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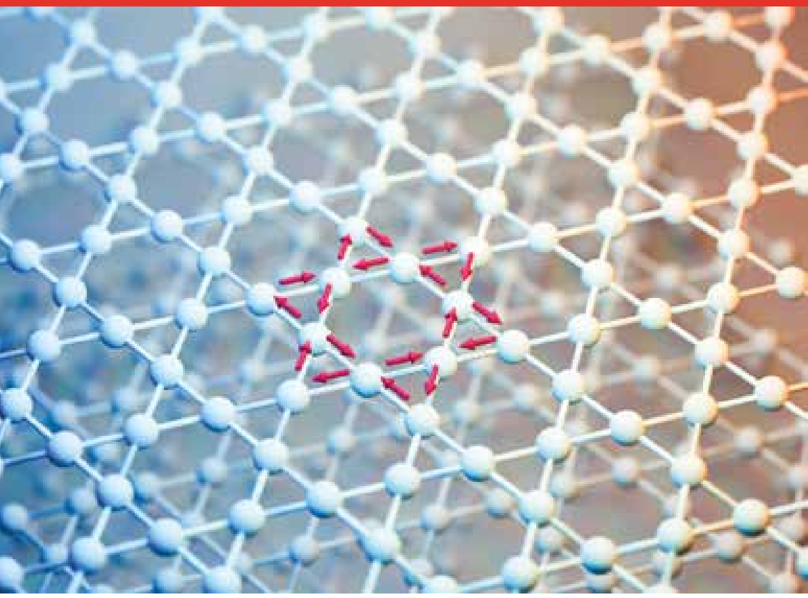

Arrangement of atoms in a Kagome lattice, as seen in a recently discovered class of materials that are superconducting and show an intriguing charge order. Read the article on p. 27
(Picture: artist´s impression: Paul Scherrer Institute/ Mahir Dzambegovic).

NASA's James Webb Space Telescope has produced the deepest and sharpest infrared image of the distant universe to date. Known as Webb's First Deep Field, this image of galaxy cluster SMACS 0723 is overflowing with detail. Credits: NASA, ESA, CSA, and STScI

Two scientists evaluate the best instrument configuration of the neutron spectrometer ThALES at the Institut Laue-Langevin to gain new insight into the microscopic couplings in high-temperature cuprate superconductors. More on p. 31. © Institut Laue-Langevin (www.ill.eu)

The Sun's south pole as seen by the ESA / NASA Solar Orbiter spacecraft (λ = 17 nm) on 30 March 2022, just four days after passing its closest point yet to the Sun. More on p. 54. Source: ESA

The SPS General Assembly appointed Prof. Felicitas Pauss as honorary member (see also SPG Mitteilungen Nr. 67, p. 10). A review of the annual meeting can be found on p. 8.

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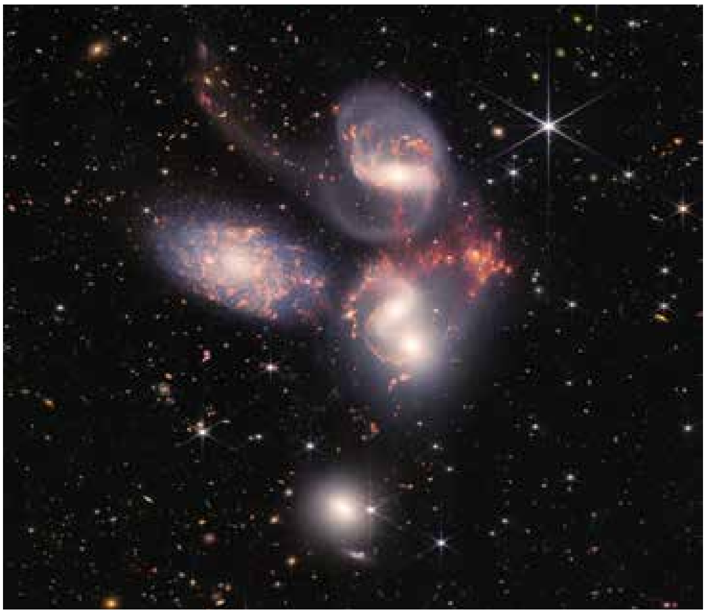
Editorial

Kann der Physikunterricht an Schulen bei der Krisenbewältigung einen Beitrag leisten?

Alice Kohli, Bernhard Braunecker



Stephan's Quintett, eine visuelle Gruppierung von fünf Galaxien, aufgenommen vom James Webb Weltraum-Teleskop. Dieses Mosaik ist das bis jetzt grösste Bild, zusammengesetzt aus fast 1000 Einzelbildern mit über 150 Millionen Pixeln zeigt es bisher nie gesehene Details. Quelle: NASA, ESA, CSA, und STScI.

Die neusten Bilder des James-Webb-Teleskops lassen die Probleme auf unserer Erde nichtig erscheinen. Was ist schon eine globale Klimakrise angesichts der unfassbaren Dimensionen des Weltalls? Was zählt ein weiterer Krieg angesichts der immensen Zeitspanne unserer Geschichte? Die Physik lehrt Demut. Doch sie soll nicht zur Tatenlosigkeit verführen, im Gegenteil. So klein unser Planet, so kurz unsere Verweildauer auf ihm – wer sich etwa die Präzision elektrischer Signale entlang unserer Nervenbahnen oder die schiere Perfektion des Ionentransports durch eine Zellmembran vergegenwärtigt, wird sich dafür einsetzen wollen, dass das Leben auf dieser Erde so lange als möglich erhalten bleibt. Es müssen daher alle Möglichkeiten genutzt werden, die existenziellen Auswirkungen aktueller Krisen auf die Menschheit zu minimieren. Das erfordert eine Stärkung der mentalen Einstellung, und deshalb zeigen wir im Folgenden, dass besonders der Physikunterricht an Schulen beitragen kann, dass junge Menschen auf Krisensituationen nicht irrational reagieren, sondern die neue Lage nüchtern analysieren und geeignete Verhaltensmassnahmen für sich treffen.

Induzierte und spontane Auslösung von Krisen

Bei der Klimaerwärmung, der Energieknappheit oder bei viralen Pandemien ist vieles neu und vieles unklar. Die oft in schrillem Ton geführten Diskussionen darüber verunsichern die Bevölkerung und mit ihr die politische Führung. Das verschärft sich dann noch dramatisch, wenn urplötzlich kriegerische Aktionen von vermeintlich befreundeten Staaten durchgeführt werden und etablierte (Handels-) Beziehungen in Frage stellen. Diese Unwägbarkeiten müssten jedoch zu keiner Krise führen, wenn man auf die Alarmzeichen, also auf die vom Verursacher erfolgten Verletzungen demokratischen Verhaltens wie die unkontrollierte Alleinherrschaft einer bestimmten Person auf Lebenszeit, die Verfolgung von politisch Andersdenkenden und die massive Einschränkung der Medienfreiheit angemessen reagiert und sich auf weitere Verletzungsschritte vorbereitet hätte.

Bei der Klimaerwärmung, der Energiekrise und der Corona-Pandemie hingegen ist dies anders, sie haben ihre Ursachen im kollektiven Umweltfehlverhalten, im globalen Raubbau von Ressourcen, beziehungsweise in der zu starken Vernetzung der Menschen. Aber auch hier ging eine sukzessive Akkumulation lokaler Konfliktpotentiale voraus, die keiner Ernst nahm, bis ab einer bestimmten kritischen Schieflage spontan irgendwo auf der Welt die Krisenauslösung erfolgte.

Kollektive Phänomene

Wie nun sowohl eine politisch induzierte *top down* wie auch eine spontane *bottom up* Auslösung sich innerhalb korrelierter Kollektive ausbreiten kann, kennt man bestens aus der Physik. Je nach Art und Stärke der Wechselwirkung zwischen den einzelnen Elementen kann es zu mehr diffusen Ausbreitungsabläufen kommen, aber auch zu resonanten Rückkopplungseffekten oder sogar zu interferenzartigen Verstärkungen wie bei einem Tsunami. Es wäre daher vorteilhaft, wenn in der Bevölkerung und vor allem bei den politischen Entscheidungsträgern ein solides Grundwissen über physikalische Kollektivvorgänge vorhanden wäre, um aus den Verlaufsmustern einer Krise die Art der inneren Kopplung zu erkennen und darauf geeignet zu reagieren.

Die Fähigkeit, Ursachen, Verbreitung sowie Kurz- und Langzeitwirkungen einer Krise realistisch einzuordnen und abzuschätzen, ist besonders für junge Menschen wichtig, denn sie leiden am stärksten unter den Einschränkungen ihrer sozialen Beziehungen, aber noch viel stärker unter den möglichen Auswirkungen auf ihre Zukunft. Auf ihre Fragen, wie sie zum Beispiel zur Eindämmung gegenwärtiger Infektionen beitragen könnten und auf welche Veränderungen ihres Lebensstils sie sich in Zukunft einstellen müssten, erwarten sie nachvollziehbare Antworten. Der Gesellschaft wiederum muss daran gelegen sein, dass junge Leute hinreichend gut informiert sind, um einen kritischen Abstand zu populistischen Krisenlösungen zu halten, die nur auf eine Destabilisierung der politischen Zustände abzielen.

Zur wichtigen Rolle des Physikunterrichts

Der Physikunterricht an Schulen ist gut geeignet, typische Krisenmuster mit den Schülerinnen und Schülern anhand von Analogien aus dem Alltag zu hinterfragen. So kann man die Ausbreitung einer Infektion am Beispiel der Wärmediffusion gut erklären. Wenn ein kalter Körper urplötzlich in eine wärmere Umgebung gebracht wird, braucht es eine gewisse charakteristische Diffusionszeit, bis er vollständig aufgewärmt ist. Mittels der Methode der Finiten Elemente kann man zeigen, dass die Diffusionszeit vom Verhältnis Wärmeleitung zu Wärmekapazität abhängt. Um die Ausbreitung zu verlangsamen, braucht es eine geringe Wärmeleitfähigkeit, sprich wenig Kontakt zwischen den Elementen, also in Pandemiezeiten besser eine Schutzmaske tragen. Hingegen sollte die Wärmekapazität gross sein und ihr könnte man mit etwas Überredung die Rolle einer Impfung zuweisen. Sollte umgekehrt eine schnelle Durchmischung der Bevölkerung ratsam sein wie bei einer Polioimpfung, entspräche dies im thermischen Modell einem aktiven Heizimpuls, allerdings mit der Gefahr einer lokalen Überheizung, also einer Überreaktion verbunden [1].

Bei der Behandlung der Energieversorgungskrise könnte man den Schülern anhand eines PID-Reglers [2] erklären, dass man beide, erneuerbare und sogenannte Bandenergiequellen benötigt, um eine stabile Versorgung zu gewährleisten. Letztere könnten fossile Techniken verbunden mit aktiver CO_2 Bindung sein, aber auch moderne nukleare Varianten. Den Schülern ist sicher klar, dass aus Effizienzgründen eine Bandenergiequelle möglichst mit konstanter Leistungsabgabe betrieben werden muss. Also braucht es ein PID-Regelsystem, dass primär die Fluktuationsdefizite der differentiellen Quellen, also der Erneuerbaren ausgleicht, hingegen den verbleibenden Rest speichert oder exportiert, das heisst in Netzwerken kreisen lässt. Das komplizierte Regelsystem kann man den Schülern im Physikunterricht anschaulich mit einer Analogie im Alltag zeigen: Bei einem Auto muss jedes der vier Räder differentiell angesteuert werden, um spontan zu beschleunigen, zu lenken, um zum Beispiel Schlaglöchern auszuweichen, während der Motor von diesen abrupten Aktionen entkoppelt sein muss. Er soll konstante Leistung erzeugen, also mit konstanter Drehzahl vor sich hinbrummen. Das zentrale Motormanagement, ein Drehmomentwandler, verteilt die aktuell vorhandene Motorleistung primär nach Bedarf an Drehmoment an die Räder, den Rest an einen Generator zur Batterieaufladung. Anhand dieses für Schüler nachvollziehbaren Beispiels ist zu hoffen, dass junge Leute sich nicht mehr durch überholte ideologische Glaubenskämpfe ‚Erneuerbare versus nukleare Technologien' verunsichern lassen, sondern ganzheitlich denkend an der Realisierung stabiler, alle Varianten einbeziehender Lösungen mitwirken.

Und ebenso könnte man der oft gespürten Frustration junger Leute über die scheinbar ungeschickten und widersprüchlichen Massnahmen der Politik in der Pandemie, die erhebliche Einschränkungen für sie mit sich bringen, entgegenwirken. Denn auch geschicktes *Durchwursteln* kann eine durchaus leistungsfähige und wissenschaftlich begründbare Methode sein [3]. Sie wird im Artikel von R. Boutellier auf Seite 57 beschrieben, und sie liesse sich sicherlich didaktisch gut vermitteln.

1 https://www.sps.ch/artikel/physiker-in-der-industrie/a-useful-sw-tool-for-thermal-estimations-in-optics-5

2 https://de.wikipedia.org/wiki/Regler

Ausblick

Globale Krisen in dem Ausmass, wie wir sie zurzeit erleben und vermutlich in Zukunft noch stärker erleben werden, können zu grosser Verunsicherung der Menschen und in der Folge zur Destabilisierung der Gesellschaft führen. Gegenseitige Schuldzuweisungen, Ausgrenzungen von Minderheiten, kopflose Trotzreaktionen sind zu erwarten und sie sind idealer Nährboden für politische Demagogen. Gerade junge Leute sollten deshalb die verschiedenen Krisenstrukturen verstehen, um nicht irrational zu reagieren. Der Physikunterricht kann hier entscheidend mitbeitragen, indem er leicht nachvollziehbare Analogien aus dem Alltag aufzeigt, die den Mechanismus einer Krise beschreiben und eventuell sogar Lösungsansätze erkennen lassen. Die moderne Didaktik sollte neben dem Primärziel der Vermittlung von Fachwissen vermehrt auch die soziale und politische Mündigkeit der Schülerinnen und Schüler in Krisenzeiten im Visier haben.

3 The Science of "Muddling Through" Author(s): Charles E. Lindblom, Source: Public Administration Review, Vol. 19, No. 2 (Springer, 1959), pp. 79-88

Successful release of the *SPS Focus 2*

The ***SPS Focus 2*** *"Impact of Physics on Swiss Society"* was sent this summer to all SPS members, but also to many federal and cantonal politicians. We already heard from various persons that its message was well received, that the flow of physical knowledge between universities and industry works well in both directions. This would allow to build up more physical understanding and competence along the entire value adding chain especially in SMEs. This is important for them to keep up internationally by implementing new technologies based on quantum physics, especially photonics, new materials, system modelling, etc.

Some remarks:

- The general message of ***SPS Focus 2***, "daring more physics", was also well received by the Swiss academies SATW and SCNAT. SATW will forward it within their networks of SMEs, while SCNAT just finished a fact sheet based on extracts of ***SPS Focus 2***, which is distributed to other science societies and to our members as well.
- The subtitle *"Investing in Education and Fundamental Research to foster Innovation"* seems to be confirmed by a recent WIPO publication *"The Global Innovation Index 2022"* with Switzerland on position 1 worldwide [1].
- On the other hand, a recent SATW study about the innovation strength of Swiss SMEs came to a more pessimistic conclusion, while the SMEs themselves and their industry associations saw it quite differently. The discrepancy is difficult to understand, but one of the main points, the reduction of R & D staff, does not necessarily mean a loss of innovation power, see our comment on page 64 of this issue.
- In ***SPS Focus 2***, where we also considered the future of Swiss SMEs, we compared the interpretation of statistical data from Eurostat with the independent judgments and expectations of many experts in physics-based industries. Both statements confirm the increasingly important role of physics for the economic prosperity of a modern society.

1 World Intellectual Property Organization (WIPO) (2022). Global Innovation Index 2022: What is the future of innovation-driven growth? Geneva: WIPO. DOI 10.34667/tind.46596

The winners of the SPS Awards 2022

The SPS Award committee chaired by Prof. Thomas Jung selected the winners for 2022 out of many submissions.
The winners presented their work at the Annual Meeting in Fribourg (with one exception). Below are the brief summaries directly provided by the winners.
Unfortunately there was no candidate for the newly introduced SPS Award **with relation to Energy Technology**, sponsored by *Hitachi Energy Switzerland AG*. We nevertheless hope to receive numerous candidatures for the next round in 2023 (see p. 66).

From left to right: Johan Chang (SPS President), Guillaume Pietrzyk (CHIPP winner), Markus Ritter, Pauline Ollitrault, Nadine Leisgang, Thomas Karg (winners of an SPS award), Stephan Allenspach (SGN winner) and Marc Janoschek (SGN president).

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

The SPS Award in General Physics is given to **Michael Denner** for his work on "Discovery of an exceptional topological insulator emerging in a Weyl semimetal with two Weyl nodes at the Fermi energy under a non-Hermitian perturbation that opens a point gap".

Exceptional Topological Insulators

Following the success of topological phases in solid-state systems, non-Hermitian physics has recently attracted a lot of interest. One of the reasons is that most experimental platforms are in fact either accidentally or tuneably lossy, such that their effective description involves a non-Hermitian Hamiltonian. Non-Hermiticity does not only give rise to new bandstructure features such as point gaps or exceptional points but also enriches the world of topological phases.

Here we introduce the exceptional topological insulator (ETI) realizing a surface anomaly — akin to the three-dimensional topological insulator — that can only exist within the topological bulk embedding [1]. Like the single surface Dirac electron, the exotic surface state of the ETI cannot be regularized in purely two dimensions. It covers the bulk energy point gap as a single sheet of complex eigenvalues or with a single exceptional point. Even though it does not require any symmetry to be stabilized, we explain how this non-Hermitian topological phase can also be inferred using symmetry-indicators of the bulk Hamiltonian [2].

The ETI can be induced universally in gapless solid-state systems and metamaterials, thereby setting a paradigm for non-Hermitian topological matter. For instance, the ETI phase emerges in a Weyl semimetal, when quasiparticles at the two Weyl nodes acquire finite but distinct lifetimes. Such a scenario is a natural result of strong electron-phonon interaction, paving the road for a future material discovery.

[1] M. M. Denner et al. "Exceptional Topological Insulators", Nat. Commun. 12, 5681 (2021)
[2] P. M. Vecsei, M. M. Denner et al. "Symmetry indicators for inversion-symmetric non-Hermitian topological band structures", Phys. Rev. B 103, L201114 (2021)

SPS Award in Condensed Matter Physics, sponsored by IBM

Nadine Leisgang received the SPS Award in Condensed Matter Physics for her work on "Discovery of a strong and electrically tunable optical resonance in bilayer MoS_2".

A strong and electrically tunable optical resonance in a two-dimensional semiconductor

Atomically thin transition metal dichalcogenides (TMDs), such as molybdenum disulfide (MoS_2), strongly interact with light. Their optical properties are governed by excitons – electrons and holes bound by Coulomb attraction – that remain stable at room temperature. The ability to additionally tune their transition energies is essential for various interesting opto-electronic applications based on light emission, detection, modulation and manipulation. This can in principle be achieved via the quantum-confined Stark effect with an electric field applied perpendicular to the sample plane.

In a single layer MoS_2, absorption can reach up to 100 %, but the optical transition cannot be electrically tuned in such devices, as the excitons have essentially no out-of-plane dipole moment due to their confinement to a single layer [1]. A large out-of-plane dipole moment requires a vertical separation of the electron and hole. We have created a novel structure that shows optical transitions with strong absorption and wide tunability in the visible range [2]. Our device consists of a double layer of MoS_2 sandwiched between an insulator and top and bottom electrodes made from the electrical conductor graphene. The main idea is to use transitions based on electrons and holes that reside in different MoS_2 layers – so-called interlayer excitons. The vertical separation between the electrons and the holes gives rise to a static electric dipole. By applying a voltage to the outer graphene layers, we generate an electric field that tunes the absorption of the two MoS_2 layers. By adjusting the voltage applied, we can then select the wavelengths at which the electron-hole pairs are formed in these layers.

This research paves the way for new approaches to developing opto-electronic devices by combining the strong light-matter interaction of excitons in TMD monolayers with the high tunability of interlayer excitons in external electric fields.

[1] J. G. Roch, N. Leisgang et al., Nano Letters 18, 1070–1074 (2018).
[2] N. Leisgang et al., Nature Nanotechnology 15, 901–907 (2020).

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

The SPS Award in Applied Physics is given to **Markus Ritter** for his work on "Identifying the fundamental working mechanisms in superconducting transistors".

Identifying the fundamental working mechanisms in superconducting transistors

The development of metallic superconducting transistors could enable new devices such as cryogenic signal routers, multiplexers, and frequency tunable resonators, for which no semiconductor counterparts exist. Recent experiments with metallic nanowire devices suggested that superconductivity can be controlled by the application of electric fields. In such experiments, critical currents were tuned and eventually suppressed by relatively small voltages applied to nearby gate electrodes, at odds with current understanding of electrostatic screening in metals. We demonstrated that this effect is linked to gate currents below 100 fA at the onset of critical current suppression in our devices [1]. Employing novel device geometries, we disentangled the roles of electric field and electron-current flow. Our results showed that the suppression of superconductivity does not depend on the presence or absence of an electric field at the surface of the nanowire but requires a current of high-energy electrons [2]. The suppression is most efficient when electrons are injected into the nanowire, but similar results are obtained when electrons are passed between two remote electrodes at a distance *d* to the nanowire (with *d* in excess of 1 μm). In the latter case, high-energy electrons decay into phonons which propagate through the substrate and affect superconductivity in the nanowire by generating quasiparticles. We showed that this process involves a non-thermal phonon distribution, with marked differences from the loss of superconductivity due to Joule heating near the nanowire or an increase in the bath temperature.

[1] M. F. Ritter et al., Nature Communications 12, 1266 (2021).
[2] M. F. Ritter et al., Nature Electronics 5, 71 (2022).

SPS Award related to Metrology, sponsored by METAS

Thomas Karg is honored with the SPS Award related to Metrology for his "Pioneering work on coupling different physical (nano) systems with laser light".

Light-mediated strong coupling between a mechanical oscillator and atomic spins 1 meter apart

Engineering strong interactions between quantum systems is essential for many phenomena of quantum physics and technology. Typically, strong coupling relies on short-range forces or on placing the systems in high-quality electromagnetic resonators, which restricts the range of the coupling to small distances. At macroscopic distances, however, coherent bidirectional coupling has remained a challenge because it becomes increasingly difficult to isolate the systems from the environment.

To realize long-distance Hamiltonian interactions, we connected two systems by light in a loop geometry [1]. The systems can exchange photons through the loop, thereby realizing a bidirectional interaction. Moreover, the loop leads to an interference of quantum noise introduced by the light field. For any system that couples to the light twice and with opposite phase, quantum noise interferes destructively and associated decoherence is suppressed. In this way, the coupled systems are effectively closed to the environment, even though the light field mediates strong interactions between them. Since the coupling is mediated by light, it allows systems of different physical nature to be connected over macroscopic distances in a reconfigurable way.

In our experiments, we used a free-space laser beam to strongly couple a spin-polarized atomic ensemble and a micromechanical oscillator held in separate vacuum chambers [2]. The coupling is highly tunable and allows us to engineer beam-splitter and parametric-gain Hamiltonians, observing normal-mode splitting and two-mode thermal noise squeezing, respectively. Moreover, we switch from Hamiltonian to dissipative coupling by applying a phase shift to the light field within the loop. This high level of control in a modular setup demonstrates the versatility of light-mediated interactions. Our method gives access to a comprehensive toolbox for hybrid quantum systems and opens up a range of new opportunities for quantum control and coherent feedback networks.

[1] T. M. Karg, B. Gouraud, P. Treutlein, and K. Hammerer, Phys. Rev. A 99, 063829 (2019).
[2] T. M. Karg, B. Gouraud, C. T. Ngai, G.-L. Schmid, K. Hammerer, and P. Treutlein, Science, 369, 174 (2020).

SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS Award in Computational Physics is given to **Pauline Ollitrault** for her work on "Solving Quantum Chemistry Problems with First Generation Digital Quantum Computers".

Solving quantum chemistry problems with first generation digital quantum computers

Predicting reaction pathways, rates, and kinetics, as well as molecular structures and dynamics, is essential for supporting the design of new materials, drugs, catalysts etc. However, this requires solving the Schrödinger equation (SE), which governs the behavior of quantum mechanical systems and whose dimension grows exponentially with the number of particles. Its direct resolution is hence limited to the smallest molecules. Although there exists a plethora of methods aiming to find approximate solutions to the SE, a trade-off between accuracy and efficiency persists. Because of these difficulties, quantum computing appears today as an interesting tool for quantum chemistry. Indeed, quantum mechanical wavefunctions could be more efficiently prepared using qubits which are quantum mechanical system.

My PhD work has focused on the design of quantum algorithms for the resolution of the molecular SE. In particular, I have adapted the equation of motion (EOM) approach to a quantum algorithm for the calculation of electronic excited states. I have then worked on extending electronic structure quantum methods to less studied but equally important vibrational structure problems [1]. Finally, I focused on the simulation the difficult non-adiabatic quantum dynamics that couple nuclear and electronic motion in molecules. To achieve this, I worked in a rather unexplored grid encoding of the problem in the quantum computer and showed how to obtain the quantum circuit for simulating these dynamics for a model Hamiltonian with product formulas [2].

[1] P. J. Ollitrault, et. al. (2020). Hardware efficient quantum algorithms for vibrational structure calculations. Chemical Science, 11(26), 6842–6855.
[2] P. J. Ollitrault, et. al. (2021). Molecular quantum dynamics: A quantum computing perspective. Accounts of Chemical Research, 54(23), 4229–4238.

Review of the SPS Annual Meeting 2022 in Fribourg

This year's annual meeting took place on the Campus Pérolles II of the University of Fribourg. We had again a few partners contributing to the program, namely the *Swiss Institute of Particle Physics* (CHIPP), the NCCR *Bio-Inspired Materials* and the *Swiss Neutron Science Society* (SGN/SSSN). Special thanks go to Claude Monney and his team from the Physics Department for their immense help and support with the local organisation.
The conference was again very successful, although we could not reach the participant numbers from last year. One reason, besides the missing Austrian colleagues, might have been competing conferences at the same time as ours. Nevertheless, nearly 370 participants attended, more than 200 oral and 34 poster presentations have been given and 6 exhibitors showed the latest lab equipments, measuring tools and more. Besides the usual ingredients like general assembly, award ceremony and conference dinner, for the first time the satellite event *Women in Physics Career Symposium* has been organised (p. 13).
An unusual high number of persons had to report sick at the last minute, which reminded everyone that the Corona virus was still around. Fortunately, in most cases co-workers were able to jump in and give the presentations of their sick colleagues, so only very few talks had to be cancelled.

Martina Hirayama, State Secretariat for Education, Research and Innovation (SERI) gave the opening speech.

In the following, we report as usual on selected topical sessions, present the winners of the Best Poster Awards (p. 14), and print the extended abstracts of those plenary talks which the speakers have kindly provided (p. 16).
Many presentations of the different sessions are available on https://indico.cern.ch/event/1119258/timetable/ .

Physics Funding in Switzerland

Funding from the Swiss National Science Foundation was the topic of this special session. Bernd Gotsmann (IBM Rüschlikon) – heading SNSF Division-II – presented statistics, evaluation procedures and trends. An increasing funding demand has led to an overall lower success rate on the basis of an approximately constant funding allocation for physics. Michele Weber (CHIPP chair) explained how decreasing success rates cascade into significant perturbations to international large-scale experiments. Finally, Thierry Giamarchi (MaNEP spokesperson) covered the impact felt by university groups. Also here, the lower application success rates are felt, and it has significant negative implications on recruitment. Effectively, funding uncertainty translate into compromised recruitment conditions and with that a weakened competitiveness of Swiss research activities. The session was concluded with a "round-table" discussion between the audience and the speakers.

Discussion round of the Physics Funding session: Michele Weber, Bernd Gotsmann, Johan Chang and Thierry Giamarchi.

It was noticed that the early career programs as PRIMA and Eccellenza suffered the biggest drop in success rate (PRIMA's success rate being zero in the last year), resulting in a future joint program. It was felt that keeping the interest of early talents high has been a challenge in the times of COVID and that, for the future, preserving the early career programs ensures arrival or return of fresh talents in the country, whether they have nationality or not. It is only through a broad and unbiased program of recruitment that solid basis for the future can be ensured. We refer here to our recently published ***SPS Focus 2***, which summarizes related statistics in chapter 4.2 (https://www.sps.ch/artikel/sps-focus/sps-focus-2).
Although there are no easy / quick solutions, it is clear that researchers, Universities and SNSF all should take respon-

The plenary speakers in Fribourg: Hatice Altug, Teresa Montaruli, Thomas Stocker, Pedro Reis, ...

sibility. Researchers in many cases request unreasonable amounts of funding. This has been addressed in the past by systematic cuts to parts of the projects, evaluated scientifically compelling and not substantially compromised by those cuts. This strategy has been recently dismissed by SNSF. This current evaluation process thus seems to generate fewer winners and more rejected applications. In a sense, we have generated a *Tragedy of Commons*. Many share the notion that this trend reduces diversity, which is believed to be advantageous for the scientific landscape (see SNSF's strategic priorities).
To reverse these trends, researchers have responsibility to make reasonable funding requests. Universities should refrain from outsourcing relevant fractions of running costs of infrastructures to third parties, aside from compulsory fees that should represent small percentages of total requests. The Swiss National Science Foundation may consider aligning the funding programs with recruitment seasons and most importantly revise policies that amplify *Tragedy of Commons* tendencies. In a time when European Community applications with leading roles are not accessible, SNSF remains a principal source of funds for Cantonal University researchers.
A solution needs to be found to resolve the tension between the competitiveness of single-PI grants vs. continuity for large-scale long-term efforts that have been identified as strategic for Switzerland. Continuous funding of scientific and technical personnel is a key ingredient for these experiments in fundamental physics.

Johan Chang, Uni Zürich, Teresa Montaruli, Uni Genève

The coffee breaks offered ideal conditions for inspiring discussions,, as well as the food selection of the lunch buffet.

KOND

The first block of the Condensed Matter session covered multiple exciting talks on electronic structures including metal insulator transitions in charge density waves of quasi-2D materials and electron hole excitations of various perovskites. We heard of intriguing interplay between magnetism and orbital order in manganite layers with superconductivity and charge density waves in heterostructures of manganites and cuprates. How subtle differences in stacking TaS_2 layers profoundly influence the electronic properties in the form of a metal insulator transition with potential technologically relevance. Supplemented by spectroscopic studies of charge density waves in the related $TiSe_2$ and how it depends on the thickness of the sample down to few tens of nm. Another exciting layered system was the metallic kagome ferromagnet Fe_3Sn_2, where magnetic excitations were probed by resonant inelastic X-ray scattering. How perovskites span from fundamental physics to technological applications was illustrated by 3 talks on respectively nickelate, $BaSnO_3$ and halide perovskites. First ever crystals of $RENiO_3$ obtained by clever chemistry and a unique furnace allowed detailed studies of metal insulator transition etc. The perovskites were also studied with ultrafast techniques to understand the early fate of electrons in photovoltaics and materials for high power electronics $BaSnO_3$.
Finally, metal organic halide perovskites where sophisticated muon spectroscopy techniques were used to understand the role of growth conditions on the grain and eventually optoelectronic structures.
Both seasoned researchers and upcoming young talents gave their presentations with great pedagogy allowing the audience to hear not only about exctiting new scientific results but also to learn about a variety of fascinating experimental techniques.

Henrik Rønnow, EPFL

... Frank Jenko, Christof Aegerter, Hans Rudolf Ott, Teodoro Laino, ...

Nonequilibrium properties of quantum materials

This special session gathered both experimentalists and theoreticians together for sharing the newest results in the field and gave rise to lively discussions. On the experimental side, a high diversity of techniques was illustrated using the pump-probe approach on the pico- or even femtosecond time scale, like photoemission spectroscopy or THz spectroscopy. New development at the Furka end station of SwissFEL aiming at time-resolved resonant inelastic x-ray scattering using soft x-rays were presented. More exotic approaches were also presented exemplifying a double-pump scheme applied to transmission electron microscope or stochastic switching of a ferrimagnetic system with a synchrotron x-ray source.
On the theory side, scientists presented the most recent developments in the context of strongly correlated systems driven out of their equilibrium state. It has been shown how, in such non-thermal quantum states, the effects of electronic interaction can be theoretically disentangled from those linked to other properties of the system. Conference speakers described the interplay between interaction and lattice distortions in several compounds and how this coupling can be responsible for new quantum states. The effect on magnetism also aroused great interest: exotic non-thermal states of skyrmion crystals, quantum dynamics in random magnets with coherent magnetic excitations, and magnetic switching by light in a spin glass were presented. The non-equilibrium behaviour of systems with sizable spin-orbit coupling was also topic of interest.
Altogether, the high-quality presentations of this session highlighted the rich research activities in Switzerland in the field of nonequilibrium phenomena in quantum materials and emphasized fruitful on-going and potential future collaborative efforts between experiment and theory.

Claude Monney and Francesco Petocchi, Uni Fribourg

New prospects in ARPES for quantum materials

The special session "New prospects in ARPES for quantum materials" highlighted the importance of various forms of angle-resolved photoemission spectroscopy (ARPES) for the discovery and investigation of novel quantum phenomena in condensed matter. A recurring theme was that with a smaller photon spot size, of the order of a few micron, experiments become feasible that one could previously only dream of. For example to locally strain or excite the crystal, apply new microscale sample preparation techniques, or to resolve a single phase when a mixture is present. The upgrade of the Swiss Light Source at the PSI to a diffraction limited source, allowing to further reduce the photon beam cross-section, will allow exactly such experiments, combined with the power and flexibility of synchrotron radiation.
The lively session showed that the Swiss ARPES community extends from Geneva to Zürich with a strong international network, and trains young scientists for leading positions both in Switzerland and abroad. The high quality not only of the talks, but also of the posters, highlights the breadth and depth of the community, which can also be seen from the many complimentary experimental set-ups at the SLS and at laser facilities in Zürich, Fribourg, Lausanne, and Geneva. To celebrate this strength and diversity "Swiss ARPES" has been created. A platform to intensify collaboration and to enhance the visibility of the Swiss ARPES community.

Hugo Dil, EPFL

Atomic Physics and Quantum Optics

This year's talks in this session illustrated the growth and diversity of the field. Indeed, light-matter interactions appear to be both intriguing and useful in more and more areas. The plenary presentation of Ataç Imamoglu introduced the use of optics methods to probe new states of matter emerging in two-dimensional materials. These materials are one of the most active area of research in condensed-matter physics and material science, but optics and quantum optics techniques prove to be particularly insightful.
The topical sessions gathered junior scientists working on fundamentals or applications of light-matter interactions. Fundamental studies involved light-matter couplings in different regimes for atoms or electrons. Applications ranged from prospects of quantum computing and quantum simulation, to optimization of light sources and detectors for light in extreme regimes: ultrashort pulses, terahertz radiation, ultrastable frequency references. Bridging towards different fields, applications also comprised efficient or tunable fluorescent molecules or nanocrystals.

Jean-Philippe Brantut, EPFL

Swiss Neutron Science on the European Scale

The special session 'Swiss Neutron Science on the European Scale' highlighted how versatile the elemental particle can be used across different research disciplines. The session reported progress on three major fields in which neutrons are used to conduct fundamental research. Notably condensed matter research, particle physics and imaging

... Dominik Brunner, Ataç Imamoglu and Laura Baudis, winner of the Charpak-Ritz Award.

on applied materials. The first part showed us how elastic and inelastic neutron scattering allows us to study the fundamental interactions in solid state materials, and how they lead to coherent quantum phenomena such as quantum spin liquid states, unconventional superconductivity, magnetic frustration and other complex magnetic long-range order. The second part of the session commented on the recent progress using ultracold neutrons to test new physics beyond the Standard Model. Here, the focus lied on research and instrument developments enabling an accurate determination of the electronic dipole moment and electric charge of the neutron, alongside progress in the search for mirror-neutron oscillations. The last part highlighted new results using imaging techniques to determine grains, orientation distributions and magnetic forces in applied materials. We also heard about the developments of new scintillators and Laue instrumentation to characterize crystals through grain-oriented neutron diffraction tomography. The lively discussion during the session and poster session testifies the high quality of the presentations, and the deep interest the scientists follow their research activities. The combined session between neutron scattering, imaging and particle physics also allowed for a mutual understanding between the various research activities neutrons can be used for.

Daniel Mazzone, PSI Villigen

Nuclear, Particle, and Astrophysics

The Nuclear, Particle, and Astrophysics session had contributions from the numerous directions of research carried out in Switzerland.
The plenary talk by Teresa Montaruli gave an overview of the status and prospects of the new generation gamma-ray *Cherenkov Telescope Array Observatory*, which will have a leading role in multi-messenger astrophysics, offering a view on the most powerful accelerators of the Universe (see p. 24).
The parallel session with six topical blocks addressed the questions on astroparticle physics and dark matter, flavour anomalies, neutrinos in the Standard Model and beyond, new physics searches and precision measurements, detectors and their performance, also for medical application. In total, 50 oral presentations and 3 posters were presented and discussed during the 4 days of the session. Exchange on the complementary approaches to fundamental questions of science between the different subfields was especially valuable and is a distinct feature of the SPS meetings.
The CHIPP prize for the best PhD thesis work in particle physics in 2022 was awarded to Guillaume Pietrzyk for the work carried out at EPFL in the scope of the LHCb collaboration, which led to determine with unprecedented precision the rare phenomenon of particle-antiparticle oscillation in the neutral charm-meson system.

