⟨S|P|S⟩ swiss physical society

Nr. 74, November 2024

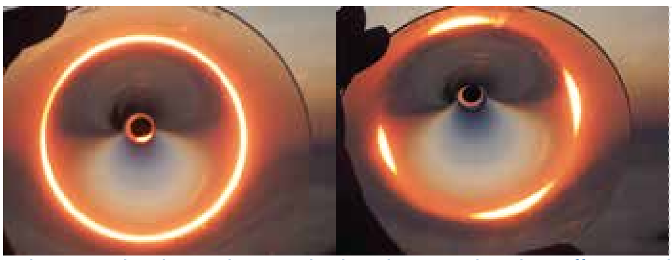
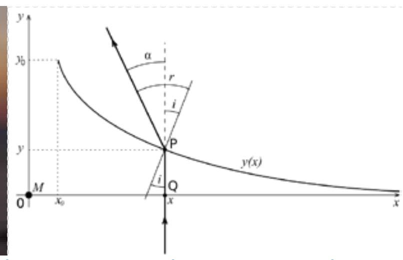
# SPG Mitteilungen
# Communications de la SSP


The president of ETH Zürich, Joël Mesot, held the opening speech at this year's Annual Meeting. Nobel Laureate 2023 Anne l'Huillier gave an exciting public lecture on the evening of the first day. The conference review is on p. 8.


The famous 5th Solvay conference in 1927 gathered many fathers of quantum mechanics. Louis de Broglie (1) has been celebrated this year in a special symposium (p. 8). In 2025 a similar symposium on Wolfgang Pauli (2) and Erwin Schrödinger (3) is planned, in the following years Paul Dirac (4), Albert Einstein (5) and others shall be celebrated.

A view into a plasma chamber. Read on p. 29 about the astonishing variety of plasma occurances and why plasma should be a topic in high school curriculae.




An optical lens with the shape of a wine glass bottom simulates the gravitational strong lensing effect: a classroom experiment to reproduce Einstein's rings, crosses and arcs (from the talk by Alice Gasparini). The session report is on p. 13.

# Inhalt - Contenu - Contents



## Vorstandsmitglieder der SPG - Membres du Comité de la SSP


**Präsidentin - Présidente**
Prof. Teresa Montaruli, Uni Genève, teresa.montaruli@unige.ch

**Vize-Präsident - Vice-Président**
Prof. Michel Calame, Empa & Uni Basel, michel.calame@empa.ch

**Sekretär - Secrétaire**
Prof. Christof Aegerter, Uni Zürich, aegerter@physik.uzh.ch

**Kassier - Trésorier**
Dr. Sebastian Siol, Empa, sebastian.siol@empa.ch

**Kondensierte Materie - Matière Condensée (KOND)**
Dr. Daniel Mazzone, PSI, daniel.mazzone@psi.ch
Prof. Ilaria Zardo, Uni Basel, ilaria.zardo@unibas.ch

**Angewandte Physik - Physique Appliquée (ANDO)**
Prof. Mike Seidel, PSI, mike.seidel@psi.ch
Dr. Fabio Avino, EPFL, fabio.avino@epfl.ch

**Astrophysik, Kern- und Teilchenphysik - Astrophysique, physique nucléaire et corp. (TASK)**
Prof. Lesya Shchutska, EPFL, lesya.shchutska@epfl.ch

**Theoretische Physik - Physique Théorique (THEO)**
Prof. Julian Sonner, Uni Genève, julian.sonner@unige.ch

**Physik in der Industrie - Physique dans l'industrie**
Dr. Gian Salis, IBM Rüschlikon, gsa@zurich.ibm.com
Dr. Valeria Bragaglia, IBM Rüschlikon, vbr@zurich.ibm.com

**Atomphysik und Quantenoptik - Physique Atomique et Optique Quantique**
Prof. Jean-Philippe Brantut, EPFL, jean-philippe.brantut@epfl.ch
Prof. Rachel Grange, ETH Zürich, grange@phys.ethz.ch

**Physikausbildung und -förderung - Education et encouragement à la physique**
Dr. Alice Gasparini, Uni Genève, alice.gasparini@unige.ch
Dr. Gernot Scheerer, CHUV Lausanne, gernot.scheerer@chuv.ch

**Geschichte und Philosphie der Physik - Histoire et Philosophie de la Physique**
Prof. Christian Wüthrich, Uni Genève, christian.wuthrich@unige.ch
Prof. Jérôme Baudry, EPFL, jerome.baudry@epfl.ch

**Energie und Nachhaltigkeit - Énergie et durabilité**
Dr. Stephan Wirths, Hitachi Energy, stephan.wirths@hitachienergy.com
Dr. Tomoko Muranaka, EPFL, tomoko.muranaka@epfl.ch

**Biophysik und Weiche Materie - Biophysique et matière molle**
Prof. Sahand Rahi, EPFL, sahand.rahi@epfl.ch
Dr. Christof Fattinger, christof.fattinger@gmail.com

**Kommission Chancengleichheit, Diversität und Inklusion - Commission Egalité, Diversité et Inclusion**
Dr. Philipp Schmidt-Wellenburg, PSI, philipp.schmidt-wellenburg@psi.ch

### Administratives Sekretariat - Secrétariat administrative

**(Mitgliederverwaltung, Webseite, Druck, Versand, Redaktion Bulletin & SPG Mitteilungen) - (Service des membres, internet, impression, envoi, rédaction Bulletin & Communications de la SSP)**

S. Albietz, SPG Sekretariat, c/o Departement Physik, Universität Basel
Klingelbergstrasse 82, CH-4056 Basel
Tel. 061 / 207 36 86, Fax 061 / 207 37 84, sps@unibas.ch

**Wissenschaftliche Redakteure - Rédacteurs scientifique**
Dr. Bernhard Braunecker, braunecker@bluewin.ch
Dr. Margherita Boselli, CERN, margherita.boselli@cern.ch


## Impressum:


Die SPG Mitteilungen erscheinen ca. 2-4 mal jährlich und werden an alle Mitglieder abgegeben.

**Abonnement für Nichtmitglieder:**
CHF 20.- pro Jahrgang (Inland; Ausland auf Anfrage), incl. Lieferung der Hefte sofort nach Erscheinen frei Haus. Bestellungen bzw. Kündigungen jeweils zum Jahresende senden Sie bitte formlos an folgende Adresse:

**Verlag und Redaktion:**
Schweizerische Physikalische Gesellschaft, Klingelbergstr. 82, CH-4056 Basel, sps@unibas.ch, www.sps.ch

Redaktionelle Beiträge und Inserate sind willkommen, bitte wenden Sie sich an die obige Adresse.
Namentlich gekennzeichnete Beiträge geben grundsätzlich die Meinungen der betreffenden Autoren wieder. Die SPG übernimmt hierfür keine Verantwortung.

**Druck:**
Werner Druck & Medien AG, Leimgrubenweg 9, CH-4053 Basel

member of the scnat swiss academy of sciences

satw technology for society

# Editorial

## Swiss IYQ 2025 Activities in the Pipeline of Physics

*Bernhard Braunecker, collecting the input from Katharina Müller (UZH), Ulrich Claessen (SATW), Johan Chang (SPS), Teresa Montaruli (SPS), Paola Catapano and Dante Larini (CERN).*

The 2025 ***International Year of Quantum Science and Quantum Technology*** IYQ 2025 marks the 100th anniversary of quantum mechanics. Many events (schools, workshops, and symposia) are planned across the globe [1]. In Switzerland, the Swiss Academy of Science (SCNAT) has initiated the Swiss Quantum Initiative (SQI) to further strengthen quantum research, technology, and application. On the grassroots level, many events are currently being planned across Switzerland, where physicists and especially SPS members are involved.

### Historical Symposia

- The ***SPS*** started its IYQ activities already this year in September with a tune-in event at the SPS annual meeting in Zürich, i.e. with a symposium about the *wave / particle duality*, remembering the epochal studies of Louis de Broglie [2].
- ***CERN*** is devoting its public event season to the quantum year. Several events are planned at its new Science Gateway venue, including talks, artistic performances, theatre plays, activities for youth and a film festival. One key highlight event will be in April 2025, celebrating the 60th anniversary of the *Bell Inequalities Theorem* by sharing its history, present-day applications and future, with a twist of pop-culture.

- The ***University of Zürich*** is planning a symposium at the end of June to illuminate the Swiss contributions to the birth of quantum mechanics and the implications on today's technologies. Additionally, it is planned to have an exhibition for students and the general public [3].
- At the joint annual meeting of **SPS** and **ÖPG** in Vienna from 18 - 22 August 2025, a special IYQ symposium will focus on Wolfgang Pauli's and Erwin Schrödinger's contributions. Both Austrian physicists were teaching in Zürich for part of their careers. Pauli was SPS Vice President from 1953 - 1955 and President from 1955 - 1957.

### Schools

Switzerland is also going to host schools and conferences on quantum computing and quantum materials research. We foresee for the moment:

- MaNEP Winter School (organized by Uni-Geneva).
- Quantum Foundations Summer school (ETHZ) 20 - 24 June 2025.
- Summer School on Quantum Computing (organized by Uni Zurich) 21 - 26 July 2025.

### Workshops & Conferences

- Correlated and Topological Quantum Matter (organized by Marc Janoschek et al.).
- Quantum spin ice materials (organized by Romain Sibille et al.).
- Quantum Science (organized by Young Physicists Forum (YPF) – Frederik van der Brugge), sponsored by SPS.
- The Swiss Quantum Days (organized by Swiss Quantum Initiative in Arosa 29 - 31 January 2025).

### Swiss Industry

Swiss industry is closely following the implementation of quantum concepts in commercially marketable products.

- ***Swissmem*** is going to set up a working group called Swiss Quantum Industry Network (SQIN). The kick-off meeting was on 29 October 2024 in Zürich [4].

### Teaching

- At the successful ***SATW TechDays***, which are held at various cantonal schools in Switzerland, young people are increasingly being offered attractive lectures on quantum technologies by physicists, such as at the TechDays in Wohlen (AG). *https://www.satw.ch/de/*

### Awards

- New SPS Award on Quantum Science and Technology sponsored by ID Quantique (see p. 37 and 58).

### Other Initiatives for Outreach

- Among the most exciting outreach initiatives is the idea to develop and operate a quantum science escape room (open to the public) at the ***University of Zürich***. Visitors will immerse themselves in the research world of the 1920s and follow the footsteps of a young researcher to solve puzzles that all have a connection to quantum mechanics in the narrower sense or to physics.

The thematic width of these fascinating activities reflects the strong engagment of many of our colleagues to explore the future potential of quantum phenomena to the general public and especially to young people. This is fully in line with the IYQ mission to convey young people a positive vision of their future. It would be desirable if all these great grassroots initiatives, in most cases done by volunteers, were supported by the SCNAT-SQI and the Swiss National Science Foundation.

---

1 An international coordination of the events has been promoted by APS and a Steering Committee has been formed (*https://quantum2025.org/en/steering-committee/*). All events will be registered and then sponsored from this page.

2 In 1924, Louis de Broglie (1892 - 1987) completed his studies with the famous dissertation *Recherches sur la théorie des Quanta*, in which he suggested that wave-particle duality could be applied to all matter.

3 see *https://www.physik.uzh.ch/de/events/Quantum25.html*

4 Gründung der Arbeitsgruppe "Swiss Quantum Industry Network (SQIN)" - Swissmem: *https://www.swissmem.ch/de/wissen/technologien/gruendung-der-arbeitsgruppe-swiss-quantum-industry-network-sqin.html*

# The winners of the SPS Awards 2024

The SPS Award committee, chaired by Prof. Hugo Zbinden, selected the winners for 2024 out of many submissions. The winners presented their work at the SPS Annual Meeting in Zürich. 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: Paolo Colciaghi, Simon Scheidegger, Lucrezia Maini, Alberto Rolandi, Patrick Lenggenhager.*

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

Quantum entanglement may play a key role in future technologies, and it is still a subject of profound debate, shaping our modern understanding of nature. It has been verified for very small systems; but amongst the questions remains the limiting size in which such quantum properties can be observed. Even more challenging is the verification of Einstein-Podolsky-Rosen paradox in large systems, as it requires stronger correlations than the simpler verification of entanglement, as well as accurate control at quantum level, and coherence.

It is therefore my pleasure to give the General Physics Prize sponsored by ABB to **Paolo Colciaghi**, for his work "Einstein-Podolsky-Rosen Experiment with two Bose-Einstein Condensates.

During his PhD work, Paolo was able to set up and perform experiments that verify, for the first time, the realisation of EPR paradox in a system of two spatially separated heavy particle Bose-Einstein condensates containing about 700 Rubidium atoms each.

This is undoubtedly, a landmark achievement in the field of quantum physics, and as such it has been acknowledge by the international physics community.

On the practical side, EPR entanglement together with quantum control in such large systems may become an important resource for quantum metrology and information processing.

**Einstein-Podolsky-Rosen experiment with two Bose-Einstein condensates**

Much of the current push in quantum technologies relies on one assumption: Quantum mechanics is valid for complex and macroscopic systems. Although recent experiments have demonstrated the entanglement of mesoscopic objects, there are some aspects of quantum mechanics that are yet to be tested beyond the few-atoms level. Among these, one of the best-known examples is the Einstein-Podolsky-Rosen (EPR) paradox, which was formulated in 1935 to point out the conflict between quantum mechanics and the classical understanding of locality and reality [1].

In our experiment, we observed for the first time the EPR paradox with two spatially separated, massive many-particle systems [2]. In close analogy to the original thought experiment by EPR, we entangle the atoms in a rubidium-87 Bose-Einstein condensate (BEC), which we then split into two separate condensates – each containing about 700 atoms. Our splitting technique preserves the coherence between the split BECs and allows us to individually manipulate them. The entanglement inherited from the initial state is strong enough for us to demonstrate the EPR paradox between the two BECs.

Our results show that the conflict between quantum mechanics and classical physics does not disappear when the system size is increased to more than 1000 massive particles. Furthermore, EPR entanglement is a valuable resource for quantum technologies. For this resource to be useful, the involved systems need to be spatially separated and individually addressable on the quantum level, as we demonstrate in our work.

[1] A. Einstein, B. Podolsky, and N. Rosen, Can Quantum Mechanical Description of Physical Reality Be Considered Complete?, *Phys. Rev.* **47**, 777 (1935).
[2] P. Colciaghi, Y. Li, P. Treutlein, and T. Zibold, Einstein-Podolsky-Rosen Experiment with Two Bose-Einstein Condensates, *Phys. Rev. X* **13**, 021031 (1935).

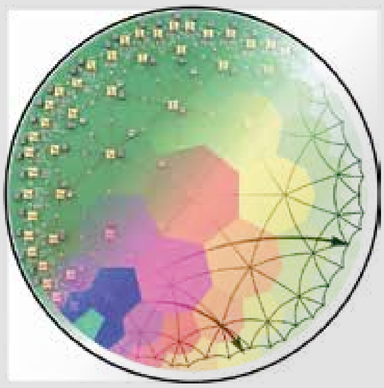
# SPS Award in Condensed Matter Physics, sponsored by IBM

The SPS Award in Condensed Matter Physics, sponsored by IBM, goes to **Patrick Lenggenhager**.

Patrick Lenggenhager made significant advancements in theoretical condensed matter physics during his doctoral studies. He conducted groundbreaking research on the topological characterization of electronic systems in crystals, particularly triple nodal points. His work extended to the innovative exploration of hyperbolic lattices, realizing negatively curved systems through electric-circuit networks and generalizing topological insulator concepts to hyperbolic geometry. His contributions have inspired further research and provided computational tools for the scientific community. Patrick's achievements demonstrate his exceptional talent and dedication to advancing our understanding of complex physical phenomena.

**Emerging avenues in band theory: multigap topology and hyperbolic lattices**

Band theory remains a foundational tool of condensed matter physics for understanding the quantum mechanical properties of crystalline solids. It relies on the description of wave functions on periodic lattices in terms of energy bands of Bloch states. My thesis [1] contributes to this cornerstone of the field by exploring two emerging avenues: multi-gap topology and hyperbolic lattices, which are tied together by the overarching concepts of symmetry and topology.
Traditionally, topological phases in materials are characterized by distinguishing between occupied and unoccupied energy bands. However, in the context of semimetals, a more nuanced partitioning of energy bands is frequently necessary. We studied manifestations and implications of such multi-gap topology, using three-fold degeneracies, or „triple points", as a concrete example. These triple points are not only conceptually significant but are also commonly found in actual materials. We have developed a classification of these triple points and their topology providing new insights into how these structures and their properties can be predicted and identified.
The second major focus of my thesis is on hyperbolic lattices—the analog of periodic structures in negatively curved space. While traditionally associated with high-energy physics and cosmology, curved spaces have gained attention in condensed matter physics as well. Our research demonstrates that hyperbolic lattices can effectively emulate curved space using metamaterials, such as electric circuit networks, and that key concepts from condensed matter physics, such as a full reciprocal-space description, can be adapted to these unique geometries. This opens up new avenues for the theoretical exploration of synthetic matter in curved space and paves the way for applications in areas ranging from fundamental physics to advanced metamaterial and network design, and potentially even quantum technologies.



*Electric-circuit network (background) implementing a hyperbolic lattice (thin black lines) using capacitors and inductors. The colored overlay shows experimental data of the voltage phase profile demonstrating wave propagation along hyperbolic geodesics (black curved arrows).*

[1] P. M. Lenggenhager, Doctoral Thesis ETH Zurich No. 29553 (2023), https://doi.org/10.3929/ethz-b-000645370

# SPS Award related to Metrology, sponsored by METAS

The SPS prize related to Metrology is awarded to **Simon Scheidegger** for his outstanding PhD thesis on precision spectroscopy of Rydberg states in the hydrogen atom. Simon used beams of highly collimated hydrogen atoms allowing him to reduce the Doppler width of the observed transitions as well as the application of controlled electrical fields for clear separation of the Stark levels. Moreover, transitions from highly exited states in the hydrogen atoms where the influence of proton size is reduced have been used. Finally, the measurement scheme also took profit of the recently developed SI-traceable frequency-dissemination network connecting ETHZ, University of Basel to METAS. Last but not least, the work even delivers also some hints towards the resolution of proton-size puzzle.

The work was published 2024 in Physical Review Letters (Scheidegger and Merkt, Phys. Rev. Lett. 132, 113001 (2024)) and received special attention through coverage in Physics Today (U. Jentschura, DOI: 10.1103/Physics.17.39) and as a Nature Research Highlight (Nature 627, 469 (2024)).

**Metrology of Rydberg-Stark states of the hydrogen atom and the proton-size puzzle**

Until recently, precision measurements in highly excited Rydberg states of the H atom with principal quantum numbers $n$ beyond about 12 were considered impossible because of large systematic uncertainties resulting from their large dc-polarizabilities and arising from uncontrollable Stark shifts caused by unavoidable stray electric fields. High-$n$ states of the H atom, however, have long natural lifetimes and would otherwise be ideally suited for precision measurements. Recently, we demonstrated how to circumvent the issue of uncontrollable Stark shifts in spectra of high-$n$ state of H by measuring the transitions frequencies in the presence of intentionally applied weak electric fields in conditions under which the Stark states are fully resolved [1]. The measured Stark shifts then enable one to accurately determine the electric fields. With this method we have carried out precision measurements of the $n = 24 \leftarrow 2\ ^2S_{1/2}(f = 1)$ and $n = 20 \leftarrow 2\ ^2S_{1/2}(f = 0,1)$ transition frequencies of the H atom and used the results to determine the ionization energy of H with unprecedented accuracy. Using the interval between the $2\ ^2S_{1/2}(f = 0)$ and $2\ ^2P_{1/2}(f = 1)$ states measured by Bezginov et al., (Science **365**, 1007 (2019)) we could derive a value of the Rydberg constant that is independent of the exact value of the proton charge radius [2]. The results contribute to resolve the proton-size puzzle, which is a discrepancy between the values of the proton charge radius obtained from spectra of muonic hydrogen and hydrogen.

[1] S. Scheidegger et al., Phys. Rev. A **108**, 042803 (2023)
[2] S. Scheidegger and F. Merkt, Phys. Rev. Lett. **132**, 113001 (2024)

# SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS Award in Computational Physics, sponsored by COMSOL, goes to **Lucrezia Maini**, whose pioneering work in developing a novel sensing concept to measure the local temperature inside the human body, surpassing the resolution of conventional infrared thermometry in clinical applications by nearly two orders of magnitude, is truly remarkable. The method, which can be used, for instance, for real-time infection monitoring on medical implants, operates without any battery or other electromagnetic component and hence avoids many side effects of state-of-the-art wireless sensors.

Lucrezia could achieve this breakthrough by exploiting the interaction of ultrasound with specific temperature-sensitive acoustic metamaterials. In designing these materials, she developed sophisticated computational models of coupled acoustic, structural, and thermal processes on the microscale. This allowed her to predict and optimize the response metamaterials before fabrication. The outstanding combination of computational and experimental work that Lucrezia Maini has demonstrated has the potential to significantly improve healthcare and inspire sensing concepts of further biomedical relevant parameters.

**Acoustic metamaterials for biomedical applications: measuring temperature with ultrasounds**

In the realm of wireless implantable devices, communication and energy supply systems are mostly based on electromagnetic coupling. This approach is limited by the strict regulatory standards concerning elevated power levels and prolonged interrogation durations, imposed to mitigate the adverse thermal effects within patients' bodies caused by electromagnetic radiation. On the other hand, acoustic waves, by virtue of their low attenuation in tissue, can achieve higher *in vivo* power levels, minimizing potential adverse effects.

My PhD project is focused on the design and integration of acoustic metamaterials to develop a fully passive temperature sensor. Demonstrated *in vitro* [1], this sensor can detect temperature gradients with a resolution close to 30 mK. This resolution surpasses conventional infrared thermometry for the detection of infections in current clinical applications. Envisioned for direct integration onto titanium prostheses, such passive sensors could facilitate real-time infection monitoring, preventing post-operative complications in patients which can lead to tissue necrosis, multiple hospitalizations, and even death.

The metamaterial, made of silicon and encapsulated in polydimethylsiloxane (PDMS), is designed to exhibit an acoustic resonance at a frequency close to 5 MHz, aligning with the standard operational frequencies of medical ultrasound transducers. This resonance is modulated by the surrounding temperature, while the metamaterial sensor is being interrogated by a commercial ultrasound transducer. The sensor is passive, meaning that all its energy supply and communication is provided by the ultrasound pulse from the transducer.

Multiphysics simulation has been used to shed light on the physical mechanism of the metamaterial and to model the frequency behavior of PDMS from experimental data [2]. In particular, the frequency and temperature dependency of the acoustic properties of PDMS, such as the speed of sound and attenuation, have been carefully modeled and calibrated to accurately describe the propagation of acoustic waves in the metamaterial model. Our findings revealed that the excellent temperature resolution stems from the strong temperature dependence of the PDMS's bulk modulus, in synergy with the high Q factor of the acoustic resonance in the metamaterial. This effect leads to a significant shift in the resonance frequency of the reflected signal with temperature.

Acoustic metamaterials could thus enable new sensing schemes for next-generation wireless implantable devices. Their potential for biomedical applications is remarkable, in particular for the development of zero-power sensing concepts, using ultrasounds as interrogation source.

[1] L. Maini, V. Genoves, R. Furrer, N. Cesarovic, C. Hierold, & C. Roman, *Nature Microsystems & Nanoengineering*, **10**(1), 8, 2024
[2] V. Genoves, L. Maini, C. Roman, C. Hierold, & N. Cesarovic, *Polymer Testing*, **124**, 2023

*The awards were given to the winners by SPS President Teresa Montaruli and the representatives of the sponsoring companies: Thomas Christen (Hitachi), Sven Friedel (Comsol), Hugo Lehmann (Metas) and Eduardo Cuervo Reyes (ABB).*

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

**Alberto Rolandi** obtains the SPS Award related to Energy research sponsored by Hitachi Energy Switzerland.

Computing is using more energy than ever with continuously increasing electricity demand. Therefore, in the digitization era it is crucial to understand the fundamental limits of energy consumption of computation, similar to the understanding of the Carnot limit in beginning of industrialization. By developing further seminal work of Rolf Landauer and others on the fundamentals of computation, Alberto Rolandi showed in the framework of quantum thermodynamics, that it is possible to strongly reduce energy consumption by considering collective processes where interactions are created along the protocol. A fundamental bound was derived and it was shown, how it could be approached with realistic control for many-body systems featuring short-range two-body interactions. Such so-called "collective advantage" is also relevant in other areas of physics, like quantum batteries. Another important achievement was the derivation of a finite-time correction of Landauer's principle beyond weak coupling, which illustrates the importance of the thermal Planck time scale for information erasure.

**Collective Advantages in Finite-Time Thermodynamics**

In this study, we explore the reduction of dissipated work ($W_{diss}$) in finite-time thermodynamic processes by exploiting collective interactions among multiple bodies. Focusing on an $N$-body system, we demonstrate that collective protocols, where interactions are dynamically introduced during the process, can significantly reduce $W_{diss}$, achieving a sublinear scaling with the system size $N$. Unlike traditional non-interacting protocols, which see a linear increase of $W_{diss}$ with $N$ ($W_{diss} \propto N$), our approach reveals that $W_{diss}$ can scale as $W_{diss} \propto N^x$ with $x < 1$. We establish fundamental limits to this collective advantage, showing that in theory, $x = 0$ is achievable, leading to a dissipation that is independent of $N$, though this requires highly nonlocal interactions.

We apply these findings to realistic models, such as spin systems with two-body interactions, and show that significant reductions in $W_{diss}$ are possible even with realistic control mechanisms. The implications of this are particularly relevant for the finite-time erasure of information, where we demonstrate a faster convergence to Landauer's bound. Our results uncover a novel collective advantage in stochastic and quantum thermodynamics, offering new strategies for optimizing dissipation in many-body systems and providing a pathway for improving the efficiency of thermodynamic tasks in practical settings.

# Kurzmitteilungen - Short Communications

## Pre-announcement: Joint Annual Meeting of ÖPG and SPS 2025

The next annual meeting, will take place at the ***University of Vienna*** in the week of ***18 - 22 August 2025***.

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, it is also planned to include again a historical symposium, this time dedicated to Wolfgang Pauli and Erwin Schrödinger, as well as having a special focus on quantum topics in the main program, thus celebrating the International Year of Quantum Science (IYQ 2025).

The detailed announcement will be published in the next *SPG Mitteilungen*, available in early 2025, as well as on our website.

# Review of the SPS Annual Meeting 2024 in Zürich

The annual meeting of the Swiss Physical Society took place from 9 - 13 September 2024 in the ETA/ETF/ETZ buildings at the Campus Zentrum of ETH Zürich.

This year's conference week included the typical events like the General Assembly, the Award Ceremony, and a conference dinner. However, it also introduced some new elements, such as the inaugural session of the *Energy, Sustainability and Environment* section. This session featured distinguished experts in these fields from institutions as Empa, PSI, CERN and others (see special report on p. 14).

The $70^{\text{th}}$ anniversary of CERN was celebrated in another special event. The introductory talk by Günther Dissertori on the past, present, and future of CERN was followed by a panel discussion addressing key themes related to CERN's legacy, the necessity for a new flagship project, and the broader impacts of its work. A more detailed report of this discussion is on p. 15.

The conference emphasized the role of professors in mentoring young researchers and the importance of fostering collaboration across fields, aligning with the spirit of the SPS. In his opening speech, ETH president Joël Mesot underscored the increasing pressures on securing fundamental research funding and the importance of professor-level participation in such gatherings, which provide valuable learning and networking opportunities for both early-career and seasoned researchers.

The opening was followed by the third edition of the special "Physics Funding in Switzerland" session. The afternoon featured the historical symposium celebrating 100 years of wave-particle duality and honouring Louis de Broglie (see

*The speakers of the "Physics Funding in Switzerland" session: Christoph Falk, Bernd Gotsmann, Stephan Cludius-Brandt and Jennifer McClung.*

below) which was also understood as warm-up meeting for Unesco's IYQ2025 (see p. 3). The first conference day closed with an engaging public lecture by Nobel laureate Anne L'Huillier titled „The route to Attosecond Pulses".

The conference was again very successful, more than 470 participants attended, more than 280 oral and 34 poster presentations have been given. 10 exhibitors showed their latest products.

We thank our partners who have contributed to the program, namely the *Swiss Institute of Particle Physics* (CHIPP), the *Swiss Neutron Science Society* (SGN), the *Swiss Society for Photon Science* (SSPh), the *Swiss Soft Days* and *Life Sciences Switzerland* (LS2).
Special thanks go to the ETH Zürich for their hospitality, the Physics Departement for their support and the local staff for their help during the conference.

In the following, we report as usual on selected topical sessions, present the winners of the Best Poster Awards (p. 21), and print the extended abstracts of those plenary talks which the speakers have kindly provided (p. 22 ff).

---

### De Broglie Symposium

The SPS meanwhile organizes a special symposium at its annual conference to remember persons, or events of epochal importance as the anniversaries of Johannes Kepler,

*The speakers of the de Broglie Symposium: Friedrich-Karl Thielemann, Tilman Esslinger, Philipp Treutlein, Henning Stahlberg.*

Wilhelm Conrad Röntgen or Blaise Pascal in the last years. This year we celebrated the centenary of a publication of the French physicist Louis de Broglie (1892 - 1987), according to which all moving matter can also be described as a wave. This discovery is one of the most remarkable scientific achievements in the famous 20s of the last century, where quantum science was inaugurated [1].

In the first of four lectures Friedrich Thielemann (Uni Basel) presented the person De Broglie and the historic 1920s (see p. 23), followed by two exciting contributions from current basic research by Tilman Esslinger (ETH Zürich) and Philipp Treutlein (Uni Basel). The last talk by Henning Stahlberg (EPFL) described the high performance level of today‘s cryo-EM (p. 25).

The symposium can be regarded as a great success, as more than 180 people of all ages(!) attended and lively questions were asked after the presentations. The positive resonance confirmed that the concept to offer presentations on history, basic research and industrial relevance is very well received.

*Bernhard Braunecker*

### 3rd Women in Physics Career Symposium

The Women in Physics Career Symposium has been successfully held for the third year at the SPS Annual Meeting. Due to its success, a new SPS Commission for Diversity, Equity, and Inclusion has been established. This commission has the goal to address broader issues related to gender balance, diversity, equity, and inclusion.


The WiP Symposium was held on Tuesday, 10 September and aimed to advance the careers of early-career female researchers in physics by establishing a professional and mentoring network. The event featured career talks by speakers from inside and outside academia, addressing different career levels.

The event was sponsored by the University of Zurich, the Paul Scherrer Institute, the University of Geneva, the Swiss Physical Society, and the Swiss Academy of Natural Sciences (SCNAT). It‘s worth noting that mentees selected for the mentoring program associated with the event were reimbursed for the standard conference fee.

The symposium, chaired by Tobias Golling (University of Geneva), opened with an inspiring morning talk by Petra Rudolf (University of Groningen). Her presentation, titled “A PhD is Not Enough ... How to Prepare for a Career in Academia” [2], addressed key strategies for pursuing a successful academic career. Petra Rudolf encouraged PhDs to undertake an academic career as it can be the most exciting and rewarding career and similarly encouraged supervisors to encourage their students. She assured that such a career is compatible with family and life balance and advised on the steps to take after a PhD towards a postdoc, how to select a good mentor and how to learn asking for advice from her/him. She gave suggestions on how to advertise oneself in a CV or online profile, she recommended to take care of getting awards and explained the steps to enter a tenure track with the many records that require commitment.

During lunch, participants and speakers had the opportunity to exchange experiences and ideas. The symposium continued with career talks by Laura Bégon-Lours (ETH Zürich), Anna Fontcuberta i Morral (EPFL), Janine Haase (Sensirion), and Ilaria Zardo (University of Basel), who

1 https://sps.ch/de/events/sps_annual_meeting_2024/de_broglie_symposium

2 https://indico.cern.ch/event/1382917/contributions/6077057/

*The plenary speakers in Zürich: Mikhail Shaposhnikov, Petra Rudolf, Günther Dissertori, Matthias E. Lauer, ...*

shared valuable insights and practical advice. The diverse contributions helped participants understand various career paths. Anna Foncuberta, herself at the threshold of a huge challenge as the President of EPFL, gave an illuminating presentation on how a positive spirit and ignoring the various dumping people that are met across the career helps to go through any difficulty. She told the story of her personal life, from the countryside of her grandfather to where she would not have ever even imagined, with an exploration will that brought her in various corners of the world. The talks are collected here [3].

The ongoing success of the Women in Physics Career Symposium highlights its crucial role in fostering mentorship and career development for female physicists, ensuring that future editions will remain a vital platform for promoting diversity and inclusion in the field.

*Martina D'Arco, Université de Genève*

---

**Theoretical Physics and Gravitational Waves**

As with the past annual meetings, the theory talks were again embedded in their respective topical sessions, which is well appreciated.

In the TASK session there were 5 theory related presentations from a total of almost 60 talks, which covered topics including dark matter and QCD aspects. In Atomic Physics and Quantum Optics 4 out of 14 talks and in the KOND sessions some 9 out of 24 presentations were on theoretical topics, similarly in Biophysics with 4 out of 44. Fewer theoretical talks were given in some of the other sessions, which are in general more experimentally oriented. The number of theory talks, as expected, varied significantly among the various sections, and constitute in general a sizeable fraction (~ 10 % - 30 %) of all contributions.

Following the successful start last year in Basel we organized again a session on gravitational waves. It took place on Wednesday afternoon and comprised 14 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 as last year well attended and much appreciated as also shown by the increased number of talks. Given this very positive development the parallel session on gravitational waves will be now definitively taken into the programm of the future SPS meetings.

*Philippe Jetzer, Universität Zürich*

*Coffee break (top) and some goodies from the apéro buffet.*

3 https://indico.cern.ch/event/1382917/timetable/#20240910

*... Andreas Wallraff, Giacomo Indiveri, Dirk Hegemann, Sven Reiche, ...*

**Startups The role of physics and physicists in developing a product ?**

At this year's annual SPS meeting, the „Physics in Industry“ session was dedicated to startup companies. Physicists and engineers from across Switzerland shared examples of how physics and engineering contributed to the development of new products in fields like Quantum Technology, Artificial Intelligence, and Optics.

Denys Sutter, founder of condenZero, opened the session by discussing the technical evolution of their low-temperature measurement system for transmission electron microscopy. He also emphasized the importance of market research and the challenges of managing finances in a startup environment. Philipp Eib, from UNISERS, offered a didactical perspective on the physics and innovation behind their semiconductor contamination analysis product.

AI accelerators were highlighted by Riduan Khaddam Aijameh, co-founder of Accelera, and Manu Nair, co-founder of Synthara, who each provided unique insights into the market for their cutting-edge technologies. Representatives from Lumiphase, Polariton, and Luxtelligence presented fascinating examples of how the demand for fast, energy-efficient optical modulators is driving innovation and how physics plays a key role in delivering products with superior performance.

From QNAMI, we learned about the use of a quantum-mechanical object to measure magnetic fields and the process of commercializing a product based on this concept. Federico Paratore, co-founder of UnboundPotential, explained the competitive advantage of their flow-battery for short-term energy storage. Finally, Catalin Cris, a patent expert from the Swiss Federal Institute for Intellectual Property, discussed the importance of intellectual property for start-ups and available resources for obtaining help in this critical area.

