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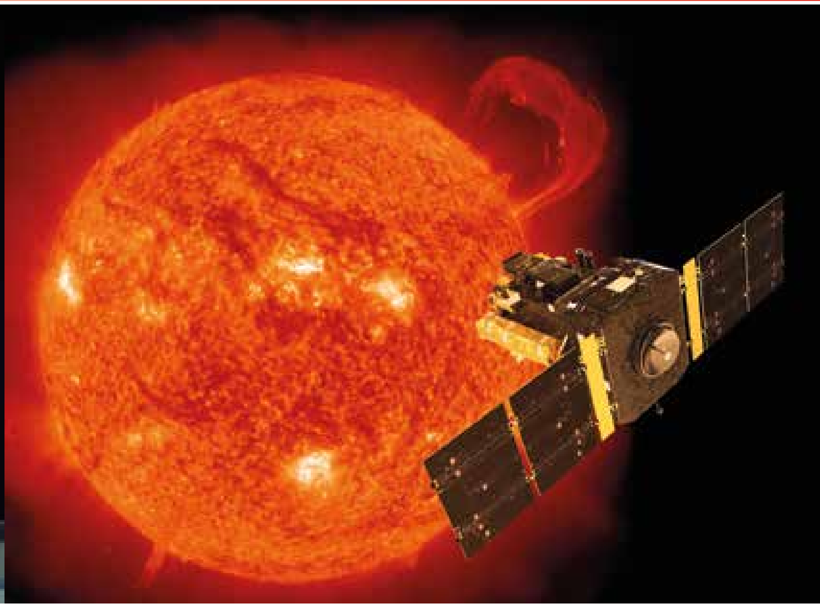
A silicium sphere helps to pave the way for the upcoming redefinition of the International System of Units (SI). Read the article on p. 26.
(Picture: © Physikalisch-Technische Bundesanstalt Braunschweig)



The SOHO mission, launched in 1995, delivers till today important information about our sun. More on p. 34.
(Picture: © ESA/NASA SOHO)

This year's award winners and a new honorary member (from left to right): Petar Jurcevic, Andrea Hofmann (SPS Awards), Maurice Bourquin (Honorary Member), Claire Donnelly, Wolfgang Tress, Lavinia Heisenberg (SPS Awards), Roland Horisberger (Charpak-Ritz Award). Missing on the picture: Giulia Grancini (SPS Award). Details on p. 4.

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Editorial

Global Warming and the Role of Science

Hans Peter Beck, SPS President

After a long, and apparently almost never-ending summer, with heat waves and droughts dominating all over the northern hemisphere of the planet, the debate is again high whether climate change is real, whether it is man-made, whether CO_2 is to be blamed, and whether or not there is anything that could be done to help the situation. Obviously, a heated debate where emotions, ideology, short term interests and belief systems seem to prevail over scientific reasoning, analysis and understanding. This is the impression one obtains at least when reading through news-paper articles and messages on social media.

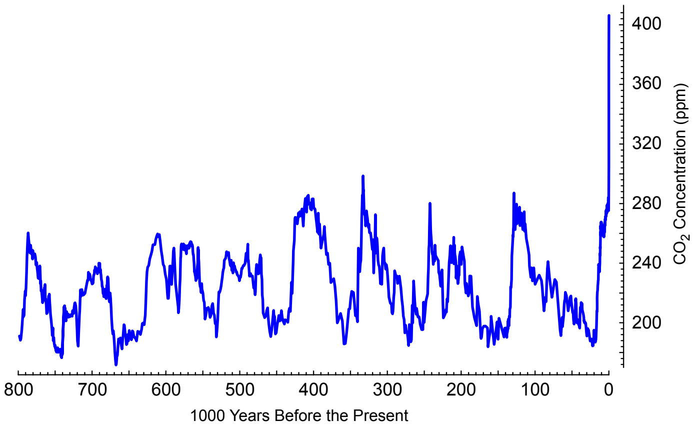
Clearly, we are in a situation where we as physicists are getting into an inner debate on how to react in public and on the political scene. We are holding strong for science being kept free and for not interfering in political discussions, as otherwise we risk science being understood as biased and therefore losing its objectivity and credibility. This is one side of a social contract we meet, and where we hold strong to it. On the other side, politicians have the duty to support science, free from their own political ideology. Furthermore, politicians have also the duty to base themselves on scientifically established knowledge to decide and implement appropriate measures. A political discourse plays an important role here. In this discourse, discrediting science and denying its findings has fatal consequences that may not (yet) be borne by the current generation, but will be by the next generation with full force. In the current debate on the role of greenhouse gases for the global average temperature in the biosphere of Earth, are apparently still unsettled.

The understanding of it, however, dates back to the early 19th century, when Joseph Fourier first hypothesized the existence of the greenhouse effect and its impact on the world's global average temperature. Svante Arrhenius came up with the first quantitative calculations on the effect that CO_2 implies for the global warming, and Edward Teller warned already in 1959, on the 100th birthday of the US oil industry, that "*At present [1959] the carbon dioxide in the atmosphere has risen by 2 per cent over normal. By 1970, it will be perhaps 4 per cent, by 1980, 8 per cent, by 1990, 16 per cent, if we keep on with our exponential rise in the use of purely conventional fuels. By that time [2000], there will be a serious additional impediment for the radiation leaving the earth. Our planet will get a little warmer. It is hard to say whether it will be 2 degrees Fahrenheit or only one or 5. But when the temperature does rise by a few degrees over the whole globe, there is a possibility that the icecaps will start melting and the level of the oceans will begin to rise.*" [1]

The scientific facts are known since long. The details on the full CO_2 cycle and that of other greenhouse gas active molecules in the atmosphere, and how this implies not only the global average temperature, but how it affects climate, weather, and the conditions for life, however, are far more complicated and inflicted. Therefore, scientific research and studies are ongoing. The message for society to take here is that the factual base is solid and decisions are needed to be taken now, waiting longer offers no solution, as the crisis will only hit stronger.

In this edition of the *SPG Mitteilungen*, the article by Stéphane Goyette introduces to the physics base of the greenhouse effect (see page 50), the article by Christoph Schär details the state of the art of high-resolution climate modelling considering the greenhouse effect (see page 18). Whether or not sustainable energy resources (solar, wind, water) will be able to feed the world's needs for electricity is a question that poses itself in direct conclusion when we want to curb releasing CO_2 stemming from fossil fuel and coal into the atmosphere. The articles from Maurice Bourquin on the potential Thorium offers replacing Uranium as nuclear fuel (see *SPG Mitteilungen* Nr. 54, p. 25 and Nr. 55, p. 34) and his public lecture at the recent SPS Annual Meeting in Lausanne 28.8.2018), and from Tim Luce on the potential that fusion power may enable one day (plenary talk at the SPS Annual Meeting, Lausanne 31.8.2018), are showing up possible roads to take. These articles take the spirit at heart of engaging in science without political constraints, but also expecting the political debate to be based on established science facts.

[1] https://www.theguardian.com/environment/climate-consensus-97-per-cent/2018/jan/01/on-its-hundredth-birthday-in-1959-edward-teller-warned-the-oil-industry-about-global-warming



Atmospheric CO_2 concentrations of the last 800,000 years reconstructed from measurements of air enclosed in ice cores from Antarctica. This time interval covers the last ice age cycles with high CO_2 concentrations during the interglacials and lowest concentrations during the peak ice ages. Added to the far right of the ice core recrod are the CO_2 concentrations directly measured in the atmosphere since 1958. This figure demonstrates that the current CO_2 concentrations, caused by the burning of fossil fuels and deforestation, are unprecedented in at least the last 800,000 years. Data are from the University of Bern, University of Grenoble and NOAA (Lüthi et al., 2008, Nature 453, 379).

The winners of the SPS Awards 2018

The SPS Award committee chaired by Professor Minh Quang Tran selected the winners for 2018 out of many submissions. The winners presented their work at the Annual Meeting in Lausanne. Below are the laudations (SPS Awards: M. Q. Tran, Charpak-Ritz Award: SFP) and the summaries written by the winners.

SPS Award in General Physics, sponsored by ABB

The SPS Prize in General Physics is awarded to **Lavinia Heisenberg** for "her pioneering and essential contributions to the exploration of alternative theories of gravity. With her work in particular on a generalized Proca-like Lagrange density for vector fields and their cosmological relevance, she has opened a new direction for fundamental research on gravitational physics."

Facets of Gravity

Numerous observations support the remarkably simple cosmological standard model, which is based on General Relativity (GR) together with two symmetry assumptions. Albeit conceptually simple, this model requires the majority of matter in the universe to be of an unknown form, and the vast majority of the energy content of the universe to be contributed by an equally unknown dark energy.

These awkward conclusions may be bypassed by replacing GR by another, further generalised theory of gravity. Under the assumptions of Lorentz symmetry, unitarity, locality and a pseudo-Riemannian manifold, any attempt at generalising the theory of gravity inevitably leads to new dynamical degrees of freedom, which can be scalar, vector, or tensor fields. The gauge fields in the Standard Model of Particle Physics motivate investigating the role that bosonic vector fields may play for the evolution of the universe. An abelian vector field with U(1) gauge symmetry does not admit a homogeneous and isotropic background. If one explicitly breaks its U(1) symmetry, the resulting generalised Proca theories are the most general vector-tensor theories with second-order equations of motion for the vector and the tensor fields alike [1].

In a further step, tensor theories can be combined with both additional scalar and vector fields into a single scalar-vector-tensor theory. This unification and the interactions it implies depend sensitively on whether the vector field has a gauge symmetry or not. The resulting theories, with or without gauge invariance, will have rich applications in cosmology and astrophysics.

We have grown accustomed to attributing gravity to the curvature of space-time. This perception has masked the fact that differential geometry provides much wider classes of objects to represent the geometrical properties of manifolds. Besides the curvature, these are torsion and non-metricity. In Einstein's theory, both non-metricity and torsion vanish. An equivalent representation of GR can however be constructed based on a flat space-time with a metric, but asymmetric connection: This teleparallel description assigns gravity entirely to torsion. Perhaps surprisingly, a third equivalent and simpler representation can be constructed on an equally flat space-time without torsion, in which gravity is purely ascribed to non-metricity. By a suitable gauge choice, the connection then vanishes completely. This representation of GR has the advantage of depriving gravity from any inertial character, and the resulting action is purged from the boundary term [2].

[1] L. Heisenberg. Generalization of the Proca Action. JCAP, 5:015, May 2014.
[2] L. Heisenberg. Cosmology with new gravitational degrees of freedom. Physics Reports, in press, 2018.

SPS Award in Condensed Matter Physics, sponsored by IBM

Petar Jurcevic is awarded the SPS Prize in Condensed Matter Physics for his contributions to a broad spectrum of topics in quantum information processing with trapped ions, including quantum correlation, quantum computation and quantum simulation.

Quantum Computation and Many-Body Physics with Trapped Ions

Over the past three decades, quantum information processing has seen incredible progress in theory and experiments. Today, we move closer to the realization of Feynman's vision of designing a fully controllable quantum device capable of simulating classically intractable problems. In this PhD work, linearly trapped ions have been used to encode spin information into two electronic states. Laser light fields have been applied to coherently manipulate these spin states, to engineer tunable spin-spin interactions and to measure the spin information.

Besides having addressed various topics of quantum information processing in our work, two experiments with regards to quantum simulations of interacting many-body systems are highlighted in particular.

The first experiment addresses a fundamental question in interacting systems [1]: how fast can information propagate in such systems? We show that a local perturbation generates entanglement, which then propagates through the entire system. Additionally, we investigate the velocity of correlation spreading for different interaction lengths, showing that the picture of a light-cone-like propagation becomes invalid for long-range interactions.

In the second experiment, we report on the first observation of a dynamical quantum phase transition, i.e., non-analytical points (kinks) in the time evolution of quenched systems [2]. We show that these phase transitions are indeed robust against deformations of the underlying Hamiltonian, i.e., changes in the interaction parameters, and uncover a previously unknown relation between these special points in time and entanglement growth.

