden phase discovered in this study [2] was found to be metastable, having a lifetime of at least 15 minutes, a time which is much longer (8 orders of magnitude) than any residual excitation possibly present in the sample after laser excitation.

The researchers also noticed that when the wavelength of the laser pulse was tuned below the optical absorption threshold of the material (i.e., in its transparency region) and circularly polarized, above a certain intensity, the photoexcitation was inducing a rigid rotation of the skyrmion crystal (Fig. 4d-e).

An intriguing observation was that such a rotation was not reversible, i.e., the system would not relax back in its initial angle position with time. Furthermore, the amount of rotation was found to be directly proportional to the intensity of the pulse and the number of pulses sent on the material (Fig. 4f). In other words, one pulse would rotate the skyrmions lattice by approximately 5 degrees, two pulses by 2×5 degrees, 3 by 3×5 degrees and so on. This is a very promising handle to control the magnetization in a deterministic way. An important question to reply was how fast such a rotation happens. Because the observed rotation is irreversible, ideally one would need an observation by single-shot Lorentz Transmission Electron Microscopy (LTEM) with a

whopping temporal resolution of few hundreds of fs to a few ps to address its dynamics. To put things in perspective, LTEM provides the best spatial resolution (down to 1 nm) to observe magnetic textures, needed to look at skyrmions and their small rotation. However, because of the Coulomb repulsion that electrons suffer when they are close to one another, keeping many of them in a short bunch necessary to observe a ps / irreversible / nm effect in one single shot is even theoretically impossible [3].

To circumvent this problem, LUMES researchers had the idea to try to rotate the skyrmions using two laser pulses instead of one, leveraging the fluence threshold observed. The protocol consisted of sending two pulses each carrying half the intensity necessary to induce the rotation, i.e., below the fluence threshold. The logic was that when the two pulses were temporally overlapped, they would obviously induce the rotation while if the two pulses were placed far apart in time they would act as individual pulses keeping the skyrmion lattice unchanged. The question was then how close or far apart the two pulses must be to induce the skyrmion to rotate.

Surprisingly, the rotation angle turned out to be an oscillating function of the distance between the two pulses (Fig. 4g). Coherent spin dynamics in Cu_2OSeO_3 were observed by ultrafast magneto-optical Kerr effect experiments in [4]. Such oscillations were ascribed to the excitation of coherent magnons launched in the material by the inverse Faraday effect, which consists in the generation of a magnetic field pulse in a strong spin-orbit coupling solid when circularly polarized light impinges on it [5].

A possible explanation for the observed coherent control of the rotation angle of the skyrmion lattice was that a first pulse drives coherent motions of the spins which can result in an overall rotation of the lattice when they are large enough. In other terms, either when the individual pulse was strong enough, or when the second pulse participated constructively in the oscillation of the spins initiated by the first pulse, the skyrmions rotated. This explanation was further supported since when the pulse separation was tuned to exactly match half the period of this oscillation, no skyrmion rotation was observed.

While this explanation could be corroborated qualitatively by theoretical calculations (see [6]), a puzzling difference of a few orders of magnitude between the predicted rotation and the reported one was observed. In addition, the rotated skyrmion crystal had a new stable spacing of 70 nm, 5 nm more compared to the initial equilibrium state, opening further questions regarding the exact mechanism.

The protocol discovered to manipulate and visualize topological magnetic patterns allows to literally decide how much to tilt spins in the material with a precision of fractions of degrees in timeframes as short as a few tens of ps while visualizing this magnetic dance. To summarize, this work is the first to demonstrate a magnetic topological phase transition by directly shaping the relaxation pathway using an out-of-equilibrium protocol [2]. In addition, the coherent control of the skyrmion crystal angle has been achieved by tuning the polarization of the laser pulse [6]. Both works

were performed using an photoexcitation energy below the optical bandgap of the compound, thus breaking ground for a novel approach to control topological magnetic state on demand at ultrafast timescales while drastically reducing heat dissipation.

Acknowledgement

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IUPAP – 100 Years of International Collaboration in Physics

Hans Peter Beck – IUPAP liaison chair Switzerland

The laws of physics are independent of national borders. Only by working together the community can efficiently challenge the physics frontiers. For a century the International Union of Pure and Applied Physics (IUPAP) has strived to assist in the worldwide development of physics, to foster international cooperation in physics, and to help in the application of physics toward solving problems of concern to humanity.

The International Union of Pure and Applied Physics

The International Union of Pure and Applied Physics (IUPAP¹) is an offspring of the International Research Council, a temporary body created after the First World War to rebuild and promote research across the sciences. IUPAP was established in 1922 with 13 member countries and held its first general assembly in Paris the following year. Switzerland was a founding member of the Union and participated with four delegates at the Constitutive General Assembly. The 12th General Assembly² was hosted in Switzerland in 1966. In October 2021, the IUPAP headquarters moved from Singapore to Geneva with an administrative office in Trieste, Italy.

International cooperation in difficult times

Originally, neither the International Research Council nor IUPAP included any of the countries of the Central Powers (the German Empire, Austria-Hungary, the Ottoman Empire, and the Kingdom of Bulgaria). Many lessons in science diplomacy had to be learned before IUPAP and the other scientific unions became truly international and physicists from all countries could apply to join. Member countries have been realized as too limiting to fulfil these high goals, whereas member territories allow the flexibility needed, such that physicists from all places can apply to join. As the IUPAP statutes state, belonging to a territory does not imply any political position of IUPAP, which seeks to assist physicists everywhere in carrying out their mission. A territory is in most cases identical to a country, but exceptions do exist, such that China and Taiwan can both be members and further, the door is open for Palestine and other unambiguously identifiable territories to adhere.

¹ <https://iupap.org/>

² <https://doi.org/10.5281/zenodo.7083334>

- Today, with 60 member territories, the Union strongly advocates that no scientist shall be excluded from the scientific community as long as their work is based on ethics and the principles of science in its highest ideals—an aspect that certainly will be further elaborated by the working group on ethics established by IUPAP in October 2021. Not all European countries are supportive of this stand since the war in Ukraine broke out.
- The IUPAP conference policies states that the principle of the Universality of Science is fundamental to scientific progress. This principle embodies freedom of movement, association, expression and communication for scientists, as well as equitable access to data, information and research materials. In pursuing its objectives with respect to the rights and responsibilities of scientists, IUPAP actively upholds this principle, and, in so doing, opposes any discrimination on the basis of such factors as ethnic origin, religion, citizenship, language, political stance, gender, or age. IUPAP should only sponsor conferences and events at institutions and in countries that uphold this principle. If scientists are excluded from attending IUPAP-sponsored international conferences by a host institution or country on the basis of any of these factors, IUPAP should register its concern at the highest level of that institution or country, and should not sponsor any future events in that country until such exclusions have been eliminated.

To face the situation and to promote international cooperation, IUPAP welcomed Ukraine as a new member in 2022. The decision to admit Ukraine was expedited to send a strong signal of support for the war-torn country, a war that has not spared its scientific institutions and the people who work there. Furthermore, IUPAP issued a statement strongly condemning the Russian aggression in Ukraine, while also expressing the principle that no scientist should be excluded from union-sponsored conferences, as long as he or she is committed to the principles of the Union. Free circulation of scientists, for scientific purposes, is a major piece of IUPAP policy to foster the development of physics. To overcome difficulties related to attending conferences in the current tense situation, IUPAP has implemented a mechanism allowing excluded scientists to participate in IUPAP-sponsored conferences using the Union — IUPAP — as their affiliation, somehow like the model applied for the Olympic Games. As a result of this, the International Nuclear Physics Conference (INPC), held in South Africa in September this year, organizers took the decision that all participants attending the conference use the IUPAP affiliation — independent of their actual home institute.

IUPAP Centennial Symposium

The main IUPAP event in 2022 was the centennial symposium. From 11 to 13 July, around 250 physicists from some 70 countries gathered to celebrate the 100th birthday of IUPAP at a symposium held at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy. About 40 % of the participants were physically present, while the rest were connected online. Various panels composed of international experts discussed important issues in alignment with the IUPAP's core aims, including: how to support and encourage early career physicists, how to improve diversity in physics, how to strengthen the ties to

physicists working in the industry, how to improve the quality of physics education, and how to promote the development of physics in developing countries.

A number of influential scientists, including Giorgio Parisi, La Sapienza, Italy, and Laura Greene, Florida State University, USA, described their roles in advising their respective governments on science. They shared some best practices in how to bridge between academia and politicians by providing evidence-based advice to their respective governments. The examples given were certainly useful across national borders.

Other prominent speakers included William Phillips, University of Maryland, USA, who covered the revolutionary quantum reform of modern metric systems; Donna Strickland, University of Waterloo, Canada, who discussed the physics of high-intensity lasers; and Takaaki Kajita, University of Tokyo, Japan, who presented 100 years of neutrino physics via an online connection with the International Conference on High Energy Physics (ICHEP) in Bologna. Renowned climate scientist Tim Palmer, University of Oxford, UK, gave a talk on climate change, arguing that a super-computing facility—modelled on the organization of CERN — would enable a step-change in actually quantifying climate change, while Stewart Prager, Princeton University, USA, outlined the growing danger of nuclear weapons, and a new project sponsored by the American Physical Society to engage physicists in reducing the nuclear threat. Dedicated panels were held to discuss the development of physics in Africa and the Middle East, Asia and the Pacific, and Latin America. It is clear that in these regions IUPAP has a large potential to foster further international collaboration. The panel focusing on the Asia-Pacific situation emphasized that the region is possibly one of the most diverse regions in terms of human development, geography, culture, language, connectivity, mobility etc. The IUPAP Centenary symposium offered an ideal platform to gather the physics community from this region close together. The second quantum revolution is on the anvil and is of critical importance for the region.

The International Year in Basic Sciences and Sustainable Development (IYBSSD)

With strong support from unions and academics around the world, IUPAP is the legal representative and main driver behind the IYBSSD. All the financial transactions of IYBSSD are handled via the IUPAP accounts, while most of the administration is carried out by the IYBSSD Secretary-General especially engaged by IUPAP for the period of this United Nations observance³.

³ https://en.wikipedia.org/wiki/Category:United_Nations_observances



IUPAP delegates at the centennial meeting 2022 in front of the ICTP building in Trieste

The IUPAP Centennial Symposium was one of the official events of the International Year of Basic Sciences for Sustainable Development, which was officially inaugurated only a few days earlier, on 8 July 2022, at the UNESCO headquarters in Paris.

In Switzerland, in November 2022, SCNAT organized the meeting *Sustainability Science Forum 2022 - Shaping Research for our Future*⁴ under the umbrella of the IYBSSD. The closing ceremony, presenting the outcome of the year, will be held in Geneva, at CERN, on 15 December 2023.

The International Decade of Sciences for Sustainable Development 2024 - 2033

The International Decade of Sciences for Sustainable Development 2024 - 2033 is the logical successor of IYBSSD, which has equally been put forward by IUPAP's influential role in finding supporting countries, going through UNESCO, and finally arriving at the General Assembly of the United Nations that proclaimed on 25 August 2023 the draft resolution A/77/L.100 proposed by Argentina, Cuba, Equatorial Guinea, Guatemala, Honduras, Hungary, Serbia, South Africa, Spain and VietNam⁵.

With this, the period 2024 - 2033 the International Decade of Sciences for Sustainable Development, and the critical role that sciences play in the pursuit of sustainable development is recognized by the United Nations, which for Switzerland implies the Swiss Academies and with it the Swiss Physical Society and others, to play a pro-active role to identify and develop activities and programmes within their mandates and using existing resources and voluntary contributions, as appropriate. Further, all academia, civil society organizations, the private sector and the media are invited to actively support the implementation of the Decade.

Commissions

IUPAP commissions promote the objectives of the Union within their areas of expertise and provide advice to IUPAP on the activities and needs of the subfields of physics they represent. There are 20 commissions defined, where Switzerland chairs C11 – Particles and Fields, Florencia Canelli (UZH). Switzerland has further representatives in commissions C9 – Magnetism, Oksana Zaharko (PSI) and C16 – Plasma Physics, Christian Gabriel Theiler (EPFL).

Working Groups

IUPAP Working Groups are international and interdisciplinary collaborations of researchers aiming to focus and develop new research fields and activities that would be difficult to resource through traditional funding programmes.

Working Group 16 – Physics and Industry is led by Christophe Rossel (em. IBM Research Europe - Zurich). The group has made good progress during 2022 (and the beginning of 2023). Advanced Laser Light Source (ALLS), CERN, JINR, Park Systems, and SESAME have been brought in as IUPAP Corporate Associated Members—a new class of IUPAP membership. This is the first IUPAP step forward to enforce the links between physicists working in academia and in industry. These new members will also strengthen

⁴ https://scnat.ch/en/uuid/i/e8069efb-c545-5a5d-a2e4-3db881fb0474-Sustainability_Science_Forum_2022_-_Shaping_Research_for_our_Future

⁵ <https://digitallibrary.un.org/record/4019134>

IUPAP's finances allowing for more activities under the auspices of the Union.

Working Group 21 – Physics for Climate Change Action and Sustainable Development is a newly created working group with the mission to identify, promote, engage, and discuss the unique role that physics has and to entrench an evidence-based approach to responses to climate change studies and the energy transition process in close collaboration with experts from other disciplines.

WG 21 is headed by Igle Gledhill from South Africa. Jean-Louis Scartezzini, retired from EPFL, is member of WG 21.

Sponsored conferences in 2022

As every year a large number of major physics conferences were sponsored by IUPAP⁶. During 2022 none of these conferences were organized in Switzerland. The situation is similar for 2023 — is it time to think about how and when to host the next IUPAP conference?

IUPAP awards

Two IUPAP awards have been bestowed to scientists with a strong link to Switzerland in 2022.

The 2022 Early Career Scientist Prize by C8 (Semiconductors) was given to Prof. Dr. Dmitri K. Efetov. He received a Diploma (M.Sc.) in Physics from ETH Zurich in 2007 and is now Full Professor (W3) and Chair of Solid State Physics at LMU Munich (C8⁷).

The 2021 IUPAP Magnetism Award and Néel Medal was given to Prof. Nicola Spaldin, ETH. The award was presented at the 2022 ICM, Shanghai, China, during 3 - 8 July 2022 (C9⁸).

Examples of Swiss involvement

A dedicated IUPAP session was organized at the annual meeting of the SPS in Fribourg⁹.

IUPAP Secretary-General Jens Vigen (CERN) gave an overview of the history of IUPAP and its relevance to a global society. IUPAP President Michel Spiro (retired from Université Paris-Saclay) presented how IUPAP promotes Large Scale Physics Projects which are collective and inclusive, gathering physicists from all over the world beyond cultural, geographical and political differences. This has been shown to becoming more and more difficult in the present times and IUPAP helps, as much as it can, to overcome the difficulties.

Michel Spiro pointed out further that IUPAP is the promoter and organizer of the International Year of Basic Sciences for Sustainable Development (IYBSSD), which is perfectly in line with the mission of IUPAP to help in the applications of physics towards solving problems of concern to humanity.

IUPAP has served the physics community for 100 years and has strong ambitions to continue to assist in the worldwide development of physics and promote physics as an essential tool for development and sustainability in the next century.

⁶ <https://iupap.org/conferences/archived-conferences/approved-conferences-of-2022/>

⁷ <https://iupap.org/who-we-are/internal-organization/commissions/c8-semiconductors/c8-news/>

⁸ <https://magnetism.eu/news/172/38-news.htm>

⁹ <https://indico.cern.ch/event/1119258/sessions/440808/#20220630>

Physics Anecdotes and Personal Recollections (27)

Optical Metrology

Bernhard Braunecker

We explain in the following measurement concepts for testing special optical systems. We focus on high resolution imaging lenses as used in airborne photogrammetry and in semiconductor lithography, which need unconventional tools to check image resolution and image distortion.

Airborne Lenses for Photogrammetry

A class of rather unconventional and expensive optical systems were the big cameras for airborne photogrammetry, recording topographic sceneries on high resolution film. These cameras were produced until 2000, then replaced by digital cameras. In their daily use, the cameras were and are exposed to heavy mechanical shocks during take-off and landing of the airplane, to strong vibrations during flight and, above all, to large temperature differences, for example, from +60°C at take-off in the desert to -40°C at an altitude of 3000 m within few minutes. Since the cameras were taken for official surveys, the focal length and the image distortion had to be tested regularly. To this purpose they had to be recalibrated by the lens manufacturer such as Leica Geosystems in Heerbrugg, but also by national authorities as USGS in the USA¹.



Fig. 1: Calibration of a film lens Universal Aviogon UAGS-2 with the electronic vertical goniometer EVG.

After arrival at the factory the focal length and the distortion of the film lenses were measured by an electronic vertical goniometer EVG (Fig. 1), while the optical resolution was visually tested with an official NATO test target by the operators. Then in most cases the lens had to be completely disassembled, all elements cleaned, sometimes some lens surfaces repolished and recoated, and remounted. Thereby the thickness of the mechanical spacers between the lens elements was recalculated and changed by some tenth of μm to correct the focal length and to bring the field distortion and the resolution back to the specification range.