The session attracted significant interest, especially among young physicists. It was inspiring to hear the speakers' journeys through innovation and entrepreneurship, and to learn about the challenges of transforming ideas into successful products.

*Gian Salis, IBM Rüschlikon*

---

**Biophysics and Soft Matter**

The Biophysics and Soft Matter (BP & SM) contributions at this year's annual SPS meeting comprehended 40 talks in 6 topical sessions and 2 poster presentations. This number is about three times higher than what our Society witnessed in the past. BP & SM presentations at the SPS Annual Meeting 2024 are available on Indico [4].

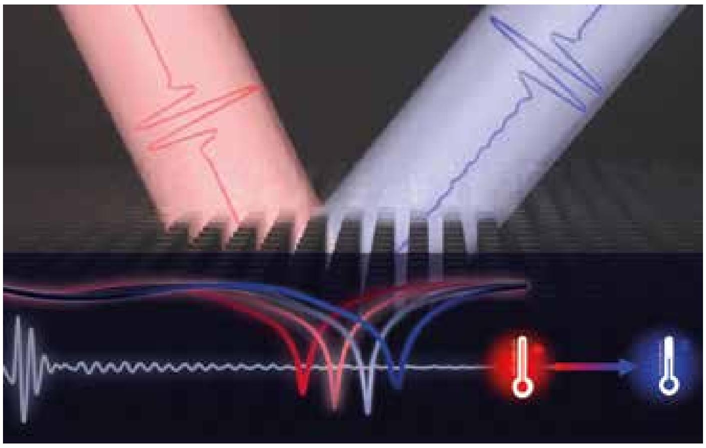
Three BP & SM sessions focused on new concepts and methods, on materials preparations and investigations, and on molecular biophysics in the context of drug discovery. Sessions 4 to 6 dealt with physics of biological systems and the modeling of these systems by physical methods. All sessions witnessed lively discussions of interesting topics presented by different research groups. The new focus of BP & SM topics at SPS was well received by the participants of the conference.

The six topical sessions were flanked by two plenary talks, the first one by Matthias E. Lauer from F. Hoffmann-La Roche described two new methods in drug discovery that were developed in interdisciplinary projects by physicists, engineers and material scientists in Switzerland. The second Plenary by Erik van Nimwegen from the Biozentrum, University of Basel, discussed basic physics in the evolution of bacterial cells in the context of systems biology.

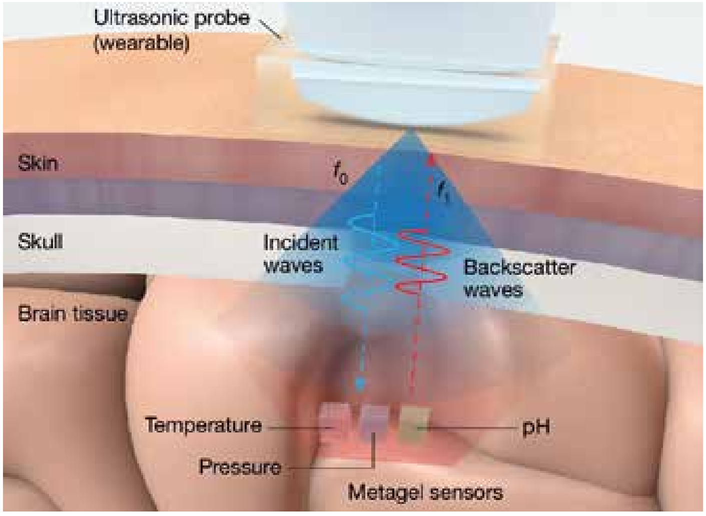
The presented topics showed impressively that the high complexity of biological questions can be significantly reduced by the possibilities provided by physics and engineering in the life sciences. This modern approach in basic research may lead to unexpected insights and novel methods in biology and to new biomedical applications. An example is illustrated by two figures from two recent publications. This contribution at the SPS meeting 'Acoustic metamate-

4 https://indico.cern.ch/event/1382917/sessions/550242/#all

*... Leonardo Senatore, Kirsten Moselund and Erik van Nimwegen. On Friday, Gabriela Hug, ...*



L. Maini et al., Nature Microsystems & Nanoengineering, 10(8), January 2024




H. Tang et al., Nature, 630, 84-90, June 2024

rials for biomedical applications: measuring temperature with ultrasounds' received the SPS Award in Computational Physics. It was presented by Lucrezia Maini from the Micro- and Nanosystems Group in the Department of Mechanical and Process Engineering, ETH Zurich, cf. p. 6.

By providing a link to the Swiss Physics Community, the new format of the Biophysics and Soft Matter session at SPS fosters fruitful exchange of ideas and interaction between researchers in the life sciences in Switzerland, both, in academia and in industry.

*Christof Aegerter, Universität Zürich, Christof Fattinger, retired from F. Hoffmann-La Roche, affiliated with ETH Zürich*

## Accelerator Science and Technology

The session dedicated to Accelerator Science and Technology covered a diverse range of research activities in Switzerland related to particle accelerators. The first four contributions focused on superconducting magnet developments with an opening talk introducing the high field magnet roadmap for particle colliders of the Swiss Accelerator Research and Technology program CHART. Non-insulated superconducting magnets are radiation resistant and can be used for specific applications requiring high but static magnetic fields. A new type of undulator magnet for light sources utilizes bulk blocks of high temperature superconducting (HTS) material, in this way reaching outstanding performance parameters. Using HTS magnets at moderate field strength, the power consumption of a future ring collider can be reduced by 20% compared to a conventional solution.

The session program continued with a beam dynamics study on beam polarization for the electron-positron version of a future circular collider (FCC). Resonant depolarization allows the collider's beam energy to be precisely calibrated, enabling precision particle physics measurements. Developments for PSI's Free Electron Laser facility SwissFEL include new types of electron sources and passive dielectric devices for adjusting the energy distribution of the electron beam. Another study by a student at the Vienna University of Technology involves the development of a special electron source using carbon nanotubes at the cathode. This source will be used for electron cooling of the antiprotons in the ELENA facility at CERN. The session concluded with beam dynamics studies aimed at the high-performance delivery of ions in the CERN complex for the LHC. While currently only uranium ions are accelerated, the range of ions to be accelerated will be expanded to include boron, oxygen, and magnesium.

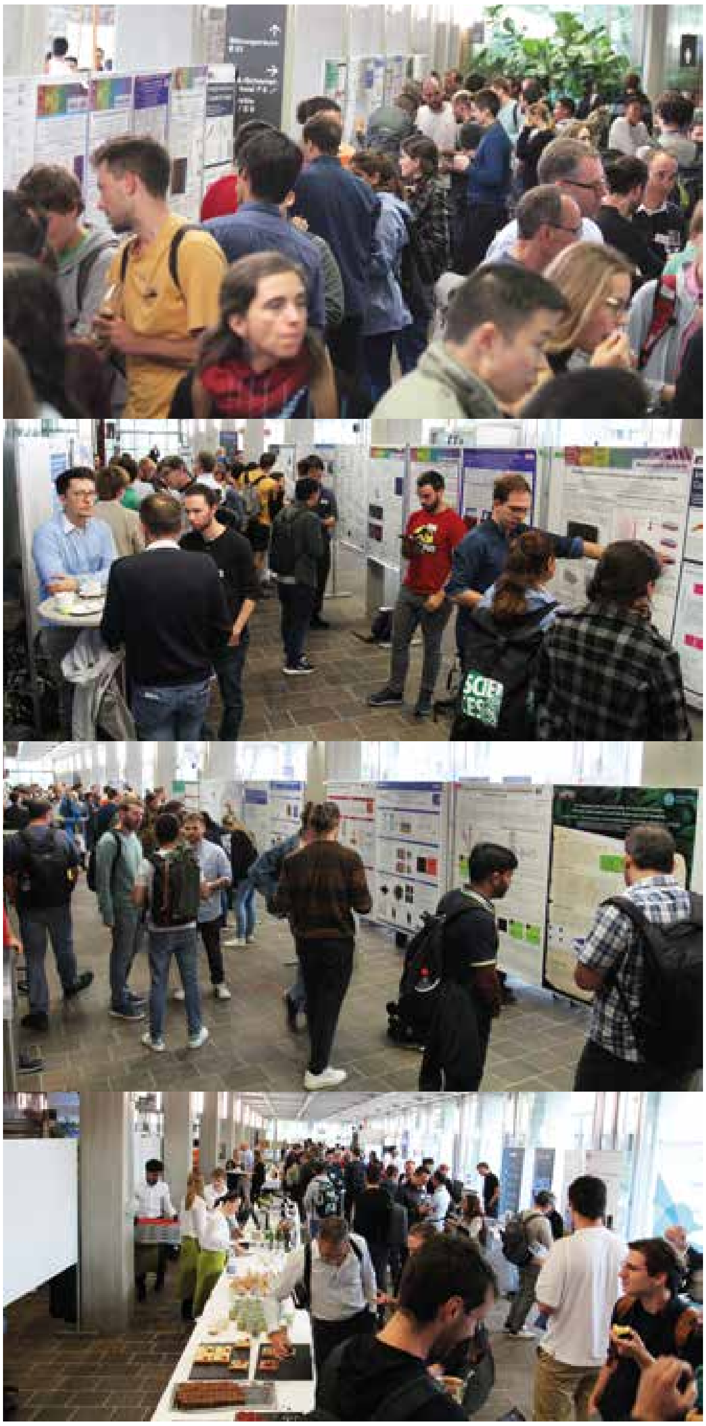
*Mike Seidel, PSI Villigen*

## Applied Physics & Plasma Physics

Six presentations were given at during the applied physics and plasma physics session held on the afternoon of 11 September 2024. Four presentations issued from the realm of magnetic confinement fusion while a fifth was dedicated to laser enhanced wet etching of fused silica and a sixth to affordable, efficient demining techniques using magnetic induction.

*... Lorenz Herrmann, Thomas Justus Schmidt, Sonja Kleiner and Patrick Koppenburg talked in the inaugural session of the Energy, Sustainability and Environment section.*

In tokamak plasmas a very abrupt loss of toroidal current, a disruption, may damage the machine and must be avoided or their effects mitigated. The first two talks of the session addressed disruptions. Edes described the analysis of disruption in the JET tokamak and comparison with the upgraded JOREK code. Wang, again using the JOREK code, described efforts to predict the creation and confinement of very non-thermal electrons during the disruption. Vadot presented novel techniques for modelling the extreme plasma edge in magnetic fusion plasmas and went on to describe efforts to parallelize the code and write the code in a parallel computing optimized language. Devlaminck described efforts to model the propagation of electron cyclotron waves in the presence of plasma turbulence. This effort is important as, in large next generation tokamaks, such wave-turbulent plasma interaction might reduce the efficiency of electron cyclotron heating and current drive schemes.



*The poster session on Tuesday and Wednesday, situated in the coffee break and exhibition area, was a place for lively interaction among the participants.*

Barbato presented work devoted to the laser enhanced wet etching of fused silica. Using extremely high energy density, ultra-short pulses of laser radiation the material properties of fused silica substrate is permanently altered leading to a greatly enhanced wet etching resolution.

Finally, Acreman, presented new, cost effective and highly efficient ways of demining land areas that have been subjected to mining or to artillery bombardment. A magnetic induction technique was described that is efficient for finding both mines and unexploded ordnance.

*Laurie Porte, EPFL*

### Atomic physics and quantum optics session

The session featured fourteen presentations spanning a wide range of topics. The highlights were four invited presentations. Two senior speakers presented the state of the art in theoretical quantum science and experimental atomic and molecular physics: the first one described the use of natural language models and machine learning to predict the properties of quantum many-body systems, while the second showed the progresses and opportunities of high-resolution spectroscopy and atomic clock techniques. The two other invited presentations were given by prize laureates, first again about precision spectroscopy and the second about quantum entanglement in ultra-cold gases.

Overall, the session reflected the most important developments in the field, both from the theory side and from the experimental side. Driven and open quantum systems were an important topic of theoretical investigations, as well as fundamental considerations on quantum mechanics. Experimental presentations showed technological and conceptual progresses towards quantum simulation and quantum computing using ultra-cold atoms and trapped ions.

*Jean-Philippe Brantut, EPFL*

### Physics education and communication: Good practice examples within the Swiss Physics Community

The session took place on 13 September and presented seven contributions covering a wide range of topics that are highly relevant for the current practice and innovation of physics education and communication:

- Integration of contemporary physics in high school physics teaching: General relativity and cosmology (Alice Gasparini, Geneva; see figure on the title page), and astrophysics and computer science (Matthieu Heller and Sebastien Murphy, Geneva).
- Hands-on physics outreach initiatives: Physics in Advent (Gernot Scheerer, Lausanne) and Youth@STEM4SF (Science, Technology, Engineering and Mathematics for Sustainable Future; Barbora Gulejova, Bern & CERN).
- Physics and Sustainability at School and at University


*The conference dinner, accompagnied by an apéro, took place in the Zunfthaus zur Schmiden in the old city of Zürich. About 170 participants enjoyed a wonderful 3-course meal in a historically appealing and cozy ambiente.*

(Peter Kreuzer, Geneva; Tomoko Muranaka, Lausanne).

- Support of young physics talents at School and at University (IYPT (International Young Physicists' Tournament), Samuel Byland, VSMP, Luzern; IPT (International Physicists' Tournament), Mathieu Suter, Zürich).

The presented projects were of excellent quality, offering unique examples of good practice of physics education and communication within the Swiss Physics Community.

Taken together, the session provided an excellent opportunity to share creativity and enthusiasm, and to foster fruitful exchange and interaction between the communities of physics researchers interested in educational matters and physics teachers. The new format of this session thus responds well to a reflection and commitment within the SPS gaining considerable momentum since roughly a decade,

*SPS President Teresa Montaruli during her after-dinner speach, presenting also the new Vice President Michel Calame.*

mirroring similar trends in the American and German Physical Societies, and hopefully still gaining in support and audience in the future

*Andreas Müller, Université de Genève*

---

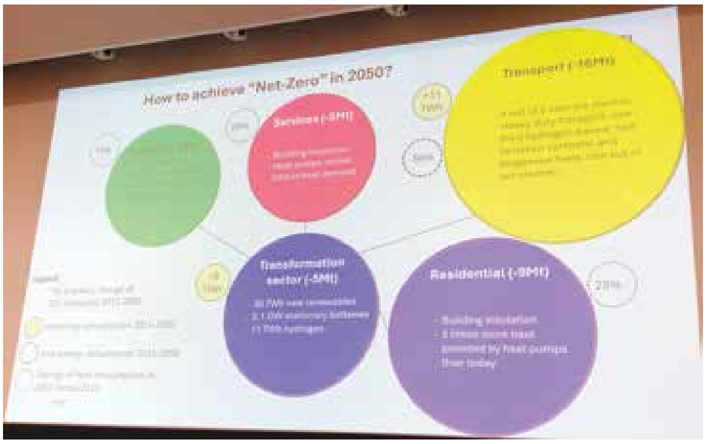
**Inauguration session of the Energy, Sustainability and Environment section: Research needs for sustainable energy transition**

This session started the discussion in the Swiss Physical Society on topics and issues related to energy and sustainability in the context of the energy transition towards carbon free technologies. The first three presentations highlighted needs and efforts in three important Swiss research organizations. Later, two presentations focused on sustainability strategies at both the institutional and individual researcher levels, particularly related to large footprint research in high energy physics. The session concluded with a panel discussion with a large number of questions from the audience and the moderator, and sincere and credible replies from the panelists. It successfully addressed pressing questions for the research community, emphasizing the critical role that researchers and institutions play in the global energy shift. However, it was just the start of an important discussion which will be continued in future SPS events with further players and views.

***The Future of the Electric Energy System: from Rotating Masses to Power Electronics*** – Prof. Gabriela Hug from ETHZ showed us Switzerland's strategic efforts in renewable energy, emphasizing the technological, regulatory, and societal shifts required for carbon neutrality. Here, she explained in detail how future power grids will become increasingly more dynamic. The replacement of traditional synchronous generators with power electronics will lead to a decreased inertia of the system and will consequently require new grid control approaches. Key discussions revolved around how alternative energy technologies, like photovoltaic and wind energy as well as fully automate grid control, are reshaping the future energy landscape. She also addressed urgent research topics and the critical need for innovation to meet the goal by mid-century.

***Materials to Devices: The importance of physics in material science & technology for sustainable energy applications*** – The second talk given by Dr. Lorenz Herrmann emphasized the pivotal role of material science in addressing the urgent need for sustainable energy generation and storage. The „Materials to Devices“ initiative at Empa was highlighted, that it accelerates the transition of basic science into practical devices such as solid-state thin film batteries, high efficiency Copper Indium Gallium Selenide (CIGS) solar cells, and quantum heat engines as thermoelectric generators. Concrete research examples ranging from fundamental research on materials to optimized manufacturing processes have been presented.

***The Swiss Energy Transition to NetZero*** – Achieving net-zero GHG emissions by mid-century requires urgent actions focusing on energy efficiency and storage. Prof. Thomas Justus Schmidt from PSI emphasized that only an integrated and transdisciplinary approach can generate the required impact to reach the NetZero target. This talk illustrated the challenges and opportunities on the path to a sustainable energy future, emphasizing the importance of collaboration across multiple fields. It was shown that the Swiss Energy transition may cost a cup of coffee per day per capita!



*Reduction targets of $CO_2$ emission have been set for each sector toward Net-Zero in 2050 (from Prof. Schmidt's presentation).*

***CERN's Strategy for Environmentally Responsible Research*** - This talk focused on CERN's commitment to combining cutting-edge scientific research with environmental responsibility. Sonja Kleiner highlighted CERN's current efforts to reduce its impact, particularly regarding energy use across its accelerators, experiments, and facilities. She also discussed how CERN is contributing to the development of new technologies that could mitigate the environmental impact of society as a whole.

***A Sustainable Future in High-Energy Physics*** - Dr. Patrick Koppenburg addressed the environmental responsibilities of the HECAP+ communities (High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics). The talk emphasized that the climate crisis demands a re-evaluation of the sustainability of research practices and infrastructure. It explored the challenges and opportunities in reducing the environmental impact of high-energy physics research, especially in the long-term, while maintaining scientific progress. The need for sustainable approaches in data processing, energy usage, and infrastructure management was underscored as vital to ensuring that these fields contribute to a sustainable future.


*The speakers and moderator Hugo Zbinden during the panel discussion closing the session.*

***Panel Discussion***
The session ended with an interactive panel discussion featuring all the speakers and addressing the question "How can physics research in Switzerland contribute to a sustainable energy future?". Due to the high level of engagement from the audience, the discussion extended beyond the planned time. Key themes included the challenges and opportunities of energy transition, row materials and other environmental impacts of energy research, and strategies for integrating sustainability into everyday research practices.

*Tomoko Muranaka, EPFL*

---

**On the future of CERN**

1954-2024
ANS / JAHRE / ANNI CERN

The future of CERN and the importance of the Future Circular Collider (FCC) was the topic of a panel discussion on the occasion of Swiss national celebration of the 70th anniversary of CERN, that took place at the SPS Annual Meeting on 10 September 2024 in the Paul Scherrer Lecture Hall at ETH Zurich.

*The CERN 70 panelists: Günther Dissertori, Fabiola Gianotti, Michael Gerber, Ben Kilminster and Florencia Canelli.*

***Fabiola Gianotti*** (CERN Director General), ***Michael Gerber*** (SERI Ambassador and Director General of International Programs & Organizations and Head of the Swiss Delegation to the CERN Council), ***Günther Dissertori*** (Rector of ETHZ) and ***Ben Kilminster*** (University of Zurich, CHIPP Chair) shared their insights and vision in a conversation lead by ***Florencia Canelli*** (Swiss Scientific Delegate to the CERN Council).

### *CERN's Legacy and Broader Contributions*

CERN has been a pillar of scientific progress, peace, and diplomacy, uniting scientists and nations for over 70 years. Primarily spearheading fundamental research in particle physics, CERN on the other hand also exemplifies "science diplomacy," bringing together a global community of 17'000 physicists and engineers, even from nations with historically strained relationships. As Dissertori highlighted, CERN's governance model, particularly its Council, which fosters collaboration between politicians and scientists from its member states, has been key to executing large-scale, complex, groundbreaking science experiments.

As emphasized in the EC report 2024 by Draghi on "The future of European competitiveness", while European leadership in many fields of science and technology may be limited, particle physics and its associated technologies stand out as areas where Europe excels. Beyond advancing particle physics, CERN drives innovations with broad societal impact. These include the development of the World Wide Web by Tim Berners-Lee in 1989, breakthroughs in superconducting magnets, and medical technologies like positron-emission tomography (PET) and hadrontherapy. These innovations, along with tools simulating radiation interactions with matter, are used in many other fields, highlighting the vast technological ecosystem that has emerged from CERN's fundamental research and collaboration with industry.

### *The Future Circular Collider (FCC)*

The panel emphasized that CERN's future depends on the approval and timely construction of an ambitious flagship project, pushing both the precision and energy frontiers. The Future Circular Collider (FCC) is the preferred option, for which the 2020 European Particle Physics Strategy (EPPS) recommended to do a feasibility study.

CERN's Council may decide on the FCC or another collider at the end of 2027 or beginning of 2028, based on the FCC feasibility study's final conclusions and updated EPPS recommendations. This large-scale project, also called the "scientific mission for the 21$^{st}$ century," is vital for advancing particle physics. The FCC would build on the success of the Large Hadron Collider (LHC), enabling new discoveries. Dissertori described the FCC as a "toolbox" due to its flexibility in operating at different energies, with various particle types, and supporting multiple experimental collaborations. It would include both electron-positron (FCC-ee) and proton-proton (FCC-hh) collisions, offering a diverse program for precision physics and new discoveries at unexplored energy scales. The long lifespan, versatility, and reusability of the FCC's civil engineering and technical infrastructure are key success factors, according to Dissertori. This continuity, also highlighted by Gianotti, has been crucial in the past and will remain so in the future, further enhancing CERN's technical facilities and accelerator complex.

The panel stressed the importance of securing a flagship project. Gianotti stated, "We don't build a big accelerator just for its own sake. We build it because there are strong physics motivations. She highlighted that the success of CERN's current flagship project, the LHC, shows its compelling physics case, attracting 80% of CERN's user community. Additionally, technological advancements at CERN benefit society and the broader scientific community, influencing other major endeavors like nuclear fusion and space exploration.

### *Challenges and the Road Ahead*

Several challenges for the FCC project were discussed, with financial and sustainability concerns at the forefront, particularly regarding energy consumption and costs. Dissertori emphasized the need to address these issues early to gain public support. For several years, CERN has been actively pursuing sustainability, focusing on improving the efficiency of current and future experiments. Gianotti also stressed the importance of environmental aspects, highlighting the ongoing efforts to develop more energy-efficient components like high-efficiency power sources and high-temperature superconducting (HTS) magnets.

Another challenge is retaining and passing on technical expertise and know-how to the next generation of scientists, which the panel deemed crucial for the project's long-term success. A prolonged gap without a major project could lead to the loss of key knowledge and momentum.

### *Crucial role of Switzerland*

Though Switzerland is a smaller country in particle physics, it has an outsized impact, with influence extending to low-energy, neutrino, and astro-particle physics. As one of the CERN host states, Switzerland is committed to pave the way for the long-term development of the organization. This intention is anchored in one of the goals of the Swiss Foreign Policy Strategy 2024-2027. In order to support the future developments of CERN a transfer of legal competence from the cantonal to the national level has taken place for construction approvals of CERN projects with strategic importance. Gerber emphasized that Switzerland is committed to ensure that CERN remains a world-leading particle physics laboratory. A flagship project such as the FCC could contribute to this. Kilminster noted that the "Swiss roadmap for particle physics" highly prioritizes the scientific potential of the FCC and recommends developing a national strategy for participating in it. Swiss institutions, through the CHART program, are leading in developing key technologies, like high-field superconducting magnets, crucial for the FCC's success.

***Conclusion***

This is a pivotal moment in CERN's and Europe's scientific history, as its future as a global leader in particle physics hinges on the timely approval and construction of the FCC. The project is vital not only for scientific exploration but also for attracting the next generation of physicists and maintaining CERN's technological leadership. As Gerber said, "If you want to have a future for CERN, there has to be a next flagship project. We truly believe in CERN, and the last 70 years have shown its immense potential. We believe in the next 70 years, CERN will continue to grow."

The discussion made it clear that while challenges lie ahead, the rewards of advancing fundamental science and its contributions to society far outweigh the obstacles.

*Barbora Bruant-Gulejova, Uni Bern & Uni Zürich, Hans Peter Beck, Uni Bern*

## New SPS Committee Members

*The following persons have been elected at the General Assembly on 9 September 2024.*
*Prof. Dr. Christof Aegerter, formerly chair of the* ***Biophysics and Soft Matter*** *section, has taken over the mandate of the Secretary (see SPG Mitteilungen Nr. 62, p. 6 for his CV).*

***Prof. Dr. Michel Calame (Vice President)***

Michel Calame is head of the Transport at Nanoscale Interfaces Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (Empa) and Adjunct (Titular) Professor for Nanosciences at the Department of Physics, University of Basel in Switzerland. After receiving a PhD in experimental condensed matter physics (high temperature superconductors with Prof. P. Martinoli) from the University of Neuchâtel, Michel Calame was awarded a Swiss National Science Foundation grant to spend a postdoctoral stay at Rockefeller University (New York, USA, with Prof. A. Libchaber) and broaden his expertise in molecular biophysics. He then joined the Physics Department and the Swiss Nanoscience Institute at the University of Basel to work on the electronic transport properties of nanoscale materials (with Prof. C. Schönenberger). In Basel, he became a lecturer and group leader being awarded a Venia Legendi for Physics in 2011 (Privatdozent) and serving as head of the Swiss Nanoscience Institute PhD School from 2013 and 2016. In 2016, he accepted an offer from Empa as lab head (Abteilungsleiter) and established the Transport at Nanoscale Interfaces laboratory (*www.empa.ch/tnilab*), leading an interdisciplinary research team of forty plus members composed of four research group with senior scientists (group leaders and/or Ass. Prof.), postdoctoral researchers and PhD students as well as engineers, technicians and apprentices.
His current research interests are in exploring the fundamental electronic, optoelectronic, and thermal transport processes and mechanical assembly processes taking place in nanoscale, low-dimensional materials and nanostructures, seeking for possible applications in information & quantum technology, energy conversion & storage as well as biochemical sensing & early diagnostics solutions. Michel Calame is also involved as scientific advisor with spin off companies.

***Dr. Sebastian Siol (Treasurer)***

Sebastian Siol is a scientific group leader at Empa – Swiss Federal Laboratories for Materials Science and Technology – and a lecturer at the University of Zurich and ETH Zurich. He received his Bachelor's and Master's degrees in Physics from the Technical University of Darmstadt, specializing in semiconductor physics and modern optics. During his PhD in Materials Science at the same institution, he studied the electronic structure of semiconductor interfaces for photovoltaic applications. After receiving his PhD in 2014, he conducted postdoctoral research at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, focusing on the discovery and development of new metastable semiconductors using high-throughput experiments. In 2017, he joined Empa as a Scientist, primarily working on the development of functional oxides and nanostructured coatings.
Since 2020, he has been leading the Coating Technologies Group in the Laboratory for Surface Science and Coating Technologies. The group uses plasma-based physical vapor deposition to develop functional thin-film materials for various applications, ranging from energy conversion and storage to piezoelectric devices and semiconductor technologies.
Sebastian Siol's research interests include the development of innovative deposition processes, the accelerated devel-

opment and characterization of new functional materials, and the surface and interface analysis of electronic materials and devices.
His main motivation for joining the board of the SPS is to contribute to the society's mission in scientific outreach for the next generation of scientists, as well as the promotion of interdisciplinary collaboration.

***Dr. Daniel G. Mazzone***
***(Section KOND)***

Daniel Mazzone did his Bachelor and Master at ETH Zurich. During his PhD at the Paul Scherrer Institut, Daniel studied the interplay between unconventional superconductivity and magnetism using neutron scattering techniques.
During his Postdoc at Brookhaven national laboratory, Daniel learned complement static and time-resolved resonant elastic and inelastic scattering techniques. His research interests range from unconventional superconductivity, over frustrated magnetism and spin liquid states in transition-metal oxides and rare-earth systems, to spin-orbit coupled quantum phenomena in strongly correlated electron systems. Upon his return to PSI in 2020, Daniel became instrument scientist of the novel neutron spectrometer CAMEA where he lead the commissioning of the instrument. Daniel continues his research on quantum materials and also contributes to neutron instrument projects such as the BIFROST instrument at the European Spallation Source. Daniel is an active member of the Swiss Physical Society, for which he contributed to the organization of the young talents day the last two years.

***Dr. Fabio Avino***
***(Section Applied Physics)***

Fabio Avino obtained his bachelor's and master's degree in Physics from the "La Sapienza" University in Roma, Italy. In 2015, he completed his Ph.D. in Plasma Physics at the Swiss Plasma Center (SPC) of the EPFL, in Lausanne, Switzerland, focusing on the study of plasma turbulence on toroidal magnetized plasmas. Afterwards, Fabio continued his research at the SPC on plasma breakdown mitigation on satellite slip-rings, in collaboration with industry (RUAG space at that time, now Beyond Gravity). In 2017, he joined the Surface, Chemistry, and Coating section at CERN as a Senior Fellow, working on magnetron sputtering for superconducting accelerating cavities in the framework of the Future Circular Collider project R&D. After 3 years, Fabio was called back to the SPC to continue the research on the satellite slip-ring development to increase the technology readiness level of the component in collaboration with Beyond Gravity and develop a first prototype. In 2020, he joined the SPC group of bio plasma applications via cold atmospheric plasmas, where he is currently covering the role of staff scientist.

*"It is a great pleasure and honor to join the board of the SPS in the applied physics section, which will start to include Medical Physics as well. I will contribute at my best to the development of a common network to promote the discussion and collaborations in this interdisciplinary field within the framework of the SPS annual meetings and SPS communications."*

***Prof. Dr. Mike Seidel***
***(Section Applied Physics)***

Mike Seidel, head of PSI Division Large Research Facilities (GFA) is working in the field of particle accelerators since 1989 and received his PhD from the University Hamburg in accelerator physics. As a Postdoc he joined the Stanford Linear Accelerator Center in 1995. In the first part of his career he worked on X-band accelerator structures, the particle physics collider HERA and vacuum systems for accelerators. After several years of engagement at DESY, Hamburg, he joined the Paul Scherrer Institute in 2006 as department head Accelerator Operation and Development with a focus on the cyclotron based High Intensity Proton Accelerator (HIPA) and the therapy facility PROSCAN. From 2020 he assumed the position of the division head Large Research Facilities, became a member of the PSI directorate and was appointed as professor for accelerator physics at EPFL. Within the European programs EUCARD-2, ARIES and the ongoing I.FAST he coordinates work packages on energy efficient accelerator concepts. He chairs the CERN Machine Advisory Committee CMAC.

***Prof. Dr. Rachel Grange***
***(Section Atomic Physics and Quantum Optics)***

Rachel Grange studied physics at EPFL in Lausanne and performed her master thesis related to holographic data storage at the Indian Institute of Technology in Delhi. Then, she moved to ETH Zurich and received her PhD in 2006 on ultrafast laser physics. She worked for the Swiss government in Bern in research policy and at OECD in nanotechnology indicators for two years. She joined back academia and was post-doc at EPFL in nonlinear optics for imaging in complex media. From 2011 to 2014, she was junior group leader at the Friedrich Schiller University in Jena, Germany. In 2015, she joined ETH Zurich as an assistant professor and since 2021, Rachel Grange is an associate professor in the field of integrated optics and nonlinear nanophotonics in the Department of Physics. The goal of her research is to understand and control nonlinear materials at the nanoscale and to design versatile compact photonic de-

vices. Recently, she worked on a miniaturized electro-optic spectrometer, random assemblies of nanocrystals for data processing, and quantum integrated circuits.
Rachel Grange is involved in mentoring, in particular women in academia. By joining SPS Section Atomic Physics and Quantum Optics, she hopes to promote the fundamental role of research in Switzerland‘s academic and industrial future. Through her enthusiasm, she would like to encourage children and young people to take up careers in science and technology.

### *Prof. Dr. Julian Sonner (Section Theoretical Physics)*

Julian Sonner obtained his PhD in theoretical physics at the University of Cambridge under the supervision of Prof. Paul Townsend (FRS) and remained there after graduation, as a Fellow of Trinity College splitting his time between DAMTP in Cambridge and the Theory Group of Imperial College in London. He subsequently spent three years in the other Cambridge, as a postdoc at MIT, before joining the faculty at the University of Geneva, where he is currently full professor of theoretical physics. His research interests range from the theory of (quantum) gravity and holographic duality to many-body quantum chaos, and he is especially interested in where these areas intersect.

### *Prof. Dr. Jerôme Baudry (Section History and Philosophy of Physics)*

Jérôme Baudry heads the Laboratory for the History of Science and Technology at EPFL.
He studied history, mathematics, sociology, and economics in Paris, before receiving a PhD in the history of science in 2015 from Harvard University (under the supervision of historian of physics Peter Galison). After three years of postdoctoral research in the SNSF/ERC project "The Rise of Citizen Science: Rethinking Public Participation in Science" at the University of Geneva, he joined EPFL in 2019 as a tenure-track assistant professor.
His research interests include the history of intellectual property and the links between science and industry, the role of amateurs in the construction of scientific knowledge from the eighteenth century to today, and the place of images and visual thinking in science and technology.
At EPFL, he teaches the history of science and technology and computational history. For a few years, lab members have also taught a course on "Experimental history of science", in which students reconstructed past artifacts and experiments (e.g., Leyden jars, the Foucault pendulum experiment, Fizeau's experiments on the speed of light).
Jérôme's interest in experimental history of science and the role of instruments in scientific practice is linked to his role as curator of the UNIL-EPFL Collection of scientific instruments [1], which has been assembled, preserved and cataloged by SPS member Jean-François Loude. From 2019, these historical instruments (mostly related to experimental physics) have been presented to the larger public through a series of exhibitions and other public engagement events. In 2024, Jérôme has also co-curated the exhibition "À bras-le-corps. Savants et instruments au Collège de France au XIXe siècle" in Paris, together with physicist Jean Dalibard.

*"I am honored to join the SPS and further the dialogue between physicists and historians. I believe that the history (and philosophy) of science has much to contribute to the education of physics students, from the bachelor to the PhD level. History is also a powerful medium for reaching out to the general public and fostering interest in, and understanding of, the physical sciences."*

### *Prof. Dr. Christian Wüthrich (Section History and Philosophy of Physics)*


Christian Wüthrich is Associate Professor of Philosophy at the University of Geneva, after a faculty appointment at the University of California San Diego where he obtained tenure. He holds an MSc in theoretical physics from the University of Bern, an MPhil in history and philosophy of science from the University of Cambridge, an MA in philosophy from the University of Pittsburgh, and a PhD in history and philosophy of science from the University of Pittsburgh. He works primarily in the philosophy of quantum gravity, with interests in the foundations of quantum physics, of general relativity, and of cosmology, as well as in metaphysics, epistemology, and the history of physics.