[1] *Quasiparticle engineering and entanglement propagation in a quantum many-body system*, P. Jurcevic, B. P. Lanyon, P. Hauke, C. Hempel, P. Zoller, R. Blatt & C. F. Roos Nature 511, 202–205, (2014)
[2] *Direct Observation of Dynamical Quantum Phase Transitions in an Interacting Many-Body System*, P. Jurcevic, H. Shen, P. Hauke, C. Maier, T. Brydges, C. Hempel, B. P. Lanyon, M. Heyl, R. Blatt, & C. F. Roos, PRL 119, 080501 (2017)

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

*The SPS Award in Applied Physics is shared between **Wolfgang Tress** and **Giulia Grancini**.*

Wolfgang Tress is awarded for his contribution to the fundamental understanding and physics of different types of emerging photovoltaic technologies based on novel organic and hybrid semiconductors, in particular of perovskite.

Understanding Perovskite Solar Cells

Inorganic-organic lead-halide perovskite solar cells have reached efficiencies above 22% within a few years of research. Achieved photovoltages of >1.2 V are outstanding for a material with a bandgap of 1.6 eV – in particular considering that it is solution processed. On the other hand, perovskite solar cells suffer from instabilities on different timescales. These instabilities due to slow processes are the origins of a scan-rate dependent hysteresis in the current-voltage curve, of light-soaking effects, and of reversible degradation on the long term.

This work on the devices physics of perovskite solar cells sheds some light on these peculiar phenomena. Using electroluminescence and further spectroscopic measurements, high luminescence yields and sharp absorption onset are identified as reasons for the high photovoltage [1]. Loss mechanisms such as recombination of charge carriers at interfaces are investigated using the temperature and light-intensity dependence of the diode ideality factor. Furthermore, defects formed by metals from the electrodes migrating into the perovskite are identified to form tail states responsible for permanent degradation.

The reversible effects are attributed to the interplay between electronic and ionic conduction in the perovskite crystal. Using various transient characterization techniques and device modeling, it is found that displaced ions change the electric field in the device and modify recombination rates [2]. Ions accumulated at interfaces to the contacts also modify charge carrier injection properties, which helps to explain the high photomultiplication effects observed in perovskite photodetectors.

These findings contribute to a better understanding of the operation principles of perovskite solar cells and pave the way towards a targeted optimization of optoelectronic perovskite devices.

[1] Bi, D. *et al.* Efficient luminescent solar cells based on tailored mixed-cation perovskites. *Sci. Adv.* **2**, e1501170 (2016).
[2] Tress, W. *et al.* Understanding the rate-dependent J–V hysteresis, slow time component, and aging in $CH_3NH_3PbI_3$ perovskite solar cells: the role of a compensated electric field. *Energy Environ. Sci.* **8**, 995–1004 (2015).

Giulia Grancini is awarded for her groundbreaking advancement in the field of physics behind new emerging photovoltaic materials and devices. In particular she advanced the fundamental knowledge of the photophysical behavior of novel perovskite solar cells, a "game changer" technology in the photovoltaic research field.

2D/3D Hybrid Perovskites for Stable and Efficient Solar Cells

Three-dimensional (3D) methylammonium lead iodide perovskite solar cells are undoubtedly leading the photovoltaic scene with their power conversion efficiency (PCE) >22%, holding the promise to be the near future solution to harness solar energy [1]. Tuning the material composition, i.e. by cations and anions substitution, and functionalization of the device interfaces have been the successful routes for a real breakthrough in the device performances [2]. However, poor stability (= device lifetime), mainly due to material decomposition upon contact with water, is now the bottleneck for the widespread of this technology. Diverse technological approaches have been proposed delivering appreciable improvements, but still failing by far the market requirements demanding 25-years lifetime. In this talk, I will show a new concept by using a different class of perovskites, arranging into a two-dimensional (2D) structure, i.e. resembling natural quantum wells. 2D perovskites have demonstrated high stability, far above their 3D counterparts. However, their narrow band gap limits their light-harvesting ability, compromising their photovoltaic action. Combining 2D and 3D into a new hybrid by interface engineering 2D/3D heterostructures will be discussed as a mean to boost device efficiency and stability together. The 2D/3D composite self-assembles into an exceptional gradually organized structure where the 2D perovskite anchors on the TiO_2 substrate, templating the growth of a highly ordered 3D perovskite on top. This results in mesoporous solar cells leading to 12.9% PCE [3]. Aiming at the up-scaling of this technology, we realize 10x10 cm^2 large-area solar modules using a fully printable, hole conductor free device configuration (i.e. where a carbon electrode is used to replace the organic hole transporter and Gold). The module delivers 11.2% efficiency stable for more than 10,000 hours with no degradation under accelerated testing conditions, leading to a record one-year stability. On the other side a 3D/2D interface will be also presented, where 2D layer lies on top of the 3D as a mean to protect the 3D underneath while also blocking the electron hole recombination at the perovskite/hole transporter interface. This results in enhanced stability without compromising the efficiency, leading to PCE = 20% stable for 1000 h [4].

[1] http://www.nrel.gov/ncpv/images/efficiency_chart.jpg
[2] Correa-Baena, J.-P. et al. Promises and challenges of perovskite solar cells. *Science* **358**, 739–744 (2017).
[3] Grancini, G. et al. One-Year stable perovskite solar cells by 2D/3D interface engineering. *Nat. Commun.* **8**, ncomms15684 (2017).
[4] Taek Cho, K. et al. Selective growth of layered perovskites for stable and efficient photovoltaics. *Energy Environ. Sci.* (2018). doi:10.1039/C7EE03513F

SPS Award related to Metrology, sponsored by METAS

Andrea Hofmann is awarded the SPS Prize related to metrology for her outstanding PhD work, which has a strong impact in many fields of solid states and metrology (specifically the dynamics of a single electron in a quantum dot coupled to a heat reservoir).

Thermodynamics at the level of a single electron

Traditional thermodynamics, which is a phenomenological theory, is built upon the so-called thermodynamic limit where the number of particles comprising a system reaches the limit of infinitely many. However, in the trend towards minimizing the system sizes, such as reducing the size of computer chips, or studying single particles as candidates for quantum bits, the thermodynamic limit is not reached. For small systems sizes, fluctuations are observed, as individual particles may have values of observables which are very different from the expectation value of the whole ensemble. Fluctuation theorems, as described below, have enhanced the understanding of these deviations. In particular, the Jarzinsky equality [1] has lead to the insight, that fluctuations of work done on a system driven out of equilibrium from an equilibrated state are explicitly related to an equilibrium parameter, namely, the free energy difference between the initial and the final state of the driven system. This equality has been tested experimentally and enables the evaluation of the free energy in systems where calculations thereof are difficult. Here, we consider the definition and measurement of heat and work in a system consisting of a QD coupled to a reservoir, where a single electron in the QD is driven up and down in energy. We analyse the fluctuations by measuring and calculating the distribution of produced heat and work obtained in single repetitions of driving the electron with the same drive protocol. We show, how the violation of the second law of thermodynamics in single repetitions of the experiment can be interpreted as a blurring in the arrow of time, and finally, we use use the distribution of work provide a test of the Jarzinsky equality.

[1] Jarzynski, C. (1997), "Nonequilibrium equality for free energy differences", *Phys. Rev. Lett.*, **78**, 2690

SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS Prize in Computational Physics is awarded to **Claire Donnelly** for her outstanding PhD Thesis “Hard X Ray Tomography of 3 D Magnetic structure” which combines breakthroughs in both experimental work and the development of computer algorithm to interpret the experimental results.

Hard X-ray tomography of three-dimensional magnetic structures

The increase in the dimensionality of a system, from two to three dimensions, can result in enhanced, or indeed completely different, properties. For magnetic materials, this increase in dimensionality can lead to novel magnetic configurations as well as new properties that can be designed and tailored, which is important for a variety of applications including high density data storage, sensor technology, motors and energy harvesting. In this work, two key challenges facing the experimental realisation of these systems were addressed: (i) the fabrication of tailored three dimensional structures, and (ii) the development of a suitable technique to observe the magnetic configuration in three dimensions.

For the fabrication, the manufacture of three-dimensional nanoscale magnetic shell structures was developed. In particular, an artificial buckyball structure with a diameter of 7 μm was fabricated, and a full structural and elemental characterisation performed using resonant X-ray tomography at the cSAXS beamline, Swiss Light Source. Following this thorough analysis, alternative fabrication techniques could then be developed to improve the quality of the magnetic shell structure, and preliminary magnetic investigations were performed, leading to a first indication of the influence of the three dimensional structure on the magnetic properties.

For the determination of the three dimensional magnetic state, hard X-ray magnetic tomography was developed in collaboration with the beamline staff at the Swiss Light Source. This is a new technique in which the three dimensional magnetic nanostructure in micrometre-sized samples can be determined without the need for assumptions about the magnetic properties of the system. In a first step, hard X-ray magnetic imaging at the nanoscale was developed, which was then extended to 3D tomographic imaging by placing the sample on a rotation stage to measure X-ray projections at many different sample orientations. To obtain the three-dimensional magnetisation vector field, a computer algorithm was developed, and its applicability tested with numerical simulations. In the first experimental demonstration of this technique, the internal three dimensional magnetic structure of a soft magnetic pillar was determined, and within the structure, magnetisation singularities called Bloch points, which were predicted 50 years ago, were observed for the first time. This ground-breaking demonstration of X-ray magnetic tomography opens the door to imaging the internal magnetic structure of a wide variety of magnetic systems.

This work represents an important step forward for the realisation of three-dimensional magnetic systems, and magnetic investigations, in particular for both the determination of structure-functionality relations in magnets and for elucidating the behaviour of fundamental magnetic structures in nanoscale systems.

Lauréat du prix Charpak-Ritz 2018

La *Société Suisse de Physique* et la *Société Française de Physique* félicitent **Roland Paul Horisberger**, spécialiste dans le domaine de la physique et du développement des détecteurs utilisés en physique des particules et dans la science des rayons X. En particulier, il a contribué notablement au développement des nouveaux détecteurs de vertex en silicium à micropistes pour les expériences DELPHI au LEP et H1 à HERA/DESY, ainsi qu'aux détecteurs au silicium à pixels du grand détecteur CMS du LHC.
La cérémonie de remise du prix a eu lieu à Grenoble le 27 août 2018.

Catherine Langlais, présidente de la SFP, avec le président de la SSP Hans Peter Beck, remettant le prix Charpak-Ritz à Roland Horisberger (à droite).

Silicon for Beauty and Structure

Roland Horisberger
Paul Scherrer Institute, CH-5232 Villigen

The early development of highly segmented and very precise silicon particle detectors happened historically in the field of high energy physics in the early 1980's. At the time this was very much driven by the needs in particle physics experiments to detect and identity pico-second long lived particles, containing beauty and charm quarks. The presentation gives a brief historical overview of this development and the driving requirements that defined its developments. Over the years the new detector technology has gone through an enormous growth and improvement in capability and complexity. This was on one hand through the growing demands on the performance of the particle tracking systems at the newest accelerators like the LHC proton-proton collider at CERN and at the same time due to the technological progress in microelectronics, symbolized by Moore's Law. The potential of using this new and precise detector technology in other domains of physics was realized early on. By now, the use of highly segmented silicon strip and pixel detectors has made a phenomenal impact in the field of photon science at synchrotron facilities and free electron X-ray laser machines. They allow now to resolve in an almost unprecedented way the structural and functional information on complex solid state systems and biological molecules. The talk recalls how in the case of the PILATUS, MYTHEN and EIGER pixel system the silicon detector revolution in photon science has happened. Furthermore it will attempt to give an outlook on how the next generation detectors might evolve, given the requirements from future photon science experiments.