When the film cameras were substituted by digital cameras, we modified the EVG goniometer to a coded vertical go-

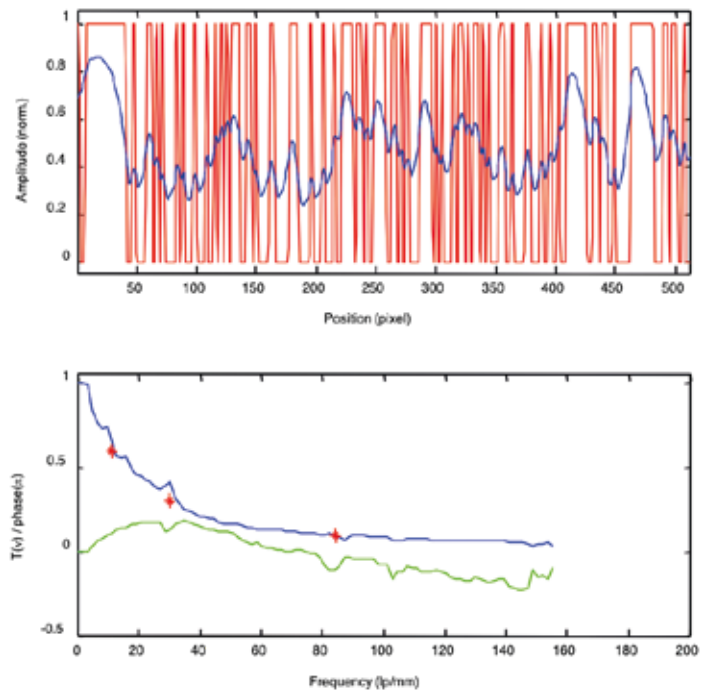


Fig. 2: CVG measurement at lens arrival, showing a lens with strong comatic aberrations. Top: Barcode object (red) and its image (blue) with bad contrast values. Bottom: MTF (blue) and PTF (green). Note that the asymmetric code profile, the low MTF values and the non-zero PTF indicate centering errors.

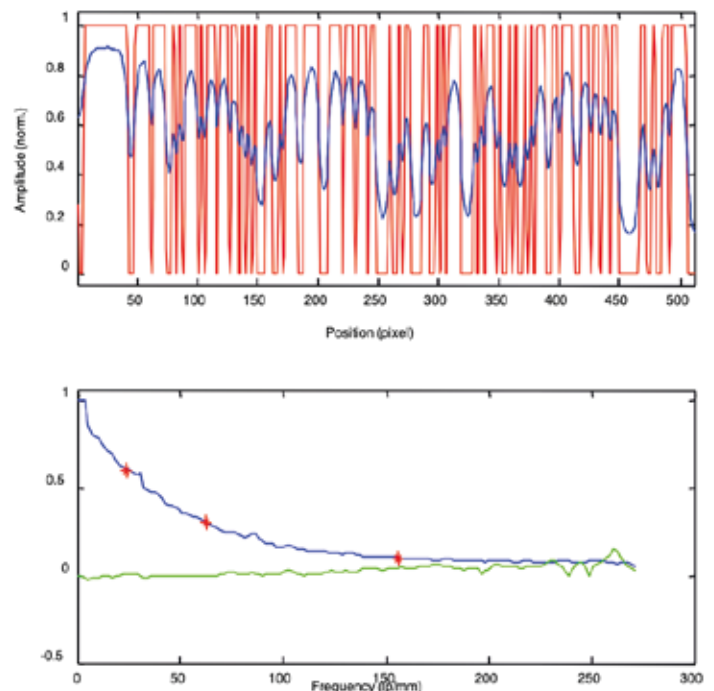


Fig. 3: After correction: Improved MTF values and PTF values nearly to zero. The barcode profile is now symmetric.

niometer CVG. A collimator with a special binary code target simulated the topographic object on ground, and was moved inside the CVG in front of the test lens. The linear codepattern could also be rotated to either point in radial or tangential direction. From all the recorded code images the information about the focal length and the field maps of

¹ <https://www.usgs.gov/>

The relation between both code pattern (red and blue in Fig. 2 and 3) is the optical transfer function OTF, defined as the Fourier transform of the point spread function PSF, that is the impulse response of the optics, i.e. the image of a point source. As Fourier transform, the OTF is complex-valued with a magnitude term called modulation transfer function MTF and a phase transfer function PTF. The PTF is zero if the PSF is symmetric, which is not the case in Fig. 2, but in Fig. 3.

distortion and resolution, both in radial and tangential directions, were obtained.

In Figs. 2 and 3 we see slightly different binary code patterns of contrast one in red and their recorded images by the test lens in blue, which contrast values decrease with higher code frequencies expressed in linepairs/mm. Fig. 2 shows the entrance measurement of a seriously damaged lens after arrival with very low contrast values and asymmetric code bars, indicating internal decentrations. After re-adjusting all lens elements, the MTF contrast values (Fig. 3) were significantly improved, and the code bars were again fully symmetric. In Fig. 4 we see left the CVG and right the spectral and radiometric calibration equipment with a large Ulbricht-sphere, together with the ADS40, the world's first digital airborne photogrammetric camera.

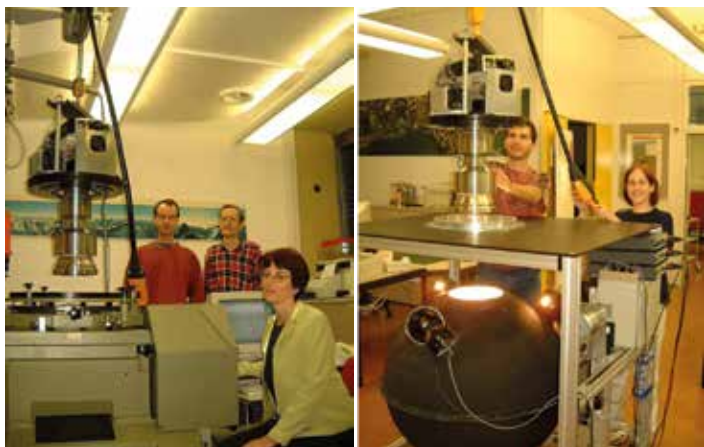


Fig. 4a: Coded vertical goniometer CVG to measure the focal length, the distortion and the OTF of a digital camera ADS40.

Fig. 4b: A large Ulbricht sphere is used for the spectral and radiometric calibration.

Testing Lithographical Systems

Our next example concerns high-performance stepper lenses as those used in chip production. A computer or memory chip consists of many superimposed semiconductor layers, where each layer has a specific current conduction pattern, and all these layers on the chip have to be carefully aligned and interconnected. The layer exposure is a three-step process: first each layer pattern is contact-copied and etched on a glass plate called *template*. Second the template is imaged about ten times smaller on a special glass plate called *reticle*. Then in the third and main step the reticle is used as the object pattern in the wafer factories, where it is imaged by big and very expensive wafer stepper lenses about five to ten times smaller on the semiconductor wafers, now with fabrication and alignment tolerances of some nm.

Reticle Production

In Fig. 5 we illustrate the second step, the reticle production, performed by a combined optical exposure and inspection system. An UV-Excimer laser emitting at 254 nm wavelength is the light source which spatial coherence is reduced by a scrambler to minimize speckle effects on the reticle². Followed by a motorized zoom lens the beam is switched to the exposing path (blue lines) to illuminate the glass template which engraved pattern is imaged about ten times smaller by the reticle imager lens (NA = 0.78) on the glass reticle, coated with photomonomer lacquer. The exposed structures become polymerized by the UV light, and protect the glass material when the reticle is chemically etched outside of the optical system (green box in Fig. 5). The monomer layer of the unexposed area is removed by water rinsing before etching.

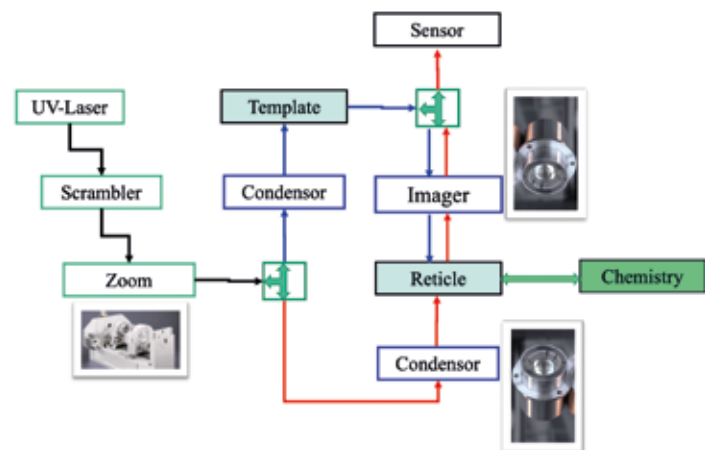


Fig. 5: Optical system for reticle exposure (blue path) and reticle inspection (red path)

The new pattern must be inspected for damages as micro-scratches caused by the chemical process. Therefore the developed reticle is re-installed in the optical system, but now the inspection path (red lines) is switched on to illuminate the reticle by a different condenser lens and to image it on a special 2D-UV-sensor. Note that both, the exposure and the inspection arrangements are part of a 'step and go' mechanical system moveable in x and y direction to cover the full reticle area which is much larger than the field of view of the optics.

All the lens optics is made from special UV-glass with high transparency at 254 nm. The imaging lens in our case weighted several kg with very tight optical tolerances, and it was suspended by so-called mechanical flexures. The reason was that the inspection as part of the 'step and go' process required that the imager lens had to be oscillated in resonance by motors along the optical axis with kHz frequency to determine the best image plane. A non-trivial mechanical challenge, since no lateral deflections were allowed.

Due to the permanent mechanical oscillation one had to control regularly the optical performance of the imager lens

² The scrambler is a hexagonal kaleidoscope where by internal reflections the laser point source is seen as extended source of six laser points, but with slightly different phases. This reduces the spatial coherence of the new virtual light source and makes the imaging processes less sensitive to coherent noise (speckle) caused e.g. by micro-scratches in the reticle glass material after chemical etching.

by analyzing so called 'on-axis' aberrations, which are defined as spherical, comatic and astigmatic axial distortions. The first one is caused by tiny dislocations of an optical element along the optical axis, the second one by tilt errors or decentering across the optical axis, and the last one by either rotational errors or by mechanical tensions.

The HPZ³ to detect comatic errors

Decentering or tilting of an optical element across the optical axis is the most likely mechanical defect, and one has to control the centering state of *all* internal lens surfaces. To this purpose a laser beam emitted from a special vario-optics is focused into the center of curvature (CoC) of the front lens surface S_1 of the test lens (Fig. 6). The reflected wavefront from S_1 , which is back focused into its CoC, is imaged by the vario onto a 2D sensor. A surface tilt angle φ_1 of S_1 relative to the optical axis of the test lens and/or the vario leads to an offset position of the laser spot on the sensor. To get rid of the irrelevant coordinate system of the vario, one mounts the test lens on a precise turntable and rotates it. Then the reflected laser spot also rotates on the sensor. Ignoring the circle's centre position and only taking the circle's diameter allows to calculate φ_1 with respect to the turntable axis, which is the best approach of the test lens axis.

As second step one repositions the vario that the laser beam is now reflected from surface S_2 . This is done by focusing the laser beam into the CoC of S_2 , *but as seen through* S_1 . Again from the diameter of the reflected laser spot circle on the sensor the tilt angle φ_2 is obtained after correcting the tilt effect of surface S_1 , using its now known tilt angle φ_1 . The process is repeated until the autoreflex of the last lens surface S_N is recorded on the sensor and the last tilt angle φ_N is found with the help of the known tilt angles φ_1 to φ_{N-1} .

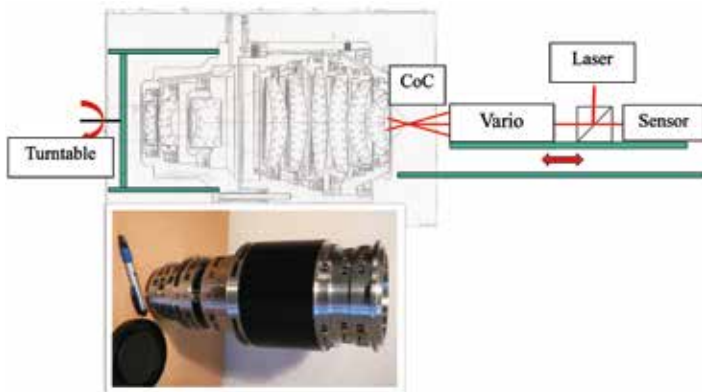


Fig. 6: The laser beam is focused by the vario (right) in the centre of curvature CoC of the first surface of the test lens (left). The autoreflex from this surface is imaged on the 2D-sensor. The test lens is rotated to become independent of the coordinate system of the vario.

The result of this kind of 'axial tomographic' iteration is the 3D map of the CoCs of S_1 to S_N . The numerical fit line through them is the best optical axis of the lens with regard to the actual decentrations. The fit weights are determined by optical tolerance calculations⁴. By considering the resid-

ual deviations of the CoCs from the best fit axis, one can decide whether the decentrations are still in tolerance, or individual lens elements must be readjusted, or as worst case the entire objective has to be sent back to the factory.

The AFZ⁵ for automatic lens centering

The HPZ concept was further expanded to increase the efficiency in production, for example for the automatic centering of all lens groups of a geodetic objective. For this purpose, each lens group mounted in a metallic cylindric housing, is clamped in the ball chuck of an automatic lathe. After the 3D position of at least two CoCs had been determined as described before, the ball chuck was adjusted by four servomotors normal to the rotation axis so that the fit axis coincided with the axis of the automatic lathe. Then the metallic cylindric housing was turned with the lathe tool and served as reference cylinder for further installing the lens group into the housing of the objective. The technology was developed by Leica for the automatic centering of triplet lenses for theodolites in large quantities with accuracies in the range of arcseconds.

Coherence Resolved Sensor

Fig. 7 shows the layout of a special interferometer developed by Leica Geosystems in 1997 for ESA^{6,7}. The vario-objective focused the laser beam in the CoCs as described above, however not the CoCs were imaged on the 2D-sensor (CCD), but the surfaces S_1 themselves by installing a Fourier lens in front of the CCD. Then the autoreflected signals from all surfaces were incident as unknown tilted, but plane WF on the sensor and could interfere there with a not tilted, perfect plane WF generated in a reference path by reflection from a perfect mirror. If the optical length in the reference path was adjusted by a movable corner cube to match both path lengths, one received interference fringes on the sensor from which the value of the tilt angle was calculated. The signal discrimination was further significantly improved by using a light source of short coherence length. When testing the method with a lens of same complexity as the lithographic reticle imager of Fig. 6, surface tilt errors could be measured with an accuracy of about 3 arcsec rms.

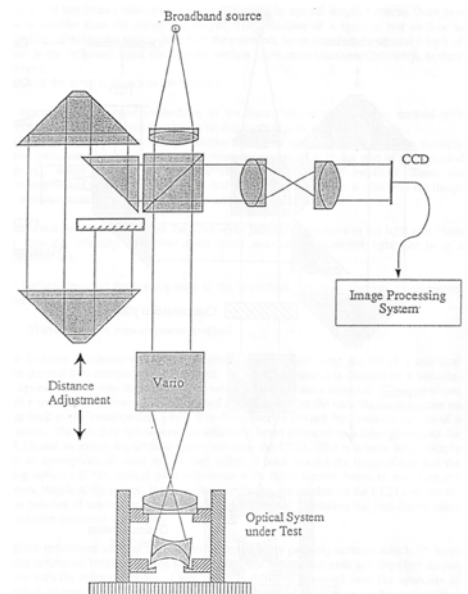


Fig. 7: Low coherence interferometer

5 Automatisches Flächen Zentriergerät AFZ

6 Design Verification and Failure Diagnosis for Precision Space Optical Systems (DTSO), ESA-Contract No. 11092/94/NL/PB.

7 PCT No. PCT/EP92/02497 Sec. 371 Date Mar. 23, 1994 Sec. 102(e) Date Mar. 23, 1994 PCT Filed Oct.30, 1992 PCT Pub. No. WO93/09395 PCT Pub. Date May 13, 1993.

3 Hoch Präzisions Zentriergerät HPZ

4 Cemented surfaces contribute less strong to the optical quality than glass-air surfaces, so their fit weight is small. Therefore if their autoreflex signal is too weak to be reliably measured, they can be ignored in the iteration in most cases.

Physicists in Industry (15)

Interview with Michel Hübner, from the Swiss Industrial Liaison Office (ILO)

The Industry Liaison Office represents the interests of the Swiss industry at International Research Organisations. This gives the office a privileged view of a specific focused industry sector, oriented towards the physics-based research market. To find out more, our editor *Antoine Pochelon* asked **Michel Hübner**, Head of the Swiss ILO Office to talk about his activity.