*"Given the interdisciplinary nature of my research, my main motivation to join the Board of the SPS is to foster an interaction between physics and its philosophical foundation and implications, and to preserve an awareness for its historical development. I am thrilled by the SPS‘s willingness to integrate these aspects of physics into its mission and am looking forward to a fruitful collaboration."*

### *Prof. Dr. Sahand Jamal Rahi (Section Biophysics and Soft Matter)*

Sahand Jamal Rahi is the head of the Laboratory of the Physics of Biological Systems and a Tenure-Track Assistant Professor at EPFL. His laboratory works at the intersection of physics and systems biology / neuroscience. He completed his PhD in theoretical statistical physics at MIT in 2010, and then changed fields and took up an Independent Fellowship

1 https://collection-lhst.epfl.ch/

at The Rockefeller University's Center for Studies in Physics and Biology. There, he began work on network inference and control of self-replication, expanding to experiments. After visiting Harvard University in 2017, he started his laboratory at EPFL in 2018.

### *Dr. Alice Gasparini (Section Education and Outreach)*

Alice Gasparini earned her first PhD in theoretical physics from the University of Geneva (Switzerland) in 2006, specializing in cosmology and gravitational waves. She then completed a postdoctoral fellowship at the University of California, Santa Barbara. In 2008, she began teaching at the secondary level and went on to obtain a MASE in mathematics (2010) and physics (2012) education. In 2021, she received a second PhD in Science Education from the University of Geneva, where she currently works as a scientific collaborator in the same department. Among other initiatives, Alice focuses on enhancing student learning and motivation by incorporating modern physics topics into the school curriculum. She continues to teach mathematics and physics at a high school in the Canton of Geneva and is committed to advancing science and mathematics education, as well as outreach efforts, in secondary schools.
Website: [https://physalice.ch/](https://physalice.ch/)

### *Dr. Stephan Wirths (Section Energy, Sustainability and Environment)*

Stephan Wirths received his PhD in Physics from the RWTH Aachen University, Germany, in 2015. After his PostDoc at the Forschungszentrum Jülich and a guest scientist position at the Paul Scherrer Institute (funded by the SNSF) he joined IBM Research Zurich as Marie-Curie Research Fellow in 2016. He joined the ABB Corporate Research Center in Baden-Dättwil, Switzerland, in 2017 as a scientist working on Silicon Carbide (SiC) chip technology, the next generation of power semiconductors. After the sale of ABB's Power Grids division to Hitachi (ABB Power Grids became Hitachi Energy) he moved to Hitachi Energy Semiconductors in 2020 as a senior R&D engineer, where he was the project leader for Hitachi Energy's SiC power MOSFET technology platform for e-mobility applications. Since 2022 he is the research team manager of the Semiconductor Packaging & Reliability Engineering team at Hitachi Energy Research in Switzerland responsible for the research on power modules supporting the energy transition (e.g. e-mobility and HVDC), SF6-alternatives for gas-insulated switchgears as well as reliability of electrical grid components. He has authored or co-authored more than 100 journal papers and conference proceedings and filed 20 patents.

*The following persons have been elected already at the extraordinary General Assembly on 26 February 2024.*

### *Dr. Tomoko Muranaka (Section Energy, Sustainability and Environment)*

Dr. Tomoko Muranaka is Sustainability Coordinator for Basic Sciences in EPFL. She studied physics at the Tokyo University of Science, then performed her MSc programme on solid state detector for charged particles at HIMAC at the Tokyo Metropolitan University. She obtained French Governmental scholarship to complete her PhD at the Université de Caen Normandie and in a laboratory in Grand Accélérateur National d'Ions Lourds (GANIL), France, for the study of dynamics of fragmentations of tri-atomic molecules such as $CO_2$. After several years of work on surface behaviours under extreme conditions for future accelerator development at CERN, she decided to start her second career. She received the second MSc in environmental sciences with a specialisation in Climate Impact from the University of Geneva, for her master thesis on natural hazard study in Valais. By combining her background as physicist and of climate impact research, she joined EPFL for integrating sustainability in basic sciences research, as well as for promoting research for sustainability issues, since 2023.

### *Dr. Philipp Schmidt-Wellenburg (Commission for Diversity, Equity and Inclusion)*

Philipp Schmidt-Wellenburg is father of three children and senior scientist in the laboratory of particle physics of the Paul Scherrer Institute. He studied physics at the Technical University München and completed his PhD at the Institut Laue-Langevin where he has investigated the production of ultra cold neutrons using superfluid helium under pressure.
After his PhD he was hired on a tenure track position in the ultra cold neutron group of the Paul Scherrer Institute. He was technical coordinator and spokesperson of the search for an electric dipole moment of the neutron, before he was awarded a ERC consolidator grant in 2022 to search for the electric dipole moment of the muon.
Since 2021, he has been a member of PSI's Equal Opportunity Committee, representingthe Center for Neutron and Muon Physics. In 2023 and 2024, he served as the spokesperson and co-spokesperson for the committee. He co-organized the annual Women in Physics Career Symposium and mentoring program and played a key role in establishing the Commission for Diversity, Equity, and Inclusion within the Swiss Physical Society.

# Best Poster Award 2024

The three best posters presented at the SPS Annual Meeting at the ETH Zürich have been honored with the Best Poster Award, each doted with CHF 200.-. A total of 24 posters competed for the award from which the poster jury selected in a two-step evaluation procedure the works of **Timothy Hume, Laura van Schie**, **Tristan Kuttner** and **Alessandra Sabatti.** Since the latter two presented related posters with the same high performance, the jury decided to share one award between them.

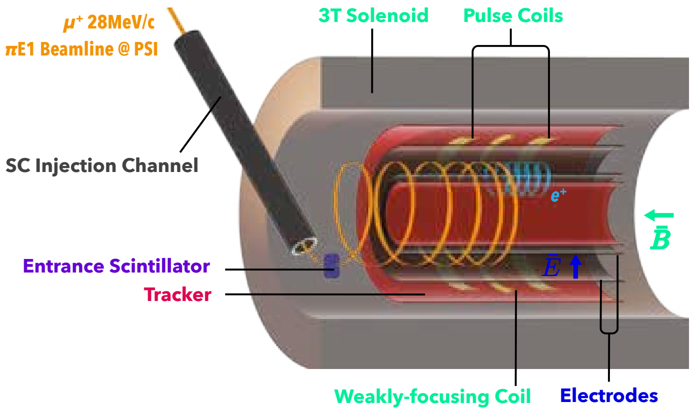
The winners conveyed the essence of their work in a brief 1-slide presentation during the poster award ceremony on Thursday, 12 September. We thank the participants for the high quality of their contributions and express our gratitude to all members of the poster jury for their hard work during the evaluation of the posters. Namely, the jury members were: Christof Aegerter, Lukas Gallmann, Björn Penning and Yves Acremann.

*The winners of the Best Poster Awards 2024: Timothy Hume, Laura van Schie, Alessandra Sabatti, Tristan Kuttner*

## Electric and magnetic field studies towards muon storage in the search for a muon electric dipole moment

*Timothy Hume [1,2], Philipp Schmidt-Wellenburg [1], (on behalf of the muEDM Collaboration); timothy.hume@psi.ch*
*[1] Paul Scherrer Institute, 5232 Villigen PSI, [2] ETH Zürich, 8093 Zürich*

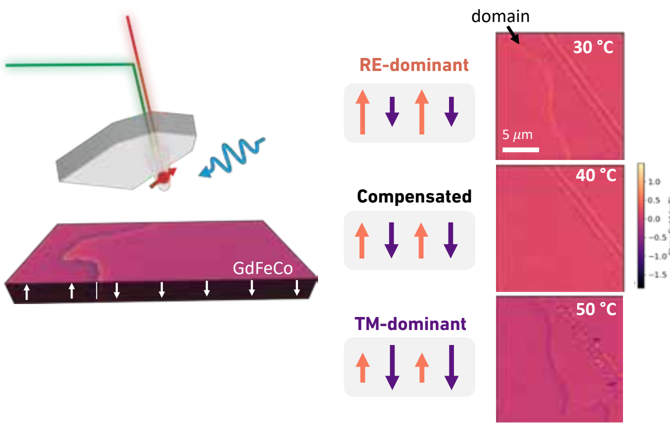
The search for the electric dipole moment (EDM) of the muon at PSI relies on a precise configuration of electric and magnetic fields. Muons will be injected into a 3 T solenoid, trapped on-demand by a pulsed radial magnetic field supplied by a four-quadrant coil array (picture), and stored within a weakly-focusing magnetic field. Sensitivity will be improved by employing the yet-undemonstrated frozen-spin technique, in which a radial electric field will be tuned to cancel the spin precession of the muon induced by its magnetic moment. Simulation studies and prototype characterisation demonstrate the proposed design sufficiently constrains systematic effects. An ultimate sensitivity goal a factor 1000 beyond the current limit will expand our reach towards new physics violating CP symmetry.




## Variation in Domain Wall Properties in Ferrimagnetic Thin Films

*Laura van Schie [1,2], Giacomo Sala [1], Christian Degen [2], Pietro Gambardella [1]*
*[1] Magnetism and Interface Physics, ETH Zürich, [2] Spin Physics, ETH Zürich*

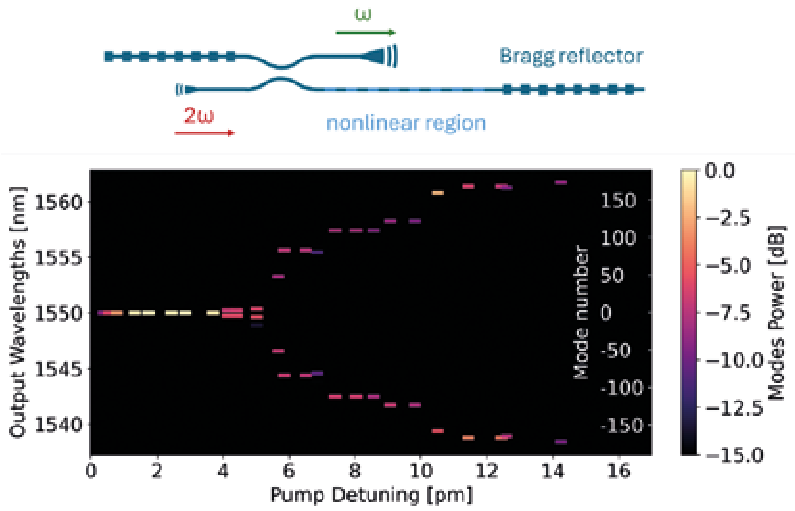
Rare-earth (RE) transition-metal (TM) ferrimagnetic materials are of interest for the development of spintronic devices, as their behaviour can be tuned to resemble either ferromagnetic or antiferromagnetic materials. While it is well established that tuning these material properties near the magnetisation compensation point can result in relativistic domain wall speeds, the effect on domain wall structure in such cases remains unknown. In this study, we use Scanning Nitrogen-Vacancy Magnetometry (SNVM) — a high-resolution and highly sensitive magnetic field imaging technique — to examine these materials over magnetisation compensation via temperature variation. We directly image the switching of the sample's behaviour from RE-dominant to TM-dominant ferromagnetism and reveal an exotic domain wall structure at the compensation point within the antiferromagnetic regime.



### Small footprint integrated optical parametric oscillator with a Fabry-Perot resonator

*Alessandra Sabatti, Jost Kellner, Andreas Maeder and Rachel Grange, Optical Nanomaterial Group, Institute for Quantum Electronics, Department of Physics, ETH Zürich*
asabatti@ethz.ch / www.ong.ethz.ch

Optical parametric oscillators (OPOs) are key components for applications such as squeezing and random number generation. Their dense integration on-chip would allow the realization of computational networks such as Ising machines. However, integrated OPOs to date feature millimeters long nonlinear regions located inside racetrack cavities, resulting in a large footprint. Here we present a thin film lithium niobate on insulator OPO where the nonlinear region is placed in a linear Fabry-Perot cavity formed by two Bragg reflectors, greatly reducing the footprint. The device features a 4 mW threshold power and a 30 nm bandwidth, limited by the mirrors reflection band. By fine tuning the input wavelength it is possible to select the desired output mode pair for signal and idler.



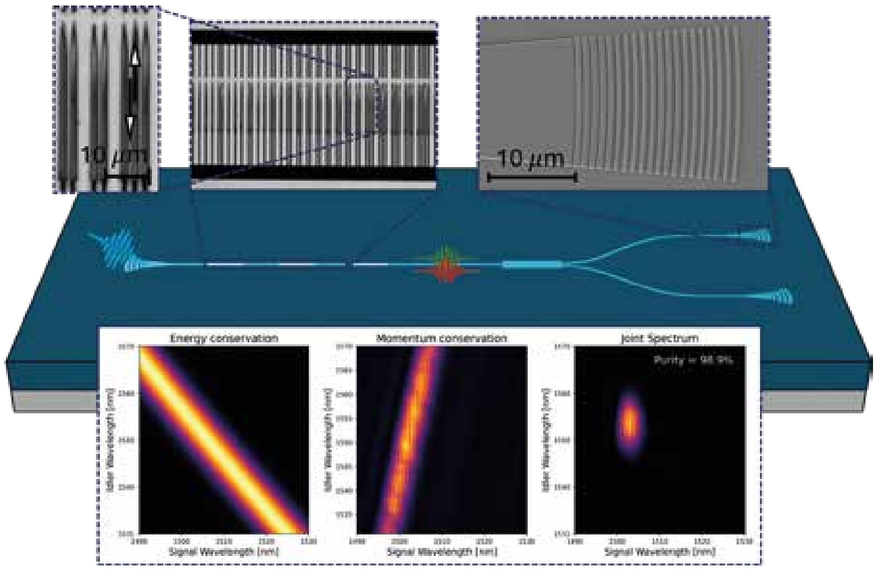

*Device scheme of the integrated OPO with a Fabry-Perot cavity (top) and plot of the OPO output modes as a function of the pump detuning (bottom).*

### Integrated lithium niobate on insulator high purity spontaneous parametric down-conversion source.

*Tristan Kuttner, Jost Kellner, Alessandra Sabatti, Andreas Maeder, Giovanni Finco, Rachel Grange, Robert J. Chapman – ETH Zürich*

Integrated photonics is a promising candidate for quantum information processing applications, there are some essential requirements a material needs to fulfil to be able to provide a fully integrated platform, among those is the ability of creating and interfering single photons.

Given its second-order nonlinearity, lithium niobate on insulator (LNOI) stands out among the contenders in integrated quantum photonics since it enables spontaneous parametric down-conversion (SPDC) as a process of creating pairs of single photons and allows for fast electro-optical tunability of integrated interferometric networks.




We engineer the dispersion relations inside integrated periodically poled LNOI waveguides, thereby tuning the SPDC phase-matching to create pure photons which can be used as a resource for bosonic quantum experiments.

# 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/articles/plenary_talks/).

The topic of Matthias Lauer's talk is covered in our series *Progress in Physics* (p. 40)

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

PT 01/2024

# Matter and Light: Louis de Broglie and our current understanding of physics

*Friedrich-Karl Thielemann, Universität Basel and GSI Helmholtz Center for Heavy Ion Research, Darmstadt*

**Louis de Broglie** 15.8.1892 (Dieppe) – 19.3.1987 (Louveciennes) was stemming from an aristocratic family, going back to Italian nobility from Piemont (with the Name Broglia). They changed the name to de Broglie, several family members became important French statesmen and since 1742 also the oldest son had regularly the title Duc.

Louis was one of four siblings, the others being 4, 17, and 20 years older than him. After the early death of his father in 1906, his much older brother Maurice started to oversee his education and future. Maurice, after a career in the French Marine Corps, studied physics and started his own laboratory. For his experiments related to X-rays and the photo effect he received high recognition in scientific circles. The impact by Maurice led Louis to choose the science branch at the lycée.

The 1911 Solvay Congress in Brussels, under the title «*The Theory of Radiation and Quanta*», had as participants the most prominent physicists of that time. It turned out that Maurice de Broglie had the honor to be secretary of the congress and was in charge of publishing the results and discussions. Louis had the chance to read all that, which turned him to studying Physics, and finishing his (undergraduate) studies with excellent exams before serving for six years in the military due to WW I. As part of his obligations he was stationed on the Eiffel Tower in charge of radio operations / signaling.

The situation around 1920: Light had been understood in terms of waves since Huygen's in 1690 (and Fresnel's extension in 1818), but Planck in 1900 [1] and Einstein in 1905 [2] postulated particle behaviors (light quanta, later called photons). Black body radiation was interpreted as a gas of light quanta with $E = h\nu$ and $p = E/c = h\nu/c = h/\lambda$, where the frequency or wavelength was related to their energy or momentum, confirmed by Compton's experiments in the early 1920s. The Bohr model of the atom (1913) [3] still considered electrons as particles, but with quantized angular momentum.

After WW I de Broglie's followed lectures by Langevin on relativity and quantum physics at the College de France. He also was in constant contact with members of his brother's experimental laboratory, which had reached international recognition. Jointly they published several articles on atomic spectra, the photo effect, and X-rays. This rejuvenated the debate on the nature of light and led to the conclusion that the particle nature of light could not be neglected. As the first after Einstein, de Broglie engaged in discussing the properties of light quanta in two articles in 1922 [4,5]. In 1923 he published three articles which revolutionized physics and secured his scientific reputation [6,7,8]. In 1924 he extended these ideas and published them in his doctoral thesis: *Récherches sur la theorie des quanta* [9]. The PhD committee (Jean Perrin, Charles Mauguin, Langevin) was enthusiastic about the brilliant thoughts of the candidate, but at that point still very skeptical about the idea of matter waves.

The basic idea was to translate the properties of light quanta/photons to particles with mass, combined with Einsteins relation $E = mc^2$. For particles with rest mass $m_0$ the total energy can also be expressed in this way with the relativistic mass $m$. In fact, de Broglie always still thought of photons having a rest mass, and that $c$ would only be the limiting (but never fully attained) velocity. With a relativistic mass $m = h\nu/c^2$ he deduced with $m_0 = m(1 - \beta^2)^{1/2}$ (and $\beta = v/c$) a limiting photon rest mass of $m_0 < 10^{-50}$ g. For particles with rest mass, like electrons, neutrons, protons … he introduced the de Broglie wavelength, according to the relation for photons $p = h/\lambda$, by utilizing the relativistic particle momentum $p$ and $\lambda = h/p$.

With the introduction of the electron wavelength, Bohr's quantization rule for atomic electron orbits $L = nh/2\pi$, i.e. quantized angular momentum, is consistent with $n{\cdot}\lambda = 2\pi r$. Therefore, the rule became easy to understand: a wave propagates along the "orbit of the electron" around the atomic nucleus. Stable orbits are those in which the waves do not get erased by interference effects and their length correspond to $n{\cdot}\lambda$. This led de Broglie to the statement: "*Nous croyons que c'est la première explication physiquement plausible proposée pour ces conditions de stabilité de Bohr -Sommerfeld.*"

For a particle with rest mass $m_0$, applying Einstein's relation, this leads via $h\nu_0 = m_0c^2$ to a frequency $\nu_0$ in the particle rest frame. The particle, however, moves with velocity $v$ with respect to the reference system of an observer. When expressing the frequency in the observer system this leads to $\nu = \nu_0/(1 - \beta^2)^{1/2}$, i.e. the observer sees this as a wave with frequency $\nu$ which propagates in direction of the particle velocity and whose frequency depends on the particle speed. The wave propagates with the phase velocity $v_{ph} = \nu\lambda = (E/h)(h/p) = E/p = mc^2/mv = c^2/v = c/\beta$, which is larger than $c$ for $v < c$. The particle moves with the group velocity $v$ (in other applications first introduced by Hamilton 1839 and Rayleigh 1877). All these discoveries made in 1923 and published finally in his 1924 thesis, led eventually to his Nobel Prize in 1929. They were summarized in a short Nature article [10] (see insert).

Thus, in 1923/24 de Broglie introduced the theory of electron waves, before understood as particles, and proposed (more generally) that particles are wave packets which move with

## Waves and Quanta.

The quantum relation, energy $= h \times$ frequency, leads one to associate a periodical phenomenon with any isolated portion of matter or energy. An observer bound to the portion of matter will associate with it a frequency determined by its internal energy, namely, by its "mass at rest." An observer for whom a portion of matter is in steady motion with velocity $\beta c$, will see this frequency lower in consequence of the Lorentz-Einstein time transformation. I have been able to show (*Comptes rendus*, September 10 and 24, of the Paris Academy of Sciences) that the fixed observer will constantly see the internal periodical phenomenon in phase with a wave the frequency of which $\nu = \frac{m_0 c^2}{h\sqrt{1-\beta^2}}$ is determined by the quantum relation using the whole energy of the moving body—provided it is assumed that the wave spreads with the velocity $c/\beta$. This wave, the velocity of which is greater than $c$, cannot carry energy.

A radiation of frequency $\nu$ has to be considered as divided into atoms of light of very small internal mass ($< 10^{-50}$ gm.) which move with a velocity very nearly equal to $c$ given by $\frac{m_0 c^2}{\sqrt{1-\beta^2}} = h\nu$. The atom of light slides slowly upon the non-material wave the frequency of which is $\nu$ and velocity $c/\beta$, very little higher than $c$.

The "phase wave" has a very great importance in determining the motion of any moving body, and I have been able to show that the stability conditions of the trajectories in Bohr's atom express that the wave is tuned with the length of the closed path.

The path of a luminous atom is no longer straight when this atom crosses a narrow opening; that is, diffraction. It is then *necessary* to give up the inertia principle, and we must suppose that any moving body follows always the ray of its "phase wave"; its path will then bend by passing through a sufficiently small aperture. Dynamics must undergo the same evolution that optics has undergone when undulations took the place of purely geometrical optics. Hypotheses based upon those of the wave theory allowed us to explain interferences and diffraction fringes. By means of these new ideas, it will probably be possible to reconcile also diffusion and dispersion with the discontinuity of light, and to solve almost all the problems brought up by quanta.

Louis de Broglie.

Paris, September 12.

group velocity. Following de Broglie's proposal, leading to the wave-particle duality of electrons, modern quantum mechanics was born when in 1925 Werner Heisenberg, Max Born and Pascal Jordan developed matrix mechanics and Erwin Schrödinger invented wave mechanics as solutions of the Schrödinger equation in 1926. From the wider acceptance at the Fifth Solvay Conference in 1927 to further refinements, and unified formalizations by David Hilbert, Paul Dirac, and John von Neumann until 1930, only a few years would pass.

Einstein and Schrödinger were both very impressed by de Broglie's thesis which motivated Schrödinger to extend the theory of matter waves mathematically towards wave mechanics and the Schrödinger equation (obtaining exactly the same solutions as Heisenberg's matrix mechanics). However, it was non-relativistic and utilized only fields, i.e. the particle nature seemed lost. This inspired de Broglie to think about how phase waves could lead to the transport of energy. In a 1924 article he searched for solving this problem [11] which led him to the statement "*This property allows the material point to be regarded as a singularity of the wave group..... rays envisaged by the wave theories would therefore in all cases be the possible paths of the quantum.*"

He continued with ideas on the "double solution" [12], i.e. that in addition to the regular solution of the Schrödinger equation $\Psi$, there must be a further solution $u$, which has a singularity where the particle is located. Then the Schrödinger wave $\Psi$ would not only have the statistical significance assigned to it by Born, but would also represent all theoretically conceivable paths of the particle, while the solution $u$ would represent the individual motion of a particle. De Broglie postulated that both waves had to be in phase and that the singularity propagates in the direction in which the phase grows fastest. He called this relationship the "law of guidance" and presented these ideas at the 1927 Solvay Conference (being mostly centered around the "Copenhagen School" of Heisenberg and Bohr) without finding much approval. Pauli made a comment: "*I read your article in the Journal de France, it is very interesting, but wrong*" (not explaining properly inelastic scattering). These experiences stopped de Broglie's research for several years.

While de Broglie remained with a high scientific recognition in France and related posts in academic life, he was not extremely active in scientific research until he read a publication by David Bohm [13], in which he found again his idea of the "Law of Guidance" or the "pilot wave theory". This theory, also known as Bohmian mechanics, was the first known example of a hidden-variable theory [1]. This encouraged him to restart his early ideas [14,15]. Its more modern version, the de Broglie–Bohm theory, interprets quantum mechanics as a deterministic theory, and avoids issues such as wave–particle duality, instantaneous wave function collapse, and the paradox of Schrödinger's cat by being inherently nonlocal (also explaining inelastic scattering in its many-particle extension). This turning away from the Copenhagen School led him, however, to some extent into scientific isolation.

[1] Entropie und Temperatur strahlender Wärme, Verh. Deutsch. Phys. Ges. 2, 237 (1900)
[2] Ueber einen die Erzeugunq und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt, Annalen der Physik 17, 132 (1905)
[3] On the Constitution of Atoms and Molecules, Philosophical Magazine 26, 1 (1913)
[4] Rayonnement noir et quanta de lumière, Journal de Physique VI, 3, 422 (1922)
[5] Sur les interférence et la théorie des quanta de lumière, Comptes Rendus 175, 811 (1922)
[6] Onde et Quanta, Comptes Rendus 177, 507 (1923)
[7] Quanta de lumière, diffraction et interférences, Comptes Rendus 177, 548 (1923)
[8] Les quanta, la thèorie cinètique des gaz et le principe de Fermat, Comptes Rendus 177, 630 (1923)
[9] Récherches sur la theorie des quanta, Annales de Physique X, 3, 22 (1925)
[10] Waves and Quanta, Nature 112, 540 (1923)
[11] Sur la dynamique du quantum de lumière et les interférences, Comptes Rendus 179, 1039 (1924)
[12] Sur le parallélisme entre la dynamique du point matériel et l'optique géometrique, J. de Physique VI, 7,1 (1926)
[13] Quantum Theory, Prentice Hall (1951)
[14] Sur la possibilité d'une interpretation causale et objective de la méchanique ondulatoire, Comptes Rendus 234, 265 (1952)
[15] The reinterpretation of wave mechanics, Foundations of Physics 1, 5 (1970)

1 "A hidden-variable theory is a deterministic physical model which seeks to explain the probabilistic nature of quantum mechanics by introducing additional (possibly inaccessible) variables." [from Wikipedia].

# Single electron imaging vs. coherent electron beam diffraction: Optimization of image contrast in cryo-EM

PT 02/2024

*Henning Stahlberg, Laboratory of Biological Electron Microscopy, Institute of Physics, School of Basic Sciences, EPFL, and Department of Fundamental Microbiology, Faculty of Biology and Medicine, UNIL, Rt. de la Sorge, 1015 Lausanne*

Cryo-transmission electron microscopy (cryo-EM) of frozen hydrated specimens is an efficient method for the structural analysis of purified biological molecules [1]. In cryo-EM, thin preparations of free-standing 100 nm thin layers of vitrified sample solution are imaged at liquid nitrogen temperature with the electron microscope to record projection images of the samples. These images have a very low signal-to-noise ratio (SNR), so that only protein particles larger than a certain size, typically > 50 kDa weight, can be localized in the foggy images. If imaged particles are sufficiently large and homogeneous in their shape and conformation, then computer image processing can be used to combine the image signal from hundreds of thousands of "single particles" into a three-dimensional (3D) reconstruction. With suitable protein preparations, this method can reveal the 3D structure of the protein at resolutions reaching 1.1 Å, so that the positions of almost all atoms in the protein can be determined in 3D [2]. This method does not require any prior sample-altering preparation, such as crystallization or fixation or labeling. It reports the structure of the proteins in (vitrified) water, therefore under near-native conditions. Cryo-EM was recognized by the Nobel prize in Chemistry in 2017 [3], awarded to Henderson, Frank and Dubochet. Jacques Dubochet is from Switzerland, his team had developed the freezing method that enabled the vitrification of biological specimens [1].

Cryo-electron tomography (cryo-ET) is an extension of cryo-EM. In cryo-ET, specific locations in frozen hydrated sections of biological tissue are imaged by cryo-EM, while tilting the sample to different tilt angles. Computer image processing later allows the reconstruction of the 3D structure of that tissue section at nanometer resolution. For this method to work, the tissue section must be thinner than a few hundred nm. Preparation of such thin "lamellae" of biological tissue is a very difficult task, which is currently being optimized in several laboratories [4]. A reconstructed 3D structure of a section from high-pressure frozen tissue can reveal the cellular structure at high resolution in its near-native state [5]. And if many identical particles of sufficient size are present in that tissue section, then cryo-ET combined with sub-volume averaging in a few ideal cases has already allowed the reconstruction of the high-resolution structure of those particles at amino-acid resolving resolution [6]. This method thereby revealed the atomic structure of those proteins directly within the cellular context.

Both methods, cryo-EM and cryo-ET, are limited by their very low SNR. Only the larger protein particles can be analyzed with these methods at highest resolution. The low SNR of conventional cryo-electron microscopy stems primarily from the sensitivity of the samples to the electron beam, forcing the operator to use only a very low number of electrons for imaging. The SNR is further limited by the image formation mechanisms in the electron microscope.

Progress in improving the SNR in cryo-EM is desperately needed. Intensive research is ongoing in several laboratories to find ways to optimize the thin samples, including attempts to reduce the primary electron beam damage onto the sample, or to boost the recovery of phase contrast signal from electrons that have interacted with the fragile sample. The primary beam damage can be reduced, if a suitable acceleration voltage for the electron beam is chosen [7].

An alternative strategy to reduce beam damage appears to be the stroboscopic imaging with single, isolated electrons that meet the sample at precise time points in at nanosecond periodicity. Such single electrons might cause less damage than an equally intensive stream of electrons that arrive at random time points. If an electron traverses the frozen specimen, it can interact with the specimen in various ways, including elastic or inelastic scattering. Electron scattering in the sample among many other effects can cause phonons in the samples, which have lifetimes significantly shorter than nanoseconds. It is not clear, what happens if more than one electron from the electron beam reaches the sample within that short time span. When considering de Broglie's wave nature of the electron beam, the continuous wave of a random-in-time arriving electron of a low energy spread and therefore longer coherence length might be different from that of one single electron. Stroboscopic single-electron illumination at nanosecond repetition rate might therefore have a less damaging effect on the sample than a random-in-time electron illumination, because each arriving electron would never encounter the specimen still in a phonon-excited state from the previous electron. Beam-damage reduction on materials sciences samples from such electron illumination has been reported [8–10]. We have implemented a 300 kV Titan Krios Transmission Electron Microscope that is equipped with a DrX.works RF cavity (Figure 1). This allows to send

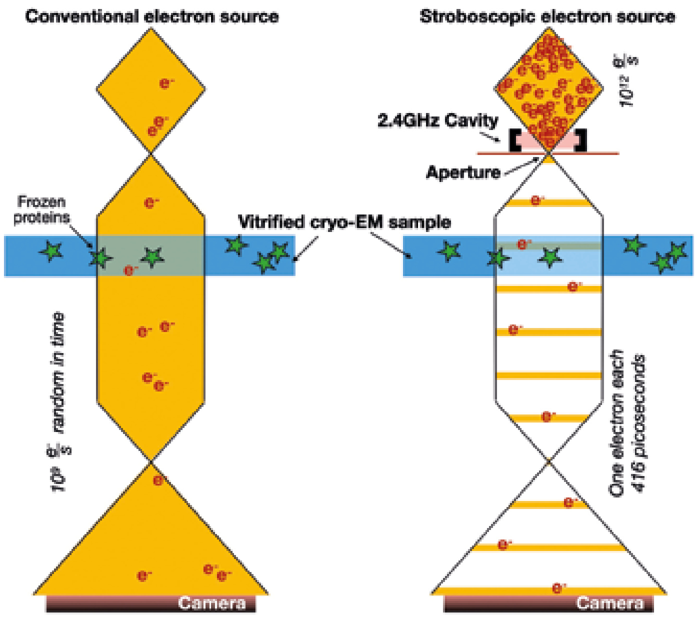



*Figure 1: Random-in-time electron illumination vs. single electron illumination. Left: The simplified electron beam path in a conventional electron microscope employs electrons that reach the sample at unknown time points during the recording of the image. Right: A stroboscopic electron source can be realized with an RF cavity in the beam to chop the beam into precisely times pulses, each containing maximally one electron.*

single electrons at 75 MHz repetition rate onto the sample. Preliminary experiments using electron diffraction on Paraffin 2D crystals suggest a 40% reduction in beam damage of single electrons vs. conventional random-in-time electron illumination, when all other imaging parameters such as dose rate, exposure time, acceleration voltage, diameter of the exposed specimen area, specimen temperature, and electron recording method remain the same. A clear explanation for this phenomena is still lacking.

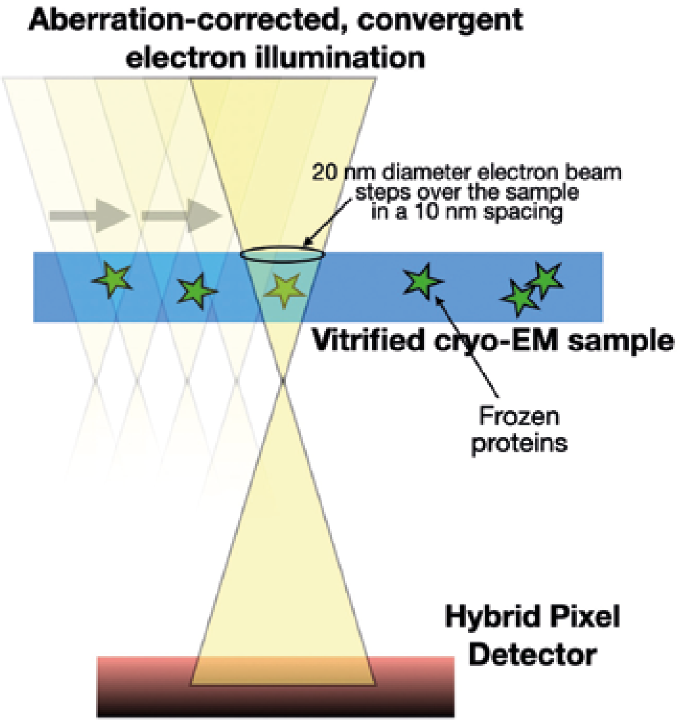



*Figure 2: 4D-STEM data collection scheme: The focused electron beam steps over the sample in a 2D raster, while for each electron beam (probe) position, a 2D detector records the electron diffraction pattern.*

Progress in improving the SNR in cryo-EM is also expected from optimizing the contrast transfer function (CTF) of the method. The CTF of the electron microscope describes how structural contrast in the sample is transferred into the recorded image. Cryo-EM conventionally offers a CTF that has only weak contrast for low-resolution features of the sample, making smaller particles invisible. This forces the microscope operator to choose between settings that either optimize image contrast or image resolution, but not both. An alternative approach is found in diffractive imaging [11]: When not recording (real-space) images with the electron microscope, but recording (reciprocal space) electron diffraction data, a very different CTF behavior of the method is appearing. Convergent beam electron diffraction, scanning the narrowly focused electron beam in a 2D raster over the cryo-EM sample, while recording for each beam position the 2D electron diffraction pattern (Figure 2), is a method that is also called “4D-STEM”. Such 4D-STEM data can be evaluated with computer algorithms to reconstruct the 2D projection image of the sample, or in some applications even the 3D structure of the sample from a single scan. Employed algorithms include iterative hybrid-input-output algorithms, ptychography algorithms, or direct tilt-corrected bright field / parallax reconstructions [12–15]. Each of these varies in its behavior with respect to CTF, SNR, dose efficiency, and capability of reaching high resolution. For dose-tolerant specimens, 4D-STEM at very high electron doses with electron ptychography analysis has by far surpassed the achievements of conventional transmission electron microscopy [12]. For frozen hydrated life sciences specimens, 4D-STEM is still in its infancy [2,13]. Nevertheless, Feynman’s famous phrase again applies to the currently ongoing revolution in electron microscopy: “There is plenty of room at the bottom” to boost image contrast and resolution in electron microscopy of life sciences specimens. These novel technologies, which still need to be transferred to cryo-EM and cryo-ET, are promising and exciting. Biology, medical research, and pharmaceutical applications stand ready to benefit from it.