Best Poster Award 2018

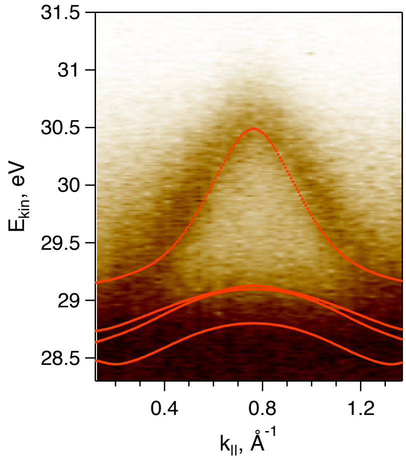
Antoine Pochelon

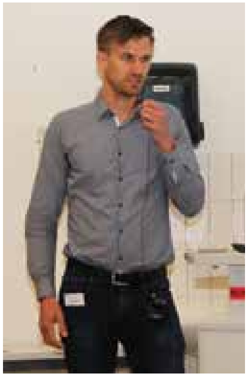
This year the SPS pursued jointly with the EPS the tradition of offering poster prizes for the three best posters presented at the annual meeting at EPFL, a stimulating way of promoting quality in poster presentation and content. Congratulation to the three winners, Serhii Polishchuk, Michael Schenk and Jaianth Vijayakumar! As usual at the Poster Award Session, the winners had to present their work in 2 minutes, 2 slides, just to transmit with efficiency the flavour of their work. I would like to thank here the members of the selection committee for their dedicated work: Rolf Allenspach, Lukas Gallmann, Klaus Kirch, Antoine Pochelon (chair of the Jury), Laurie Porte, Susmita Saha and Andreas Schopper.

Valence band mapping of $CsPbBr_3$ perovskite single crystals by angle-resolved photoemission spectroscopy

Serhii Polishchuk et al., Laboratory of Ultrafast Spectroscopy, EPFL

$CsPbBr_3$ is a perovskite semiconductor with outstanding optoelectronic properties. Nonetheless, the material's band structure was not yet experimentally measured. By applying angle-resolved photoemission spectroscopy utilizing an extreme-UV light, a direct view of the electronic structure in the whole surface Brillouin zone has been achieved. The mapped valence band is in agreement with ab-initio DFT (density functional theory) calculations (see the figure). The measured band dispersion is related to the hole effective mass, a key optoelectronic property, and compared with the theory and previous experiments. The larger measured quasi-particle mass, as compared to the calculations, hints at many-body effects, compatible with a polaron model.

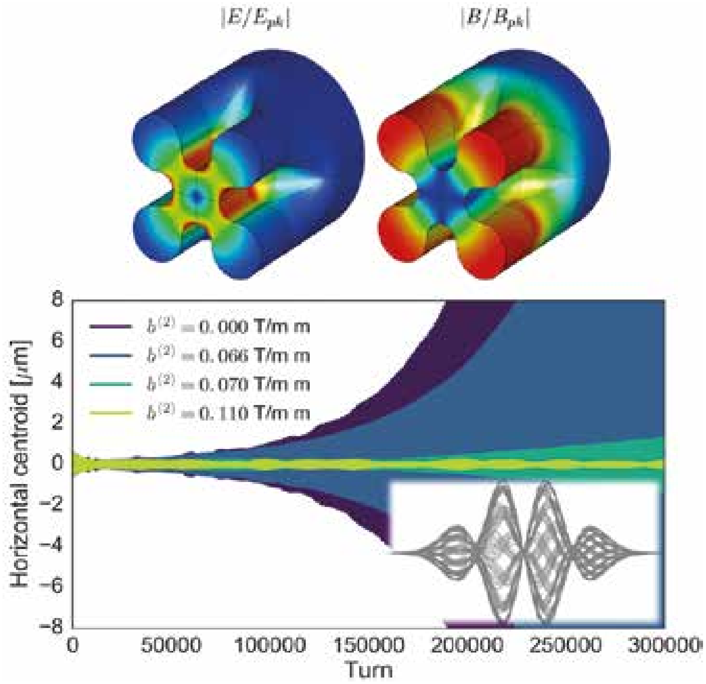




A novel approach to Landau damping of transverse collective instabilities in hadron colliders

Michael Schenk et al., CERN and EPFL

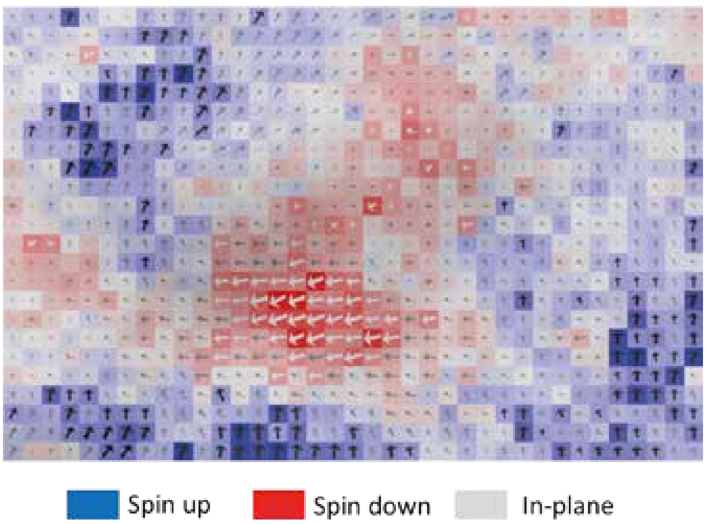
Charged particle beams in accelerators, such as the Large Hadron Collider (LHC) at CERN, can be driven unstable through electromagnetic interactions with their surrounding structures (figure, bottom). This leads to particle losses and lower event rates in the detectors. Currently available mitigation tools against these phenomena will be less effective in future, high energy, and high brightness colliders like the High Luminosity LHC. In our group, we are studying a novel approach to suppress such instabilities employing a radio frequency quadrupole cavity (figure, top). Promising results on the performance of this new method were obtained by carrying out simulations with tracking codes developed in-house, LHC experiments, as well as theoretical studies. For more information see: https://orcid.org/0000-0001-9438-812X



Presence of Néel Skyrmions like out-of-plane spin structures in magnetic thin films with in-plane anisotropy

Jaianth Vijayakumar et al., Swiss Light Source, PSI Villigen

Out-of-plane (OOP) domains in magnetic thin films with in-plane (IP) anisotropy have not been observed due to the simultaneous requirement of high IP and OOP anisotropy energies. Similarly, skyrmions, which are topological spin structures formed due to Dzyaloshinskii-Moriya interaction (DMI), are also not found in IP magnetized systems. However, by using X-ray photoemission electron microscopy 3D magnetometry (shown in the figure), we find that Ta/Co/Pt heterostructure with DMI grown on a rough surface, develop OOP spin structures with in a dominant IP anisotropy. We find that the orientation of OOP spin is dependent on IP spin orientation and from micromagnetic simulation we find that these OOP spin structure can be chiral in nature, resembling a Néel skyrmion.



Reconstructed XPEEM image indicating the coexistence of IP and OOP spins and the arrows inside each pixel represent the magnetization magnitude.

Report on the Annual Meeting 2018 in Lausanne

This year the Annual Meeting took place at the EPFL. CHIPP and NCCR MARVEL came as well, which in addition to the different domain sessions allowed a good participation. Undeniably, the great advantage of national conferences of this type is that it provides a quasi-unique local viewpoint on progress in the diverse area of physics, representing a welcome complement to the specialized international conferences.

This conference had a special focus on energy. A plenary talk discussed the energy transition in Switzerland. The first evening public lecture dealt with the Thorium nuclear plant line. Furthermore, a plenary talk on the international large fusion machine ITER in construction detailed its future experimental programme, which was complemented by a public screening of a large audience film on the world fusion research effort. Obviously, these plenary presentations were all in resonance with the opening plenary talk on climate modelling, linking climate changes with anthropogenic greenhouse gases emission.

Pierre Vandergheynst, EPFL Vice-President for Education, Harald Brune, director of the Institute of Physics, and SPS President Hans Peter Beck welcomed the conference participants with opening notes.

As mentioned in the opening of the conference by Hans Peter Beck, about 360 physicists and students gathered in this 2018 Annual Meeting, with a total of 283 contributions (208 orals and 75 posters). The additional participation of CHIPP and NCCR MARVEL at this year's meeting contributed to the global success of this meeting. There were 8 plenary talks, 3 public events, of which two evening talks and the projection of a film closing the meeting.

The General Assembly, having taken place on the first afternoon, gathered 29 participants. This year saw a large number of board members coming to the end of their term, leading to a broad renewal of the board. The "History of Physics" section has been renamed to "History and Philosophy of Physics", enlarging the scope. Maurice Bourquin was unanimously elected as new Honorary Member.

The evening public lecture on Open Science given by Martin Vetterli, President of EPFL, attracted a large public interested in this major and inevitable change in progress in our current habits.

The conference dinner Thursday evening took place at the *Casino de Morges*, a nice place to gather for the aperitif by the lake under the plane trees. The large, well-decorated rooms have made it a convivial dinner place, especially with the nice menus served. Our President Hans Peter Beck thanked the organizers of the conference, in particular Giovanni Dietler, chair of the local organizing committee. As a sign of appreciation, the outgoing board members were thanked with beautiful bottles of wine that had grown under the sun of the region of Morges.

This year, the SPS decided to honour the winners of national and international Physics Olympiads and Tournaments at the gymnasial and university level. Thus they were invited to take part in the Award Ceremony on Wednesday and to

a program of laboratory visits in the afternoon, which was a great success, in particular among the gymnasium students. There is indeed a strong desire among these students to better understand what a physicist's life is like after university studies. This is clearly a track to develop further to meet the demands of these young people!

Antoine Pochelon

Condensed Matter (KOND) and related focused sessions

The KOND section organised a diverse program with invited as well as contributed talks and more than 50 % of all poster presentations. We were delighted to host two fascinating plenary talks. The first was given by *Nicola Marzari* from EPFL who highlighted the importance of computational support in the discovery of new materials. In particular, as Director of the NCCR MARVEL, he outlined the strategies that are being pursued to accelerate the design and discovery of materials with new functionalities. In a second plenary talk, *Ursula Keller* from ETH Zürich spoke about transient electric-field-driven dynamics in condensed matter, underlining the recent progress in ultrafast lasers with the optical generation of electric fields going from terahertz up to petahertz frequencies. This opens the way to explore novel quantum-mechanical regimes in materials such as diamond and GaAs, which will be extended to the more complex correlated electron systems in the future.

In the general KOND program, *Romain Sibille* gave a very informative talk on neutron scattering evidence for a quantum spin ice. There were also a variety of interesting contributed talks, mainly considering spin, orbital and charge degrees of freedom in complex oxides, but also superconductors, and employing various techniques including spectroscopy, photoemission, and Hall effect measurements.

Another highlight in the KOND sessions was the Award Talks from *Claire Donnelly*, *Wolfgang Tress*, *Andrea Hofmann*, *Giulia Grancini*, and *Shang Gao* covering topics as broad as x-ray magnetic tomography, perovskite solar cells, single electron physics and frustrated magnets.

In addition to the general KOND program, four groups of co-organisers contributed focused sessions, which were all well-attended by advanced researchers and young scientists (postdocs and PhD students) from various Swiss academic institutions: (i) Magnetism and spintronics at the nanoscale, (ii) SwissFEL - Recent advances and Future Opportunities, (iii) Advanced Electronic-Structure Developments and Applications, and (iv) Advances in Topological Materials.

The session “Magnetism and Spintronics on the Nanoscale”, organized for a third time at the SPS meeting, focused on the investigation of the properties of magnetic materials at a variety of different length and time scales. The session included two invited presentations from *Harald Brune* (EPFL) and *Rolf Allenspach* (IBM Research-Zurich), sixteen contributed talks and fifteen posters, and was divided into two parts. The first part was mainly focused on “Nanomagnetism” and the second part concentrated on “Spintronics and its device applications”. Several interesting fields of magnetism were discussed, with topics including Skyrmions, domain wall motion, artificial spin systems, the spin Hall effect, spin wave dynamics and magnetoelectric effects. For characterization, various laboratory-based techniques and large-scale facility methods were covered. The discussion

Poster session just started...

at the poster session was very lively and warm congratulations go to *Jaianth Vijayakumar*, Paul Scherrer Institute, for winning a prize for his poster on Neel Skyrmions in a magnetic thin film with in-plane anisotropy.

For the second successive year, the SPS meeting hosted the session “SwissFEL - Recent advances and Future Opportunities”. With the first SwissFEL experiments started in November 2017, this session has been honoured by the contribution of 8 national and international invited speakers and 10 contributed talks. This session was focused on the recent scientific output delivered by the SwissFEL in the field of ultrafast dynamics in condensed matter and time resolved chemistry. In addition an emphasis was given to future opportunities from the second beamline for soft x-rays currently under construction at the SwissFEL.