To optimise Swiss industry outlets for major large-scale international research projects and infrastructures, the need to establish a liaison body between Swiss industry and these major international players was identified. Who initiated the installation of the Industry Liaison Office (ILO)?

Officially, the Liaison Office was set up in 2015, on the initiative of SERI (State Secretariat for Education, Research and Innovation) with the support of two laboratories: the Swiss Plasma Center at EPFL, (national competence centre for fusion technology), and the PSI (national competence centre for accelerator-related technology). Later joined the University of Geneva, (representing the astronomy national science) and SWISSMEM, the Swiss umbrella association for machine-tool, electronics, and metallurgy.

The role of the ILO is to support the Swiss industry in obtaining contracts at these projects (measured as the geo-return factor) This in two modes: on one hand, to identify within the public *Invitations to Tender* regularly published, those which would suit the competences of Swiss companies. On the other hand, to promote Swiss technologies among the various engineering teams inside the research organisations. In marketing terms, we would call this a push and a pull mode. Either the industry develops a product that fits the needs of the research facility, or the industry suggests a new product/service to attract the client by locking the tender procedure in its favour. Switzerland, with its high prices and an industry culture of innovation and quality must, more than any other country, be proactive in suggesting its pioneering technologies.

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<https://www.swissilo.ch>



1986: EPFL Physics Master's degree

1986-2007: works for different telecom companies in France and Switzerland

2007: joins CSEM as Section leader

2012: joins SERI as ILO for ITER

Since 2015: ILO for eight International Research Organisations.

However, didn't the role of ILO already exist before 2015 with the ITER project?

Indeed, fifteen years ago the ITER project was virtually unknown, both in Switzerland and in Europe. The first official ILO position in Switzerland was opened simultaneously with the creation of the European ITER agency F4E (Fusion for Energy) to disseminate information about the ITER project. Today it has become almost a standard business practice, having every participating country nominating an ILO function for each large European research organisation.

How is the management of the Swiss ILO organized? For instance, what are the roles of SERI and the other members? Are the PSI, the SPC (EPFL), UNI GE and SWISSMEM advisory bodies?

A convention fixes the rights and obligations of all partners forming the Swiss ILO Steering Committee. SERI animates the Steering Committee and provides the secretariat. SERI supports financially the activity, though in-kind contributions are provided by each member such as: office accommodation, travel expenses, support for communication, website and other marketing activities. In the current four-year term, EPFL is providing the accommodation for the ILO office.

Who are the members of the steering committee?

To date, members include directors of the national academic centres whose scientists are already cooperating with the international organisations in question. It should be borne in mind that in many cases, solutions provided by Swiss industry on our national installations are subsequently used as a springboard to obtain contracts for equivalent needs on international physics installations.

A typical example is the development for the TCV tokamak at EPFL of specific plasma heating power supplies implemented first on national scale, and afterwards, on the larger-scale ITER project.

What are the major international research organisations in which Switzerland participates? And which ones are the most profitable for the industry?

They fall basically into three categories: fundamental, applied and energy research (see box).



Figure 1: The ESO VLT site in Chile (with nine optical telescopes visible here). © ESO

Fundamental research (Elementary particles and Universe observatories)

- CERN (European Organization for Nuclear Research) – Geneva, Switzerland
- ESO (European Southern Observatory) – Munich, Germany
- SKA (Square Kilometre Array) – Manchester, United Kingdom

Applied research (Material sciences)

- ESRF (European Synchrotron Radiation Facility) – Grenoble, France
- Eu-XFEL (European X-Ray Free Electron Laser) – Hamburg, Germany
- ILL (Institut Laue Langevin) - Grenoble, France
- ESS (European Spallation Source) – Lund, Sweden

Energy (Fusion research)

- ITER (International Thermonuclear Experimental Reactor) – St Paul-lez-Durance, France

The total financial value of contracts acquired by Switzerland per year at these facilities is about 100 million CHF. As a comparison, the return of contracts from ESA (European Space Agency) to Swiss companies is at the level of 150 million CHF. CERN picks up most of this value for two reasons. The available procurement budget at CERN is ten times higher than that of any of the other facilities. Switzerland is a host state to CERN, and many procurements for commodity services and infrastructures are therefore going to companies located in the Geneva area. The ITER program, with its substantial procurement budget, has generated revenues of the order of ten million CHF every year for Swiss companies in the last fifteen years.

In our current relationship with the European Union, i.e., the rejection of the framework agreement in May 2021 by the Swiss government, what is the impact on these various research infrastructures? Have they been affected?

Switzerland's agreements with these research infrastructures are governed either by inter-governmental agreements, or by agreements between Switzerland and the European Union. The only organisation impacted at the institutional level by the rejection of the framework agreement is the ITER project. It is the Euratom Agreement, a bilateral agreement signed 1973 falling under the jurisdiction of the European Union, related with nuclear energy research, that could not be renewed for 2022. This means that Swiss companies are not anymore eligible in tendering procedures arising within the ITER project.



Figure 2: The ITER construction site (with the 60-meter-high tokamak assembly hall). © ITER

Luckily, many pre-studies were made by Swiss industries over the first ten years of the project so that Swiss technologies, now in production phase, can hardly be circumvented or replaced at this late project phase. Exceptions to include extra-member state technologies always do exist. Today, up to six Swiss strategic technologies are considered as essential for the first ITER plasma phase.

Your work as a liaison between international organisations and Swiss industry undoubtedly gives you a privileged viewpoint on the qualities, strengths and perhaps also the weaknesses of Swiss industry. Can you give us a picture of Swiss industry as you see it from the role of ILO?

Yes, of course. In fact, you can look at things in different ways. Let's start with the highlights.

First of all, Switzerland has a long tradition of participation in European organisations and related scientific projects, such as ESA, JET, CERN. The past cooperation experience between scientists and industries in these programs is a very strong asset. We weren't born yesterday! Then, Switzerland is renowned for delivering products and services with remarkably high added value. In the big science market, we need components, with the highest reliability and excellent level of maintenance. A component delivered to CERN might not be as critical as the one going on a space program, however, in a complex accelerator chain such as LHC, with most equipment operating in a radioactive protected zone, a high MTBF (Mean Time Before Failure) and fast troubleshooting is a prerequisite for any component. The lifetime of an accelerator is at least 20 years.

Moreover, for many components performance is more important than price. The construction cost of a new facility or an infrastructure upgrade are typically in the cost range of 1 billion CHF. When it comes to implementing complex optical, electrical, or precision mechanical based sub-systems, and here I refer to components such as sensors or actuators, where the Swiss industry excels, only the best product on the market will be considered. No compromise will be taken for the ultimate quality of science made at these facilities. A cost difference of a few ten thousand CHF on a sub-system will be seen as affordable. The Swiss-made label works!

In the same perspective not to be forgotten is our know-how in machine tooling and material engineering. Switzerland is per capita the strongest machine-tool export country, after Germany. Due to the harsh physics environment (high radiation, high magnetic fields, ultra-high vacuum, extreme heat or extreme cold) in physics-based facilities, the demand goes at the extremity of the technology scale for many material machining and assembling tasks. There is a fantastic cumulative knowledge in Switzerland of all types of materials, metal alloys, ceramics, and handling processes.

Switzerland's advantage in this market is also that the industrial landscape is made up of small to medium size enterprises (SMEs), everywhere between lake and mountains! These companies, because they are limited to small production series, are very project-oriented and dedicated to their customer. These qualities fit the scientific project culture: unique, complex, engineering-focused, co-operative, long lasting, multi-cultural and multi-disciplinary, requiring trust and commitment. I like to say that in Switzerland every worker on the shop floor knows the end customer!

Now coming to the drawbacks.

The research applications are seen as prestige projects. A project reference on, let us say CERN, is rewarding for any company. Engineers are enthusiastic to work on projects that push technology to the limits with a high international exposure. Nevertheless, an entrepreneur will observe that the time scale for project acquisition is slow in comparison to the private sector. He may complain about the administrative burdens related to the international / European Union public tendering environment. Furthermore, there can be a perception of uncertainty on the return on investment. This is due to the strong international competition as well as the low and rather cyclic production volumes.

In a strong economy country like Switzerland, these unfavourable arguments can be decisive for declining interest. Projects are seen as a distraction from the more immediate and profitable markets in which the high-tech companies are usually active (semiconductor, consumer goods, energy, MedTech, automotive, etc..). Then when an offer has been placed and when it comes to the commercial negotiations, I have sometimes the feeling we lack the necessary fighting spirit. Research projects are by nature first of a kind and can be a bit unpredictable, typically with an incomplete technical specification at project launch. This does not always match with the Swiss conservative and risk-averse mentality. Here we can learn from the Southern European countries that have more proactive attitudes when doing sales in the big science market.

And perhaps, to conclude, tell us about the areas in which Swiss industry makes a particularly important contribution.

It is true that in the supplier network, there are strong areas of excellence recognised at the international level. You will see that they are also distributed somehow along geographical regions in the country.

Instrumentation would be one of these. One can typically think of a particle detector, where multiple skills are required to design a product. A combination of know-how in semi-conductor chip design, in optics, in fast signal processing electronics and system control. An emblematic company in this field would be *Dectris*, a spin-off from PSI, in Baden, offering state of the art X-ray detector systems to most synchrotron facilities all around the world.

Another Swiss supplier strength would be *power electronics*. Accelerator systems use very specific electronic devices to accelerate particle bunches. High-power amplifiers require special design techniques, with a deep understanding of electromagnetic phenomena. The excellence of our poly-technical schools and the historical heritage of the Brown Boveri group in high voltage electrical engineering keep this activity alive, mostly in the greater Zurich area. In this field, *Ampegon* delivers high-power pulsed amplifiers to drive the accelerating RF cavities in many research centres.

A further area of competence relates to *vacuum and cryogenic* components. This industry know-how is very densely distributed along the Rhine River, sometimes called the "Swiss Vacuum Valley". Whenever it comes to selling the highest quality vacuum valves, bellows, gauges or pumps, strong Swiss industries such as *VAT*, *Weka*, *Mewasa*, *Inficon* or *HSR* will be invited to participate in tenders or team up for



Figure 3: A forged and rolled Aluminium magnet body at Imbach AG (prepared for the CERN High Luminosity LHC project). © CERN

the design of advanced vacuum systems. This very regional expertise stems from the former *Balzers* company (the name of a town in Liechtenstein) which was progressively split into smaller entities in the 90's.

As well mostly in Eastern Switzerland in the *optics* domain, companies such as *WZW*, *Fisba*, *Swissopic* or *Schott* in Yverdon have an international reputation for the ultra-fine machining of glass and the engineering of thin films layers on top, to be integrated as lenses or mirrors in diverse scientific instruments. As an integrator of these components, *Leica Geosystems* sells Laser Trackers to most research facilities helping them guiding precisely and visualize over distance very big structures to be assembled.

In the *precision mechanisms* domain, we find some outstanding Swiss firms that develop ad hoc solutions designed for the complex environments of physics, where sensors or actuators are to be positioned at micrometre accuracy. As an example, *MPS Microsystems* in Bienne/Biel has developed micro-positioners that can quickly and simultaneously place 1000 fibre optics points across the focal image of any optical telescope instrument.

Finally Swiss timing matters. A non-disputable asset of the Swiss industry is *timing devices* for the control and synchronization of the many heterogeneous and distributed equipment found along a large-scale science infrastructure and through which particles will fly at almost the speed of light. For this purpose, we find atomic clock manufacturers in Neuchâtel such as *T4Science* and *Oscilloquartz* or ultra-short pulse laser manufacturers in the Zurich region such as *NKT Photonics Switzerland* (ex *Onefive*) or *Menhir Photonics*.



Figure 4: The optical set up with NKT Photonics lasers at Eu-XFEL (triggering chemical reactions at the femtosecond level). © Eu-XFEL

History and Philosophy of Physics (33)

Pauli Principle and Stability of Matter

Norbert Straumann, Institute for Theoretical Physics University of Zürich, CH–8057 Zürich

1 Introduction

In a recent article we described how Wolfgang Pauli arrived at the exclusion principle hundred years ago, before the advent of quantum mechanics. One of the immediate great qualitative successes of quantum mechanics was that it implies the stability of atoms. A much less obvious consequence of the theory is that ordinary matter in bulk, held together by Coulomb forces, is also stable.

The mystery of this fact before the dawn of quantum mechanics was described by Jeans in 1915 with the following words [1]:

“There would be a very real difficulty in supposing that the (force) law $1/r^2$ held down to zero values of r . For the force between two charges at zero distance would be infinite; we should have charges of opposite sign continually rushing together and, when once together, no force would be adequate to separate them (...). Thus matter in the universe would tend to shrink into nothing or to diminish indefinitely in size.”

In quantum mechanics the electrons cannot fall into the nuclei.

We begin this article with the stability and size of atoms and then to the much less obvious consequence of the stability of matter in bulk. Four decades after non-relativistic quantum mechanics was developed, Dyson and Lenard gave the first rigorous proof of the stability for matter in bulk [2]. For this the Pauli principle for the electrons is essential, while the statistics of the nuclei does not matter. This was the beginning of a lot of remarkable work by several authors, in particular by F. J. Dyson, A. Lenard, E. H. Lieb, W. Thirring, and others.

Atoms and ‘ordinary’ matter in bulk, consisting of a system of N electrons and k nuclei with charges Z_1e, \dots, Z_ke , can be well described by the mutual Coulomb interactions. For the discussion that follows we use the Hamiltonian

$$H = T_e + V_{eK} + V_{ee} + V_{KK} \quad (1).$$

T_e is the kinetic energy of the electrons, and the three potential energies V_{eK} , V_{ee} , V_{KK} are the Coulomb energies between the electrons and nuclei, among the electrons and among the nuclei, respectively. We treat the nuclei as infinitely heavy in fixed positions $\mathbf{R}_1, \dots, \mathbf{R}_k$ (Born-Oppenheimer approximation). Since we are mainly interested in lower bounds of the ground state energy of the system, this is not a serious simplification; if the nuclei are treated dynamically, the nuclear kinetic energy adds a positive contribution.

Two different notions of stability are useful.

(i) *Stability of the first kind:*

$$E(N, k, \underline{R}) := \inf_{\psi} \langle \psi, H\psi \rangle$$

is finite for every N, k , and fixed positions $\underline{R} = (\mathbf{R}_1, \dots, \mathbf{R}_k)$ of the nuclei.

(ii) *Stability of the second kind:* Assuming that $Z_j \leq Z$ for all $j = 1, \dots, k$, then

$$E(N, k) := \inf_{\underline{R}} E(N, k, \underline{R}) \geq -A(Z)(N + k),$$

where A depends only on Z .

2 Stability of atoms

The stability of the first kind for isolated atoms is obvious, even without the Pauli principle for electrons. The remarkable fact is that the exclusion principle guarantees stability of the second kind. This can easily be demonstrated.

For a single atom the Hamiltonian is

$$H_N = \frac{1}{2m} \sum_{i=1}^N \mathbf{p}_i^2 - Ze^2 \sum_{i=1}^N \frac{1}{|\mathbf{x}_i|} + e^2 \sum_{i < j} \frac{1}{|\mathbf{x}_i - \mathbf{x}_j|} \quad (2).$$

Since the last term gives a positive contribution to the ground state energy, a lower bound for the ‘unperturbed’ Hamiltonian H_0 (without the mutual Coulomb repulsion) gives a rough lower bound for H_N . But the ground state energy for H_0 is obtained by filling up the Balmer levels. The last completely filled level has principal quantum number n_0 determined by

$$2 \sum_{n=1}^{n_0} n^2 \leq N \leq 2 \sum_{n=1}^{n_0+1} n^2,$$

i.e., $\frac{2}{3} n_0(n_0 + \frac{1}{2})(n_0 + 1) \leq N \leq \frac{2}{3} (n_0 + 1)(n_0 + \frac{3}{2})(n_0 + 2)$.

The ground state energy E_0 of the unperturbed Hamiltonian satisfies in units of $Z^2 Ry$

$$-\sum_{n=1}^{n_0+1} \frac{2n^2}{n^2} \leq E_0 \leq -\sum_{n=1}^{n_0} \frac{2n^2}{n^2}, \quad 1$$

i.e. $-2(n_0 + 1) \leq E_0 \leq -2n_0$. For large N , $n_0 = (\frac{3N}{2})^{1/3} + O(1)$ the ground state energy E_N of H_N is thus bounded as

$$E_N \geq -2 \left(\frac{3}{2} \right)^{1/3} N^{1/3} (1 + O(N^{-1/3})) Z^2 Ry \quad (3).$$

This inequality implies stability of the second kind. For a neutral atom this lower bound is proportional to $Z^{7/3}$.