### References:

[1] Dubochet J, Adrian M, Chang JJ, Homo JC, Lepault J, McDowall AW, Schultz P: Cryo-electron microscopy of vitrified specimens. *Q Rev Biophys* 1988, 21:129–228.
[2] Küçükoğlu B, Mohammed I, Guerrero-Ferreira RC, Ribet SM, Varnavides G, Leidl ML, Lau K, Nazarov S, Myasnikov A, Kube M, et al.: Low-dose cryo-electron ptychography of proteins at sub-nanometer resolution. *Nat Commun* 2024, 15:8062.
[3] Cressey D, Callaway E: Cryo-electron microscopy wins chemistry Nobel. *Nature* 2017, 550:167–167.
[4] Schaffer M, Pfeffer S, Mahamid J, Kleindiek S, Laugks T, Albert S, Engel BD, Rummel A, Smith AJ, Baumeister W, et al.: A cryo-FIB lift-out technique enables molecular-resolution cryo-ET within native Caenorhabditis elegans tissue. *Nat Methods* 2019, 16:757–762.
[5] McCafferty CL, Klumpe S, Amaro RE, Kukulski W, Collinson L, Engel BD: Integrating cellular electron microscopy with multimodal data to explore biology across space and time. *Cell* 2024, 187:563–584.
[6] Tegunov D, Xue L, Dienemann C, Cramer P, Mahamid J: Multi-particle cryo-EM refinement with M visualizes ribosome-antibiotic complex at 3.5 Å in cells. *Nat Methods* 2021, 18:186–193.
[7] Peet MJ, Henderson R, Russo CJ: The energy dependence of contrast and damage in electron cryomicroscopy of biological molecules. *Ultramicroscopy* 2019, 203:125–131.
[8] Choe H, Ponomarev I, Montgomery E, Lau JW, Zhu Y, Zhao Y, Liu A, Kanareykin A, Jing C: Mitigation of radiation damage in macromolecules via tunable ultrafast stroboscopic TEM. *bioRxiv* 2020.05.15.099036, 2020, doi:10.1101/2020.05.15.099036.
[9] Kisielowski C, Specht P, Freitag B, Kieft ER, Verhoeven W, van Rens JFM, Mutsaers P, Luiten J, Rozeveld S, Kang J, et al.: Discovering hidden material properties of $MgCl_2$ at atomic resolution with structured temporal electron illumination of picosecond time resolution. *Adv Funct Mater* 2019, 29:1–7.
[10] Van den Bussche EJ, Flannigan DJ: Reducing radiation damage in soft matter with femtosecond-timed single-electron packets. *Nano Lett* 2019, 19:6687–6694.
[11] Gemmi M, Mugnaioli E, Gorelik TE, Kolb U, Palatinus L, Boullay P, Hovmöller S, Abrahams JP: 3D electron diffraction: The nanocrystallography revolution. *ACS Cent Sci* 2019, 5:1315–1329.
[12] Chen Z, Jiang Y, Shao Y-T, Holtz ME, Odstrčil M, Guizar-Sicairos M, Hanke I, Ganschow S, Schlom DG, Muller DA: Electron ptychography achieves atomic-resolution limits set by lattice vibrations. *Science* 2021, 372:826–831.
[13] Zhou L, Song J, Kim JS, Pei X, Huang C, Boyce M, Mendonça L, Clare D, Siebert A, Allen CS, et al.: Low-dose phase retrieval of biological specimens using cryo-electron ptychography. *Nat Commun* 2020, 11:2773.
[14] Varnavides G, Ribet SM, Zeltmann SE, Yu Y, Savitzky BH, Dravid VP, Scott MC, Ophus C: Iterative phase retrieval algorithms for scanning transmission electron microscopy. arXiv:2309.05250, 2023, doi:10.48550/arXiv.2309.05250.
[15] Yu Y, Spoth K, Muller D, Kourkoutis L: Dose-efficient tcBF-STEM imaging with real-space information beyond the scan sampling limit. *Microsc Microanal* 2021, 27:758–760.

PT 03/2024

# Physics of the early universe and the intensity frontier of particle physics

*Mikhail Shaposhnikov, Institute of Physics, EPFL, CH-1015 Lausanne, mikhail.shaposhnikov@epfl.ch*

Particle physics investigates small distances $l \lesssim$ Fermi ~ $10^{-13}$ cm whereas cosmology considers large distances: $l \gtrsim$ parsec ~ $10^{18}$ cm. Both domains of physics overlap and strongly influence each other in the early Universe when it was hot and dense, and the interactions between elementary particles were decisive.

What kind of particle physics should be used to study the Early Universe? A natural candidate is the Standard Model (SM) of particle physics. It was invented in 1967 and completed with the discovery of the Higgs boson at the LHC 45 years later, in 2012.

SM describes strong, weak and electromagnetic interactions of all known elementary particles. It is a self-consistent theory that describes physics at tiny and enormous energies, possibly running up to the Planck scale $10^{19}$ GeV. The SM is consistent with *almost all* experiments in particle physics.

However, it is not the final story. The SM does not describe neutrino masses and oscillations, the Dark Matter (DM), and cannot explain why we have more baryons than antibaryons in the Universe. Thus, new physics is required. In addition, several theoretical challenges, such as the flavour and generation structure of the theory and its unification with gravity, remain open problems. Unfortunately, neither theory nor observations can give a solid prediction of the energy scale of new physics and thus point out where to search for it.

The search for new physics can be naturally divided into three frontiers. The *high-energy frontier* is associated with heavy new particles with relatively strong coupling to the SM fields. Experiments with higher and higher energies should be conducted to pursue this goal. The same type of particles can be searched indirectly at the *precision frontier*, experiments looking at deviations from the SM in rare processes, where these heavy hypothetic particles can enter the loop diagrams. Finally, the *intensity frontier* experiments are searching for relatively light feebly interacting particles (FIPs). FIPs cannot be found either in the energy or in precision frontier experiments. In the present situation, all directions should be explored.

A lot of research was guided up to now by the so-called “naturalness” paradigm, predicting relatively strongly interacting new particles with masses right above the Fermi scale. The considered theories include low-energy supersymmetry, large extra dimensions, or composite Higgs bosons. So far, no new particles predicted by these theories have been found at the intensity and precision frontier type experiments, challenging this concept.

A possible strategy is to solve the experimental problems of the SM by minimal means without introducing new interactions and having a minimal number of new elementary particles. This can be achieved by the extension of the SM in the neutrino sector. In the SM, the neutrino states differ from the other quarks and leptons - they come only in left-handed chirality states. This ensures that they are massless and that the lepton flavours are conserved - a fact that was taken for granted at the time the SM was conceived. Adding the right-handed neutrino components (see

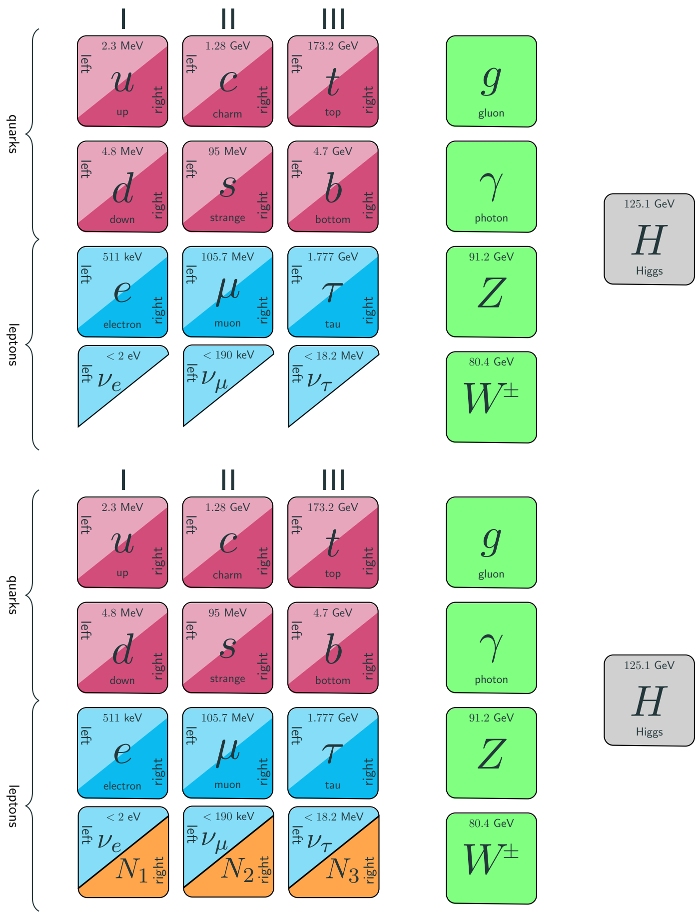



*Figure 1: Particle content of the SM (top) and its extension in the neutrino sector (bottom). The upper left (lower right) corners of the fermion boxes correspond to the left-handed (right-handed) states.*

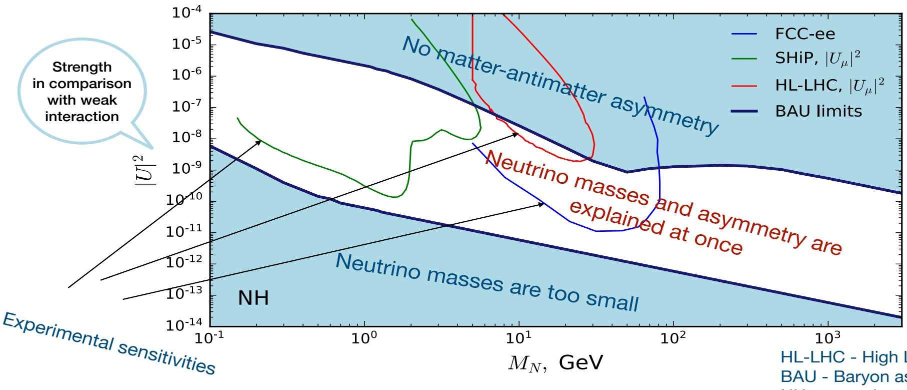
Fig. 1), called “Heavy Neutrino Leptons” or HNLs for short, leads to a “Neutrino Minimal SM”, or $\nu$MSM, which is capable of solving the problem of neutrino masses and oscillations, Dark Matter and baryon asymmetry of the Universe simultaneously (Asaka and MS, *Phys. Lett. B* **620** (2005) 17). One extra neutrino state would solve the solar neutrino puzzle; two would explain atmospheric neutrino oscillations and all experiments in neutrino physics together with the baryon asymmetry of the Universe, whereas the third leads to a natural DM candidate.

The model can be tested experimentally in new experiments at the *intensity frontier* of particle physics, such as SHiP [1] at CERN, for HNL masses below 5 GeV, or at future accelerators FCC-ee (Future Circular Collider at CERN [2]) or CEPC (Circular Electron Positron Collider in China [3]) running at the Z-pole for heavier HNLs, see Fig. 2. The same experiments may search for all types of FIPs, such as hidden photons, dark scalars, axion-like particles, etc. The searches of FIPs are also a part of experimental programs of the plethora of other running or planned experiments (NA62, Darklight, Belle II, CMS, T2K, Dune, Atlas, NA64, Mathusla, Faser, etc). The sterile neutrino DM candidate can be searched in

1 https://ship.web.cern.ch

2 https://fcc.web.cern.ch

3 http://cepc.ihep.ac.cn




HL-LHC - High Luminosity Large Hadron Collider
BAU - Baryon asymmetry of the Universe
NH - normal neutrino hierarchy

*Figure 2: The observed value of BAU can be reproduced if the mass and mixing angle between HNLs and active neutrinos is between the dark blue curves. Experimental sensitivities of future experiments are also shown. Taken from Klarić et al., Phys. Rev. Lett.* ***127*** *(2021) 111802.*

X-ray telescopes such as XRISM [4] or Athena [5].

This extension of the SM has an exciting connection with neutrino physics, unifying together the HNL properties with neutrinoless double beta decays, CP-violation in neutrino oscillations, and the type of neutrino mass ordering.

In the SHiP experiment, the high-intensity proton beam (with CERN SPS energy of 400 GeV) hits the target and produces strange, charmed or beauty mesons. These mesons decay mainly into the SM channels but sometimes produce FIPs, HNLs in particular. An example of the process is the decay of charmed D-meson as $D \rightarrow \mu N$. Subsequently, the decay of FIPs into SM particles, such as $N \rightarrow \mu^{\pm}\pi^{\mp}$ can be registered in a detector. The sensitivity of the SHiP detector (in terms of the number of exotic HNL events) will be ~ $10^4$ times better than in the previous experiments, opening a huge domain of unexplored parameter space. Heavier HNLs can be searched in $e^+e^-$ collisions with energy tuned to $Z$-boson resonance in the sequence of reactions $e^+e^- \rightarrow Z \rightarrow \nu N$, $N \rightarrow \mu^{\pm}\pi^{\mp}$.

In conclusion, feebly interacting particles (HNLs in particular) can be a key to the phenomena which the Standard Model of particle physics cannot explain: neutrino masses and oscillations, baryon asymmetry of the Universe, and dark matter. Hopefully, we will be soon at an exciting point in history: the future experiments at the intensity frontier such as SHiP and FCC-ee in the $Z$-resonance mode have chances to uncover the origin of neutrino masses and baryon asymmetry of the Universe, while X-ray telescopes - the origin of DM in the Universe.

4 https://www.xrism.jaxa.jp/en/
5 https://www.cosmos.esa.int/web/athena

# Attosecond Pulses from X-ray Free-electron Lasers: Status and Outlook

**PT 04/2024**

*Sven Reiche, Paul Scherrer Institut*

In Free-electron Lasers (FELs), a relativistic electron beam is injected into the periodic magnetic field of an undulator. This induces transverse velocity components in the electrons‘ motion, causing them to oscillate. This oscillatory motion allows the electrons to couple with the transverse components of a co-propagating radiation field. During one undulator period, the radiation field slips ahead of the electron beam by one wavelength. Notably, after half a period, the radiation field has slipped by 180 degrees, but the electrons' transverse velocity has reversed. As a result, the energy exchange between the electrons and the field is maintained, accumulating resonantly over multiple periods. The change in energy depends primarily on the initial phase relationship between the electron and the radiation field at the undulator entrance.

With sufficiently high radiation power and a high-quality electron beam (low energy spread), the sinusoidal energy modulation shifts the electrons longitudinally, where higher-energy electrons move forward while lower-energy ones fall back. This leads to the formation of a micro-bunching structure in the current profile, which emits coherently, amplifying the radiation field. This enhances the feedback loop between energy modulation, micro-bunching formation, and coherent emission, resulting in exponential growth in the FEL process. At saturation, the beam is strongly bunched, producing coherent emission.

During this process, the radiation field can only slip by one wavelength per undulator period, limiting the interaction length. In the X-ray regime, this leads to the formation of a single radiation spike, typically lasting a few hundred attoseconds. However, in normal operation, multiple independently formed spikes can occur throughout the electron bunch, typically 20-100 fs in duration. If the electron beam can be manipulated to support lasing in only a short subsection, a single X-ray spike can be generate with attosecond pulse duration.

The most straightforward method to achieve this is through non-linear compression, where a single current spike of a few kA is produced, followed by a low-current trailing tail that does not support lasing [1]. This method is robust against machine jitter, in contrast to low-charge operation and full-linear compression. Other methods include manipulating the electron bunch by emittance spoiler foils [2] or inducing a notch in the induced energy spread in the so-called laser heater [3]. More efficient methods, especially for high-repetition FELs, rely on self-modulation schemes. One approach leverages naturally occurring current spikes at the head or tail of the bunch. The spike emits coherently in the IR or visible region, modulating the electron energy, which is then compressed into a local current spike [4]. Alternatively, a strong undulator taper can compensate for the changing beam energy during the radiation slippage, allowing the FEL process to occur only at locations with strong local energy chirp [5].

Self-modulation can also be achieved by manipulating the electron beam during its generation, where space charge forces induce similar energy modulation [6]. If this modulation is driven by an external laser [7,8] instead of self-modulation, the resulting attosecond pulse can be locked to the laser's timing, reducing the timing jitter caused by electron bunch arrival fluctuations.

All of the methods mentioned so far result in pulse durations dictated by the FEL process, selecting a single spike rather than altering the spike duration itself. The pulse duration is weakly dependent on beam parameters, requiring an eightfold increase in current to reduce pulse duration by a factor of two. Alternative approaches, such as strong superradiance, aim to achieve shorter pulses by exploiting power levels above FEL saturation [9]. However, this process is rather inefficient, requiring very long undulators, and it can be challenging to initiate the process.

Other short-pulse techniques can be realized using a pseudo-oscillator configuration, where the electron beam is delayed after passing through a short undulator section. This produces a train of attosecond pulses, analogous to laser oscillator modes, with pulse duration now determined by the low number of undulator period rather than the FEL process [10]. Combining this with current or energy modulation can further confine lasing to specific parts of the electron beam. In this configuration, the radiation slippage and electron beam delay must match for successful amplification, though modifications can be made to produce a single attosecond spike [11,12].

Experimentally, the attosecond research group at LCLS currently holds the record for the shortest X-ray pulse at 100 attoseconds. Other facilities, such as the European XFEL and SwissFEL, have also demonstrated attosecond pulse generation and made these pulses available for user experiments.

**Suggested Reading:**
[1] S. Huang et al, PRL 119, 154801 (2017)
[2] P. Emma et al, PRL 92, 074801 (2004)
[3] A. Marinelli et al, PRL 116, 254801 (2016)
[4] J. Duris et al, Nature Photonics 14, 30-36 (2020)
[5] J. Duris et al, PRAB 23, 020702 (2020)
[6] Z. Zhang et al, New J. of Phys. 22, 083030 (2020)
[7] E. L. Saldin et al, PRSTAB 9, 050702 (2006)
[8] A. Zholents, PRSTAB 8, 040701 (2005)
[9] Wang et al PRL132, 035002 (2024)
[10] N. R. Thompson et al, PRL 100, 203901 (2008)
[11] T. Tanaka et al, JSR 23, 1273 (2016)
[12] T. Tanaka, PRL 114, 044801 (2015)

## Physics and Education - A Journey into Plasma Physics

**PT 05/2024**

*Dirk Hegemann, Empa, Plasma & Coating Group, Lerchenfeldstrasse 5, CH-9014 St.Gallen, dirk.hegemann@empa.ch*

More than 99% of all visible matter in the universe is in the plasma state, and plasmas are present in a wealth of interesting phenomena from astrophysics to everyday devices. Yet, this is an area completely underrepresented in physics teaching at schools and in physics teacher education. Therefore, a journey into plasma physics is undertaken to discover the „hidden champion", providing some reasons why the topic of plasma is important for a „general culture" in physics. Plasma phenomena from the universe to the Earth, from materials science to gas conversion and further to plasma fusion are covered, regarding its societal importance.

Plasma is considered as an additional state of matter next to solid, liquid, and gas. It is distinguished by a substantial number of free charge carriers such as electrons and ions resulting in a collective behavior, that is, the plasma reacts as an ensemble to external electromagnetic fields. Plasma activation occurs when electrons are ripped off their atoms or molecules by receiving energy. The energy can be delivered by heating or by electromagnetic fields, in special cases also by chemical reactions (as in a fire) or friction (triboplasma). A fully ionized plasma by heating requires high temperatures of several 10‘000 K (thermal plasma). Plasma activation by electric fields, on the contrary, result in heating the electrons up to several electronvolt (1 eV corresponds to about 11‘600 K). Since the heavy gas particles remain at much lower temperatures, a non-equilibrium state (non-thermal plasma) is formed, which is only weakly ionized. As sufficient energy needs to be provided for ionization in order to sustain the plasma, numerous inelastic collisions occur to excite atoms and to dissociate molecules, also causing the emission of light. If for example air is activated into the plasma state – as in auroras (polar lights) or lightning – a multitude of reactive species is formed, comprising reactive oxygen and nitrogen species (RONS), positive and negative ions, electrons, and phonons. Hence, a plasma also induces physicochemical effects. It is argued that organisms exposed to strong lightning in clouds and in volcanic activity, therefore, had to develop antioxidant strategies,

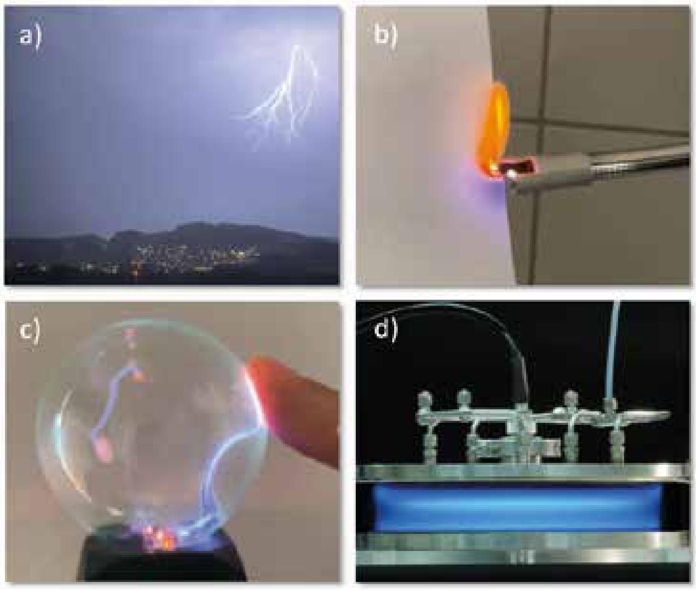



*Figure 1: Electrically activated, non-thermal plasmas: a) lightning (air plasma at atmospheric pressure), b) plasma lighter (air plasma at atmospheric pressure, around 1‘000°C), c) plasma ball (neon / 5 % xenon plasma at 1‘000 Pa), and d) lab-scale plasma reactor ($CO_2$ plasma at 10 Pa).*

helping them to get more robust and eventually evolve into higher life such as animals and plants living on land. Some examples of electrically excited plasmas are displayed in Figure 1.

During the evolution of the universe, shortly after the big bang, particles were formed by cooling to about 100‘000 K that were fully ionized (age of ions). Further cooling below about 60‘000 K allowed the formation of neutral atoms (age of atoms) that contributed to the formation of stars by gravity (age of stars and galaxies). The core of a star became hot again to start a thermal plasma and fusion reactions, also emitting high energetic radiation. By flooding the universe with such electromagnetic energy, reionization started resulting in a fully ionized interstellar space at very low pressure. The stars – as our Sun – also emit charge carriers, the solar wind. A planet protected by an electromagnetic field – as our Earth – screens most of the energetic plasma particles, however, at the polar regions, these particles can follow the magnetic field lines. Thus, the upper atmosphere can be activated forming auroras, that is, a non-thermal plasma at low pressure. Lightning is another electrically excited plasma – at atmospheric pressure. Their different plasma characteristics, resulting in an extended plasma or a channelized arc, are related to the different pressure ranges in which they occur. Nature thus tells us about thermal and non-thermal plasmas, existing at low and atmospheric pressure.

Can plasma also be exploited for technology? Indeed, and it has a strong impact on our way of life. Non-thermal plasmas benefit from their non-equilibrium conditions, since only the electrons are picking up energy from the electric field within collisions with heavy particles, which remain cold. Electron impact reactions can thus be used to generate light or to drive chemical reactions in dry and low-temperature conditions by providing the right energy per molecule in the range of several eV. Plasma-based gas conversion allows ozone synthesis (in an oxygen plasma), purification of exhaust air (by fragmentation of volatile organic compounds) or valorization of climate gases such as $CO_2$ and $CH_4$ into useful raw materials (hydrogen and organic carbon-based materials). The latter might contribute to the storage of surplus energy from renewable sources.

Furthermore, non-thermal plasma enable the modification of material‘s surfaces. During plasma-surface interaction, again, energies in the range of eV are deposited, allowing to steer chemical reactions, densification, and ablation. As a standard process to clean and activate surfaces, plasmas are thus used for adhesion promotion. More sophisticated applications are enabled by plasma deposition and plasma etching processes, typically conducted at low pressure. From hydrocarbon gases, hard diamond-like carbon films (around 1-3 µm thick) are deposited, e.g., on tools and engine parts, to enhance wear resistance and to reduce friction. Hydrophilic, porous plasma polymer films on contact lenses increase the wearer‘s comfort, while hydrophobic plasma coatings can replace PFAS (per- and poly-fluorinated alkyl substances causing environmental and health issues) on textiles, membranes etc. The largest field benefitting from plasma processing, however, is microelectronics. Conductive, semiconducting and insulating films are deposited at the nanoscale combined with etching steps to build transistors and other elements for integrated circuits, solar cells, and LEDs. This way, plasma largely contributes to meet „Moore‘s law“. Gordon Moore (Intel) predicted in 1965 that the number of transistors on an integrated circuit might double every two years with minimal rise in cost. Further reducing structure widths (currently at 3 nm) and exploiting 3D architectures might allow to fulfill Moore‘s law for another couple of years. These developments have already changed our life – consider for example the capabilities of a smart phone – and are further driven by the required computational power for artificial intelligence (AI) and robotics.

Finally, also thermal plasmas are used by mankind. Plasmas at „moderate“ temperatures around 10‘000 to 20‘000 K enable plasma welding and plasma cutting as well as waste treatment by providing a local, switchable heat source. But also much higher temperatures in the range of 100 Mio. K can be induced by plasma technology, contributing to the research on fusion for energy production. While magnetic confinement fusion requires extended plasmas at low pressure confined by complex electromagnetic fields, inertial confinement fusion is based on plasma shock waves, compacting a fuel in small bullets to extremely high densities and temperatures to start fusion reactions.

The plasma state thus covers a remarkably wide range of densities and temperatures (Figure 2). Although life on earth happens in life-friendly conditions allowing the coexistence of water as ice, liquid, and vapor, cascades of plasma events were required to enable life: steady energy delivery from the sun as well as ionized solar wind interacting with the earth magnetic field and lightning, both delivering RONS. By mankind, plasma technology has been developed to provide a powerful tool to modify materials, to conduct chemical reactions at low temperature, or to use thermal plasma applications that all play a role in our daily life. Plasma physics might thus be well-suited for physics teaching, as well, and collaborative work of plasma physics specialists and physics education experts should be undertaken in order to develop approaches to include plasma physics in high school physics teaching in a fruitful way.

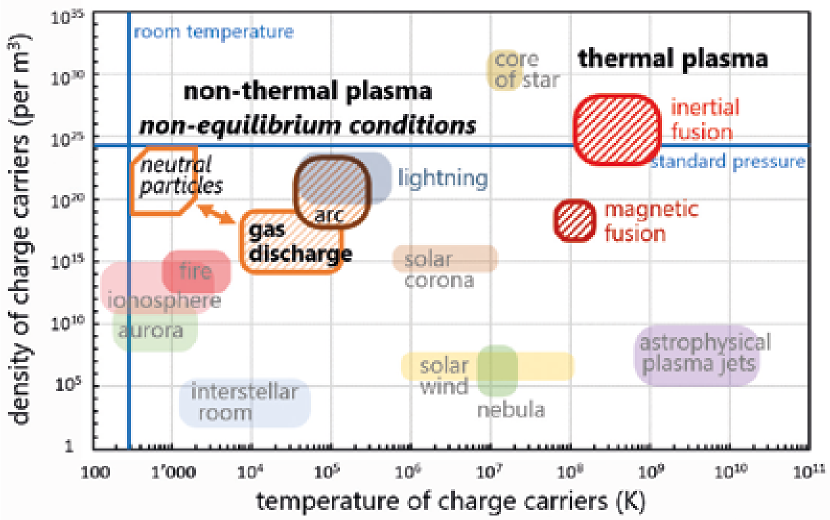



*Figure 2: Variety of technically used plasmas (bold) and natural plasmas (toned down). While non-thermal plasmas are weakly ionized comprising hot electrons and cold gas particles (non-equilibrium conditions), thermal plasmas can be fully ionized obtaining high temperatures.*

# Neuromorphic Intelligence: spiking neural network and on-line learning circuits for brain-inspired technologies

PT 06/2024

*Giacomo Indiveri, Institute of Neuroinformatics, University of Zurich and ETH Zurich*

Artificial neural network and deep learning algorithms have made tremendous progress, allowing us to achieve impressive results in Artificial Intelligence (AI) applications, such as image recognition, natural language processing, or autonomous driving. However, despite these advancements, conventional and artificial intelligence technologies cannot match the performance of biological ones for many practical tasks that involve real-time processing of sensory data and closed-loop interactions with the environment. One of the reasons for this gap is that neural computation in biological systems is organized in a way that is very different from the way it is implemented in today's deep networks.

Typically, AI algorithms run on digital computing systems based on the von Neumann architecture using Boolean logic, bit-precise digital representations, time-multiplexed and clocked operations. In addition they are often implemented on large and power-hungry platforms, often distributed across multiple machines in server farms, which are requiring increasing amounts of energy in a way that is not sustainable [1, 2]. Conversely, biological neural systems carry out low-power and reliable computation using analog components that are inherently noisy and operate in continuous time. These components typically communicate among each other with all-or-none discrete events (spikes), thus using a combination of analog computation and digital communication. Moreover, they form distributed, event-driven, and massively parallel systems, and they feature considerable amount of adaptation, self-organization, and learning with dynamics that operate on a multitude of time-scales. One of the reasons biological systems carry out computation using orders of magnitude less energy than digital computers is because in these systems computation is tightly linked to the properties of their computational embodiment, to the physics of their computing elements, and to their temporal dynamics.

One promising approach for bridging both the performance and efficiency gap between the biological and artificial neural systems is to develop a new generation of ultra-low power and massively parallel mixed-signal analog/digital computing technologies, that use the physics of silicon and emerging memory technologies to emulate the biophysics or real neurons. This approach is the "neuromorphic engineering" one [3, 4], originally proposed in the early '90s [5]. Similar to how AI architectures and models originally proposed in the 80's became popular in the early 2000's, neuromorphic computing is starting to show its full potential only now, thanks to the progress made in both VLSI and emerging memory technologies, as well as the in computational neuroscience, which has revealed many principles of computation used by (analog and noisy) neural systems for making robust and reliable computation.

Indeed, analog signal processing offers several advantages compared to digital signal processing, including lower complexity, lower latency, and lower power consumption. However, analog circuits, both biological and electronic, also face critical limitations, such as susceptibility to noise, limitations in accuracy and reproducibility, and challenges in scaling. By using neural action potentials (i.e., "spikes") as binary all-or-none events, alongside population coding, adaptation, plasticity, and learning, animal brains achieve an optimal synergistic integration of analog and digital processing [6].

Neuromorphic processors built using analog circuit for implementing neural dynamics, and digital circuits for transmitting and routing digital spikes among the neurons can also achieve an optimal balance between low-power and robustness [7, 8]. By integrating memory elements in both the analog fabric (e.g., the synapse cross-bars) and the digital one (e.g., the routing tables), these neuromorphic systems can also optimally combine the efficiency of in-memory computing with the flexibility of neural network configuration (e.g., to implement multi-layer feed-forward networks, recurrent networks, convocational networks, etc.) Moreover, by exploiting the low-power features of the analog circuits and the programmability of the digital routers in these neuromorphic processors to implement real-time brain-inspired neural networks, this approach will enables the development of ultra-low power neuromorphic intelligence devices that can operate in resource-constrained setups with low-latency and fast reaction time requirements.

In addition to carrying out signal processing through the dynamic properties of neurons and synapses, spike-based learning features can be added to the silicon neurons and synapses, to form "perceptrons" [9] that can be trained as binary classifiers [10]. As the analog synapse and neuron circuits are affected by devise mismatch and device-to-device variability, the accuracy of such classifiers is typically low and cannot compete with that of digital systems. However, thanks to this mismatch, multiple neurons act as diverse "weak classifiers". As a consequence, unlike with bit-precise digital circuits, it is possible to use *ensemble techniques* and aggregate multiple neuromorphic classifiers to increase their average accuracy [11, 12]. Figure 1a shows an example of a neuromorphic processor comprising multiple rows of neurons and a matrix of synapses forming a layer of spike-based learning neurons. By converting input signals into spike trains, each of these perceptrons can be trained to recognize different patterns (e.g, see Fig. 1b). By combining multiple of these perceptrons, the accuracy of the whole ensemble increases, consistent with the boosting theory [11].

Rather than competing with high-accuracy, but high energy, deep learning networks implemented on Graphical Processing Units (GPUs) and Central Processing Units (CPUs), neuromorphic computing technologies can complement conventional AI approaches in those application areas that require low-power, and for classification problems that can be solved with shallow networks [14]. This became particularly relevant in recent times, as the number of sensors and sensory processing applications has been increasing steadily, as well as the requirements and needs to reduce energy consumption.

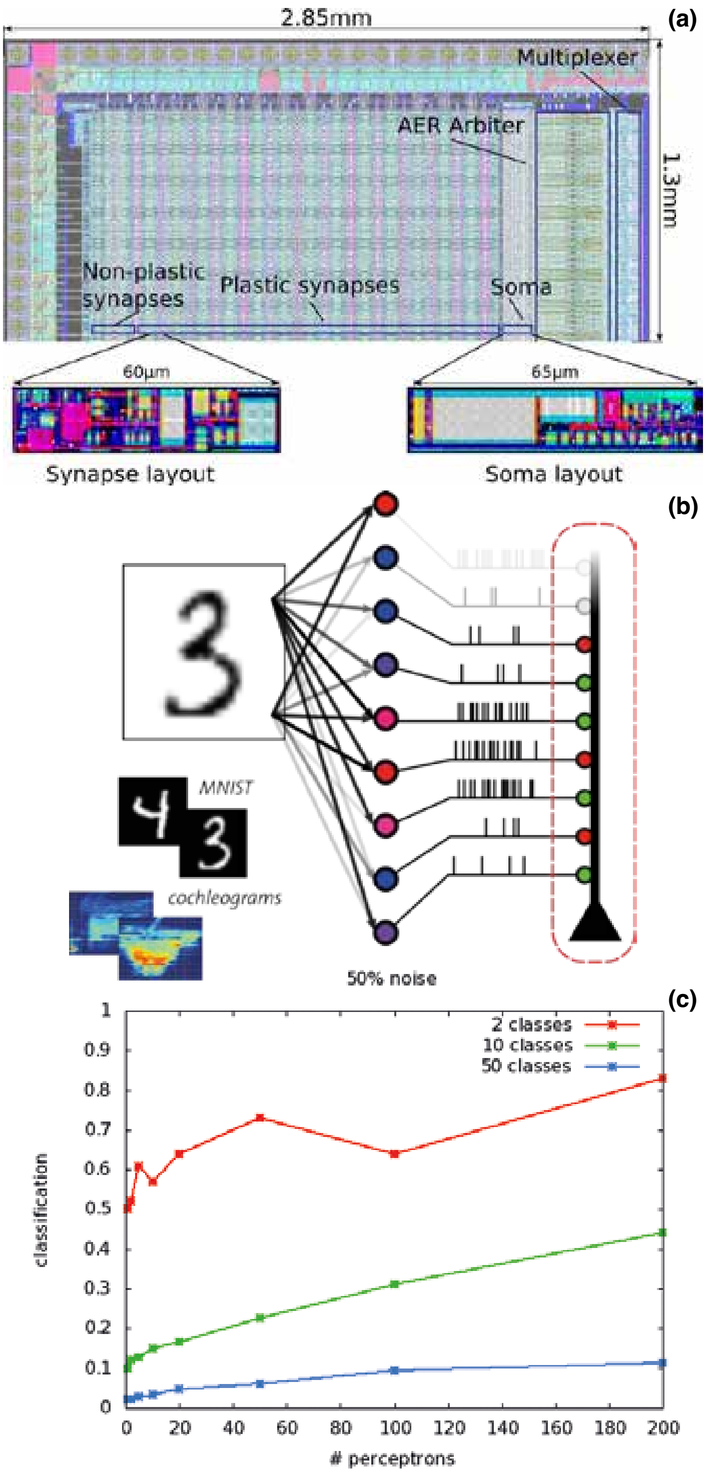



*Figure 1: (a) Example layout of a mixed-signal neuromorphic processor, with analog synapse and neuron circuits and digital routing blocks; (b) Schematic diagram of a silicon neuron used as a perceptron used to classify images of handwritten digits, converted into spike-trains, adapted from [13]; (c) Classification rates using random uncorrelated patterns with 50% noise. Each class is generated from a prototype pattern by adding Gaussian noise on each component. As predicted by ensemble and boosting theory, the performance scales with the number of (noisy) classifiers, adapted from [13].*

The progress in VLSI and memristive technologies is enabling the construction of complex neuromorphic processing systems with many cores and up to $10^6$ neurons [15]. The bottleneck that this approach is facing currently is not from the implementation aspects, but from the theory and modeling aspects: given the possibility and requirement to compute with analog neurons and synapses that carry out processing through the physics of their computing substrate and through their real-time dynamics, what are the network architectures and computational primitives that enable the desired performance? As animal brains, ranging from insects to humans, represent an existence proof that these primitives exist and are very powerful, the best strategy to exploit neuromorphic computing technologies is to follow a highly interdisciplinary approach, combining notions of physics, neuroscience, computer science and electrical engineering [16]. Only by following a holistic "co-design" approach that takes into account all these disciplines can real progress be made in this domain. Even though AI algorithms and software developments are making headlines, research and development on neuromorphic computing could lead to breakthroughs for building a new generation of autonomous intelligent systems [17].