Lesya Shchutska, EPFL

Biophysics, Medical Physics and Soft Matter

One session on Biophysics, Medical Physics and Soft Matter was held on Monday 27 June with 6 contributed talks. The talks covered a wide range of topics all through the different fields, with one talk in medical physics focusing on radioisotope production that will be used in combined diagnosis (imaging) and radiotherapy setups. In Biophysics, there were two talks describing different possibilities of applying forces and analyzing the structure of biomolecules, with a particular emphasis on the citric acid cycle and the experimental challenges faced in this endeavor. Finally, there were three presentations regarding soft matter with an emphasis on self-organization in polymerization processes and structure formation in block copolymers, triblock terpolymers as well as polydisperse assemblies of spherical particles. This last case was studied using simulations, whereas the previous ones were studied experimentally. In all of these soft matter issues, the inspiration comes from the desire to understand the self-organization in biological systems, which directly links these presentations back to Biophysics as well.

Although the total number of posters was lower than usual, their quality stayed high. The winners of the Best Poster Awards are presented on p. 14.

Christof Aegerter, Uni Zürich and Christof Fattinger

Education and Promotion of Physics

While this section was not represented with a full session, a plenary talk by Christof Aegerter (Uni Zürich) was dedicated to the topic "Physics & Education – Perspectives from

About 150 persons attended the apéro and conference dinner at the mensa of the university, close by the conference location.

Condensed Matter and Biophysics". In a very nice presentation (see p. 21), enhanced by experimental demonstrations e.g. about photonic crystals providing the physical basis of structural colours of e.g. butterfly wings, or about reversibility and irreversibility in highly viscous fluids, C. Aegerter convincingly succeeded to convey a flavour of the breadth and the interest of condensed matter and biophysics in a way accessible to a broad public.
This was the second talk of this format after "Physics & Education - Perspectives from Particle Physics" last year in Innsbruck (H. P. Beck, CERN / Universities of Bern and Fribourg). Similar presentations for other areas of physics would be a most valuable way to promote physics at school, in particular for teachers.

Andreas Müller, Uni Genève

Physics at Work in Industry

Physics is far from being an “academic pastime” as the discipline, and physicists in general, are pivotal for innovation and progress for industry and society. This has become vividly clear with this year’s “Physics at Work in Industry” sessions of the SPS section *Physics in Industry* where eleven speakers showcased the diversity of physicists’ jobs, in fields ranging from finance to quantum computing, in companies ranging from small, specialized startups to large multi-national enterprises. Hence, physics is central for tech-reliant industries where deep technical knowledge, analytical thinking and problem-solving skills are key to success. What’s more, there are many tasks such as stock market modelling where a physics background can provide extraordinary perspectives. For students and postdocs, these inspiring and often quite nonlinear and surprising career paths gave an excellent account of what opportunities are out there for physics graduates, as can be seen in the more detailed article on page 47 of this issue.

Thilo Stöferle, Andreas Fuhrer, IBM Rüschlikon

Theory

As for the past annual meetings of the SPS, the theory talks were again embedded in their respective topical sections, which is by now well appreciated.
In the TASK sessions there were this time only 4 theory related presentations from a total of about 50 talks, which covered broad topics going from dark matter searches to neutrino physics, new physics searches and precision measurements. In the ARPES session there was one theory talk out of 15, whereas in the session on "Nonequilibrium properties of quantum materials" 5 of the 12 talks were on theory aspects. The KOND sessions included some 7 theory talks (out of 47) with topics ranging from strongly correlated systems to superconductivity. The number of theory talks, as expected, varies significantly among the different sections, however, from the above quoted numbers it emerges that the theory talks are in general a sizeable fraction (~10 - 30%) of all contributions. As compared to the previous year meeting in Innsbruck the fraction of theory talks seems to be somewhat less. There were also theory talks in the plenary sessions, we mention here in particular the nice talk by Frank Jenko on the problem of the plasma confinement in fusion devices.

Philippe Jetzer, Uni Zürich

During their "After Dinner Speeches" Johan Chang, SPS President (top), and Claude Monney, local conference organiser (bottom), thanked leaving board members, the conference helpers and last but not least all participants who made the conference a success.

Satellite Event: Women in Physics Career Symposium

A successful first edition of the "Women in Physics Career Symposium" was organized as satellite event to the annual SPS meeting by the University of Zurich, the Paul Scherrer Institute, and the Swiss Physical Society, with the support of the Swiss Academy of Natural Sciences (SCNAT) and the International Union of Pure and Applied Physics (IUPAP). The goal of this symposium was to help female early-career researchers in physics to meet successful role models at various stages of their careers, as well as to get connected to mentors to support their own career. This was achieved through a series of inspiring career talks given by *Claire Donnelly* (Max Planck Institut für chemische Physik fester Stoffe, Germany), *Jennifer Schober* (École Polytechnique Fédérale de Lausanne), *Chiara Mariotti* (Istituto Nazionale di Fisica Nucleare, Italy, and CERN) and *Ana Akrap* (Université de Fribourg), who provided in-depth insights in the ups and downs of their own careers through sharing key moments. In addition, a key note talk presented by *Gillian Butcher* (Chair of the working group "Women in Physics" at the International Union of Pure and Applied Physics) summarized an impressive amount of advice and resources for female researchers. Finally, a podium discussion moderated by *Kirsten Moselund* (Paul Scherrer Institute and EPFL) that allowed participants to ask questions completed the event. This supportive atmosphere spurred conversation among participants who had the opportunity to learn from their peers how to navigate a career in physics at different stages, ask questions, share career advice, gain information and expand their network. Interactions and moments captured by Visual Artist and Designer Nathaniel Miller, who created live sketches and drawings of the event in real-time, documented stories of women and science in a one-of-a-kind way. As a result of the event 21 female early-career physicists were connected to experienced mentors who will regularly meet with them during the next year to support their careers. During the symposium dinner the organizers and SPS leadership decided to turn this first event into a sustainable feature of the annual SPS meeting.

Marc Janoschek, PSI Villigen

Nearly 80 participants joined the Women in Physics Career Symposium on 1 July.

New SPS Committee Members

Prof. Dr. Teresa Montaruli (Vice-President)

My research activity started in 1994 when I had my master degree on neutrino oscillations and then worked on neutrino searches from the cosmos, namely on dark matter and on establishing neutrinos as a powerful messenger of the universe. I was awarded the Duggal Award in 1998 and continued to work on neutrino astronomy in the ANTARES undersea telescope since 1999 and in KM3NeT. In 2005 I joined the IceCube experiment when I moved to USA and joined the Faculty of the University of Wisconsin-Madison where I was tenure in 2007. Major contributions to IceCube, some realised when I moved as Full Professor to the University of Geneva, are the identification of significant neutrino signals from the blazar TXS 0506+056 and the starburst galaxy NGC 1068, both published in renowned journals. In 2007 I had also started work on gamma-ray astronomy and hardware in the HAWC gamma-ray extensive air shower experiment and I became the Swiss Coordinator of the Cherenkov Telescope Array Observatory (CTAO). CTAO is now in the Swiss Roadmap for large research infrastructures of the State Secretariat for Education, Research and Innovation (SERI). In 2022, I became responsible for the construction of the camera plane and simulation of the payload TERZINA on-board the satellite NUSES, a prototype for Cherenkov detection from space.

I teach at undergraduate and graduate student level. Our group offers plenty of PhD and master thesis opportunities of work on a broad portfolio of experiments. I have also been the Chair of the APPEC Consortium in 2019 and 2020 and led the astroparticle community through the update of the European Particle Physics strategy. Given this task that I recently concluded, I thought it will be possible for me to provide useful contribution as vice-president of the Swiss Physical Society, a society with long-standing tradition and also international strong links. Communication, fostering education and engagement of the public in Physics and Astrophysics are for me crucial points as well as strong links to innovation and high-tech industry, ensuring the annual budget for good managing of these activities and the annual meetings, which represent the flagship of SPS and bring together all the different branches of the Swiss community.

Prof. Dr. Lesya Shchutska
(Section TASK)

Lesya Shchutska is an experimental particle physicist and currently she is a tenure-track assistant professor at EPFL. Her research aims at testing boundaries of the Standard Model of particle physics and looking for new particles which could reveal the nature of dark matter. In the course of her research path she has been working in various operating and planned experiments, such as CMS at the LHC or SHiP at SPS, and currently Lesya is a member of the LHCb and SND@LHC collaborations.

Her career was driven by the fascination by physics since young age, motivating Lesya to take up the challenges of Olympiads and pursue particle physics since the first years of University studies, where she joined the LHCb collaboration at CERN. Lesya obtained a PhD from EPFL in 2012, working on the Positron-Electron Balloon Spectrometer for the precise measurement of the cosmic rays. This work has been awarded by a CHIPP prize in 2011. Following this, for the first postdoctoral position at the University of Florida, Lesya joined the CMS experiment, where she mainly concentrated on the new physics searches in leptonic final states. In 2017, she received an ERC Starting Grant to carry out heavy neutral lepton searches with the CMS detector allowing her to start a group at the ETH Zürich as an assistant professor. Shortly after, in 2019, Lesya has moved back to EPFL as a tenure-track assistant professor and rejoined the LHCb collaboration in a new role.

Particle physics research plays a significant role in Switzerland, as well as Switzerland is one of the flagship countries in the particle physics landscapes, hosting CERN and PSI laboratories. The future of particle physics is being shaped these days, and it is crucial to have bridges and collaborations with the other research activities in the country, and to connect with the society in general. The Swiss Physical Society is one of the main platforms for such activities, and Lesya is honoured to be able contribute to this important goal in her new role.

Alice Kohli
(Editorial team)

Alice Kohli is a physicist and a journalist by training. She finished her Bachelor studies in Physics at the University of Zürich in 2006 and went on to obtain a Master's degree in Journalism from the University of Hamburg in 2009. Starting out as a science journalist for *20 Minuten*, she further explored the field of news journalism and data journalism at *Neue Zürcher Zeitung*, where her work was awarded with several prizes, among others the European Press Prize and the German reporter prize. After NZZ, she worked as an investigation specialist in the field of economy and human rights for the Swiss NGO *Public Eye*. In February 2020, she returned to University of Zürich and obtained her Master's degree in Physics in April of 2022. Alice Kohli now works as a freelance journalist and high school Physics teacher. She hopes to awaken in her students the same curiosity for the laws of nature that has carried her through her entire career.

Best Poster Award 2022

The three best posters presented at the annual meeting of the SPS at the University of Fribourg have been honored with the Best Poster Award, each doted with CHF 200.-. A total of 23 posters competed for the award from which the poster jury selected the works of **Abraham Hernández, Lisa Sommer**, and **Thomas P. van Waas** as the final winners in a two-step evaluation procedure.

The winners conveyed the essence of their work in a brief 1-slide presentation during the poster award ceremony on the last day of the meeting. We thank the participants for the high quality of their contributions and express our gratitude to all members of the poster jury for their hard work during the evaluation of the posters. Namely, the jury members were: Lukas Gallmann, Dirk Hegemann, Claude Monney and Andreas Fuhrer.

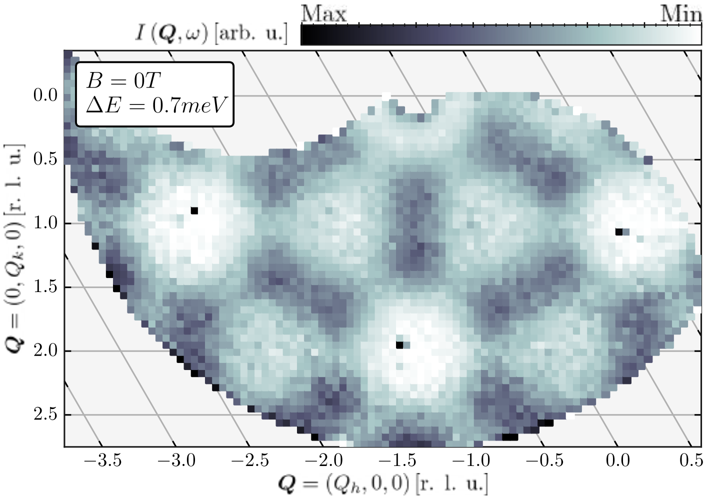
Lisa Sommer, Thomas P. van Waas, Abraham Hernández

Neutron Scattering Study of Field-Induced Dynamics in the Quantum Spin Liquid Candidate $YbBr_3$

Abraham Hernández, B. Roessli, C. Wessler, J. Lass, D. Mazzone, M. Bartkowiak, C. Niedermayer, M. Kenzelmann, Paul Scherrer Institut (PSI), Laboratory for Neutron Scattering and Imaging. CH-5232 Villigen PSI.

The study of magnetic properties of crystalline materials wherein interactions between neighboring ions are of effective reduced spatial dimensionality is a fruitful avenue of research due to predicted exotic physical phenomena, ranging from topologically non-trivial states of matter, to entire classes of quantum spin liquids [1].
The subject of our study is the rare-earth compound $YbBr_3$, which hosts an excellent realization of an effective spin-1/2 2D honeycomb system at low energies.
As supported by high-quality inelastic neutron scattering experiments, quantum fluctuations of the spins are believed to be enhanced by 1) frustrated exchange interactions between nearest- and next-nearest neighboring ions and 2), due to field-induced non-collinearities in the spin structure.
The former is evidenced by the broad scattering continuum observed above well-defined magnetic excitations in the extended Brillouin Zone [2], whilst the latter is supported by an observed dramatic damping of the spin waves in the field-canted phase [3].

[1] Broholm, C., et al. "Quantum spin liquids." Science 367.6475 (2020)
[2] Wessler, C., et al. "Observation of plaquette fluctuations in the spin-1/2 honeycomb lattice." npj quantum materials 5.1 (2020)
[3] Hernandez, A., et al. "Neutron Scattering Study of Field-Induced Dynamics in the Quantum Spin Liquid Candidate $YbBr_3$." Master's Thesis. University of Basel (2022)

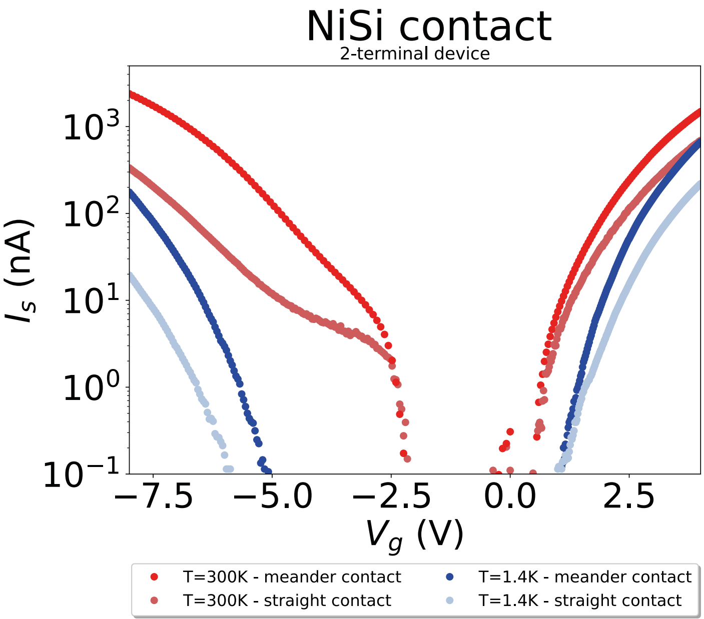


Measured neutron scattering intensity as a function of wavevector at constant energy. At 0.7 meV, a broad continuum is observed in the extended Brillouin Zone.

Schottky contacts for silicon spin qubits

Lisa Sommer, IBM Research

Silicon fin field-effect transistors (FinFETs) are used in classical CMOS electronics but are also an attractive platform for the implementation of spin qubits. Transistors usually have highly doped contacts that determine device polarity (n-type or p-type). In order to avoid detrimental dopant diffusion into the quantum device, our FinFET quantum dots have Schottky contacts formed by a silicide with an intrinsic silicon substrate. Here, contact resistance is governed by the choice of silicide and contact geometry which affect Schottky barrier height and width respectively. In our work, we study the behavior of PtSi (p-type), NiSi (ambipolar) and ErSi (n-type) Schottky contacts at cryogenic temperatures and investigate their potential as a low resistance contact materials using different contact geometries.

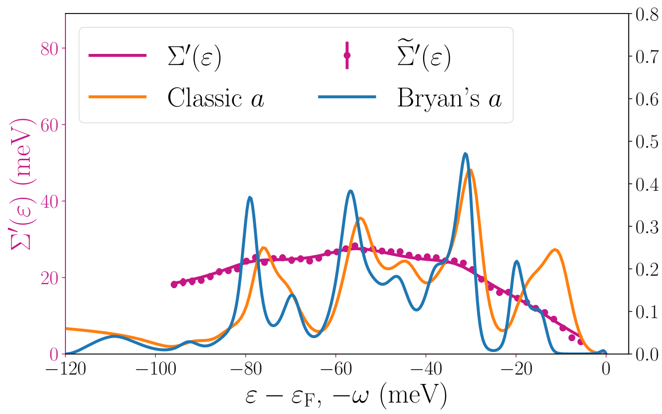


Bayesian inference on electron-boson interaction from ARPES self-energies

Thomas P. van Waas, PSI Villigen

Electron-boson interaction (EBI) in 2-dimensional electron liquids (2DELs) provides insight in the foundations of these rich physical systems. We have quantified the EBI of a 2DEL in a $CaTiO_3$ thin film on a $SrTiO_3$ substrate in terms of the Eliashberg function $a^2 F(\omega)$ based on the quasiparticle self-energy $\Sigma(\varepsilon)$ obtained from angle-resolved photoemission spectroscopy. This extraction was performed with the Maximum Entropy Method (MEM) [1], involving a Lagrange multiplier a times the information entropy to constrain the solution based on physical intuition of the overall shape of $a^2 F(\omega)$. Among other improvements compared to existing work, we used a MEM formulation that treats a probabilistically, allowing for the identification of individual bosonic modes [1].

[1] Van Waas *et al.*, unpublished.



Plenary Talks

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

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

Large Research Infrastructures in Switzerland; History, Results and Opportunities

PT 1/2022

Hans Rudolf Ott, Laboratorium für Festkörperphysik, ETH Hönggerberg, CH-8093 Zürich

Considering the size of the country and its population, Switzerland hosts a respectable number and diversity of large research facilities (RI). With respect to size and prestige, CERN, the internationally embedded and financed institution in Geneva, is at the top of the list.

Large research infrastructures are usually serving international or at least national user communities by providing facilities that, in general and for various reasons, are not hosted by universities or single private RIs. Exceptions in the Swiss landscape are briefly mentioned below. In this limited overview we concentrate on RIs in Switzerland serving communities active in experimental research topically linked to natural sciences in a broad sense.

An early large-scale RI in Switzerland

In 1922, the Schweizerische Naturforschende Gesellschaft (SNG), currently the Schweizerische Akademie der Naturwissenschaften (SCNAT), asked a newly founded committee to establish and manage a high alpine research station at Jungfraujoch (JFJ). With some delay, an International Foundation "High-alpine research station Jungfraujoch" was founded in 1930. Among the founding members were representatives of various countries such as the German Kaiser Wilhelm Gesellschaft, the Royal Society in London, Austria's Akademie der Wissenschaften, the Université de Paris, the Fonds National de la Recherche of Belgium and, as the local actors, the SNG and the Jungfraubahn Gesellschaft. The well known SPHYNX building hosting the laboratories and the observatory was completed in 1937. With the participation of an international user community, research activities in fields such as physiology, meteorology, glaziology, radiation research, cosmic radiation and astronomy have been pursued since then.

Today the JFJ is a prime site of many global networks for atmospheric monitoring, contributing important data to the Global Atmosphere Watch (GAW) of the World Meteorological Organization (WMO). For this reason it is particularly important that, because of an increasing flow of tourists at the JFJ, measures to preserve pristine environmental conditions are successfully implemented soon.

Research of small units of matter requires larger installations

After the discovery of the neutron in 1932, nuclear physics became a new prime topic of research in physics but required a new experimental tool in the form of particle accelerators based on high-voltage generators. Next to pioneering work done in the UK and the USA, a particularly new and important development was due to E. A. Lawrence in Berkeley. He successfully introduced the cyclotron principle combining high voltage providing energy to and magnetic fields for track keeping of the charged particles in the circle-shaped device. The 27-inch version of the accelerator provided a maximum energy of 5 MeV. In Switzerland, the first cyclotron was installed at ETH Zürich after 1940. Under the guidance of P. Scherrer, the apparatus was designed and built in a collaboration between scientists at ETH and industry involving the Maschinenfabrik Oerlikon (MFO) and Brown Boveri Corporation (BBC), reaching an energy of 15 MeV.

The design and construction as well as the following upgrading of the installation was the beginning of a long and lasting tradition of accelerator research and development in Switzerland and of the continuing education and provision of know-how for the following generations of physicists and engineers.

An unexpected opportunity for Switzerland: The Founding of CERN and its Success Story

In the context of "Research in Europe" after 1950, a major step was taken at the UNESCO Conference 1951 in Paris, namely the founding of the Conseil Européen pour la Recherche Nucléaire (CERN). During one of its first meetings the installed CERN Council decided to establish a new laboratory in Geneva. In 1954, backed by a positive public voting of the Canton of Geneva, the European Organisation for Nuclear Research, still named CERN, was established involving 12 member states at the time. The first installation in the form of a 600 MeV proton synchrocyclotron was inaugurated in 1957, intended to serve for experiments in nuclear- but also particle physics. The next device, intended to be used entirely for particle-physics experiments was inaugurated in 1959 and reached 28 GeV. With this machine the particles W and Z were discovered in 1983. A new tunnel for the large electron-positron (LEP) collider with a circumference of 27 km was completed in 1988 and served to study the properties of the W and Z bosons up to energies exceeding 100 GeV. At the end of 2000, the LEP collider was shut down. In 2008, the Large Hadron Collider (LHC), built up in the LEP tunnel, went into action and on July 4, 2012, the collaborations around the detectors CMS and ATLAS announced the observation of a particle consistent with the expected Higgs boson!

From its beginning, Swiss researchers were significantly involved in research activities offered by the installations at CERN.

From nuclear- to particle physics in Switzerland

In October 1959, after the retirement of P. Scherrer, his successor J. P. Blaser immediately attempted to initiate research in particle physics including the planning of a new national laboratory, the Swiss Institute for Nuclear Research (SIN), hosting a proton accelerator covering the medium-energy range, typically 600 MeV, and providing free access to interested researchers at Swiss universities.

The planning process finally resulted in an installation providing intense beams of π- and μ mesons based on a new concept of the proton accelerator in the form of a ring cyclotron that promised to produce high proton currents. With respect to particle physics, the SIN infrastructure first served, as intended, to enhance the topical competence of Swiss physicists in that field and to prepare them for experimental activities at CERN in order to be able to contribute significantly to upgrades and technical improvements of existing and new installations and, of course, their use. Experiments at SIN, increasingly attracting an international clientele, concentrated on high-precision experiments in order to test theoretical predictions for rare and/or theoretically forbidden processes in the appropriate energy range.

A representative example of current interest are experiments to determine the radius of the proton via measurements involving Laser spectroscopy on muonic hydrogen.

Beyond 1988: Extending into other fields of research with new installations

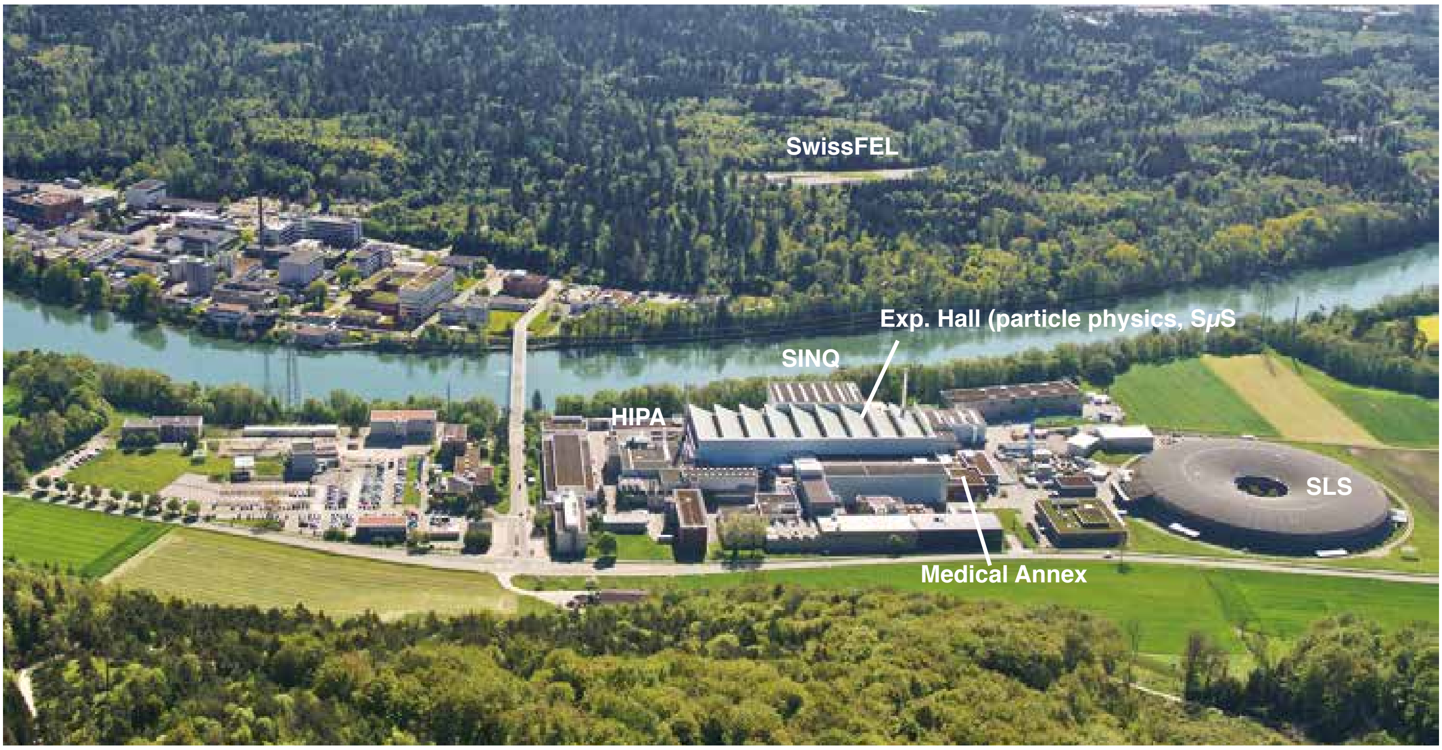
The next decisive step in our context was the merger of the Federal Institute for Reactor Research (EIR) in Würenlingen, and SIN in Villigen, both situated on directly opposite banks of the river Aare in 1988, forming a new national institute, the *Paul Scherrer Institute (PSI)*.

An early cooperative effort between the two institutions with respect to large installations was the planning and construction of a *spallation neutron source (SINQ)* for structural and spectroscopic investigations of condensed matter, by using the intense 2 mA proton beam of the upgraded high intensity proton accelerator (HIPA). Due to steps onto new technological territory, the implementation of the installation took some time and first experiments started only in 1996. Nevertheless, SINQ was the first continuous neutron source for the intended purpose, based on an accelerator instead of a nuclear reactor. Currently, the instrumentation of SINQ comprises 19 different stations for studies of structure, structural dynamics, spectroscopy and imaging of condensed matter.

Around 1990, PSI was planning its future by considering the diversification of its activities into other research areas; new ideas for extending its infrastructure for particle-physics oriented research were not supported by the federal authorities. At the time, high-intensity light sources employing electron synchrotrons were regarded as promising new installations for multidisciplinary research in, for instance, condensed matter physics, chemistry, biology and engineering. In mid 1995 the concept of an internationally competitive and user oriented *Swiss Light Source (SLS)* was worked out; the federal parliament approved it in 1997 and its construction started in mid 1998. First experiments were due in 2001!

After a modest beginning with a few typical instruments, a dedicated effort during the following years resulted in a diverse set of high-quality instrumentation, part of which is allowed to be used by industrial firms for proprietary research. The high quality of the source and respective instruments resulted, for example, in contributing to reveal the structure of complicated molecules such as the 70S ribosome complexed with mRNA and tRNA, which was honoured with the Nobelprize in 2009.

The successful operation of SLS encouraged the management of PSI to consider a new challenge - the design and construction of a "low-cost" but internationally competitive Free Electron Laser (Swiss-FEL). The project started in 2007 and first coherent light was obtained in 2017. To reach the goal some new technical solutions had to be found and, with respect to financial aspects, the completion of the installation was planned to be reached in 3 phases, the last ending in 2029. The first operative beamline ARAMIS delivers short wavelength x-ray radiation since 2018. The



complexity of the installation requires close collaborations between PSI and interested, technically qualified industrial companies.

Examples of other accelerator-based installations at PSI

Even before the above-mentioned merger, beams of pions and muons from sources based on SIN's proton accelerator were used for various applications. For example, muons emitted from the *Swiss muon source (SμS)* are used as microscopic probes for studies of condensed matter, especially for measurements of internal local magnetic fields. With the enhancement of the primary proton-current density in the PSI era, a new station delivering muon beams of energies tunable over four decades could be realized, the first of its kind in the world. With this innovation, muons can also be used to probe surface layers and/or thin films, an attractive possibility for a new group of users worldwide.

Using particles, first pions and later, after the merger, protons, were and are used for medical purposes in *proton cancer therapy*. The method uses high-tech installations that were developed in house and are applied on a growing number of patients including children.

Considering the present status of PSI, Swiss researchers but also international science communities have access to a broad spectrum of large research infrastructures at the same site and thus may profit from a situation that is quite extraordinary across the globe.

Centro Svizzero di Calcolo Scientifico (CSCS)

The rapidly growing amount of data that are harvested at the existing large research infrastructures requires a solid support from sufficiently large computer centers, either on site or off campus, in order to cope with the situation. At present, the CSCS in Lugano assumes this national task in Switzerland. Since 2011 it is recognized as a User Laboratory in the ETH Domain, assuming the role of High-Performance Computing and Networking. CSCS is a nationally and internationally (Europe and overseas) well connected facility with a world-class infrastructure based on a hybrid CRAY XC50 system. Supercomputing services, interactive computing and long-term storage services are either generally accessible via a peer-review process in the user program or provided as infrastructure services to externally funded and managed platforms.

Large infrastructures at Universities

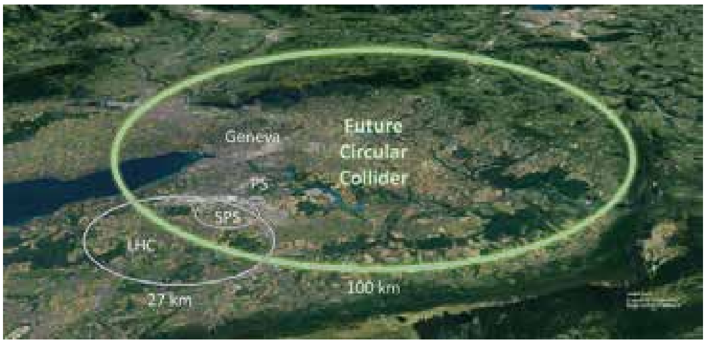
Grown out of former research activities in nuclear physics employing a van de Graff tandem accelerator, the laboratory for Ion Beam Physics (LIP) is now hosted by the Physics Department at ETHZ. Its activities are dedicated to the development of innovative instrumentation and experimental methods related to experiments using ion beams in fields such as archeology, geosciences, climate history, materials sciences, as well as radio-carbon dating related to art, mainly paintings, and objects of historic interest. The laboratory is involved in projects within Switzerland and abroad. For example, in 2019, the LIP was involved in collaborations with 199 institutions in 38 countries, including 48 partners based in Switzerland, a remarkable performance.

The Swiss Plasma Center (SPC) at EPFL is based on early activities of a Plasma Physics Laboratory established in 1961, then run by a national committee for nuclear energy. The institution was renamed Center for Research in Plasma Physics (CRPP) in 1968 and joined EPFL in 1973, headed by Francis Troyon, a pioneer in Swiss fusion research. Today SPC is a national laboratory with specific facilities in an academic environment and a member of the EURO*fusion* Consortium since 2014. It hosts the basic plasma research installation TORPEX and operates the TCV, a versatile Tokamak device with variable configuration. SPC is the Swiss representative in the projects ITER (International Thermonuclear Experimental Reactor under construction in Cadarache (France) and DEMO, a future prototype commercial fusion reactor. SPC's current aims are a successful implementation of ITER and to significantly contribute to the development of scientific and technological aspects of DEMO, including the education of ITER/DEMO generations of scientists and engineers.

Swiss Extra Contribution to Secure the Future of CERN

For scientific and technological reasons, it is clearly in the interest of Switzerland that CERN continues to be the place of choice for experimental research in high-energy physics at the present site. The primary goal of the Swiss CHART initiative under the auspices of SERI is, as a host country, to provide an extra effort to support the CERN project „*Future Circular Collider*" by contributing significantly to CERN's FCC feasibility study and to generally enforce the future development of accelerators beyond existing technologies. Of the currently active 19 projects, 9 are dedicated to developing superconducting magnets that meet the standards of the accelerator that is planned for the FCC.

CHART, founded in 2015, also provides opportunities to motivate and offer activities for young scientists and professionals in corresponding fields of activities and to enhance and secure the standards of levels of education in various ways. Emerging results of CHART activities are intended to provide support for the development and upgrading of accelerator installations at PSI.



Apart from offering first-rate research opportunities for Swiss-based scientists, all the mentioned RIs play an important role at the international level and, as user institutions, offer open access to researchers also from abroad. Often the construction of these infrastructures and their upgrading is based on implementing innovative ideas with the help of demanding engineering work and craftsmanship, also with benefits to Swiss-based industries.

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Monitoring carbon dioxide emissions from space

PT 2/2022

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Achieving the goals of the Paris Agreement to limit global warming to no more than 2 °C above pre-industrial levels requires drastic cuts to CO_2 emissions, mainly from fossil fuel use. The wide-ranging impacts of the war in the Ukraine on shortages in gas supply, fuel prices and the economy across Europe made us aware of our continuing dependence on fossil fuels and the challenges of radically transforming our energy supply system to renewable sources. Yet, there is no time to lose to tackle this enormous challenge as climate change is progressing fast with increasingly devastating impacts on our environment and society (IPCC, 2022). The 197 signatory parties of the Paris Agreement commit to reduce emissions to levels compliant with the 2 °C target, but current pledges are not sufficient [Rogelj et al., 2016] and the even more ambitious goal of a 1.5 °C increase seems already out of reach [Geiges et al., 2020].

The Enhanced Transparency Framework of the Paris Agreement requires from all countries to provide transparent information on the implementation and achievement of their national objectives. A central element of this framework is a biennial submission of emission inventories derived *bottom-up* from statistical data and emission factors to quantify the activity of all sources in a country and the corresponding emissions. The generation of these National Inventory Reports (NIR) is labor-intensive and subject to significant uncertainties depending on the type of source. Developed countries already have the infrastructure in place, but developing countries face many challenges when compiling the necessary information due to a lack of resources and reliable statistical data.

The atmospheric science community has developed over many years an alternative *top-down* approach, which estimates emissions directly from atmospheric concentration measurements from ground-based networks and satellites. The link between atmospheric concentrations at a given location and emissions upstream is thereby established by an atmospheric transport model. The method provides fully independent information to verify the bottom-up inventories [Nisbet and Weiss, 2010], which is increasingly recognized by inventory builders and policy-makers as a critical element of quality control [Perugini et al., 2021]. As one of the first countries worldwide, Switzerland started publishing top-down emission estimates in an Annex of the official NIR already in 2016.

Europe's Copernicus Anthropogenic Carbon Dioxide Monitoring satellite mission CO2M

Since the general increase in atmospheric carbon dioxide (CO_2) concentrations is the main driver of climate change, significant investments are made into the expansion of the current CO_2 measurement capability and especially into the development of new satellites [Crisp et al., 2018; Janssens-Maenhout et al., 2020]. CO_2 is not only of interest due to the role of anthropogenic emissions but also in the context of the natural carbon cycle. Land vegetation and oceans have absorbed more than 50 % of the CO_2 released into the atmosphere by human activities since pre-industrial times, but their storage capacity is increasingly threatened by climate change [Canadell et al., 2007]. Until recently, these processes have been investigated primarily using ground-based in-situ observations, but since the launch of the Japanese satellite GOSAT in 2009 [Kuze et al., 2009] and the U.S. satellite OCO-2 in 2014 [Crisp et al., 2015], they are increasingly studied also from space. These satellites have provided invaluable insights into the distribution of CO_2 and the global carbon cycle, but their potential to quantify anthropogenic emissions is limited due to their poor global coverage preventing frequent observations of individual sources.

The European Space Agency in collaboration with the European Commission and EUMETSAT is therefore developing in the Copernicus Earth Observation Programme an Anthropogenic Carbon Dioxide Monitoring (CO2M) mission [Janssens-Maenhout et al. 2020; ESA 2020; Sierk et al. 2021], a constellation of possibly three polar orbiting, sun-synchronous satellites to be launched from 2025. CO2M will carry an imaging spectrometer for measuring CO_2, methane (CH_4) and nitrogen dioxide (NO_2), as well as a multi-angle polarimeter and a three-band cloud imager. Different from GOSAT and OCO-2, it will provide images of column mean dry mole fractions of CO_2 (denoted XCO_2) over a comparatively wide swath of 250 km and will offer global coverage within three days (Fig. 1). The imaging capability and the small ground-pixel size of 2 km × 2 km will allow CO2M to map plumes of strong localized sources, like power plants and cities. This was demonstrated in studies using synthetic XCO_2 observations generated by sampling the output of a high-resolution atmospheric transport model along simulated satellite orbits and adding realistic measurement noise (Fig. 2).