It is not difficult to derive also an *upper bound* proportional to $N^{1/3} Z^2$, using the variational principle with the Slater determinant belonging to the shell state considered above. Using also the fact that the exchange term is non-positive, as well as the virial theorem for the direct Coulomb term, one easily finds

¹ The variable n in the numerator results from the degree of degeneracy of the H-states; the variable n in the denominator as reciprocal of the energies of the H-atom. Both n are identical.

$$E_N \leq -2\left(\frac{3}{2}\right)^{1/3} \left(1 - \frac{N}{2Z}\right) N^{1/3} (1 + O(N^{-1/3})) Z^2 Ry \quad (4).$$

These bounds can be improved.

We note that the *Thomas-Fermi theory* gives for neutral atoms

$$E_N^{TF} = -1.5375 Z^{7/3} Ry \quad (5).$$

3 Size of large atoms

We are interested in an inequality for the size of an atom in its ground state, defined as

$$r := \left\{ \frac{1}{N} \left\langle \sum_{i=1}^N \mathbf{x}_i^2 \right\rangle \right\}^{1/2},$$

where the angular bracket denotes the ground state expectation value. One expects, for instance on the basis of the Thomas-Fermi theory, that $r > \text{const } N^{-1/3}$.

As a first ingredient we use the following operator inequality ($\hbar = 1$):

$$\frac{1}{2} \sum_{i=1}^N (\mathbf{p}_i^2 + \omega^2 \mathbf{x}_i^2) \geq \omega N^{4/3} \frac{3^{4/3}}{4} (1 + O(N^{-1/3})).$$

This is obtained as the previous inequalities for E_0 of H_0 , using that the energy levels of an isotropic harmonic oscillator are $= \frac{3}{2} + n\omega$, with degeneracies $g_n = 2 \cdot \frac{1}{2}(n+1)(n+2)$.

Taking now the expectation value of this inequality with the ground state of $H_{N\omega}$ and setting

$$\omega = \frac{4}{3^{4/3} N^{4/3}} \left\langle \sum_{i=1}^N \mathbf{p}_i^2 \right\rangle$$

leads, up to $N^{-1/3}$ corrections, to

$$\left\langle \sum_{i=1}^N \mathbf{x}_i^2 \right\rangle \geq \frac{(3N)^{8/3}}{16 \left\langle \sum_{i=1}^N \mathbf{p}_i^2 \right\rangle}.$$

Finally, we use the virial theorem for $H_N(\langle T \rangle = |E_N|)$ and the previous lower bound (4) to conclude that in units with $\hbar^2/2m = 1, e = 1$:

$$\frac{1}{2} \left\langle \sum_{i=1}^N \mathbf{p}_i^2 \right\rangle \leq \left(\frac{3}{2}\right)^{1/3} N^{7/3} (1 + O(N^{-1/3})).$$

Together this gives

$$\left\langle \sum_{i=1}^N \mathbf{x}_i^2 \right\rangle \geq \frac{9 \cdot 6^{1/3}}{32} N^{1/3},$$

i.e.

$$r \geq 0.71 N^{-1/3} (1 + O(N^{-1/3})) \quad (6).$$

Supplementary remarks

For matter in bulk it is not possible to arrive at energy estimates in such an explicit and elementary fashion as for (3) and (4), and one has to use more general methods. As a nice illustration of these, we show how one arrives at a quite accurate lower bound without solving a differential equation, but by making use of the following *Sobolev inequality* [3] for any $\psi \in L^2(\mathbb{R}^3)$ whose (weak) derivatives are also in $L^2(\mathbb{R}^3)$:

$$\langle \psi, T_e \psi \rangle = \|\nabla \psi\|_2^2 \geq K_s \|\psi\|_6^2 = K_s \|\rho_\psi\|_3 \quad (7),$$

where $\rho_\psi := |\psi|^2$ and $K_s = 3(\pi/2)^{4/3} \simeq 5.5$ (this numerical value is known to be optimal). This inequality (which is a special case of a whole class), allows us to bound the ground state energy of hydrogen like atoms as

$$E \geq \inf_\rho \left\{ h(\rho) : \rho(\mathbf{x}) \geq 0, \int_{\mathbb{R}^3} \rho d^3x = 1 \right\} \quad (8),$$

with

$$h(\rho) = K_s \|\rho\|_3 - Z \int \frac{\rho(\mathbf{x})}{|\mathbf{x}|} d^3x \quad (9).$$

It is straightforward (a nice exercise for students) to find the minimizing ρ , and to show that it gives the lower bound

$$E \geq -\frac{4}{3} Z^2 Ry.$$

This instructive calculation is from Lieb's review paper [4].

One does not loose much by using an even weaker inequality, which has the advantage to be generalizable to many electron systems. This is obtained from (7) with the help of Hölder's inequality:

$$\|fg\|_1 \leq \|f\|_p \|g\|_{p'}, \quad \left(\frac{1}{p} + \frac{1}{p'} = 1, p \geq 1\right).$$

For $p = 3, p' = \frac{3}{2}$ this implies for a normalized ρ

$$\int \rho^{5/3} \leq \|\rho\|_3 \|\rho^{2/3}\|_{3/2} = \left(\int \rho^3\right)^{1/3} \left(\int \rho\right)^{2/3} = \left(\int \rho^3\right)^{1/3}.$$

Hence,

$$\langle \psi, T_e \psi \rangle \geq K_1 \int_{\mathbb{R}^3} \rho_\psi(\mathbf{x})^{5/3} d^3x \quad (10)$$

for $K_1 = K_s$, but K_1 can be improved to $K_1 = 9.57$. Instead of (9) we now have the simpler functional

$$h(\rho) = K_1 \int \rho^{5/3} d^3x - Z \int \frac{\rho}{|\mathbf{x}|} d^3x \quad (11),$$

but the lower bound comes out only slightly worse.

For antisymmetric N -electron wave functions, Lieb and Thirring [5] were able to generalize (10), where now ρ_ψ is the one-particle density, normalized as $\int \rho_\psi = N$. With the help of this generalized inequality they were able to bound $\langle \psi, H_N \psi \rangle$ in terms of the Thomas-Fermi energy functional ².

4 The Dyson-Lenard-Lieb-Thirring Theorem

I have already mentioned that Dyson and Lenard gave in 1967 a proof of the stability of matter in the sense of (3). This proof was long and involved a large number of estimates. Even in sharp estimations it is unavoidable that about a factor two is lost per page. For a total of 40 pages of the paper one would thus expect a loss of about $2^{40} \sim 10^{14}$, and this is what actually happened. In his preface to Lieb's *Selecta* [4] Dyson writes:

“Our proof was so complicated and so unilluminating that it stimulated Lieb and Thirring to find the first decent proof. Why was our proof so bad and why was theirs so good? The reason is simple. Lenard and I began with ma-

² Lieb and Simon [6] showed much earlier that the Thomas-Fermi theory becomes exact in the limit $Z \rightarrow \infty$, with the number of nuclei fixed.

thematical tricks and hacked our way through a forest of inequalities without any physical understanding. Lieb and Thirring began with physical understanding and went on to find the appropriate mathematical language to make their understanding rigorous. Our proof was a dead end. Theirs was a gateway to the new world of ideas collected in this book."

Heuristic considerations

On a heuristic level it is easy to understand the stability of the second kind of Coulomb dominated matter. Consider a neutral system of N electrons and N_z nuclei with charge Ze and mass m_z ($m_z \simeq Am_N$, $m_N =$ nucleon mass). Screening effects reduce the effective interactions essentially to one between nearest neighbors. Thus the Coulomb potential energy is roughly (for bosons and fermions)

$$V_{Coul} \approx -N_z \frac{(Ze)^2}{(R/N_z^{1/3})},$$

where R is the dimension of the system. For the kinetic energy we have $T \approx Np^2/2m$, where p is the average momentum of the electrons. Roughly speaking, the Pauli principle allows at most one electron in a de Broglie cube $(\hbar/p)^3$, and thus $p \geq N^{1/3}\hbar/R$. For the total energy of the system, we therefore obtain the approximate inequality – including for later purposes also the Newtonian potential energy $-\frac{1}{2}N_z^2 Gm_z^2/R$ of the nuclei

$$E \geq N \frac{p^2}{2m} - \frac{1}{2} \left(\frac{N}{Z} \right)^2 \frac{Gm_z^2}{\hbar N^{1/3}} p - \frac{Ne^2 Z^{2/3}}{\hbar} p \quad (12).$$

The minimum of the right hand side is attained for the average electron momentum p_0 , given by

$$Np_0/m = \frac{1}{2} \left(\frac{N}{Z} \right)^2 \frac{Gm_z^2}{\hbar N^{1/3}} + \frac{Ne^2 Z^{2/3}}{\hbar} \quad (13),$$

in terms of which the ground state energy is $E_0 \approx -Np_0^2/2m$. Ignoring the gravitational interaction, this is *linear* in N :

$$E_0 \approx -N \cdot Ry \quad (14).$$

For the electron density $n_0 \approx (p_0/\hbar)^3$ and the matter density ρ_0 we obtain, if a_0 denotes the Bohr radius,

$$n_0 \approx Z^2/a_0^3, \quad \rho_0 \approx AZm_N/a_0^3 \approx 10 \text{ g/cm}^3 \quad (15).$$

If we would treat the electrons as bosons, we would only have the restriction imposed by the uncertainty relation, $p \geq \hbar/R$, and instead of (14) we would obtain

$$E_0 \approx -N^{5/3} \cdot Ry \quad (\text{bosons}) \quad (16).$$

This $N^{5/3}$ law was established rigorously by Lieb for *fixed positions of the nuclei*. However, when the nuclei are also treated dynamically the $N^{7/5}$ law, discussed earlier, holds.

Rigorous bound

Lieb and Thirring [5] have established the rigorous bound

$$E(N, k) \geq -\text{const} \cdot \left\{ N + \sum_j^k Z_j^{7/3} \right\} Ry \quad (17),$$

with a constant of about 20 instead of 10^{14} in the work of Dyson and Lenard. The main step of the proof consists in

bounding the ground state energy in terms of the Thomas-Fermi functional. Instead of minimizing this functional, Lieb and Thirring used a theorem of Teller stating that *atoms do not bind in Thomas-Fermi theory* (see [6]). In this way a lower bound in terms of a lower bound of the Thomas-Fermi functional for atoms was obtained, for which a previous result of Lieb and Simon could be used.

5 Stability and instability of cold stars

Once gravity becomes important we can no more expect stability of the second kind, because of the purely attractive and long range character of the gravitational interaction. Let us begin with some heuristic considerations.

'Newton begins to dominate Coulomb' when the last two terms in (16) become comparable, i.e., for the 'critical' electron number

$$N_c \approx Z \left(\frac{Z}{A} \right)^3 \alpha^{3/2} \left(\frac{M_{Pl}}{m_N} \right)^3.$$

Here α is the fine structure constant and M_{Pl} the Planck mass. Numerically this is about the number of electrons in Jupiter.

For $N \gg N_c$ we can neglect the Coulomb contribution in (12) and then obtain from (13)

$$p_0/mc \approx \frac{1}{2} \left(\frac{A}{Z} \right)^2 \frac{m_N^2}{M_{Pl}^2} N^{2/3}.$$

This shows that the electrons become relativistic for

$$N > N_r := \left(\frac{Z}{A} \right)^3 \left(\frac{2M_{Pl}}{m_N} \right)^{3/2} \quad (18).$$

Therefore we treat the electrons in (16) relativistically. In units with $c = 1$ we then have

$$E_0(N) \approx \inf_p \left\{ N \sqrt{p^2 + m^2} - \frac{1}{2} \left(\frac{N}{Z} \right)^2 \frac{Gm_z^2}{\hbar N^{1/3}} p \right\} \quad (19).$$

One readily sees that *the minimum only exists* for $N < N_r$. The corresponding limiting mass

$$M_r = (N_r/Z) m_z \approx 2.8 \left(\frac{Z}{A} \right)^2 \frac{M_{Pl}^3}{m_N^2} \quad (20)$$

is close to the *Chandrasekhar mass*.

The delayed acceptance of the discovery by the 19 year old Chandrasekhar that quantum theory plus special relativity imply the existence of a limiting mass for white dwarfs belongs to the bizarre stories of astrophysics.

The Fowler theory of white dwarfs is just the Thomas-Fermi theory, whereby the white dwarf is considered as a big "atom" with about 10^{57} electrons, and the Chandrasekhar theory is its relativistic version. In other words, the basic Chandrasekhar equation is the same as the relativistic Thomas-Fermi equation (for details see [11]). For white dwarfs the (semi-classical) Thomas-Fermi approximation is ideally justified (a rigorous result will be mentioned below).

In this context the following close historical coincidence is interesting. Thomas' paper [7] was presented at the Cambridge Philosophical Society on November 6, 1926. (Fermi's work was independent, but about one year later.) On

the other hand, Fowler communicated his important paper [8] on the non-relativistic theory of white dwarfs about one month later, on December 10, to the Royal Astronomical Society. I wonder who first noticed the close connection of the two approaches.

It is worthwhile mentioning that Lieb and H-T. Yau have shown [9] that Chandrasekhar's theory can be obtained as a limit of a quantum mechanical description in terms of a semi-relativistic Hamiltonian.

In a quantum mechanical description of white dwarfs the proper model to analyze would be a Hamiltonian for electrons and ions with Coulomb and gravitational interactions, for which the kinetic energy of the electrons is the relativistic one:

$$T_e = \sum_{i=1}^N [\sqrt{\mathbf{p}_i^2 + m^2} - m] \quad (21).$$

Unfortunately, a rigorous analysis of this model has (to my knowledge) not yet reached a satisfactory stage. A somewhat more modest goal has, however, been reached.

The Coulomb forces in white dwarf material establish *local* neutrality to a very high degree. For this reason the Coulomb interactions play energetically almost no role. (The corrections can be estimated and are on the few percent level.) The spatial distribution of the nuclei and hence their momentum distribution is much the same as those of the electrons. Based on these considerations it is reasonable to expect that the relevant Hamiltonian is

$$H_N = T_e - \sum_{1 \leq i < j \leq N} \frac{G(m_Z/Z)^2}{|\mathbf{x}_i - \mathbf{x}_j|} \quad (22)$$

($m_Z/Z \simeq (A/Z)m_N$ is the mass in the star per electron).

It is now natural to compare the ground state energy

$$E(N) = \inf_{\psi} \langle \psi, H_N \psi \rangle$$

with the semi-classical energy of the Thomas-Fermi theory:

$$E^{TF}(N) = \inf \left\{ \mathcal{E}^{TF}(n) : \int n = N \right\} \quad (23),$$

where

$$\mathcal{E}^{TF}(n) = \int_{\mathbb{R}^3} \varepsilon(n(\mathbf{x})) d^3x - \frac{\kappa}{2} \int \frac{n(\mathbf{x})n(\mathbf{x}')}{|\mathbf{x} - \mathbf{x}'|} d^3x d^3x' \quad (24).$$

Here $\kappa = G(m_Z/Z)^2$ and

$$\varepsilon(n) = \frac{1}{\pi^2} \int_0^{p_F(n)} [\sqrt{p^2 + m^2} - m] p^2 dp \quad (25),$$

where $p_F(n)$ is the Fermi momentum belonging to the number density n :

$$p_F(n) = (3\pi^2 n)^{1/3} \quad (26).$$

Lieb and H-T. Yau have proved the following

Theorem. Fix the quantity $\tau = \kappa N^{2/3}$ at some value below the critical value τ_c of the Chandrasekhar theory ($\tau_c \simeq 3.1$). Then

$$\lim_{N \rightarrow \infty} E(N)/E^{TF}(N) = 1 \quad (27).$$

If $\tau > \tau_c$, then

$$\lim_{N \rightarrow \infty} E(N) = -\infty \quad (28).$$

As a corollary one can show that the ratio of the critical numbers of electrons for stability becomes 1 in the limit $G \rightarrow 0$.

This demonstrates that we can study H_N by means of the semi-classical approximation. This is, of course, not surprising. Indeed, corrections to the Thomas-Fermi approximations are of the order $N^{-1/3}$, i.e., of the order 10^{-19} for $N \sim 10^{57}$. (In contrast to this tiny number for white dwarfs, corrections of the order $Z^{-1/3}$ for atoms are not negligible.)

For an analogous discussion of *boson stars*, I refer again to [9]; see also [10].

6 Concluding remarks

For neutron stars such a quantum mechanical description is not possible, since general relativity has to be used. We are then bound to use a semi-classical description à la Thomas-Fermi, but from what has been said in the last section there can be no doubt that this is an excellent approximation.

When GR is used as the correct theory of gravity, the exclusion principle still influences the magnitudes of limiting masses for stars. But while in Newtonian gravity theory the total energy of a system can be indefinitely negative, this is not the case in GR. The positive energy theorem implies that it is impossible to construct an object out of ordinary matter, whose total energy is negative. (For a detailed proof and discussion, see, e.g., [11]). As a system is compressed to take advantage of the negative gravitational binding energy, a black hole is eventually formed which has positive total energy. This is, however, another story.