## References

[1] D. Patterson, J. Gonzalez, Q. Le, C. Liang, L.-M. Munguia, D. Rothchild, D. So, M. Texier, and J. Dean, "Carbon emissions and large neural network training," *arXiv preprint arXiv:2104.10350, 2021*. https://doi.org/10.48550/arXiv.2104.10350.

[2] A. Mehonic and A. J. Kenyon, "Brain-inspired computing: We need a master plan," *Nature*, vol. **604**, no. 7905, pp. 255–260, 2022. https://doi.org/10.1038/s41586-021-04362-w.

[3] C. Mead, "Neuromorphic Engineering: In Memory of Misha Mahowald," *Neural Computation*, vol. **35**, pp. 343–383, 2023. https://doi.org/10.1162/neco_a_01553.

[4] E. Chicca, F. Stefanini, C. Bartolozzi, and G. Indiveri, "Neuromorphic electronic circuits for building autonomous cognitive systems," *Proceedings of the IEEE*, vol. **102**, no. 9, pp. 1367–1388, Sep. 2014. https://doi.org/10.1109/JPROC.2014.2313954.

[5] C. Mead, "Neuromorphic electronic systems," *Proceedings of the IEEE*, vol. **78**, no. 10, pp. 1629–36, 1990. https://doi.org/10.1109/5.58356.

[6] P. J. Gebicke-Haerter, "The computational power of the human brain," *Frontiers in Cellular Neuroscience*, vol. **17**, Aug. 2023. https://doi.org/10.3389/fncel.2023.1220030.

[7] O. Richter, C. Wu, A. M. Whatley, G. Köstinger, C. Nielsen, N. Qiao, and G. Indiveri, "DYNAP-SE2: A scalable multi-core dynamic neuromorphic asynchronous spiking neural network processor," *Neuromorphic Computing and Engineering*, vol. **4**, no. 1, p. 014 003, Jan. 2024. https://doi.org/10.1088/2634-4386/ad1cd7.

[8] S. Moradi, N. Qiao, F. Stefanini, and G. Indiveri, "A scalable multicore architecture with heterogeneous memory structures for dynamic neuromorphic asynchronous processors (DYNAPs)," *IEEE Transactions on Biomedical Circuits and Systems*, vol. **12**, no. 1, pp. 106–122, Feb. 2018. https://doi.org/10.1109/TBCAS.2017.2759700.

[9] F. Rosenblatt, "The perceptron: A probabilistic model for information storage and organization in the brain," *Psychological Review*, vol. **65**, no. 6, pp. 386–408, Nov. 1958. https://doi.org/10.1037/h0042519.

[10] N. Qiao, H. Mostafa, F. Corradi, M. Osswald, F. Stefanini, D. Sumislawska, and G. Indiveri, "A reconfigurable on-line learning spiking neuromorphic processor comprising 256 neurons and 128k synapses," *Frontiers in neuroscience*, vol. **9**, p. 141, 2015. https://doi.org/10.3389/fnins.2015.00141.

[11] R. Schapire and Y. Freund, *Boosting: Foundations and Algorithms*. MIT Press (MA), 2012. https://doi.org/10.7551/mitpress/8291.001.0001.

[12] R. Schapire, "The strength of weak learnability," *Machine learning*, vol. **5**, no. 2, pp. 197–227, 1990.

[13] F. Stefanini, "Robust online learning in neuromorphic systems with spike-based, distributed synapses," Ph.D. dissertation, ETH Zurich, 2013.

[14] D. V. Christensen et al., "2022 roadmap on neuromorphic computing and engineering," *Neuromorphic Computing and Engineering*, 2022. https://doi.org/10.1088/2634-4386/ac4a83.

[15] P. A. Merolla, J. V. Arthur, R. Alvarez-Icaza, A. S. Cassidy, J. Sawada, F. Akopyan, B. L. Jackson, N. Imam, C. Guo, Y. Nakamura, B. Brezzo, I. Vo, S. K. Esser, R. Appuswamy, B. Taba, A. Amir, M. D. Flickner, W. P. Risk, R. Manohar, and D. S. Modha, "A million spiking-neuron integrated circuit with a scalable communication network and interface," *Science*, vol. **345**, no. 6197, pp. 668–673, Aug. 2014. https://doi.org/10.1126/science.1254642.

[16] G. Indiveri, "Introducing „neuromorphic computing and engineering"," *Neuromorphic Computing and Engineering*, 2021. https://doi.org/10.1088/2634-4386/ac0a5b.

[17] "Big data needs a hardware revolution," *Nature*, vol. **554**, no. 7691, pp. 145–146, Feb. 2018. https://doi.org/10.1038/d41586-018-01683-1.

# In Memoriam Günther Rasche (5. Mai 1934 – 14. Juli 2024)

*Günther Rasche (1934 – 2024) kam 1956 als Physikstudent an die Universität Zürich. Damals war mit Walter Heitler (1904 – 1981) eine der führenden Persönlichkeiten der europäischen Physik an der Universität Zürich tätig, die viele Physiker aus ganz Europa nach Zürich zog, so auch Rasche. Von 1968 bis zu seiner Emeritierung 2001 war er Professor für theoretische Physik am Institut für theoretische Physik der Universität Zürich, und seit 1974 Mitglied der SPG.*

Günther Rasche wurde am 5. Mai 1934 in Mülheim an der Ruhr geboren. Er studierte von 1953 bis 1956 in Göttingen Physik und Betriebswirtschaft. Seine fundierten Kenntnisse der letzteren sollten sich später positiv auf das Wohlergehen des Institutes für theoretische Physik auswirken. 1956 wechselte er nach Zürich, wo er bei Hans Staub 1958 in Experimentalphysik diplomierte. 1961 doktorierte er bei Walter Heitler mit der Dissertation *Untersuchungen zum statistischen Modell der Mesontheorie* [1]. Seine akademische Laufbahn setzte er mit Postdoc-Stellen in Dublin und in London fort, kehrte aber immer wieder an die Universität Zürich zurück. Dort habilitierte er sich 1967 als Privatdozent. 1968 wurde er Assistenzprofessor, 1969 ausserordentlicher und 1977 ordentlicher Professor für theoretische Physik. In den folgenden Jahren bis zu seiner Emeritierung 2001 war er mehrmals Gastprofessor in Canberra, Australien sowie in Stockholm. Neben seiner Forschung in der Physik mit Fokus auf die Kern- und Mittelenergiephysik erweiterte er sein Interesse in den letzten Jahren zunehmend auch auf wissenschaftsgeschichtliche Themen; hier brachten seine langjährigen Kontakte zu Walter Heitler viel Interessantes ans Licht.

Günther Rasche war nicht nur ein engagierter Forscher, sondern auch ein ausgezeichneter Lehrer, der die Schwierigkeiten der Studierenden ernst nahm. Mit seiner Menschlichkeit, seiner Geradlinigkeit und seinem Interesse für organisatorische Fragen war er von 1989 bis 2001 ein hervorragender Leiter des Instituts für theoretische Physik sowie von 1992 bis 1994 Dekan der Mathematisch-naturwissenschaftliche Fakultät. Viele seiner ehemaligen Studierenden, Mitarbeitenden, Kollegen und Kolleginnen aus der ganzen Welt kamen immer wieder zu Besuchen zurück nach Zürich.

Sein wissenschaftliches Interesse war zunächst geprägt von den markanten Entwicklungen in der Feldtheorie der 50er Jahre einerseits, und deren Anwendungen auf Mesonen und Nukleonen, den damals bekannten stark wechselwirkenden Elementarteilchen, andererseits. Die heute gültige Quark-Theorie war erst in ihren Anfängen, ebenso die (nicht)abelschen Eichtheorien. In seiner Doktorarbeit untersuchte er ein spezifisches Modell für die Meson-Nukleon Wechselwirkung im Hinblick auf seine physikalische Konsistenz. Danach wandte sich Rasche, oft zusammen mit seinen langjährigen Kollegen William Woolcock aus Canberra und Geoffrey Oades aus Aarhus, Präzisionsrechnungen für Meson-Nukleon Wechselwirkungen zu. Das Ziel dieser Arbeiten war (und ist es), theoretische Vorhersagen oder Erklärungen für Experimente mit hoher Genauigkeit zu finden. Weiter arbeitete er an allgemeinen Fragen zur mathematischen Behandlung von physikalischen Prozessen. Günther Rasche war immer interessiert an aktuellen Fortschritten und Erkenntnissen in der experimentellen Physik und war eine gerngesehene Kontaktperson zu experimentellen Gruppen, sowohl am Institut an der Universität als auch am Paul Scherrer Institut (PSI).

Eine wichtige Entwicklung begann um 1970 mit der Zusammenarbeit mit Wolfgang Jaus, der seit 1966 am Institut war. Sie entwickelten einen Formalismus, um die für die Berechnung der elektromagnetischen Korrekturen der supererlaubten Beta Zerfällen zu berechnen. Diese Zerfälle ermöglichen es, eine der fundamentalen Grössen in der Teilchenphysik genau zu messen, das Element $V_{ud}$ der Quark-Mischungsmatrix. Diese Grösse ist sehr sensitiv auf Effekte neuer (noch unentdeckter) Teilchen und Kräfte. Es hat sich gezeigt, dass die Resultate von Jaus und Rasche bis heute Geltung haben und entsprechend weiterentwickelt werden. So wurde beispielsweise der grundlegende Artikel von Jaus und Rasche von 1970 auch in diesem Jahr bereits dreimal zitiert, 54 Jahre nach seiner Publikation.

Günther Rasche hat, zusammen mit seinen Kollegen Wolfgang Jaus, Armin Thellung, Norbert Straumann und Günter Scharf, das Institut für theoretische Physik seit Anfang der 70er Jahre bis zu ihren Altersrücktritten Anfang des 21. Jahrhunderts, geprägt und Generationen von Physikstudierenden in die theoretische Physik eingeführt. Auch nach seiner Emeritierung war er für seine Kollegen ein wichtiger Ansprechpartner in hochschulpolitischen Fragen, der mit seiner reichen Erfahrung und hervorragenden Menschenkenntnis wertvolle Anregungen zur weiteren Entwicklung des Physik-Instituts an der Universität Zürich geleistet hat.

Die Universität Zürich, die Kolleginnen und Kollegen und die ehemaligen Studierenden gedenken Günther Rasche in Dankbarkeit für seine Beiträge zum Erfolg und Wohlergehen unseres Institutes.

*Katharina Müller, Universität Zürich*

1 https://doi.org/10.5169/seals-113268

# Obituary for Thomas Maurice Rice

Prof. Thomas Maurice Rice, Professor at ETH Zurich, Fellow of the Royal Society and Member of the National Academy, passed away on July 18th 2024 at the age of 85.

Maurice Rice was born on January 26th 1939 in Dundalk, Ireland, as the second son of James and Maureen Rice. He grew up in Dundalk with his two siblings and attended Coláiste Rís, a local Christian Brothers School. At the young age of 17, he began his undergraduate studies in physics at the University College Dublin. His academic journey took an important turn in 1960, when he moved to the University of Cambridge to pursue his Ph.D. under the guidance of Volker Heine. At Cambridge's Cavendish Laboratory, Maurice first encountered Phil Anderson, a meeting that ignited his enduring interest in condensed matter physics and led to many fruitful collaborations in the years to come.

Following his Ph.D., Maurice Rice undertook postdoctoral research at the University of California, San Diego, where he joined Walter Kohn's group. It was during this time in Southern California that he met Helen Spreiter, whom he married in 1966. That same year, he joined the Theory Group at Bell Labs in New Jersey, eventually becoming its head. Bell Labs' collaborative and intellectually stimulating environment, where experts on virtually every subject could be found just down the hall, profoundly influenced Maurice's approach to science. During this period, he met again Phil Anderson and collaborated with many other colleagues, including Bill Brinkman, Bert Halperin, and Patrick Lee.

After 14 productive years at Bell Labs, he started pursuing the idea of leading his own research team. Through his Swiss wife Helen, he had been in touch with many of the Swiss physicists at Bell Labs, most of whom were ETH graduates. He appreciated the idea of a favorable environment at ETH with its stable funding and ample research opportunities. In 1982, Maurice Rice was appointed full professor in theoretical physics at ETH Zurich where he enjoyed mentoring students and young researchers until his retirement in 2004 and even beyond.

Throughout his career, Maurice Rice published numerous influential papers in condensed matter physics. Early in his career, he explored topics such as electron interactions in metals, the fate of superconductivity in low-dimensional systems, and excitonic insulators. His time at Bell Labs left an indelible mark on his scientific style, resulting in classic works that exemplified the synergy between experimentalists and theorists. Particularly notable among these were studies on electron-hole liquids in optically pumped semiconductors and the electronic properties of charge and spin density waves. His pioneering work with Bill Brinkman on the metal-insulator transition advanced the understanding of charge localization due to electron correlations, a concept that remains highly relevant today.

After moving to Switzerland, Maurice Rice helped transform ETH Zurich into a leading center for research on heavy fermion systems and unconventional superconductivity, collaborating closely with experimentalist Hans-Ruedi Ott. His seminal work with Kazuo Ueda on the microscopic understanding of heavy fermions and the symmetry properties of their superconducting states became foundational knowledge. Their proposal to examine power-laws in the low-temperature limit as indicators of nodal gaps has turned into a standard practice for characterizing new superconducting materials.

With the discovery of the cuprate high-temperature superconductors by Georg Bednorz and Karl Alex Müller at IBM Rüschlikon—just a few kilometers from ETH Zurich— Maurice's research took a new direction that would shape his work for decades to come. This emerging field allowed him to fully leverage his extensive research experience and had a profound impact on its further development. His most renowned contribution, carried out in collaboration with Fuchun Zhang, was the identification of the crucial role played by the "Zhang-Rice singlet" in hole-doped copper oxides. This key concept provided a solid microscopic foundation for the t-J model introduced by Phil Anderson in support of his resonating valence bond (RVB) theory. Building on this idea, Maurice, along with Claudius Gros and Bob Joynt, observed that Cooper pairs with d-wave symmetry provided the energetically most favorable state—a crucial early insight into the pairing symmetry later confirmed by experiments, in parts inspired by several of Maurice's previous proposals, such as the phase sensitive tests for the superconducting order parameter.

While Maurice was active on many fronts in condensed matter physics, the research closest to his heart centered on how Anderson's RVB concept could unlock the mysteries of the exotic normal state in doped cuprates, particularly, the enigmatic pseudogap phase. His scientific journey led to the study of ladder-shaped systems and the effects of strong Umklapp scattering, which he examined through functional renormalization group methods together with Carsten Honerkamp and Manfred Salmhofer. This work culminated in the development of the Yang-Rice-Zhang (YRZ) theory, a powerful phenomenological approach that offers a remarkably consistent description of the pseudogap phase's main features.

Maurice left an immense and lasting legacy in the field of condensed matter physics in Switzerland. Through his passionate teaching and enthusiastic approach to research, he established a new school of modern theoretical condensed matter physics, deeply influenced by his experience at Bell Labs, where close collaboration between theorists and experimentalists was key. His numerous students – including undergraduates, doctoral candidates, and postdocs at ETH Zurich – have continued to carry forward his pioneering spirit and dedication to research and education.

Throughout his career at ETH, he has been a dedicated and influential figure in the Swiss physics community. Notably, he was among the founding members of the NCCR MaNEP (Materials with Novel Electronic Properties, 2001–2013) under the leadership of Øystein Fischer from the University of Geneva. This initiative profoundly shaped the field of materials-oriented condensed matter physics in Switzerland. In collaboration with Øystein, he co-chaired the first international conference on high-temperature superconductivity in 1988, marking the beginning of the M2S (Materials and Mechanisms of Superconductivity) conference series, which has since become a prestigious tri-annual event.

Maurice's outstanding research achievements have been recognized with several prestigious awards, including the Hewlett-Packard Europhysics Prize and the John Bardeen Prize. His contributions earned him the election as an honorary member of the Royal Irish Academy, as member of the National Academy of Sciences of the United States, and as Fellow of the Royal Society. The University of Ireland in Dublin conferred upon him an honorary doctorate, Doctor honoris causa, in recognition of his significant impact on the field and he was elected as honorary member of the Swiss Physical Society.

Maurice was an extraordinary mentor and colleague, whose personality, wealth of experience, and boundless enthusiasm inspired everyone who had the privilege of working with him. He will be profoundly missed by all who knew and collaborated with him.

*Manfred Sigrist, Gianni Blatter and Bertram Batlogg*

# Kurzmitteilungen - Short Communications

## DOI Index for Articles from the *SPG Mitteilungen*

It was the concern of the SPS editorial team for many years to provide all authored scientific articles in the *SPG Mitteilungen* with a ***Digital Object Identifier*** DOI. It denotes according to ISO 26324 a digital index for physical, digital or abstract objects that is as unique and permanent as possible. The DOI system is operated by the International DOI Foundation and has so far mainly been used for online articles in scientific journals. It allows to store all relevant metadata at a central server, which assures the upload, curation and sharing of the data through an easy to use web interface.

After some evaluation, the SPS board decided to use ***Zenodo*** (*https://zenodo.org/*), a CERN data centre-backed repository for scientific data, regardless of the size and format. Zenodo strongly advocates open science, open access and is itself coded with open source software.

In order to collect the articles published in our journal, a Zenodo community has been created (*https://zenodo.org/communities/swiss_physical_society/*) gathering our uploads and allowing for an easy overview even if the specific DOI index of an article is not known.

Currently over 30 articles are available, starting with those from the *SPG Mitteilungen* No. 69. Future articles will be added simultaneously with their upload to our own website. Past articles might be added on an irregular base.

With DOI our authors benefit from a broader distribution of their work and better visibility. A few examples of already available uploads:

- Chiggiato, P., & Kersevan, R. (2024). Developments for the FCC-ee vacuum system. *SPG Mitteilungen - Communications de la SSP*, **72**, 26–33. *https://doi.org/10.5281/zenodo.10676736*
- Maggiore, M. (2024). Einstein Telescope: the exploration of the Universe with Gravitational Waves. *SPG Mitteilungen - Communications de la SSP*, **73**, 38–40. *https://doi.org/10.5281/zenodo.13208963*
- Straumann, N. (2023). Pauli Principle and Stability of Matter. *SPG Mitteilungen - Communications de la SSP*, **71**, 50–53. *https://doi.org/10.5281/zenodo.10137942*
- Leuchs, G. (2023). Are Maxwell's equations intimately related to the quantum vacuum? *SPG Mitteilungen - Communications de la SSP*, **70**, 48–49. *https://doi.org/10.5281/zenodo.10108149*
- Montaruli, T. (2023). Observing the highest energy phenomena in the universe with multi-messengers. *SPG Mitteilungen - Communications de da SSP*, **69**, 22–28. *https://doi.org/10.5281/zenodo.8025588*
- Braunecker, B. (2023). Hybrid Energy Systems. *SPG Mitteilungen - Communications de da SSP*, **69**, 44–46. *https://doi.org/10.5281/zenodo.8025736*

It is planned to add DOI indices also to certain other SPS publications like our *SPS Focus* series.

# Nobel Prize in Physics 2024


*Image credit: Royal Swedish Academy of Sciences.*

On October 8, the Royal Swedish Academy of Sciences announced the attribution of the 2024 prize in Physics to **John J. Hopfield** (Princeton University, NJ, USA) and **Geoffrey E. Hinton** (University of Toronto, Canada) "***for foundational discoveries and inventions that enable machine learning with artificial neural networks.***" With the Nobel prize in chemistry attributed one day later for computer-based protein modeling and structure prediction, Artificial Intelligence (AI) was particularly emphasized this year for its capability to help solving complex problems.

Artificial Neural Networks (ANNs) were inspired by biological neurons in the brain, having a branching dendritic structure and connections regulated by synapses. Similarly, ANNs consist of nodes interconnected by weighted couplings which can be trained to perform complex tasks [1]. Studies of complex systems are rooted in statistical physics. And the structure of ANNs shows similarities with models in statistical physics describing for instance the interaction between spins in magnetism.

The fascination of J. J. Hopfield and G. E. Hinton for the brain led them to build on methods and principles from physics to venture into the complexity of memory and biological systems. This endeavor is not without remembering that of E. Schrödinger who expressed his fascination for living systems in his book "What is Life?" published in 1944 (Cambridge University Press). This year's Nobel prize in Physics can well be perceived as a plea for a truly interdisciplinary approach to scientific practice and research.

*Michel Calame*

1 Scientific Background to the Nobel Prize in Physics 2024, The Nobel Committee for Physics, https://www.nobelprize.org

# Nobel Prize in Chemistry 2024

This year's Nobel Prize in Chemistry is about proteins, life's ingenious chemical tools. It has been awarded with one half to **David Baker** (University of Washington, USA) "***for computational protein design***" and the other half jointly to **Demis Hassabis** and **John M. Jumper** (both affiliated with Google DeepMind, London, UK) "***for protein structure prediction***". Both discoveries open up vast possibilities with enormous potential.

*Drawings of the Nobel prize laureates in Chemistry 2024. From left to right: David Baker, Demis Hassabis and John M. Jumper. Picture from Nobel Prize Outreach.*

The diversity of life testifies to proteins' amazing capacity as chemical tools. Proteins control and drive all the chemical reactions that together are the basis of life. Proteins function as hormones, signal substances, antibodies and the building blocks of different tissues. Proteins generally consist of 20 different amino acids, which can be described as life's building blocks.

In 2003, David Baker succeeded in using these building blocks to design a new protein that was unlike any other protein. Since then, his research group has produced one imaginative protein creation after another, including proteins that can be used as pharmaceuticals, vaccines, nanomaterials and tiny sensors.

In proteins, the amino acids are linked together in long strings that fold up to make a three-dimensional structure, which is decisive for the protein's function. Since the 1970s, researchers had tried to predict protein structures from amino acid sequences, but this was notoriously difficult. However, four years ago, there was a stunning breakthrough.

In 2020, Demis Hassabis and John Jumper presented an AI model called AlphaFold2. With its help, they have been able to predict the structure of virtually all the 200 million proteins that researchers have identified. Since their breakthrough, AlphaFold2 has been used by more than two million people from 190 countries. Among a myriad of scientific applications, researchers can now better understand antibiotic resistance and create images of enzymes that can decompose plastic. AlphaFold2 is broadly applied for protein structure prediction and protein engineering in the life sciences, both in academia and in industry. That life scientists can now predict protein structures and design novel proteins for a particular function confers the greatest benefit to humankind.

*Summary from the webpage of the Royal Swedish Academy of Sciences by Christof Fattinger*

Articles illuminating the scientific content of both Nobel prizes in more detail will be presented in the next issue of the *SPG Mitteilungen*.

# Neuer SPG Preis für Arbeiten auf dem Gebiet der Quantenwissenschaften und -technologie
# Nouveau prix de la SSP pour des travaux dans le domaine de la science et des technologies quantiques

Die Firma **ID Quantique** (*www.idquantique.com*) stiftet ab 2025 einen SPG Preis, der jährlich für eine hervorragende wissenschaftliche Arbeit auf dem Gebiet der Quantenwissenschaften und -technologie verliehen wird.

ID Quantique (IDQ) wurde 2001 von vier Physikern der Universität Genf als Spin-off gegründet und ist heute ein bekanntes Unternehmen mit Vertretungen und Entwicklungslabors auf mehreren Kontinenten. Dank des ausgeprägten Engagements, ständiger Innovationsbereitschaft sowie der Flexibilität und Expertise des Teams konnte sich IDQ als führendes Unternehmen in den Bereichen Quantenkryptografie, Zufallszahlengeneratoren und wissenschaftliche Instrumente etablieren.

ID Quantique bietet hochleistungsfähige Quantenverschlüsselungslösungen für die Datenübertragung an. Durch den Einbau der Quantenkryptografie in bestehende Netzwerkverschlüsselungskonzepte gewährleistet IDQ einen dauerhaften Schutz sensibler Daten, selbst vor Bedrohungen durch Quantencomputer, bei denen die meisten herkömmlichen Verschlüsselungsalgorithmen versagen. Die Produkte von IDQ werden von Regierungen, Unternehmen, Industriekunden und akademischen Forschungslabors in über 60 Ländern weltweit eingesetzt.

Darüber hinaus entwickelt und vermarktet IDQ auf der Quantenphysik basierende Zufallszahlengeneratoren, die in verschiedenen Bereichen wie Sicherheit, Simulationen und Spielen als Maßstab einer echten Zufallserzeugung gelten.

Schließlich bietet ID Quantique Lösungen zur Detektion einzelner Photonen im sichtbaren und nahen Infrarotbereich an, die auch gepulste Laserquellen, elektronische Komponenten wie Zähler und Zähl- und Synchronisationskomponenten sowie photonische Detektionslösungen umfassen. Die Anwendungen betreffen verschiedene Bereiche wie Quantenphysik, Kommunikation, Biowissenschaften und Materialien. Mit 20 Jahren Erfahrung ermöglicht die Produktpalette von IDQ den Kunden, komplexe wissenschaftliche und industrielle Probleme mithilfe modernster Werkzeuge und Instrumente zu lösen, die durch ein solides, in zahlreichen Kooperationen erworbenes Fachwissen unterstützt werden.

L'entreprise **ID Quantique** (*www.idquantique.com*) offrira dès 2025 un prix de la SSP, qui sera décerné chaque année à un travail scientifique exceptionnel dans le domaine de la science et des technologies quantiques.

Fondée en tant que spin-off en 2001 par quatre physiciens de l'Université de Genève, ID Quantique (IDQ) est aujourd'hui une entreprise de renommée mondiale, avec des bureaux et des laboratoires d'ingénierie répartis sur plusieurs continents. La passion continue, l'innovation constante, ainsi que la flexibilité et l'expertise d'une équipe dévouée ont permis à IDQ de s'imposer comme un leader dans les domaines de la cryptographie à sécurité quantique, de l'instrumentation scientifique et de la génération de nombres aléatoires.

ID Quantique propose des solutions de sécurité quantique à haute performance pour la protection des données en transit. En intégrant la cryptographie quantique aux produits de chiffrement de réseau existants, IDQ assure une protection durable des données sensibles, même face aux menaces des ordinateurs quantiques, qui pourraient compromettre la plupart des algorithmes de chiffrement conventionnels. Les produits d'IDQ sont utilisés par des gouvernements, des entreprises, des clients industriels et des laboratoires de recherche universitaire dans plus de 60 pays à travers le monde.

Par ailleurs, IDQ développe et commercialise des générateurs de nombres aléatoires basés sur la physique quantique, considérés comme la référence en matière de véritable hasard dans divers secteurs, tels que la sécurité, les simulations et les jeux.

Enfin, ID Quantique offre des solutions de comptage de photons pour les régions visibles et proches infrarouges du spectre optique, incluant des sources laser pulsées, des composants électroniques de comptage et de synchronisation, ainsi que des solutions de détection photonique. Ces applications couvrent des domaines variés tels que la physique quantique, les communications, les sciences biologiques et les matériaux. Fort de 20 ans d'expérience, la gamme de produits d'IDQ permet aux clients de résoudre des problèmes scientifiques et industriels complexes grâce à des outils et instruments de pointe, soutenus par une expertise solide acquise à travers de nombreuses collaborations.

# Progress in Physics (104)

## Exploiting correlations in gamma ray detection to non-invasively monitor nuclear reactors

*Oskari Pakari, Vincent Lamirand, EPFL*

***Autonomous monitoring of nuclear reactors is a challenging task, yet a crucial component of the International Atomic Energy Agency's (IAEA) efforts to ensure compliance with the non-proliferation treaty. At EPFL, we recently demonstrated that so called ‚gamma noise', i.e., correlations in gamma detection events, can be used to reliably monitor a research reactor from meters away, a distance to the reactor core much higher than expected [1] or commonly performed using neutrons only. This newly gained flexibility could enable new inspection tools for the IAEA, but could also aid in the monitoring of spent reactor fuel or damaged reactors.***

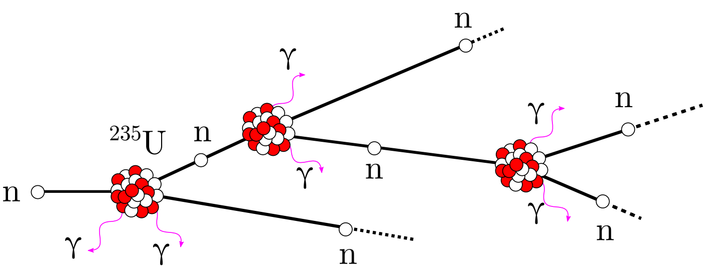



*Figure 1: A fission chain in time: An initial neutron causes a heavy nucleus, e.g. Uranium-235, to fission, releasing energy, neutrons, and gamma rays. The newly liberated neutrons can subsequently induce another fission, causing a chain reaction.*

### Nuclear energy and the IAEA

Climate crisis scenarios, such as those outlined by the UN IPCC [2], suggest that nuclear energy could play a critical role in providing low-emission electricity to reduce global reliance on fossil fuels. The World Energy Council's 2019 World Energy Scenarios report [3] projects an overall increase in the absolute amount of installed nuclear power across various plausible pathways until 2060.

However, nuclear energy remains a strategically sensitive technology due to the potential availability of special nuclear material (SNM) from the fuel cycle. The International Atomic Energy Agency (IAEA) leads non-proliferation efforts to ensure the peaceful use of nuclear energy, which includes controlled technology transfer to non-nuclear states, treaty facilitation and verification, as well as inspections and monitoring of nuclear facilities worldwide.

Given the anticipated growth in nuclear power installations, there will be a corresponding need to improve safeguard efforts. As part of its R&D plans [4], the IAEA seeks to improve existing safeguard technologies to effectively address emerging technological trends, particularly in the context of inspections and reactor monitoring. This includes novel approaches for non-proliferation monitoring tailored to small modular reactors (SMRs), which, due to their smaller size and design, present unique challenges. Often, safeguarding measures require inspectors to manually verify the declared inventory of a facility through item identification and counting. Autonomous monitoring of nuclear reactors using radiation signatures is therefore a key area of development.

### Methods for reactor monitoring

Common radiation signatures used to monitor nuclear reactors include neutrons, gamma rays, and antineutrinos. Recent studies showed that large-area neutron detectors placed at stand-off distances (i.e., beyond the reactor vessel) can track a reactor's power evolution [5]. These methods only provide simple information (reactor on/off, and approximate power level), and the signal may be vulnerable to tampering through deliberate source positioning. Similarly, antineutrino detectors have been shown to be able to track a reactor's power evolution, with the added advantage of providing information about the antineutrino spectrum [6]. Antineutrino measurements are, however, still subject to significant uncertainties, and provide information only on the order of weeks, typically applicable to power systems above 100 $MW_{th}$. Moreover, detector volumes of 3'000 liters or more are necessary to achieve significant detection rates, posing challenges in terms of cost and mobility. Consequently, both neutron and antineutrino detectors are currently inadequate for detecting fuel composition changes that occur on a timescale shorter than a week, potentially allowing time for secondary use activities and signal tampering in smaller and lower-power facilities.

To address the need for real-time measurement of both the reactor's current state and changes in fuel composition, so called "noise measurements" may offer a viable method. By exploiting the temporal correlation between subsequent detector counts, it is possible to directly observe a reactor's fission chain propagation (see infobox). A common approach in noise analysis involves measuring the excess variance caused by temporal correlation, as compared to a strictly Poisson random process where variance equals the mean.

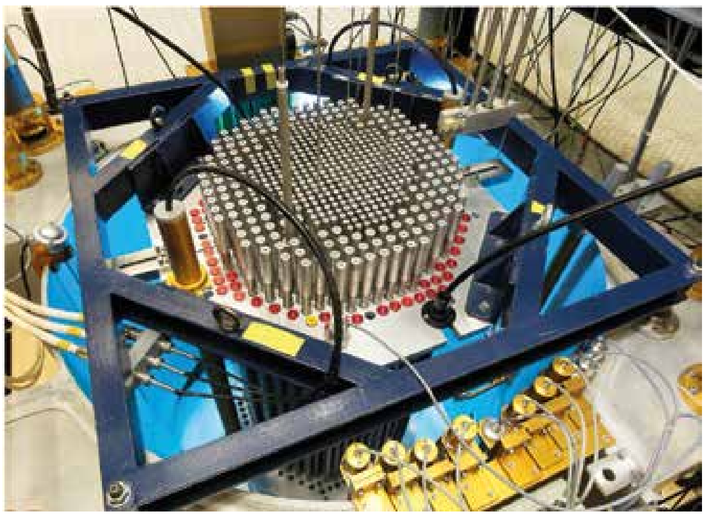


*Figure 2: The CROCUS reactor at EPFL. The blue light stems from a lamp, as with a maximum power of 100 W, the Cerenkov radiation is not intense enough to be visible.*

### Correlations in detection events

Observing a standard radioactive sample, the detection events in time are randomly distributed. This is due to a special property of radioactive decay: it is spontaneous and has a constant probability in time. Measuring a source for some amount of time would therefore yield a Poisson distribution in the events detected per interval of time. This translates into the variance of detection events per time interval being equal to the mean value. However, in a nuclear reactor, events in time are potentially correlated: each fission releases 2-3 neutrons and 3-7 gamma rays on average, and thus successive detection events could stem from successive fission events. The thereby induced correlation in the detector signal causes the variance of the detection events per time interval to increase with larger time intervals. The correlation is directly related to the time-dependent behavior of the system. This behavior was initially described by R. Feynman in 1956 when describing the neutron population of the LOPO 'water boiler' reactor at Los Alamos National Laboratory [7].