The session on "Advanced Electronic-Structure Developments and Applications" has successfully attracted 17 contributions, with 10 oral presentations and 7 posters. The oral presentations were organized in two sessions, with the first one focusing on new developments and the second one on applications. Each session was headed by invited talks given by *Wei Chen* from the Catholic University of Louvain-la-Neuve, Belgium and *Giacomo Miceli* from EPFL, respectively. Both sessions were well received by a large audience mostly composed of PhD students and postdocs, and gave rise to lively interactions during the question time.

The session “Advances in Topological Materials” included two invited talks, 14 contributed oral presentations, distributed over two sessions, and 5 posters. The invited talks were given by *Alexey Soluyanov*, University of Zürich and *Ming Shi*, PSI who focused primarily novel topological electron-

This year's plenary speakers: Christoph Schär, Almut Kirchner, Maurice Bourquin, Nicola Marzari, ...

ic phases in materials, while in many contributed talks other kinds of physical realizations of topological matter were considered. Notably, the sessions included contributions from both experiment and theory researchers well outside the NCCR MARVEL community. Both sessions were well attended resulting in discussions that extended beyond the session duration.

Laura Heyderman

TASK

The "Teilchen-, Astro- und Kernphysik" (TASK) session was once more organized jointly with the Swiss Institute for Particle Physics (CHIPP). This is now the fourth time that SPS-TASK and CHIPP join their forces in holding their annual meetings together. CHIPP started with its board meeting already on the morning of Tuesday the 28th and held its CHIPP general assembly meeting just before the official start of the SPS meeting in the afternoon of the very same day.

On Tuesday, in an integral part of the SPS award ceremony, where the winners of the various SPS prizes are honoured, the CHIPP prize for the best PhD thesis work in particle physics was given to *Claudia Tambasco* from EPFL for her outstanding contributions to "Landau Damping Limitations in High Energy Hadron Colliders" in the field of particle accelerator physics. In the plenary session on Thursday, Claudia had the opportunity to present her fascinating studies to a wide audience from all fields of physics.

Another plenary talk related to TASK was given by *Gino Isidori* of University of Zürich who spoke about "Hints of New Physics from flavor-changing processes". This talk was a perfect introduction to the first TASK session, which had yet another five dedicated contributions to this hot topic. In total, the TASK and CHIPP community submitted 54 talks and 18 posters covering a variety of fields that were organised in seven topical sessions on high-energy physics, on low-energy physics, on accelerator physics and related technologies, on the search for dark matter, on astrophysics, on neutrino physics, and last not least on detector developments and data reconstruction. The many presentations spanned over a wide range of topics from presenting new developments in detector and accelerator technologies for current and future projects to discussing the latest physics results and their impact on theoretical predictions, whether in agreement with the Standard Model or beyond the Standard Model Theory. Lively discussions on the experimental and theoretical aspects of physics continued to take place among the many participants during poster sessions and during lunch and coffee breaks.

Again, the TASK sessions were a big success and the quality of the presentations with a wide spread of topics have shown once more the deep involvement that Swiss physicists and Swiss students have in small and big size international collaborations.

All TASK related slides presented at the plenary as well as at the TASK sessions are available from the conference web page under https://indico.cern.ch/event/716246/timetable/ .

Andreas Schopper

Physics Beyond University

This session was organized by the "Physics in Industry" section of the SPS with the purpose to show students and postdocs alternative paths and application fields of physicists in industry and other sectors, also showcasing some inspirational, unusual career paths. In front of a packed room, the invited speakers presented an exciting, broad spectrum of industry backgrounds. We got an impression of physicist workplaces and environments from start-ups to large industrial companies, from physicists in education, project management, IP law, insurance risk modelling and basic as well as applied research and development.

... Gino Isidori, Martin Vetterli, Ursula Keller, Tilman Pfau, ...

Richard Steinacher, developer and project leader at Geopraevent, introduced their high-resolution radar (interferometric and Doppler), which they use to monitor natural disaster risks, issue real-time alerts and even automatically close mountain roads. Deploying reliable systems, built of mostly commercial radar components, in extreme environments is a breath-taking example where applied physics meets mountaineering.

As *Mirja Richter* from Sensirion pointed out, her work as intellectual property (IP) manager comprised a switch from driving her own "narrow" scientific projects to the pleasure of being involved in a very broad range of different innovation projects. In her role, idea management and the ability to listen and read extremely carefully are key skills. Besides this, physicists are generally regarded as a kind of Jack-of-all-trades at Sensirion.

Although nuclear power is an established base energy provider, *Bruno Zimmermann*, head of the nuclear fuel division at the power plant Gösgen, explained how they are working on making it more versatile: Adaptive production of electricity depending on power grid load and the parallel generation of radioisotopes for medical therapy are the frontiers that they are exploring in an interdisciplinary team of engineers and researchers.

Stephan Schnez from ABB's corporate research division gave insight into how a senior scientist gets to do technology pre-studies jointly with start-up companies that are potential acquisition candidates. Transferring innovations to the business units and infusing technologies into very distributed global development teams are key tasks when working as project manager for such a global player in battery and power applications.

... Timothy C. Luce, Beat Jeckelmann.

Salomon Billeter, head of casualty R&D core at Swiss Re, offered a completely different perspective: Transitioning from modelling physics to modelling of insurance risks. In the era of Big Data, statistical approaches and cross-disciplinary teams are able to tackle the rising challenges.

Located at the interface between academic and industrial research *Francesca Venturini*, Professor at the ZHAW Winterthur, used examples from her own career at Bruker Biospin and Mettler Toledo to point out the many gaps when transitioning from university to industry. Everything changes: the environment (academic vs. product oriented), the required skill set (technical vs. "soft skills") and even the technical know-how.

CSEM is a private, non-profit Swiss research and technology organization that develops micro technology innovations for industrial partners. *Christian Bosshard* heads the CSEM centre in Muttenz and gave an exciting overview of the many interesting projects that he was involved in. Examples focused on optical technologies ranging from flexible photovoltaics to smart windows that adapt to the season.

Nikola Pascher, head of R&D at Nanosurf, surprised the audience with the statement that even though their work is focused on improving atomic force microscopes, they still might want to publish their results in the Journal of Potato Research, as their AFMs are used for checking the quality of graphene based sensors on potato sorting machines. Atomic resolution at ambient conditions as well as ultra-high sensitivity in cell-mass measurements are pushing the technology's scope of application into many other fields.

The apéro in the garden of the Casino de Morges.

Last but not least, *Eugen Voit*, retired CTO from Leica Geosystems / Hexagon, presented a vision of industrial R&D where knowledge is transformed into money, in contrast to academia where money is transformed into knowledge. His advice to those of us that want to create something useful or make a difference was to follow the guidance of serial bank-robber Willie Sutton: Go where the money is!

Thanks to the great engagement of the speakers, both students and also the more senior people in the audience were able to get very interesting insights into the workplace of physicists in a work environment "beyond university". The lively discussions after each of the talks and the continued interaction with the speakers during the coffee break showed the great interest in getting a glimpse of the non-academic paths that may also be available after a PhD or master's degree in physics.

Thilo Stöferle and Andreas Fuhrer

About 150 participants enjoyed the exquisite conference dinner in the Casino de Morges. It was also the opportunity for SPS President Hans Peter Beck to thank a) Giovanni Dietler (left) for the perfect local organisation of the annual meeting, b) the leaving committee members for their support and dedication to the Society during their respective terms.

Biophysics and Medical Physics

The Biophysics and Medical Physics session was held on Wednesday, August 29, with invited and contributed talks. The first lecture should have been by *Andrea Rinaldo* (ENAC - EPFL), about the spatial organization of river networks and of the ecosystems they sustain. Unfortunately, because of last minute administrative problems, Prof. Rinaldo could not attend and could not be replaced.
The second invited speaker has been *Sahand Jamal Rahi*, who only recently joined the Institute of Physics at EPFL. His research focuses on the elucidation of the structure of signalling networks in single-cell and multicellular organisms. Using theoretical arguments, Prof. Rahi can devise the most appropriate structure of the signal, so that the response of the organism can unambiguously allow deciding which reaction network is used for sensing and signal amplification. The predictions are then experimentally tested in model cases.
This talk was then followed by five short (15 minutes) contributed talks.

After the break, the session resumed with two invited talks. First, *Matteo Dal Peraro* (SV - EPFL) told about Molecular Dynamics simulations of membranes and of membrane proteins, followed by *Marcos Gonzales-Gaitan* (Uni GE) who explained how a fundamental tool of statistical physics, namely scaling theory, can rationalize a plethora of experiments about the morphogenesis of the fruit-fly wing within a single framework. In this way, it is possible to distinguish between the general processes governing the formation of the tissue and the detailed parameters that instead set these specific time- and length-scales. These two presentations were followed by four more contributed talks.

Paolo De Los Rios (on behalf of Giovanni Dietler)

History and Philosophy of Physics

The History and Philosophy of Physics 2018 session has seen an interesting mixture of historical and philosophical talks devoted to very different aspects of physics. *Claus Beisbart* opened the session giving the audience a rich survey of points of view on the epistemological significance of computer simulations in physics that triggered many questions. *Eckard Wallis* discussed next how astronomers and physicists promoted or reacted to the progressive replacement of time measurement techniques from astronomical observations to the use of atomic clocks. The case of the pioneering role of Neuchâtel in the use of atomic clocks offered an alternative point of view on the Swiss expertise on time measurement devices. *Stéphane Fischer* from the Ge-

Coffee breaks and lunch buffet in the main hall gave opportunities for vivid conversations.

neva Museum of History of Science presented the collection of scientific instruments belonging to Marc-Auguste Pictet, one of the foremost Geneva physicists. It gave the audience the opportunity to ponder on the importance of preserving the instruments obsolete for current research but crucial for understanding physics progress and history. *Bernhard Braunecker* presented next a thrilling perspective on the history and on the technical means to achieve more and more precise star catalogues. In particular he reported on how the famous Farnese globe was shown to be most probably based on the lost catalogue of Hipparcos. Finally *Jan Lacki* used the opportunity of this year's celebration of the 250th anniversary of Joseph Fourier to comment how his achievements in the study of heat diffusion can be compared to the contemporary work of Sadi Carnot.
The session was followed by a fair number of participants, which shows the on-going interest in historical and philosophical matters.

Jan Lacki

Atomic Physics and Quantum Optics section

Research highlights in atomic physics and quantum optics (APQO) were presented in a broad range of talks and posters. The presentations showed that atomic and optical systems play a major role in exploring quantum physics and in developing novel applications in quantum technology.

In his plenary talk, *Tilman Pfau* from the University of Stuttgart gave an exciting overview over recent experiments with Rydberg gases in miniaturized atomic vapour cells. These systems provide a scalable technological platform that allows one to harness the advantages of room-temperature atomic vapours, such as intrinsic reproducibility, strong and tunable nonlinearities and well-developed techniques for coherent control, for novel applications in quantum technology. In recent experiments with such miniaturized vapour cells, an on-demand single-photon source, a sensitive microwave detector and a trace gas sensor were demonstrated, and many further applications are currently being explored.

The topical sessions featured an SPS award talk by *Petar Jurcevic*, who presented his beautiful experimental results on quantum computation and many-body physics with trapped ions. The following speakers reported, among others, the observation of the Einstein-Podolsky-Rosen paradox in a many-body system, new results on exciton-polariton condensation and a range of novel optomechanical techniques for quantum control of micro- and nanomechanical oscillators.

Since the connection of academic research and industry was a focus of this year's SPS meeting, the APQO sessions also featured an extended talk by researchers from CSEM Neuchâtel on MEMS atomic vapour cells for quantum technologies, nicely complementing the plenary talk. A main application of such cells are small and portable atomic clocks, as was reported in further presentations. Further topics of the APQO program included the development of novel laser sources, transport measurements with ultracold fermions and quantum-logic spectroscopy of molecular ions.

In summary, the APQO sessions once more showed that the field of atomic physics and quantum optics is advancing at a fast pace, with many different systems and approaches providing an impressive degree of control over matter at the quantum level.