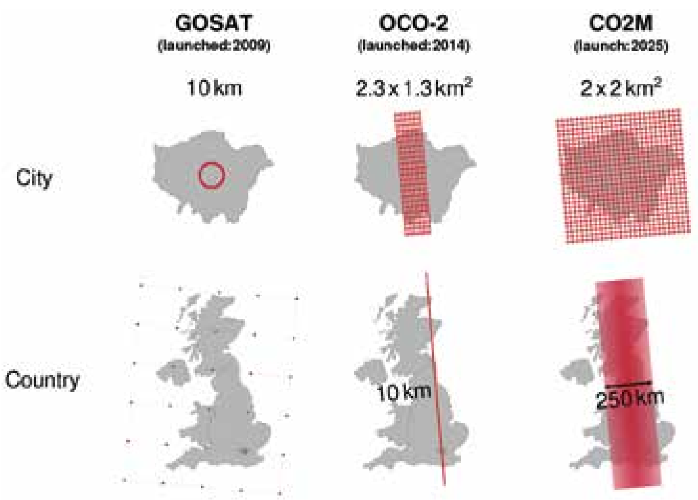

Figure 1: Comparison of the sampling patterns of GOSAT, OCO-2 and the planned CO2M satellites (adapted from ESA 2015, credit O. Schneising, IUP-Bremen)

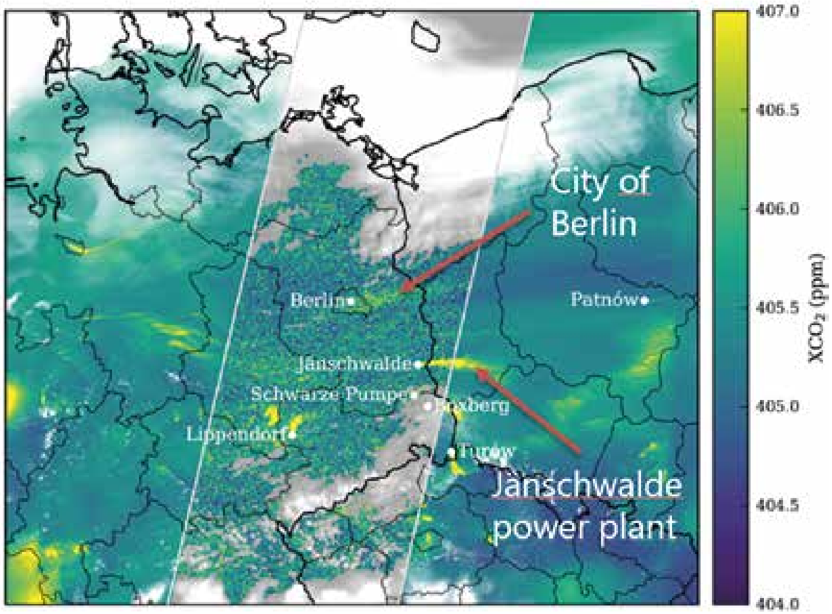

Figure 2: Simulated CO2M observations over eastern Germany and Poland showing the CO_2 plumes of individual power plants and the city of Berlin. The CO_2 simulations were performed with the atmospheric transport model COSMO-GHG. The two grey lines denote the border of the satellite swath. Realistic measurement noise was added to the synthetic observations (adapted from Kuhlmann et al., 2019).

Accurately measuring CO_2 from space

Variations in XCO_2 caused by anthropogenic emissions and biospheric activity are very small, mostly well below 1 % compared to its atmospheric background of more than 400 ppm, as such the measurements need to have extremely high precision and accuracy. Furthermore, they need to be sensitive to CO_2 near the surface to capture the signals from human emissions and exchange with the biosphere at the surface. To meet these demanding requirements, CO2M will leverage on the concepts developed for OCO-2. It will measure top-of-the-atmosphere radiances with a pushbroom imaging spectrometer in three spectral bands in the near infrared (NIR) and short-wave infrared (SWIR) with medium to high spectral resolution [Sierk et al. 2021] (Fig. 3). The radiance in these bands is dominated by sunlight reflected at the Earth's surface into the line of sight of the instrument. XCO_2 is derived from the ratio between the total column of CO_2 retrieved in bands SWIR-1 (weak CO_2 absorption) and SWIR-2 (strong CO_2 absorption) and the total column of air represented by O_2 retrieved in NIR. However, photons may have also been scattered by aerosol and clouds in the atmosphere. This scattering introduces uncertainties in the length of the atmospheric path traveled by photons, which, in turn, introduces uncertainties in the abundance of CO_2 since the amount of sunlight absorbed depends on the product of CO_2 number density and atmospheric path length. Scattering also affects the sensitivity to CO_2 near the surface where most sources and sinks are located. The width and resolution of the spectral bands were chosen carefully to quantify the CO_2 and O_2 number densities and the various effects on atmospheric path length as accurately as possible. Nevertheless, measurement uncertainties generally increase with a higher number of scattering particles (aerosol, ice cloud particles) and with lower surface reflectance. Optically thick clouds also preclude measurements over much of the Earth's surface. Only about 10 % of all measurements of OCO-2 pass the strict cloud screening and other quality criteria. Measurements over dark ocean surfaces can only be made while collecting data in the direction of the sun-glint, where the sunlight can be highly polarized. To further improve the accuracy and overall data yield, CO2M will therefore carry an additional multi-angle polarimeter and cloud imager to better account for the impact of aerosol and clouds.

Monitoring anthropogenic CO_2 emissions

The ability to quantify emissions from strong localized sources has already been demonstrated in numerous studies based on real or simulated satellite observations. However, Europe's ambition is to develop a system that allows quantification and regular monitoring of CO_2 sources at all scales, which also requires the ability to distinguish between anthropogenic emissions and the natural carbon cycle [Janssens-Maenhout et al., 2020]. This will not be possible with spaceborne observations alone but will require a holistic approach integrating observations from satellites and ground-based networks with bottom-up CO_2 emission maps and improved modeling of the natural carbon cycle. The integration of all available top-down and bottom-up information will be accomplished with an operational data-assimilation system that is currently developed by the European Centre for Medium Range Weather Forecast (ECMWF) in collaboration with many research partners in the framework of Copernicus [Balsamo et al., 2021]. An important near-term goal is

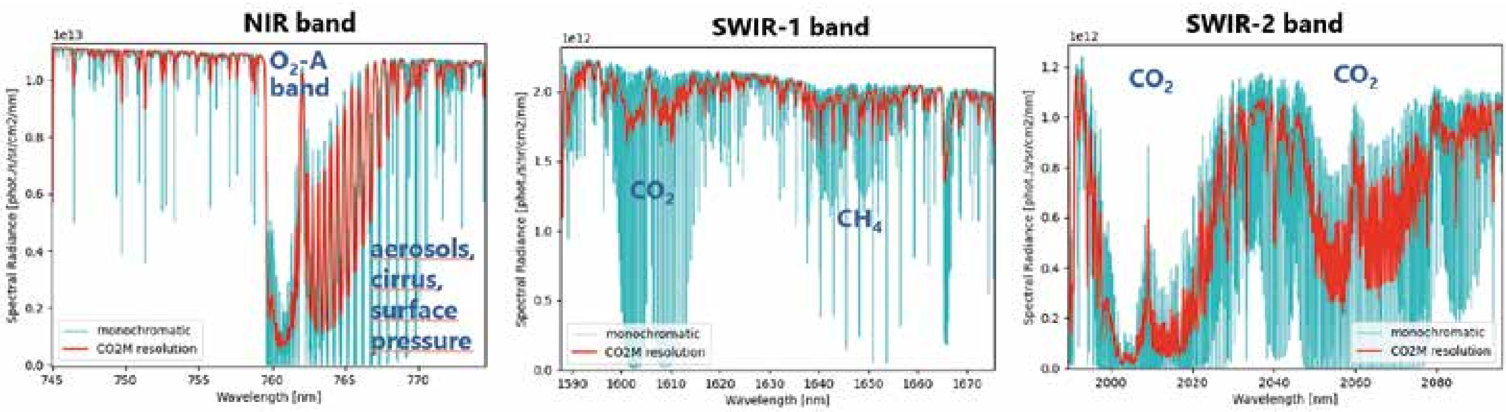

Figure 3: Simulated CO2M measurements of top-of-the-atmosphere radiances in three spectral bands in the near-infrared (NIR) and in two short-wave infrared bands with weak (SWIR-1) and strong (SWIR-2) CO_2 absorption bands, respectively. Parameters retrieved in the respective spectral ranges are shown in dark blue letters (adapted from Sierk et al., 2021).

to support the second *Global Stocktake* of the Paris Agreement in 2028, which will assess the collective effort of all countries to reduce greenhouse gas emissions against the 2 °C target based on data collected prior to the end of 2026. Europe is therefore pushing hard to launch the first CO2M satellites already in 2025.

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Physics & Education - Perspectives from Condensed Matter and Biophysics

PT 3/2022

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Physics education has in the past often been centred either on technological applications or the very large or small scales of the universe. As a middle ground, everyday phenomena, biological or soft matter systems are however also very useful to particularly stimulate students without an innate interest in Physics. In this presentation I will show how simple experiments on everyday phenomena can excite children for the subject of Physics. In addition, I will show how a standard Physics curriculum can be adjusted to cover the same topics with an emphasis on living matter and biological phenomena. This is not only useful for introductory lectures for life science students, but can also be used in high schools in order to increase the level of interest of the students by connecting the subject to their world.

Physics is often perceived as dry and technical at least partly due to how it is taught given examples that can be treated exactly using abstractions that take into account the essence of a phenomenon. While this abstraction from the actual system is one of the core strengths of Physics, such problems often do not speak to the imagination of students. Thus while treating the 'big questions' of Particle and Astro-Physics is useful to show the extent of the physical understanding from the smallest to the largest structures, which gets those students motivated that usually end up studying Physics, there is a large class of students that may not be excited by the subject in this way. Therefore, in order to get students interested, while still showing the strengths of physical abstractions, it is very useful to use real world examples, often from biological systems to grab the students attention and then explain these phenomena using the abstraction of Physics. Basing the Physics content in a context that is relevant to the students then also leads to an increased retention of the subject [1].

While there is no type of example that will be of interest to everyone, it is important to use many different types of hooks to get the students attention and have such examples present for many different Physics concepts. This ranges from questions of energy production, which are of particular interest at the moment, to sustainability, where the basis of climate change is thoroughly based on Physics, to debunking conspiracy theories concerning the moon landing using ballistic analysis of the dust of the lunar rover [2]. One aspect, which is of particular interest in reducing gender imbalances in Physics is the use of biological examples [3, 4]. Therefore, I will discuss two such examples in detail below. However, I would like to begin with a set of examples that shows that an understanding of Physics can also be used to see beautiful structures in the world around us that are perceived as inherently beautiful, such as spectral colour in rainbows and related phenomena. However, understanding what gives rise to these phenomena also means that one knows in what circumstances they are likely to appear such that one can keep an eye out for them. In the example of a rainbow, whenever the sun is visible when it rains, a look away from the sun often reveals a rainbow. Knowing that there is always a secondary, faint and reversed rainbow about 10 degrees further out makes that one can almost invariably also perceive the secondary if the primary is seen. In Fig. 1 below, there are four less well-known examples of such structures, mostly based in optics, that appear relatively often, but are mostly overlooked due to the fact that one does not pay attention.

Fig. 1: Examples of beautiful structures that can be observed much more easily when understanding the physical basis of their appearance. Top left: When only a thin layer of water freezes on a pool or a lake, i.e. when the temperature is not too far below freezing, on can observe the freezing front that shows a self-similar structure of freezing arms akin to an 'ideal snowflake' magnified to a length scale of about 10 cm as in the picture shown. Top right: When street signs, particularly white ones, have been re-painted and the sun is high in the sky, an almost circular 'glassbow' can be observed when the sun is in the back. This is because to increase reflection of the street signs, small glass spheres are added to the paint as retro-reflectors to increase the reflectivity in the direct back-direction, whatever the direction of illumination. Thus with the sun in the back, only a small angular range of about 25° is illuminated with reflected light and the dispersion of glass leads to a dependence of the maximum angle on the colour. This is basically exactly the same as a rainbow, except that glass spheres take the role of reflector rather than spheres of water and due to their higher index of refraction, the angle is smaller, such that a full circle is more easily observed. Bottom left: A similar circular spectrum can be observed when watching a large field of fog with the sun in the back. In contrast to the above example, here the angular opening of the spectrum is due to diffraction of the light at the small (roughly 50 µm sized) droplets of fog. From the angular opening of the spectral ring, the size of the fog droplets can thus be determined. Bottom right: In situations when there is rain, but also a small haze, raindrops reflect light in the limited angular range known from a rainbow. Due to the haze, the incoming light from the sun is however not strictly parallel, but distributed over a range large enough to mix the different colours of the rainbow resulting in a 'white rainbow'.

On the side of biological examples, the concept of interference can be introduced not only using the double slit, or the working principle of noise reducing headsets (a real-world example with a close connection to most students), but also with the colouration of many insects. As an example of this, the blue of the butterfly morpho menelaus (see Fig. 2) with its striking blue colour is highly instructive. In order to show that the colouration originates from something else than a pigment, one can add a drop of ethanol to the butterfly wing, which changes its colour to green [4]. This reverts when the ethanol evaporates. The reason behind this is the layered structures on the scales of the butterfly, whose distance and refractive index contrast lead to constructive interference in reflection for blue light [5, 6]. Adding ethanol changes the refractive index contrast, thus changing the condition for constructive interference. Knowing the layer thicknesses and distances, as well as the refractive index, the reflectivity can be well modelled as a Bragg-mirror, where the demonstration can actually be explained quantitatively with just some little abstractions.

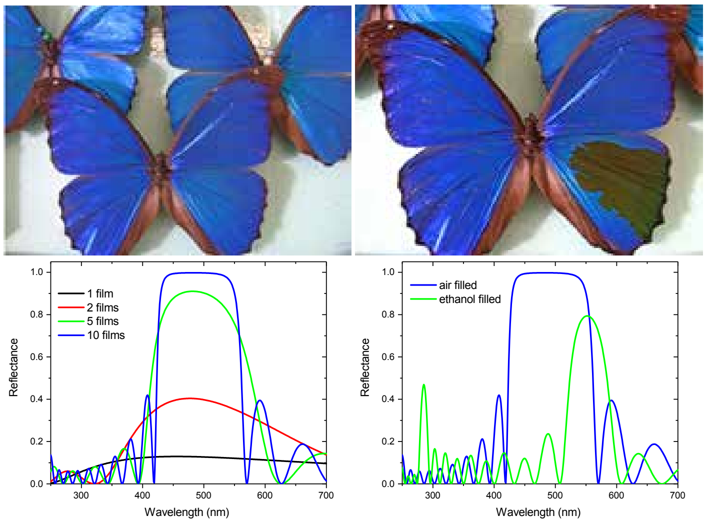

Fig. 2: Structural colours as an example of optical interference appearing in biology. The blue colour of the butterfly morpho menelaus is not due to a pigment as can be shown by the experiment in the top two panels, where some ethanol is added to the butterfly wing [4]. The striking blue colour is changed to a green, which reverses to blue after the ethanol is evaporated. The blue colour can be explained by the constructive interference of light from reflections on small lamellae roughly 80 nm thick and 100 nm apart that happen predominantly for blue light due to the path length difference [5]. Modelling this as a Bragg mirror of 2 to 10 layers (bottom left) shows a reflection predominantly in the blue. Filling the spaces between the layers with ethanol and performing the same model calculation shows that the maximum now shifts to the green (bottom right) [4].

This principle of structural colouration is very widespread in nature and not just limited to insects, but also observed in birds [7] and even colour-changing lizards, where the colour change is actually due to the changing of the spacing of refractive structures [8]. These principles can even be used to create colours that do not contain any pigments [9].

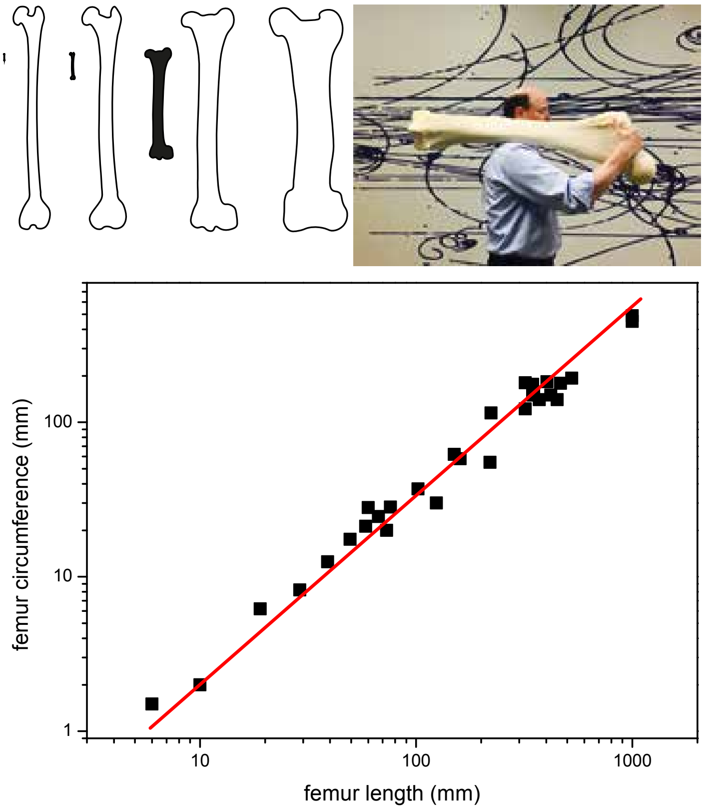

Fig. 3: The scaling of the structure of bones gives insights on the mechanical loads and stability of biological structures. Larger animals therefore have much sturdier bones than smaller animals as can be seen from comparing different bones drawn to the same length (top left). This is particularly striking in elephant bones, which make for an impressive demonstration (top right). Quantitatively, the scaling can be explained by the breaking due to buckling or twisting, which both have the same scaling law of the diameter growing with the length to the 5/4th power [4]. This is in contrast to the argument made by Galilei, which argues with compressional or tensile strength that would lead to a power law with an exponent of 3/2 [10].

As a second example, consider the thigh bones of different animals shown in Fig. 3, top left, when they are drawn to the same length. As the animal that the bones come from get bigger, the width to length ratio increases. This is particularly striking when comparing for instance the bones of an elephant (Fig. 3 top right) to that of a cat. This example was actually already known to Galilei and is discussed in his (second) dialogues [10]. There, he argues that compressional and tensile strength scales with the cross-sectional area of the bone, whereas the weight scales with the volume of the animal and thus with the cube of the bone's length. Taking together data from many different animals, this can actually checked quantitatively, indeed showing a power-law dependence of the bone diameter on the bone length given by $d \propto L^{5/4}$ (Fig. 3 bottom). However, this is different from the expectation due to Galilei's argument, which would have been $d \propto L^{3/2}$. A more careful analysis [4] shows that the load due to buckling, which leads to the breaking of bones is in fact limiting the bones' size and does lead to the observed scaling behaviour. Incidentally, the breaking due to twisting gives the same scaling.

This example shows several things apart from mechanical principles at the heat of this argument. For one, the usefulness of scaling arguments in obtaining physical laws and how this can be made quantitative. Moreover, it shows that even the great scientists of the past, such as Galilei can occasionally be not quite correct, but that this can be observed by empirical data and does not diminish their stature. Finally, one can then discuss that these bone structures are not in fact genetically determined but the growth of bones is in fact dependent on mechanical forces [11], which in a self-regulatory way leads to the bones having the ideal structure to carry the load they are exposed to. This is known as Wolff' law and for instance explains why bones are hollow inside as there are no mechanical stresses along the neutral fibre, such that bone is degraded in these places. Similarly, this shows why there is no such scaling of bone size in fish as they live in a buoyant environment [12]. Finally, in anthropological studies, it forms the basis of determining which of our humanoid ancestors started walking on two legs, as the correspondingly different mechanical load leads to different bone structures [11]. In spite its wide range use and long history, its biochemical basis is still actively studied [13–16].

In conclusion, the teaching of Physics can benefit greatly by anchoring the concepts covered in real world examples that have a direct connection to the students experience. Of particular interest here can be biological examples, which are of interest to many students that are not too keen on technical examples. This does however not mean that solely such examples should be used, but in order to keep the interests of a large cohort of students, it should pay out to broaden our usage of examples, while not forgetting the ones that have been established as very useful in the past.

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The Cherenkov Telescope Array Observatory

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In this article, we describe the status of the *Cherenkov Telescope Array Observatory* (CTAO) and some of its science cases of interest for the Swiss Community involved in it. CTAO is dedicated to the measurements of gamma-rays from the ground between 20 GeV up to about 300 TeV. Gamma-rays are emitted in acceleration processes happening in powerful accelerators typically generated by catastrophic events, such as shocks of supernova remnants, pulsars and pulsar wind nebulae, or jets of black holes, by exotic objects populating our universe, such as magnetars or the so-called Fermi Bubbles departing tens of kiloparsecs from the core of our galaxy.

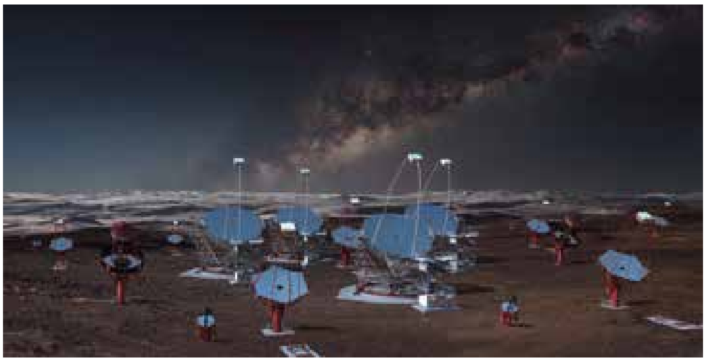
The Large-Sized Telescope (LST) prototype, the LST-1, passed its Critical Design Review (CDR) in June 2020. Credit: Otger Ballester (IFAE)

Gamma-rays are detected indirectly by measuring the Cherenkov light emitted by the electromagnetic showers they generate in the atmosphere. The atmosphere is used as a calorimeter. In this calorimeter also numerous cosmic ray hadronic showers are generated, representing a background for the measurement of gamma-rays from astrophysical point-like or extended sources. The electromagnetic showers can be discriminated among the 5 orders of magnitude more numerous hadronic showers by using an imaging technique, *Imaging Air Cherenkov Telescopes* (IACT). A mirror, composed of many facets, focuses the Cherenkov light produced by gamma-rays as a flash in the atmosphere lasting about 5 ns on the plane of a camera with ns-sensitive photosensors. A telescope can reconstruct the image of the source as a probability density distribution of many gamma-ray events. These produce elliptical images in the camera with their main-axis pointing to the center when the telescope is on axis with respect to the source. When multiple telescopes observe the same shower the precision in reconstructing the source improves as well as the background rejection capability.

CTAO will be a distributed research infrastructure composed of two arrays of tens of telescopes, one in the North at La Palma in the Canary islands and the other at the ESO site of Paranal in Chile, the Headquarter in Bologna at the Istituto Nazionale di Astrofisica [1] (INAF) premisis, a data science management centre in DESY-Zeuthen, and 4 off-site data centres processing the about 2 Pbyte per year data from the sites and about 20 Pbyte per year of simulated data. Switzerland will host one of the four offsite data centres at the supercalculus centre of CSCS. This data centre is being developed for astronomy with big data in Switzerland in synergy with the *Square Kilometre Array Observatory* (SKAO). CTAO involves the University of Geneva (UNIGE), ETHZ, EPFL, and the University of Zürich and it is coordinated by UNIGE.

CTAO is a landmark in the European Strategy Forum of Research Infrastructures (ESFRI) roadmap together with SKAO and the *European Extremely Large Telescope* (E-ELT) and it is the first priority of the APPEC (AstroParticle Physics European Consortium [2]) roadmap. The final submission of the application process to the European Community for the establishment of its final legal entity has been submitted. In 2023 the ERIC [3] will be in place and the construction works, which already started, will proceed at full speed and last 5 years. CTAO will lead the multi-messenger field as gamma-rays allow to reconstruct the morphology of sources, allowing to understand how particles are accelerated and how they escape from the sources, as well as the evolution with age of the source. This is being already observed by the current generation of arrays *Major Atmospheric Gamma Imaging Cherenkov Telescopes* [4] (MAGIC) and *High Energy Stereoscopic System* [5] (H.E.S.S.), and CTAO will have improved sensitivity by about a factor of 10.

Switzerland has a long-standing tradition in high-energy astrophysics and joined CTAO in 2005 also founding its initial interim legal entity, the CTAO GmbH. MAGIC is coordinated by ETHZ and UNIGE also participates to it. The two MAGIC telescopes, with mirror diameter of 17 m, are located close to the first of the CTAO telescopes, the *Large*



This image illustrates all three classes of the 99 telescopes planned for the southern hemisphere at ESO's Paranal Observatory, as viewed from the centre of the array. This rendering is not an accurate representation of the final array layout, but it illustrates the enormous scale of the CTA telescopes and the array itself.
Credit: Gabriel Pérez Diaz (IAC)/Marc-André Besel (CTAO)/ESO/ N. Risinger (skysurvey.org)

1 http://www.inaf.it/en

2 https://www.appec.org/

3 https://research-and-innovation.ec.europa.eu/strategy/strategy-2020-2024/our-digital-future/european-research-infrastructures/eric_en

4 http://magic.mppmu.mpg.de/

5 https://www.mpi-hd.mpg.de/hfm/HESS/

Size Telescope (LST-1) with 23 m mirror diameter. This is already producing first results for science commissioning. The contribution of Swiss institutions has been discussed in detail as well as the potential of the observatory in the current multi-messenger scenario including neutrino telescopes, such as *IceCube* and gravitational wave interferometers. As gamma-ray bursts have been recently measured by MAGIC and H.E.S.S. and the *Laser Interferometer Gravitational-Wave Observatory*[6] (LIGO) and *Virgo*[7] have seen gravitational waves in coincidence with gamma-rays, we expect to unravel the mistery on gamma-ray bursts. Also neutrino telescopes and MAGIC have seen a joint flare of a blazar, a flaring black hole in the core of an active galaxy. which is most probably responsible with other similar powerful sources for the extragalactic cosmic rays and the gamma-ray background light. CTAO will also search for dark matter by looking at the possible signature of axions in gamma-ray spectra from blazars or scanning the galactic centre and other massive clusters searching for the annihilation or decay products of dark matter in standard particles.

CTAO had also many technology-returns for instance in the field of photosensing with silicon detectors, digital electronics, advanced analysis based on machine learning and likelihood methods. CTAO will take data for about 20 - 30 years serving a broad community of enthusiastic scientists and powering the multimessenger network with many alerts, while fascinating the broad public unraveling the highest energy universe.

6 https://www.ligo.caltech.edu/

7 https://www.virgo-gw.eu

The dawn of Language Models in Chemistry and Beyond

PT 5/2022

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Introduction

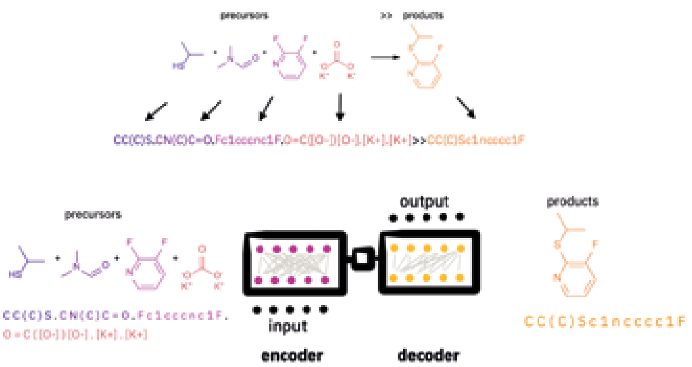
What exactly is a "language"? Experts define it as a system of spoken, written, and signed symbols in conjunction with grammar rules, used for human communication. Approximately 6,500 languages exist in the world. Some are more alike than others, but each reflects a specific culture. Chemistry, similar to any other natural science, constitutes a language unto itself, using of the characteristic graphical elements instead of words and with rules (grammar) that guarantee the meaningfulness of the message (sentence). Modelling chemical language offers the potential to capture the behavior of the physical laws governing the described chemical phenomena without the need of solving complex mathematical equations, much like linguists explore language to learn more about humanity.

The relationship between language models and chemistry could be both surprising and intriguing. On the one hand, the sheer number of languages demonstrates that, despite the universality of language among humans, there is also a great deal of diversity. Therefore, the parallelism between a field-specific language such as Chemistry and a natural language should not be surprising. On the other hand, the structure, grammar, and inflection of different languages all demonstrate how language evolves and changes in various contexts. Similarly, the field of chemistry, along with all other natural sciences, evolved over time as a result of the continuous collection and interpretation of new experimental evidence.

Physical laws describe the behavior of natural phenomena at a very detailed level, whereas language captures their coarse description. This is what links chemistry and languages and puts language modeling in a better position compared to the mathematical laws that govern physical phenomena. In fact, in the chemistry space, the use of language models results in being a more successful tactic to predict the behavior of physical systems, such as chemical reactions compared to solving many body equations. At the same time, physical laws continue to be very effective in explaining what we observe. The use of language modeling could be easily expanded far beyond the realm of chemistry, and similar comparisons could be extended to any other branch of natural science.

Natural Sciences and Language Models

Over the past couple of centuries, chemistry has evolved into a data-driven science. Experts in the domain have gathered a large number of observations and constructed a domain-specific representation with the primary goal of structuring experimental observations, identifying commonalities, and rationalizing observed chemical reactivity with rules. A similar process occurred centuries before in Physics, with the only difference being that the preferred representation for the description of natural phenomena (such as planet orbits or cannon ball trajectories) was math with its symbols and formalism, rather than a completely new made-up collection of symbols. Despite differences in the representation, all disciplines have collected experimental data and developed governing rules (or equations) for the phenomena in question. In essence, the rules (or equations) are an approximation that fits a large number of experiments.



Forward reaction prediction cast as translation task between the language of the precursors and the language of the product.

Insofar as a language is a structured system of communication, math and chemistry are languages in their own right. In fact, in order to be so defined, a language must have its grammar and its vocabulary (words or representation symbols). The development of a chemical symbolism with its own rules describing the reactivity between two or more molecules, or the development of a series of mathematical symbols representing specific observed or thought concepts, is nothing more than the development of an independent language. Languages have played a significant role in human history, so it should come as no surprise that one of the most active fields of research in Machine Learning today is the development of technologies with the goal of mastering natural languages, including text creation, translation, and emotional analysis.

However, not too long ago, language models were restricted to narrow topics and often unusable by context shifts. Today, thanks to innovations in model architecture, training methods, and distributed computing, they are advancing rapidly. Neural networks are being used to translate languages, answer questions, summarize texts, generate articles that are indistinguishable from those written by humans, and answer complex scientific questions spanning chemistry to biology.

Today, language models are becoming an integral part of our lives due to the expanding AI's capacity to recognize context and their rapid adoption into more sophisticated workflows.

But what exactly is a language model? A language model is a probability distribution over a set of word sequences. By training on text corpora in one or more languages, language models generate probabilities and solve specific tasks.

Language Models for Chemistry

The use of language models in the chemical domain necessitates the use of a machine-processable domain language. Despite the fact that humans have traditionally used diagrammatic representations, almost all of the work in machine learning applied to molecules relies on *line notation* (a typographical method using printable characters) for entering and representing molecules and reactions. SMILES (**S**implified **M**olecular-**I**nput **L**ine-**E**ntry **S**ystem) is a very popular line notation in chemoinformatics that contains the same information as a diagrammatic or graphical representation.

However, the SMILES notation is more helpful in the context of language modelling than drawings because it represents a linguistic concept rather than a computer data structure. SMILES is a real language, albeit one with a limited vocabulary (atom and bond symbols) and few grammar rules. The compactness of SMILES, compared to other line notations, facilitates the learning of language architectures, and reduces the amount of data required.

In chemical language modelling, SMILES can be used as "words" to represent molecules (reactants, reagents and products) as well as chemical reactions in language models. This approach emerged as one of the most effective, scalable approaches to capturing human knowledge and modelling processes in chemistry, in large part due to the use of effective line representations for chemical data. In the last 3 years, the IBM Research team showed the high performance of language models in machine learning tasks for synthetic organic chemistry, such as predicting chemical reactions [1-2], design of retrosynthetic routes [3], digitizing chemical literature [4], predicting detailed experimental procedures [5] and yields [6], designing new fingerprints [7], and promoting sustainable processes [8]. Predicting the result of a reaction involving multiple reactants or reagents, for instance, is framed as a translation task of a sentence representing precursors using SMILES notation into a sentence representing products using the same notation. Thanks to the use of similar types of architectures [9], language models demonstrated high quality and ease of use of application in a wide range of problems in chemical synthesis.

The use of language models in chemistry extends far beyond the realm of the digital experience, with language architectures serving as key enablers [5] in the development of autonomous laboratories for the synthesis of chemical compounds, with remote access possible via cloud technologies [10].

The ability to recover 3D features from 1D sequences when trained with biocatalytic data [11], the avoidance of tedious data curation campaigns to remove noise in datasets [12], and the mimicry of human performance in the design of chemical disconnection strategies [13] are all examples of areas where language models are recently demonstrating their full potential.

Back to the Future: Language will be key

And this is only the start of a larger structural revolution across all natural sciences. Natural language modelling has recently resembled an arms race, as big AI companies build models with ever-increasing numbers of parameters ingesting ever-increasing amounts of knowledge in specific domain languages. For the time being, number of parameters, volume of training data and computational resources define the state of the art in language processing as well as the domain in which these technologies have the most success and impact.

This explosion, whether for social or scientific applications, makes it more important than ever for models to track subtle shades of meaning when contextualizing words or molecules with specific functional groups, grasp narrative logic in capturing the correct semantic or reactivity in chemical reactions, and infer words or molecules that are free of bias with respect to specific topics. In social applications, gender and ethnicity are very important aspect; in Chemistry, obsolete chemical processes over novel, greener, and more sustainable alternatives may be the aspects to monitor. But there is one thing that won't change: languages were important in the past for the evolution of humans, and they will continue to be important in the future for the advancement and acceleration of scientific research.

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Progress in Physics (92)

Exotic quantum phases in new kagome materials

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The kagome lattice, named after a pattern of Japanese basketry, is a well-known theoretical playground for studying the interplay between frustrated geometry, correlations, and topology. In a recently discovered family of materials, these features combine with superconductivity and an unusual charge order to produce an even richer and more intriguing combination of physical phenomena. The compounds KV_3Sb_5, CsV_3Sb_5, and RbV_3Sb_5 fill a long-standing gap in the available scope of quantum materials and open several avenues for future research.

I. Introduction

The kagome pattern is inspired by a pattern of Japanese basketry and formed by corner-sharing triangles (see Fig. 1a). The crystal lattice derived from this pattern (see Fig. 1b) has been a popular playground in condensed matter physics for more than seventy years. The unique geometry gives rise to frustration, correlated quantum orders, and topology, owing to its special features: the electronic structure shows a flat band, inflection points called 'van Hove singularities', and Dirac cones (see Fig. 1c and d).

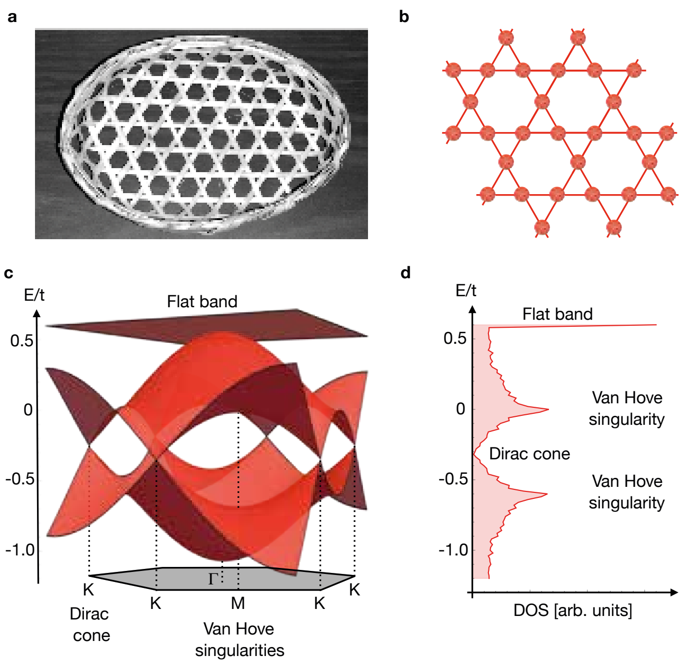

Fig. 1: Kagome systems and their electronic structure. ***a.*** *The kagome pattern originates from Japanese basketry (taken from [1]).* ***b.*** *The kagome lattice consists of corner-sharing triangles.* ***c.*** *The electronic structure contains van Hove singularities, Dirac cones, and a flat band.* ***d.*** *Flat band and van Hove singularities drastically enhance the density of states (DOS), thereby promoting interactions.*

The flat band results from the destructive quantum interference of states localized on the three sublattices, promoting interactions and possibly fractional states. Similarly, van Hove singularities can give rise to correlated orders, too: in graphene, for instance, doping to a van Hove singularity would allow for chiral d-wave superconductivity [2]. In the case of the kagome system, such orders can be enriched by the geometrical frustration of the underlying lattice. Additionally, the Dirac cones give rise to non-trivial topology once spin-orbit coupling is considered, which opens a small gap. However, a material realizing the kagome interplay between frustrated geometry, correlations, and topology has been long awaited. The discovery of the family of kagome metals KV_3Sb_5, CsV_3Sb_5, and RbV_3Sb_5 — commonly abbreviated to AV_3Sb_5 — recently brought this search to a successful end: Realizing motives from the iconic kagome band structure, they exhibit the sought after interaction phenomena by a high-temperature charge order as well as a superconducting instability at lower temperatures [3-7].