In 1956, Feynman et al. [7] demonstrated that the shape of this excess variance over an arbitrary time bin size can be represented by an analytical function. By fitting this function to detector signals, the "prompt decay constant" $\alpha$ of the system can be determined, which reflects the average length of prompt fission chains. This measurement can then be compared to previous data or code predictions of $\alpha$ to assess reactor operation, schedule compliance, or potential changes in fuel composition.

Previous noise experiments conducted in CROCUS using high-efficiency neutron detectors indicated that correlations from fission chains are statistically indiscernible from background beyond 20 cm from the fuel [8]. This observation was interpreted as an intrinsic limitation of neutron noise, limiting the applications of the noise method to research.

### The CROCUS reactor at EPFL

CROCUS is a uranium-fueled and light water-moderated reactor, which was previously used mainly for teaching purposes. With a maximum allowed power of 100 W (i.e. a maximum total neutron flux of about $2.5 \times 10^9$ $cm^{-2} \cdot s^{-1}$), it belongs to the category of zero-power reactors, where pure neutronics are studied without thermal feedbacks induced by power. After its moving from Avenue de Cours in Lausanne, it reached its first divergence with its current design on the EPFL campus in 1983. From an education point of view, which remains its primary motivation, it is continuously employed for EPFL students in Physics in their second and third year of Bachelor, as well as for students in the joint EPFL/ETH Zurich Swiss Master programme in Nuclear engineering since 2008, in close collaboration with the Paul Scherrer Institute (PSI). It also hosts internships, Master semester projects and Master theses.

Research programmes in CROCUS were rejuvenated in 2014, following the appointment of a new professor, and the assembling of a new team. Over the past decade, an expertise and a unique set of experimental results were obtained, along and thanks to developments in nuclear instrumentation. The core consists in two interlocked fuel zones with different fuel and pitches which, despite being an additional complexity, are also a challenge of interest for deterministic codes, towards their experimental validation. Although CROCUS lacks flexibility in fuel type and configuration, its low technological uncertainties, operation precision and stability, reflector and interpin space, and general accessibility, revealed it to be a perfect candidate for reference, but also atypical experimental endeavours.

### Gamma-ray noise for novel reactor monitoring

Our research indicates that gamma-ray noise methods offer a more affordable, compact, and simple monitoring tool, providing direct information on fission chain propagation. For noise measurements, the detectors do not require calibration beyond a simple visual inspection of oscilloscope signals, as the relevant information is encoded in the timing between pulses, allowing for a relatively fast setup.

A significant limitation of applying fission chain correlation analysis to reactor monitoring is the potential for thermal-hydraulic noise (i.e., mechanical vibrations due to coolant flow) to overpower the fission correlation signals. Consequently, the proposed technique may not provide useful information for reactors operating above 100 kW, although this remains to be tested in the future.

### References

[1] O. Pakari, T. Mager, P. Frajtag, A. Pautz, and V. Lamirand, "Gamma noise to non-invasively monitor nuclear research reactors," *Scientific Reports*, vol. 14, no. 1, p. 8409, 2024.

[2] H.-O. Pörtner, D. Roberts, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, and (eds.), "IPCC: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," *Cambridge University Press. In Press.*, 2022.

[3] T. Kober, H.-W. Schiffer, M. Densing, and E. Panos, "Global energy perspectives to 2060 – WEC's world energy scenarios 2019," *Energy Strategy Reviews*, vol. 31, p. 100523, sep 2020.

[4] IAEA Department of Safeguards, "Long-term R&D plan, 2012–2023, STR-375," tech. rep., IAEA, Vienna, Austria, 2013.

[5] B. M. van der Ende, L. Li, D. Godin, and B. Sur, "Stand-off nuclear reactor monitoring with neutron detectors for safeguards and non- proliferation applications," *Nature Communications*, vol. 10, apr 2019.

[6] C. Stewart, A. Abou-Jaoude, and A. Erickson, "Employing antineutrino detectors to safeguard future nuclear reactors from diversions," *Nature Communications*, vol. 10, aug 2019.

[7] R. P. Feynman, F. De Hoffmann, and R. Serber, "Dispersion of the neutron emission in U-235 fission," *Journal of Nuclear Energy*, vol. 3, no. 1-2, pp. N9–69, 1956.

[8] O. V. Pakari, *Experimental and numerical study of stochastic branching noise in nuclear reactors.* PhD thesis, École polytechnique fédérale de Lausanne (EPFL), 2020.

# Progress in Physics (105)

## Structural Biology and Interaction Analysis in Drug Discovery.

*Matthias E. Lauer, Roche Pharma Research and Early Development,*
*Roche Innovation Center Basel, F. Hoffmann-La Roche Ltd, Grenzacherstrasse 124, CH-4070 Basel*

Molecular biology studies the selective, spatial and timely recognition of molecules in cells. Evolution has tuned molecular recognition to orchestrate replication and adaption in biology. Only few elements are shaping biological matter, but the diversity and complexity of the resulting particle space is fantastically complex.

### The challenge

A drug molecule is a particle that exposes a distinct recognition surface, engineered to take selective therapeutic action in an environment crowded with comparably composed matter. Different therapeutic modalities enable this. Immunotherapies are based upon humanized recombinant antibodies, antisense oligonucleotides and gene therapies modulate genes associated with diseases. The tablet is an oral dosage form, condensing a small molecule in a stable crystal structure. This soft matter solid state is required to match a reasonable dissolution profile and an appropriate shelf life stability. Once dissolved, the drug molecule must withstand a digestive bio-chemical environment with an acceptable drug metabolism. All drug molecules are exposed to body compartments and the immune system; they have to pass biological barriers and organs, a cell membrane, or the brain-blood barrier, to finally reach the anticipated target destination at a free and pharmacologically relevant concentration. The physical, chemical, and physiological information stored in a small molecule has to match a delicate and complex drug property profile in order to become a 'true drug'. This profile covers a multitude of independent aspects. Most importantly, the drug molecule has to be safe, and the processes to manufacture medicines require it to meet the highest quality standards.

### The experimental approach

Target based drug discovery of small molecules follows a hierarchically organized funnel approach (Figure 1). It is experimental and computational guided by scientifically generated data, as well as the experiences collected over many decades. The first step of the discovery workflow has to satisfy the fundamental necessity to identify random chemical matter which can principally engage with the selected target. High-throughput screening reveals the engagement likelihood of any given library member with the anticipated target, resulting in a series of screening hits. These hits are

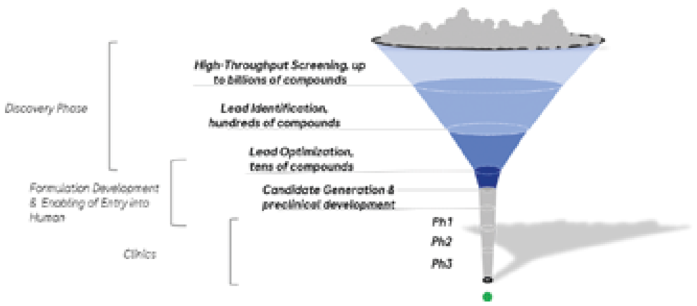



*Figure 1: The funnel of small molecule drug discovery process leading to clinical candidate compounds.*

structurally classified based upon repetitive structural motifs, and wider physicochemical properties. An alternative method which enables to screen the engagement of billions of molecules with a given target is the DNA-Encoded-Library-Technology (DELT). In addition to screens with synthetized molecules, in-silicon screens based upon prior structural information and virtual libraries are being employed as well. Often, different screening tools complement each other and feed the wider aim to generate a meaningful and rich series of chemically diverse starting points in a Lead Identification phase. The subsequent Lead Optimization phase merges structural motifs and novel chemical design ideas to consequently improve the compound properties into classes of potent lead structures, from which a clinical lead series and finally the clinical candidate are selected. These in-vitro experiments are complemented by cellular experiments and in-vivo studies to verify the mechanism of action of how the compound interacts with the drug target and to explore the wanted potential clinical mode of action of that mechanism. Overall the complexity of the general discovery challenge is smaller, if the selectivity, affinity and activity of the compound becomes large. Together these parameters define part of the potency of a compound. A general reduction of the required dose or the drug exposition at the target site most efficiently reduces undesired properties, all those which are concentration dependent, such as off-target effects, solubility or a poor membrane permeability. Structural knowledge in combination with biophysical interaction data provide an experimental foundation to design and improve molecules. Therefore, understanding this experimental foundation will help simplifying and accelerating the iterative optimization process of molecules with the chance to deliver highly potent and well-tolerated medicines.

Surface Plasmon Resonance, invented decades ago, is most established to determine the dissociation constants and binding kinetics of drug-target complexes with high throughput. Structure determination pipelines are applied in the entire pharmaceutical industry. They are based upon protein x-ray crystallography and cryogenic transmission electron microscopy (cryoTEM). Together these methods are the current technical standard to guide medical chemists and enable rational drug design.

### The experimental limitation of the approach

The workflows, the throughput, the automation and analysis pipelines towards guiding structure determination and interaction analysis are continuously refined globally and across the pharmaceutical industry. Decades of broad and in-depth drug discovery have generated a wealth of structural information and interaction insights. Fundamentally, this knowledge space is sufficiently closed to predict structural models of proteins with high confidence, by the knowledge of the target sequence. The engagement of synthetic small molecule binders is challenging to predict.

The experimental approaches, as well as the in-silicon predictions, are constrained by the fact that the entire available information is gathered on recombinant proteins. Our structural and biophysical knowledge is limited to targets which can be expressed at the liter scale, to be isolated and purified in the milligram scale and with suitable homogeneity. The interaction analysis of binders requires a clean buffer environment, and the protein target space that satisfies this method's immanent needs has been explored in depth.

A novel discovery space could be unlocked, if rational drug design would be amendable to endogenous drug-protein complexes, supramolecular assemblies, or particles which are simply too vulnerable to be isolated with classical biochemistry in sufficient yields.

**Innovative technologies are needed**

Analytically, it is a challenge to measure the biophysical interaction of molecules in an environment crowded with biological matter, because selective recognition and non-specific interactions cannot be sufficiently distinguished. Physically, the formation of a drug-target complex generates a *de novo* particle which occupies a constantly larger volume than the target or the binder by themselves. Together, they form a changed mass and the optical properties are being changed. These local concentration modulations are minute and not reliable to quantify in situations where interaction noise is present due to non-specific interactions and thermal diffusion. The masking or shielding of the recognizing surfaces by non-specific interactions reduces the likelihood of a compound to engage. The affinity-selectivity ranking made under artificial constrains can be misleading, in some cases. New innovative approaches are reaching our horizon and attention, they manage targets to be studied in cell lysate and body fluids.

**Focal Molography, an optical diffractive biosensor**

Focal Molography orchestrates and sorts the binding activity of millions of individual molecules into a surface pattern acting as a 'two dimensional diffractive lens', the 'molecular hologram' or mologram (Figure 2). The laser light which passes through the lens becomes detectable in a focal spot. The light in the spot is a holographic signal created from millions of individual binding events in the mologram. The trick is that the mologram orchestrates selective recognition and non-selective interactions of molecules coherently in space. Through this key principle, unspecific or random binding events are suppressed and do not contribute to the signal being measured in the focal spot, and the measurement applies the spatial lock-in amplification principle in an analogous manner [1,2].

Experimental data generated with Focal Molography are astonishing. For instance dissociation constants in the single-digit nanomolar concentration range can be reliably calculated from real time binding curves gathered in cell lysates. Peptides, which are conjugated to the mologram are selectively recognizing the protein target, at minute analytic concentrations. Multiplexed real-time binding curves were collected in serum and human-derived body fluids. Focal Molography unlocks a novel target opportunity space under cellular background conditions and biophysical interaction analysis of compounds with endogenous proteins.

**CryoWriter, a microfluidic robot for structure determination with cryoTEM**

Interaction analysis without structural knowledge of the drug-target complex is insufficient to guide medical chemists through an informed drug molecule optimization process. Technically, one million particle micrographs are enough to reconstruct a protein structure, large scale expression and purification cycles are not mandatory to feed a cryoTEM structure determination pipeline. The particles require to be embedded in an ultrathin amorphously-vitrified water film in random distributions and orientations. The preparation of suitable thin films is a preparative challenge, and timewise, a bottleneck of the structure determination workflow, even though if proteins are available in large amounts and in good quality.

The cryoWriter is an innovation of the Thomas Braun Laboratory at the Biozentrum of the University of Basel and is currently being developed by a company in Basel. It matured into a versatile-modular, microfluidic-automated, biochemical laboratory (Figure 3). The environmental control and a multitude of sensory feedbacks enable the genera-

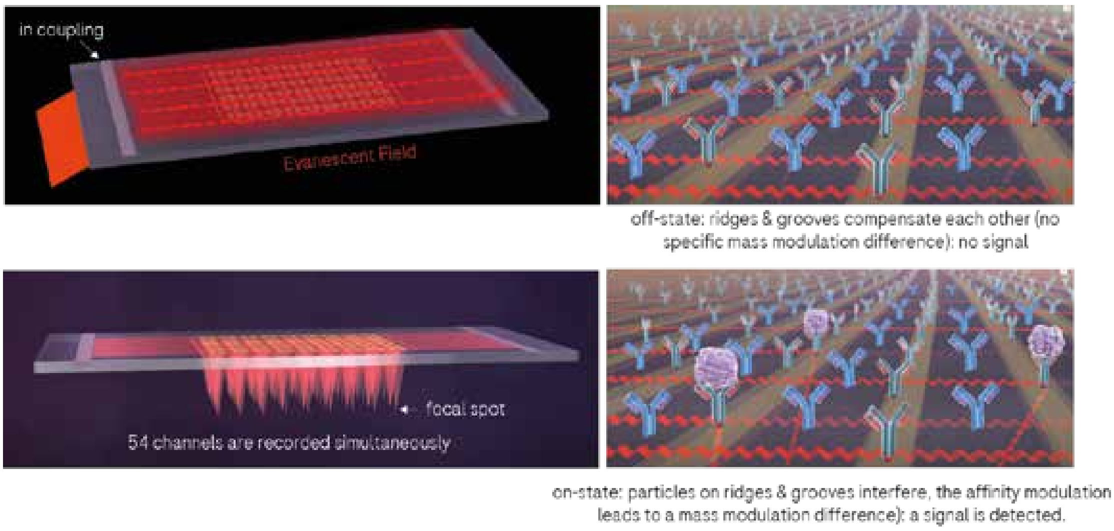



*Figure 2: Diffractive Optical Biosensor. Dark Field Illumination (top left); coherent laser light is coupled into a planar waveguide on a sensor chip. The light passes the diffractive lens, the mologram (top right). The mologram is a periodic grating of selective recognition elements in the ridges, and mass matched reference elements in the grooves. Analyte molecules in a biological liquid have a larger likelihood to be captured by the ridges, because of the higher affinity of selective recognition elements. Analyte binding leads to a mass density modulation which is related with the periodicity of the grating (bottom right). Light diffracted by the ridges interferes with the light diffracted by the grooves; the ridges and grooves are two interfering gratings. The diffracted light intensity is detected at the focal spot of the mologram (bottom left), and is related to the coherent mass density modulation on the mologram.*

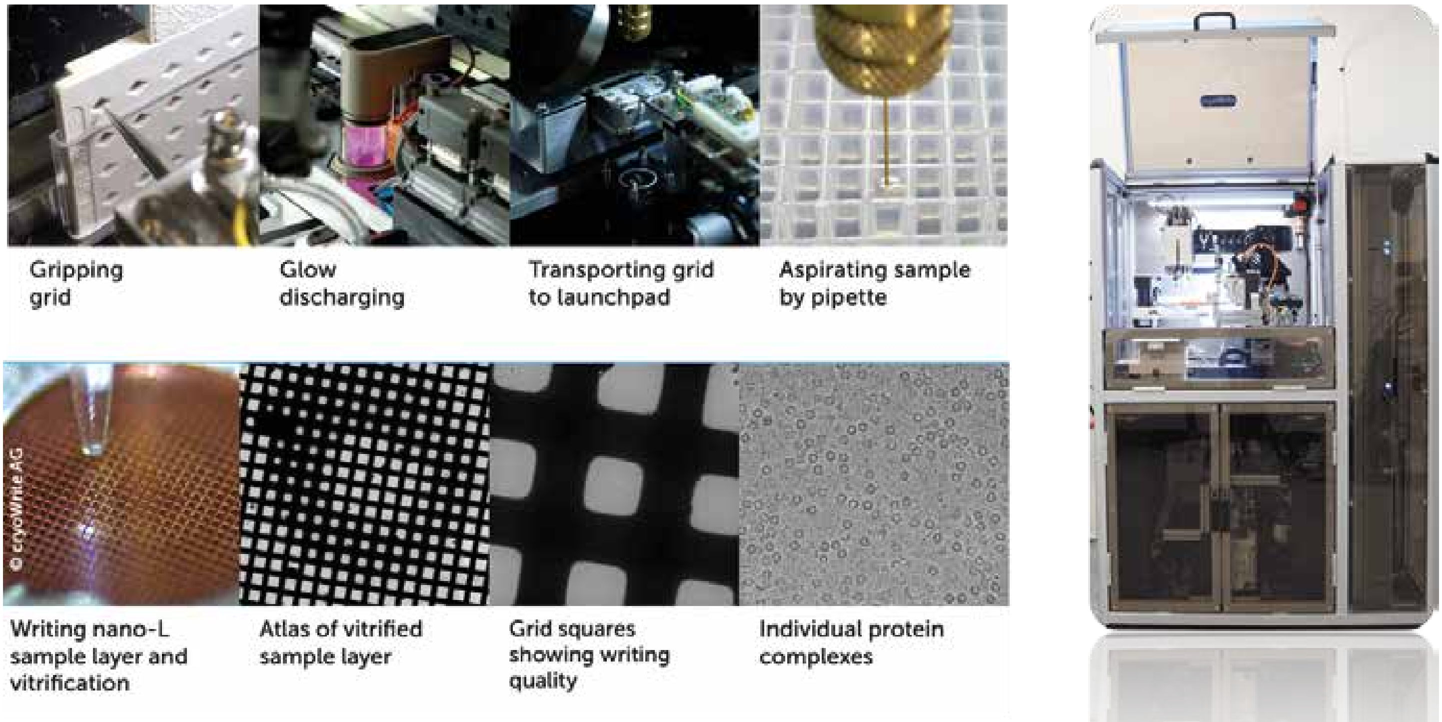



*Figure 3: cryoWriter, a microfluidic laboratory to prepare grids with nanoliter aliquots for structure determination with cryoTEM.*

tion of promising samples for electron microscopy in a novel way. A key element is the tinny nozzle, this can be freely moved and positioned with micrometer accuracy in space. Nanoliters of liquids are pipetted with picoliters accuracy, from different well-plates to a sample incubator. A counterpart is the tweezer which manages the automated delivery of sample supports. These supports are called grids, and this tweezer manages its transport through different destinations of the cryoEM sample preparation workflow; to the plasma chamber, and to the launch pad, where thin films are deposited to be plunge-vitrified in liquid ethane. This launch pad is controlled to a temperature close to the dew point, and in our hands the robot delivers suitable grids from minute aliquots with accuracy and repeatability. A modular software orchestrates the interplay of these modular devices, thus that a multitude of operation workflows and conditions can be creatively explored in a short time.

Beyond enabling suitable grids for structure determination in a much shorter time, the robot is appealing because it is compatible with a magnetic bead purification device, which already enabled solving the structure of the endogenous human proteasome from 1 microliter of a cell lysate [3].

The combination of breakthrough technologies can reveal novel mechanistic insights into molecular recognition processes as they underlie cellular processes and diseases. Interaction data gathered with Focal Molography can be complemented with structural data gathered with cryoTEM. Magnetic bead purification with verified high affinity binders can directly be used to trap their corresponding target from microliter aliquots using the cryoWriter. The methods enlighten a novel experimental drug discovery space, molecular recognition cascades in molecular biology, and beyond applications in biomarker discovery, diagnostics or even real-time monitoring of biotechnological processes.

## Collaboration towards novel technological breakthroughs

Innovative technologies have the chance to reach a transformative impact if fueled by the long-term commitment and passion of scientists across different disciplines and institutions. All starts with an invention; Dr. Christof Fattinger (Focal Molography) and Dr. Thomas Braun (cryoWriter). An academic home for Focal Molography was found in the groups of Prof. Dr. Janos Vörös and Prof. Dr. Petra Dittrich at the ETHZ, and the group of Dr. Thomas Braun at the Biozentrum of the University Basel. The development of a product prototype required the focus and motivated the foundation of start-ups; the lino Biotech AG and the cryoWrite® AG. It requires the laboratory infrastructure, experts and applicants in academia and industry to transform novel technology developments into robust data which enable the discovery of innovative molecules and novel therapies.

## References

[1] Frutiger, A., Blickenstorfer, Y., Bischof, B., Forró, C., Lauer, M., Gatterdam, V., Fattinger, C. and Vörös, J. **2019**. "Principles for Sensitive and Robust Biomolecular Interaction Analysis: The Limits of Detection and Resolution of Diffraction-Limited Focal Molography." *Phys. Rev. Applied* (11), 014056.
[2] Frutiger, A., Fattinger, C. and Vörös, J., **2021**. "Ultra-Stable Molecular Sensors by Sub-Micron Referencing and Why They Should Be Interrogated by Optical Diffraction—Part I. The Concept of a Spatial Affinity Lock-in Amplifier." *Sensors* 21, 469.
[3] Schmidli, C., Albiez, S., Rima, L., Righetto, R., Mohammed, I., Oliva, P., Kovacik, L., Stahlberg, H. and Braun, T., **2019**. "Microfluidic protein isolation and sample preparation for high-resolution cryo-EM." *Proc Nat Acad Sc*, 116(30), pp.15007-15012.

The presentations of Dr. Andreas Frutiger [1] and Dr. Luca Rima [2] in the *Biophysics and Soft Matter* session at the SPS Annual Meeting 2024 provide further information.

1 https://indico.cern.ch/event/1382917/contributions/6028698/
2 https://indico.cern.ch/event/1382917/contributions/6028727/

# Milestones in Physics (28)

## Laser photoacoustic spectroscopy for trace gas sensing: from past to present

*Markus W. Sigrist, ETH Zürich, John-von-Neumann-Weg 9, CH-8093 Zürich*

### 1. Introduction

The photoacoustic (PA) effect – discovered by Alexander Graham Bell in 1880 [1] – describes the production of sound upon the absorption of modulated radiation. First, it has been a phenomenon restricted to solids and later to liquids. With the advent of lasers, however, the detection and monitoring of trace gases has attracted great interest. Of course, there exist many non-spectroscopic techniques for sensitive gas detection such as gas chromatography – often combined with mass spectrometry – but optical techniques often offer several advantages such as lack of any sample preparation. Among the laser-based methods there again exist several schemes to effectively detect the absorption of light in a gaseous sample with high sensitivity: multi-pass absorption in a special gas cell, cavity-enhanced methods like cavity ringdown [2], or photoacoustic detection [3] which is probably the most robust technique applicable also in harsh environments. In the following we focus on this latter method.

Gas detection is preferentially performed in the mid-infrared (Mid-IR) at wavelengths between, say, 3 and 15 µm. This region is also called fundamental IR where the absorption is typically 100 times stronger than in the near-IR. Figure 1 shows the mid-IR wavelength region with a selection of absorbing molecules ranging from $H_2O$ vapor, $CO_2$, nitric oxides to hydrocarbons, but neither oxygen ($O_2$) nor nitrogen ($N_2$). Hence, the molecules can be distinguished by their specific line spectra. Absorbing molecules are excited to higher vibrational-rotational states. After a non-radiative lifetime $\tau_{nr}$ of typically µs to ns, a relaxation to translational energy takes place which results in a slight temperature increase. If the incident radiation is modulated (or pulsed) the temperature modulation can be detected as a sound, e.g., with a microphone.

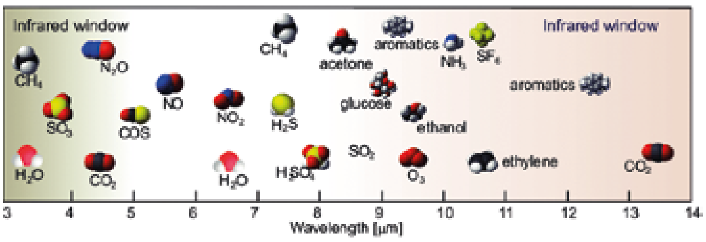



*Fig. 1: Mid-infrared wavelength region with selection of strongly absorbing molecules in a graphical representation [DRS Daylight Solutions, San Diego, USA].*

### 2. Theory

In a simple form the amplitude $S(\lambda)$ of the microphone signal can be written as [3]:

$$S(\lambda) = C \cdot P(\lambda) \cdot N_{tot} \cdot c \cdot \sigma(\lambda) \qquad (1)$$

where $P(\lambda)$ denotes the incident light power, $N_{tot}$ is the total number density of molecules, $c$ the concentration of absorbing molecules and $\sigma$ their absorption cross section at the incident wavelength $\lambda$. $C$ in units of Vcm/W is the so-called cell constant which depends on the photoacoustic gas cell geometry and is usually determined by calibration measurements with a certified gas mixture (absorbing gas with known absorption cross section diluted in a non-absorbing buffer gas).

Eq. (1) is valid only under certain conditions:

(i) Absorption not saturated and small in the sense that $\alpha L \ll 1$, where $L$ denotes the absorption path length and $\alpha$ is the absorption coefficient given by $\alpha(\lambda) = N_{tot} \cdot c \cdot \sigma(\lambda)$. This condition is easily fulfilled as we are interested in trace gas detection, i.e. in small concentrations $c$.

(ii) $\omega \ll \tau_{nr}^{-1}$, $\omega \gg \tau_{diff}^{-1}$, where $\omega$ denotes the circular modulation frequency and $\tau_{diff}$ the thermal diffusion time. This limits $\omega$ to a typical range of $10\ s^{-1} < \omega < 10^5\ s^{-1}$.

Eq. (1) implies that the PA signal $S(\lambda)$ is directly proportional to the absorbed power. The PA effect is a zero-background technique and thus inherently sensitive because – unlike in a radiation transmission measurement where the ratio between transmitted and incident intensity is close to one – without absorption of radiation there is no sound generation (apart from noise).

The sensitivity can also be expressed by the minimum detectable absorption coefficient $\alpha_{min}$

$$\alpha_{min} = \frac{S_{min}}{CP} \qquad (2)$$

where $S_{min}$ is the noise-limited minimum microphone signal $S$. Typically, values for $\alpha_{min}$ of $10^{-8}$ cm$^{-1}$ are achieved for a signal-to-noise ratio SNR = 1. One can then evaluate the minimum detectable concentration $c$ of a given gas in a non-absorbing buffer gas such as synthetic air or $N_2$ and one gets:

$$c_{min} = \frac{1}{N_{tot}} \cdot \frac{\alpha_{min}}{\sigma} = \frac{S_{min}}{N_{tot}\, CP\sigma} \qquad (3)$$

With typical numbers $\sigma \approx 10^{-18}$ cm$^2$ (molecular absorption cross section in the mid-IR), $N_{tot} \approx 10^{19}$ cm$^{-3}$, $\alpha_{min} \approx 10^{-8}$ cm$^{-1}$ one obtains $c_{min} \approx 10^{-9}$, i.e. ppbV concentrations or densities of µg/m$^3$ can be detected. Often, power-normalized noise equivalent absorption data (NNEA) are given to better compare detection limits. NNEA is obtained from $\alpha_{min}$ by:

$$NNEA = \frac{\alpha_{min} \cdot P}{\sqrt{\Delta f}} \qquad (4)$$

where $\Delta f$ denotes the equivalent noise detection bandwidth [4].

In a real-world application one normally deals with multi-component gas mixtures such as ambient air, industrial process gases or exhaled air in a medical application, and not with single gases diluted in a non-absorbing buffer gas as considered so far. In this case the microphone signal $S(\lambda)$ is composed of contributions of individual gas components as expressed in Eq. (5):

$$S(\lambda_i) = S_i = CP(\lambda_i)\, N_{tot} \sum_{j=1}^{n} c_j \sigma_j(\lambda_i) \qquad (5)$$

with $\lambda_i$ being a specific wavelength. There are $n$ gas components with $j$ as the running index, i.e., $c_j$ denotes the concentration of the j[th] component and $\sigma_j(\lambda_i)$ its absorption cross section at the specific wavelength $\lambda_i$, $N_{tot}$ is the total number density. A (possible) phase factor is not considered here. The concentration $c_j$ of the j[th] component can then be deduced by

$$c_j = \frac{1}{CN_{tot}} \sum_{i=1}^{m} [\sigma_j(\lambda_i)]^{-1} \left( \frac{S(\lambda_i)}{P(\lambda_i)} \right) \qquad (6)$$

where $[\sigma_j(\lambda_i)]^{-1}$ is the inverse of the matrix $[\sigma_j(\lambda_i)]$.

The nature of the matrix $[\sigma_j(\lambda_i)]$ determines the effectiveness of deriving the individual gas concentrations in a multi-component mixture by Eq. (6). In the ideal case the matrix is diagonal, i.e., a set of wavelengths $\lambda_i$ can be found with absorption of only one component at each $\lambda_i$. However, in the normal case, the absorption spectra of individual components overlap and interfere with each other and it is not straightforward to discriminate among the various known compounds and/or to even identify any unexpected compounds in a mixture. Using fitting procedures like principal component regression, partial least squares, a Levenberg-Marquardt algorithm, a mix-match algorithm or several other approaches that have been developed in the past [3], measured spectra are in practice fitted with spectra from databases such as HITRAN [5] or the Pacific Northwest National Laboratory database [6] which contains more than 300 molecular spectra, to finally evaluate multi-component spectra and determine concentrations of individual compounds. It should be emphasized, however, that despite sophisticated data analyses, interfering absorptions can still somewhat increase the minimum detectable concentrations $c_{min}$ for single gases as introduced above in Eq. (3).

### 3. Experimental arrangements

The first trace gas measurements using PA spectroscopy (PAS) have been performed by Viengorov in 1938 [7] and by Luft in 1943 [8]. With the advent of lasers with high spectral brightness, sensitive miniature electret microphones (as used, e.g., in hearing aids), lock-in detection and amplification, PAS underwent a renaissance. These new tools enabled trace gas detection and analysis. Pioneers of that time were Kerr and Atwood [9] as well as Kreuzer [10] who entered the ppbV ($10^{-9}$) concentration range.

Figure 2 shows a schematic of a typical experimental setup for trace gas detection using PAS. It includes a light source (typically a tunable laser), a chopper (or other kind of modulation scheme), eventually a lens to guide the laser beam through the cell, the PA gas cell itself equipped with one (or more) microphones M, a power meter for signal normalization and lock-in amplifier for processing the normalized microphone signal S/P. As light sources lamps, LEDs (including mid-IR LEDs), line tunable CO and $CO_2$ lasers, optical parametric oscillators (OPOs), difference frequency generation (DFG), later quantum cascade lasers (QCLs) and interband cascade lasers (ICLs) as well as frequency combs have been employed. Instead of mechanical choppers, pulsed lasers or direct current modulation is used, particularly for semiconductor lasers.

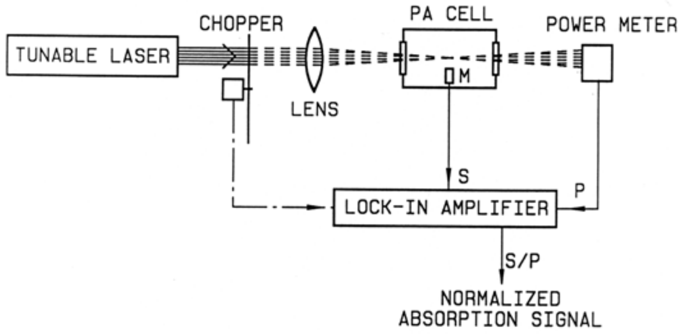



*Fig. 2: Typical experimental setup for photoacoustic gas measurements*

In the field of PA cell configurations, the development of new cell designs is ongoing. Already in early times, acoustically resonant cells were constructed to benefit from a PA signal enhancement by the Q-factor of the acoustic resonance. Also multi-pass arrangements were presented to benefit from the enhancement of absorbed power within the cell. Both items were combined in a cell design shown in Figure 3 [11]. This cell also included a microphone array of 16 microphones arranged radially around the cylindrical cell body to further enhance the PA signal amplitude. The cell was operated at the first longitudinal acoustic resonance frequency of 1252 Hz with a Q-factor of 70. The Brewster windows and gas in- and outlets are located at pressure nodes of the first longitudinal resonance thereby minimizing both window heating and gas flow noise (up to 1.5 l/min flow rate). The number of beam passes is 36 resulting in a total beam pathlength of 23.68 m. A typical application of this cell is discussed below in the section *Applications*.

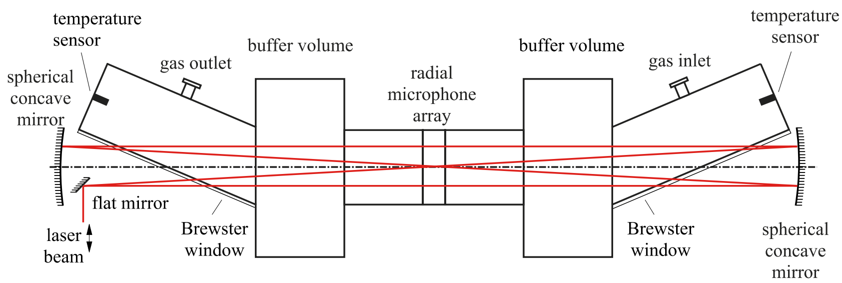



*Fig. 3: Multipass resonant photoacoustic cell, equipped with a radial array of 16 microphones [11].*

Numerous PA cell geometries have been presented throughout the time. An example is a multifunctional cell reported by Liu et al. [12]. The cell is equipped with three separate acoustic resonators combined in a single device. These resonators have different lengths and thus operate at different resonance frequencies. Three near-IR distributed feedback diode lasers operating at 1396 nm, 1653 nm, and 2004 nm have been used for the detection of water vapor, methane ($CH_4$) and $CO_2$, respectively. The entire cylindrical cell (including buffer volumes) measures 22 cm in length with a diameter of only 5 cm. Minimum detection limits of 0.2 ppm for $CH_4$ (with 400 s integration time), 12 ppm for $CO_2$ and 0.1 ppm for water vapor (with 100 s integration time each) could be achieved corresponding to NNEA values of a few times $10^{-9}$ cm$^{-1}$ W Hz$^{-1/2}$. This unique cell geometry significantly reduces the size for multi-laser PAS for multi-pollutant analysis.

Recently, 3D printed PA cells have been introduced by various authors. Bauer et al. [13] presented this new methodology for the construction of a miniaturized polymer-based resonant PA cell. The inner acoustic cylindrical resonator has a length of only 10 mm and a diameter of 1.8 mm. On each side of the cylinder, two buffer volumes of $\lambda_{ac}/4$ are added ($\lambda_{ac}$ being the wavelength of the acoustic resonant wave (1st longitudinal mode)) in order to reduce the gas flow noise. A MEMS microphone is employed to record the PA signal. A near-IR diode laser at 1582 nm wavelength was used to determine acetylene ($C_2H_2$) with a minimum detectable concentration of 750 ppbV (SNR = 3) for a 35-s averaging time and an average laser power of 22 mW.