Philipp Treutlein

Applied Physics and Plasma Physics

On Tuesday August 28, *Christoph Schär* from ETHZ opened the scientific program with a talk about the greenhouse effect along with high-resolution climate modelling by reminding that climate change is one of the most complex scientific challenges impacting societal and economic issues. His presentation discussed the progress made recently, especially regarding the very high resolution modelling and has shown some recent progress in this field of study.

On Friday, a well-attended and lively combined topical session on Applied and Plasma Physics took place.

The first 3 talks of the session were dedicated to Applied Physics presentations. *Jakub Drs* from the University of Neuchâtel started by presenting his work on broadband THz sources based on thin-disk laser oscillators. The recent advances in Kerr lens mode locking of thin-disk laser oscillators enable to obtain pulses of less then 50 fs with several Watts of output power. Without requiring any additional compression or amplification stage, such pulses are suitable for generating broadband THz pulses by optical rectification in gallium phosphide. This frequency range is of much interest as a diagnostic tool of complex molecular systems.

The following two talks were given by two researchers from the Paul Scherrer Institute, both addressing the recent technological advances in using proton beams as a radiation therapy approach for treating cancers. The first of these two talks, given by *Marco Schippers*, provided a very nice overview of the challenges of developing this advanced radiation system, in particular the challenge of transferring this technology from laboratory into the clinic. The second of these two talks, given by *Konrad Nesteruk*, then focused on the advantages of making use of superconducting magnets, allowing reducing the size and weight of the so-called gantries that direct the path of the proton beams. Improved optics of these gantries also allows a larger energy acceptance, which leads to improved treatment, as different particle energies are required to cover the full tumour thickness.

The second part of the session, dedicated to Plasma Physics, started with a talk by *Alexandra Waskov*, presenting her work, which is actually at the interface between Plasma Physics and Plant Biology. This project, which is based on a collaboration between the Swiss Plasma Center (SPC) at EPFL and the Department of Plant Molecular Biology at the University of Lausanne, studies the potential benefits of treating plant seeds with room temperature, non-thermal plasmas. It appears that such treatment may lead to improved germination and growth, as well as increased disease resistance. The biological mechanisms taking place remain to be fully understood.

The final two talks addressed fusion-related plasmas, more particularly the conditions at the edge of future tokamak-type fusion reactors. A talk given by *Dario Vaccaro* from the SPC addressed the design of gas baffles, which are key elements of the divertor chamber where magnetic field lines intersect the reactor wall and a significant fraction of the heat is deposited. The purpose of these baffles is to increase the pressure of neutral particles in the divertor, enabling an improved (higher dissipative) divertor regime.

To study conditions relevant to those found in the vicinity of the divertor, the basic plasma device TORPEX at the SPC has been modified by introducing an internal coil enabling to generate both closed field-line and X-point configurations. Results from first characterization of the turbulence in these particular TORPEX configurations have been presented by *Paolo Micheletti*.

Stephan Brunner and Stéphane Goyette

Why showing a science film at annual meetings?

The audience of 70 people that attended the screening of the film on fusion research that closed the meeting on Friday afternoon - almost as many people as in the morning plenary session - gives a first element of an answer. Before the main film, a short film resulting from a 3-days training course on *how to better communicate science* – "Sun in a box" – received merited applause. "*Let there be Light*" by Mila Aungh-Thwin is a mainstream Canadian film intended for a broad non-scientific public. As was heard coming out of the film, what is striking is its objectivity. Indeed, it does not sell fusion as a reality that does not have big hurdles. In fact, you are marked by the force put in this transgenerational endeavour. Unfortunately, the film doesn't show as much as one would wish of the governmental funded research and, for a contrasted story-telling, gives a relatively large share of time to small firms. But all the scientists in fusion have a dream for the planet, a huge enthusiasm with which they are capable of great projects, even if the way to success is long. And this dream is also making the public and naturally the funders dream. Remember for example the time it took to develop LIGO and Virgo and the incredible impact on the general public it had when the first gravitational wave signals appeared. Even with challenging issues - infrastructure, organizational, human and political, such a film has a strong potential to generate vocations for young people.
The scientific balance of the day on fusion was ensured by the morning plenary lecture by Tim Luce, head of ITER science program, and after the film, by a visit to the Swiss Plasma Center, that showed the implication of Switzerland in the European and world fusion research effort, at which twenty young people participated.

Antoine Pochelon

Pre-announcement: Joint Annual Meeting 2019

The next Annual Meeting will take place at the ***University of Zürich***, in the week of ***26 - 30 August 2019***. The well established tradition of organising the conference every second year jointly with the Austrian Physical Society (ÖPG) will continue. Further partners, e.g. the *MaNEP association*, will also contribute.

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 Spring 2019, as well as on our website.

New Committee Members

PD Dr. Lukas Gallmann (Secretary)

Lukas Gallmann studied physics at ETH Zurich from 1993 to 1998. With his interest in lasers and ultrafast science sparked, he joined the Ultrafast Laser Physics group of Prof. Ursula Keller in the Department of Physics at ETH Zurich to pursue a doctorate on methods for the generation and characterization of some of the shortest pulses of light. Following his doctorate, Lukas Gallmann joined Contraves Space AG as an Optical Engineer R&D in 2002, where he worked on optical and laser systems for applications in space. In 2005, he returned onto the academic track with a postdoctoral stay at the Lawrence Berkeley National Laboratory and the University of California in Berkeley in the group of Prof. Stephen R. Leone. During his postdoctoral research, he entered the newly emerging field of attosecond science, which enabled direct time-domain spectroscopy of extremely fast electronic processes in gas and condensed phase. In autumn 2006, Lukas Gallmann returned to the Ultrafast Laser Physics group of Prof. Keller to pursue a habilitation, which he completed in 2012. In 2016, he was promoted to a permanent academic staff position at ETH Zurich.

Lukas Gallmann's research interests are fundamental light-matter interactions at the frontier of experimentally accessible time scales and the development of new sources and techniques in the context of strong-field and attosecond science. His research is increasingly moving towards attosecond time-resolved studies on solid-state systems, where he explores the response of the bulk electronic system to strong optical fields or studies the dynamics of photoemission at the solid-vacuum interface.

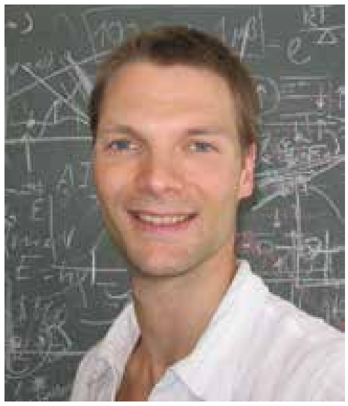
He enjoys the breadth of his research field that spans from technologically driven developments to experiments that touch very fundamental physical concepts.

Dr. Dirk Hegemann (Treasurer)

Dirk Hegemann is leading the group Plasma & Coating in the Advanced Fibers Laboratory at Empa, St.Gallen. He is

a physicist and has applied this background to interdisciplinary research in various fields, particularly materials science and plasma physics/chemistry, the analysis and modification of polymer surfaces, thin film deposition and etching, large scale processing, and biomaterials. He studied science at the Technical University Darmstadt, Germany, obtaining a Diploma in Physics and a Ph.D. (Dr. rer. nat.) for research on hard and oxidation resistant plasma coatings (1999). After working with the Fraunhofer Institute for Interfacial Engineering and Biotechnology in Stuttgart, Germany, Dirk Hegemann moved to Empa, St.Gallen, in 2003, where he pursued his studies on low temperature plasma processing with the focus on plasma coatings on flexible polymer materials and soft matter. His current research interests comprise fundamental and applied studies on low temperature plasmas including supervision of PhD students and teaching at universities as well as transferring plasma processes to industry.

Prof. Dr. Henrik M. Rønnow (Co-chair of the KOND section)



Henrik Ronnow was born in Copenhagen in 1974. He got his master's degree in physics in 1996. Having earned his doctorate in 2000, he left Denmark for training at the Laue-Langevin Institute in Grenoble. Between 2000 and 2002, he held a Marie Curie Fellowship hosted by the Atomic Energy Commission.

In 2002 he was appointed as an invited researcher at the NEC Laboratories in Princeton, then at the University of Chicago's James Franck Institute. In 2003, he became a researcher at the Laboratory for Neutron Scattering of ETH Zürich and at the Paul Scherrer Institute. In 2007 he was appointed Assistant Professor at Ecole Polytechnique Federale de Lausanne (EPFL). In 2012 he was promoted to Associate Professor.

Prof. Dr. Leonid Rivkin (Chair of the section "Applied Physics")

Lenny Rivkin was born in Odessa in 1954. He studied physics in Novosibirsk and Cambridge USA, graduated from Harvard University with AB in Physics in 1978 and received his PhD in Physics from Caltech in 1985. He worked on several accelerator projects at Stanford Linear Accelerator Center, which was followed by a year at LEP, CERN, Geneva.

Lenny joined the Paul Scherrer Institute (PSI) near Zürich in 1989 and worked on the design, construction and commissioning of the Swiss Light Source. In 2006, he became Deputy Director at PSI, Head of the Department of Large Research Facilities at PSI and professor of particle accelerator physics at EPFL.

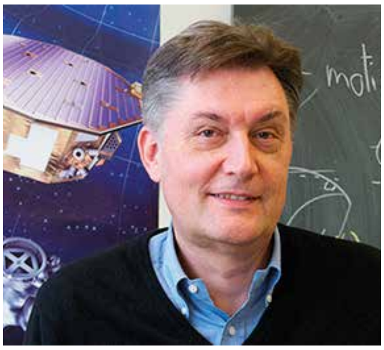
At the Paul Scherrer Institute (PSI) he is engaged in the development of novel bright synchrotron light sources, including the future X-Ray Free Electron Laser project SwissFEL.

High intensity proton beams are used to produce powerful sources for neutron scattering and bright muon beams. Developments of accelerator applications for life sciences include hadron therapy of tumors and coherent sources of X-rays for phase-contrast imaging. Projects at CERN include work on future upgrades of LHC and associated accelerators, as well as research and development towards the future high energy frontier electron-positron linear collider.

Dr. Laurie Porte (Chair of the section "Applied Physics")

Laurie Porte got his PhD in 1992 from the University of Strathclyde, Glasgow, United Kingdom, on Electron Cyclotron Emission Diagnostics.
He continued at the JET Joint Undertaking, Oxfordshire, UK, in his field on plasma and fusion research, before going 1997 as a PostDoc to the University of Los Angeles, and 1999 to the MIT in Boston (while working at the FZ Jülich in Germany).
In 2001, Laurie Porte joined the CRPP-EPFL, where he took over responsibilities for the operation of the gyrotron heating systems of the Tokamak a Configuration Variable (TCV).

Prof. Dr. Philippe Jetzer (Chair of the section "Theoretical Physics")



Philippe Jetzer obtained his PhD from ETHZ in 1985 and became a PostDoc in the theory department of University Geneva. Further stages involved the theoretical astrophysics studies at Fermilab, and a fellowship at CERN's theory division.
Following stages with the University of Zurich, LBL Berkeley, and PSI, ETHZ, his research brought him finally to University of Zurich in 2001. Philippe Jetzer is a member of the scientific team responsible for LISA Pathfinder, and along with Domenico Giardini, Professor of Seismology and Geodynamics at ETH Zurich, is a prominent representative of Switzerland in the international project running under the leadership of ESA, the European Space Agency.

Prof. Dr. Claus Beisbart (Chair of the section "History and Philosophy of Physics")

Claus Beisbart works in fields in which physics and philosophy touch or intersect. He has obtained Ph.D. degrees in both fields from the Ludwig Maximilan University Munich. His postdoctoral research led him to Oxford, Konstanz, Dortmund and Pittsburgh. Since 2012, he is Professor for Philosophy of Science at the University of Bern. There, he is a member not just of the Institute of Philosophy, but also of the Oeschger Centre for Climate Change Research and the Center for Space and Habitability. His current research interests focus on probabilities in physics, relativity theory and the epistemology of simulation and modeling. He is looking forward to foster interdisciplinary exchange between physicists, philosophers and historians of physics in the SPS.