II. New kagome materials KV_3Sb_5, CsV_3Sb_5, and RbV_3Sb_5

The compounds KV_3Sb_5, CsV_3Sb_5, and RbV_3Sb_5 are formed by a structurally perfect two-dimensional kagome net of vanadium atoms, which is interwoven with a hexagonal antimony lattice (see Fig. 2a) [3]. Surrounding this core are additional antimony honeycomb layers, furthermore encapsulated by the triangular lattice of either K, Cs, or Rb. The three-membered family, therefore, crystallizes in the hexagonal P 6/mmm space group.

Interestingly, the layered structure gives rise to a quasi-two-dimensional electronic structure, as highlighted for instance by density functional theory results (see Fig. 2b). The band structure is metallic, with just a few bands crossing the Fermi level. These bands form three distinct features, changing only slightly as a function of k_z: (i) a quasi-two-dimensional electron pocket around the Γ point (i.e. the center of the Brillouin zone), (ii) several van Hove singularities at the M point, and (iii) Dirac bands at the K point. Consequently, except for a flat band (which is situated far from the Fermi level and only partially flat), all features of the two-dimensional kagome lattice are present, with a mul-

Glossary

Dirac cone – Feature in the electronic band structure with linear dispersion, where valence and conduction band are conically shaped. Dirac cones act as sources and sinks of Berry curvature, being essential for topological phases.

Van Hove singularity – Point in the electronic band structure with vanishing group velocity and singular density of states.

Charge order – Phase in strongly correlated materials, where interactions lead to a reordering of charges. The charge order transition is usually accompanied by symmetry breaking, for instance if charges reorder in a superlattice, breaking the original translational symmetry of the underlying crystal.

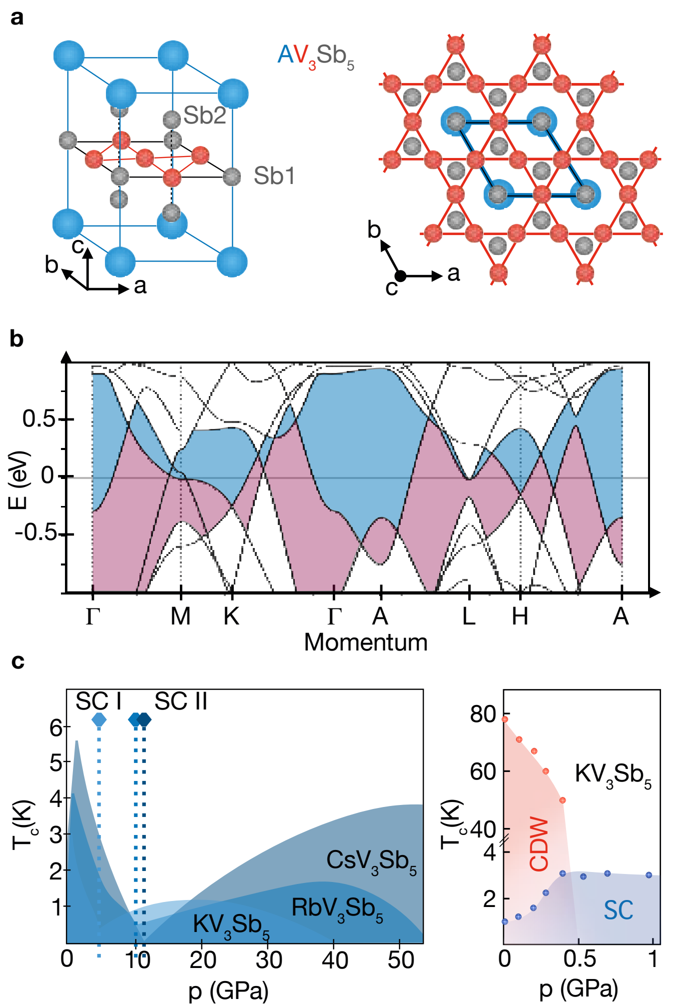

*Fig. 2: Exotic quantum phases in the kagome materials AV_3Sb_5. **a.** AV_3Sb_5 forms a layered structure in the P6/mmm space group. The vanadium kagome lattice is interwoven with a hexagonal antimony lattice, further encapsulated by an antimony honeycomb sheet. The family of kagome superconductors is formed by outer hexagonal sheets of A = K, Cs, Rb (taken from [33]). **b.** Band structure of KV_3Sb_5 along high symmetry directions in the Brillouin zone. The direct gap (shaded area) carries a non-trivial Z_2 topological index (taken from [33]). **c.** All members of the family show a superconducting phase diagram with two domes. The charge-ordered phase in KV_3Sb_5 enters competition with superconductivity at around 0.5 GPa and is suppressed as pressure increases. Depiction reproduced from [33], following data from [8, 9, 16, 17].*

titude of van Hove singularities at the Fermi level. Importantly, these compounds are non-magnetic, differentiating them from previously known magnetic kagome systems, like for instance Fe_3Sn_2.

The presence of van Hove singularities at the Fermi level promotes interactions, resulting in a set of correlated phases: when cooling below room temperature, all compounds show the onset of a charge order, with slightly varying critical temperatures (T_{CO} = 78 K, 94 K, and 102 K for A = K, Cs, and Rb, respectively [8-10]). When considering even lower temperatures, the charge order coexists with a superconducting phase (T_{SC} = 0.93 K, 2.5 K, and 0.92 K for A = K, Cs, and Rb, respectively [11-13]). When pressure is applied, the charge order is rapidly suppressed and superconductivity is promoted to higher transition temperatures, revealing their competing nature. For higher pressures, a second superconducting dome appears, separated from the first one (see Fig. 2c) [8, 9, 16, 17]. Even though both charge order and superconductivity are robust and have been observed in a wide range of samples and techniques, the exact nature of these phases still remains to be determined.

III. Evidence for chiral charge order

The unique feature of AV_3Sb_5 is the emergence of a *chiral* charge order with both electronic and magnetic anomalies. The charge order is commonly believed to be driven by the van Hove singularities at the Fermi level, opening a strongly momentum-dependent gap [16-18]. Additionally, experiments provide evidence for a chiral charge order: the ordering vectors obtained from scanning tunneling microscopy show anisotropic intensities, defining a chirality (see Fig. 3a) [19-21]. This chirality can be switched by an external magnetic field, indicating the presence of orbital currents [22-24]. Such currents would break time-reversal symmetry, which is supported by Kerr effect measurements [25-28]. Theoretically, these features could be explained by a complex order parameter realizing a higher angular momentum state, dubbed *unconventional*, in analogy to superconducting orders [30].

The unconventional nature of the charge order reflects in special transport signatures: time-reversal symmetry breaking is reflected by a giant anomalous Hall effect and an anomalous Nernst signal (see Fig. 3b) [31]. Moreover, the chiral nature of the charge order could be mirrored in an observed electronic magneto-chiral anisotropy (see Fig. 3c) [32].

While the emergence of a charge order can be regarded as a common phenomenon, the chiral and higher angular momentum nature is truly exceptional [33]. The emergence of all of these features is a hallmark of the kagome platform, combining geometrical frustration, charge order, and topology.

IV. Superconductivity and its interplay with the charge order

Upon lowering the temperature of the material, AV_3Sb_5 is found to also enter a superconducting state. The mechanism of superconductivity is reflected in the symmetry of Cooper pairing, which, on the kagome lattice, holds promise for unconventional phases. The spin and orbital aspects of the superconducting order are, however, still under investigation: experimental evidence exists for both a singlet [34] or a triplet spin structure [35-37], while the band structure was observed to be either fully gapped [11, 34, 40, 41] or having gap nodes [20, 36, 38, 40]. Interestingly, the pairing nature seems to differ between the three compounds: while KV_3Sb_5 and RbV_3Sb_5 show a nodal superconducting gap structure [23], CsV_3Sb_5 displays a two-gap (s+s)-wave symmetry in muon spin relaxation experiments [42]. The complex Fermi surface structure with multiple gaps [20, 36, 38, 40] inspired a multitude of theoretical proposals, including f-wave order parameters (see Fig. 4a) [43], pair density waves [44] and higher charge Cooper pairs [45]. The latter charge-4e and charge-6e superconductivity could explain recent experiments on a so-called "thick-rim geometry", showing oscillations of the resistance with an unusual periodicity that would be explainable with such exotic pairings [46]. Even though the low-temperature behavior of AV_3Sb_5 is not yet conclusively understood, the presence of a chiral charge or-

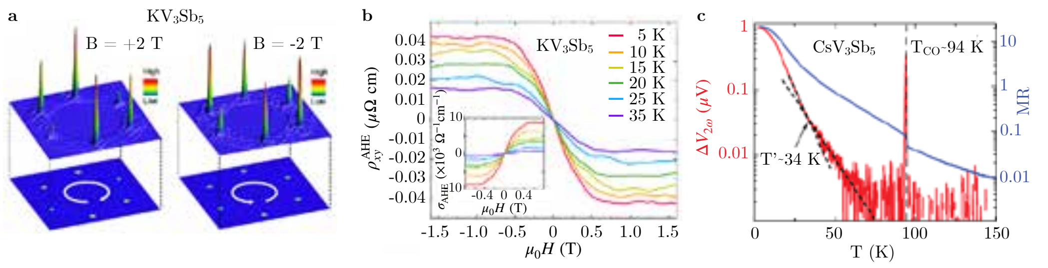

*Fig. 3: Chiral charge order in AV_3Sb_5. **a.** Chirality reversal of the spectroscopic 2x2 vector peaks under an applied magnetic field in KV_3Sb_5 indicates the chiral nature of the charge order (taken from [19]. **b.** Large anomalous Hall effect (AHE) indicates time reversal symmetry breaking: ρ_{xy}^{AHE} is obtained by subtracting the ordinary Hall background at various temperatures. The inset shows the corresponding conductivity σ_{xy}^{AHE} at various temperatures (taken from [29]). **c.** Log-scale temperature dependence of $\Delta V_{2\omega}$ and magnetoresistance ratio MR. The transition into the CDW state is evident as a sharp spike in $\Delta V_{2\omega}$, while the significant increase at lower temperature suggests the onset of chiral ordering (taken from [32]).*

der fuels hopes for likewise unconventional features. One piece of evidence in this direction is the critical scaling of the superfluid density with the critical temperature, placing AV_3Sb_5 close to unconventional superconductors with a low density of Cooper pairs (see Fig. 4e) [22].

However, the presence of two correlated orders — charge order and superconductivity — begs the question of whether they act as accomplices or opponents: while they can result from the same interaction terms, they compete for gapping out the same Fermi surface. The competition of both orders can be manipulated by straining the samples, applying pressure, or carrier doping, showing suppression of the charge order and enhancement of superconductivity (see Fig. 2c and 4 b,c) [8, 9, 16, 47-49]. Surprisingly, once the charge order is suppressed, all three compounds show a nodeless superconducting gap with time-reversal symmetry breaking (see Fig. 4d) [23, 50].

The multifaceted possibilities to manipulate the orders offer a unique opportunity to study the interplay of superconductivity and charge order, possibly leading to the design of systems with higher critical temperatures.

V. Discussion

The kagome materials AV_3Sb_5 show an exciting range of physical properties, with several details still under investigation. These observations have to be carefully analyzed with respect to the employed experimental probes: for instance, surface sensitive as compared to bulk specific techniques lead to different observations of the translational symmetry breaking in the charge-ordered regime. Moreover, whether the charge order entails an additional transition to a nematic order, is still under discussion. Apart from different experiments, strain in the sample or different chemical compositions can also lead to divergent results. For instance, nodes in the superconducting gap might disappear when the charge order is suppressed by pressure, strain, or doping (see Fig. 4d). Consequently, the character of the superconducting phase is strongly dependent on the competition with the preceding charge order.

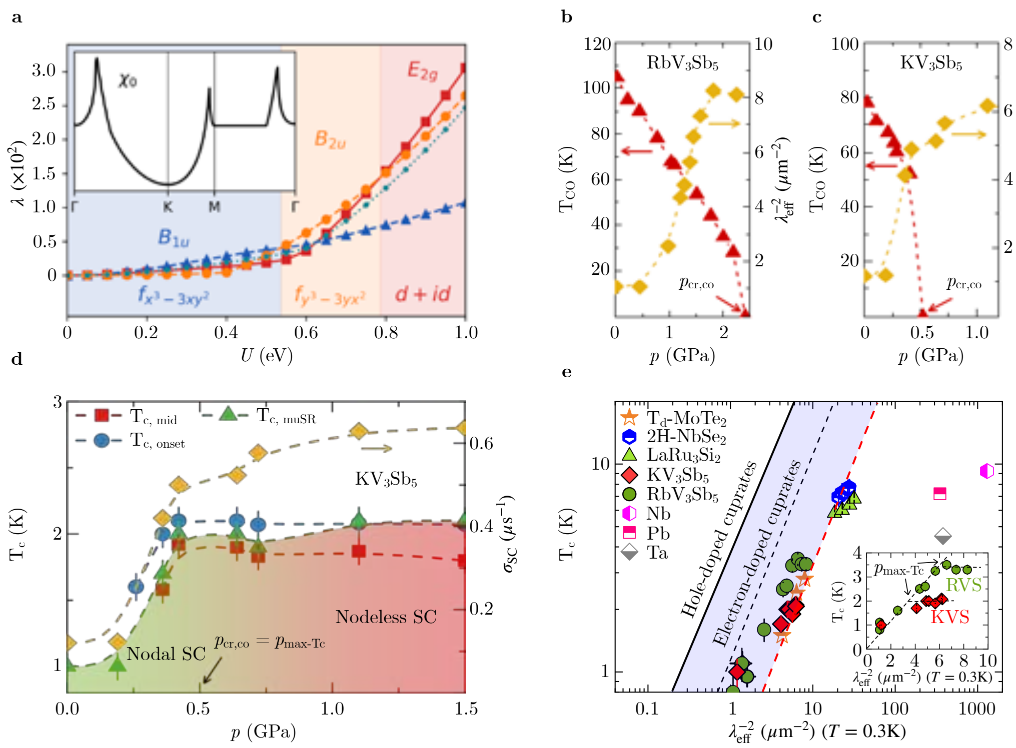

*Fig. 4: Superconductivity in AV_3Sb_5. **a.** Theoretical proposal for the superconducting order parameter. Pairing strength eigenvalues λ for the dominant superconducting instabilities are displayed as a function of the on-site Coulomb interaction U. Continuous (dashed) lines indicate triplet (singlet) pairing. Two distinct f-wave solutions dominate for smaller interaction scales until a d-wave solution dominates for larger U. The upper left inset depicts the largest eigenvalue trajectory of the bare susceptibility χ_0 along the high-symmetry path (taken from [43]). **b.** and **c.** Pressure dependence of the superfluid density and the charge order temperature T_{CO} for RbV_3Sb_5 and KV_3Sb_5 (taken from [23]). **d.** Pressure dependence of the superconducting transition temperature and the base-T value of the superconducting muon spin depolarization rate. Crossover from nodal to nodeless superconducting pairing is denoted by color (taken from [23]). **e.** Plot of T_c versus the superfluid density in logarithmic scale obtained from muon spin relaxation experiments in KV_3Sb_5 and RbV_3Sb_5, with comparison to the kagome superconductor $LaRu_3Si_2$ as well as for the layered transition metal dichalcogenide superconductors Td-$MoTe_2$ and 2H-$NbSe_2$ (dashed red line) and various conventional Bardeen-Cooper-Schrieffer superconductors (taken from [23]). Inset shows the plot in a linear scale.*

VI. Future Perspectives

AV_3Sb_5 is a valuable resource for building quantum matter by design, opening several avenues for future research. The quasi-two-dimensional structure of AV_3Sb_5 naturally leads to the question of whether thin layers or even monolayers can be exfoliated. Thin films would allow to form Moire structures by gating, stacking, or twisting, promising exciting future developments. Moreover, the engineering by strain and pressure offers to manipulate the phases in a controlled manner. This could also facilitate the further exploration of the superconducting phase. Additionally, the unique transport signatures provide interesting questions for the future: How is the nonlinear response reflected in the superconducting regime? How can the strong anomalous Hall effect be manipulated or modified? Understanding the response to external fields could pave the way to potential applications.

The family of kagome materials AV_3Sb_5 fills a long-standing gap in the available scope of quantum materials, showing exciting orders emerging from strong correlations. The possibility to engineer and tune these phases holds promise for even more exciting discoveries.

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Progress in Physics (93)

Uniaxial strain as an efficient way to decouple intertwined degrees of freedom in high-temperature cuprate superconductors

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Felix Bloch's description of a particle in a periodic lattice in 1930 defines an important cornerstone of modern condensed matter physics. It showed that quantum mechanics can be used to describe collective phenomena in solid state materials and led to microscopic descriptions of fundamental material properties in metals or insulators. These theories, however, treat the electrons as if they were independent quasiparticles, which is not valid for strongly correlated electron systems. These materials display a multitude of macroscopic quantum phenomena that we can understand only if we resolve the coupling among the electronic spin, charge, orbit and lattice degrees of freedom. One example is copper-oxide materials in which high-temperature superconductivity coexists with charge and spin order. Using uniaxial pressure as an external tuning parameter four recent publications led by Swiss researchers have brought new insight into the coupling among the various degrees of freedom in La-based cuprates, and how their fluctuations enable high-temperature superconductivity.

In correlated electron materials novel coherent phenomena and their inherent functional properties frequently arise from deeply intertwined electronic charge, spin, orbital and lattice degrees of freedom. Prominent examples are unconventional superconductivity, skyrmions, multiferroicity, materials with a giant magnetoresistance, or hidden order states. Although, the importance of coupled degrees of freedoms is widely appreciated, how this coupling is realized microscopically often remains a key issue. A model example is unconventional superconductivity in cuprate materials, where it is thought that the macroscopic zero-resistance state arises from charge (CDW) and spin-density wave (SDW) fluctuations [1–4]. To this date, however, it is unclear how the salient charge and spin degrees of freedom are coupled to enable high-temperature superconductivity.

Almost all high-temperature cuprate superconductors share a generic phase diagram such as shown in Fig. 1a for the case of $La_{2-x}Sr_xCuO_4$ (LSCO). The inclusion of holes on the Cu-site effectively suppresses the correlated antiferromagnetic Mott state of La_2CuO_4, and triggers a superconducting *d*-wave state for $0.05 < p < 0.28$. The superconducting state competes with long-range density-wave order, whose nature varies across the different cuprate families. In $YBa_2Cu_3O_{7-y}$, for instance, superconductivity coexists only with CDW order [5, 6]. In LSCO and $La_{2-x}Ba_xCuO_4$ (LBCO), however, also SDW and signatures for pair-density wave order (a spatially modulated superconducting order parameter) are found [1–3]. It is thought that SDW and CDW order are connected in LSCO and LBCO, but the two orders possess a very different temperature and doping dependencies (see Fig. 1b). This raises the question how the different density-wave states are microscopically coupled in cuprate materials, and how their fluctuations enable the emergence of high-temperature superconductivity. Four peer reviewed publications led by Swiss scientists have recently brought new insight into these questions [7–10].

Scattering techniques are a very efficient tool to study the electronic and lattice degrees of freedom in solid state materials. In La-based cuprates charge order appears at wavevectors $\mathbf{Q}_{CDW}$ (in reciprocal lattice units (rlu)) which are offset by $\mathbf{q}_{CDW} = (\delta_{CDW}, 0, 0)$ and $(0, \delta_{CDW}, 0)$ with respect to structural Bragg peaks. SDW order is found at wavevectors $\mathbf{Q}_{SDW}$ which are shifted by $\mathbf{q}_{SDW} = (\delta_{SDW}, 0, 0)$ and $(0, \delta_{SDW}, 0)$ away from the antiferromagnetic wavevector $\mathbf{Q}_{AF} = (1/2, 1/2, 0)$ with $\delta_{SDW} = 1/2\delta_{CDW} \approx 0.12$ for $La_{1.88}Sr_{0.12}CuO_4$. The structure

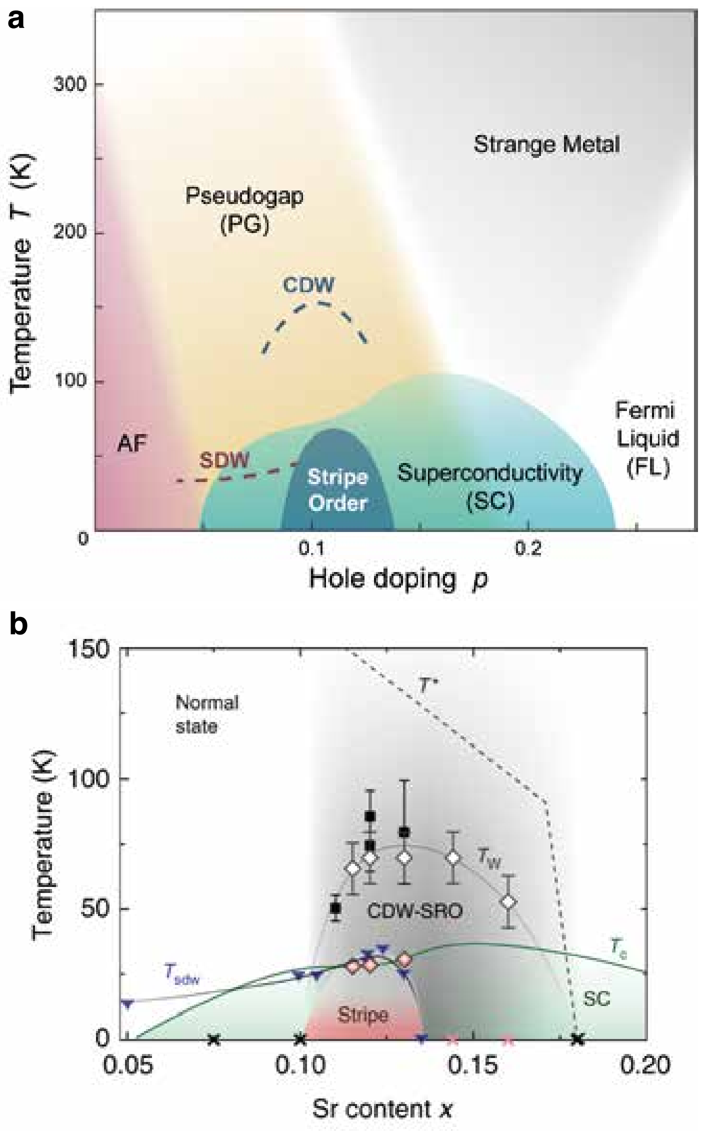

Fig. 1. Representative phase diagram of cuprate high superconductors. ***a****: doping and temperature (pT) phase diagram of $La_{2-x}Sr_xCuO_4$, where p denotes the number of holes per Cu site (with courtesy of Jaewon Choi (Diamond Light Source - UK).*
b*: Close up of the phase diagram into the region for $0.05 < p < 0.2$. The holes were included into the system via Sr substitution on the La site (published in [3] under Creative Commons Attribution 4.0 International License).*

of the charge-spin density-wave order is widely believed to consist of uniaxial charge-spin stripes [1, 2, 11–14] (see Fig. 2b), although other, checkerboard-type structures were also proposed in the past [15–24] (see Fig. 2a). In fact, regular diffraction experiments do not allow distinguishing the two cases (see Fig. 2a and b for the case of CDW order). This is because a multi-domain state with a single propagation vector in each domain triggers the same diffraction pattern as when two phase-related wavevectors coexist in a single domain. One way to differentiate between the two scenarios is to use an extrinsic tuning parameter that breaks the symmetry on a macroscopic scale [25, 26]. As shown in Fig. 2a and b a repopulation of the CDW/SDW domains is expected in the stripe-order case, whereas the two wavevectors are not expected to be affected differently in checkerboard structures. Three recent experiments have set out to clarify the structures and coupling between the CDW, SDW orders and the lattice in $La_{1.88}Sr_{0.12}CuO_4$ [7–9], using uniaxial pressure cells that were designed at the University of Zurich to optimize the needs for each scattering experiment (see Fig. 2c).

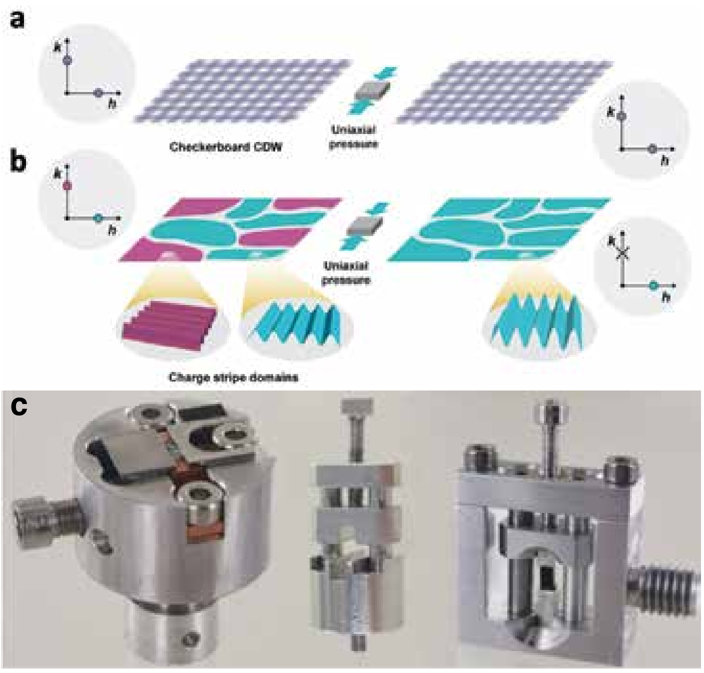

*Fig. 2. Revealing the density-wave ground states via uniaxial pressure. **a** and **b**: Schematic representation of the two possible CDW ground states and how they are affected by uniaxial pressure (Reprinted figure with permission from [7]. © (2022) by the American Physical Society.). **c**: Uniaxial pressure devices used in [7–9]*

Using elastic x-ray and neutron scattering an international collaboration led by researchers from the University of Zurich and the Paul Scherrer Institut studied the response of CDW and SDW order in $La_{1.88}Sr_{0.12}CuO_4$ upon uniaxial pressure along the Cu-O bond direction [7, 8] (the tetragonal a-axis). Concentrating on two independent Bragg peaks, they observed that the CDW and SDW intensities are redistributed at a compressive strain of $\epsilon_a = \Delta a/a \approx 0.02$ % while the Bragg peak positions and correlation lengths remained unchanged (see Fig. 3). This provides direct evidence for charge-spin stripe order in La-based cuprates, and effectively rules out other multi-**Q** single domain structures. The scientists further found that CDW and SDW orders response to uniaxial pressure in a similar manner. In both cases the application of pressure along one of the Cu-O directions favors the domain with wavevector along the perpendicular

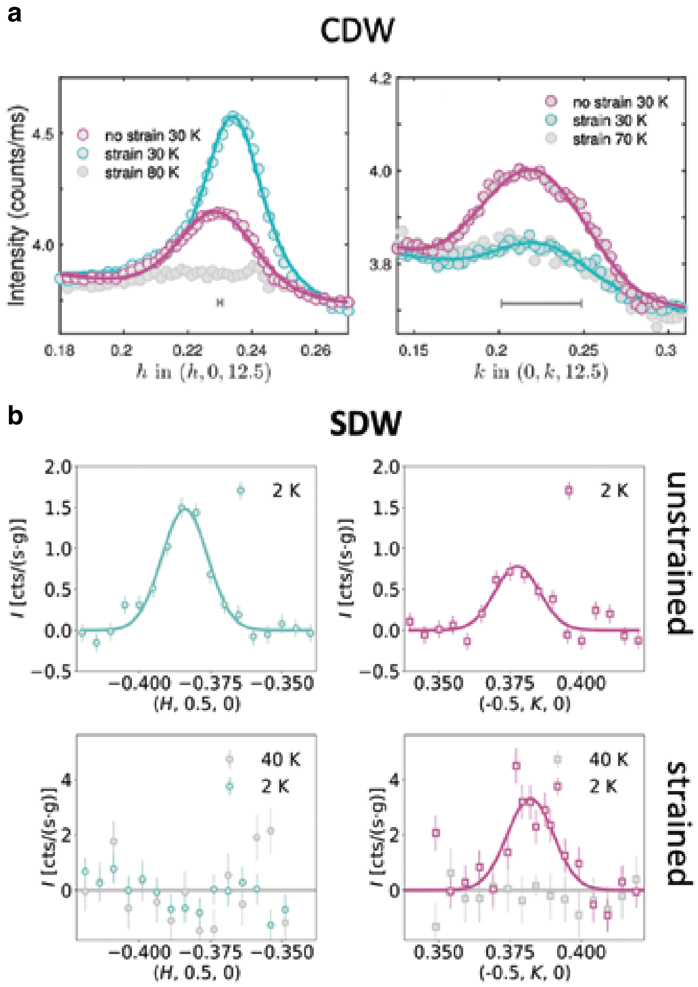

*Fig. 3. Uniaxial charge spin-order in La-based cuprates. **a** and **b**: Repopulation of CDW and SDW domains upon uniaxial strain along the Cu-O bond direction, respectively (Figure **a** was reprinted with permission from [7]. © (2022) by the American Physical Society. Figure **b** was taken from [8])*

direction. This strongly suggests an intertwined microscopic coupling between CDW and SDW order, and indicates that the putative pair-density wave also consists of uniaxial stripes. Finally, these results attest that uniaxial charge-spin stripe fluctuations are involved in the emergence of high-temperature superconductivity.

Further insight into these fluctuations and their coupling to the lattice degree of freedom was obtained by the same

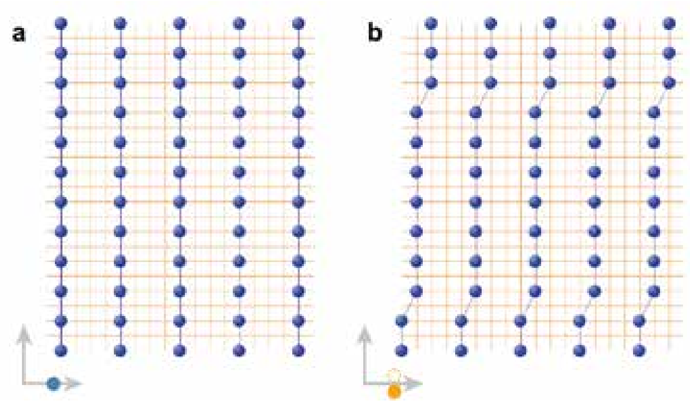

*Fig. 4. Modest uniaxial pressure depins transverse stripe kinks. **a** and **b**: Schematic representation of the uniaxial stripes and transverse kinks originating from transverse stripe fluctuations. Modest pressures align the stripes along the Cu-O directions, whereas large strains generate a single stripe domain (published in [9] under Creative Commons Attribution 4.0 International License).*

collaboration using resonant x-ray scattering [9]. Transverse stripe fluctuations have been predicted to promote superconductivity by enhancing the Josephson coupling along the c-axis [27]. While such fluctuations are extremely challenging to probe directly, they are also thought to trigger stripe kinks such as shown in Fig. 4a and b. The kinks cause a small inconmmensuration perpendicular to the CDW wavevector, ie. CDW diffraction peaks are often observed at $\mathbf{q}_{CDW} = (\delta_{CDW}, \delta_{\perp}, 0)$ and $(\delta_{\perp}, \delta_{CDW}, 0)$ with $\delta_{\perp} \neq 0$. Using modest ($\epsilon_a < 0.02$ %) uniaxial strain along the Cu-O bond direction, the scientists studied the transverse pinning properties of the charge stripe order. They found that uniaxial strain first aligns the stripe domains along the Cu-O bond direction, before a single domain state is established at larger pressures. This suggests that low-energetic transverse stripe fluctuations are necessary for high-temperature superconductivity and allows the state to coexist with static stripe order.

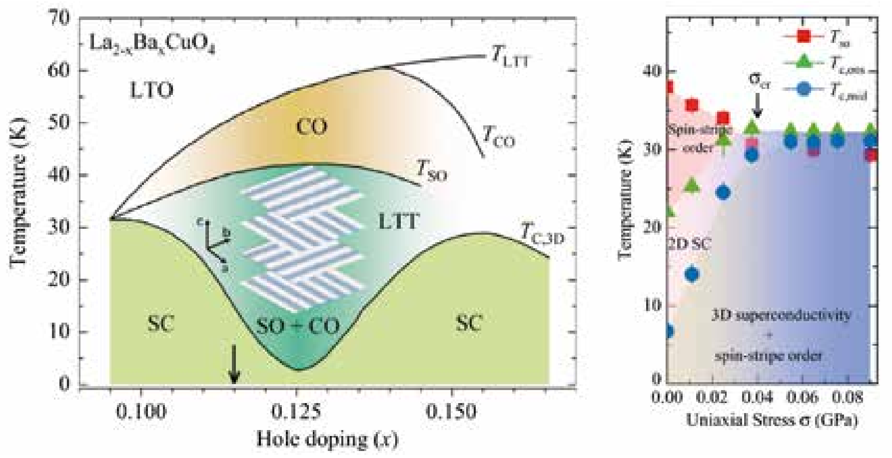

*Fig. 5. Uniaxial pressure dependence in $La_{2-x}Ba_xCuO_4$. **a**: pT -phase diagram, **b**: Evolution of the spin-stripe order and superconductivity under uniaxial strain along an in-plane axis close to the Cu-Cu bond direction (Reprinted figure with permission from [10]. © (2020) by the American Physical Society.)*

The aforementioned publications did not reveal any changes in the competition between superconductivity and stripe order under uniaxial pressure along the Cu-O bond direction of LSCO [7–9]. Interestingly, another international collaboration led by researchers from the Paul Scherrer Institut has observed a different behavior in LBCO when uniaxial pressure is applied along an in-plane axis close to the Cu-Cu bond direction [10]. The *pT*-phase diagram of LBCO is shown in Fig. 5a, overall following the same behavior as LSCO (see Fig. 1). LBCO, however, features an additional structural transition above x > 0.09 enabling the stripe domains to alter along the c-axis (see Fig. 5a). As a result the competition between superconductivity and stripe order is enhanced, leading to an almost complete suppression of superconductivity at x = 1/8 where stripe order is strongest. Signatures of the pair-density wave order are often observed as an additional transition in the resistivity and is often referred to two dimensional superconductivity [10]. Combining muon spin rotation and magnetic susceptibility measurements the scientists studied the uniaxial pressure dependence of the SDW order and onset of the two superconducting order parameters in $La_{1.885}Ba_{0.115}CuO_4$. Figure 5b shows their main result, demonstrating a strong competition between stripe order and superconductivity. In fact, a pressure of ~ 0.02 GPa is sufficient to reach an identical transition temperature of all three orders. This demonstrates that the different coherent phenomena are energetically almost degenerate at ambient conditions, and suggests that they arise from stripe fluctuations.

Despite the progress made through these four publications, a plethora of scientific questions remain unresolved and require further investigation. Dedicated studies on LSCO and LBCO under pressure along different crystal directions will gain further insight into the coupling between stripe order and superconductivity. Further scattering experiments will be needed to understand how stripe order is related to the lattice degrees of freedom, and future experiments directly assessing the dynamic properties will be unavoidable to gain a deeper understanding into the pairing mechanism of high-temperature superconductivity. The aforementioned studies, however demonstrate how uniaxial pressure, a particular clean tuning parameter, can be used to efficiently study the coupling among different degrees of freedom. These developments will be also key in shining new light on other quantum phenomena in correlated electron materials.

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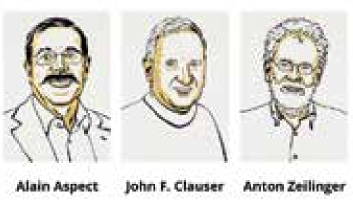
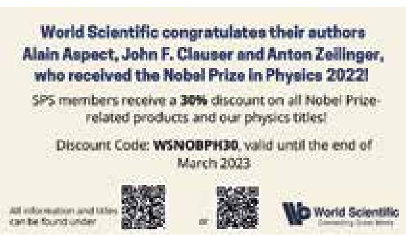
Kurzmitteilungen - Short Communications

The Nobel winners 2022 have been announced

Alain Aspect, ***John Clauser***, and ***Anton Zeilinger*** are to be awarded the 2022 Nobel Prize in Physics for their work demonstrating the violation of Bell inequalities, research that has paved the way for quantum information science. Clauser, Aspect, and Zeilinger designed and performed experiments that tested whether some of the most counterintuitive predictions of quantum mechanics could be explained by intrinsic properties that predetermine the outcomes of possible measurements.

In 1972 Clauser and Stuart Freedman put such local hidden-variable theories to the test by generating pairs of entangled photons and analyzing the measured polarizations of the particles. In the early 1980s, Aspect (Université Paris–Saclay and École Polytechnique in France) and his colleagues reinforced Clauser's findings with more robust experimental setups that closed a major loophole. In addition to performing even more stringent Bell tests, Zeilinger (University of Vienna) is one of the leaders of the burgeoning field of quantum information science. He and his colleagues have demonstrated quantum teleportation, entanglement swapping, and other quantum state manipulation techniques that are essential for the development of quantum computers, communication networks, and cryptography schemes.





A testable paradox

The experiments devised by the laureates have their roots in one of Albert Einstein's famous gedanken experiments. In 1935 Einstein, Boris Podolsky, and Nathan Rosen—collectively known as EPR—described their concerns with the phenomenon of quantum entanglement, in which a single wavefunction describes two particles, no matter the distance between them. As Bell summarizes: "For after observing only one particle the result of subsequently observing the other (possibly at a very remote place) is immediately predictable." One way around such a counterintuitive reality is for a local mechanism to inbue the particles with properties that predetermine the results of future measurements.