Acknowledgements

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History and Philosophy of Physics (34)

Daniel Bernoulli's Research in Basel and the "Physikalisches Kabinett" in the "Stachelschützenhaus"

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On 22 September 2023 the inauguration of the "Stachelschützenhaus" at Basel's Petersplatz (St. Peter's Square) as an EPS Historic Site was hosted by the University of Basel. In the following article we will focus first on Daniel Bernoulli's career path, before discussing his major scientific achievements and finally adding some aspects of the inauguration ceremony (the colloquium talks, the visit of today's laboratories in the Stachelschützenhaus, and the unveiling of the plaque).

Daniel Bernoulli (1700 - 1782, a member of the world-renowned Bernoulli family of mathematicians and scientists that had been based in Basel since 1623) studied medicine in Basel, Heidelberg and Strasbourg.



Fig. 1: Portraits of Daniel Bernoulli: (left) Basel, ca. 1720 - 25 (Historisches Museum Basel), (right) by Johann Rudolf Huber (1744) (Wikimedia).

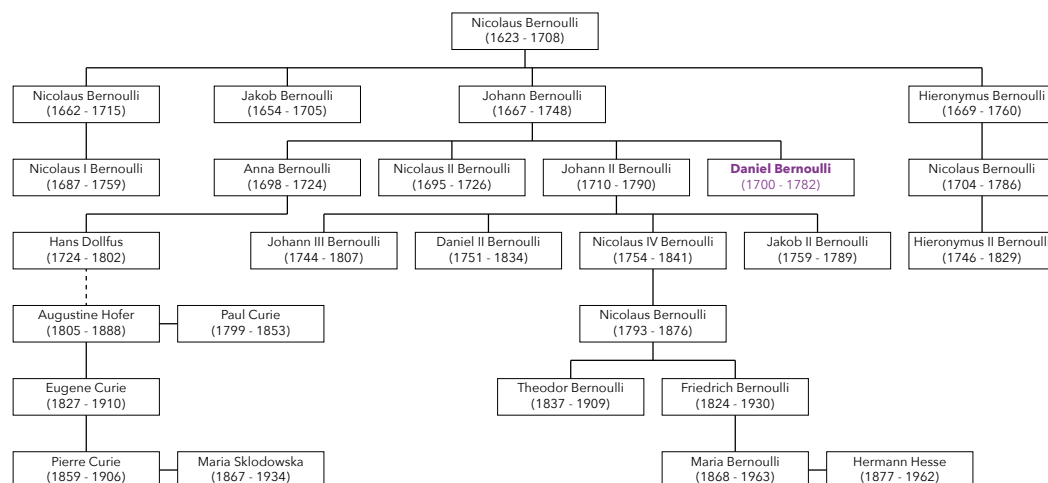


Fig. 2: (Part of) The Bernoulli Family Genealogy (according to <https://galileo-unbound.blog/2020/10/06/the-bountiful-bernoulli-of-basel/>). Daniel Bernoulli was born in Groningen in 1700, where his father Johann (I) Bernoulli then held a chair. After his uncle Jacob (I) had died in 1705, the family returned to Basel.

Daniel Bernoulli's career

He obtained his doctoral degree in 1721 with a thesis on the mechanics of respiration. He was the first in history to approach this topic in a mathematical way. Utilizing the methods of exact sciences, also in applications for solving problems in physiology and engineering, was to become the trademark for his entire career in research. In 1724 he published his first little book, "Exercitationes", which treated among other things the Riccati differential equation. This attracted so much attention that in 1725 he was appointed to the newly founded Academy at St. Petersburg, jointly with his brother Nicolaus II, a gifted mathematician.

After his brother's early death in 1726 he began planning to return to Basel, but was only able to do so when a chair – actually in anatomy and botany – became vacant in 1733. Only in 1750 he would become professor of physics at the University of Basel. From then on until 1776, he gave remarkable physics lectures, including experiment demonstrations, and was highly active in his favorite research field.

He published studies related to medical aspects (such as blood circulation, cardiac work, medical statistics, and epidemiology) and applications of mathematical physics to practical problems in mechanical and nautical engineering, but his main dedication was to physics problems with a strong mathematical footing.

His overall scientific oeuvre includes 74 papers and he won no less than ten of the yearly prizes of the Paris Académie des Sciences for topics in astronomy, physics and its applications to nautical engineering: the determination of positions at sea by various timekeeping devices (1725, 1745 - 47) and compasses (1743), the geometry of the solar system (1734), the optimal shape of anchors (1737), the theory of the tides (1740), magnetism (1744 - 46), ocean currents (1751), the propulsion of ships (1753), and the reaction of their pitching and rolling motion (1757). Many of these aspects can be characterized by his approach to solve physics problems via being a pioneer in the development of mathematical physics, using the powerful calculus of Leibniz in Newton's theories! A more detailed account of his scientific work in general as well as at the University of Basel is given e.g. in refs. [1-5].



Fig. 3: Original copy of Bernoulli's "Hydrodynamica" printed by Johann Reinhold Dulsecker (Strasbourg) in 1738 [6]

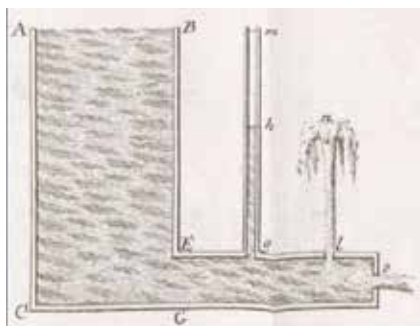


Fig. 4: Pressure reduction due to Bernoulli's equation "an increase in speed of a flowing liquid leads to a decrease in its pressure" (in the right part where the liquid is moving) [6].

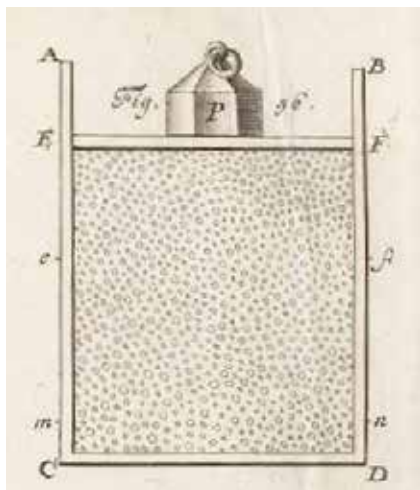


Fig. 5 Bernoulli pioneered a molecular model of gases in order to explain the Boyle-Mariotte law. He derived macroscopic properties of a gas from microscopic movements of its particles [6].

his physical intuition prevailed, leading to an early form of what would become Fourier analysis. He made fundamental contributions to the theory of collisions, the theory of tides, winds and marine currents, the longitude problem (with the aid of an inclination compass for measuring not only the horizontal component of the Earth's magnetic field but also the perpendicular component to the earth's surface at a given location), as well as the geometry and dynamics of the so-

Main scientific achievements

His most comprehensive work, the "Hydrodynamica" (authored mainly in St. Petersburg, completed and announced in 1734, but finally printed at Strasbourg only in 1738) achieved a fundamental advance in fluid mechanics and laid the foundations for later progress. The important distinction between hydrostatic and hydrodynamic pressure is due to him. He formulated a special form of the "Bernoulli equation" for incompressible and frictionless fluids, treated elastic fluids for the first time and marked the beginnings of the kinetic theory of gases.

In other fields, too, Daniel Bernoulli was always interested in a close connection between mathematical methods and their applications. He investigated special techniques for solving algebraic equations, dealing with continuous fractions, and solving questions of probability theory. He wrote on the composition of forces, their "true measure" and their conservation, analyzed the oscillations of mechanical systems (chains, vibrating strings and blades). In the course of a debate with Euler and d'Alembert on the vibrations of a string,

lar system. Bernoulli also undertook a determination of the work of the human heart (arriving at about 0.6 W compared to today's values of 1 to 1.5 W) and developed a statistical model for epidemics (in the context of smallpox inoculation).

Bernoulli was the first to point out the decomposition of the motion of bodies into translational and rotational motions (a structure that resembles Lagrange's Analytical Mechanics, since all results appear as a consequence of a single principle, in this case the conservation of energy). The above-mentioned Bernoulli's law of flow (the energy theorem for stationary flows) is today the general basis for fluid dynamics (hydrodynamics and gas dynamics) and thus also for the technology of aviation. Bernoulli was able to sketch (although not in full detail) the equation of state analyzed by Van der Waals a century later. Based on experimental evidence, he was also able to conjecture certain laws which were not verified until many years later; among them was Coulomb's law in electrostatics (see again [1-5]).

The South Wing of the Stachelschützenhaus, where the Physics Cabinet (Physikalisches Kabinett) was located in the 18th century

The Stachelschützenhaus was initially erected in 1519/20 (other sources give 1546) [8-10] and served for training the municipal Crossbow Guard. In 1709 a first extension was built to the north, in 1729 a second wing to the south, in order to house the University's collection of physical instruments. The professor of physics and botany at that time, Benedict Staehelin (1695 - 1750), started a collection of physical devices and instruments that he had acquired for demonstration purposes. Optical, pneumatic, and mechanical appliances were ordered from the British instrument maker Francis Hawksbee. In 1747, after some rumors about neglect of the laboratory by Staehelin, due to illness, the mayor requested a report from the medical faculty about the

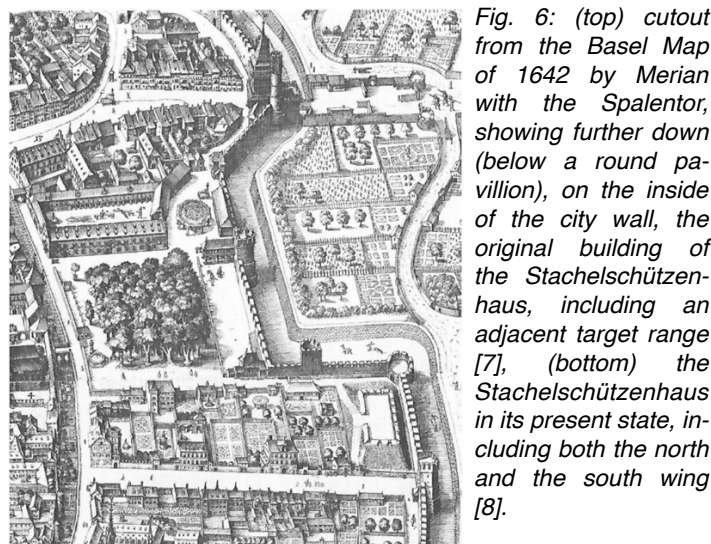


Fig. 6: (top) cutout from the Basel Map of 1642 by Merian with the Spalentor, showing further down (below a round pavillion), on the inside of the city wall, the original building of the Stachelschützenhaus, including an adjacent target range [7], (bottom) the Stachelschützenhaus in its present state, including both the north and the south wing [8].



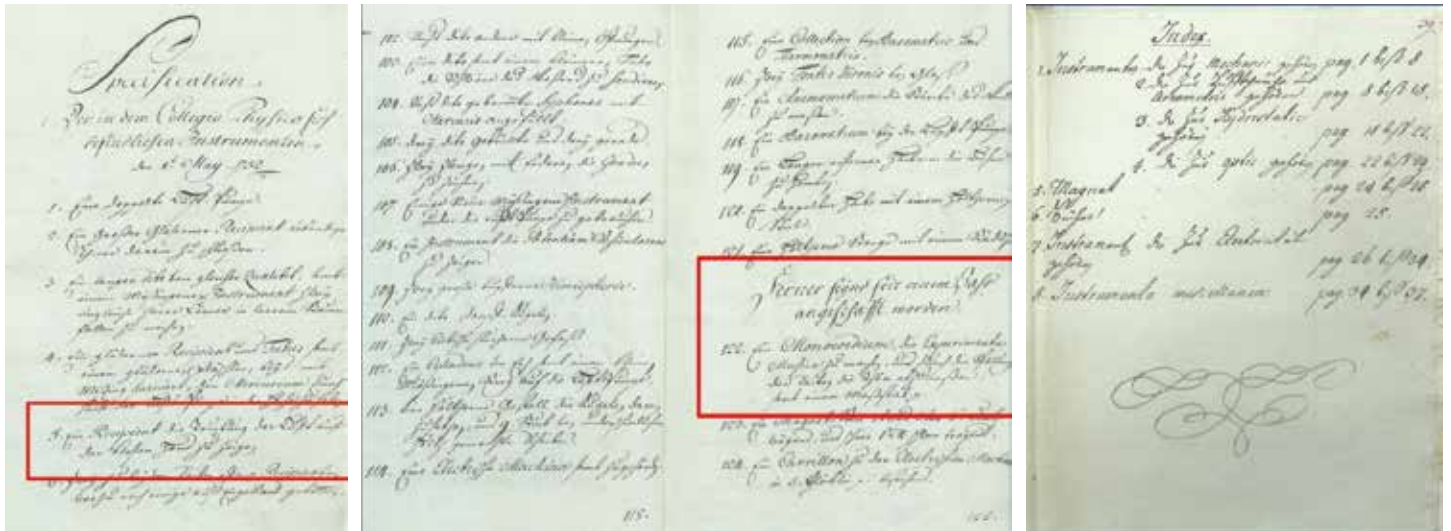


Fig. 7: Excerpts of Bernoulli's 1752 inventory of the Physics Cabinet: (left) indicating (via red borderlines) a water barometer with the water level inside recording the air pressure, (middle) a monochord, demonstrating the change of the sound frequency with the changing tension of cords, (right) the overall index of all devices (from the Basel State Archive [11])

status of the collection. The latter was undertaken by Daniel Bernoulli, leading to the request of more money for the necessary improvements and an assistant position to keep it in optimal shape. After Bernoulli became professor of physics in 1750, he greatly expanded the Physics Cabinet by adding many instruments for his research, a 1752 inventory includes more than 130 items. Additional acquisitions with a value of several hundred pounds extended the inventory to a list of 40 pages in 1757.

As a professor of Physics Daniel Bernoulli performed his experimental activities in the "Physikalisches Kabinett" (Physics Cabinet) in the south wing of the Stachelschützenhaus. Some of the many instruments of his Physics Cabinet are still in existence today. Among them is the experiment for the demonstration of the "hydrostatic paradoxon" which vividly demonstrates that the pressure in a liquid is independent of the shape of the vessel and depends only on the height of the liquid column. Some of these early experimental devices are today in the possession of the Historisches Museum Basel and on display in the Haus zum Kirschgarten, where one finds instruments and experiments that were acquired by Daniel Bernoulli and his predecessor Benedikt Staehelin.

Figs. 8 - 11 show objects at display in the Haus zum Kirschgarten of the Historisches Museum Basel [12]. In the lecture hall of the Physics Cabinet, Bernoulli held lectures



Fig. 8: "Hydrostatic Paradoxon" Device for demonstrating the Hydrostatic Paradox, with the following description: A wide and a narrow vessel are screwed on the same cylinder. If the water column is the same, the bottom pressure in both vessels is the same. This hydrostatic paradox states that the gravitational pressure exerted by a liquid in a vessel on the bottom of the vessel, while dependent on the level of the liquid, is, on the other hand, independent of the shape of the vessel and thus of the quantity of liquid contained - an example of the fundamental insights of Daniel Bernoulli. Manufacturer: Johann Ulrich Goetz (1694 - 1758), Basel, 1728, since 1757 in the collection of the Institute of Physics of the Univ. of Basel (photo Salome Noah, Basel).



Fig. 9: Musschenbroek's pyrometer (thermal expansion meter), as an example for Bernoulli's lectures with experiment demonstrations: The device was used to demonstrate the expansion of metal under heat. In this process, an iron rod is heated by six spiritus flames and its expansion or coefficient of expansion is indicated by a special transmission mechanism with a pointer on a dial. The pyrometer of this type was invented in 1731 by the Dutchman Pieter van Musschenbroek (1692 - 1761). Made by Jean Pierre Charme, Paris, ca. 1752, iron, brass, wood; purchased by Prof. Daniel Bernoulli (photo Salome Noah, Basel).

Fig. 10: One of the first horseshoe magnets ever made, carrying more than 30 kg, made by the goldsmith Johann Dietrich in 1755, who built several instruments for the Cabinet (photo Maurice Babey, Basel).



Fig. 11: A "sparkling wheel" which was set in rotation by emitting sparks from the end-point of the curved needles and a carillon with tinkling little bells rung by charged pendulums (photo Historisches Museum Basel).

with experimental demonstrations over a wide variety in the subfields of physics for students as well as the general public, which enjoyed great popularity for a quarter of a century. This included also aspects of "entertainment physics" (see Fig. 11). After Daniel Bernoulli's death in 1782 the chair of physics was given to a physician, Johann Jakob Thurneisen the Younger (1756 - 1804), who showed little inclination to use the cabinet, so that the premises fell into disrepair. Thereafter the Stachelschützenhaus has been utilized for quite a number of purposes; presently it is the domicile of the Institute for Medical Microbiology at the University of Basel.