Prof. Dr. Andreas Müller (Co-chair of the section "Education and Promotion of Physics")

Andreas. Müller has a physics background with studies at the universities of Heidelberg, Grenoble and Göttingen and several years of doctoral and postdoctoral research (among other places, Max-Planck-Institutes for Nuclear Physics/Heidelberg and for Biophysical Chemistry/Göttingen).
A long lasting engagement for physics education in parallel to his science research resulted in a shift into and habilitation in this field (1997). The following steps were work as research scientist at the Institute of Science Education (IPN, Kiel) and nomination for a chair of physics education (Landau/Ger). Ever since, he has continuous experience for more than 15 years in science teacher education and science education research.
His current interests in research and development are, among others, the following:
- science of everyday phenomena, cross-disciplinary connections of physics with the other sciences, hands-on-experiments
- empirical investigations and research based development in science education, in particular about context orientation and about the role of tasks and exercises in for effective learning.

In science teacher education, his main goal is to establish a good synthesis of the practical know-how of experienced teachers on the one hand, and the large body of research-based knowledge about teaching and learning available nowadays on the other hand.

Furthermore, our highly esteemed scientific editor ***Bernhard Braunecker*** has agreed to serve for one year also as ***Vice-President***.

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/).
The topic of Gino Isidori's talk has already been covered in our series *Progress in Physics* (*SPG Mitteilungen* Nr. 54, p. 11), Maurice Bourquin's theme has been presented as two-parter in the *SPG Mitteilungen* Nr. 54, p. 25 and Nr. 55, p. 34. The talk of Beat Jeckelmann is presented also as full *Progress in Physics* article on p. 26 in this issue.

Climate Change: From the Greenhouse Effect to High-Resolution Climate Modeling

PT 1/2018

Christoph Schär, Atmospheric and Climate Science, ETH Zürich, schaer@env.ethz.ch

Climate change is one of the most pressing societal and economic issues, but also one of the most complex scientific challenges. There is overwhelming evidence that anthropogenic climate change is already happening. Global mean temperatures are rising, polar sea ice is decreasing, glaciers are retreating, sea level is rising, and the atmospheric water content is increasing. The most recent European summer fits well into this pattern. Over the Swiss Plateau, the summer 2018 ranked as the third warmest in the long-term data series. Detailed analysis demonstrates that the summer warming of the last decades has been very pronounced (Fig. 1). The temperatures of the last decades (1991-2018, red bars in bottom panel) exhibit a shifted statistical distribution in comparison to the past (1864-1990, blue bars). Between the two periods there has been a mean summer warming of 1.8 K. This warming amounts to about 2 standard deviations of the 1864-1990 distribution. Even the coldest summer since 1991, the summer 1996, is significantly warmer than the 1864-1990 mean. These observations, along with many others, demonstrate that the climate system is experiencing a pronounced shift far beyond natural variations.

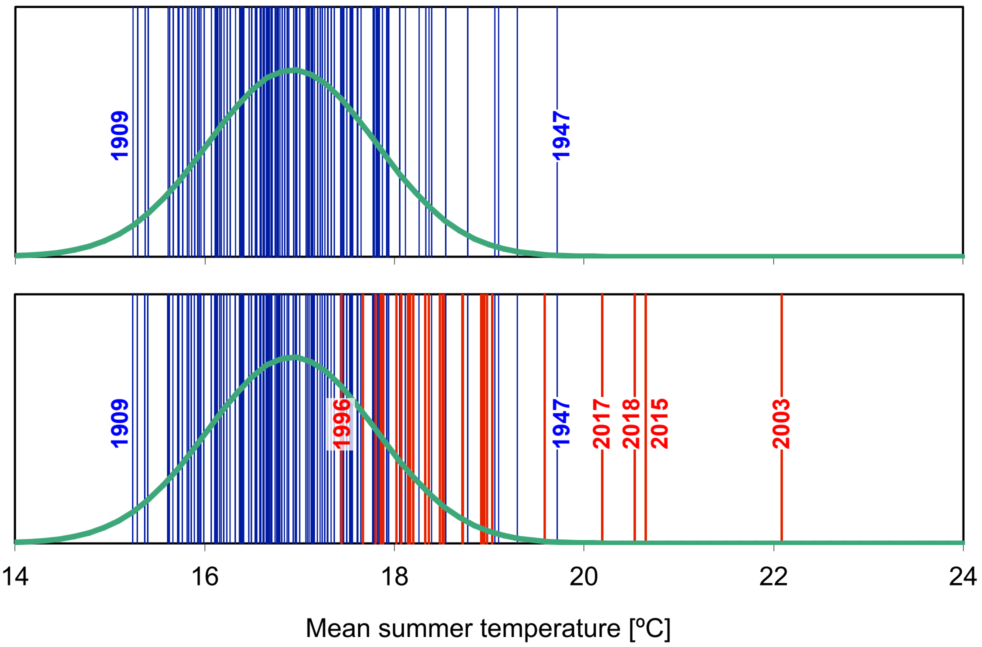


Fig. 1: Summer temperatures over the Swiss plateau (average of stations Geneva, Basel, Bern and Zurich) from 1864-1990 (blue, both panels) and 1991-2018 (red, bottom panel). Extreme summers are annotated. The green curve shows a Gaussian fit for the 1864-1990 period. The warming between the two periods is evident: even the coldest summer of the 1991-2018 period (the summer 1996) is warmer than the 1864-1990 mean. (updated from Schär et al., 2004, http://dx.doi.org/10.1038/nature02300

While 30 years ago there has been a vigorous debate regarding the reasons behind this warming, all recent assessments of the UN Intergovernmental Panel on Climate Change (IPCC) conclude that the prime reason behind global warming is due to the anthropogenic greenhouse emissions.

The physical principles behind the greenhouse effect are now well understood. Early studies of Joseph Fourier (1824) and John Tyndall (1861) identified the role of greenhouse gases for the climate system, and isolated H_2O and CO_2 as the most important atmospheric gases able to absorb infrared radiation. Already in 1896, Svante Arrhenius provided a first estimate of the effects of increasing atmospheric CO_2 concentration. His model of the Earth's energy balance was the first of its kind. It accounted for incoming solar and outgoing terrestrial (infrared) radiation, included the forth-power Stefan-Boltzmann law (then referred to as Stefan's law), and considered absorption by H_2O and CO_2 gases. Arrhenius estimated that a doubling of CO_2 would lead to a warming of about 5.4 K. In discussing his results, he did focus on the role of CO_2 variations for the ice ages, but he also mentioned that "the world's present production of coal reached in round numbers 500 millions of tons per annum [...]. Transformed into carbonic acid, this quantity would correspond to about a thousandth part of the carbonic acid in the atmosphere." According to current estimates, the emissions in 1895 amounted to about 406 million tons of carbon.

Today's annual anthropogenic emissions of carbon are estimated to about 10 billion tons of carbon, about 25 times more than in 1895. The prime reason of these emissions is the exploitation of fossil fuels. While some fraction of the emissions are absorbed by the oceans and the land surfaces, about 50% remain in the atmosphere and contribute to the accumulation of atmospheric greenhouse gases. Consistent with these figures, the atmospheric CO_2 concentration is currently rising by about 0.5%/year.

While the evidence for a man-made influence on the climate system is rapidly mounting, uncertainties in climate change projections have remained staggeringly large. For instance, current estimates of the equilibrium global-mean warming in response to a doubling of atmospheric CO_2 concentrations amount to 3 ± 1.5 K. During the last 40 years, this estimate has neither significantly shifted nor narrowed. The main cause behind the slow progress in projecting climate change is the representation of clouds in climate models, especially of small-scale convective clouds (i.e. thunderstorms, rain showers, shallow convective cloud layers). While the projected geographical patterns of climate change are converging across different climate models, the amplitude of these patterns is sensitive to the representation of clouds. These uncertainties make it difficult to plan and develop adequate response strategies, which are essential to reduce global warming and adapt to climate change.

With the advent of high-resolution climate models, there are now promising prospects, as it becomes feasible to formulate the models much closer to first principles and to refine the horizontal resolution of global climate models from today 50-100 km to 1-2 km in the future. In essence, this will allow resolving convective clouds explicitly, and thereby representing crucial physical processes and feedbacks on a physical basis rather than using semi-empirical parameterization schemes.

The potential of high resolution is demonstrated by regional climate models, which show that the mesoscale structure of atmospheric phenomena is much more credibly simulated at high resolution (Fig. 2). The forthcoming increase in resolution is also important in the context of extreme events (e.g. heavy precipitation and flash flood events), which are characterized by small spatial and temporal scales and thus require high resolution. Recently it has become feasible to conduct such simulations at continental scales over decadal time periods.

Models of this type are currently used to better understand and project heavy precipitation events in a future climate. Previous theoretical studies have suggested that heavy hourly events increase by between 6 and 14% per degree warming. Results from high-resolution climate models suggest that the increase in extreme precipitation intensity will likely be near the lower value of 6% per degree warming, corresponding to the Clausius-Clapeyron rate. Assuming a warming of 5°C by the end of the century under a business-as-usual scenario (IPCC RCP8.5), this would yield intensity increases of about 30%. Such results are essential for the dimensioning of critical infrastructures with long life times, for instance bridges, dams and hydrological runoff systems.

Currently major initiatives are underway to expand the computational domains of high-resolution regional climate models to global scales, or to refine the horizontal resolution of global models to km-scale. Estimates show that about a 100-fold increase in computational power will be needed. In addition, new approaches are required to handle input/output, as the memory bandwidth is increasingly becoming the crucial bottleneck (as opposed to the computational power in the past), and it is essential to better exploit future hardware architectures (such as GPU-based supercomputers). It appears feasible that within 10-20 years computers and models will enable km-scale global simulations over centennial time periods, and it is hoped that these advanced modeling systems will help to reduce current uncertainties in climate change projections.

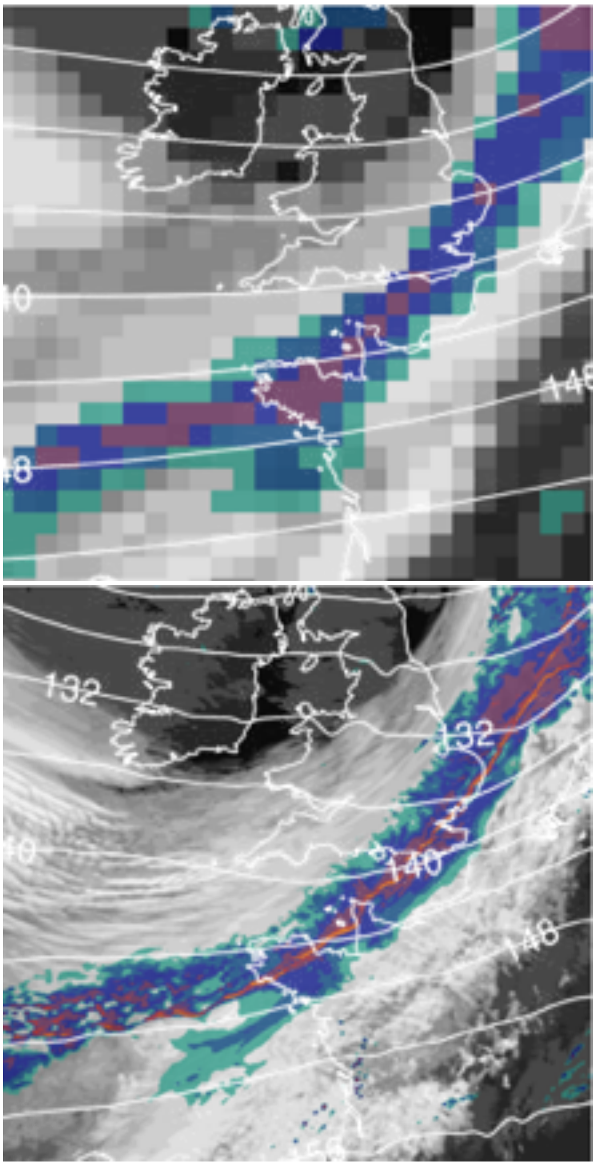


Fig. 2: Zoomed snapshots of a simulated cold front at horizontal resolutions of 50 and 2 km, respectively, showing visualizations of simulated clouds in grey, and precipitation intensity in color. The 2 km simulation (lower panel) is able to represent the narrow cold-frontal rainband (the reddish band of heavy precipitation), which is responsible for halting the scale collapse. Decade-long simulations of this type are currently used to better understand and project the fate of heavy precipitation events in a changing climate. (from Leutwyler et al., 2017, http://dx.doi.org/10.1002/2016JD026013).