Most recently, Zhang et al. [14] presented a special type of a so-called differential Helmholtz PA cell. Its geometry is illustrated in Figure 4. The cell consists of two cavities separated by a tube. The laser beam passes through one cavity in a multi-pass configuration, realized by retro reflectors. Each of the two cavities is equipped with a microphone. Microphone 1 records the actual gas absorption-related PA signal while microphone 2 only records any noise (with opposite sign). The cell was tested with acetylene ($C_2H_2$) as probe gas at a laser wavelength of 1.53 µm. Although not at its fundamental strong absorption a minimum detection limit of 14 ppb at an (enhanced) laser power of 1 W and 400 s averaging time was achieved.

More applications of conventional PAS studies are presented below.

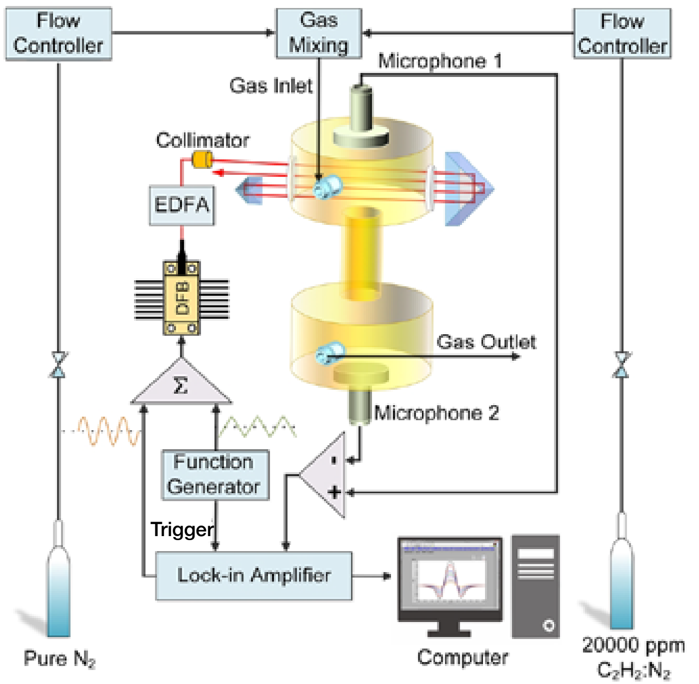



*Fig. 4: Setup of PAS sensor with multi-pass-retro-reflection-enhanced Differential Helmholtz PA cell and distributed-feedback (DFB) diode laser excitation with erbium-doped fiber amplifier (EDFA) [14].*

A completely different novel approach to (conventional) PAS gas detection named quartz-enhanced PAS (QEPAS) has been pioneered by Kosterev et al. [15]. It uses a quartz tuning fork (QTF, as employed in watches) as sensing element instead of the conventional PA cell equipped with one or more microphones, and operates at the high QTF resonance frequency of typically 32.8 kHz with an unusual high Q-factor of ca. 20'000. The QTF can be used in open space as a miniature sensor, but is often equipped with a tiny microresonator in the form of a sound tube to enhance the signal, as illustrated in Figure 5. Unlike in conventional PAS, the laser energy is not accumulated in the gas but rather in the QTF. This permits an energy accumulation time of typically 300 ms, considerably longer than in conventional PAS. Furthermore, the mode of the resonance frequency at $2^{15}$ Hz (≈ 32.768 kHz) corresponds to a symmetric vibration where the prongs of the QTF move in opposite directions, while the antisymmetric vibration is piezoelectrically inactive. This offers the benefit that ambient noise does not generate a signal. However, the high resonance frequency requires special attention, particularly for gas pressure-dependent measurements and for multi-species detection, as the condition (ii) mentioned above, i.e., that the nonradiative molecular relaxation time $\tau_{nr}$ is longer than the modulation cycle, may not be fulfilled any more. Furthermore, unlike in conventional PAS with a cell, a good laser beam quality is required for QEPAS as the space between the forks of the QTF is narrow (0.2 - 0.3 mm). Emphasis has thus been put into new QEPAS developments which include a novel customized clamp-type QTF which proves advantageous for lasers with poor beam quality while maintaining the high Q-factor of $> 10^4$ [16]. In the meantime QEPAS has been commercialized by CDP Systems Corp. (Moscow) and Thorlabs, Inc. (Newton, USA). Further QEPAS applications are discussed below.

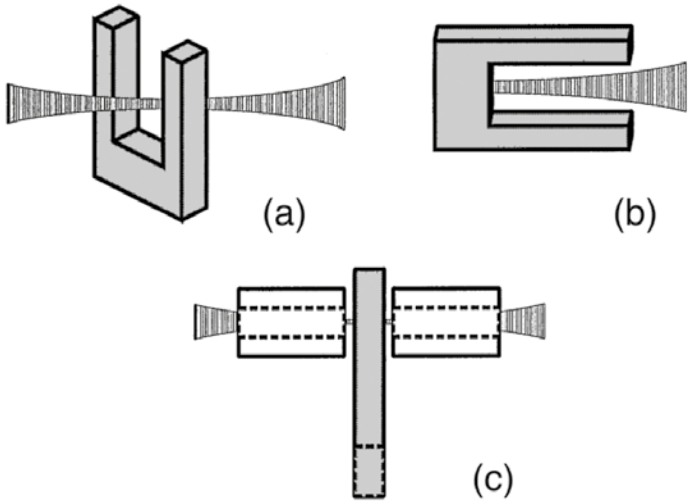



*Fig. 5: Optical configuration for QEPAS detection with a quartz tuning fork (QTF) [15]:*
*(a) Laser beam perpendicular to the QTF plane (usual configuration).*
*(b) Laser beam in the QTF plane.*
*(c) An acoustic microresonator is added to enhance the signal.*

A further approach named cantilever-enhanced PAS (CEPAS) differs from both conventional PAS and QEPAS as it still uses a PA cell but a cantilever as pressure sensor instead of a microphone, MEMS or QTF. The configuration is illustrated in Figure 6 [17]. The movement of a thin (≈ 5 - 10 µm thick) silicon cantilever is measured interferometrically with a diode laser. This way, displacements well under 1 pm up to mm can be detected. In the meantime, the method has been commercialized by Gasera Ltd., Turku, Finland, and successfully been applied in various applications. The reported detection sensitivities are comparable or even better than those achieved with PAS and QEPAS measure-

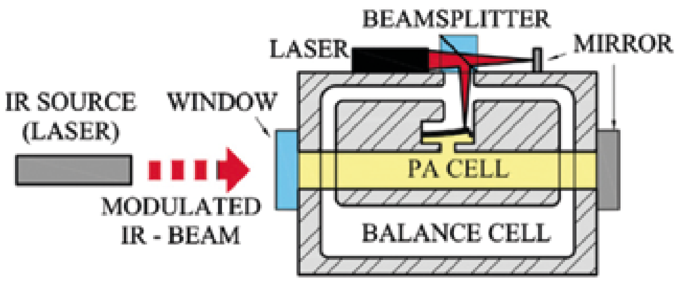



*Fig. 6: Setup for cantilever-enhanced PAS (CEPAS). Instead of a microphone a cantilever is used whose movement is recorded interferometrically [17].*

ments. As example, in an experiment with a QCL at 5.64 µm with a power of 47 mW a detection limit for formaldehyde ($CH_2O$) of around 1.5 ppb (SNR = 3) in a non-resonant operation of the CEPAS systems was reported, corresponding to a NNEA coefficient of 6.5 × $10^{-10}$ $Wcm^{-1}Hz^{-1/2}$ which was claimed one order of magnitude better than realized with previous PA systems [18]. More recent CEPAS applications are discussed below.

## 4. Applications

Most PAS, QEPAS and CEPAS studies focus on novel devices, high sensitivity, etc. generally performed in a well-controlled laboratory environment. As example, an ultrahigh sensitivity was very recently reported for a carbon monoxide (CO) and nitrous oxide ($N_2O$) detection, namely sub-ppt concentrations, achieved with a doubly resonant PA cell and a QCL around 4.57 µm wavelength [19]. However, there are only few true field studies.

As a representative early example of PA trace gas monitoring in ambient air a mobile $CO_2$ laser-based PA system is presented which was installed in a trailer and employed in a street tunnel study [20]. The focus was on the continuous monitoring of $CO_2$, ethene/ethylene ($C_2H_4$) and ammonia ($NH_3$) emissions alongside a dual-lane highway at the exit of the "Gubrist" street tunnel near Zürich. A Teflon tube sucked the air 15 m inside the tunnel near the wall and flowed the air continuously at a flow rate of 0.5 l/min through the multi-pass PA cell described above and shown in Fig. 3. A photo of the trailer and a view inside are displayed in Figure 7. Both a $^{12}CO_2$ and a $^{13}CO_2$ laser were used side by side, both sealed off and automatically and consecutively set at selected laser transitions, i.e. at wavelengths characteristic for strong $C_2H_4$ and $NH_3$ absorptions, respectively, and minimum spectral

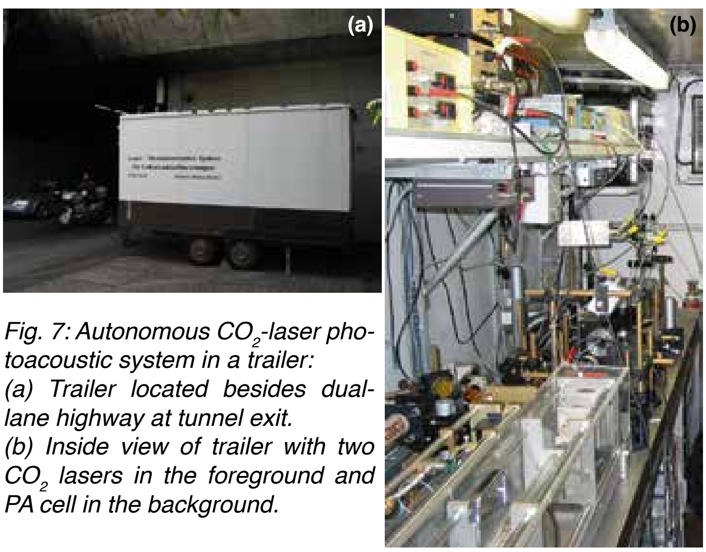



*Fig. 7: Autonomous $CO_2$-laser photoacoustic system in a trailer:*
*(a) Trailer located besides dual-lane highway at tunnel exit.*
*(b) Inside view of trailer with two $CO_2$ lasers in the foreground and PA cell in the background.*

interferences, notably by $CO_2$ and $H_2O$ vapor, for selectively detecting $C_2H_4$ and $NH_3$. The $CO_2$ concentration was recorded with an independent device. The system was calibrated with certified gas mixtures before actual gas measurements were taken. For the measurement campaigns, the beams of the $^{12}CO_2$ and a $^{13}CO_2$ laser were alternatively directed through the PA cell via a computer-controlled flipper mirror. A time resolution of typically 1 min for a single measurement of one gas was achieved. The results of a 1-week measurement campaign of the three gases $C_2H_4$, $NH_3$ and $CO_2$ are plotted in Figure 8. In addition the traffic count is shown at the bottom. There is obviously a good correlation with traffic counts and gas concentration peaks. The concentration fluctuations are true variations due to the excellent time resolution. All concentrations are above the background concentrations and well above the individual detection limits. It should be noted that this is one of the few studies employing a computer-controlled and totally stand-alone system.

Another example of a true field PAS study concerns aircraft measurements of $C_2H_4$ from industrial sources near Houston, Texas (USA). Again, a $CO_2$ laser was used and concentration fluctuations in the low ppb-range of ethene ($C_2H_4$) during flights of typical 1 hour were recorded yielding good agreement with gas chromatographic measurements on air samples collected during the flight [21].

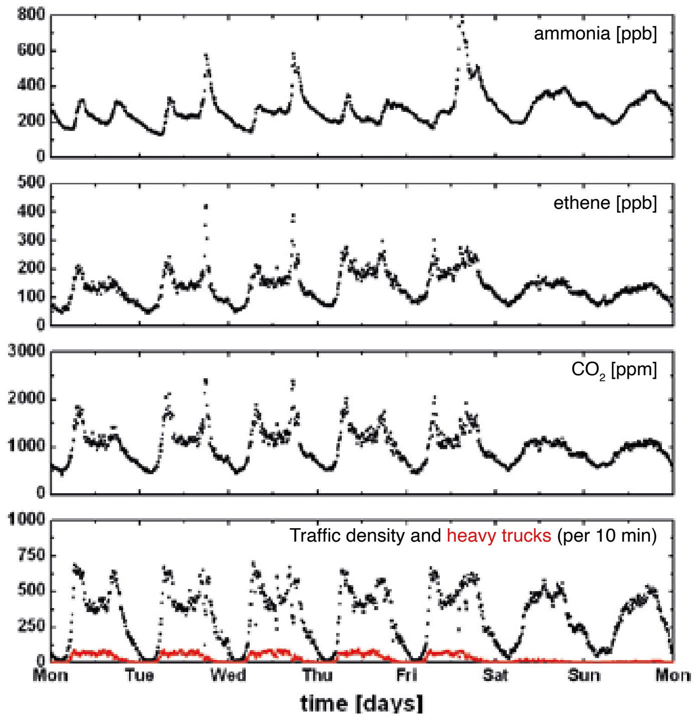



*Fig. 8: Temporal development of ammonia ($NH_3$) ethene ($C_2H_4$), $CO_2$ and traffic counts per 10 min (from top to bottom) during one week [20].*

A further aircraft PA study was reported by Bozoki [22] who realized a diode-based near-IR PA system for the simultaneous recording of the atmospheric water vapor and total water concentration. This is a good example for the practicability, robustness and long-term reliability of the PA method which results from the proper selection of the hardware components and the development and application of self-checking and self-correcting algorithms in order to optimize the system performance before deployment and to warrant an optimized operation throughout airborne measurements.

In a recent QEPAS application, a system was realized that contains three QCLs operated at three different wavelengths for detecting ammonia ($NH_3$), nitrogen dioxide ($NO_2$) and sulphur dioxide ($SO_2$) under well controlled humidity conditions (in order to take the strong influence of water vapor on $\tau_{nr}$ into account [23]). Minimum detectable concentrations of 2.4 ppb ($NH_3$), 9 ppb ($NO_2$) and 9.3 ppb ($SO_2$), well below their abundance in air for all pollutants, were reported for an averaging time of only 0.1 s.

CEPAS applications have increased since their introduction in 2003. The first combination of CEPAS with a frequency comb has been realized by Sadiek et al. in 2018 [24]. Such an arrangement combines the broad spectral range and high spectral resolution of frequency combs with the small sample volume of CEPAS.

In a more recent study an exceptionally high detection sensitivity has been reported for hydrogen fluoride (HF). A continuous-wave (CW) optical parametric oscillator (OPO) with a power of 950 mW, tuned to a strong HF absorption line at 2476 nm, was employed. It should be noted that during a 15 s gas exchange cycle the gas cell was always closed for 6 s to record the PA signal. In this configuration a detection limit of 2.5 ppt was achieved [25]. However, the restriction of a closed cell, i.e., without flowing gas, may impede continuous *in situ* measurements.

A most recent CEPAS measurement has been performed on tritiated water (HTO) in the gas phase [26]. Since the CEPAS method offers high sensitivity in a small sample volume (11 ml in this case), it is particularly suited when working with radioactive samples. A QCL emitting at ≈ 7.32 µm was employed and directed through the PAS cell. The actual measurement was performed in a sample-and-hold configuration, i.e. a sample was transferred to the cell from a continuous by-pass flow and the cell valves were then closed during the spectral measurement. A water sample with enriched amount of HTO was used. Time series measurements with varying water and HTO concentrations were carried out. The sample in the cell was renewed every 60 s, the measurement itself (in stop-flow mode) was performed for 30 s. A HTO detection limit of 0.88 ppb for SNR = 1 and 60 s measurement time is claimed.

## 5. Conclusions

Photoacoustic spectroscopy has not lost its timeliness but has instead entered various fields and has experienced numerous new developments and applications. In trace gas sensing, it offers several benefits compared to other conventional yet also to other optical techniques: it is a robust and rather simple method, easy to implement, requires neither sophisticated alignment nor special optics and represents a rather low-cost sensor. Furthermore, it offers high sensitivity and a high specificity (particularly important for multi-species samples) can be achieved with an appropriate narrowband tunable laser source. Applications range from selective detection of single species in a controlled environment in the lab to field experiments (on the ground or even including airborne systems) for ambient air monitoring, to industrial process monitoring or explosives detection and also include biological and medical areas, e.g., breath monitoring for disease diagnostics.

## References


[1] A. G. Bell: *Amer. J. Sci.* **20**, 305-324 (1880)
[2] G. Berden and R. Engeln, Eds.: “Cavity Ring-Down Spectroscopy: Techniques and Applications”, Wiley, Chichester, UK (2009)
[3] M. W. Sigrist: “Photoacoustic Spectroscopy for Gas Sensing: Basics, Theory, Experimental Systems and Applications”, in *Advances in Spectroscopic Monitoring of the Atmosphere*, ed. by W. Chen, D. S. Venables, and M. W. Sigrist, Elsevier, Inc., Amsterdam, NL (2021), chapter 5.1, pp. 225-269.
[4] A. Elia, C. Di Franzo, V. Spagnolo, P. M. Lugarà, and G. Scamario: *Sensors* **9**, 2697-2705 (2009)
[5] L. Rothman et al.: *J. Quant. Spectrosc. Radiat. Transfer* **130**, 4-50 (2013)
[6] S. Sharpe, T. Johnson, R. Sams, P. Chu, P. Rhoderick, and P. Johnson: *Appl. Spectrosc.* **58**, 1452-1461 (2004)
[7] M. L. Viengorov: *Dokl. Akad. Nauk SSSR* **19**, 687-688 (1938)
[8] K. F. Luft: *Z. Tech. Phys.* **5**, 97-104 (1943)
[9] E. L. Kerr and J. G. Atwood: *Appl. Opt.* **7**, 915-921 (1968)
[10] L. B. Kreuzer: *J. Appl. Phys.* **42**, 2934-2943 (1971)
[11] M. Nägele and M. W. Sigrist: *Appl. Phys. B* **70**, 895-901 (2000)
[12] K. Liu, J. Mei, W. Zhang, W. Chen, and X. Gao: *Sens.& Actuators B Chem.* **251**, 632-636 (2017)
[13] R. Bauer, G. Stewart, W. Johnstone, E. Boyd, and M. Lengden: *Opt. Lett.* **39**, 4796-4799 (2014)
[14] C. Zhang, S. Qiao, Y. He, and Y. Ma: *Opt. Express* **32**, 848-856 (2024)
[15] A. A. Kosterev, Y.A. Bakhirkin, R. F. Curl, and F. K. Tittel: *Opt. Lett.* **27**, 1902-1904 (2002)
[16] Q. Wu et al.: *Opt. Lett.* **47**, 4556-4559 (2022).
[17] V. Koskinen, J. Fonsen, K. Roth, and J. Kauppinnen: *Vib. Spectrosc.* **48**,16-21 (2008)
[18] C. B. Hirschmann, J. Lehtinen, J. Uotila, S. Ojala, and R. L. Keiski: *Appl. Phys. B* **111**, 603-610 (2013)
[19] Q. Nie, Z. Wang, K. Duan, M. Hu, M. Du, and W. Ren: *Opt. Lett.* **49**, 3648-3651 (2024)
[20] D. Marinov and M. W. Sigrist: *Photochem. Photobiol. Sci.* **2**, 774-778 (2003)
[21] J. A. de Gouw et al.: *Environm. Sci Technol.* **43**, 2437-2442 (2009)
[22] Z. Bozoki: “Airborne application of a photoacoustic instrument”, in *Advances in Spectroscopic Monitoring of the Atmosphere*, ed. by W. Chen, D. S. Venables and M. W. Sigrist, Elsevier, Inc., Amsterdam, NL (2021), chapter 5.2, pp. 270-284.
[23] P. Patimisco et al.: *Sensors* **23**, 9005 (2023), 12 pp.
[24] I. Sadiek, T. Mikkonen, M. Vainio, J. Toivonen, and A. Foltynowicz: *Phys. Chem. Chem. Phys.* **20**, 27849-27855 (2018)
[25] T. Tomberg, M. Vainio, T. Hieta, and L. Halonen: *Sci. Report* **8**, 1848 (2018)
[26] J. Karhu, M. Nyman, M. Siitari-Kauppi, and T. Hieta: *Photoacoustics* **29**, 100443 (2023), 6 pp.


**Markus W. Sigrist** obtained his PhD degree in Physics from ETH Zürich in 1977. After a postdoctoral stay at the University of California in Berkeley he returned to ETH Zürich, and, following habilitation, was awarded the title of Professor for Experimental Physics in 1996. He was Adjunct professor at Rice University in Houston (USA), guest professor at the Université du Littoral in Dunkerque (France) and later at the Chinese Academy of Sciences. From 1998 until his retirement in 2013 he headed the *Laser Spectroscopy and Sensing Laboratory* at ETH. His research focused on sensing applications ranging from trace gas detection in ambient air, industrial process control and agricultural monitoring to medical sensing such as surgical smoke analysis, breath analysis and non-invasive glucose sensing. Markus Sigrist authored or co-authored over 200 publications in refereed journals as well as several book chapters and books. He is a member of several professional societies and a fellow of *optica*.

# Physics Anecdotes and Personal Recollections (30)

## Start-Ups, Roll-Outs and Neutrons

*Bernhard Braunecker*

### Flow of Knowledge

Our economic prosperity depends on two pillars: the universities and the manufacturing industry. While the universities are responsible for education and innovation, the industry has to ensure the necessary profit, which in turn allows the governments to finance the universities. It is important that innovation knowledge flows seamlessly from universities to industries, and should not be interrupted when an expert involved enters a new phase of her or his live.

### Phases of Life

Let us divide our life into three phases: phase P1 are the first 30 years, the years of education, followed by phase P2, our active job years, and finally by phase P3 when we retire at the age of 65. But between them we have to master phase transitions, which from P1 to P2 means to find a satisfying job, to learn running a business and to take responsibility for employees. Such a change is often accompanied by some kind of *culture shock*, especially when you have to concentrate on daily business issues and no longer on innovations. The second phase transition from P2 to P3 is even more frustrating, when suddenly you are no longer responsible for business decisions. Then the knowledge flow from research to industry in the first case is obviously faltering, and in the second case, from industry into private life, valuable knowledge may even get lost.

It makes sense – also from a national-economical point of view – to create some kind of institutions between the phases to damp the personal culture shock and to avoid the loss of expertise. Suitable instruments in the first interface are the well-know start-up companies, and those for the second one we will call roll-out companies.

### Start-Ups

Let us consider those start-ups which are located close to universities, founded and driven by Post Docs. Their aim is to transfer verified research results into first market products. The innovative power of start-ups is high, but there is usually little or no business experience, thus the risk of failure is relatively high. Special agencies as *Innosuisse* provide best support in business coaching to survive the first critical years.

### Roll-Outs

It makes sense to keep access to the experts' know-how when they become retired. Some companies ask retired colleagues to take care of patents, or offer to be members of a taskforce to solve unexpected internal problems. But this is psychologically critical, and retired experts should better look for options to continue their creativity, and to this purpose the setting up of an own company for a limited period of time is an attractive possibility.

### Golden Rules to run a Roll-Out Firm

- It is a fact that you only can keep your professionalism in your previous working field. The difference is that you are now free to think about applications outside the business view of your former company that are attractive and challenging. The advantages of an own firm, such as a GmbH [1], are the deduction of investment and operating costs from tax, and the limited liabilty for risks up to a certain harmless amount of money.
- But don't be too innovative! Customers and their companies are only interested in new applications or products as long as they can be understood and managed by the their internal marketing and sales organizations.
- Your personal network is important, since contacts to companies must always go top/down. But no top manager will decide against his experts. This is probably the most difficult psychological barrier to penetrate the ‚clay layer' of middle management, who don't like external ideas.
- Concerning your own roll-out firm: try to minimize fixed costs. Instead of keeping a permanent staff, a loose network of retired colleagues is optimum. The team comes together when required and is paid on a time basis. Communication takes place virtually, so your experts can be spread all over the world. Such a cooperation can be very efficient, and even complex tasks can be professionally solved in a very short time, as will be shown next.
- Try to offer working demonstrators or even prototypes to your customer by cooperating with an institute of a FHS [2] or a specialized SME. A demonstrator is the best way to convince the middle management that your idea can be further developed to industrial maturity by them.

### Example: Neutron Microscope

Our team of freelancers for lens design, coatings, mechanical construction and production technology was asked by a group at PSI some years ago to develop a special optics for neutron microscopy. While in X-ray imaging metallic objects can be detected inside organic materials, it is the opposite case when using neutrons, as it allows to visualize e.g organic objects inside a metallic housing.

To this purpose the object is illuminated by a collimated beam of thermal/cold neutrons and its cast shadow is projected onto a thin scintillator crystal. The resulting fluorescence pattern is imaged onto a CCD-array with a high-performance microscopic lens (Fig. 1). Our team finished the complicated optic design within few months, including the intensive discussions of the manufacturing tolerance settings with a potential optics supplier.

1 Gesellschaft mit beschränkter Haftung (Limited liability company)

2 Fachhochschule, University of Applied Science

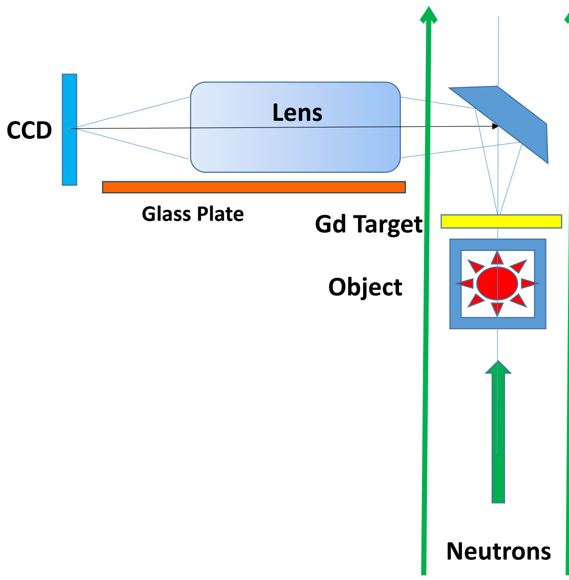



*Figure 1: Optical microscope to image the fluorescence light on a CCD from a neutron stimulated Gd target.*

The challenge for the optical layout is that even if the objective is placed outside the incident neutron beam, a certain exposure of the optical components by strayed neutrons can not be excluded. Since the optical design of the objective showed tight tolerance values for the glass materials, there must be certainty to what extent the refractive indices can change over a working period of 5 to 10 years by the neutron impact.

### Technical Details

The cold or thermal neutrons after having penetrated the object under test are registered by a special target sensor, using the fact that cold neutrons are strongly absorbed by the rare earth element gadolinium $^{157}$Gd. The neutron excitation causes fluorescence in the green spectral range. The scintillator target sensor is a 2D-array of 2000 light pipes of 5 µm diameter, doped with Gd. The telecentric objective with F-No = 1.25 images the Gd-target of size 10 × 10 mm$^2$ onto a CCD of size 50 × 50 mm$^2$, characterized by a P43 spectral Illumination profile. Details of the project including system aspects can be found in [3] (Fig. 2).

### Glasses

If a glass is exposed to radioactive radiation as in space projects, so-called radiation-resistant glasses must be used instead of normal glasses. They are stabilized by the addition of cerium oxide. There is a lot of experience with high-energy particles or gamma radiation, but less with neutrons.

The reason is that thermal neutrons are strongly absorbed by the isotope Borium $^{10}$B, which is as $B_2O_3$ an important component of many optical glasses. The glasses turn brown under neutron irradiation by the reaction $^{10}$B(n,α)$^7$Li producing α-particles of about 2.3 MeV, but even worse, the refractive indices will change. Since it was unclear to which amount this would happen, the risk of radiation damage had to be minimized by the optics design. First the objective was placed outside and perpendicular to the incident neutron beam, which led to a minimum distance between Gd sensor and front lens element of 60 mm, and to a free diameter of the first lens of 76 mm. (Fig. 2) This resulted in a large construction size of the optics, and to the tight tolerance values already mentioned. Since neutrons are also scattered at the object under test, we chose as second step *fused silica* as material for the first three lenses, which is also radiation resistent for neutrons. For the following lenses, however, one needed different glass materials to achieve apochromasy.

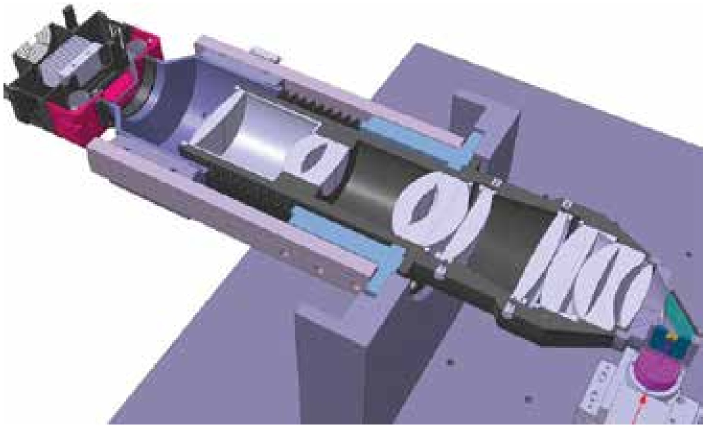


*Figure 2: Schematic of cross-sectional view of the PSI Neutron Microscope showing (from right to left): the sample holder (pink), adaptor with the scintillator screen (green and yellow), the dedicated magnifying objective composed of 13 individual lenses (light grey), and a CCD detector (red and black).*

Since PSI estimated a neutron flux of $10^7/(cm^2 \cdot s)$ (including 10% scattering at the target) at their location of the sample, which would lead to a fluence of Ø = $6.3 \cdot 10^{14}/ cm^2$ for a service life of 10 years, assuming 20% under beam exposure, the third step of our optical layout was to select for the remaining lenses boron free glass material [4].

However, it was surprising that some glasses of our first design as N-LAF2, N-LAK22, N-SK16, N-PSK3 from SCHOTT contained up to 20 weight% of $B_2O_3$ (Fig. 3). As it could not be excluded that the objective type would also be used at other neutron locations with stronger neutron intensities and larger beam diameters, we decided as third step to redesign the objective using glasses that were low in boron oxid as N-SK2 and N-BAK2 with maximum 4.8 weight% of $B_2O_3$.

The absorption of thermal neutrons by borium produces α-particles of about 2.3 MeV by the reaction $^{10}$B(n,α)$^7$Li. The absorption cross section is $\sigma_{WQ} = \mu(^{10}B) \cdot 3837$ barns = 768 barns using the isotope abundance factor $\mu(^{10}B) = 0.2$ (Fig. 4) [5].

Then the absorption constant in N-BK7 is $k_{N\text{-}BK7} = \sigma_{WQ} \cdot N_{Vol} = \sigma_{WQ} \cdot \eta_1 \cdot \eta_2 \cdot \rho_{N\text{-}BK7} \cdot N / A(B)$, using the Avogadro-Constant $N = 6.02 \cdot 10^{23}$/Mol. The atomic weight of borium is A = 10.8 g/Mol leading to $\eta_1 = A(B_2) / A(B_2O_3) = 21.6$ g / 69.6 g = 0.31. The factor $\eta_2 = 0.14$ describes that N-BK7 includes

3 *Progress in High-resolution Neutron Imaging at the Paul Scherrer Institut – The Neutron Microscope Project*, Pavel Trtik, Eberhard H. Lehmann, Neutron Imaging & Activation Group, Laboratory for Neutron Scattering & Imaging, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland, VI European Conference on Neutron Scattering (ECNS2015) IOP Publishing, Journal of Physics: Conference Series 746 (2016) 012004 doi:10.1088/1742-6596/746/1/012004

4 Private communication of E. H. Lehmann (PSI), 18.02.2014

5 *Precision Determination of the Slow Neutron Absorption Cross Section of B10*, G. J. Safford, T. I. Taylor, B. M. Rustad, and W. W. Havens, Jr., Phys. Rev. 119, 1291 – Published 15 August 1960

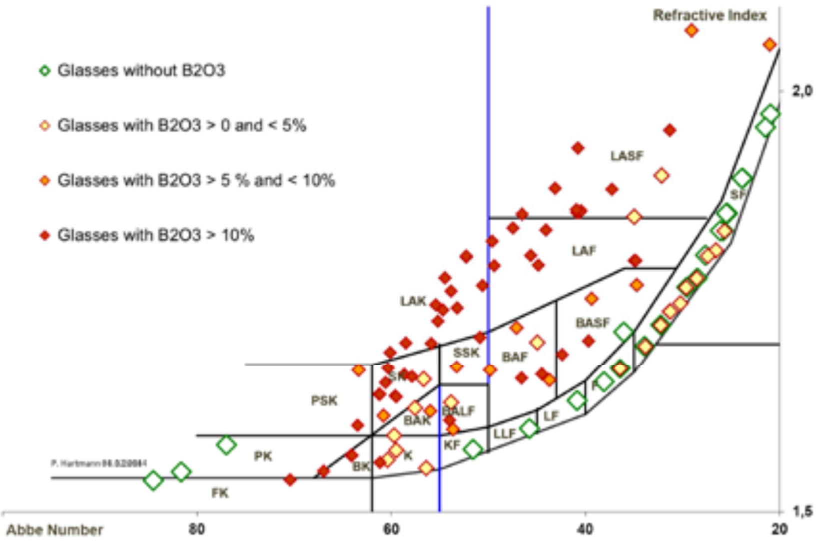
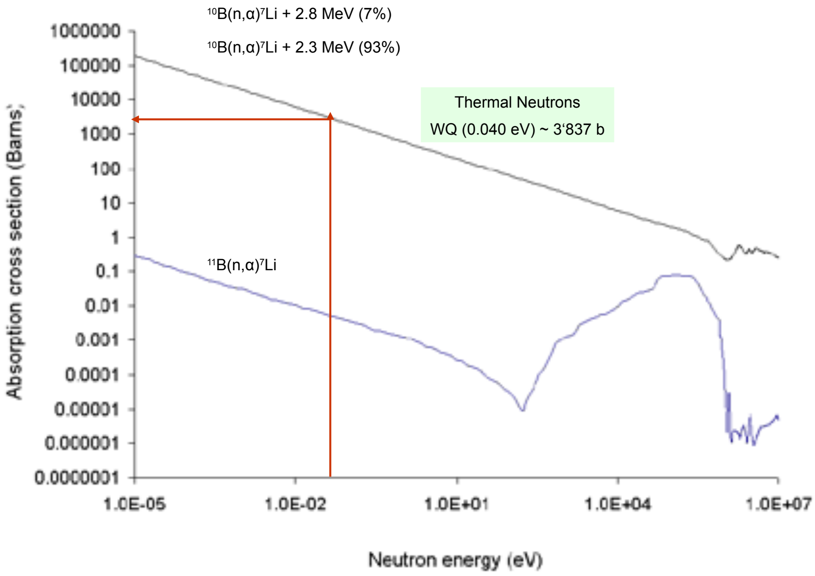



*Figure 3: Abbe Diagram, indicating the amount of $B_2O_3$ in optical glasses (Private communication of P. Hartmann, SCHOTT AG, 25.2.2014)*




about 14 weight% $B_2O_3$, and $\rho_{N\text{-}BK7} = 2.5$ g/cm³ is the density. This leads to $k_{N\text{-}BK7} = 768 \cdot 10^{-24}$ cm² · 0.31 · 0.14 · 2.5 g/cm³ · 6 ·10²³ / 10.8 g = 4.6 cm⁻¹.