The question raised in the EPR paper was largely a philosophical one until Bell, a Northern Irish theoretical physicist, came along. In 1964 he proved a theorem that local hidden variables cannot reproduce all the statistical predictions of quantum mechanics (see the article by Reinhold Bertlmann, *Physics Today*, July 2015, page 40). Most importantly, he derived an inequality that must be obeyed by any local deterministic theory, and he proposed an experiment—albeit one that would be impractical to perform—in which a violation of the inequality would rule out all those theories.

Extract from the "Updated Report: 2022 Nobel prizes in Physics", from Physics Today, 5.10.2022

The SPS warmly congratulates the three collegues on the high honor. More detailed reports on the awarded works are planned for the next issue of the *SPG Mitteilungen.*

Milestones in Physics (25)

Higgs Physics

Michael Spira, Theory Group LTP, Paul Scherrer Institut, CH-5232 Villigen PSI

The Standard Model (SM) of elementary particle physics describes the properties and fundamental interactions of all known elementary particles. This model is based on the gauge principle for the description of all three interactions incorporated by this model. The interactions are based on the gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$, where $SU(3)_c$ describes the strong interactions [1], $SU(2)_L$ the isospin interactions acting only between the left-handed fermions and $U(1)_Y$ the hypercharge interactions that differ between left- and right-handed fermions, too. The isospin and hypercharge interactions are partly unified in the electroweak interactions [2] that are spontaneously broken. The strong interactions are mediated by eight gluon fields, while the electroweak interactions are mediated by three *W* fields and the hypercharge *B* boson which mix and yield the two charged $W^\pm$ bosons, the neutral *Z* boson of the weak interactions and the photon of the electromagnetic interaction. While the gluons and the photon are massless gauge fields, the weak gauge bosons $W^\pm$ and *Z* develop masses close to the 100 GeV scale. These gauge boson masses require the spontaneous symmetry breaking of weak interactions in order to formulate a consistent weakly interacting theory. This is realized by the introduction of the scalar Higgs sector that is characterized by a scalar potential that contains a non-trivial minimum describing the electroweak ground state. In this minimum the Higgs field develops a non-zero field strength so that all particles interacting with the Higgs field acquire masses due to their interaction with this constant background field component of the neutral Higgs field. The fluctuations of the Higgs field around this background field predict the existence of one scalar Higgs boson which constitutes the remainder of electroweak symmetry breaking in terms of the Higgs mechanism [3]. The mass generation due to the interactions with the Higgs vacuum expectation value implies the interactions of massive particles with the Higgs boson to grow with the corresponding particle masses.

The discovery of a bosonic particle with a mass of (125.09 ± 0.24) GeV [5] turned out to be in agreement with the SM Higgs boson within the present uncertainties of all production and decay modes. Its coupling strengths to SM gauge bosons, i.e. *ZZ*, W^+W^-, and fermion pairs as τ, μ leptons and bottom quarks as well as the loop-induced couplings to gluon and photon pairs, have been measured with accuracies of 10 – 50%. All measurements are in agreement with the SM predictions within their uncertainties [4, 6], see Fig. 1. In addition, there are very strong indications that the newly discovered boson carries zero spin and positive CP-parity, i.e. possible deviations from these hypotheses are strongly constrained by the accuracy of present experimental data. Thus there is increasing evidence that this particle is indeed the long-sought SM Higgs boson. Its discovery is of vital importance for the mathematical consistency of the SM and the success of the predictions for the precision electroweak observables which are in striking agreement with measurements at LEP and SLC [7]. The discovery of a Standard-Model-like Higgs boson at the LHC completed the Standard Model (SM) of electroweak and strong interactions. The existence of the Higgs boson is inherently related to the mechanism of spontaneous symmetry breaking while preserving the full gauge symmetry and the renormalizability of the SM [8], since the Higgs boson permits the SM particles to be weakly interacting up to high-energy scales consistently [9]. However, with the knowledge of the Higgs-boson mass all its properties within the SM are uniquely fixed, i.e. the SM does not allow the Higgs couplings to the SM particles to deviate from their unique predictions. The minimal model as realized in the SM requires the introduction of one isospin doublet of the Higgs field that leads after spontaneous symmetry breaking to the existence of one scalar Higgs boson.

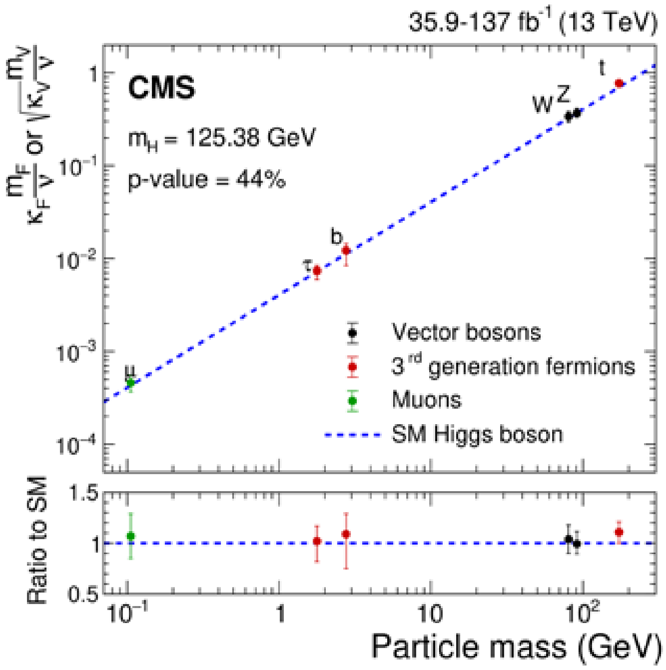


Figure 1: Higgs-boson couplings to SM particles as a function of the SM-particle mass: Prediction (dashed line) and measurements. From [4].

There are several fundamental questions that are, however, left open by the SM as e.g. the nature of Dark Matter, the baryon asymmetry of the universe or the stability of the electroweak against the Planck or grand unification scale, known as the hierarchy problem [10]. These motivate extensions of the minimal model which cover e.g. extensions of the Higgs sector or the gauge sectors, or supersymmetric extensions as prominent and highly motivated examples. If New Physics consists of heavy particles or is strongly interacting with a large confinement scale descriptions in terms of linear or non-linear effective field theories provide a useful and to a large extent model-independent framework to parametrize remnant effects of these BSM models. However, in all these cases precise predictions within the SM are highly mandatory to allow for the maximal sensitivity to BSM effects that will appear as deviations from the SM predictions. This precision is highly desirable because all still allowed

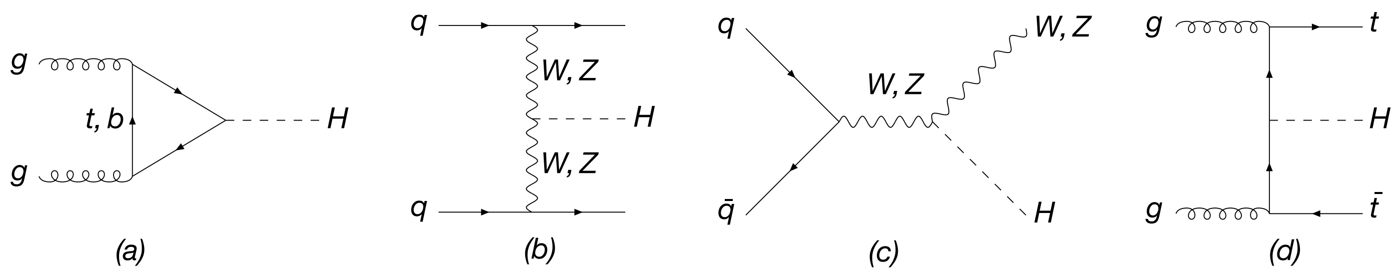


Figure 2: Generic diagrams contributing to the dominant Higgs-boson production processes at lowest order.

BSM extensions appear to be quite SM-like for the plethora of observables measured so far. Several BSM extensions lead to similar effects on the SM processes so that for an indirect detection of New Physics the precision of the SM predictions is one of the main limiting factors.

Higgs Boson Production

The dominant Higgs boson production process at the LHC is gluon-fusion, $gg \to H$, which is mediated by top-quark and to a lesser extent bottom-quark loops [11], see Fig. 2a. The bottom-quark contribution amounts to about 5 % for the measured value of the Higgs boson mass of about 125 GeV. The perturbative QCD corrections are known up to next-to-next-to-next-to-leading order (N^{3}LO) [12], while the full quark-mass dependence is known up to one perturbative order below (NNLO) [13]. They enhance the production cross section by about a factor of more than two [14]. The electroweak corrections on the other hand are known up to next-to-leading order (NLO) where they amount to about 5 % [15].

The next largest SM Higgs boson production process is vector-boson fusion (VBF), $qq \to qqH$, which generates the Higgs boson by the fusion of two (off-shell) W,Z bosons that are radiated off the initial-state quarks [16], see Fig. 2b. The higher-order corrections to VBF have been calculated up to N^{3}LO for the QCD part [17] and up to NLO for the electroweak corrections [18]. Both of them amount to about 10 % for the total cross section.

The Higgs-strahlung mechanism, $q\bar{q} \to Z/W + H$, where the Higgs boson is radiated off a virtual Z or W boson [19], see Fig. 2c, is further suppressed compared to the previous production mechanisms, but plays a highly relevant role in extracting the leading $H \to b\bar{b}$ decay in strongly boosted kinematical configurations [20]. The QCD corrections have been determined up to NNLO [21], while the electroweak corrections are known at NLO [22]. The QCD corrections increase the cross section by about 30%, while the electroweak part ranges at about 10 %.

The last relevant production mechanism within the SM is Higgs bremsstrahlung off top quarks, $q\bar{q}, gg \to t\bar{t}H$ [23], see Fig. 2d, which plays a special role due to its high sensitivity to the top-quark Yukawa coupling. For this process the full NLO QCD [24] and electroweak corrections [25] are known within the SM. The QCD corrections are only of moderate size, increasing the production cross section by about 20 %. The electroweak corrections are small.

Higgs Boson Decays

The Higgs boson of the SM dominantly decays into bottom quarks, $H \to b\bar{b}$. In the past the higher-order QCD corrections to this decay mode have been determined up to N^{4}LO in the limit of small quark masses [26], while they are known up to NLO with full quark-mass dependence [27]. The electroweak corrections are known at NLO [28], while beyond, the mixed two-loop QCD-electroweak corrections are known [29]. With the present status the residual theoretical uncertainties have been estimated to be about 0.5 % for $H \to b\bar{b}(c\bar{c})$ [30]. The branching ratio of the leading decay mode $H \to b\bar{b}$ amounts to about 58 %. The same corrections are also valid for the subleading decay $H \to c\bar{c}$ with a branching ratio of about 3 %. The NLO electroweak corrections are applicable to the decay $H \to \tau^+\tau^-$ as well, which contributes a branching ratio of 6 % and the rare decay $H \to \mu^+\mu^-$ that reaches a branching ratio of 2 × 10^{-4}. For all Higgs decays into fermions the residual theoretical uncertainties amount to about 0.5 % [30]. One of the next relevant decay modes is the loop-induced Higgs decay into gluons, $H \to gg$, that develops a branching ratio of about 8 %. The NLO QCD [31] and electroweak [32] corrections are known completely. While the QCD corrections enhance the partial width by about 70 % the electroweak corrections are moderate, enhancing the gluonic decay width by about 5 %. The limit of heavy top quarks, which is described by an effective Lagrangian for the Higgs couplings to gluons, has been shown to be a reasonable approximation of the full relative QCD corrections at NLO. Within this limit the QCD corrections to the gluonic decay mode are known up to N^{4}LO [33]. The estimated residual theoretical uncertainties amount to about 3 %, originating from uncalculated higher orders and the missing finite top-mass effects beyond NLO [30]. The Higgs decay into photons, $H \to \gamma\gamma$, plays a very significant role in the experimental study of the SM Higgs boson. It develops a branching ratio of about 2 × 10^{-3}. In particular, the photonic Higgs boson decay channel played a crucial role in the discovery of the Higgs boson at the LHC in 2012. The QCD [34] and electroweak [35] corrections to this decay have been calculated up to NLO completely. QCD corrections beyond NLO are only known in the limit of heavy top quarks [36]. For the photonic decay mode the total theoretical uncertainties have been estimated at the level of 1 % [30]. For the rare decay $H \to Z\gamma$ the situation is a bit different. This SM Higgs boson decay reaches a branching ratio of about 1.5 × 10^{-3}. The full NLO QCD corrections have been calculated in the past and are known to be small [37], while the electroweak corrections are completely unknown. This results in the estimate of the related theoretical uncertainty of about 5 % [30], i.e. of the assumed expected size of the electroweak corrections. Finally, the decay modes of the SM Higgs boson into 4-fermion final states are mainly

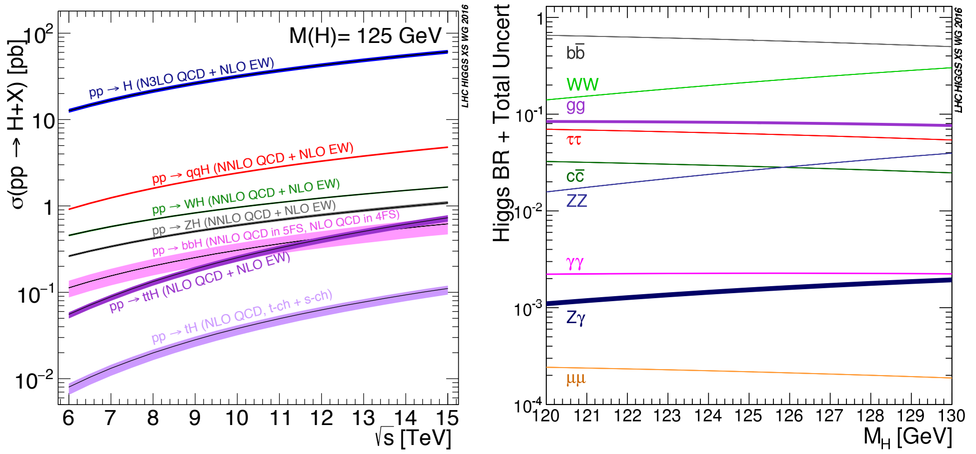


Figure 3: Left: Higgs boson production cross sections at hadron colliders as a function of the c.m. energy within the SM. The size of the bands indicates the residual theoretical uncertainties, while the included perturbative orders with respect to QCD and electroweak (EW) corrections are written close to each of the curves. Right: Branching ratios of the SM Higgs boson as a function of the Higgs mass for the dominant channels at the LHC. The size of the bands reflects the estimated theoretical and parametric uncertainties. Both plots are taken from [30].

induced by on- and off-shell intermediate W and Z bosons, $H \to WW/ZZ \to 4f$. The QCD (in the case of quarks) and electroweak corrections are completely known at NLO [38] resulting in an estimate of the residual theoretical uncertainties of about 0.5 % [30]. The decays into four charged leptons have been the other discovery channel of the Higgs boson in 2012.

Higgs Boson Pair Production

A crucial experimental goal is the measurement of the Higgs potential, since the formation of a non-trivial ground state with a finite vacuum expectation value of the Higgs field causes electroweak symmetry breaking so that an experimental verification of the Higgs potential itself is of highest interest. The parameters describing the Higgs potential are the Higgs mass and self-interactions of the Higgs field. The production of Higgs-boson pairs is the first class of processes that offers the direct access to the trilinear self-coupling of the Higgs boson as a first step towards the full Higgs potential. This process will become visible at the final stage of the LHC program. The Higgs boson pair production cross sections are illustrated in the upper plot of Fig. 4 for the SM Higgs mass of 125 GeV as a function of the c.m. energy of the hadron collider for the individual production mechanisms depicted in Fig. 5. The dominant Higgs boson pair production mechanism is provided by the gluon-fusion process $gg \to HH$, while the other production modes as vector-boson fusion (VBF) $qq \to qqHH$, double Higgs-strahlung $q\bar{q} \to W/Z + HH$ and double Higgs bremsstrahlung off top quarks $q\bar{q}, gg \to t\bar{t}HH$ are suppressed by at least one order of magnitude. The individual production modes roughly follow the pattern of single-Higgs boson production but are smaller by about three orders of magnitude in general. Since the trilinear Higgs coupling contributes only to a subset of diagrams of each production process the sensitivity to the trilinear Higgs coupling is reduced due to the dominance of the continuum diagrams. The slope of the gluon-fusion cross section as a function of the trilinear Higgs coupling λ follows the rough behaviour $\Delta\sigma/\sigma \sim -\Delta\lambda/\lambda$ around the SM prediction as can be inferred from the lower plot of Fig. 4. This implies that the uncertainties of the production cross section are immediately translated to the uncertainties of the extracted trilinear self-coupling so that the reduction of the theoretical uncertainties is crucial for an accurate extraction of the trilinear self-interaction from the experimental measurements. This feature translates to a similar situation for the distributions as well. The trilinear coupling develops a significant contribution for Higgs-pair production closer to the production threshold, while it dies out for large invariant Higgs-pair masses. In the last range, however, statistics will be small in experiment so that the bulk of reconstructed events will emerge from the region closer to the threshold.

The gluon-fusion mechanism $gg \to HH$ is mediated by top- and to a much lesser extent bottom-quark loops, see Fig. 5a. The

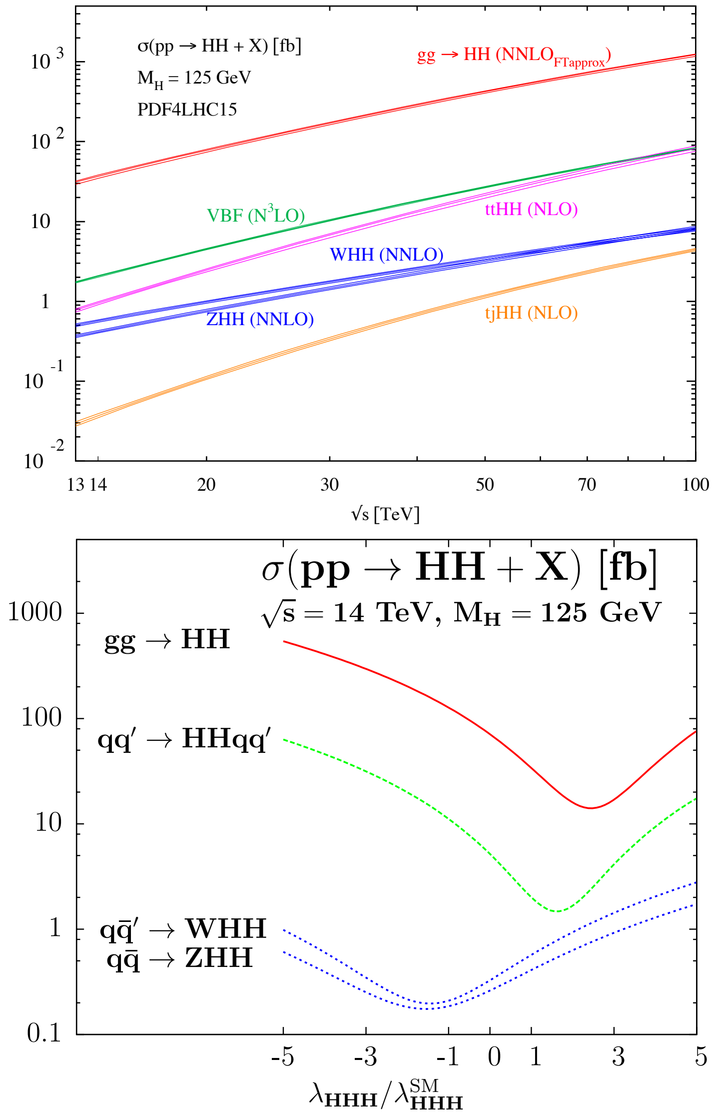


Figure 4: Top: Higgs boson pair production cross sections as a function of the c.m. energy of the hadron collider for a Higgs mass of 125 GeV. The bands represent the estimates of the residual theoretical uncertainties. From [39]. Bottom: Dependence of the Higgs pair production cross sections on variations of the trilinear Higgs self-coupling in units of the SM-value. From [40].

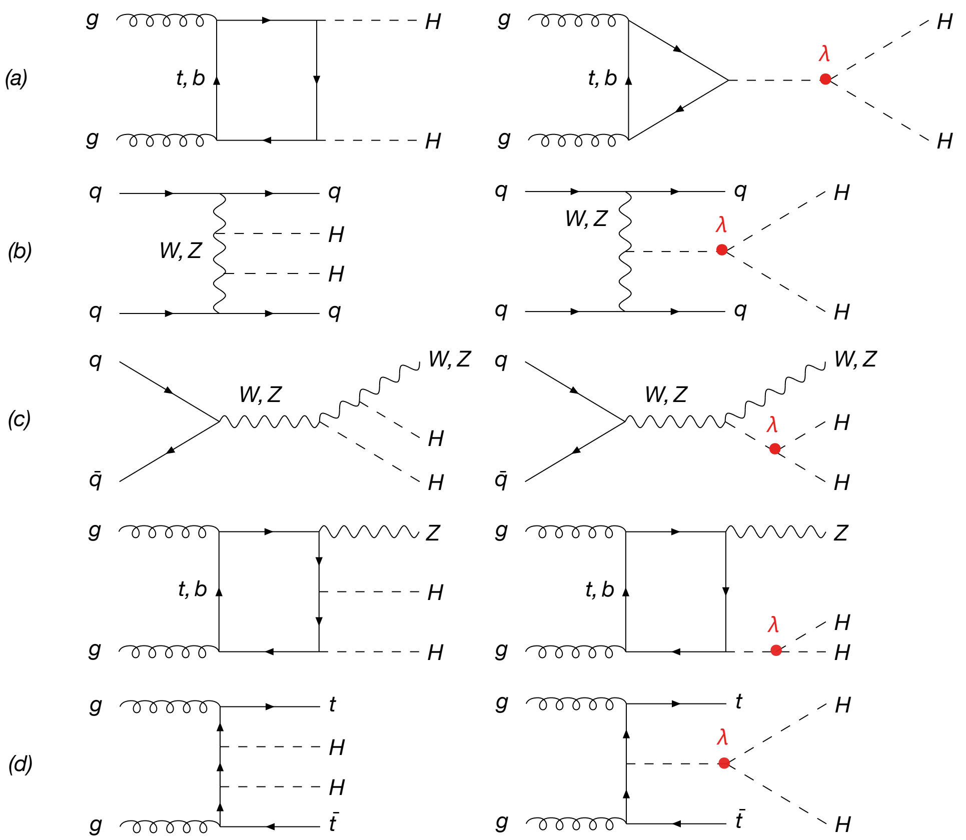


Figure 5: Diagrams contributing to Higgs-boson pair production: (a) gluon fusion, (b) vector-boson fusion, (c) double Higgs-strahlung and (d) double Higgs bremsstrahlung off top quarks. The contribution of the trilinear Higgs coupling is marked in red.

full NLO QCD corrections have been calculated recently [41, 42]. Analogous to the single-Higgs case they enhance the cross section by about 100 %. The NNLO QCD corrections to the total cross section have been obtained in the heavy top-quark limit. They imply an additional moderate rise of the total cross section by about 20 % [43]. Very recently, the N^{3}LO QCD corrections to the total cross section became available and turned out to be small, affecting the total cross section at the few per-cent level only [44]. The factorization and renormalization scale dependence has been reduced to about 5 %. In order to obtain an estimate of the residual theoretical uncertainties, however, the uncertainties due to the scheme and scale choice of the virtual top mass have to be taken into account as well. These latter effects increase the theoretical uncertainties to a level of 20 – 25 % [42]. The electroweak corrections to this process are unknown. They are expected in the 10 %-range for the total cross section.

As in the single-Higgs case Higgs-boson pair production by vector-boson fusion, $qq \to qqHH$, is dominated by t-channel W- and Z-exchange contributions, see Fig. 5b. Beyond LO, the NLO, NNLO and N^{3}LO QCD corrections are known for the t-channel contributions and increase the cross section by about 10 % [45]. The residual theoretical uncertainties for the QCD part have been estimated at the per-cent level from the renormalization and factorization scale dependence at the LHC. Moreover, the electroweak corrections have been calculated at NLO [46]. They range at the 10 %-level for the total cross section as well, but are larger for distributions in kinematical regions with a large scale involved as e.g. large transverse momenta.

The Higgs boson pair produced via double Higgs-strahlung arises in association with a W or Z boson, see Fig. 5c. The NLO and NNLO QCD corrections can be translated from the conventional Drell-Yan process, since the final state is only weakly interacting [40]. A difference to the Drell-Yan process, however, emerges from the additional loop-mediated $gg \to ZHH$ process that contributes to the NNLO QCD corrections. The higher-order QCD corrections increase the production cross sections by about 30 %. The $gg \to ZHH$ subprocess contributes another 20 – 30 % to ZHH production and thus has to be taken into account for a reliable prediction. The residual theoretical uncertainties as determined from the factorization and renormalization scale dependence amount to about 3 % for WHH production and to about 4 % for ZHH production. The electroweak corrections to double Higgs-strahlung, however, are unknown.

Higgs-boson pair production in association with top quarks, see Fig. 5d, is suppressed by more than an order of magnitude compared to the dominant gluon-fusion mechanism and thus plays a subleading role at the LHC, but is of similar size as vector-boson fusion. Recently, the NLO QCD corrections have been determined. They modify the total cross section by about 20 % [47]. The renormalization and factorization scale dependence has been reduced to less than 10 % so that the total theoretical QCD uncertainties for this production process amount to about 10 % at the LHC. Also for this process electroweak corrections are unknown.

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History and Philosophy of Physics (30)

Machine learning in physics – philosophical perspectives on new tools

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In most fields of physics, machine learning (ML) is all the rage. Physicists use ML algorithms to analyze data, to cast predictions or to emulate computer simulations. But what exactly is machine learning? How trustworthy are its results? What are possible pitfalls? And how does ML impact on the methodology of physics? The aim of this article is to discuss initial answers to these questions on the basis of recent philosophical work.

1 Introduction

In this day and age, research in physics (and elsewhere) is profoundly shaped by the use of computers. Interestingly, though, there is not just one way in which computers are used. Rather, there are various computer-based methods. Whereas computer simulations have been run since the advent of the digital computer in the midst of the 20th century and since then spread almost everywhere, the excitement about some kinds of machine learning (ML), e.g. deep learning, is of more recent origin. But what exactly is happening here? What kind of method is machine learning? How does it fit into the methodological toolbox available to physicists? And how does the method shape research in physics?

Some of these questions have provoked far-reaching claims. For instance, in a piece that appeared in the magazine "Wired", Anderson [2008], has argued that "[t]he new availability of huge amounts of data, along with the statistical tools to crunch these numbers, offers a whole new way of understanding the world. Correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all."

Claims of this kind cannot be examined using the tools of physics alone. This is why philosophers of science have started thinking about machine learning and its use in science. The aim of this paper is to provide a philosophical appraisal of ML by addressing the above questions. To have a contrast foil, I will often compare ML to computer simulation. I will mostly develop my own take on ML, but still refer the reader to the most important philosophical work on the topic so far, with the hope that readers will obtain an impression of what philosophers have been discussing.

I start with a few recent examples in which machine learning was used in physics (Sect. 2). I then turn to the concept of machine learning and provide some crucial distinctions in Sect. 3. In Sect. 4, I address the question in how far we can trust results of ML. This will bring me to an intensely discussed problem about ML, its black box character, or – as philosophers call it – its opacity (Sect. 5). In Sect. 6, I discuss the question of what ML means for the future of physics.

Since ML is developing fast, I cannot offer more than a first attempt at appraising ML in physics. In this paper, I concentrate on physics, but most of my claims can be generalized to other sciences.

2 Machine learning in practice– three examples

To begin our inquiry, it is useful to have a few examples of ML applications at hand.

The first example is from high energy physics in which ML is often used for the analysis of data. For instance, the NOvA experiment is intended to detect possible neutrino oscillations [Aurisano et al. 2016]. For this purpose, the composition of a neutrino beam is measured using two detectors that are kept at different distances from the source of the beam. The original beam consists mainly of mu-neutrinos. If mu-neutrinos oscillate into different flavors, the detector farer removed from the source is expected to identify more electron- or tau- neutrinos than the other detector, which is quite close to the source.

Fig. 1. One of the NOvA detectors. Source: R. Hahn, Fermilab, via wikimedia commons, https://commons.wikimedia.org/wiki/File:NOvA_Near_Detector.jpg (public domain).

For this experiment to succeed, it is crucial to identify the flavor of the neutrinos using a detector (see Fig. 1). The physical basis of this is charged current (CC) interaction resulting in a charged lepton. Depending on the flavor of the incoming neutrino, a muon, an electron or a tau is produced. These particles or their decay products are detected using an array of scintillators that produce photons detected via fibers. If a charged particle produces light detected by a fiber, this counts as a hit.

To infer the presence of certain charged particles, and thus, effectively, of a certain type of neutrino, from a pattern of hits, Aurisano et al. use a network consisting of several neural networks. The network has two input layers that take data from two planes. The outputs of the network can roughly be interpreted as set of probabilities for the interaction channels, most of which are associated with a specific type of neutrino. The network was trained using results from computer simulations. In these simulations, the products resulting from a known interaction channel are followed through a detector. The simulation outputs thus comprise a huge set of simulated patterns of hits belonging to each interaction channel. Using the training data, the network is taught to infer the interaction channel from a pattern of hits. After the training phase, the network is used on real data to infer the interaction channel.

As the authors show, their method is more efficient than previous ones, which were partly based upon the reconstruction of the trajectory of the charged particle. In general, the introduction of neural networks has helped to improve the efficiency of particle detections. Radovic et al. [2018, Table 1], show how detection efficiency has been increased via machine learning. For instance, due to ML, a 2.5 σ event in the $H \rightarrow \tau^+\tau^-$ channel in the ATLAS experiment became a 3.4 σ event.

My second example is from weather and climate prediction. Predictions of these kinds are commonly made using general circulation models (GCMs) that trace the physics of the atmosphere and are evaluated using computers. But running computer simulations to solve a GCM is computationally expensive. Scher [2018] has thus trained a deep neural network (DNN) to learn the dynamics of a simple GCM. The basic idea was to feed the network with many examples of two model states with a given temporal distance, e.g. one day. Once the network had been "accustomed" to the model dynamics in this way, it was applied to new model states and requested to make a prediction. Both regarding the weather and the climate, the network reproduced the results of the GCM with high accuracy. Here, climate predictions were obtained by consecutively making predictions for the next day and averaging over time. The simulations and the network outputs were compared using a standard metric, viz. a normalized 500-hPa geopotential height. In these units the errors were small (less than 0.06 for a six-day prediction).

The same method can also be used with real data with the aim to predict the real weather, as demonstrated by Weyn et al. [2019]. They trained several neural network models using reanalyzed data (roughly real data complemented using numerical methods). For computational reasons, they defined a state using one characteristic only (500-hPa geopotential height) as measured on a set of grid points spanning the Earth (some of their models used two more variables, but still fell short of what physicists take to provide a full physical state description). It proved useful to use two consecutive states separated by 6 hours as input and to "tell" the model using many examples how the next two consecutive states look like. The predictions of the trained model proved quite good, in particular better than persistence (the atmospheric state doesn't change) and the so-called barotropic model, but not better than a full-fledge physical model (cf. Fig. 4).

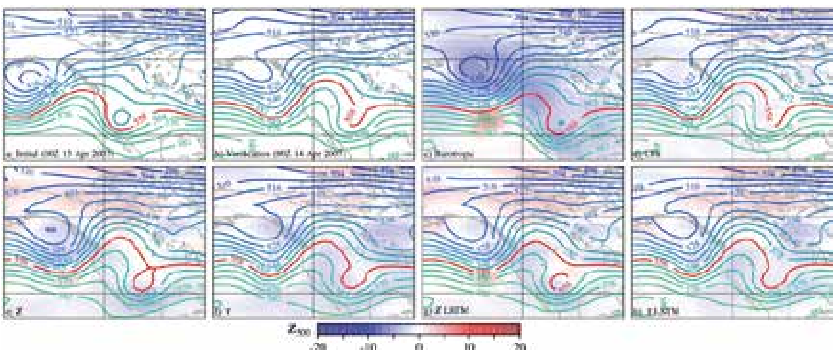

Fig. 2. The performance of several ML models in predicting the weather. Panel a shows the initial condition; panels c and d non-ML models; panels d through g show ML models. The color indicates deviations from the true prediction (cf. panel b).

My third example is about so-called trees, e.g. regression or decision trees. I illustrate it using photometric data from galaxies. Assume that, for each galaxy in a sample, the apparent magnitude in various energy bands has been measured; so we have, say, five measurements per galaxy. A tree arises if the galaxies are step by step split into groups and subgroups. This yields a partition or classification of the galaxies into groups, subgroups and so on. The classification can then be used to classify new galaxies for which the same information on apparent magnitudes in energy bands has been measured. What is most remarkable is that the classification is constructed automatically using data alone. To define sub-classes, the galaxies still available are split into two or more groups in such a way as to optimize a certain function. For instance, the partition is supposed to yield maximum information gain [Carrasco Kind & Brunner 2013 and references therein] or to minimize resubstitution error [Carliles et al. 2010]. In the simplest case, the iterated splitting of subgroups is stopped if subgroups become smaller than a predefined threshold.

If an additional characteristic, e.g. the redshift, for the original set of galaxies is known, then for each last-level subgroup, the average of the redshift can be taken. This redshift can then be assigned to any new galaxy that is assigned to the subgroup following the tree (this method is used by [Carliles et al. 2010]).

Nowadays, this method is much refined. For instance, in the same way in which forests comprise many trees, so-called random forests arise if random subsamples of the data are used to train several trees (see [Ho 1995; Breiman 2001] for random forests). Each new galaxy is classified using all trees, and the results are aggregated to make a prediction [Carliles et al. 2010 and Carrasco Kind & Brunner 2013].

3 What is machine learning?

So much for some examples of ML. But what is machine learning in general? The basic idea of ML is that a computer "learns" something from data: A rule, a law, a principle or at least a method to infer information on new items is learned or inferred from data (see [Mitchell 1997] for a classic introduction). Regarding many ML algorithms, we can distinguish between a learning and an application phase. For some ML algorithms, though, the distinction crumbles because new applications of the algorithm are used to further improve it.

At first sight, the fact that ML infers principles or rules from data distinguishes them sharply from computer simulations, e.g. climate simulations based upon general circulation models. The latter are built upon physical laws, theories or at least model assumptions. In any case, in computer simulations, physical hypotheses about the target systems are implemented in a machine. The point of using the computer is to run calculations to evaluate what the hypotheses imply. Machine learning algorithms, by contrast, are not based upon physical hypotheses in this way (for computer simulations see e.g. [Humphreys 2004, Ch. 5]).

On a closer look, however, the difference is less pronounced than it may first seem. On the one hand, an ML algorithm that has not yet been fed with data is not a *tabula rasa*. The ML algorithm contains some structure or some assumptions to start with. For instance, if physicists build up trees, they have to decide whether they prefer a binary tree, where groups are always divided into two subgroups, or whether they are more flexible than that. Also, the function to be maximized during each split has to be determined. Likewise, the use of a network (more on that below) requires certain choices on the part of scientists to begin with. On the other hand, many computer simulations are tuned to data before they are used to cast predictions. That is, many simulations have free parameters (often related to processes the details of which are not known), and the parameters are determined such as to maximize agreement with available data. As a consequence, the difference between machine learning applications and computer simulations is not sharp, but really a matter of degree because both methods can involve some optimization using data. But even simple ML algorithms typically contain more free parameters than fairly complicated computer simulations. Also, in ML, the parameters that are optimized are not physical characteristics (momentum, temperature, field strength, …), but rather characterize a network. By contrast, in computer simulations, the free parameters have often physical meaning (for instance, an unknown conductivity).

What further complicates matters is the fact that some new ML algorithms are based upon physical assumptions [Kashinath et al. 2021]. For instance, it is possible to enforce that energy is conserved by a network. Still, the incorporation of physical assumptions is not generic for ML.

What kind of thing then is a machine learning application, e.g. a tree or a network, that has been prepared using data? It is certainly correct to say that it is an algorithm or a function that maps inputs to outputs. Another possible answer is that it is a model. There is nothing wrong with this answer if we keep in mind that this model need not be a dynamical model (for instance a classification tree will typically not contain information on how the items evolve in time). Also, it is a kind of model for which the model assumptions can often not be put down in an informative way. In what follows, I will interchangeably speak of ML models, algorithms or applications. I will take it that ML *methods* are more general; for instance, trees can be seen as an ML method.