PT 2/2018

The Transformation of the Energy System – Challenges and how to meet them

Almut Kirchner, Prognos AG, Vice Director and leader of department energy and climate protection policy

The current energy system finds itself in the beginning of a transformation process of which until now only targets and fundamental determinants are known. To meet the strategic goal of a medium global warming of under 1.5 - 2 K, a drastic reduction of greenhouse gases until 2050 is necessary. The energy system in the long run will have to work without fossil hydrocarbons: No electricity production based on coal or natural gas, no heating systems and industrial process heat based on mineral oil products or natural gas, no transport based on gasoline, diesel fuel, kerosene. Some industrial processes like production of iron and steel, cement and basic chemical products which are fundamentally dependent on hydrocarbons (coal for steel, naphtha for chemical products) will meet additional challenges.

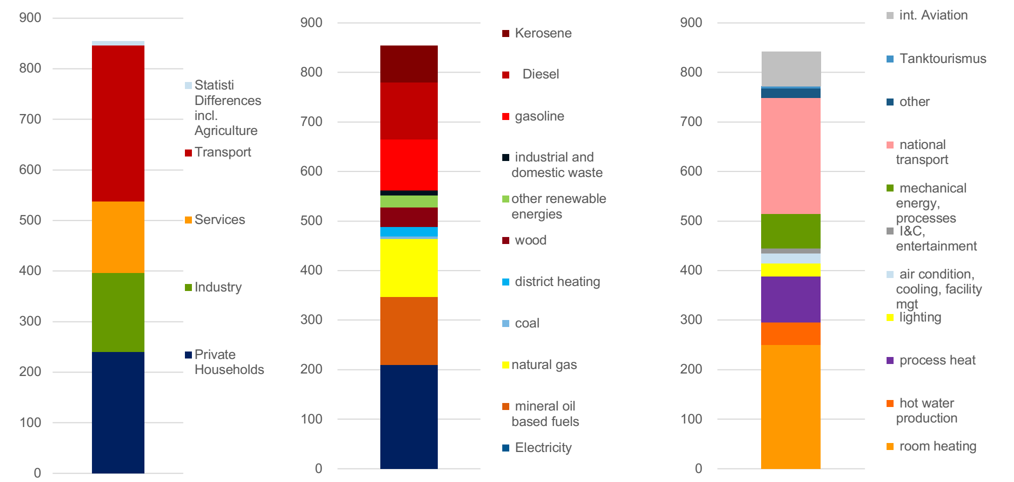
If – for reasonable reasons – electricity based on nuclear fission is no longer admissible and does not provide a „loophole“, all forms of energy utilization as well as production have to change fundamentally and drastically.

In the Swiss energy system more than two thirds of final energy consumption are provided by mineral oil products and natural gas (Graph 1) Switzerland‘s electricity production consists mainly of hydropower (nearly 60 %) and nuclear power (Graph 2). So-called „new“ renewable energies like photovoltaics, solar thermal energy and wind energy contribute up to now only very small amounts of energy in comparison to the overall demand. Part of the energy transition will be the phase-out of nuclear power.
The transformation will necessarily include additional electricity consumption in the mobility and the heat sector.

The future energy system will have to decrease the use of fossil-carbon-based fuels and increase the use of renewable sources drastically. (Graph 3)

Limits are found mainly due to potentials of alternative and renewable energy sources: Most of the „alternative“ energy sources are derived from solar radiation (solar, wind, biomass, partly also hydropower and wave energy) and are harvested on surfaces with limited energy density. Especially sustainably produced biomasses as energy carriers are sought after – and compete directly with the food chain, material use and ecological needs – meaning that under an overall perspective they are rather scarce.

The regional and temporal structure of energy use and energy production – especially electricity production – will change which in turn will call for developments in the infrastructure as well as the relationships between acteurs (i.e. „prosumer“ – combined consumers and producers) and business models for production as well as for services. (Graph 4)

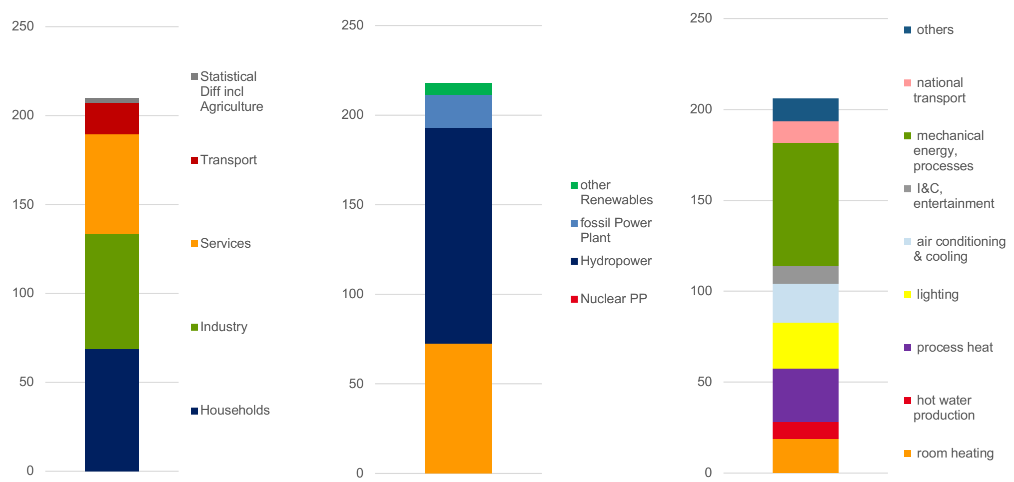


Sectors
Source: FOE Global Energy Statistics 2016

Energy Carriers
Source: FOE, Gobal Energy Statistics 2016

Purposes of consumption
Sources: FOE, Energy Statistics 2016, Prognos 2017

Graph 1: Final Energy Consumption in Switzerland 2016 – by sectors, carriers and consumption purposes, in PJ

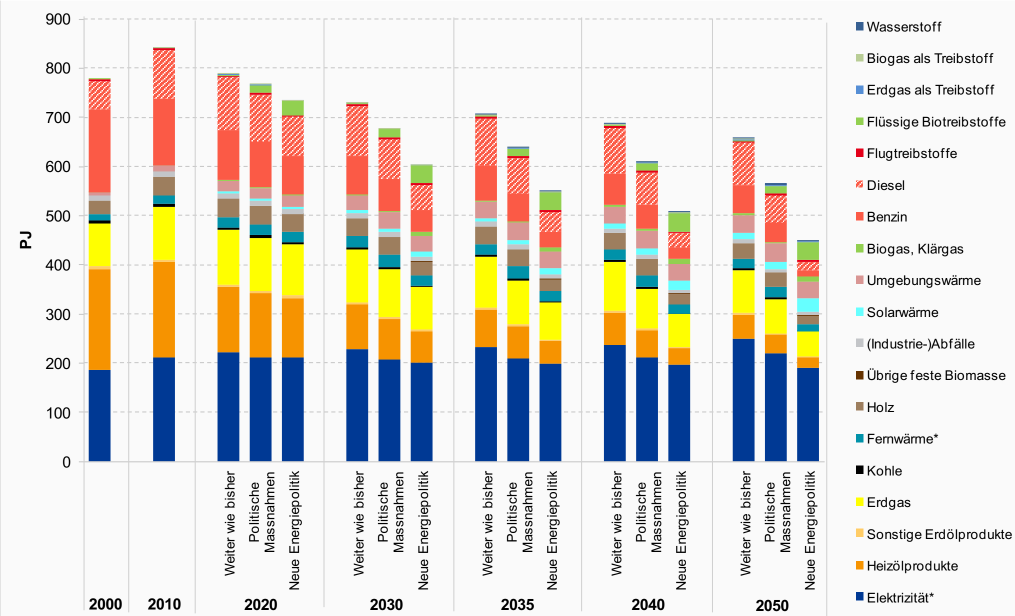


Sectors
Source: FOE Global Energy Statistics 2016

Production technologies
Source: FOE Global Energy Statistics 2016

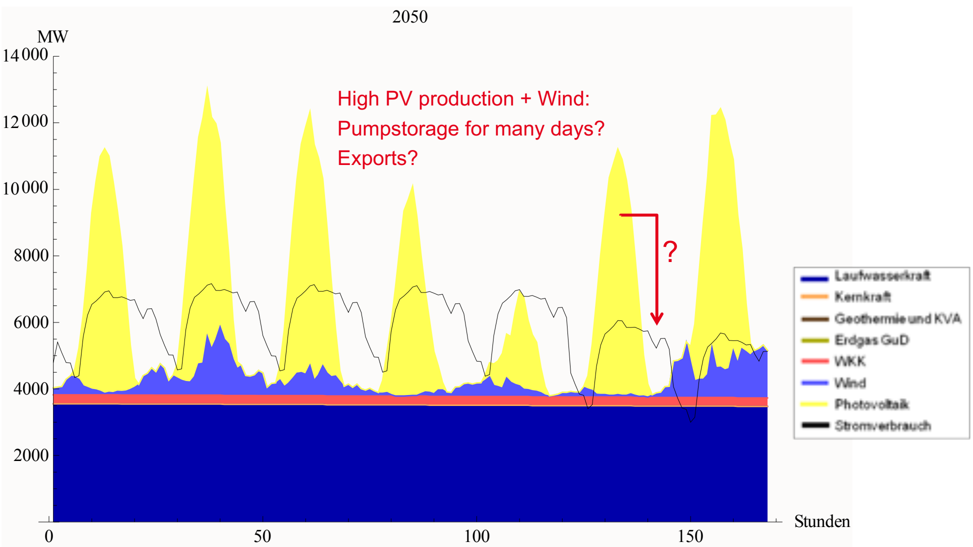
Purposes of consumption
Sources: FOE, Energy Statistics 2016, Prognos 2017

Graph 2: Electricity (net consumption) in Switzerland 2016 – by sectors, production technologies and consumption purposes, in PJ



Graph 3: Scenarios for the Swiss Energy System up to 2050:
Final Energy Consumption by energy carriers, in PJ. Source: Prognos (2012)

Example End of may, 2050: options for dispatch



Graph 4: Near-Carbon free Scenario for Switzerland 2050: electricity demand and production, dispatch options for hydropower in one week in summer, in MW. Source: Prognos (2012)

Especially in the transport sector technology shifts as well as organisational shifts are needed. Several alternative technologies are in different states of development which will lead to interesting technological competitions with open results.

Future energy use will need strongly increased efficiency (technologies) to meet the limited potentials of renewable energy sources specificyally as well as in absolute values. Fortunately, this is a „no-regret-option“ and an enabler for more technology openness with respect to different renewable and technological solutions. The ratio of electricity in the energy mix will be increased as well as that of biomasses. Electricity will be produced mainly from renewable sources, and numerous technologies for storage, flexibility and transformation in storable energy carriers will (have to) be developed. If the decarbonisation targets are very ambitious, probably significant capacities for production of synthetic renewable energy carriers will have to be established in countries with favourable production conditions – leading to new imports.

International flows and dependencies of raw materials will change („from oil to lithium or cobalt“).

Expectably yet unknown or only experimentally understood technologies will occur that may have the pivotal role of „game changers“ (e.g. direct biological or catalytical production of hydrogen via algae and sunlight, electricity storage technologies with minimum use of rare metals…) – which may facilitate the transformation but as well lead to stranded investments due to structural change.

The transforming as well as the transformed system requires new digital solutions and business models to guarantee for efficient and stable operating procedures. These are connected with numerous security issues which have to be included in the system development.

The transformation of the energy system is a complex task that interweaves technological as well as societal and economic requirements and developments.