The neutron intensity ratio I(d) / I(0) = exp(-$k_{N\text{-}BK7}$ · d) would drop to 50% for $d_{0.5} = -\ln(0.5) / k_{N\text{-}BK7}$ = 1.5 mm. This is in good agreement with experiments at PSI-SINQ which showed a transmission loss of approximately 50% of a 1.8 mm thick glass disc made of borosilicate glass N-BK7 when irradiated with a neutron fluence of $5.7 \cdot 10^{15}$/cm² [6]. A 10 mm thick glass plate made of N-SK16 with a boron content of 19.3 weight% would be sufficient to shield the objective (Fig. 1).

Part of the lens design work was to discuss the design, including the tolerances for components and assembly, with potential suppliers in Switzerland, the Czech Republic and Germany. This includes the mechanical accuracy specifications (centering angles, glass thicknesses, air gaps) and narrower specifications of the optical glass parameters such as refractive indices and dispersion values. Here it became apparent that the companies investing in modern production technology allowed tighter mechanical tolerances in order to be able to accept standard glass tolerances. This gave them a cost advantage when submitting tenders.

6 Private communication of E. H. Lehmann (PSI), 15.07.2013

*Figure 4: Absorption cross factor $\sigma_{WQ}$ of borium isotopes as function of neutron energy.*

# Geopolitical Olympiads

## A Review of the 30th Edition of the Swiss Physics Olympiad

*Louis Zünd, Physik Olympiade*

Why did a delegation consisting of four young Swiss physicists from Switzerland participate at the Northern-Baltic Physics Olympiad (NBPhO), knowing that this competition is usually open for talented youth from Estonia, Finland, Latvia as well as Sweden? And why did half of usually participating countries abstain from this year's International Physics Olympiad (IPhO), among them Switzerland which did not join the competition for the first time after a long series of uninterrupted participations? And how are these two puzzling facts connected to each other? The short answer is geopolitics. The long answer follows in this article trying to establish the idea that despite their timeless and incontestable nature the discipline of physics and perhaps even more astonishingly young people challenging themselves in that very natural science are not isolated form events happening in the rest of society. That is to say that Physics Olympiads can also be political or to put it the other way round, they are also subject to political issues.

However, let us begin from the very beginning which dates back to August 2023. As every year, the first round of the Swiss Physics Olympiad was launched. In a short online exam Swiss students could prove their skills and knowledge of physics in questions ranging from simple mechanics to quantitative guessing. The online exam was indeed open for entire classes participating during their lessons or private persons in the case of students participating individually. By the end of September a new record of participants was reached. Following a trend initiated already the years before, the total number of students taking part in the first round of the Physics Olympiad almost excelled the symbolic value of one thousand participants. Out of these a bit less than two hundred were selected to pursue the competition in the regional finals taking place simultaneously in Bern, Lausanne and Zürich. Twenty-eight of them scored so well in a couple of theoretical problems that they qualified for the national finals which took place as usual at Neue Kantonsschule in Aarau in early spring of this year. Again, along with this additional step of more refined selection, the exam questions became longer and more demanding. To give some examples, the finalists had to theoretically analyse the decay of pions and work on thermoelectrical effects in an experiment of three hours duration. For sure, the examination was challenging, however, the capacities and competences of the young physicists were even greater, resulting in brilliant performance during the national finals. The best of the best were then given the possibility to continue the course even further by joining an international competition.

*A participant solves a theoretical question as part of the national finals of the Physics Olympiad. (© Markus Meier)*

It is at this point that things became different than usual or, in other words, that the effect of geopolitics on such a seemingly innocent and unproblematic domain, as is the case for Physics Olympiads, became so evident that it could not be denied any further. Indeed, the International Physics Olympiad was planned to take place in Isfahan, Iran, where it eventually was also executed. However, since the Swiss Federal authorities strongly discouraged from travelling to Iran, the board of the Swiss Physics Olympiad decided to abstain from the IPhO as long as it was to take place in Iran. As a consequence, together with other delegations the Swiss Physics Olympiad tried to convince the organizers to set up an alternative event. Among the propositions were a second venue in a different country. Nevertheless, the organizers of the 53rd edition of the International Physics Olympiad did not relent. As soon as this became clear, it was evident for the Swiss delegation that they needed to look for an alternative event by themselves. Two ideas were generally imaginable: either all the countries abstaining from the IPhO taking place in Iran would organize some common alternative Olympiad or every country would need to find their own way. Out of lack of time the first option was never seriously engaged. Thus, the Swiss Physics Olympiad entered into contact with various regional Olympiads such as the Balkan Physics Olympiad (BPO) or as mentioned the Northern-Baltic Physics Olympiad. After some clarifying discussions, four Swiss students were finally granted guest participation at the NBPhO. This was lucky insofar as together with the Swiss delegation of the European Physics Olympiad (EuPhO), it allowed a total number of nine students to compete internationally, the five best finalists going to EuPhO and the finalist number six to nine going to NBPhO. What made the participation even the better were the outstanding scores marked by the Swiss team. At the NBPhO David Reichmuth won a bronze medal. Additionally, Felix Bergmann and Florian Brauss were both awarded a honourable mention, Noelia Cheridito being the fourth team member. The final balance in terms of noble metal gain during the EuPhO taking place in Kutaisi, Georgia, is even more remarkable. Elias Bauer and Kenneth Arockia, both having received the SPG Nachwuchsförderpreis/Prix de la Relève as a sign of their extraordinary achievement during the national finals, Fynn Krebser as well as Ferdinand Ornskov all received a bronze medal which made this attendance at an international contest the most successful in terms of medals won during the whole history of Swiss participation. On top of that Elias Baumann, the fifth team member, earned a honourable mention. In conclusion, however turbulent and uncertain the organizing of an alternative to the IPhO might have been, the results with which the Swiss delegation returned to their home country outweighed all challenges imposed by greater societal issues.

Medals and prices won are one thing. However, when listening to the participants of the Physics Olympiads, it never takes a long time until a profound fascination for physical phenomena, a deeper understanding of natural events or interpersonal aspects such as meeting like-minded people with a shared passion emerge as the most precious things they keep from their Olympic experiences. That might be also the point where the two ends meet, namely on the one hand the political side of science contests or perhaps science in general and timeless, unchangeable laws of physics and an almost as perpetual passion for the discipline on the other hand. Physics Olympiads are both influenced by other parts of society and characterized by a proper character resisting to those sudden shifts.


*The Swiss delegation at the European Physics Olympiad in Kutaisi, Georgia. From left to right: Elias Bauer, Kenneth Arockia, Elias Baumann, Fynn Krebser and Ferdinand Ornskov. (© Physik-Olympiade)*

# 7th Workshop on Energy for Sustainable Science at Research Infrastructures (ESSRI)

*Tomoko Muranaka, EPFL*

### Conference Overview

The ESSRI [1] workshop brings together every two years experts mainly from accelerator fields to discuss sustainable development and operation of research infrastructures (RIs). Mike Seidel, co-chair of the Applied Physics section of the SPS, is on the organizing committee. This year's workshop was organised by CIEMAT in collaboration with CERN, ESRF, DESY, PSI, ESS and ERF, held from 25 - 27 September 2024 in Madrid, with over 110 participants featuring four plenary and four parallel sessions. The opening session was led by Frederick Bordry who emphasised the need for tackling energy issues head on and set the stage for discussions on contributions from the RIs.

### Plenary Highlights

The plenary sessions featured prominent speakers on energy management and sustainability strategies of accelerator facilities (BNL, ICFA, ALBA, ISAS), but also challenges and opportunities in nuclear technology in Switzerland, offshore wind power projects in Spain, fusion research, and energy storage. In the first plenary, Ortwin Renn introduced the community to a new transdisciplinary approach to facilitating the energy transitions in Germany with case studies. He discussed the further potential of transdisciplinary studies in the energy transition and adaptation to hard science RIs. This social science lecture provided participants with a new perspective on accelerator facility operations and energy issues. Then, Allen Weeks, Vice-Chair of the European Research Infrastructure Consortium (ERIC) Forum, presented key findings from the community and recommendations on energy management. Their report advocates for the creation of crisis response for the RIs with a focus on sustainable practices. The Energy Gap plot [2] made by the HECAP+ initiative was firstly presented by Rakhi Mahbubani and subsequently recounted many times at the conference, indicating that this is the most pressing issue for research facilities.

### Parallel Sessions

The session ***Energy-Efficient Technologies, Experiments*** featured presentations on developments on superconducting / permanent magnets and accelerator components either for upgrading or for new projects. The $Nb_3Sn$ coatings on RF cavities showed very promising results for cryogenic power savings. The session's chair, Serge Claudet, stressed the importance of completing studies on environmental and societal impacts to make the new technologies truly sustainable alternatives, rather than a technical demonstration.

*S. Claudet summarized the session on energy-efficient technologies and experiments. Discussions ranged from detailed technical problems and solutions to the overall project strategy.*

1 Workshop website: https://agenda.ciemat.es/event/4431/

2 Environmental sustainability in basic research: a perspective from HECAP+: https://arxiv.org/abs/2306.02837


*ESSRI has been held in Europe every two years since 2011. This time the contributions from the American institutes made the conference more global and active.*

As the first time in the series of workshops, the session on ***Life Cycle Evaluation*** was held with a successful number of participants with a vital discussion session at the end. The session chair Denise Volker placed emphasis that we are in the process of understanding and of scaling up the analysis by sharing the various Life Cycle Assessments (LCAs) received from the different RIs. In order to obtain meaningful results, it is necessary to build up a database of specific components that are particularly used in RIs, and to set boundaries on what and to what extent is an important element. The importance of conducting LCAs from the pre-project design stage was also identified.

In the session of ***Energy and Sustainability on Future Research Projects***, opportunities to reduce energy consumption and greenhouse gas emissions in current and future RIs were presented in detail; the large scale heat pump in BNL to heat on-campus buildings by compressing low grade waste heat from the electron-ion collider, the electric power analysis and simulation tool in KITTEN and the plan to add battery storage were just a few examples. Thomas Roser reiterated that the RI's, as publicly funded facilities, need to lead by example in energy reduction.

The session ***Energy management at Research Infrastructures*** chaired by Roberto Losito delved into energy and other natural resources issues, for example, development of sustainability metrics of research infrastructures, study on future operation scenario and sensitivity as a function of availability of resources and carbon cost, forecasting helium consumption, and decarbonisation of the concrete industry. With regard to development of waste heat recovery, the CERN programmes collaborating with local communities as well as the internal site, and the EU project FlexRICAN were shared.

**Conclusion and Future Outlook**

The workshop closed with remarks from the chair J. M. Pérez who reflected the key discussions, particularly emphasizing the positive outcome in technical development and observed trend such as public-private approaches. Areas for improvement were highlighted as continuing to improve and update the portfolio of critical technologies, developing student programmes, and importance of involvement from space research infrastructures.

The organizers announced that the next ESSRI will take place from 30 September to 2 October 2026, in Salerno, Italy, promising continued dialogue on these critical issues.

# Kurzmitteilungen - Short Communications

## Jost Bürgi-Symposium, 26. April 2025

The program will start with a talk about Benjamin Bramer, a relative and foster son of Bürgi, giving some insight into Bürgi's private and scientific life. It is followed by five presentations on the topic ***Clocks***, closely associated with the name of Bürgi.

*https://www.jostbuergi.com/symposium-2/*

***Venue:*** Kronensaal, Hauptgasse 2, 9620 Lichtensteig

| Expert-Workshop | |
|---|---|
| 10:00 - 10:45 | *Zu Leben und Werk von Bürgis Ziehsohn Benjamin Bramer (1588-1652)*, **Peter Ullrich**, Universität Koblenz |
| 10:45 - 11:30 | *Wie entstehen meine Uhren?*, **Miki Eleta** [1] |
| | ***Break*** |
| 11:45 - 12:30 | *Timekeeping before the pendulum: on the controversies around Verge and Foliot machines*, **Robert Cailliau** [2] |
| | ***Lunch*** |
| ***Clocks, from Bürgi's time to the modern age*** | |
| 13:45 - 14:25 | *Die sogenannte Horizontale Tischuhr und das Wandern von Uhrmachern und Formen im 16. und 17. Jahrhundert*, **Peter Plassmeyer**, Staatliche Kunstsammlungen Dresden |
| 14:30 - 15:20 | *Vom mechanischen Zeitmesser zum Luxusgut*, **David Seyffer**, IWC Schaffhausen [3] |
| | ***Break*** |
| 15:35 - 16:15 | *Atomuhren*, **N.N.**, CSEM Centre Suisse d'Electronique et de Microtechnique, Neuenburg |

1 *https://www.mikieleta.ch/de/startseite/*

2 Robert Cailliau and Tim Berners-Lee developed hypertext software at Cern in 1990, which later led to the creation of the World Wide Web.

3 IWC JOURNAL: Besuch in den IWC Archiven: *https://www.iwc.com/ch/de/articles/journal/iwc-archives.html*

# Warum rechnet Jost Bürgi bei seinen Logarithmen mit 9 signifikanten Ziffern?

*Fritz Heiniger*

**Zusammenfassung** [1]

*Warum rechnet Jost Bürgi bei seinen Logarithmen mit 9 signifikanten Ziffern? Er und C. Rothmann wollten die Rektaszension der Sterne über eine genaue Zeitmessung in Sternzeit ermitteln. Diese sollte dann möglichst genau in Winkelgrade – Winkelminuten umgerechnet werden, ohne irgendwelche Rundungsfehler, daher vorausschauend die extrem hohe Anforderung an die Rechengenauigkeit bei den Logarithmen. Zum Tragen kam diese Genauigkeit aber nicht, denn die Zeitmessung blieb, trotz der beträchtlichen Fortschritte Jost Bürgis in Richtung Sekundenuhr, hinter den Erwartungen zurück.*

### Motivation von Jost Bürgi in Hinsicht auf einen verbesserten Sternkatalog

*Figur 1: Sekundenuhr um 1580 mit wenig Verzierungen, ein Messinstrument.*

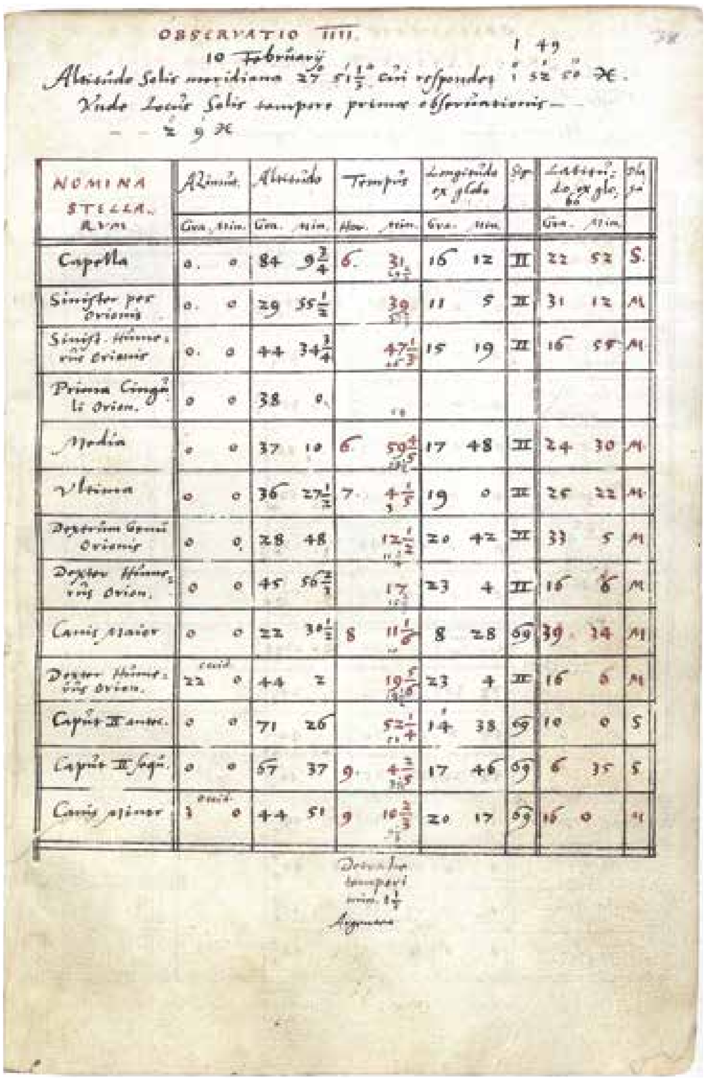
Die Anstrengungen von Jost Bürgi um eine höhere Rechengenauigkeit, sowie um die Verbesserung der Messinstrumente und Uhren, gingen alle in die gleiche Richtung: Der Kasseler Stern-Katalog von Landgraf Wilhelm IV sollte der beste seiner Zeit werden – und er wurde es schliesslich auch. Dabei massen der Astronom und Mathematiker Christof Rothmann und Jost Bürgi tatsächlich die Rektaszension der Sterne in Sternzeit mithilfe eines Quadranten von Jost Bürgi und mit Hilfe der von Bürgi verbesserten Sekundenuhr (Figur 1).

Man verfügt noch heute über einen Teil der Original-Messjournale aus den Jahren 1585 - 1587 von Rothmann und Bürgi.

Zum Einsatz kam der von Bürgi modifizierte Quadrant. Er war so aufgestellt, dass der 90°-Bogen genau im Meridian, also in Nord-Süd-Richtung stand. Wenn der Beobachter einen hellen Stern im Visier hatte, ging dieser notwendigerweise durch den Meridian, was bedeutete, dass man seine höchste Höhe über dem Südhorizont und zugleich die Zeit des Durchgangs messen konnte. Daraus ergab sich dank Kenntnis der Höhe des Himmelsäquators in Kassel einerseits die Deklination des Sterns, andererseits dank genauer Kenntnis der Referenz-Sternzeit [2] am Beobachtungsort und dank den präzisen Uhren von Jost Bürgi auch die Rektaszension.

Diese präzisen Uhren von Bürgi waren sogenannte Verge & Foliot – Uhren mit der von Bürgi erfundenen Kreuzschlag-Hemmung, die aber in Sonnenzeit geeicht waren. Die Messung der Rektaszension war dann eigentlich einfach: Man richte eine Visiervorrichtung in die Nord-Süd-Richtung aus und messe den Zeitpunkt in Sonnenzeit des Durchgangs eines Sternes durch den Meridian.

Zu diesem Zeitpunkt entspricht die Rektaszension des Sternes gerade der Durchgangszeit, umgerechnet in Sternzeit. Um weiter die Sternposition dann auf eine Bogenminute genau zu erhalten, muss man die Sternzeit in Winkelgrade umrechnen. Man kann aber auch gleich direkt die Sonnenzeit in Winkelgrade umrechnen, ohne Umweg über die Berechnung der Sternzeit. Es entsprechen 1 Sterntag = 86'164.09 Sonnenzeit-Sekunden ziemlich genau dem Winkel 360 ° = 21'600 ' Bogenminuten. Die gewünschte Genauigkeit der Sternvermessung von 1 Bogenminute braucht also eine Messgenauigkeit der Sonnenzeit von ca. 4 Sekunden. [Der Umrechnungsfaktor von Sonnenzeit in sec zu Bogenminuten beträgt 0.25068448 (8 Signifikanten) und der Umrech-




*Figur 2. Journalseite von den Messungen in Kassel. In der Spalte ganz links jeweils der Name des beobachteten Sterns. In der dritten Spalte "Tempus" sieht man die Zeitmessung eingetragen. Ganz fein darunter offenbar die Messzeit einer zweiten, nicht genau gleich kalibrierten Uhr.*

1 Dieser Artikel erschien zuerst auf https://www.jostbuergi.com. Wir danken dem Autor für diese adaptierte Version.

2 Am Ort des Frühlingspunkts, auf den man die Messung der Rektaszension bezieht, ist ja kein Stern, den man als Referenz hätte mit einmessen können.

nungsfaktor zurück von 1 Bogenminute in 1 Sekunde Sonnenzeit beträgt 3.98907824 (9 Signifikanten)].

Es würde aber ausreichen, hier mit 5 höchstens 6 Signifikanten zu rechnen, um die gewünschte Genauigkeit zu erreichen.

Viel kritischer war es wohl, in der Zeitmessung die 4 Sekunden Genauigkeit zu erreichen. Die Zeiteinträge im Messjournal von Fig. 2 sind denn auch höchstens auf Bruchteile von Minuten genau. Das Verfahren durch Zeitmessung die Rektaszension der Sternörter zu bestimmen, ist erst nach der Entwicklung der Harrison H4 Marine Chronometer für die britische Seefahrt ein Standard geworden. Bürgi war hier seiner Zeit weit voraus.

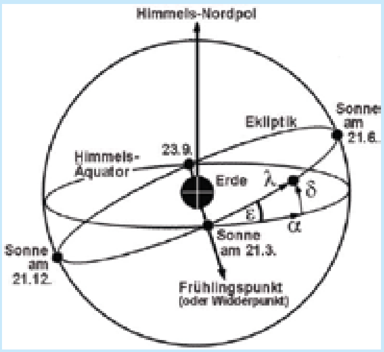
Tycho Brahe ist denn auch bei der direkten Messung der Rektaszension der Sternörter über die Winkel mit 5 signifikanten Ziffern ausgekommen und für die Berechnung der Planetenbahnen durch Kepler hat das offenbar auch ausgereicht.

**Horizontal-System**

Das Horizontal-System ist das jedem Himmelsbeobachter am besten vertraute Koordinatensystem. Er befindet sich in dessen Ursprung und der Horizont ist die Bezugsebene. Der Winkel über Horizont zum Himmelskörper ist dessen Höhenwinkel (Elevation) und die Abweichung des Punktes, in dem der Vertikalkreis durch den Himmelskörper den Horizont schneidet, von der Süd-Richtung ist das Azimut.

**Äquatorial-System**

Man denke sich die Erde umgeben von der Himmelskugel und den Erdäquator auf diese Himmelskugel projiziert als sogenannten "Himmelsäquator". Die Koordinaten eines Sterns in Bezug auf den Himmelsäquator heissen Rektaszension und Deklination, beide gemessen ab dem "Frühlingspunkt".




*Äquatorialsystem zur Sternbeobachtung*

Betrachtet man die Bahn der Sonne, so beginnt diese ab dem Durchlaufen des Schnittpunkts zwischen Himmelsäquator und Ekliptik (d.h. der Umlaufebene der Erde um die Sonne, projiziert auf die Himmelskugel) für einen Beobachter am Äquator oder irgendwo auf der nördlichen Halbkugel aufzusteigen. Das ist jeweils im Frühling um den 21. März der Fall, daher der Name "Frühlingspunkt". Der Himmelsnordpol steht dabei senkrecht auf der Ebene durch den Himmelsäquator. Um ihn dreht sich für einen Beobachter auf der Erdoberfläche der Sternenhimmel.

**Messung von Sternörtern**

Das rotierende Äquatorialsystem ist im Gegensatz zum Horizontalsystem unabhängig vom Ort des Beobachters. Bezieht man sich auf dieses System, so sind die Positionsangaben für einen Himmelskörper allgemein gültig, egal wo und wann die Beobachtung stattgefunden hat. Sternörter in Sternkarten werden also idealerweise in Rektaszension und Deklination angegeben. Die Rektaszension wird dabei üblicherweise im Zeitmass statt im Bogenmass ausgedrückt. Die Angabe im Zeitmass nimmt Bezug darauf, dass die scheinbare Rotation der Sterne um die Erde proportional zur Zeit ist und Zeitdifferenzen einfacher als die Winkel bestimmt werden können. Wenn ein Stern z. B. am Äquator eine Sternstunde nach dem Frühlingspunkt aufgeht, so hat er die Rektaszension 1h, entsprechend etwas mehr als 15° (in einem Sterntag zu 86164.09 s = ca. 23 Std. 56 Min. bewegen sich die Sterne nämlich scheinbar auf einem vollen Kreis mit 360°).

# Kurzmitteilungen - Short Communications

## PiA – Physik im Advent

**Inspirierende Experimente für Schüler und ganze Klassen vom 1. bis zum 24. Dezember 2024**

*Physik im Advent* [1] ist ein spezieller Adventskalender, bei dem Jungforscherinnen, Jungforscher, Schulklassen sowie alle die Lust haben, 24 physikalische Rätsel und Experimente zum Selberexperimentieren anpacken.

Vom 1. bis zum 24. Dezember wird jeden Tag per Video-Clip ein Experiment zum Nachmachen vorgestellt. Auf der Webseite können die Fragen im Laufe desselben Tages beantwortet werden, und am darauffolgenden Tag wird die Auflösung ebenfalls per Video gezeigt.

Die Teilnahme bei *Physik im Advent* ist gratis und steht allen offen. Für Schülerinnen und Schüler aus der ganzen Welt ab dem Alter von 11 bis 18 Jahren, einzeln, als Klasse oder auch für ganze Schulen, gibt es zahlreiche Preise zu gewinnen. Jüngere und ältere Schülerinnen und Schüler, Eltern, Studierende und Lehrkräfte sind auch herzlich eingeladen, können aber bei der Preisverteilung nicht berücksichtigt werden.

Darüber hinaus fördert die Schweizerische Physikalische Gesellschaft Preise für Schulmannschaften und für einzelne Schüler und Schülerinnen, die an Schweizer Schulen eingeschrieben sind, in einer eigenen nationalen Verlosung. Es lohnt sich daher besonders, mitzumachen. Gesponsert werden die Schweizer Preise von der Schweizerischen Physikalischen Gesellschaft, der Akademie der Naturwissenschaften Schweiz, supermagnete.ch und der Metrohm Stiftung

*Kontakt: Gernot Scheerer, gernot.scheerer@hotmail.de*

1 https://physik-im-advent.de

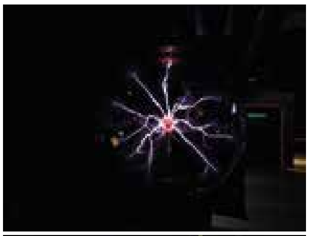
# Tagesausflug ins Technorama

**Bericht einer Gewinnerklasse des *Physik im Advent* 2023 Wettbewerbs**

Am regnerischen Freitag, dem 21. Juni 2024 hat unsere Klasse einen Ausflug ins Technorama gemacht. Die Eintritte dafür hatten wir bei einem Physikwettbewerb (Physik im Advent 2023) gewonnen. Es gab eine Organsisationsgruppe von fünf Kindern, welche die Workshops, den Tagesablauf, die Reise sowie die Elterninformation im Vorhinein sorgfältig geplant und dabei die Wünsche der Klasse berücksichtigt haben.

Als wir im Technorama ankamen, mussten wir zuerst 15 min warten, bis wir um 9 Uhr endlich reingehen durften. Bis dahin beschäftigten wir uns am Brunnen vor dem Gebäude. Im Technorama bekamen wir zuerst einmal ein Schliessfach für unsere Klasse. Dort konnten wir unsere Jacken und Rucksäcke hineinlegen. Schliesslich wurden wir von zwei Mitarbeitern des Technoramas - einem Mann und einer Frau - aus dem Technorama abgeholt. Der Mann erzählte uns, dass am Sonntagabend in das Technorama eingebrochen worden war. Also begaben wir uns in den Keller und sammelten dort Indizien (Hinweise) über den Tathergang. Wir gingen anschliessend in ein Labor, um die Beweisstücke zu untersuchen. An den verschiedenen Tischen konnten wir in Gruppen herausfinden, ob zum Beispiel das Blut auf dem Taschentuch, das wir gefunden haben, echt war oder nicht. Oder wir konnten Fingerabdrücke eines Glases nehmen, Erde genauer untersuchen und Haarproben unter dem Mikroskop anschauen. So konnten wir die Personen entlasten, die nicht für den Einbruch infrage kamen und den Täterkreis eingrenzen.

Nach dem Workshop legten wir eine Znünipause ein. Danach gingen wir in den zweiten Stock, wo wir vom Organisationsteam einen Gruppenauftrag bekommen haben.



Wir mussten ein Experiment auswählen, dieses fotografieren und einen kurzen Text dazu schreiben. Der Auftrag machte sehr viel Spass. Um 11 Uhr besuchten wir die Blitzshow. Diese ist sehr empfehlenswert für Kinder, die sich für Strom interessieren. Wir durften danach auch den ersten Stock in Gruppen genauer erkunden. Alle Knaben gingen in ein Spiegelkonstrukt, welches sie auch «ihre Base» nannten. Als wir von Eindrücken gesättigt waren, gab es eine Mittagspause. Weil der Regen nach dem Essen nachgelassen hatte und wir uns frei im Technorama bewegen durften, machten sich alle Kinder auf den Weg nach draussen. Dort gab es auch sehr viele spannende Stationen. Man konnte sich zum Beispiel vor eine Windmaschine stellen, was viel Spass machte.

Um 14 Uhr traf sich die ganze Schulklasse zum zweiten Workshop: «Kalt, kälter, schockfrosten»! Wir experimentierten im Labor mit Crushed Ice und durften anschliessend in 3 min Himbeereis mit flüssigem Stickstoff herstellen. Dieser Workshop machte grossen Spass und wir freuten uns darüber, dass wir das Eis am Schluss essen durften. Der Workshop hat unseren Tag im Technorama toll abgerundet und wir nahmen viele Eindrücke mit nach Hause.

Wir bedanken uns vielmals dafür, dass die SPG die Kosten für die Hin- und Rückreise für für diesen Ausflug übernommen hat!

*Lerngruppe MC aus Brütten*

Swiss Physical Society / Société Française de Physique

# Call for nominations for the Charpak-Ritz Prize 2026

The *French Physical Society* and the *Swiss Physical Society* have created a joint prize in 2016, the **Charpak-Ritz Prize** to highlight the tight relationship between the two Societies and to keep the memory alive of ***Georges Charpak*** and ***Walther Ritz*** who both have profoundly contributed to physics in their respective times.

The prize distinguishes exceptional contributions in physics or in its development to honour, in odd years, a physicist (or a small team of physicists) who has produced significant contribution in France, and, in even years, a physicist (or a small team of physicists) who has produced significant contributions in Switzerland.

We are inviting nominations for the **Charpak-Ritz Prize 2026** to honour significant contributions achieved in Switzerland. The nomination file shall comprise the usual items (CV, laudation, list of publications as well as the most important publications, reference letters, …). Self-nominations will not be considered and nominations of board members of the two Societies during their mandate are not accepted. The dossier shall be sent to the *Swiss Physical Society* in electronic format as pdf files with the mention "Nomination for the Charpak-Ritz prize 2026".

A short-list of the three best evaluated candidates will be sent to the *French Physical Society*, who will take the final decision.

**awards@sps.ch**

**Deadline: 31 May 2025**

The award will be given at the annual meeting of the *French Physical Society* in 2026.

# Ausschreibung der SPG Preise für 2025

Auch im Jahr 2025 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**
- 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**
- SPG Preis gestiftet von der Firma *Sensirion AG* für eine hervorragende Forschungsarbeit auf dem **Gebiet der Sensorik, Detektion und Überwachung**
- SPG Preis gestiftet von der Firma *ID Quantique* für eine hervorragende Forschungsarbeit auf dem **Gebiet der Quantenwissenschaften und -technologie**

Die SPG möchte mit diesen Preisen **junge** Physikerinnen und Physiker in der Frühphase ihrer Karriere auszeichnen, d.h. ab Beginn ihres Doktorats bis spätestens 5 Jahre nach Abschluss der Dissertation und vor Erhalt einer akademischen Festanstellung, bzw. bei einer Anstellung in der Industrie spätestens 5 Jahre nach Abschluss der Dissertation.
Die eingereichten Arbeiten müssen entweder in der Schweiz, oder falls im Ausland, von Schweizer Staatsbürgern, oder von Ausländern, sofern die Arbeiten aus Schweizer Fördermitteln zu mindestens 50% unterstützt werden, ausgeführt worden sein. Die Beurteilung der Arbeiten erfolgt auf Grund ihrer wissenschaftlichen Bedeutung, Qualität und Originalität.

Der Antrag muss folgende Unterlagen enthalten:

A) **Motivationsschreiben** des Kandidaten, welches eine auch für Nicht-Spezialisten verständliche Beschreibung der Arbeit, ihre Bedeutung für das Forschungsgebiet, sowie den persönlichen Beitrag des Kandidaten daran enthält.
B) **Lebenslauf**, einschließlich aber nicht beschränkt auf Ausbildung und Anstellungen, Preise, Führungsaufgaben und Forschungserfolge, eingeladene Vorträge, Patente, usw.
C) **Liste der wichtigsten Publikationen** (maximal 10).
D) 1 oder maximal 2 **Empfehlungsbriefe** (vom Betreuer der Dissertation und / oder einem unabhängigen Spezialisten).

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

**awards@sps.ch**

## Einsendeschluss: 01. März 2025

Die Preise werden an der gemeinsamen Jahrestagung 2025 in Wien überreicht. Das Preisreglement befindet sich auf *www.sps.ch*.

# Annonce des prix de la SSP pour 2025

En 2025, 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**
- 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**
- Le prix SSP offert par l'entreprise *Sensirion AG* pour un travail de recherche d'une qualité exceptionnelle dans le **domaine des capteurs, de la detection et de la surveillance**
- Le prix SSP offert par l'entreprise *ID Quantique* pour un travail de recherche d'une qualité exceptionnelle dans le **domaine de la science et des technologies quantiques**

La SSP distingue avec ces prix des travaux scientifiques exceptionnels de **jeunes** physiciens et physiciennes en début de carrière, à partir du début du travail de doctorat jusqu'à 5 ans après l'obtention d'une thèse doctorat et avant l'obtention d'un poste académique fixe, ou jusqu'à 5 ans après l'obtention d'une thèse doctorat pour les postes en industrie.
Les travaux soumis doivent avoir été effectués soit en Suisse, soit à l'étranger par des ressortissants Suisses, soit à l'étranger par des ressortissants d'autres nationalités, pour autant que 50% au moins des fonds soutenant la recherche citée soient d'origine Suisse. L'évaluation s'effectue selon des critères d'importance scientifique, de qualité et d'originalité du travail soumis à la compétition.

Une nomination complète contient:

A) Une **lettre de motivation** du candidat incluant une description du travail compréhensible par des non-spécialistes et soulignant son importance pour le domaine ainsi que la contribution personnelle du candidat.
B) Un **CV** comprenant au moins, sans devoir s'y limiter, l'éducation, les expériences professionnelles et les compétences du candidat, les prix obtenus, les tâches de supervision ainsi que les réalisations en matière de recherche, les conférences invitées, les brevets, etc.
C) Une **liste des publications les plus pertinentes** (dix au maximum).
D) Une à deux **lettres de soutien** au maximum (provenant du directeur de thèse et / ou d'un spécialiste indépendant).

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

**awards@sps.ch**

**Délai: 1 mars 2025**

Les prix seront attribués à la réunion annuelle commune qui se tiendra en 2025 à Vienne. Le règlement des prix se trouve sur www.sps.ch.