The inauguration of the Stachelschützenhaus as an EPS Historics Site

The importance of the laboratory of Daniel Bernoulli, where he performed his ground-breaking research as a true pioneer in the field of physics in Switzerland, Europe, and world-wide, has been the main aim to propose the “Stachelschützenhaus” as a Historic Site of the European Physical Society (EPS) in order to serve as a truly important place for the historical development of physics [13]. The proposal was accepted and on 22 September 2023 the inauguration took place in form of a twofold event: As part of the regular Physics Colloquium of the University of Basel the symposium included an introduction to EPS activities and the EPS Historic Sites project by Anne Pawsey (EPS Secretary General), an extended scientific and historical overview by Martin Mattmüller (Bernoulli-Euler Zentrum) about Daniel Bernoulli and his Physics Cabinet (from which much of the text of the above sections is drawn), and finally a review of today’s understanding of Astrophysical Gas Dynamics and its relation to the framework of Bernoulli’s Theorem in Fluid Dynamics by Stephan Rosswog (University of Hamburg and Stockholm University).

Stephan Rosswog gave a general introduction to fluid dynamics and under which conditions Bernoulli’s law actually applies, i.e. flows are stationary, the entropy of the system stays constant, and the acting forces can be derived from a

potential Ψ . This leads to the fact (with $\mathbf{v} \cdot \mathbf{grad} B$ being a directional derivative and the specific enthalpy h being expressed via the specific energy u and the pressure divided by the density $h = u + P/\rho$) that the “Bernoulli constant” B is conserved on stream lines. For a vanishing change in the specific energy u and the density ρ this leads - when multiplying by ρ - to the well-known equation $\frac{1}{2} \rho \cdot v^2 + P + \rho \cdot g \cdot z = \text{const}$, when utilizing the gravitational potential with height z .

In an eloquent talk he further discussed details of computational methods in general relativistic hydro-dynamics with the code SPHINCS_BSSN [14], applied to one of the most exciting discoveries in astrophysics: neutron star mergers (first observed in 2017), responsible for the emission of gravitational waves, the ejection of heavy elements up to U and Th, so-called kilonova observations in visible and infrared light, plus a short gamma-ray burst (see Fig. 13). This topic has followed him since his PhD in Basel in 1999 [15]. More generally he concluded how fluid dynamics is today a highly active and important research field with a huge range of applications in astrophysics, industry, weather predictions, aviation, special effects in movies etc., and that Bernoulli’s law has many applications in every-day life and state-of-the-art astrophysics.

After Rosswog’s talk followed a walk to the Stachelschützenhaus and a short introduction by Rainer Gosert and Klaudia Nägele (Medical Microbiology, Univ. of Basel) about the present activities in clinical virology (the study of viruses and virus-like agents, including their classification, disease-producing properties and genetics) in the Stachelschützenhaus, accompanied by a visit to the present laboratories. Afterwards the EPS Historic Site plaque was unveiled by the EPS General Secretary and the local organizers (Philipp Treutlein, physics department chair, Ernst Meyer, president of the platform MAP within the SCNAT, and Friedrich Thielemann), followed by an aperitif and dinner with enjoyable and enlightening discussions.


“Bernoulli’s Law”

- Assumptions:
 - “stationary”: $\partial_t \vec{v} = 0$
 - forces from potential: $\vec{f} = -\nabla \Psi$
 - isentropic: $\nabla s = 0$
 - \implies from thermodynamics: $\nabla h = T \nabla s + \frac{\nabla P}{\rho}$ (h : specific enthalpy)
 - apply to Euler equation: $\partial_t v + (\vec{v} \cdot \nabla) \vec{v} = -\frac{\nabla P}{\rho} + \vec{f}$
 - vector identity: $\nabla \left(\frac{1}{2} v^2 \right) = \vec{v} \times (\nabla \times \vec{v}) + (\vec{v} \cdot \nabla) \vec{v}$

$$\implies \vec{v} \times (\nabla \times \vec{v}) = \nabla \left(\frac{v^2}{2} + h + \Psi \right) \quad | \cdot \vec{v}$$

$0 = \vec{v} \cdot \nabla B \quad \text{with} \quad B \equiv \frac{v^2}{2} + h + \Psi$

12



Daniel Bernoulli
1700 - 1782

Fig. 12: Deriving the Bernoulli law for specific conditions (from Rosswog’s talk, see text).

Fig. 13: A binary stellar system leads after two supernova explosions to a neutron star binary which, after merging due to gravitational wave emission, causes the ejection of heavy elements and the observation of a kilonova and a short gamma-ray burst. This has a major impact on the evolution of the abundance pattern of heavy elements in our galaxy (from Rosswog’s talk).

We thank Jasmine Brüderlin (Basler Staatsarchiv) and Gudrun Piller (curator of the Haus am Kirschgarten) for the permissions to use Figs. 7 and 8 - 11, respectively, in this article.

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Fig. 14: (top) Plaque for the EPS Historic Site "Stachelschützenhaus", (bottom) organizers and speakers in front of the plaque and the south wing of the Stachelschützenhaus: Ernst Meyer, Gina Guarnatnam (communication coordinator EPS), Friedrich-Karl Thielemann, Martin Mattmüller, Anne Pawsey (EPS General Secretary), Philipp Treutlein (department chair, Physics Dept. Univ. of Basel), Stephan Rosswog; photos Dominik Plüss, Universität Basel.



Physics and Society

Fukushima tritiated water release – What is the polemic all about?

Hans Peter Beck, Laboratory of High Energy Physics, University of Bern, Sidlerstr. 5, CH-3012 Bern

A mere amount of **2.2 grams (780 TBq)** of tritium, diluted in $1.25 \cdot 10^6 \text{ m}^3$ water, contained in 1047 tanks at the Fukushima Daiichi nuclear power plant are being released to the Pacific Ocean. The operation is scheduled to last over 30 years, with not more than releasing **62 mg (22 TBq)** of tritium annually. The outcry in the world's press and the world's population is huge and countries like e.g. China are protesting aloud and are even banning Japanese seafood being sold in their domestic market. The outcry is real, the perceived fears are real, the havoc created on the Japanese fish market is real, but the danger is non-existing. The panic results from over-regulations initiated by the International Commission on Radiological Protection (ICRP) and similar bodies worldwide, prohibiting a reliable assessment of dangers and are thereby also preventing a solid risk analysis of real dangers.

1 The tsunami that changed it all

On 11 March 2011 a magnitude 9.1 undersea earthquake in the Pacific Ocean triggered a tsunami that with a height of 14 m when reaching Japan's Pacific coastline brought unbound destruction. 20'000 lives were lost, entire towns were devastated, and the tsunami was also at the cause of the Fukushima Daiichi nuclear disaster [1]. The nuclear reactors shut down automatically upon registration of the earthquake, but the reactor cores still needed ongoing cooling. Flooding of the area caused the failure of the emergency power generators and resulted in a loss of reactor core cooling that finally led to nuclear meltdowns. The released heat from the meltdown was at the cause of hydrogen explosions, where reactor core material from three reactor cores was carried into the atmosphere or directly washed out into the ocean.

Regarding radiation exposure, 96 % of the workers at Fukushima Daiichi NPP were exposed to less than 50 mSv. A total radiation dose of greater than 200 mSv was observed in nine workers. Of these, two workers were exposed to greater than 600 mSv, with 679 mSv being the highest. There

were no deaths from radiation exposure in the immediate aftermath of the incident [2].

2 The problems with Linear No-Threshold and ALARA

Over 110'000 residents in the surrounding areas were evacuated, causing 2'268 non-radiation disaster-related deaths due to many stress factors implied [3]. On the long-term impact, the maximum predicted eventual cancer mortality and morbidity estimate according to the scientifically flawed and heavily disputed linear no-threshold (LNT) hypothesis is about 1800 residents [4]. The LNT hypothesis of ionizing radiation – induced mortality and morbidity assumes that every increment of radiation dose, no matter how small, constitutes an increased cancer risk for humans. LNT is presently the most widely applied model for radiation risk assessment. However, no adverse health effects among Fukushima residents have been documented that are directly attributable to radiation exposure from the Fukushima Daiichi nuclear power station accident [5]. LNT is at the base of all radioprotection measures and regulations, but

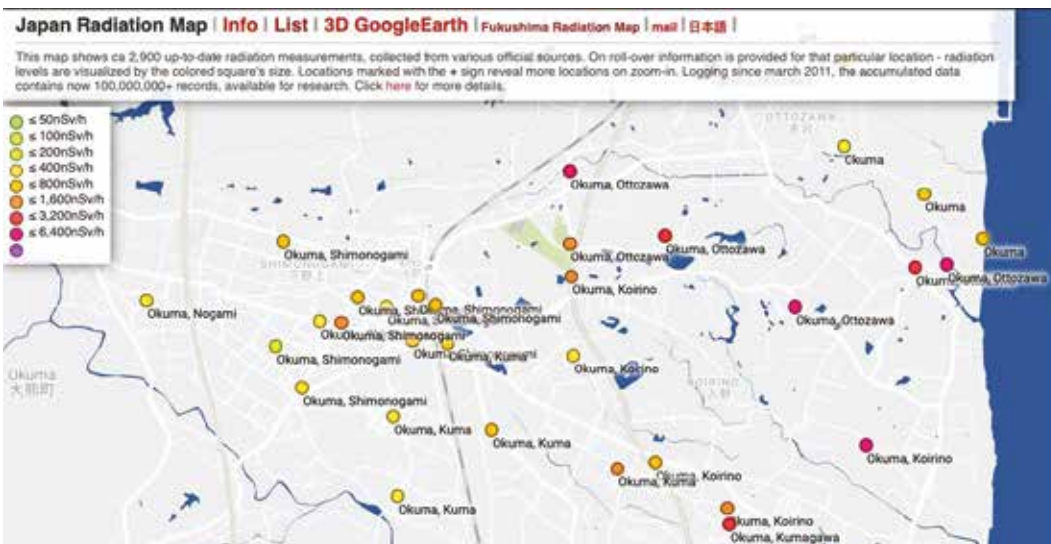


Fig. 1: Japan radiation map as of 1 September 2023, showing radiation measurements in the Fukushima region [12].

LNT completely ignores the body's capability to heal any damage made to any of its cells [6-9]. LNT's base assumption is that radiation damage accumulates over time without any healing process taking place. LNT also turns a blind eye to the rate at which radiation is absorbed, and diligently ignores whether a given amount of radiation is absorbed in a fraction of a second or is accumulated evenly over the full course of a year.

A wide range of literature exists, which is based on empirical data collected over decades, that shows LNT overestimates effects of low-level radiation by orders of magnitude - see e.g. [6-9] and references mentioned therein. The Swiss Federal Office for Public Health states in [10] still carefully that "the minimum dose at which an effect can be detected varies according to the observation of the collective and is around 100 mSv" and Ref. [7] reports that low dose rates are even beneficial, in stark contrast to the LNT hypothesis: "low dose rates improve tumour suppression, inhibit cancer formation and protect against neoplastic transformation", which is also confirmed in Ref. [6].

One can argue that LNT's intention is to be safe, and radiation shall be as low as reasonably achievable, also called ALARA [11]. However, ALARA ignores known empirical molecular biology data [6,7,9] and ignores risk factors other than radiation exposure that need to be factored in when making decisions to mitigate harm or when defining regulations to mitigate risks. One easily comes to the conclusion that the evacuation radius around the Fukushima Daiichi plant was way too big and that evacuated people could have reoccupied their homes rather quickly within weeks, after the most active short-lived nuclides have decayed, and that the current LNT and ALARA based scheme created a lot of harm unnecessarily.

3 Clean-up work

The cleaning of the area around the Daiichi nuclear plant is ongoing still today. Radiation levels have become acceptable in most places or, in some places, are not higher than when flying at cruise altitude in a passenger airplane (2000 - 7000 nSv/h, depending on latitude), Fig. 1.

Water that was used to cool the melted-down reactor cores got contaminated and is still stored in large tanks at the

Daiichi site [13]. Radionuclides in the contaminated water can be and are filtered out, but this is not possible for the tritium dissolved in water. Tritium (T) is chemically identical to hydrogen (H) and binds to oxygen (O), forming tritiated water T-O-H and T-O-T, chemically non-distinguishable from ordinary water H-O-H.

A slow release into the ocean of diluted tritiated water with an activity below 1500 Bq/l is the agreed way to dispose of the tritiated water, where WHO defines 10'000 Bq/l as tolerable for drinking water [14]. As an alternative solution, vaporization of the tritiated

water into the atmosphere was discussed but not pursued. TEPCO, the Tokyo Electric Power Company that operates the Daiichi nuclear plant and responsible for the cleaning and decontamination, plans to cap the annual level of tritium released at 22 trillion becquerels ($22 \cdot 10^{12}$ Bq or 22 TBq) annually over more than 30 years [13].

This release, which started on 24 August 2023, is heavily discussed, and was leading to headlines in major newspapers worldwide. However, releasing tritiated water is common practice, where China who openly condemns Japan for its release of tritiated water is not so quite innocent and regularly releases tritiated water at an order of magnitude higher than the Fukushima tritiated water release, as is reported by the Japanese Government and illustrated in Fig. 2.

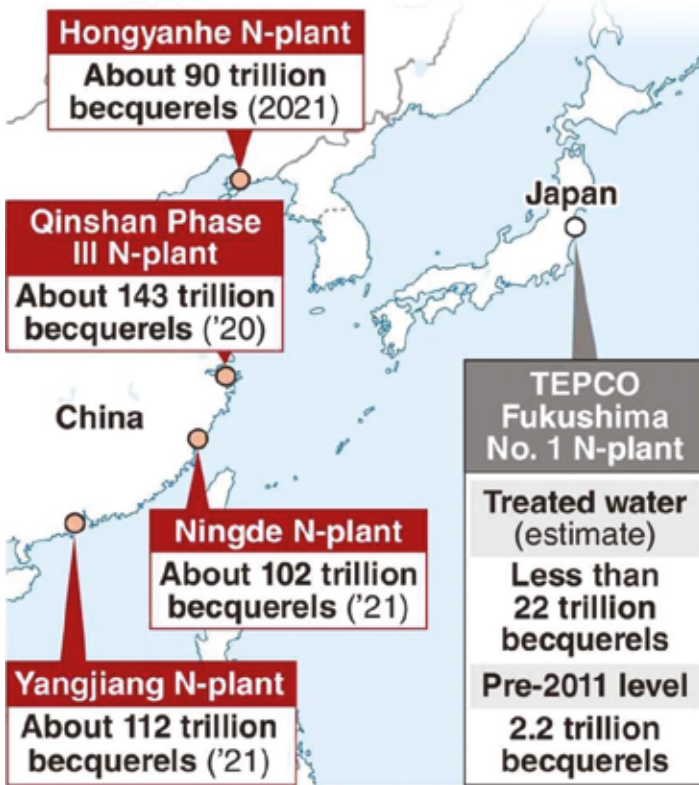
4 Estimating the dangers

The question arising is, what is exactly the danger related to tritiated water with an activity of 1500 Bq/l and of releasing 22 TBq annually to the ocean?

Tritium is a beta emitter with a half-life of 12.32 years. The beta particle, i.e. the decay electron, has an endpoint energy of 18.6 keV, with an average energy of 5.7 keV. Such electrons are immediately slowed down in water and even at their maximum endpoint energy, their maximum range in water is less than 7 μm before they come to a standstill and can't do any harm anymore. Swimming in tritiated water is completely harmless, as decay electrons are not capable of penetrating the skin's epidermis, which has a thickness of 30 - 50 μm , even then when a tritium decay shall happen in the ultimate direct vicinity and targeted at 90° to the swimmer's bare skin. Nor can such decay electrons penetrate through fish scales.

Drinking tritiated water is, however, different as the decay electron is ultimately absorbed inside the body. When ingesting tritiated water, the body takes it as ordinary water and passes it through the body's digestive system, where some of it passes fast through the metabolic system and some of it is deposited inside the body's cells, and released after some time. A biological half-time of 10 days for 99.00 %, of 40 days for 0.98 % and of 350 days for 0.02 % of the ingested tritium is reported in Ref. [16]. A biological

Tritium levels in water from Japanese, Chinese N-plants



Source: Japanese government document compiled for other countries ahead of TEPCO's discharge

Fig. 2: Annual release of tritiated water in China and at the Fukushima Daiichi site in Japan [15].

half-time of tritium in human body of $T_{1/2}^{bio} = 12$ days is considered here for simplicity, which covers by a good margin the absorbed dose rate of the small fraction of the ingested tritium that stays long inside the human body.