Within machine learning, a distinction is drawn between supervised and unsupervised ML (where the distinction is not exhaustive due to so-called reinforcement learning; e.g. [Martín-Guerrero & Lamata, 2021]). In supervised ML, learning is achieved using a series of labeled data in a training phase [e.g. Mohri et al. 2018]. The examples may be images, and the label may classify them, e.g. whether they show a dog. The task of the trained algorithm then is to find the correct label for new data that still lack a label. Unsupervised

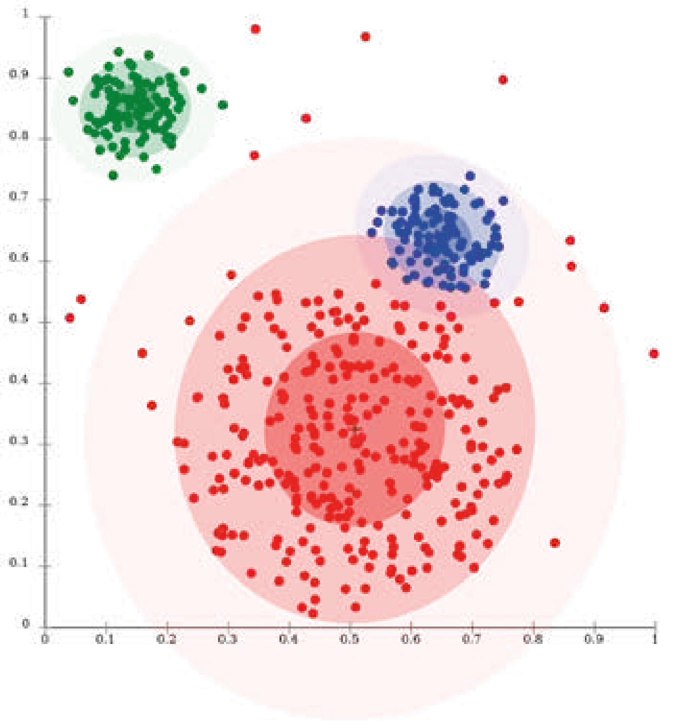

Fig. 3. Clustering algorithms form clusters of items in spaces spanned by all kinds of variables. Source: user Chire via wikimedia commons, https://commons.wikimedia.org/wiki/File:EM-Gaussian-data.svg (CC BY-SA 3.0).

learning does without a stage at which correct labels are provided to the computer. An example of unsupervised learning is clustering, in which the algorithm constructs a classification by grouping together items that are close to each other in some sense (see [Mikuni & Canelli 2021] for an example; see Fig. 3).

The current hype around ML is mainly due to the use of neural networks (see [Buckner 2019] for a philosophical introduction). These are mathematical models of interconnected neurons. Very often, the neurons are ordered in layers. The neurons from each layer are connected to neurons from the previous and the next layer (see Fig. 4). Often, there is first an input layer in which each neuron takes a number from some input (e.g. information on a pixel in a pixelized image). That information is further propagated and processed along the connections (synapses). In the mathematical model of the neuron, each neuron from the next layer obtains a number that is calculated by putting together the numbers taken by some neurons from the previous layer using a function. We can think of the numbers associated with the neurons as their degrees of activation. The functions thus determine

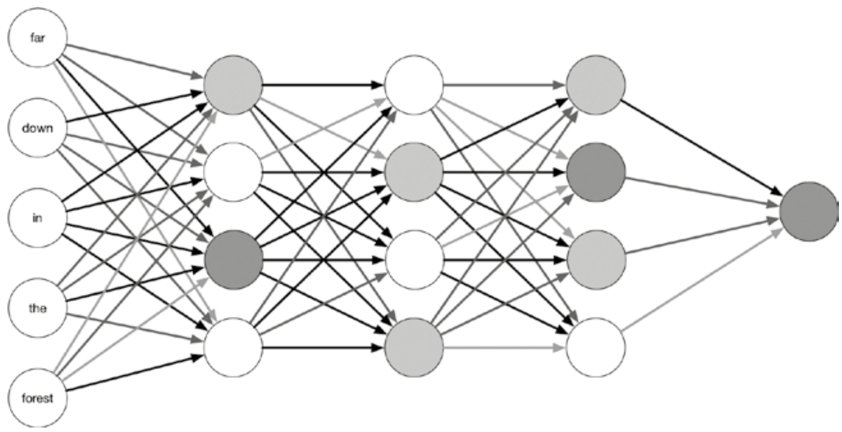

Fig. 4. A neural network (here taking words as inputs). Source: E. Hvitfeldt and J. Salge, Supervised Machine Learning for Text Analysis in R, https://smltar.com/, Fig. 8.1 (CC BY-NC-SA 4.0).

how activation is spread in the network. The final layer is an output layer. The functions contain some parameters, and the point of the training is to tune these parameters in such a way that the network output reproduces the labels for the input data in an optimal way. Technically speaking, the optimization involves a loss function that punishes deviations of the network output from the correct labels from the training. Of course, a lot of network structures have been tried (see [Bishop 1994] for the basics of neural networks and [Aggarwal 2018] for a more recent overview). Also, it is common to combine several networks in intricate ways. For instance, in so-called Generative Adversarial Nets, a network is supposed to find out whether an input has been produced by another network or contains real data [Goodfellow et al. 2014].

Computer simulations have a very specific primary task: Given information referring to a system and to one or more instances of time, they infer information about the same system, but for a different instance of time. The primary task of ML algorithms is much more general. During the learning phase, they infer a general rule or at least a general method to judge single cases. Often, this method cannot be put down in a simple way, so it is unnatural to say that the ML algorithm infers a general hypothesis. When a trained network is applied to new input data, then the task of the algorithm is again running an inference, but this time for a single case. What exactly the inference is about differs from case to case. Sometimes, items are classified; in other cases, predictions are inferred. Note also that networks cannot just classify input data, but also produce data of the kind of the input.

4 The justification of machine learning results

Can we trust the results of ML applications? This question is particularly urgent if important decisions are based upon ML applications, for instance in medicine (see [Ryan 2020] and [Nickel 2022]). In what follows, I will bracket the question to what extent human beings are willing to trust ML as a matter of fact. Rather, the focus will be on the reasons to trust the results of ML applications. Put differently, the question is what justification there is for ML results [Corfield 2010].

The only reason to trust a rule or method that has been inferred using ML is its relation to data. For supervised machine learning, we can point to the fact that it has been trained to reproduce the labels of the training data. Moreover, machine learning algorithms are usually tested using additional data before they are used in practice. If the test results agree with the test data to a sufficient degree, then there are additional reasons to trust the algorithms. If unsupervised machine learning constructs a classification, the latter can be justified by saying that it organizes the data in some optimal way, for instance by proposing groups the assignment to which is maximally informative in some sense.

This kind of justification contrasts with the way in which results from computer simulations are justified [Beisbart 2019a, b]. Results of computer simulations obtain some of their justification from prior knowledge. For instance, climate simulations rely upon the Navier-Stokes equations that constitute prior knowledge. But this prior knowledge does not suffice to justify the simulation results [Winsberg 1999]. The main reason is that physical laws or theories that constitute prior knowledge have to be complemented with assumptions about the target system, e.g. its boundary conditions, and initial conditions to obtain simulation results. Typically, assumptions about the details of the target systems are less certain than the theories upon which the simulations are built. For this reason, the justification of a simulation has a data-related part: To further justify the simulation, it is shown to reproduce data from the target system. So we can say that the justification of computer simulations draws on two sources: prior knowledge and agreement with data. In the justification of ML, the component of prior knowledge is typically missing. This is not to say that that ML methods do not contain any kinds of assumptions; surely, what a network can do is restricted by its set-up. Still, these constraints do not amount to assumptions that we can take to constitute prior knowledge. Things are of course a bit different, when learning by machines is constrained by prior physical knowledge (see e.g. [Lu et al. 2021]).

The fact that computer simulation results are based upon prior knowledge has an interesting consequence: Many simulation programs are so complicated that it is non-trivial to know whether the prior knowledge has adequately been taken into account. More concretely, one may ask whether a climate computer simulation really solves the Navier-Stokes equations – at least to reasonable approximation. As a consequence, simulation scientists try to make a case that their simulations do in fact “solve the equations right” [Roache 1997, 124]. Activities that serve this purpose are commonly referred to using the label “verification”. Verification in this sense is often contrasted with validation which is supposed to show that the program is „solving the right equations“ [ibid.]. Since ML do not rely on prior knowledge, verification is not an issue for them.

It thus seems as if the justification of supervised ML only relies on its agreement with data (cf. [Schubbach 2021]). One may say that the justification is exclusively a matter of the previous track record of an ML algorithm. This means that we are justified to trust a new classification or prediction of an ML model only to the extent that it has so far been successful in its past. This justification seems philosophically problematic; it has the form of an enumerative induction:

1. The algorithm has been correctly inferred the required information in case 1.
2. The algorithm has been correctly inferred the required information in case 2.
3. …
4. Thus, the algorithm will correctly infer the required information in a new case.

Many philosophers think that this kind of inference is only justified under certain conditions, for instance if it is about natural kinds [Ellis 1998] or if the best explanation of the regularity observed thus far implies that it will continue in the next few cases ([Harman 1965]; cf. [Mitchell et al. 1986] for a related idea in the ML literature). Conditions of these kinds may also tell scientists to what class of new cases the inference may be applied. This is a vital issue regarding ML algorithms: For which class of inputs can we expect correct classifications or predictions from ML models? Or how well do ML algorithms generalize?

The enumerative induction just indicated would of course not be problematic if one or the other of the above conditions was fulfilled, in particular if we had a good explanation of the previous success of an ML model. The problem, however, is that we do not currently have such an explanation for many ML models. More generally, in this day and age, scientists do not well understand the working of ML, as we will see in the next section. As a consequence, if there is justification to take ML outputs to be correct, then this is only due to the massive success they had in the past. Accordingly, justification and explanation come apart for ML models [see Schubbach 2021].

5 The opacity of machine learning

Machine learning algorithms are often described as black boxes or as opaque [Shwartz-Ziv & Tishby 2017]. In particular, scientists do not understand much about how neural networks learn and how they arrive at their verdicts for new cases. Things are a bit better when it comes to other ML methods, but let us focus on neural networks in this section.

To better understand the black-box character of neural networks, a comparison to computer simulations proves illuminating once more. Computer simulations are also often dubbed opaque. In philosophy, Paul Humphreys has famously proposed to call a process opaque if it contains too many relevant steps to be followed by a human being [Humphreys 2004, 2009]. Computer simulations do in fact contain so many computational steps that a human being cannot in reasonable time trace how a computer simulation program arrives at its output. The same is, as a side note, true of computer-aided proofs in mathematics too [Tymoczko 1979]. The point also generalizes to most ML models (not just neural networks): A human being cannot follow the steps during the learning phase; and even the application of an ML application to a new case involves so many calculations that humans cannot follow them, at least not in reasonable time. For instance, if a new input is processed in a neural network, for each node (neuron) in the network, a function has to be evaluated, and this becomes practically impossible if there are too many nodes.

But it seems that neural networks are opaque in an even deeper sense, and this marks another contrast with computer simulations (see [Boge 2022] and [Boge & Grünke forthcoming] for a first comparison). The point is that we do not even understand on a more coarse-grained level what a neural network is doing. In a computer simulation, scientists can tell a story on what the simulation program is doing. They know the physical equations that the program is supposed to solve and they know the numerical methods implemented in the machine. If they have some understanding of the model, they may even be able to reason about the results of the computer simulation. Regarding neural networks, physicists lack such a story. They can of course say that the network processes information following the connections among neurons. But there is no easy way to translate this story into a story about the target system. Typically, researchers do not know on which features a network picks up. They do not know to which details a neural network that classifies images is sensitive.

This deeper lack of understanding requires a broader notion of opacity than that offered by Humphreys [Beisbart 2021]. A suitably broader notion of opacity covers all features of a method that make it difficult to understand why its results have been arisen. Computer simulations and ML models share the feature that they involve many computational steps that cannot be followed by a human. At the same time, ML models pose the additional difficulty that we lack a story on how they work on the target system.

Scientists are of course well aware of this problem and try to render ML models more interpretable or explainable. A motivation is that the lack of explainability is often taken to be hamper trust in the models (see [Lipton 2018] for various motives for interpretable models). So far, various approaches have been taken. For instance, saliency maps highlight those pixels from a picture to which a neural network is very sensitive in the following sense: If the information in the pixels is only slightly changed, the output of the ML algorithm changes (see Fig. 5). A different strategy is to understand the relation between ML input and output using simple models, e.g. regression models. Interestingly, also ideas from statistical physics have been used to explain ML (see [Carleo et al. 2019, Sect. II]; see also [Mehta et al. 2019]). Research on interpretability is currently a thriving field. An interesting philosophical question is what kinds of explanations are most fruitful to improve interpretability [Beisbart & Räz 2022].

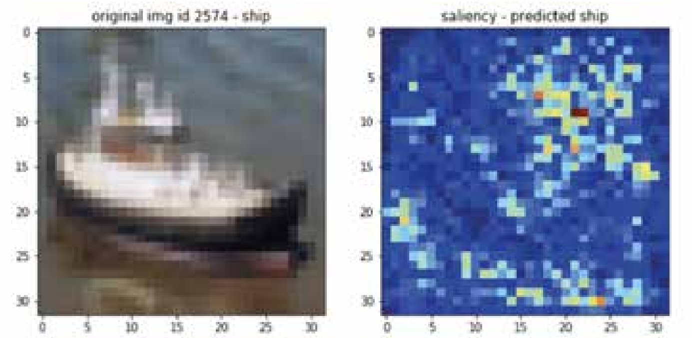

Fig. 5. A saliency map (right panel) for the working of a network on the image of a ship (left panel). Source: M. Kana, https://towardsdatascience.com/practical-guide-for-visualizing-cnns-using-saliency-maps-4d1c2e13aeca.

A slightly different philosophical question that has recently drawn some attention is the degree to which interpretability is really needed. In a recent paper, Sullivan [2022] has argued that neural networks can help to improve the understanding of a target system despite being opaque to researchers. This point may be illustrated using a comparison to instruments used for observations (e.g. telescopes or microscopes; cf. [Humphreys 2004] for this comparison). It is arguable that a physicist does not need to understand a microscope to use it correctly or justifiably. Likewise, it may be suggested, a physicist can make progress by using an ML model without understanding much about it. But there are good reasons to think that physicists have to understand their ML algorithms if they want to use them to understand a real-world target system [Räz & Beisbart 2022]. A strong kind of understanding requires knowledge about the causes behind a phenomenon. But we cannot trust that machine learning algorithms pick up on the real cause of its target system. Often, reliance on correlations is sufficient to make reasonable predictions.

6 Machine learning and scientific method

A broader philosophical question is how ML (combined, maybe, with the use of Big Data) will impact on research done in physics? Are we in the midst of a broad scientific revolution that will have a profound impact on the methodological toolbox of science and on our very understanding of science? It is too early to answer this question in depth, but let me briefly discuss two points.

Anderson, in his famous 2008 article, suggests that ML-based predictions render theories largely superfluous. The idea seems to be that, so far, theories have been a most efficient means to make predictions, but that ML models that are trained on suitable data are better than theories.

Anderson is correct in contrasting ML models with theories. In philosophy of science, theories are often understood to be small sets of fairly simple hypotheses (axioms) from which scientists can infer a lot of information. Philosopher Lewis [1973] has coined speech of a best system: a description of aspects of the world that achieves an optimal balance between strength (information content) and simplicity. Machine learning is different: While allowing for a lot of inferences, we cannot say that it consists of a small set of simple axioms.

But, at least to my mind, Anderson overestimates the power of ML models. He may be correct for many predictions: ML models may outrank theories in their predictive capacities in certain fields. But physics is not just about prediction. Physicists also want to understand the world, and at least currently, it is not clear how ML models help much in this respect. Theories, by contrast, can help to improve our understanding of certain systems. One way in which they do this is to unify phenomena that often seem disconnected from each other. As is well-known, Newton's theory of gravity provided a unified treatment of the movement of the planets and free fall on Earth. This unification helps us to grasp various connections between different systems, and this grasp seems to be essential for understanding (see [Kvanvig 2003, 192] on grasping and [Gijsbers 2013] for the connection between understanding and unification).

At least in some cases, good understanding can lead to better predictions. Climate research is an example in point. Due to climate change, we are currently leaving a regime that has been present for generations. To be able to predict how the climate will evolve and whether we risk to cross certain tipping points, we need a deeper understanding of the climate [Jebeile et al. 2021]. Just extrapolating climate observations will not lead us very far. What ML models can infer from the observations may be valid for the regime in which the observations were taken. There is no good justification to extrapolate them into the future. By contrast, we know that the foundations of our climate models, viz. the basics of hydrodynamics, are still valid in the new regime.

A different debate concerns scientific method (see [Gillies 1996] and [Pietsch 2021]). Up to some approximation, our understanding of scientific inference, and, indeed, scientific inference itself, has moved from inductivism to hypothetico-deductivism. According to inductivism, scientific inference is bottom-up: On the basis of observations pertaining to particular cases, a general law or theory is inferred, e.g. using enumerative induction. According to hypothetico-deductivism, by contrast, hypotheses are not derived from the data; rather, in a first step, hypotheses are formulated, which are then subjected to testing. The claim that hypotheses come first is very prominent in Popper's writings (e.g. [Popper 1934]; see Fig. 6). Against this background, it may be argued that ML induces a push-back: Contemporary ML methods do not start from hypotheses, but rather from the data. They infer rules or prediction methods on the basis of rather minimal assumptions.

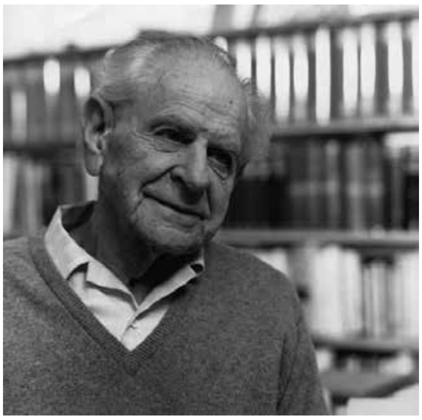

Fig. 6. Karl R. Popper (1902-1994) claimed that scientific research starts with hypotheses. Source: L. Douglas-Menzies via wikimedia commons, https://commons.wikimedia.org/wiki/File:Karl_Popper2.jpg (no restrictions).

There are two possible counters to the claim that some sort of inductivism is revived using ML. A first counter questions that ML is properly described as inductivist. For instance, Pietsch [2016, 2021] has argued that ML models search for causes. Inferring causes moves beyond the simple generalization implicit in enumerative induction. It may also be argued that ML models are not completely free of hypotheses, but rather contain huge sets of hypotheses from which the data are supposed to select the best fitting ones. A second counter stresses the importance of theory (see above) and points out that theories cannot be taken from the data using ML. The point then is that ML, even if it may be inductivist, needs to be complemented with methods that do not reason bottom-up.

7 Conclusions

To summarize: The broad idea behind machine learning is that computers learn rules or methods to run more inferences. It would go too far to claim that ML algorithms learn from scratch, but it is certainly true that they need not involve physical laws or theories and that they rather tune sorts of "all-purpose models" to data. This is a contrast to computer simulations, which are built upon physical hypotheses. As a consequence, the results of ML models cannot be justified in terms of physical laws or prior knowledge; rather, the only justification comes from agreement with the data. This kind of justification is not built upon an explanation of why an ML model has been successful in the past. More generally, the workings of ML models are difficult to understand. It is plausible that this makes it difficult to understand the real world with ML models only. Despite that, ML models will allow for substantial progress in physics and elsewhere.

ML methods also raise interesting general questions that move beyond philosophy of science. One question is to what extent ML algorithms are good models of human cognition (see e.g. [Buckner 2019]). Another, more pressing question is how we should, and should not, use ML models from a moral point of view. These questions are beyond the scope of this article, but "food for thought" for the next years.

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Physicists in Industry (14)

Physics at Work in Industry

Lisa Sommer, Leonardo Massai (IBM Research Europe – Zurich)

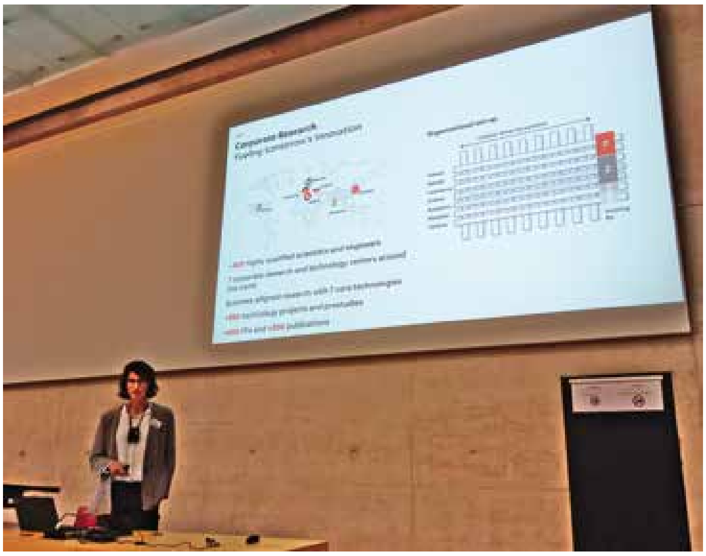
While studying physics at university, students get a good overview and insight into typical physicists' careers in academia. Despite this most obvious career path, there are a lot of other opportunities, where physicists can thrive with their knowledge, skills and mindset. Examples for this are startup companies, technology-reliant industries in a wide range of sectors, patent offices or even insurance and finance companies.

These career paths in industry, from barely hatched startups to well-established companies with a long history, were the focus of the industry session titled "Physics at Work in Industry" of this year's annual meeting of the Swiss Physical Society in Fribourg, chaired by Thilo Stöferle from IBM Research. As the following summaries show, this path results in innovative ideas and inspiring stories.

Diego Casadei, first speaker of the session, introduced himself talking about his 20-years long research experience in particle and radiation detectors for high-energy physics in laboratories (ATLAS/CERN) and space (ESA Solar Orbiter). He then decided to change his horizon by moving to industry, quickly becoming the general manager of **Cosylab Switzerland**, a company specialized in providing control systems. He explained how he was able to quickly adapt the expertise that he had attained during his physics research years to fit the industrial work. The ability of solving complex problems and of critical thinking, both common to a scientific mind, are important character traits for meeting industry challenges. This is especially so when used in combination with entrepreneurship and good management skills – with the latter two subjects unfortunately not part of a typical physics student curriculum.

The next presentation was from ***Beat Ruhstaller***, ZHAW Professor, founder and CEO of **FLUXiM AG**. His spin-off company focuses on simulation software and measurement hardware providing its products to the display, lighting, and photovoltaics community worldwide. He underlined the importance of understanding the customer needs as well as differentiating the product over other competitors, especially for a startup. "Think about the nail when developing the hammer" is the useful take-home lesson. Moreover, he also discussed the differences between selling software and hardware, where the "banana concept" (release a product and let it mature at the customer) does not work well for the latter.

Elena Mengotti, working as R&D senior scientist at **ABB Schweiz AG**, talked about how she entered directly in the industry world after her physics Ph.D. at ETH Zürich. At ABB a great majority of the scientists have a Ph.D. but they work in a broad variety of topics and fields, from power supply electronics to manufacturing systems. Elena Mengotti's work currently focuses on characterizing and improving the reliability of wide band gap semiconductors, SiC in her case. For this she develops innovative tests and analyses the failure modes of these devices under real-world conditions.



A patent attorney plays an important role in the protection of intellectual property of a company or university. The ins and outs of this were discussed by ***Torben Müller***, a patent attorney at **Bohest AG**. In an era where information is so easily accessible over the internet, it has become much easier for ideas to be stolen. This is a major risk for companies, especially when a market requires significant investments in cutting-edge research. During the presentation, Torben Müller gave an overview of different classes of IP rights: he presented classic examples such as the first patents for sewing and a car, highlighting also the very specific patent language that is used. He granted us a look behind the curtain of the interdisciplinary work of a patent attorney that spans from law to technology, being in contact everyday with experts and clients.

When talking about fabrication processes of advanced micro and nano devices, physics plays a fundamental role. This was clear in ***Felix Holzner***'s presentation, working at

Lab14 (previously **RSBG AMT**). The company includes a wide variety of highly specialized sub-companies such as Specs, Heidelberg Instruments, Multiphoton Optics, Osiris, 40-30 and Notion Systems. This allows Lab14 to have a broad portfolio in fabrication and analysis technologies, spanning from hard- and software for laser/e-beam lithography systems, surface analysis tools, to printed circuit boards and micro-optics. Attractive to prospective physics graduates, Lab14 has currently more than 70 open positions in these independent sub-companies.

An interesting talk was given by ***Tobias Vancura***, CEO of **CO_2 Börse AG**, offering support for Swiss car importers in the processing of the CO_2 levy or CO_2 tax. He gave an overview of his career path, starting with a physics education and a transition to the industry world after his Ph.D. at ETH Zürich. He held various positions, ranging from founding the startup Nanonis, to managerial roles in multinational corporations such as Mettler Toledo. He explained that he always benefitted from his general skills in simulation and automation that he acquired during his studies. He also shared his experience on how to shape a team and acquire enough funding to buy an already established company. The latter allowed him to leapfrog over the usual period of high financial risk and founding struggle that most startups experience in their first few years of existence.

How do you connect quantum field theory with the alternative investments industry? ***Christof Schmidhuber***, with more than two decades experience at various positions and companies in **finance** and now professor at ZHAW, talked about doing exactly this in his career journey. He presented surprising analogies, e.g., that the shares of financial assets can be modeled by molecules of a lattice gas, where the lattice represents the social network of investors in the background. Driving the analogy with an interacting gas further, one can investigate phase transitions and derive scaling laws in finance using quantum field theory.

For many industrial processes and research laboratories, vacuum instrumentation plays an important role. ***Bernhard Andreaus***, currently Director of Product Evolution & Application at **Inficon AG**, explained past and current challenges of the technology in pressure measurements and gas composition analysis, and how to overcome those. Especially interesting is that the challenges and innovations never seem to stop, and although the company has a long history, Inficon constantly reinvents to be state-of-the-art in terms of vacuum instrumentation.

Hightec MC AG started as a thin film division of Brown, Boveri & Cie. (BBC) in 1979 and has been an independent company since 1992. ***Samuel D'Hollosy*** is currently the Research and Development Manager at Hightec and he told us that one of their markets is superconducting multilayer flexible cryogenic cables, which are interesting for space, aircraft and medical applications. But also, quantum computing is a field in which they participate in, since high-frequency interconnects with a high electrical and low thermal conductivity at ultracold temperatures are critical for such systems. He mentioned that the scaling to larger sizes is very challenging, since buckling from stress has a major impact on the interconnect quality. He also stated that external collaborations for specialized test equipment are very important for such a relatively small company

Industry and academia are living from new ideas, and collaborations between them can help to bridge the gap from fundamental research to being successful in the market. The importance of this topic was described vividly by ***Christof Fattinger***, who had been working at **Roche** since 1989. He is interested in extremely sensitive detection of transparent matter, especially biomolecules. For that, a minimally invasive detection technique in a crowded sample is needed, which he developed in an interdisciplinary project together with ETH Zürich. The method is called 'focal molography', which is based on a nanoscale biological grating, the mologram. When a desired molecule binds to this grating, the light diffraction intensity in the focal spot changes measurably. Christof Fattinger hereby exemplified that within such kind of collaborations, new innovative ideas are enhanced and may lead to new further scientific investigations as well as spin-off companies that can mature the idea to marketable products.

Daniel Egger's talk was an interesting presentation of how a very non-linear career journey can lead to some surprising combinations of scientific disciplines. He told us about his path from accelerator physics, over superconducting qubits to financial risk management and finally back to developing novel quantum computing applications and algorithms. After his Ph.D., he did not want to go to the US, so instead, he decided to work in the financial sector in risk management, where he investigated risk factor models using Monte Carlo simulations. After a few years, he missed the thrill of discovering new things. This is why he is currently working at **IBM Research** where he can combine the worlds of quantum computing and financial risk management, by developing algorithms for quantum computers to calculate the risk.

About 40 people attended the "Physics at Work in Industry" sessions at the SPS Annual Meeting 2022 in Fribourg.

Overall, this year's Industry session gave a broad view of possible career opportunities outside of the academic environment. From startups to established tech companies, a wide range was presented, with exciting insights. Especially the uniqueness of each of the career paths and the often close interaction between industry and academia were thrilling to see. It illustrated, how this can lead to new innovations in the industry sector or result in new physical concepts and analytical tools for the benefit of academia and society in general.

Physics and Society

The current uncertainty in the public, in the media and in politics about the fragile energy supply situation in the next months is triggered by the crisis of the Ukrainian war. Since nobody knows when the war will end and if then a new war by another big political player will be launched leading to other supply problems e.g. in microchips, short term pragmatic solutions are asked, no long term visions. There is no doubt, times have changed, and we live in an unexpected new political situation where new questions must be answered.
Even if it is understandable that the supply of energy is primary, this must not be at the expense of climate protection programs. If gas-fired power plants have to be used, then the binding of their CO_2 emission must be tackled with the same priority. This is technically possible, but was not yet seriously pushed. All the many actual studies concerning the new assessment of the energy supply situation up to 2050 which are rather conservatively biased, i.e. describing extensively mainstream technologies, have to be extended to new system configurations including modern nuclear technologies.
And apparent contradictions have to be solved: Switzerlands does not have own seasonal gas storage facilities, but has contracted a gas storage facility in France. But is *pacta servanda sunt* still valid in crisis situations? On the other hand Switzerland has no institutional agreement with the EU to actively participate e.g in the allocation of electricity capacity. This can have negative impact on the Swiss grid stability and import capability.
The following article of W. Kröger critically analyses the current energy supply situation, and what has to be reviewed with respect to an optimized long term strategy.

BB

Secure Supply of Electricity to Switzerland: Need for Adaptation

Wolfgang Kröger

1. Present situation

In 2021, Switzerland's national electricity consumption was 62.5 TWh; after deducting transmission and distribution losses, the final electricity consumption was 58.1 TWh - up 4.3 % from 2020 and slightly above the 2019 pre-Corona level. Net electricity generation fell to nearly 61.5 TWh, resulting in an import surplus of 2.4 TWh. Hydropower contributed about 61.5 %, nuclear just under 29 %, and conventional-thermal and remaining renewables (such as waste, biomass, solar, and wind) 10.3 % [1]. Natural gas plays a marginal role in electricity generation in Switzerland but accounted for 15.4 % of final energy consumption. With a slight decline in per capita consumption, the share has grown steadily in recent years because prices were low and gas was considered politically assured and environmentally friendly, especially compared to oil. Households accounted for about 42 % of consumption, 34 % industry and services 22 %. 80 % of the gas is burned on average in winter.

The theoretical capacity of the big water reservoirs, which are important for hydropower, are just under 9 TWh when completely filled. After deduction of the former minimum reserve, about 8 TWh would be available for power generation in winter, according to experience just under a quarter of domestic winter consumption. Their filling level at the end of September 2022 was slightly above 82 %, 3.3 % lower than average of last 20 years [2].

1.1 Inventory gas supply and gas shortage

Switzerland no longer has its own gas production and purchases 3/4 of the gas it consumes via Germany. Before the restrictions, Russian gas accounted for 43 % of the import mix [3].

Switzerland is a transit nation for gas embedded in the international transmission network (ENTSO-E) (Fig.1). About 80 % of the transit capacity of the Swiss pipeline is used for gas transport to Italy from France and mainly from Germany, with respective feed-in and metering stations close to the Swiss border; a turbine-driven compressor station is located in Ruswil (LU). The remaining 20 % cover about 80 % of Switzerland's annual gas consumption of 3.6 billion m^3; the volume stored in the pipeline is 15 million m^3, so if it were theoretically fully utilized, it would only cover Switzerland's demand for about one day.

The transit pipeline is operated by Transitgas AG, in which Swissgas AG has a 51 % share-holding. Since 2018, the transit pipeline can also be operated in the opposite direction ("reverse-flow"), i.e., from south to north. This is a "negotiating trump card" of strategic importance for Switzerland and of great interest to Germany as an option when Russian gas must be compensated by supplies via Italy from Azerbaijan, North Africa and increasingly also from Liquefied Natural Gas (LNG). For LNG transport by maritime vessels four terminals are already in operation in Italy and an additional one is under construction [1].

Switzerland does not have own seasonal gas storage facilities. As a substitute, it has contracted a gas storage facility in France (Etrez, near Lyon) to secure 35 % of its demand for the coming winter. Gas importing companies must build up mandatory stocks for a 4 ½ months requirement, which can be realized in the form of extra light heating oil. This helps alleviate supply shortages, especially for households as "protected customers." Many dual-fuel plants (in addition to in private households, especially in industry) can / should be switched back from gas to oil.

The gas storage facilities in the EU are (as of 8 August 2022) about 78.3 % full, over a tenth more than at the same time last year. Gas storage facilities in France are even filled

1 The EU has 26 LNG terminals in operation, including 7 in Spain (with no adequate pipeline-connection to France), 4 in France and one in Belgium, the Netherlands and Lithuania each, none in Germany; numerous terminals are under construction or at a planning stage in various countries, including 2 to 3 permanent terminals in Germany. In 2021 LNG (80 billion m^3) accounted for up to 80 % of total extra-EU gas supply.

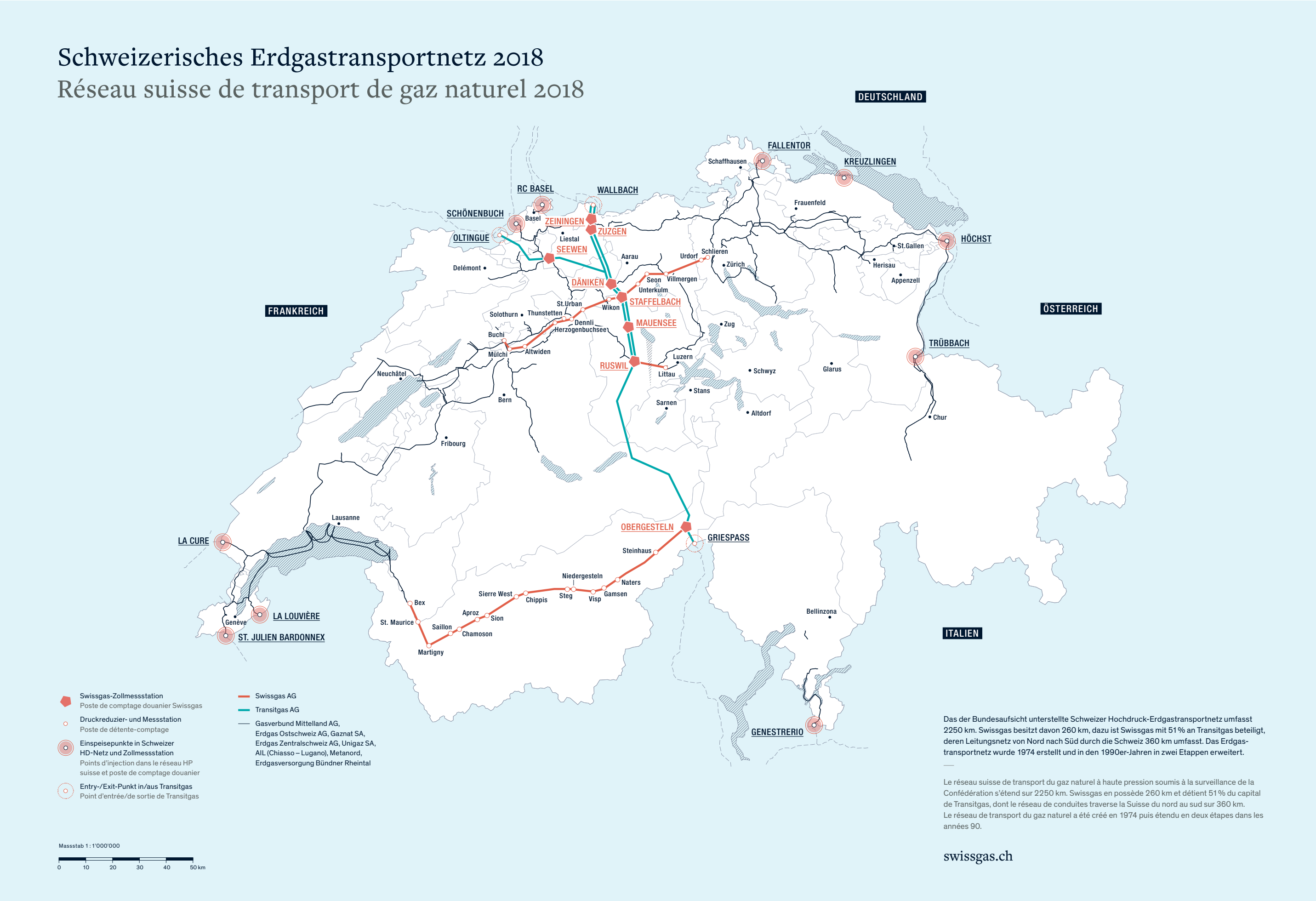


Fig. 1: Feeding into the transit line of Switzerland, part of the European network

to just over 90 % and in Germany to just over 81 % (https://agsi.eu). Germany, with a pre-Ukranian crisis gas share of just under 13 % of electricity generation and 27 % of primary energy supply, is aiming to fill its storage facilities to 95 % by early November. To achieve this goal, according to the Federal Network Agency, "low level supplies (from Russia) could affect gas transfers to other countries" (https://www.bundesnetzagentur.de).

1.2 Lack of institutional agreements as a challenge for gas and electricity

Switzerland is thus integrated into the European (ENTSO-G, https://www.entsog.eu) network with mutual dependencies and interests in terms of gas supply. It is currently negotiating solidarity agreements with neighboring countries, including Germany. These threaten to fail because an overarching framework agreement with the EU is lacking and, following the Federal Council's decision to break off the negotiations, seems to be a distant prospect.

Switzerland is also an important transit country for electricity supply [2] and, with 41 cross-border lines, an essential part of the European network; however, network bottlenecks at home and abroad limit the exchange capacity [4]. The synchronized (ENTSO-E, https://www.entsoe.eu) network serves 530 million people and covers 30 countries. This now includes Ukraine and Moldova, which can be disconnected to protect the European network, if necessary, for example, due to war. Switzerland also lacks a corresponding agreement for electricity exchange with neighboring countries; it is on hold. It remains to be seen whether efforts to reach bilateral agreements between contracting parties can lead to success and remedy the situation.

If an electricity agreement is not reached, this will have a negative impact on both grid stability and import capability. As in the case of gas, Switzerland has only observer status in "electricity committees", from which it cannot actively participate in the increasingly dynamic allocation of electricity capacity. An increase in unplanned electricity flows through the country is to be expected, with partial and temporary congestion of the Swiss grid as a consequence. Swissgrid, as the grid operator, will then have to intervene in system operation via national or international "dispatch" to restore the balance between production and consumption to stabilize the frequency and keep the grid stable (see box). This is becoming increasingly difficult and challenging, not least because of the increasing share of intermittent and variable energy sources such as solar and wind in electricity production, and usually requires high costs.

It is well known that the power system is increasingly operated at its limits, dangerous violations of so-called N-1 security criteria are on the rise [7]. Likewise, the probability of large scale and prolonged outages ("blackouts") is also increasing. Recent examples affected western Switzerland on 15 November 2019, with problems in the transmission

2 Traditionally, Switzerland has been important for electricity transport to Italy, but this is diminished, e.g., by underground cabling between Austria and Italy.

Stability of the European transmission network - influencing variables (with real-time monitoring) and security requirements

- Physical principle: synchronized, interconnected transmission grid, faults can spread across Europe due to limited technical separation capabilities
- Control objective: balance between consumption and production (or vice versa)
- Control parameters (with real-time monitoring):
  - Frequency: 50 Hz, short-term allowable variation 800 mHz (at 49 Hz=too little power produced, then load shedding: at 51.5 Hz=too much power produced, then all solar systems cutoff the grid)
  - Voltage: 380/220 kV
- N-1 Safety Criteria: Legally binding requirement that if one element of the network, e.g., a line, fails unplanned, then the active remaining elements must be able to cope with the changed current flows without triggering shutdown cascades or significant consumption curtailments (ENTSO-E Handbook).

network caused by high import demand from France following the shutdown of nuclear power plants after earthquakes in the south, as well as a split of the European grid on 8 January 2021, for about one hour, triggered by a fault in a substation in Croatia.

With regard to a possible electricity shortage due to a lack of imports, the new EU rule is important, according to which EU countries must reserve 70 % of cross-border capacity for trade among EU member states, starting in 2025 at the latest, after it came into force in 2021. This poses the risk that Switzerland – especially in the winter months – can import significantly less electricity than would be necessary. A shortcoming that is already becoming apparent and will intensify in the future [7]. Even more, without agreements at the highest level, it is extremely questionable whether neighboring countries, in view of their own import strategies, are able and / or willing to supply electricity out of sheer solidarity if they themselves find themselves in a shortage / crisis.

In recent years, Swiss energy companies have invested considerably in the expansion of renewable energies, especially in wind farms abroad; according to a survey by "Energie Zukunft Schweiz", their annual production is estimated at 10.5 TWh. Under the new 70 % regulation, however, Switzerland's secure supply can only be guaranteed by investing in expansion at home, which presupposes a corresponding willingness to invest. Expansion is currently also (still) severely hampered by lengthy objection processes. The 380 kV line between Mörel and Ulrichen, which is urgently needed to transport electricity from the Valais to the Central Plateau, is currently under construction and is expected to be ready for operation after a long delay at the end of 2023 [3].

3 https://www.swissgrid.ch/de/home/projects

2. Energy law and energy perspectives

2.1 Assumptions

The current SFOE study Energy Perspectives 2050+ [6] goes beyond the Energy Act that came into force on 1 January 2018 and shows whether and how the Swiss energy system can be climate-neutral by 2050 at the latest, i.e., have "net zero" CO_2 emissions [4]. In addition, security of supply is to be ensured even if nuclear energy is phased out, if possible, without electricity imports and without the use of fossil fuels. The study optimistically assumes that all European countries will strive for a drastic reduction of CO_2 emissions and honor commitments made, and further that the storage capacities needed for CO_2 storage will be provided by foreign countries. The study makes key underlying assumptions that highlight major challenges and point to possible misconceptions, (see the table below), in particular when taking the current challenging situation and foreseeable developments into account.

Key basic assumptions of the SFOE study "Energy Perspectives 2050+"[6].
Switzerland remains embedded in European networks, export and import possibilities are guaranteed.
The required technologies are available (conservatively, no quantum leaps / "miracle technologies" are assumed) or must / could be made available and deployed in the next 30 years. These include Carbon Capture and Sequestration (CCS) and Negative Emission Technologies (NET), which are considered commercially available to offset residual emissions from 2035 onwards.
Contrary to the previous assumption in the existing Energy Law, electricity consumption in the end-use sectors is projected to increase to 63.2 TWh by 2050, about 11 % more than in 2019, with the highest rate of increase in the transport sector (more than a factor of 5.5).
The investment requirement by 2050 of 1,400 billion CHF anyway increases by 109 billion CHF for "net zero," resulting in an amount of more than 50 billion CHF annually that is considered "feasible" (compared to GDP, e.g., 709 billion CHF in 2020).

2.2 Estimates of future electricity demand, electricity exchange

In general, it is predicted that primary energy consumption in Switzerland will decrease rather than increase, despite rising population numbers and needs. The reason for this is the assumed reduction in per capita consumption in view of the strong increase in energy efficiency, e.g., in buildings, as a result of higher efficiency of electric drives and electrification in general.

On the other hand, the figures for future electricity demand fluctuate: The draft bill on the Energy Act still optimistically assumed a decrease. However, more recent studies indicate increases because of the desired "sector coupling" with increasing electricity requests in new areas, especially in mobility (electric vehicles), heating and cooling of buildings (heat pumps), and to meet the energy demand of advanc-

4 Net-zero means, that remaining emissions must be compensated by extraction of the equal amount from atmosphere by natural or engineering solutions.

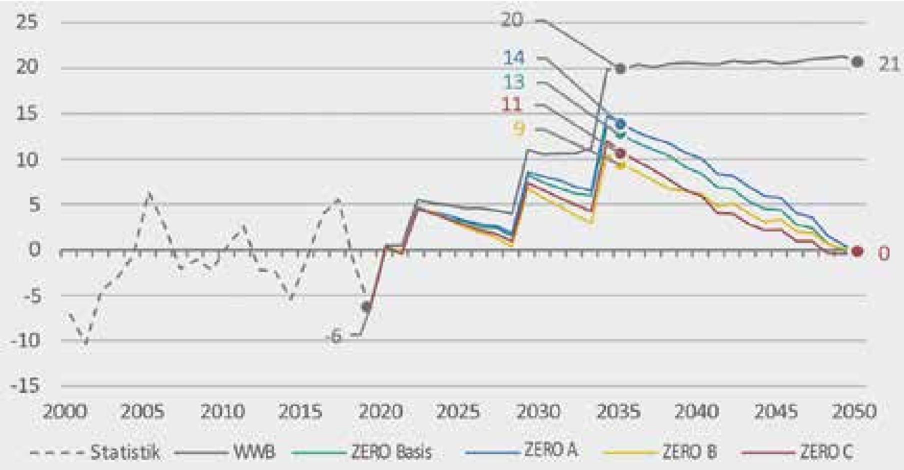


Fig. 2: Annual import balance (comparison of ZERO and WWB scenario variants) [6, Fig. 8].

ing digitalization. While according to [6] the estimated values until 2050 were "only" 11 %, according to other studies with different model assumptions and input data they are up to more than 50 % [7] or even 100 % in OECD-countries (OECD-IEA). This parameter is of crucial importance for the security of supply to be guaranteed and the strategy to be chosen must be put to the test for Switzerland including the assumptions made and the data used, thereby taking pessimistic considerations and extrapolation of uncertainties.

The assumption that reported import balances (Fig. 2) are acceptable because import opportunities are assured in the future amounts to an electricity import strategy, which is highly questionable and risky, especially in view of the emerging import needs of many countries, including those that have been exporting nations like Germany or have great difficulties in maintaining and modernizing their production fleet like the fleet of nuclear power plants in France [5].

2.3 Assessment of technologies, their availabilities, and usages

According to [6] the Swiss energy strategy 2050+ relies on a mix of hydropower and other renewable energies such as wind and - above all - photovoltaics, together with the availability of the necessary seasonal and time-of-day storage technologies and adequate transport infrastructures, as well as gas-fired reserve power plants and electricity exchange with other countries. In addition, CCS and NET are needed to compensate for unavoidable CO_2 residual emissions.

While some technologies have reached commercial maturity and viability, others are in small-scale demonstration (hydrogen production and transport) or even experimental stages (such as power-to-X, NET, synthetic fuels). This results in significant uncertainties and threats for the energy system of the future. In addition to a careful sensitivity analysis, there is a lack of comprehensive consideration of the security of required resources (such as sufficient raw materials for batteries when e-cars penetrate the market, see GTK report 2021 [8], and import dependencies (for "commodities" such as wind turbines and PV panels).

It is noticeable that mostly in the studies, as also in [6], technologies that correspond to the current mainstream are treated rather favorably, close to wishful thinking. Unpopular technologies such as nuclear energy, on the other hand, are either not treated at all, not comprehensively, or dismissed with reference to the 2017 energy strategy vote, rather pejoratively; the recent study of Swiss academies [7] is limited to mentioning striking disadvantages such as high investment requirements, lack of market maturity, and production of radioactive waste. The demanded open discussion would have to take place, free of taboos, and include all technologies including modern nuclear technology with their strengths and weaknesses in a fact-oriented and comprehensive way. The aim should be to achieve an optimized system with a maximum of diversity and import independence and thus security of supply and to counter the considerable uncertainties and imponderables.

Not everything that seems to be useful and is available is actually used consequently. For example, the rate at which PV systems and wind farms are currently being added is far too low and would have to be increased fivefold in the long term to keep pace with the growing demand for "green electricity". The same applies to the expansion of associated storage facilities, required transmission lines and distribution grids at different voltage levels, and other infrastructure elements that contribute to mitigating the grid control problem without rotating masses for frequency stabilization.

3. What to do, notably in the longer term?

3.1 Review the cornerstones of the energy strategy

The unexpected events of the recent past and the developments that have been conjured up have revealed - hitherto only feared - short- and longer-term dangers for our energy supply. They force a review of the cornerstones of our energy strategy and their adaptation to new circumstances and a shifted perspective: climate protection and decarbonization of our energy system, respectively, as an overarching paradigm seems to have taken a back seat and must be balanced with security of supply. A balance has also to be found between what is desirable and what is feasible, between downplaying and scaremongering. For example, the importance of Russian gas for our energy supply should not be underestimated, but because of its small share it should not be overestimated either; for domestic electricity production, as has been explained, it plays practically no role although backlashes of the European electricity market are to be considered. Sober consideration should be the order of the day; the financial and economic "ability to afford" must be given greater consideration again, and scientifically proven facts should once again play a more important role.

All technical possibilities and behavioral changes that help to significantly save energy / electricity and use it more efficiently are to be increasingly exploited and supplemented by realistic, concrete targets on a timeline ("roadmap"). The

5 Out of 56 units at 18 sites, 32 units are temporarily shut down for extended maintenance and repair of corroded pipes. 27 are said to get back to operation by the end of 2022, the remaining by mid-February 2023.

expansion of renewable energy sources, especially photovoltaics on and at buildings, is insufficient and must be accelerated as already triggered by politics, despite all difficulties (considerable land requirements, acceptance problems, preservation of legal foundations). In addition, there are essential elements of the overall system such as storage and grids. With the necessary clarity, the corresponding persuasion work must be done, governance processes and new participation models (e.g., "prosumer" cooperatives) must be developed and implemented. R&D efforts, especially in storage technologies and alternative fuels, including demand-side measures, must be intensified.

3.2 Widening the field of view

Scenarios of possible futures with varying assumptions have to be developed and their complexity has to be taken into account moderately. These include possibly changing social, political and economic conditions at national, regional / European and international level, but also currents at the meta-level such as military aggression as well as deglobalization / state autonomy instead of globalization with their effects on Switzerland. This is certainly difficult, but the mostly practiced mere extrapolation of today's conditions and framework conditions over decades (2020 - 2050) is not sufficient, is short-sighted and has proven to be too risky.

3.3 Defusing foreign dependence

Everything must be done politically to ensure that Switzerland is embedded in international agreements and exchange with other EU countries. However, it cannot be assumed that this will be successful precautionary measures need to be considered. Domestic electricity production must be increased, if possible, without causing additional CO_2 emissions. For this reason, also because of new import dependencies, use of gas - and even more so of oil - should only be considered as a fuel for (backup) power plants, or only to a very limited extent as a kind of emergency measure, even if these, such as Combined Cycle Gas Turbine (CCGT) power plants, can be used flexibly and are technically mature and have quite high efficiencies.

3.4 Rethinking the role of nuclear energy

The safe, trouble-free continued operation of the existing Swiss nuclear power plants must be ensured. In addition, long-term operation beyond the 50 years assumed so far should be examined as an option. An operating life of 60 years is economically attractive and is now standard for new plants but is also the practice for "old plants" in many countries after appropriate testing, with the USA as the pioneer [9].

The opinion that there is no need for new nuclear power plants in Switzerland to contribute to the generation of "green electricity" must be reconsidered. Energy strategies of other countries such as France, the USA and China contradict this. In addition to further developed concepts of the "Generation III / III+" available today, they also rely in the longer term on novel reactor and fuel cycle concepts of the so-called Generation IV. A special role is played by "super-safe" modular reactors of small to medium power, so-called SMRs. They are considered to be commercially deployable in the near future, especially if they continue to use water as a coolant and make evolutionary use of the technology of today's light water reactors, LWRs [10].

The realization of a new construction project in Switzerland is tied to many challenging pre-requisites:

- To the corresponding strong societal-political will,
- the willingness of the electricity industry and financiers to invest,
- the availability of a suitable concept and competent, probably non-European industrial partners, and
- the availability of the necessary specialists, workers, and materials.

Assuming that these conditions are met, the many hurdles are overcome, and project steps can be advanced in parallel, a realization period of 16 to 18 years, i.e., until around 2040, seems feasible.

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Kurzmitteilungen - Short Communications

Pre-announcement: Joint Annual Meeting of SPS and ÖPG 2023

The next annual meeting, as usual every two years together with our Austrian colleagues, will take place at the ***Universität Basel*** in the week of ***4 - 8 September 2023***.

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. The detailed announcement will be published in the next *SPG Mitteilungen*, available in early 2023, as well as on our website.

Getting close to the Sun: A space mission on a journey of discovery

Louise Harra, PMOD/WRC, ETH-Zürich

On 9 February 2020, late in the evening in Cape Canaveral, Florida, a spacecraft was launched on a United Launch Alliance Atlas V rocket. The spacecraft is a European Space Agency spacecraft called Solar Orbiter [Müller et al., 2020]. Its mission has been in the making for more than 20 years, and the teams involved are from around Europe and the US. The spacecraft uses planetary fly-bys past Venus and the Earth to gain enough energy to not only get in close to the Sun, but also slowly push itself out of the ecliptic plane to peer down at the solar poles. The mission just reached its first close science perihelion in March/April 2022, getting as close as Mercury, at a distance only 0.28 A.U. from the Sun.

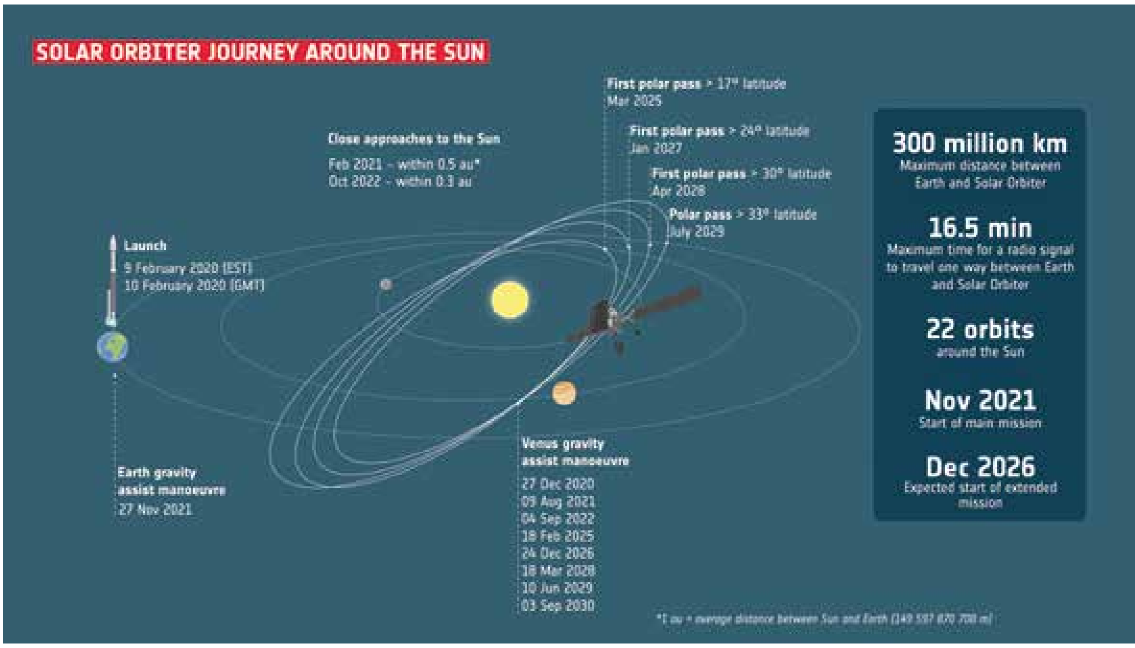

Figure 1: Solar Orbiter's journey around the Sun. Courtesy ESA.

What is new about the Solar Orbiter mission?

The Solar Orbiter mission was developed over more than two decades. The two novel aspects of the orbit are that the spacecraft gets in close to the Sun (within 0.3 A.U.) and that it uses Venus and Earth fly-bys to get into its orbit and to slowly move out of the ecliptic plane to have a view of the solar poles for the first time. The spacecraft will reach 33 degrees latitude.

Planetary fly-bys have been used extensively before in different spacecrafts. The biggest challenge for Solar Orbiter was the Earth fly-by in November 2021, which placed the mission in its final science orbit. At the closest approach the spacecraft reached 460 km above the Earth and flew through the space debris around this zone. It was carefully tracked by the ESA team to minimize the risk of collisions. The fly-by was successful, and no orbit adjustments were required for debris avoidance.

Different technologies had to be developed in order to achieve the novel orbital goals. This included the development of a heat shield at the front of the spacecraft which reaches a temperature of 500° C in order to keep the instruments at around room temperature. The solar panels must be able to tilt away from the Sun when it is at its closest to protect them from the intense heat impact. The mission has telescopes on board with optics, filters and electronics. The heat shield protects them, and the telescopes were designed with clear apertures as small as possible together with special baffle structures to reject the heat flow without limiting the optical field of view. Careful attention had to be given to the aggressive radiation environment, and special radiation resistant electronics components and sensors were developped.

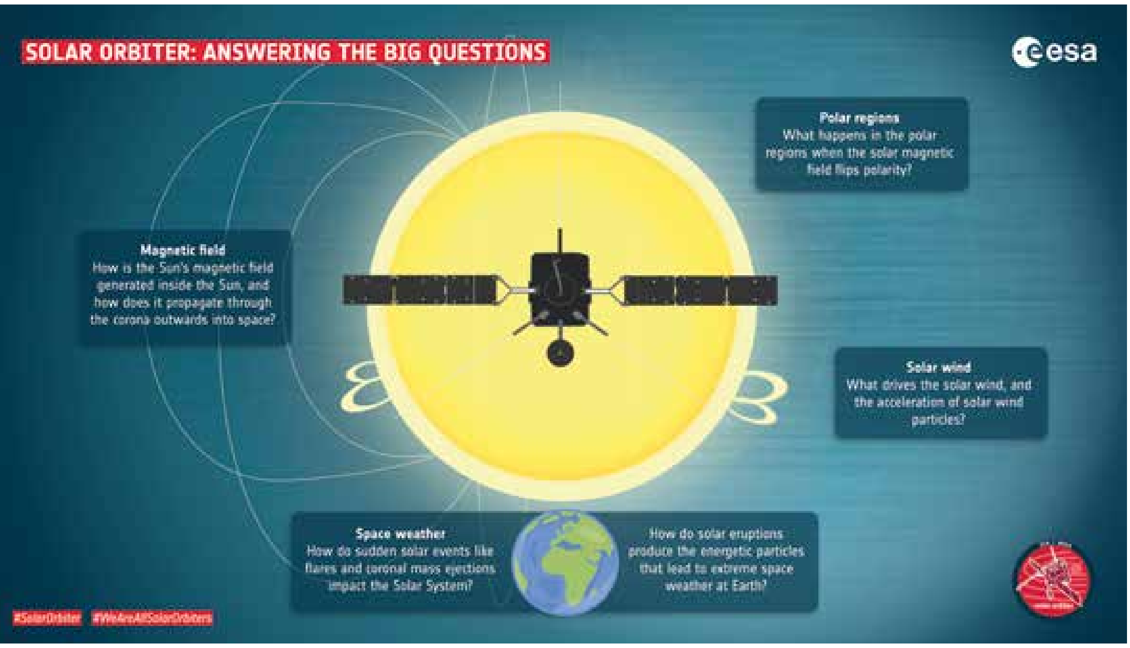

Figure 2: The major science goals of the Solar Orbiter mission. Courtesy ESA.

Other huge challenges are the large distance from the Earth and the situations when the spacecraft is behind the sun losing the contact to Earth. This is different with previous solar missions, where daily contact is possible. Then the observing modes can be updated regularly to adjust for the changing solar activity, and data can be downloaded daily. With Solar Orbiter this is not the case and consequently highly efficient digital compressing schemes of selected measurement data as solar flares must be applied.

Scientific goals

A summary of the goals of the mission are shown in Figure 2. They are related to the formation and dynamics of the heliosphere, asking what drives the solar wind and solar eruptions? This is vital to understand space weather, which has an increasing impact on technologies that we are reliant on Earth, such as GPS, communication systems and electricity nets. In addition, we will explore the solar poles for the first time ever with telescopes.

The two big novelties of the mission orbit are the closeness to the Sun and that it will observe the solar poles for the first time. The mission will reach 0.28 A.U. In addition, the mission will make use of Venus fly-bys to get enough energy to observe out of the ecliptic plane. The highest inclination reached will be 33 degrees. The overarching question is 'How does the Sun create and control the Heliosphere?', with 4 key questions:

1) How and where do the solar wind plasma and magnetic field originate in the corona?
2) How do solar transients drive heliospheric variability?
3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?
4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Getting in close to the Sun allows us to probe pristine solar wind and study the sources. This is challenging to do from Earth orbit due to the large distances, and the mixing of solar wind sources enroute to the Earth. There are two types of solar wind – fast and slow. The fast wind is steady while the slow wind is dynamic. The fast wind is reasonably well understood but the slow wind is more mysterious. There are many theories put forward to explain the slow solar wind, but its significant variation in many parameters and the complexity of the magnetic field around the activity belt have made it hard to pinpoint. Getting in close improves the understanding significantly.

The solar poles have yet to be explored. These are key for understanding the fast solar wind, and how the solar cycle functions. The solar cycle is hard to predict with great accuracy. The cycle of activity lasts around 11 years, and its magnitude varies. We have been nearly blind to the polar magnetic fields, and these are a key component in the magnetic cycle. This aspect will become progressively important in the latter stages of the mission as the inclination angle increases.

Instruments

Solar Orbiter has an extensive suite of ten instruments onboard. These are provided by countries around Europe, and the US. There are two categories of instruments – those that measure the solar wind as it passes the spacecraft (in-situ instruments) and those that image what is happening on the Sun (remote sensing instruments). The energy from the Sun comes in the form of electromagnetic energy across the whole spectrum, particles, waves [1] and magnetic fields, which require different technical solutions to measure (see Figure 3).

There are four in-situ instruments that measure the energetic particles that flow past the spacecraft (Energetic Particle Detector, EPD), the magnetic field around the spacecraft (Magnetometer, MAG), the variation in magnetic and electric field (Radio and Plasma Waves, RPW) and properties of the solar wind (Solar Wind Plasma Analyser, SWA). These instruments are at multiple locations on the spacecraft, the boom and antennae (see Figure 3).

Six remote sensing instruments image the Sun across the electromagnetic spectrum, as well as the solar disk, and the solar wind that leaves the Sun. The six instruments image through the solar atmosphere (Extreme Ultraviolet Imager, EUI), image out to 4.1 solar radii (coronagraph, METIS), perform magnetic field measurements of the surface (Polarimetric and Helioseismic Imager, PHI), take images of the solar wind (Heliospheric Imager, SoloHI), do spectroscopy of the solar atmosphere (Spectral Imaging of the Coronal Environment, SPICE), and detect the high energy hard X-ray emission (X-ray Spectrometer/Telescope, STIX).

1 Waves are produced on the Sun all the time - for example triggered by plasma convection streams shaking the magnetic fields.

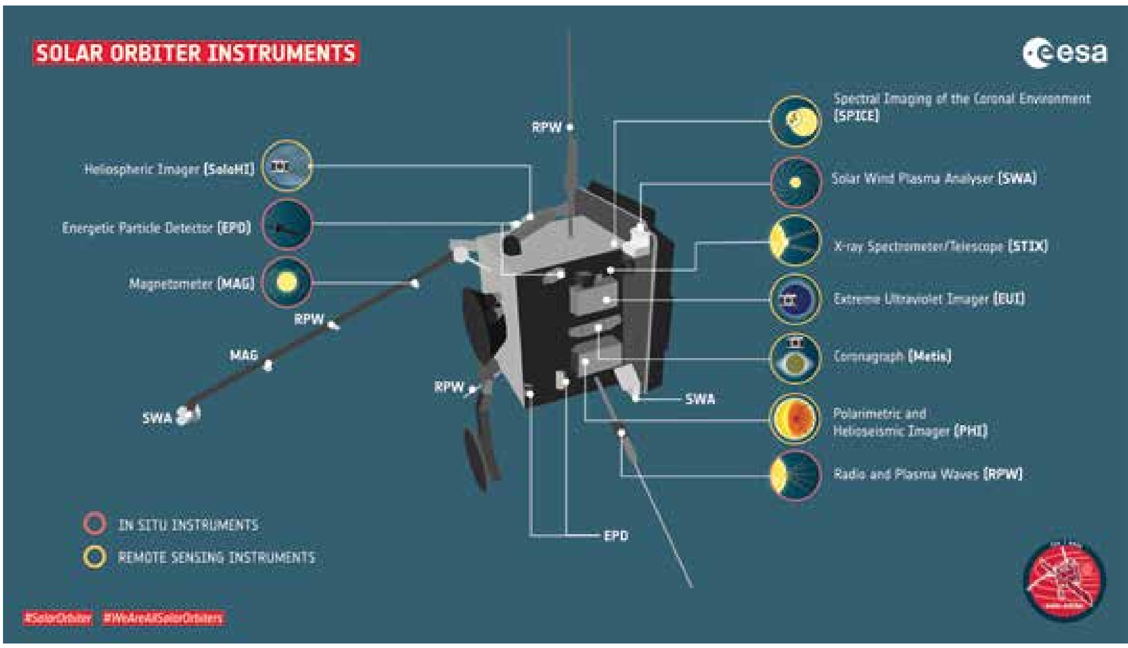

Figure 3: The instruments are labelled on the spacecraft. Courtesy ESA.

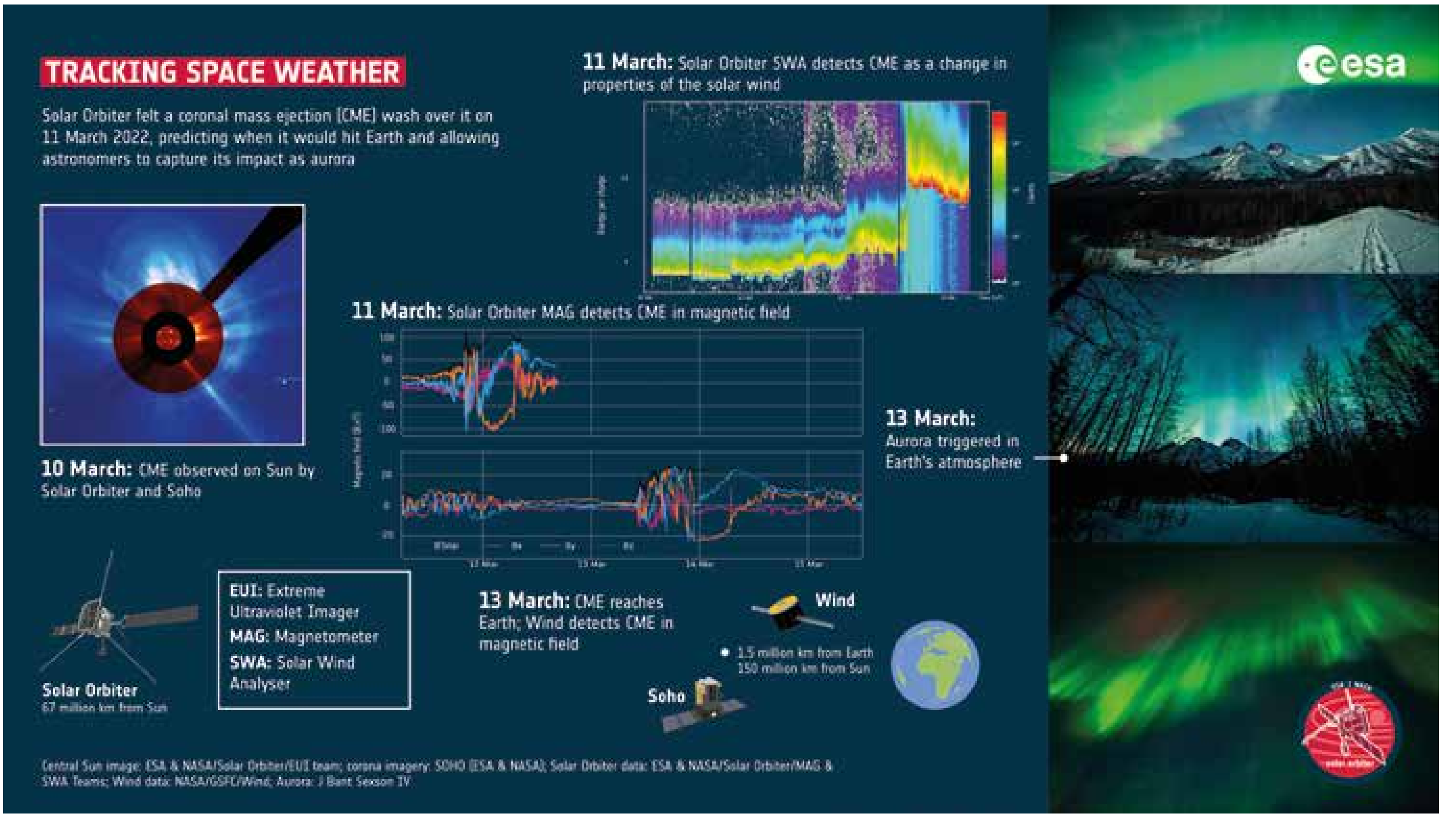

Figure 4: An example of coronal mass ejection measured with the Solar Orbiter instruments. This storm impacted the Earth. Courtesy ESA.

The instruments were all commissioned and are operating nominally. The instruments papers are all available here for detailed information:
https://www.cosmos.esa.int/web/solar-orbiter/a-a-solar-orbiter-special-issue

Results so far

One of the main goals of Solar Orbiter is to understand the sources of the solar wind and coronal mass ejections and how these drive the heliosphere. In the cruise phase, the in-situ instruments were operational most of the time, enabling opportunities for measuring through a comet's tail and in the Venus atmosphere. Now we are in the science phase, using the full set of instruments to understand the wide range of activity on the Sun. An example of how the instruments are used together is shown in Figure 4. A solar eruption was observed by the imaging instruments leaving the Sun on 10 March 2022. This eruption travelled past the spacecraft on 11 March and hit the Earth on 13 March triggering beautiful aurora.

The Sun is dynamic and ejects particles, waves and magnetic fields on small and large scale. The dynamic behaviour is driven by the magnetic field and its subsequent heating of the Sun's outer atmosphere (the corona). Figure 5 shows an image of the corona taken with the Extreme Ultraviolet (EUV) full Sun imager [2] onboard of Solar Orbiter. The bright regions show plasma of more than 1 million K. These are the sources of solar flares which are fast increases in radiation from the Sun. In addition, ejections of gas and magnetic fields can happen here, but also from 'quieter' regions. The corona is seen to extend right to the edge of the image and indeed it expands and flows right through the heliosphere. If you look at the image again, but away from the brightest regions, you can see small-scale bright regions across the whole of the solar disk. Solar Orbiter is observing these at the smallest scales ever seen, and these tiny brightenings are likely to feed into the solar wind and the heating of the outer atmosphere.

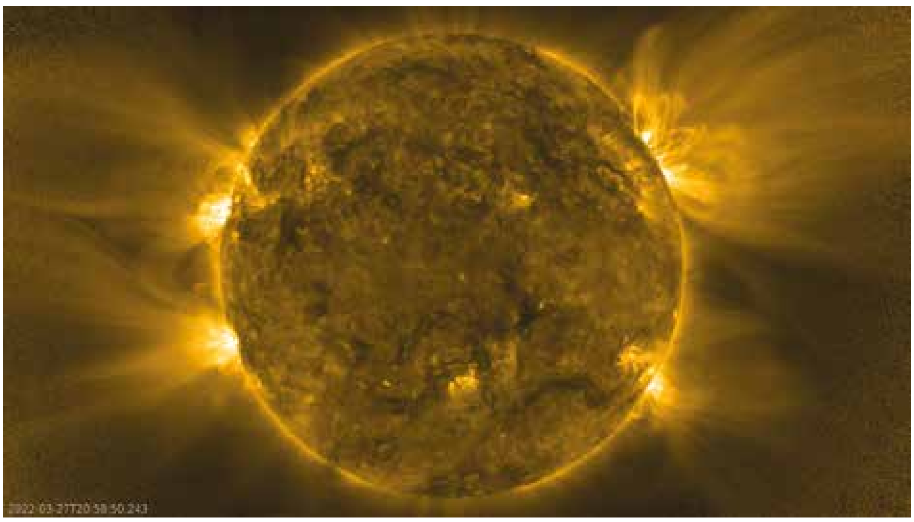

Figure 5: Image of the Sun at the closest approach in March 2022. The image is an EUV image which shows plasma at around 1 MK. ESA & NASA/Solar Orbiter/EUI Team

Results from the cruise phase are published in a special A&A edition [3].

Observing with other space and ground-based facilities

The orbit of Solar Orbiter provides wide-ranging opportunities for coordination with other facilities in both ground

2 The full Sun Imager is one of three telescopes on the EUI platform.

3 https://www.aanda.org/component/toc/?task=topic&id=1340

and space. Figure 1 illustrates the orbits of Solar Orbiter. In some parts of the orbit the spacecraft will observe the Sun from the Earth view (but closer). In other orbits, the spacecraft will provide a view from an angle to the Earth which provides opportunities for stereoscopy. And finally at some parts of the orbits the spacecraft will be behind the Sun providing the only imaging data on the backside of the Sun. Observing campaigns are already taking place with spacecraft such as NASA's IRIS mission [De Pontieu et al., 2014] and JAXA's Hinode mission [Kosugi et al., 2007], and preparations are underway to carry out joint observing with the new 4 m solar telescope on Maui [Daniel K. Inouye Telescope, Rimmele et al., 2020]. We have many opportunities to observe alongside our other solar explorer, NASA's Parker Solar Probe [Fox et al., 2015]. Launched in 2018, its orbit takes it closer to the Sun than Solar Orbiter but it is 'blind' with no telescopes directly pointing at the Sun.

The future of Solar Orbiter

The mission has just completed its first science perihelion. The data is released to the international community and is freely available on ESA's Solar Orbiter archive (*https://soar.esac.esa.int/soar/*). The first science meeting following launch took place in September 2022, with a huge over-subscription of abstracts for contributed talks. The second special journal edition of results will follow this meeting.

Solar Orbiter is just at the beginning of its exciting journey. The next perihelion happens in the autumn 2022. With each perihelion, the altitude of the spacecraft will increase, slowly revealing the solar poles. Each perihelion provides new scientific opportunities of discovery. The team encourages collaboration and the scientific community involved is wide ranging – from solar dynamo, solar flares, solar wind, space plasmas. These scientific results will also inform the behaviour and activity of other stars.

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Muddling through: How to tackle problems we don't understand

Roman Boutellier, ETH Zürich

In 2022 we fight a heavy inflation, close to 100% in Turkey. USA and EU are battling 9 % and all Central Banks are increasing interest rates, big increases not seen since decades. The same banks reassured the public just a few months earlier that price increases were only temporary, and the Economist is even discussing whether the long-term goal of 2 % inflation should be increased to 3 or 4 %. Every student of economy knows the "Quantity Theory of Money", the formula describing the problem: MV = PT or expressed in growth rates:

growth rate money supply + growth rate velocity of money = inflation rate + growth rate output.

By definition, the formula is true, but all parameters are estimates for the past and guesswork for the present and the future. Past recessions tell us that especially the velocity of money is not sufficiently predictable for use in policy. Nobody understands the problem fully. The solution? Let's increase interest rates a little bit and perhaps another little bit next month based on guesses of experts. Nobody knows whether this triggers a recession or not, whether increases should be 0.25 % or 0.75 %. Effects may be delayed by years from the measures taken. We only know, it worked in the past. Increasing interest rates brought down inflation, in most cases with a recession. Nobody knows how to set the parameters that guarantee a reasonable inflation without recession. But many economists believe that there is such a magic number.

Take a contrasting problem based on natural science: Mid-January 2020 Moderna decided to develop a vaccine against Covid-19 based on its profound know-how in handling mRNA with the help of Lipid Nano Particles. A clear strategy with a precise goal built on 9 previous vaccine-developments with the same technology. Some 10 months later the first person got its jab. Because the new vaccine is fully chemically produced in a proven network of more than 120 global specialists scaling up was achieved in weeks. A precise assessment of the situation combined with a precise goal and a detailed plan how to solve the problem led to a successful product. Everybody was surprised how quickly it was possible to develop a new vaccine. Most people think that a similar approach is possible for complex societal problems like vaccinating whole populations.