Drinking one litre of tritiated water with 1500 Bq/l equates to

$$N_0 = \frac{A}{\lambda} = \frac{A}{\frac{\ln 2}{T_{1/2}}} = \frac{1500 \text{ s}^{-1}}{\ln 2} \cdot 12.32 \cdot 365.25 \cdot 86400 \text{ s} = 841 \cdot 10^9$$

ingested tritium nuclei. Where $A = 1500 \text{ s}^{-1}$ is the activity, λ the decay constant, and $T_{1/2} = 12.32$ years is the half-life of tritium that needs to be converted in units of second.

The number of tritium decays, during the time these ingested nuclei reside in the body, follows as

$$N_{\text{decay}} = \int_0^{\infty} \lambda N_0 e^{-\lambda_{\text{bio}} t} e^{-\lambda t} dt = N_0 \frac{\lambda}{\lambda_{\text{bio}} + \lambda} = 0.0027 \cdot N_0 = 2.2 \cdot 10^9,$$

where $\lambda_{\text{bio}} = \frac{\ln 2}{T_{1/2}^{bio}} = 6.7 \cdot 10^{-7} \text{ s}^{-1}$ is the biological decay constant, defining the rate at which tritium is washed out from the human body. With an average energy of $E_{\text{avg}} = 5.7 \text{ keV}$ per tritium decay, a total energy dose of $E = N_{\text{decay}} \cdot E_{\text{avg}} = 12.8 \cdot 10^{12} \text{ eV} = 2.0 \cdot 10^{-6} \text{ J}$ is thereby absorbed.

Assuming a person to be 80 kg of mass, and the tritium evenly distributed, this results in an energy dose of $D = E / 80 \text{ kg} = 26 \cdot 10^{-9} \text{ J kg}^{-1} = 26 \cdot 10^{-9} \text{ Gray}$. The radiative weighting factor for electrons is just one, such that this number is also

its equivalent value in units of Sievert. We can therefore conclude that drinking one litre of tritiated Fukushima water results in an absorbed dose of 26 nSv.

If the integration time is limited to the first 24 hours only (rather than to infinity, as performed here above), the number of decays during the first day after ingestion follows as $N_{\text{decay}}^{24h} = N_{\text{decay}} \cdot (1 - e^{-(\lambda_{\text{bio}} + \lambda) \cdot 24h}) = N_{\text{decay}} \cdot 5.6\% = 0.13 \cdot 10^9$, leading to an exposure of 1.44 nSv in the first day, and correspondingly, to 1.36 nSv in the following day, etc.

Understanding these values needs some context. For instance, banana are radioactive beta emitters themselves, due to their relatively high level of potassium, and with it, its radioactive variant potassium-40. Eating a single banana leads to an exposure of 100 nSv, which is often referred to as the banana equivalent dose [17]. Eating a single banana, therefore, corresponds already to drinking four (!) litres of tritiated Fukushima water.

In Switzerland, an average person is exposed to 6.1 mSv annually from environmental radiation and medical diagnostic, corresponding to an average rate of 750 nSv/h [18]. This means that drinking 1 litre of tritiated water corresponds to about 120 seconds of an average person's exposure in Switzerland. In turn, when flying at cruise altitude in a commercial airplane, the dose rate is up to tenfold, due to cosmic radiation. Therefore, drinking one litre of tritiated water corresponds to a few 10s of seconds flight at cruise altitude.

If we took the non-diluted tritiated water instead, which is $1.25 \cdot 10^6 \text{ m}^3$ of tritiated water at an average concentration of 620 kBq/l and resulting to a total amount of 780 TBq, which by the way corresponds to a mere 2.2 grams (!) of pure tritium, that are being released [13], things become slightly different — but are still not alarming.

Drinking one litre of non-diluted tritiated water with 620 kBq/l, results to an exposure of 11 μSv , equivalent to 16 hours of average exposure in Switzerland, or a 100 minute flight, or eating 11 bananas, which can be spread to eating one banana a day for 11 days.

Releasing 22 TBq annually (62 mg per year (!)) into the ocean, where the tritiated water quickly dilutes to extremely small values does not cause harm in any way. Plastic and other toxic chemical waste that finds its way unhindered into the world's seas in turn are of a real concern. The tritium vanishes with a half-life of 12.32 years, where toxic chemicals and other waste stay.

The time it takes to release the full amount of the tritiated water can be estimated by $780 \text{ TBq} \cdot (1 - \alpha t) \cdot e^{-\lambda t} < 22 \text{ TBq}$, where $\alpha = 22/780 \text{ year}^{-1}$ is the annual release rate, t is time, and λ is the tritium decay rate. When the remaining amount has reached 22 TBq the final year has come. After ~ 31 years, all the tritiated water will be released, four years shorter than a simple estimate from dividing $780 \text{ TBq} / 22 \text{ TBq year}^{-1} = 35.5$ years would result in and taking into account the tritium that will decay while still being inside the tanks.

5 A brief history of radiation protection

Drinking the full amount of 2.2 g tritium (780 TBq) leads to a lethal dose.

$$N_0 = \frac{A}{\lambda} = \frac{780 \cdot 10^{12} \text{ s}^{-1}}{\ln 2} \cdot 12.32 \cdot 365.25 \cdot 86400 \text{ s} = 4.4 \cdot 10^{23}$$

tritium nuclides would be absorbed, of which a fraction decays in the first 24 hours:

$$\begin{aligned}
 N_{\text{decay}}^{24\text{h}} &= \int_0^{24\text{h}} \lambda N_0 e^{-\lambda_{\text{bio}} t} e^{-\lambda t} dt \\
 &= N_0 \frac{\lambda}{\lambda_{\text{bio}} + \lambda} \cdot (1 - e^{-(\lambda + \lambda_{\text{bio}}) 24\text{h}}) \\
 &= 0.15 \cdot 10^{-3} \cdot N_0 = 6.5 \cdot 10^{19}.
 \end{aligned}$$

These lead to an absorbed energy in the first day of

$$E^{24\text{h}} = N_{\text{decay}}^{24\text{h}} \cdot E_{\text{avg}} = 3.7 \cdot 10^{23} \text{ eV/day} = 60 \text{ kJ/day},$$

corresponding to an absorbed dose of $D^{24\text{h}} = E^{24\text{h}}/80 \text{ kg} = 745 \text{ J kg}^{-1} \text{ day}^{-1} = 745 \text{ Gray/day} = 745 \text{ Sv/day}$.

This dose is definitely and undisputedly deadly! - But what dose would be tolerable not causing harm?

Defining what levels of absorbed dose are acceptable and non-harming has a long history, of which here only the time after the end of World War II is briefly recapitulated. In 1951, the International Commission on Radiological Protection (ICRP) dose rate limit for the general public was set to 4.4 mSv/week (which was defined as 0.5 Röntgen per week in the then used units), which leads to an average of 0.63 mSv/day [19]. From this, the then tolerated dose would have resulted in ingesting 1.8 µg tritium (0.66 GBq) to be safe. This amount of tritium is contained in 1060 litres of concentrated tritiated water inside the Fukushima tanks - or in 440'000 litres of the diluted tritiated water at 1500 Bq/l – still at the tolerable radiation dose as they were valid in 1951 !

Ever since 1951, ICRP's recommendations were made more stringent - never on empirical data, but always based on the LNT hypothesis and the ALARA principle. Indeed, in the report of Sub-Committee I in the 1954 recommendations, it was stated that *'since no radiation level higher than the natural background can be regarded as absolutely "safe", the problem is to choose a practical level that, in the light of present knowledge, involves a negligible risk'*. However, the Commission had not rejected the possibility of a threshold for stochastic effects [19].

In 1959, ICRP's publication 1 [20] appeared, defining a new limit of 50 mSv/y for nuclear workers and 5 mSv/y for the public. ICRP's publication 9 [21], recommended in 1966 that *'all doses be kept as low as is readily achievable, economic and social consequences being taken into account'* and publication 22 [22] reported in 1973 that *'the optimum level of protection might be found by means of differential cost-benefit analysis and that the principle described in Paragraph 52 of Publication 9 was the principle of optimisation of protection.'*, which is referring to keep radiation doses as low as is readily achievable. Publication 26 [23] from 1977 finally set the limit to 5 mSv/y for nuclear workers and 1 mSv/y for the public, again based on principles of reducing radiation as much as possible, arguing on ethical grounds, under the assumption of the LNT hypothesis.

Applying 1 mSv/y results in an average of 2.7 µSv/d. Hence, ingesting 8 ng of tritium is still today considered tolerable, if no other exposures are assumed. This allows drinking 4.6 litres of the

concentrated tritiated water at 620 kBq/l, or drinking of close to 2000 litres of the diluted tritiated water at 1500 Bq/l !

Certainly, keeping radiation doses low is good intention of ICRP and similar bodies. However, if the derived limits are not based on scientifically, empirically collected data, but are based only on assumptions such as LNT and on a principled fear, regulations become biased towards other avoidable hazards. The non-necessary evacuation of 110'000 people following the Fukushima accident and causing stress-related deaths, where zero radiation-related deaths are to be mourned, is such an example [3].

Another example follows from the turning off of functional electricity-producing nuclear power plants from a principled fear of radiation, as e.g. Germany does. To compensate for the lost electricity production, Germany reactivates old coal plants [24], emitting huge amounts of CO₂ into the atmosphere. Although filtering systems are employed at modern coal plants, the environment is still polluted with fly ashes that are not only also radioactive themselves, but due to micro particles released, are at the cause of lung diseases, cardio-vascular problems and premature deaths, as is shown in Fig. 3 and discussed in [25]. Over 24 (30) premature deaths are to be mourned per TWh of generated electricity from coal (brown coal), but this could be $\mathcal{O}(1000)$ times less if electricity is produced from nuclear power instead, where disasters like Chernobyl and Fukushima have already been accounted for [25].

The LNT hypothesis and the ALARA principle deserve a deep reevaluation, and possibly need to be abolished to make place to new and better suiting regulations [6-9]. Indeed, no radiation harming effects can be detected below 100 mSv [10], and Refs. [6,7], to name only two, report about beneficial effects of low-dose-rate radiation. ICRP's publication 9 [21], recommended in 1966 that *'economic and social consequences being taken into account'*, when it introduced the ALARA principle. It seems that economic and social consequences have been forgotten all about when evacuations are ordered unnecessarily, when nuclear power plants have to give way to reactivating old coal plants, or when the resources spent to handle 2.2 grams of tritium are nowhere in balance to the extremely limited danger these 2.2 grams effectively pose.

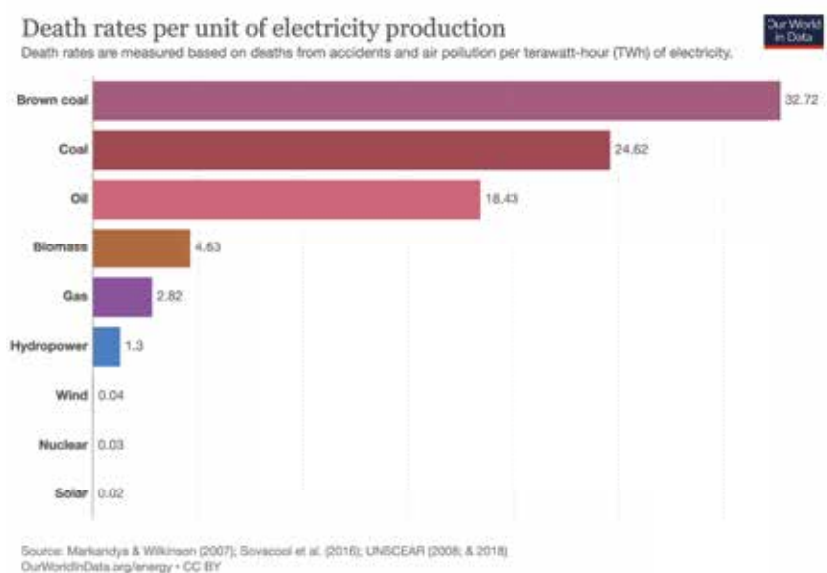


Fig. 3: Mortality from electricity production by energy source [25].

6 Conclusion

In conclusion, the Fukushima disaster could have been prevented with better protection of the emergency cooling system. The core meltdowns caused wider damage that, however, is still a local disaster, but not a world crisis [4,5], where [4] calculates mortality and morbidity numbers for various world regions based on LNT, while also criticising its use at low-dose rates. The evacuation of the surrounding population was causing severe stress-related harm [2] and was most likely unnecessary. This is easy to say in the aftermath, but a different and more reasonable approach could have been taken if LNT, ALARA, and the principled fear of radiation would not have prevented proper risk assessment and sensible decision taking.

The release of 2.2 g (780 TBq) of tritiated water is of zero concern at the current rate and activities - 62 mg/a (22 TBq/a) over more than 30 years. Releasing tritiated water is also a standard procedure done by many countries, including China.

The released water is of drinking water quality, as defined by WHO [14].

Tritium is produced naturally when cosmic rays penetrate through the atmosphere, and therefore, water collected from rain has a tiny activity of about 1 – 2 Bq/l [26] just from tritium alone [26]. These, together with other radiocative nuclides constantly produced in the high atmosphere, enter the oceans when it rains, these also rain on our heads and these we also drink on a daily basis. The annual global precipitation volume is about $5 \cdot 10^{14} \text{ m}^3$ [27], and hence, 10^{16} TBq of tritium rains on Earth annually, dwarfing the Fukushima release by five orders of magnitude.

Plastic and other toxic chemical waste that finds its way unhindered into the world's seas are in turn of a real concern. The tritium vanishes with a half-life of 12.32 years, where toxic chemicals and other industrial waste stays.

Over-regulations from the strict adoption of the flawed linear no-threshold hypothesis and the resulting ALARA principle are at the cause of creating fears that are unnecessary. These are also prohibiting proper risk analyses and the scientific assessment of real dangers. Proper risk assessments are vital in times when decisions need to be taken. An urgent revision of the radio-protection regulatory framework is not easy to achieve, but given the havoc it produces worldwide, it is of a pure necessity.

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SATW Technology Outlook 2023

Lukas Gallmann

One of the key responsibilities that the Swiss Academy of Engineering Sciences (SATW) has been tasked with by the Swiss Confederation is the early identification of technologies that will become relevant for Switzerland in the coming years. The results from this activity are published in a Technology Outlook every two years. Its most recent edition has just been released to the public on 15 September 2023 in an opening event at ETH Zurich.

While the future is difficult to predict, the regularly updated publication acts as an independent and objective source for orientation and guidance within the ever evolving technology landscape. As such it aims equally at assisting administration and industry in making strategic decisions and

identifying opportunities. The SATW Technology Outlook 2023 was compiled from interviews with 183 experts from 89 institutions, covering a broad range of 32 technologies.

The technologies covered in the 2023 edition are grouped into four main categories: digital world, manufacturing processes and materials, energy and environment, and life sciences. For consideration in this future-oriented report, a technology needs to have at least been successfully demonstrated in the laboratory, but should not already have been developed beyond prototype status.

These technologies were then evaluated with regards to their economic significance and the available research competence in Switzerland. Based on this, the technologies are

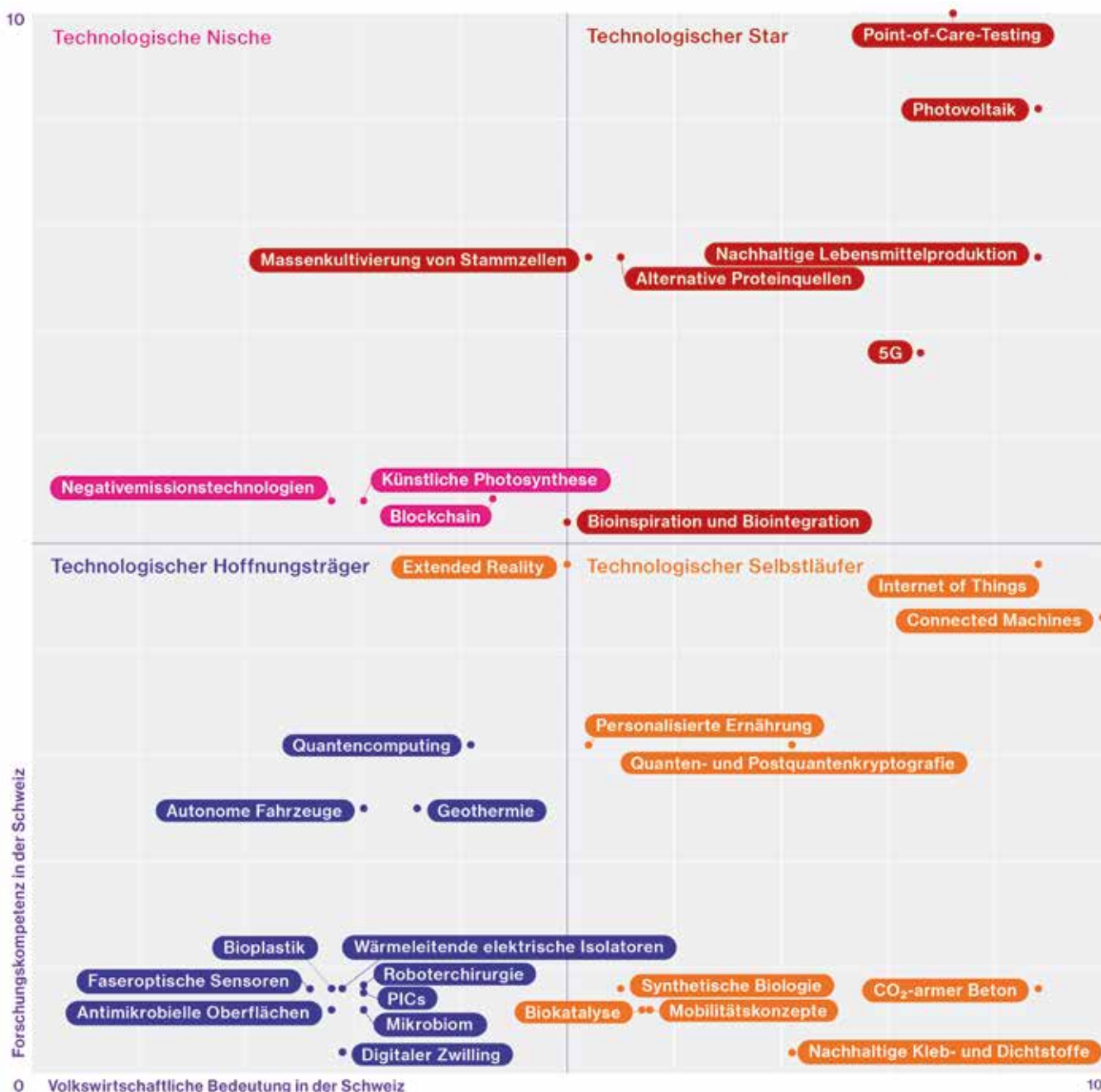


Figure 1: Technologies studied in the Technology Outlook 2023 and their evaluation in terms of existing research competence in and economical relevance for Switzerland. Based on this analysis the technologies are grouped into four quadrants, which cover technological hopefuls at the bottom left and the technological stars at the top right. Surefire successes are found at the bottom right, technological niches at the top left.

again sorted into four groups: stars (high economic impact and research competence), hopefuls (with still low economic impact and available research competence), niche technologies and surefire successes (low economic impact and high research competence and vice versa). All 32 technologies and their position in the resulting diagram are illustrated in Figure 1.

Physics-driven technologies

While physicists and physics as a whole are involved in the development of a wide range of technologies covered in the report, a few stand out that are strongly physics-driven.

Photovoltaics is an undisputed star amongst the considered technologies with large economic impact and strong technological competence in Switzerland. While some aspects of it are technologically firmly established and already part of a global mass market, there is still a strong push to develop more efficient, cheaper or environmentally more friendly photo cells or to develop solutions for new applications of photovoltaics. As such, photovoltaics will remain a field of very active research and development in the years to come and much of this heavily builds on physics expertise.

Photonics and quantum technologies are two domains of physics that form the foundation for progress in the fields of fiber-optic sensors, photonic integrated circuits, quantum computing and quantum cryptography. Fiber-optics sensors and photonic integrated circuits are still considered technological hopefuls. The potential of the former stems from the fact that optical sensors can withstand adverse environments and are less prone to interferences compared to their electronic counterparts. The fiber-optic implementation allows them to be integrated into many materials and structures. This also enables applications in medicine.

Photonic integrated circuits are structures for the processing of optical signals on a chip. For example, certain operations heavily used in machine learning and artificial intelligence can be executed on photonic integrated circuits rather than traditional silicon electronics. The benefit of photonic circuits lies in the fact that the same operations can be executed in a much more power-efficient way. This is expected to have a major impact on power consumption in future computing applications.

On the quantum side, also quantum computing is still considered a technological hopeful. Its promise of solving certain problems that are computationally too expensive or even impossible to solve with classical computers is widely known amongst physicists. Nevertheless, it is expected that more time is still needed until this technology can clearly demonstrate its superiority over classical approaches and have a corresponding economical impact.

The field of quantum cryptography is already more firmly established and is considered a surefire success in the latest Technology Outlook. Quantum key distribution and quantum random number generation are the most mature technologies in this field. However, the report also stresses the importance of new quantum encryption protocols (also known as post-quantum cryptography) that are able to withstand attacks with non-classical computers for future secure communication needs.

That quantum technologies have gained traction beyond fundamental science is also reflected in the fact that UNESCO is expected to officially proclaim the International Year of Quantum Science and Technology for 2025.

Technological evolution

It is also illustrative to see how the rating of different technologies by the involved experts evolved over the years. While from one biannual report to the next, some technologies may have been added to or dropped from consideration, 19 out of the 31 fields covered by the Technology Outlook 2023 have been monitored since 2019 and 26 are shared with the 2021 report. Technologies may be dropped because their relevance declined or because they evolved beyond the bounds of the considered technology readiness levels, i.e., they're now an established part of the industrial technological portfolio.

From a physics perspective, it is noteworthy that since the 2021 report, both quantum technologies have seen a positive development in economic importance and research competence. Quantum cryptography has even crossed the threshold from a 'hopeful' to a 'surefire success'. Between the two reports, the experts detected a small decline in research competence in photovoltaics, while its economic importance for Switzerland grew. The exact reasons for the perceived decline are unclear – the indicated small change may not be significant.

Overall, autonomous vehicles and digital twins have lost the most on the economic importance scale, while alternative protein sources and quantum cryptography are the biggest winners since the Technology Outlook 2021. Some of this also reflects the evolution of the zeitgeist over the last years.

To grasp the latter, the Technology Outlook also analyzes how much certain topics are talked about by monitoring discussions on Twitter (now 'X'). While photovoltaics and quantum computing are the winners amongst the top-five discussed technologies, blockchain and extended reality have lost the most momentum on this medium.

Physics remains an important driver of technology

The findings of the Technology Outlook 2023 convey a very positive message to us physicists. It is encouraging to see physics-heavy technologies receiving plenty of attention in public outlets such as the analyzed Twitter discussions. Irrespective of the importance of public perception, the report also shows that physics clearly remains an essential driver behind a number of technologies that are considered critical for our future – from an economical as well as a societal point of view. A broad overview of the impact of physics on the Swiss society can also be found in *SPS Focus* Nr. 2 from August 2022.



<https://technology-outlook.satw.ch/en/>

Glowing Heads - Shining Medals

A Review of the 29th Edition of the Swiss Physics Olympiad

Louis Zünd, Schweizerische Physikolympiade

When in 1967 15 students from five different countries met in Warsaw for the very first International Physics Olympiad (IPhO) the event must have resembled rather a gathering of some physics cracks. Yet, 56 years later more than 400 students from more than 80 different nations competed from 10 until 17 July in Tokyo for the title of the best newcomer physicist. Among them were five students from Switzerland who achieved exceptional results. Whereas the IPhO as an event truly underwent a great development, it is tempting to state the same about the results of the Swiss participants, especially, since the Swiss team also performed extraordinarily well at the European Physics Olympiad (EuPhO), which this year took place from 16 to 20 June in Hanover. Of course, all the enthusiastic volunteers and supporters behind the Swiss Physics Olympiad hope that this upward trend proves to be a lasting one. Instead of looking further into the crystal ball, however, let's celebrate this year's achievements and look back on the past Olympiad year.

As usual, the first item on the agenda of young physics enthusiasts took place between mid-August and the end of September last year. During that time, individual students with a vivid interest in physics or entire school classes could participate in the first round exam which is an online test of 40 minutes length testing various domains of physics. Out of 838 participants the best 135 were invited to prove their knowledge and skills at the second round exam taking place in the four corners of Switzerland. Still, in order to provide them with a possibility to deepen their physical understanding but also to create a first platform for exchange with like-minded students a preparation camp was organized beforehand in a camp house in Vordemwald. During one week in November the students could prepare themselves for the second round exam by following lectures on electrodynamics, solving exercises on oscillations and waves, and practicing problem solving strategies. If they did all of that with success and scored among the best 28 participants, they qualified for the national finals.

Again, aiming not only at pure competition but rather at opening the participants' minds for new physical horizons and thereby fostering their interest in the study of matter and energy, a preparation weekend at EPFL was offered to the qualified students. Apart from providing deeper insights into topics such as data analysis, alternating current or rotation of solid bodies, this preparation event put a special emphasis on experimental training since the exam at the national finals would not only consist of three theoretical problems and a couple of smaller theory questions but also of two experiments. All parts together amounted for a total length of six and a half hours spread over two days.

Finally, on the weekend of 18 and 19 March 2023 the time was ready for the best newcomer physicists of Switzerland to compete at Neue Kantonsschule Aarau. The sweat was running and the heads were glowing because of the tough

but fascinating physical phenomena treated by the final round exam. Students were for example asked to do calculations for a space mission to Jupiter or to reveal the famous twin paradox in special relativity. On the experimental part, they had to find a way to determine the radius of a wooden piece without actually using any ruler.

However, the national finals were not only about physics in a strict sense but also about connecting with people sharing the same interests. Between and after the exams was enough time for participants to share their difficulties faced during the examination, to play card games together, and to find new friends. The intense weekend was concluded under big applause for the five gold medallists Adrian Serrano Capatina, Piranavan Subaharan, Daniel Gonzalez Filipov, Bruno Pontecorvo, and Kodai Tsutsui, the first two of which were additionally awarded the "Nachwuchsförderpreis / Prix de la Relève" of the Swiss Physical Society for their exceptional achievements. It was also these young physicists representing Switzerland at the IPhO in Tokyo and coming home with one silver medal (Daniel Gonzalez Filipov), two bronze medals (Adrian Serrano and Kodai Tsutsui) and one honorable mention (Bruno Pontecorvo). Another three honorable mentions were awarded to Bruno Wetton, Elias Baumann as well as Luis Jost during the EuPhO in Hanover and Elvin Fu returned even with a bronze medal in his luggage. Overall, Adrian Rutschmann, the team leader of the Swiss IPhO delegation, judges the results as outstandingly high this year.

These excellent results close the annual Olympic cycle and the organizers gradually transition from feeling great pride in the brilliant performance of this year's participants towards the preparation for the upcoming Olympiads. Every cycle enables a new generation of students to develop their passion for juggling with formulas and finding explanations for the behavior of matter in time and space.



Piranavan Subaharan (left) and Adrian Serrano Capatina (middle) were awarded by SPS Secretary Lukas Gallmann the "SPG Nachwuchsförderpreis / Prix de la Relève de la SSP" for scoring the two best results at the national finals of the Swiss Physics Olympiads.
Picture: Markus Meier.

Ausschreibung der SPG Preise für 2024

Auch im Jahr 2024 sollen wieder SPG Preise, die mit je CHF 5000.- dotiert sind, vergeben werden.

- SPG Preis gestiftet von der Firma *ABB Schweiz AG* für eine hervorragende Forschungsarbeit auf **allen Gebieten der Physik**



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- SPG Preis gestiftet von der Firma *IBM Research GmbH* für eine hervorragende Forschungsarbeit auf dem **Gebiet der Kondensierten Materie**

- SPG Preis gestiftet vom *Eidgenössischen Institut für Metrologie METAS* für eine hervorragende Forschungsarbeit **mit Bezug zur Metrologie**



- SPG Preis gestiftet von der Firma *COMSOL Multiphysics GmbH* für eine hervorragende Forschungsarbeit auf dem **Gebiet der computergestützten Physik**



- SPG Preis gestiftet von der Firma *Hitachi Energy Switzerland AG* für eine hervorragende Forschungsarbeit **mit Bezug zur Energietechnik**



Die SPG möchte mit diesen Preisen **junge** Physikerinnen und Physiker in der Frühphase ihrer Karriere, auf alle Fälle vor Erreichen einer akademischen Festanstellung oder bevor sie mehr als drei Jahre in einer Start-up Firma oder in der Industrie tätig sind, für hervorragende wissenschaftliche Arbeiten auszeichnen.

Die eingereichten Arbeiten müssen entweder in der Schweiz oder von Schweizerinnen und Schweizern im Ausland ausgeführt worden sein. Die Beurteilung der Arbeiten erfolgt auf Grund ihrer Bedeutung, Qualität und Originalität.

Der Antrag muss folgende Unterlagen enthalten:

Beschreibung der wissenschaftlichen Arbeit, die prämiert werden soll, inklusive eines wissenschaftlichen Gutachtens. Ein Lebenslauf des Kandidaten, sowie zusätzliche Informationen, die die wissenschaftliche Leistung unterstreichen. Dazu gehören eine Aufstellung der Publikationen in renommierten Zeitschriften und von Einladungen zu Vorträgen, sowie Informationen über eventuell erhaltene Fördermittel, über angemeldete und erteilte Patente, über akademische Preise und Auszeichnungen, etc. Die Relevanz und der Impact dieser Arbeit in ihrem wissenschaftlichen Gebiet sollen deutlich herausgestrichen werden.

Diese Unterlagen werden elektronisch im "pdf"-Format direkt an das Preiskomitee eingereicht (große Dateien bitte komprimieren (zip) oder zum Download bereitstellen):

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Einsendeschluss: 01. März 2024

Die Preise werden an der SPG Jahrestagung 2024 in Zürich überreicht. Das Preisreglement befindet sich auf www.sps.ch.

Annnonce des prix de la SSP pour 2024

En 2024, la SSP attribuera à nouveau des prix de CHF 5000.- chacun, à savoir:

- Le prix SSP offert par l'entreprise *ABB Schweiz AG* pour un travail de recherche d'une qualité exceptionnelle dans **tout domaine de la physique**



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- Le prix SSP offert par l'entreprise *IBM Research GmbH* pour un travail de recherche d'une qualité exceptionnelle en **physique de la matière condensée**

- Le prix SSP offert par *l'institut national de métrologie de la Suisse METAS* pour un travail de recherche d'une qualité exceptionnelle **faisant référence au domaine de la métrologie**



- Le prix SSP offert par l'entreprise *COMSOL Multiphysics GmbH* pour un travail de recherche d'une qualité exceptionnelle dans le **domaine de la physique numérique**



- Le prix SSP offert par l'entreprise *Hitachi Energy Switzerland AG* pour un travail de recherche d'une qualité exceptionnelle **faisant référence au domaine des technologies énergétiques**



La SSP distingue avec ces prix des travaux scientifiques exceptionnels de **jeunes** physiciens dans la première étape de leur carrière et qui n'ont pas encore atteint une position permanente universitaire ou qui ne travaillent pas depuis plus de trois ans dans l'industrie.

Les travaux soumis doivent avoir été effectués en Suisse ou par des citoyens Suisses à l'étranger. L'évaluation s'effectue selon des critères d'importance, de qualité et d'originalité du travail soumis à la compétition.

Une nomination complète contient:

Une description du travail scientifique soumis, y compris une lettre de référence. Un curriculum vitae du candidat, ainsi que des informations supplémentaires qui mettent l'accent sur les réalisations scientifiques, notamment une liste de publications dans des revues prestigieuses, des invitations de présenter à des conférences importantes, ainsi que des informations sur des requêtes reçues, des brevets en attentes ou délivrés, des prix ou d'autres distinctions académiques, etc. L'importance et l'impact de ce travail dans son propre domaine scientifique doivent être clairement présentés.

Ces documents seront envoyés électroniquement en format "pdf" directement au comité de prix (svp. compressez les très grands fichiers (zip) ou mettez les à disposition pour téléchargement):

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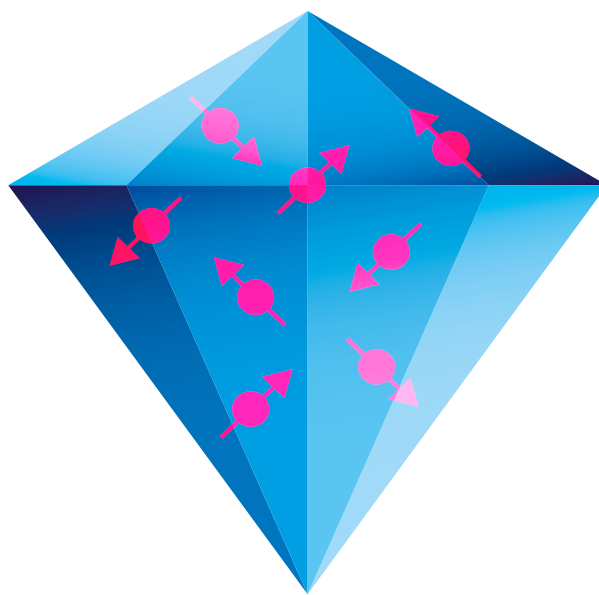
Délai: 1 mars 2024

Les prix seront attribués à la réunion annuelle de la SSP qui se tiendra en 2024 à Zürich. Le règlement des prix se trouve sur les pages web de la SSP: www.sps.ch

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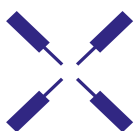
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