However, the problem starts anew: How to convince a population to get vaccinated? Up to the end of 2020 the pandemic had been fought with measures perceived as a cacophony: Masks no, masks yes, full lockdowns, partial lockdowns, testing yes and no, …… In the newspapers an outcry started "We want a clear strategy how to fight the pandemic, we

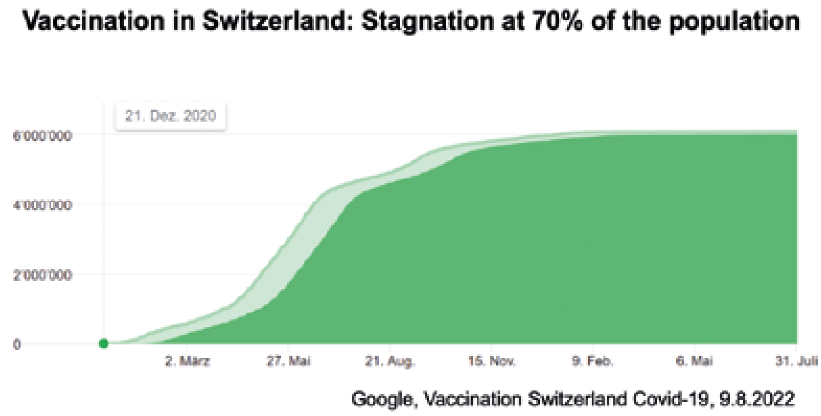

Figure 1: Vaccination in Switzerland: Stagnation at 70% of the population

want to know when we can go back to normal life, lets replace existing governmental structures through a crisis-staff with experts, …." The vaccination program was evidence based, science driven and nevertheless not accepted.

Science alone does not convince. Once again, the government was forced into muddling through: Trying step by step to convince the population to get vaccinated. Some measures were successful, others not. Government and population went through a social learning process with limited success. Polio has been fought with vaccines since more than 70 years and is still not eliminated. The same can be expected for Covid-19. Obviously to develop a vaccine is much easier than to apply it (Fig.1).

Let's make a thought-experiment. In Switzerland, Mr. Berset, the minister responsible for health would have declared in March 2020: "We must achieve a compromise between protecting the population and protection of the economy: After consulting universities, CEOs, political parties and experts we come to the conclusion the balance we reasonably can achieve is a decline in our GDP of 2.9 % and 11'000 deadly casualties". Would the minister still be in charge? The two numbers are what Switzerland has achieved. Nobody set a precise goal, nobody articulated a strategy based on evidence. Many experts tried to reduce the complexity to one number: Excess mortality, beds occupied in intensive care units, positive test rate or the R-value. Whenever the R-value was below 1, administrators and the public cheered. In eastern Switzerland ski lifts opened when R was at 0.97 forgetting that the value published was 0.97 with a margin of 0.14. With R at the upper bound, R = 1.11, infections would have gone up by a factor of 2.5 within 3 weeks! And the upper bound has the same probability as the average. But the decision taken by the administrators was perceived as evidence based, science driven. Looking back, we must accept, that the Swiss government achieved a reasonable result in its fight against Covid-19, without a clear strategy, just by taking measures based on a constant learning process. It never communicated a full solution, nor a finite goal - only the next steps to be realized. Means and goals went together, means were the tool to describe the goal and to get public support.

In 2018, a few months before his death, Kofi Annan gave a speech in Zürich. "I was asked to reorganize the United Nations within 6 weeks. I complained to Lavrov, the Russian foreign minister about this mission impossible. Lavrov told me that God organized the whole world within 6 days! I was impressed - but after a while I answered: Dear mister Lavrov - don't forget, He was working alone!" We sometimes forget that human beings do not follow precise laws in their behavior, they adapt to perceived situations with all the big differences depending on their specific situation, their personal experiences and goals. In Western Europe we have brought down child mortality from 200 to less than 5 per 1000 births without an explicit program, without a formulated strategy, but with thousands of investments in clear water, sanitation, better food, and hygiene (Fig. 2). Sometimes humanity solves problems indirect, without even getting aware that there is a problem.

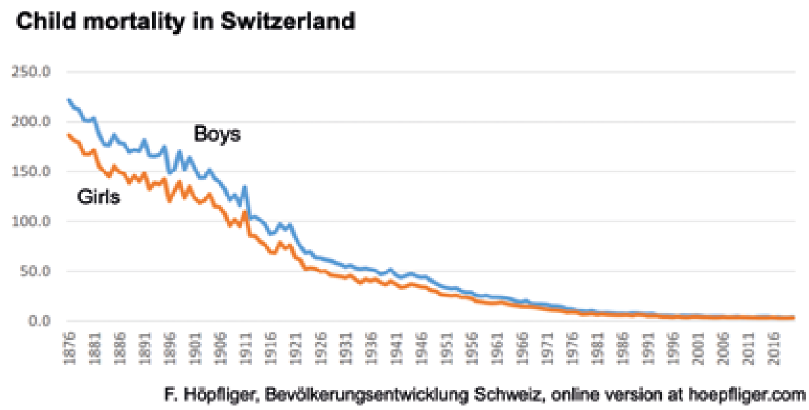

Figure 2: Child mortality in Switzerland

Looking back to Corona crisis in 20 years, what will we remember? Certainly, mRNA, and hopefully that in times of a real crisis, whenever deep fog lies before our eyes, nobody understands fully what is going on, muddling through, learning step by step is a humble and effective approach to manage a crisis.

Roman Boutellier made his PhD in mathematics at the ETH in Zürich, and after a year at Imperial College in London and 2 Himalayan expeditions, moved into industry: first as an optical designer at Kern in Aarau, then at Leica in Heerbrugg as Head of Technology and Member of the Executive Board. In 1993 he was appointed to the HSG, as Professor for Innovation and Logistics. Six years later, he returned to industry as CEO of SIG in Neuhausen. In 2004 he took over the professorship for Technology Management at ETH and in 2008 moved to the Executive Board of ETH, Vice-president Personnel and Resources.

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Rückblick auf das Jost Bürgi Symposium 2022

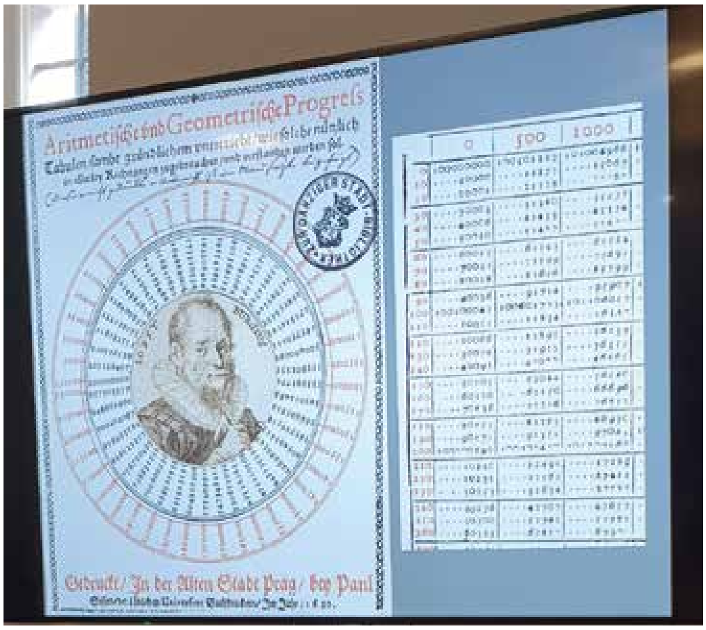
Bernhard Braunecker

Bereits zum sechsten Mal fand in Lichtensteig (SG) das Jost Bürgi Symposium statt, am Freitag 29. April dieses Jahres der Workshop für Historiker und am Samstag 30. April 2022 das Bürgi-Zukunftsforum. Während beim Workshop [1] die Person, die Zeit und das Wirken von Bürgi und Zeitgenossen im Mittelpunkt der Referate und Diskussionen standen, diente beim Zukunftsforum [2] seine Person mehr als Vorbild eines unkonventionell denkenden Machers. Wegen seiner nicht-standesgemässen Bildung erfuhr Bürgi manche Benachteiligung, der er durch aussergewöhnliche Leistungen als Uhrenmacher und Astronom den Boden entzog.

Das Schwerpunktsthema des Workshop war ***Historische Kartographie und Globenkunde***, mit folgenden Referaten von Wissenschaftlern der Uni Zürich: Jost Schmid-Lanter: *Ein Erd- und Himmelsglobus Notkers des Deutschen*, Lisa Weigelt: *Die Gough Map*, Jolanda Brennwald: *Fra' Mauro's Mappamondo* und Raoul DuBois: *Das Heiligen Land Darstellen*. Alle Referentinnen und Referenten zeigten anhand beeindruckender Exponate, wie präzise man zu jener Zeit das experimentelle Wissen gesammelt, verdichtet und entsprechend visualisiert hatte. Man spürte immer den Pioniergeist, die aufgeregte Stimmung des Entdeckens neuer Gebiete und faszinierender Kulturen.

Ein weiterer bemerkenswerter Beitrag kam von Daniel Muzzulini, Mathematiker an der Zürcher Hochschule der Künste, über *Jost Bürgi in Drehung: Kreisdiagramme und Rechenscheiben im frühen 17. Jahrhundert*, mit dem Behandeln logarithmischer Kreisdiagramme. Man kannte sie in der Renaissance als Volvelles (rotierende Zahlenscheiben mit winkelcodierten Exponentialfunktionen), und mit ihnen ließen sich nicht nur mathematische Operationen wie die Multiplikation durchführen, sondern auch musiktheoretische Fragen veranschaulichen, damals wie heute.

Interessant war auch ein Vortrag von Prof. Roman Boutellier über *Sinnlose Modelle*, der die unterschiedlichen Denkansätze von Naturphilosophen wie Kepler, Galilei und Newton auf der einen Seite und das mehr pragmatische Machervorgehen von Leuten wie Bürgi auf der anderen Seite beschrieb.



Auszug aus dem Vortrag von Daniel Muzzulini

Kurzfristig wurde der Vortrag von Prof. Peter Ullrich eingereicht zum Thema *Wo waren die Ursprünge von Bürgis Mathematik? Eine Reise von Leyden bis Samarkand*: Über Bürgis mathematische Ausbildung gibt es einige wenige Hinweise. So hat er zum Beispiel das Buch «Vanden Circkel» von Ludolph van Ceulen aus Leyden studiert. Offen hingegen ist die Frage, wie Bürgi zu der hochgenauen Bestimmung des Sinus-Wertes von 1° kam, die schon anderthalb Jahrhunderte vor ihm Ghiyath ad-Din Dschamschid bin Masʿud bin Muhammad al-Kashi in Samarkand behandelt hatte.

Beim Zukunftsforum war das Schwerpunktthema die Bewältigung von Krisen. In den ersten beiden Referaten wurde behandelt: Was sind Krisen und wie sind sie strukturiert? Wie kann man sie verhindern bzw. zum Guten wenden? Wie funktioniert die Krisenbewältigung in der Politik (Referenten Hans Altherr, Mathias Müller)? Und wie kann die Jugend didaktisch auf die Bewältigung vorbereitet werden (Referenten Fritz Heiniger, Roman Oberholzer)? Anschliessend wurde in zwei Vorträgen behandelt, wie man mit physikalisch-technischen Ansätze zur Krisenbewältigung beitragen kann. So ist die Messung der CO_2 Anteile in der Atmosphäre, von der Erde und von Satelliten aus vorgenommen, die notwendige Vorstufe zu realistischen Aktionen (Vortrag Dominik Brunner, Empa). Im zweiten Vortrag von Dejan Seatovic, FHS OST wurde der kombinierte Einsatz von Drohnen und Robotern in der Landwirtschaft behandelt, um klima- und umweltfreundlicher die Ernteerträge zu sichern.

1 https://www.jostbuergi.com/experten-workshop/

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

When the Physicists' Tournament is moving to Colombia

Evgenii Glushkov, EPFL

Going back to the "offline" world after two COVID years was a challenge for all of us. No exception to this was the International Physicists' Tournament (IPT), which was held online in 2020-21 [1]. The organizing committee, naturally, felt the fatigue of the participants and their push for an in-person tournament in 2022 and did their best to make it happen. The choice of the hosting country was, however, not an easy one. Not many institutions were willing to start organizing an international event facing the uncertainties from ever-changing COVID-related restrictions. At least, in Europe...

A sudden glimpse of hope came from the other side of the Atlantic. Several former IPT participants from Colombia, which first joined the IPT in 2016 [2] and has rapidly developed the tournament across the country, were willing to welcome the participants for the IPT 2022. While the enthusiasm of the Colombian organizers was overwhelming, the executive committee of the IPT had to be cautious. If the IPT was indeed to be held for the first time ever outside Europe, in South America, would it pose a higher participation barrier for teams from other countries? Would they be able to come? Would they be safe there?

However, fortune favours the brave. And the IPT committee was brave enough to give the Colombians the carte blanche to host the IPT 2022 at the Industrial University of Santander (UIS), in the sub-tropical city of Bucaramanga. The unusual choice of the host institution, announced in December, 2021, naturally sparked varied feedback from the IPT community. Some team leaders were worried about getting enough funding to send the teams to Colombia, the others were concerned by the safety aspects or the ecological footprint of such travel. But most of the students were ecstatic to discover a new destination (same as the executive committee members).

You don't have to take my word for it! Here is what a member of the Swiss team, Tobia Fjellman (EPFL), says about the IPT 2022: "*The week we spent in Bucaramanga (Colombia) for the international stage of the competition, although short when compared to the 8 months long preparation, was an incredible experience. The days were intense and the nights short. Getting to discuss about the problems with physicists from around the world that often took different approaches than yours was extremely interesting and enriching. The fact that the atmosphere throughout the week was about positivity and growth made it easier to keep going. The activities lead by the Local Organising Committee in addition made us explore some of the local traditions and specialties.*"

The Swiss team at the Chicamocha canyon in Bucaramanga, Colombia.

And some specialties we did experience! All 150 participants were taken on a bus trip over the 3000-metre-high Colombian mountains to discover the famous Chicamocha canyon (also chosen as a graphical symbol of this IPT edition). They then had a chance to stroll around an ancient Colombian town, have a chat with local young people, watch a theatrical play from Colombian folklore, taste Colombian fast food and much more! And to make this journey absolutely unforgettable all the buses with IPT participants were stuck at night for a couple of hours in a kilometre-long traffic jam on a mountain road, so that the organizers had to scavenge some food and drinks for the whole crowd from nearest gas stations. A unique Colombian experience, I must say! But everyone stayed so relaxed and the atmosphere was filled with such positive vibes that I would without a doubt do it again! Such a warm Colombian attitude, filled with genuine smiles, was an inherent part of the IPT 2022 and made each and every participant feel welcome during the tournament!

Irrespective of all the adventures, all the teams worked hard on polishing and presenting their solutions during the tournament. The Swiss team showed an impressive dynamic from the beginning and first made it into the semi-finals and then pushed themselves to the Grand Final, facing the teams of Brazil and France. And, even though, they couldn't beat these two behemoths of the IPT, they demonstrated to everyone some great physics and fantastic team spirit (their beautiful report on measuring the Boltzman's constant using Johnson's noise thermometry, as well as the reports of two rival teams, can be watched on the official IPT Youtube channel [3]).

Now, the success of the Swiss team at the IPT 2022 (as well as the winning teams from France and Brazil) is not

1 *SPG Mitteilungen* Nr. 65, p. 64

2 *https://iptnet.info/history/*

3 *youtube.com/c/InternationalPhysicistsTournament*

The Swiss team winning the bronze at the IPT 2022. Photo: Evgenii Glushkov

mere luck, but a logical result of a systematic preparatory workflow that has been implemented at EPFL for several years already and, more recently, also introduced at ETHZ. In particular, the students who wish to participate in the IPT are forming a group in the beginning of the winter semester and are provided with all necessary means and guidance to successfully work on the problems. Extremely important here is that the students are actually given ECTS credits for their IPT-related work, so it is in fact becoming a part of their always dense curriculum. The other important aspect is the coaching of the team by the experienced participants from previous years, as well as faculty enthusiasts. Here I can't but mention the names of Jean-Marie Fuerbringer and Jean-Philippe Ansermet from EPFL, who have been coaching the Swiss team during the last few years, and thank them for their passion towards the IPT! Naturally, the successful performance of the Swiss team would have been impossible without the continuous support from the SPS, which is very much appreciated by all the participants!

While you're reading this article about the highlights of the IPT 2022, the next season of the tournament has already started! The new list of exciting physics problems has been published [4], the next host has been announced [5], the teams are being formed and the Swiss selection is not too far on the radar! So, in case you want to join the IPT adventure (be it as a participant or as a juror) – now is the best time to drop a line at *switzerland@iptnet.info*. See you at the IPT 2023 very soon!

4 *https://iptnet.info/problems/*

5 *https://www.youtube.com/watch?v=Y4VRRV_u-LA*

Review of the 2022 Young Physicists Forum: Green Energy Physics

Nicola Ramseyer [1], Frederik van der Brugge [2], Toni Berger [3]
[1] Universität Bern, [2] ETH Zürich, [3] Universität Basel

The YPF 2022 in summary

As in previous years, the committee of the Young Physicists Forum (YPF) organized a three-day forum for physics students from all Swiss universities to attend. After two years of online forums due to the pandemic, the 2022 Forum could finally take place again as an in-person event. From 8 - 10 April, our committee was able to offer six lectures on the topic of "Green Energy Physics" at the ETH in Zürich as host university.

Here, the expression "Green Energy Physics" served as an umbrella term, covering both renewable energy sources such as solar and wind as well as nuclear energy from fission and fusion, all in the context of a carbon-neutral future of mankind's energy production. The Forum was directly linked to the massive shift in energy supply that is currently happening on a global scale and aimed to present to the audience the role that physics might play in this attempt to solve the imminent energy crisis. This rendered the 2022 YPF event extremely contemporary and, undoubtedly, the most political YPF held so far, a circumstance which may be excused by the fascinating physics that can be accommodated in a forum on "Green Energy Physics". We were happy to see that many physics students shared this view, seeing that nearly 40 participants from all throughout Switzerland were willing to spend their weekend in Zürich to attend this Forum, to learn more about the latest innovations in this field and to connect with other like-minded, physics-enthusiastic peers.

The lectures were held by 4 professors, one senior scientist and one PhD student, offering a great mix of perspectives to our audience. All 6 lecturers presented their work very enthusiastically and provided for a highly adequate contextual backbone of our Forum.

Apart from the lectures, the program was completed with a tour of the ETH main building and archives, as well as a tour through the Quantum Device Lab on the ETH Hönggerberg. Having 2 lectures on each day and a tour on Friday and Saturday allowed for a relaxed schedule with additional fun events, like a quiz, and as such offered plenty of room for the students to connect to each other, which is indeed the core objective of the YPF.

Looking back at the YPF 2022, it is fair to say that the students all showed a great interest in the topic and the Forum, with some lectures taking far more than the initially planned hour due to the quantity of questions asked. The atmosphere was amicable, which shaped a group of initially unfamiliar students into a very pleasant circle of new acquaintances. The students readily exchanged ideas across university and language "borders", and all of this left us with no doubt that the 2022 YPF event was a success and worth our efforts.

Vibrant Participation

The students were invited to participate in the Forum via an invitation email sent to all physics student associations of Swiss Universities, which they then shared with their students. Registration for this year's forum required the students to pay between 10 and 50 CHF participation fee, depending on their individual needs (additional public transportation ticket for two days and/or a hotel room for two nights). In total, 39 participants took part, most of which came from the EPFL and the University of Geneva. Nevertheless, we can proudly announce that all Swiss universities that offer physics as a course of study were represented amidst our participants.

Themes adressed

The meeting point of this year's event was on Friday, 8 April, at the fountain in the main building, just a minute away from the room where all lectures were held. The YPF committee welcomed the participants, shortly introduced themselves and explained the idea behind this year's event and its organization. The two lectures on Friday focused on innovative ways to use solar energy.

The starting lecture was given by Prof. David Tilley (University of Zürich), with the title "Semiconductor-Heterojunction Approaches to Solar Water Splitting". He reviewed the general ideas behind photocatalysis and why the production of Hydrogen is a viable way to store energy. He continued to go into quite some depth about his research and how useful semiconductor materials are constructed. Tilley's lecture was content-wise rich in information on a multitude of approaches and some material science and included many chemistry topics, which challenged the audience while opening new perspectives to the participants. This allowed for many questions and discussions following the lecture.

This was followed by a talk by the PhD student Remo Schäppi, who presented a way to use solar energy to create hydrocarbon fuels. He explained why air-travel is very likely to stay fuel dependent in the foreseeable future and that decreasing the carbon footprint requires work on the synthesis of hydrocarbon fuels for the aviation industry out of CO_2 from the air and water content. He also presented their working prototype in-depth, which is located at the ETH, and impressed with his knowledge of the entire machinery, ranging from the filtering process to gather CO_2 and H_2O over the flexible focusing of light onto one of two reactor cores, to the materials used in the reactor to induce a maximum gain of CO and H_2. These elements are then used on site to synthesize the desired fuels via the well-established Fischer-Tropsch process.

The day was concluded by a tour through the ETH main building and the Einstein archives with a view on original handwritten notes of Einstein, both of which were graciously offered by the ETH without charge. Both the architectural history and the story of Albert Einstein's time at the Polytechnikum, as it was called back in the day, allowed the participants to put their time at the ETH into a wider frame.

The two lectures on Saturday focused on the two most prominent ways of gaining nuclear energy. Opening the morning lecture, Prof. Andreas Pautz, head of the Nuclear Energy and Safety Division (NES) at the Paul Scherrer Institut and professor of nuclear engineering at EPFL, held the lecture "New Nuclear Reactor Concepts for Improved Safety and Sustainability: from Generation-III to Generation-IV and beyond". He showcased various concepts that were developed to drastically reduce nuclear waste and the risk for the public. He also listed various reasons as to why nuclear energy still plays a major role in securing emission-free electricity. This invited students to ask more policy-based questions, which allowed for wide-ranging discussions.

Prof. Pautz was then followed by his colleague, Prof. Christian Theiler, introducing us to fusion energy with a lecture titled "Nuclear Fusion - Basic Concepts, Current Status and Next Steps". Prof. Theiler discussed the engineering problem of having to contain plasma at multiple million degrees Celsius, and how to produce the constituents of said plasma in the first place. He framed these issues by showing current tokamak reactor designs, possible improvements and how the next two major fusion research projects, ITER and DEMO, are implementing these, leading towards the goal of unlimited clean energy.

Having no lectures planned in the afternoon gave us the opportunity to host a little quiz with questions about fundamental physics, Fermi problems and the latest political scandals. Although we declared the participation to be voluntary, the majority of people played, which made it all the more enjoyable.

The next official destination was the Quantum Devices Lab on ETH's Hönggerberg campus, where PhD student Graham Norris of the Wallraff Group was as kind as to offer our audience a tour of their laboratory. The Quantum Device Lab is conducting research on a range of quantum

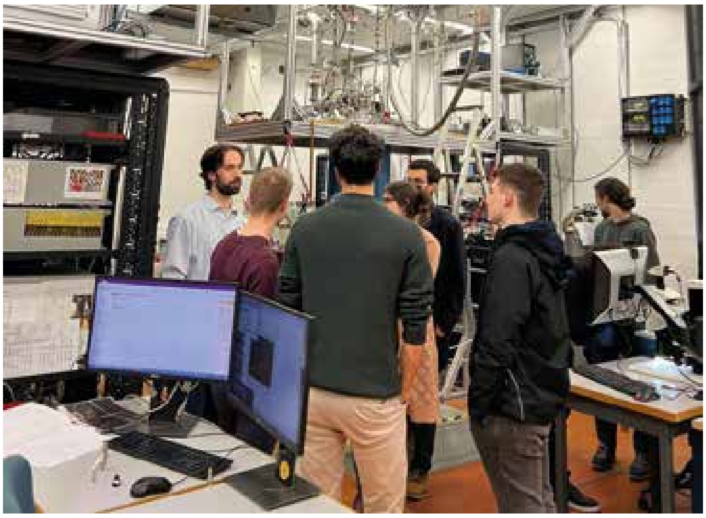


Fig. 1: A group of participants discussing with Graham Norris (left) during the Quantum Device Lab tour.

systems and their potential applications, including work on quantum computing and quantum information processing. Graham's tour offered our participants insight into the venue of world-leading research in this field, represented by a large underground lab filled with cryogenic systems, measurement devices and computers. The students were also given the chance to look at the group's own quantum circuit under a microscope, a particularly magic sight for many of our crowd.

On Sunday morning, the fifth lecture of the weekend was given by Prof. Evelina Trutnevyte, head of the Renewable Energy Systems group at the University of Geneva. Her lecture "Computer models for the energy transition" offered an entirely different view on the general aspect of green energy. Instead of researching a particular source of electricity, her work allows gaining a holistic perspective on the infrastructure of the electric grid and energy sources needed to establish a renewable energy future. Which energy sources are currently used to cover how much of a share? What has to be done to achieve a working energy grid, covering the growing need for power and also the demand for low emissions? This lecture again allowed the students to think about how to implement science on a policy basis and what role the society plays in the energy transition.

After some avid discussions, Dr. Duccio Testa, senior scientist at the Swiss Plasma Center, took centre stage and held the last lecture of the event. His talk picked up where Prof. Theiler stopped and presented techniques to actually heat a plasma to the required temperatures, including Ohmic heating, laser heating and particle beam heating. Each of these techniques comes with its own set of problems and limits, giving rise to the task of finding an optimal distribution of heating mechanisms. He then continued by explaining the importance of the geometry of the magnetic field inside the reactor to allow for optimal containment and, at the same time, a high yield of fusion energy. It was also shown how a collaboration with Deep Mind gave rise to an AI able to adjust the internal magnetic field in real-time to respond to leaking plasma or other issues. Dr. Testa closed his talk with a video, showcasing the jaw-dropping magnitude of the ITER project in France.

Being the last lecture of the event, the subsequent intensive round of questions extended the length of the lecture to well above an hour, making for an adequate finish to the weekend. After three days with a total of six utterly fascinating lectures, it was then time to end the physical journey into the future of energy. During this weekend, the relevance of this topic became increasingly clear, not only from a scientific viewpoint, but also in the context of our everyday life. Each lecturer had a slightly different view of what the future will hold, but they all agreed in essence, namely that a monumental shift on the landscape of energy is already happening, and that an even more monumental shift will be required to solve our energy crisis. What role nuclear, solar and fusion energy will play in this shift will be decided by the public, the market and, last but not least, scientists.

Fig. 2: Lecture hall during the presentation given by Dr. Duccio Testa (besides Whiteboard) on "Technological and Engineering aspects of Fusion and its links to Physics".

Fig. 3: Group photo of most participants and committee members taken in front of the lecture hall at ETH Zürich on the last day of the event, before saying Goodbyes.

Overall, it was a fantastic experience to organize this event. The mix of the participating students allowed for a very social atmosphere, interesting conversations and a fun time. Additionally, we greatly appreciated the received feedback on what can be improved in the following years, especially since it was the first in-person event for all members of the YPF committee. While we could always count on the experience of retired committee members, it was still an entirely new challenge to put together such an event. Nevertheless, we are proud of what we could offer to our audience and are confident that the YPF 2022 was a worthy comeback to the in-person format after the online forums during the pandemic.

Credits & outlook

More information about the 2022 "Green Energy Physics" Forum (including abstracts as well as lecturers' biographies) can be found on our website: https://www.young-physicists.ch/forum-2022 . We also thank all our lecturers for their time to prepare such excellent lectures and to travel to Zürich to hold their talks. Their dedication to their field of work truly left a strong impression on all participants.

The next Forum is planned to be held in April 2023. At this point, we would also like to express our thanks to Toni Berger, the President of this year's committee, who will leave the YPF in September. His guiding hand played a crucial role in the success of the 2022 forum. In this matter, we were also as lucky as to find three new members, namely from the Universities of Basel and Zürich as well as the EPFL, which will complement next year's YPF committee.

Innovationskraftanalyse der Schweizer Industrie

Bernhard Braunecker

Die SPG veröffentlichte kürzlich die zweite Ausgabe ihrer ***SPS Focus*** Reihe unter dem Titel **Impact of Physics on Swiss Society**. Darin wird aufgezeigt, dass bei kleineren und mittleren Unternehmen (KMU) in Zukunft neben den traditionellen Ingenieurkompetenzen vermehrt auch profunde Kenntnisse in Physik erforderlich sein werden. Nur so lässt sich das Chancenpotential neuartiger Technologieansätze vollumfänglich nutzen, wenn sie zum Beispiel auf reinen Quantenphänomenen wie Single Photon Physics beruhen. Das wird ein Umdenken in der KMU-Industrie, aber auch in den mit ihnen eng verbundenen Fachhochschulen erfordern, bei denen Physik im Vergleich zu den Ingenieurwissenschaften traditionell eine untergeordnete Rolle spielt. Das Umdenken wird jedoch ein aufwändiger und auch psychologisch schwieriger Prozess werden, da die Innovationsstärke der KMUs von der Öffentlichkeit und somit auch von den KMUs selber als sehr hoch einschätzt wird, so dass kein unmittelbarer Handlungsbedarf gesehen wird. Das ist dann anders, wenn die ausländische Konkurrenz urplötzlich vorlegt und die KMUs unvorbereitet trifft. Die dann übliche Reaktion, Kompetenz einzukaufen, verfängt bei modernen Technologien nicht, da man sie auch *verinnerlichen* muss. Da trifft es sich nun gut, dass die SATW die Innovationsstärke bei den KMUs ebenfalls kritisch beurteilt und ein Umdenken einfordert.

Die SATW Studie *Innovationskraftanalyse der Schweizer Industrie: eine Aktualisierung* [1] soll auf alarmierende Fehlentwicklungen im produzierenden Gewerbe der Schweiz verweisen, so dass zuständige Entscheidungsträger aus Industrie und Politik geeignete Gegenmassnahmen einleiten können. Eine frühere SATW-Analyse aus dem Jahr 2018 belegte bereits damals, dass die Stellung der Schweiz im internationalen Wettbewerbsvergleich nicht so aussergewöhnlich gut ist, wie es immer angenommen wird. Vor allem die mangelnde Innovationskraft bei den KMUs machte schon damals Sorge, da fast 60 % der Beschäftigten in der Schweiz in KMUs, also in Firmen mit weniger als 250 Mitarbeitern tätig sind (Stand Jahr 2018), und sie so fast ein Drittel mehr zur Wirtschaftskraft der Schweiz beitragen als die Grossunternehmen.

Die statistischen Daten, die der neuen SATW Studie zugrunde liegen, basieren auf Erhebungen und Umfragen der KOF [2] und auf Daten des Bundesamts für Statistik für die Jahre 2011 - 2018. Untersucht wurden Technologiebereiche gemäss der in der Schweiz gängigen NOGA Klassifizierung [3], wobei bei den KMUs, wenn man als Mass ihrer wirtschaftlichen Bedeutung die Anzahl der Mitarbeiter heranzieht, die Bereiche Metallherstellung und -erzeugnisse, Nahrungsmittel, (Druck, Holz, Papier) sowie Fahrzeuge und Maschinen dominieren, während die Sparten Chemie, Pharmazie, aber auch Elektronik und Instrumente eine eher untergeordnete Rolle spielen, da sie mehr das Wirkungsfeld von Grossfirmen sind.

Für Industriephysiker, die traditionell mehr bei Grossfirmen tätig sind, wären die Ergebnisse der Studie weniger von Belang, wenn nicht wie oben erwähnt in Zukunft auch bei KMUs mehr Physiker tätig sein müssen, um international mithalten zu können. Die in der SATW-Studie vermerkten wesentlichen negativen Auffälligkeiten sind

- die Abnahme der Beschäftigten in F&E und gleichzeitig ihre vermehrte Beschäftigung in immer weniger Unternehmen,
- der geringe Innovationsgehalt vieler heutiger KMU-Produkte, da mehr auf kleine Verbesserungsschritte mittels traditioneller Technologien gesetzt wird als auf den Einsatz disruptiv-neuer Technologien, und man so die attraktive Chance eines Marktöffners vergibt.

Das statistisch belegte und nahezu alle NOGA-Sparten betreffende Verhalten ist nun in der Tat besorgniserregend, aber dennoch sollte im Einzelfall überprüft werden, ob die genannten Bewertungskriterien ausreichen, um auf einen Rückgang der Innovationsstärke zu schliessen. Gerade florierende KMUs sehen die Notwendigkeit, ausserhalb der Schweiz Dependancen zu gründen oder strategische Allianzen einzugehen. Dann übernehmen diese neuen Kollegen oder Partner manche der F&E Aufgaben, wenn sie besseren Zugriff auf Ressourcen haben oder auch besser vernetzt sind. So profitiert man bei anspruchsvollen F & E Fragestellungen oft von den US-Kollegen, da sie über ihre Kontakte zu grossen Universitäten auch Zugriff zu den Forschungszentren des Militärs haben, während asiatische Kollegen mehr Kompetenzen aufweisen, eine moderne Massenproduktion zu optimieren. Dann ist der scheinbare Rückgang an F&E Aktivitäten in der Schweiz eher ein starkes Signal, international die Weichen zu stellen.

Und auch der nur inkrementell gesteigerte Innovationsgehalt Schweizer Produkte ist nicht immer ein Zeichen mangelnden Erfindungsgeistes, sondern hat oft handfeste, nichttechnische Gründe. Um wirtschaftlich erfolgreich zu sein, müssen Marktakzeptanz und Vertriebsfähigkeit gegeben sein. Wenn nun komplexe Technologien quasi über Nacht eingeführt werden, müssen in aufwändiger Weise der Vertrieb umgeschult und die von ihm betreuten Kunden sensibilisiert werden. Dann nimmt man lieber, solange es geht, inkrementelle Produktverbesserungen vor, um das Risiko im Griff zu haben.

Dennoch ist die SATW Studie von grosser Bedeutung, um rechtzeitig Indizien einer Fehlentwicklung zu erkennen, sie zu benennen und entsprechend zu agieren. Mit der zunehmenden Komplexität neuer und der Grundlagenphysik entstammender Technologien sind regelmässig durchgeführte Analysen dieser Art von hoher volkswirtschaftlicher Relevanz.

1 https://www.satw.ch/de/frueherkennung/innovationskraftanalyse-der-schweizer-industrie-eine-aktualisierung

2 Konjunkturforschungsstelle der ETH Zürich

3 NOGA: **No**menclature **G**énérale des **A**ctivités économiques

SPS swiss physical society

Société Française de Physique

Call for nominations for the Charpak-Ritz Prize 2024

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 2024** 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. 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 2024".

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 2023

The award will be given at the annual meeting of the *French Physical Society* in 2024.

Ausschreibung der SPG Preise für 2023

Auch im Jahr 2023 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 von der Firma *Oerlikon* für eine hervorragende Forschungsarbeit auf dem **Gebiet der Angewandten Physik**
- SPG Preis gestiftet vom *Eidgenössischen Institut für Metrologie METAS* für eine hervorragende Forschungsarbeit **mit Bezug zur Metrologie**
- SPG Preis gestiftet von der Firma *COMSOL Multiphysics GmbH* für eine hervorragende Forschungsarbeit auf dem **Gebiet der computergestützten Physik**
- SPG Preis gestiftet von der Firma *Hitachi Energy Switzerland AG* für eine hervorragende Forschungsarbeit **mit Bezug zur Energietechnik**

Die SPG möchte mit diesen Preisen **junge** Physikerinnen und Physiker in der Frühphase ihrer Karriere, auf alle Fälle vor Erreichen einer akademischen Festanstellung oder bevor sie mehr als drei Jahre in einer Start-up Firma oder in der Industrie tätig sind, für hervorragende wissenschaftliche Arbeiten auszeichnen.
Die eingereichten Arbeiten müssen entweder in der Schweiz oder von Schweizerinnen und Schweizern im Ausland ausgeführt worden sein. Die Beurteilung der Arbeiten erfolgt auf Grund ihrer Bedeutung, Qualität und Originalität.

Der Antrag muss folgende Unterlagen enthalten:

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

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

awards@sps.ch

Einsendeschluss: 01. März 2023

Die Preise werden an der gemeinsamen Jahrestagung 2023 in Basel überreicht. Das Preisreglement befindet sich auf *www.sps.ch*.

Annonce des prix de la SSP pour 2023

En 2023, 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'entreprise *Oerlikon* pour un travail de recherche d'une qualité exceptionnelle dans le **domaine de la physique appliquée**
- Le prix SSP offert par *l'institut national de métrologie de la Suisse METAS* pour un travail de recherche d'une qualité exceptionnelle **faisant référence au domaine de la métrologie**
- Le prix SSP offert par l'entreprise *COMSOL Multiphysics GmbH* pour un travail de recherche d'une qualité exceptionnelle dans le **domaine de la physique numérique**
- Le prix SSP offert par l'entreprise *Hitachi Energy Switzerland AG* pour un travail de recherche d'une qualité exceptionnelle **faisant référence au domaine des technologies énergétiques**

La SSP distingue avec ces prix des travaux scientifiques exceptionnels de **jeunes** physiciens dans la première étape de leur carrière et qui n'ont pas encore atteint une position permanente universitaire ou qui ne travaillent pas depuis plus de trois ans dans l'industrie.
Les travaux soumis doivent avoir été effectuées en Suisse ou par des citoyens Suisses à l'étranger. L'évaluation s'effectue selon des critères d'importance, de qualité et d'originalité du travail soumis à la compétition.

Une nomination complète contient:

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

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

awards@sps.ch

Délai: 1 mars 2023

Les prix seront attribués à la réunion annuelle commune qui se tiendra en 2023 à Bâle. Le règlement des prix se trouve sur les pages web de la SSP: www.sps.ch