Prognos AG has explored the necessary transformation processes in Germany and in Switzerland in detailed energy system scenarios and presents the main results as well as open questions – especially interesting ones for practical physicists (and a few for theoretical ones). Crucial fields of development are material sciences (e.g. for storage and energy transformation technologies), system controlling and regulation technologies and digital as well as other „material“ and infrastructure-related safety and security technologies.

References (inter alia):

Prognos AG, infras AG, Energieperspektiven für die Schweiz bis 2050, im Auftrag des Bundesamts für Energie, Bern, 2012
BCG, Prognos AG, Klimapfade für Deutschland, 2018, im Auftrag des BDI, Berlin

ITER—An Essential Step Toward Fusion Energy

PT 3/2018

Timothy C. Luce, Director of ITER Science and Operations Department and ITER Chief Scientist
ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul-lez-Durance (France)

Figure 1: Picture of the ITER site

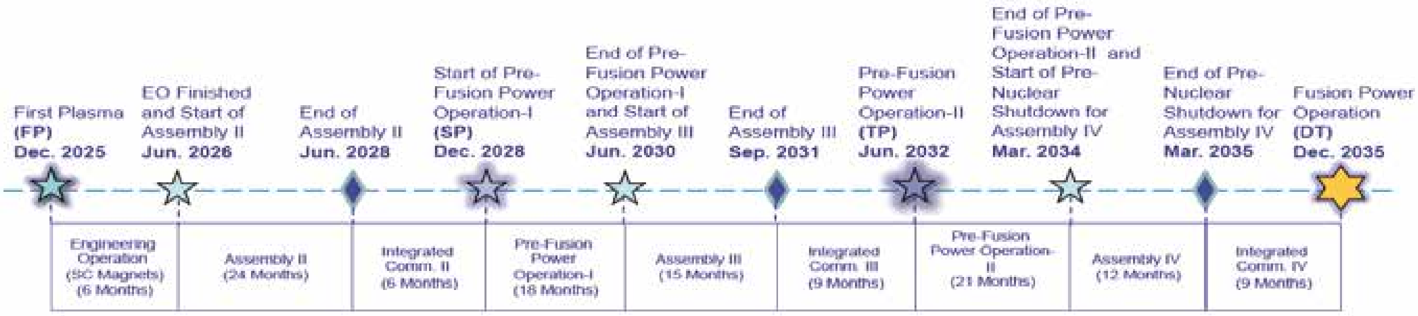
Fusion reactions hold enormous potential for clean, sustainable energy production from more equitably distributed resources, but a demonstration of technical and economic viability remains to be carried out. The ITER tokamak [1], now under construction in France, represents an essential step toward a practical technical demonstration of fusion energy. The Project Specifications set specific goals this step: 500 MW of fusion power with a power gain Q (ratio of fusion power to input power) of 10 for at least 300 s and in-principle steady-state operation with Q = 5. These goals place ITER at the threshold of the conditions suitable for baseload power plant operation, consistent with the goal of minimizing physics uncertainty in the next-step device, which would be a prototype power plant.

The ITER Organization is charged with the construction and exploitation of the tokamak. It is the result of a Joint Implementing Agreement of China, the EU (through Euratom, so including Switzerland), India, Japan, Korea, Russia, and the US. Nearly 90% of the components required for the tokamak and balance of plant are supplied through in-kind contributions by Domestic Agencies formed by the Members for this purpose.

1 For a description of the ITER («the way» in Latin) see https://www.iter.org/

In November 2017, the 50% completion point for activity required for First Plasma (design, fabrication, assembly, and commissioning) was passed. In the last three years, most of the buildings seen in the site (photograph above) have been constructed and installation of many plant systems has begun. Progress is accelerating toward the achievement of First Plasma, scheduled for the end of 2025.

In order to reach the fusion conditions specified above, ITER will be fueled with a nearly 50-50 mixture of the two heavy isotopes of hydrogen, namely, deuterium (D) and tritium (T). The fusion reaction between these two isotopes has the highest cross-section at temperatures readily achievable even in present-day tokamaks (1-2 · 10^8 K). The D-T reaction has two by-products—a neutron with 14.3 MeV energy that contributes to volumetric heating of the blankets surrounding the plasma and an alpha particle with 3.4 MeV energy that slows down within the plasma for 'self-heating'. In addition to the distributed heating from the 14.3 MeV neutron, reactions of these neutrons with lithium in the blankets in future fusion devices will be used to breed the tritium fuel needed, since tritium does not occur in significant quantities in nature due to a relatively short half-life (12.3 years). Prototypes of these tritium breeding systems will be tested on ITER, but not of sufficient size to breed its own fuel.



Reaching the fusion goals specified above will require a substantial technical commissioning and physics research effort. There are two major phases of operation—Pre-Fusion Power Operation and Fusion Power Operation. An overview of the schedule following First Plasma up to the beginning of the first Fusion Power Operation campaign is shown below.

A brief discussion of the objectives of each part of the schedule is given here. The full details are in the ITER Research Plan, which has just been released as an ITER Technical Report (*https:www.iter.org/technical-reports*). In the Pre-Fusion Power Operation (PFPO) phase, consisting of two campaigns, only hydrogen or helium fuel will be used. This limits the neutron generation to very low levels, allowing personnel access to tokamak building to maintain the equipment during this phase of commissioning.

At First Plasma, the basic components of the tokamak, the magnets and the vacuum vessel, will be demonstrated to function together as intended. This is the culmination of a year-long 'Integrated Commissioning' of the tokamak assembly and the basic plant services required to make plasma. The goal is >100 kA plasma current for >0.1 s. These are modest compared to the baseline design of 15 MA plasma current and the possibility to sustain lower plasma currents for as long as 3000 s, but the purpose is primarily to commission the tokamak assembly. Following First Plasma, commissioning activities continue for six months of Engineering Operation, including taking the toroidal field magnets to full design parameters (5.3 T).

After this, the in-vessel components to handle the high heat and particle fluxes and protect the vacuum vessel and magnet from the plasma will be installed. When complete the first of the PFPO campaigns will focus on the commissioning of the basic controls and protection systems required for later phases. One of the three heating systems (20 MW of electron cyclotron heating at 170 GHz) will be fully implemented and commissioned. Thus it will be possible to initiate modest physics studies, primarily focused on comparing the achieved plasma confinement to the predicted values.

In the next shutdown, the full complement of heating systems will be installed (33 MW of negative-ion-based neutral beams at 1 MeV and 20 MW of ion cyclotron heating at 40-55 MHz), as will nearly all of the diagnostics. The main goal of the following PFPO campaign is to fully commission the heating systems and qualify all of the controls and protection systems up to full plasma current. All major systems and controls needed for the Fusion Power Operation (FPO) phase should be tested by the end of this phase. While the main focus is again on system commissioning in this phase, a modest physics research program will be possible.

In the last assembly phase prior to FPO, the last major system, the tritium processing plant, will be completed and commissioned. Upon receipt of a license from the French nuclear regulator, the FPO campaigns can begin. At this point, the research program focuses on the Project goals introduced above. In the first FPO campaign, the focus will be on reaching transiently (~50 s) the 500 MW at Q = 10 goal. When successful, this will be the first time that dominantly self-heated or 'burning' plasmas have been produced in a tokamak. In the second FPO campaign, the research program will focus on extending the burning plasma regime to >300 s and initiating the research on steady-state plasmas that have large self-heating for up to 3000 s. In the third campaign, optimization of the steady-state scenario pointing toward Q = 5 will be the focus. Following this, the facility has significant design lifetime that can be used for fusion physics or technology research, depending on the results of the first campaigns and the interests of the ITER Members.

Achievement of the ITER Project goals will be a landmark in the quest for energy production from fusion. The vision of the fusion community is that it will be analogous to the flight of the Wright brothers to the aviation industry—a proof of principle that both establishes a vision for what is physically possible and a trigger for technological innovation and development leading to the rapid industrialization of fusion for energy production.

Kurzmitteilungen - Short Communications

Mercury Space Mission BepiColombo

On 19 October 2018, the European-Japanese spacecraft BepiColombo is scheduled to launch aboard an Ariane 5 from Europe's Spaceport in Kourou, French Guiana. Two satellites should be placed at different orbits around the near-solar planet Mercury after a seven-year flight. The European probe 'Mercury Planetary Orbiter' (MPO)' should then map the planet's surface by images and lidar measurements

from a low orbit of about 1000 km altitude crossing the poles in order to determine the inner composition of the planet. To this end, the shape of the craters and the surface structures are investigated, as well as the composition and dynamics of the residual atmosphere. The Japanese probe 'Mercury Magnetospheric Orbiter' (MMO)' should analyse Mercury's magnetic field and its interaction with the solar wind. Besides the massive solar radiation, special challenges are the large temperature differences: while on the sun side of the planet temperatures of about +430°C prevail, on the night side the satellites have to cope with -180°C in only a few hours. The reason for the long travelling time of 7 years are nine swing-by manoeuvres at Earth, Venus and Mercury to properly slow down the speed to exactly meet the orbit conditions.
http://sci.esa.int/bepicolombo/

BB

Nachruf Prof. Dr. Verena Meyer
(04.06.1929 – 21.07.2018)

Kurz nach ihrem 89. Geburtstag starb in Zürich Prof. Dr. Verena Meyer, Ehrenmitglied der Schweizerischen Akademie der Geistes- und Sozialwissenschaften und der Schweizerischen Physikalischen Gesellschaft, die sie von 1975 bis 1977 präsidierte.

Anschliessend an ihre Gymnasialzeit in Zürich studierte Verena Meyer Physik an der Universität Zürich (1948-1954), arbeitete dann als Assistentin am Physik-Institut und promovierte bei Hans Staub in experimenteller Kernphysik (1958). Nach einem Aufenthalt als Postdoktorandin in Minnesota kehrte sie 1960 zurück an ihr Heimatinstitut, lehrte und forschte zunächst als Dozentin und ab 1962 bis zu ihrer Emeritierung 1994 als Professorin. Dekanin der Philosophischen Fakultät II (heute Mathematisch-Naturwissenschaftliche Fakultät) (1976-1978), Rektorin (1982-1984) und Prorektorin für Forschung (1984-1986) waren die weiteren Aufgaben, denen sie sich an der Universität Zürich stellte. Von 1975 bis 1984 war Verena Meyer Mitglied der Abteilung IV des Nationalen Forschungsrats des Schweizerischen Nationalfonds, den sie seit 1981 auch leitete. Von 1987 bis 2000 präsidierte sie den Schweizerischen Wissenschaftsrat und war bis 1996 zusätzlich Mitglied der Energieforschungskommission des Bundes.

Portrait von 2002. Quelle: Journal, Universität Zürich, 40. Jhg, Nr. 4 (2010) "Unsere Charakterköpfe, Im Fokus, Mit Ecken und Kanten"

War es erstaunlich oder nur Zufall, dass mit Verena Meyer ausgerechnet aus der Physik, einem Studiengang mit minimalem Frauenanteil, die erste und bisher einzige Rektorin der Universität Zürich stammte, und sie auch in ihren späteren Funktionen als Pionierin wirkte? Sorgfältige Analyse des Problems, Planung und Konstruktion eines passenden Experiments, das dessen Untersuchung erlaubt und oft eine mutige Weiterentwicklung bekannter Techniken erfordert, und schliesslich kritische Betrachtung der Messdaten zeichnen unsere Forschungsdisziplin aus. Mit dieser Methodik vertraut war sie gut gerüstet für ihre administrativen Aufgaben an der Hochschule und die spätere einflussreiche Tä-

Verena Meyer im Gespräch mit Ernst Brun an der Feier zum 70. Geburtstag von Walter Kündig

tigkeit in der Schweizer und internationalen Wissenschaftspolitik. Die für sie charakteristischen Eigenschaften, sich bescheiden und frei von persönlicher Eitelkeit in den Dienst der Sache zu stellen und mit harter Arbeit sowie natürlicher Autorität ihr Umfeld beeinflussen zu können, halfen dabei ausserordentlich. Sie beeindruckten uns schon als Studierende, wenn sie uns einfühlsam und geduldig in Vorlesung und Praktikum, und später im Labor als Doktormutter zur Seite stand.

Die mächtigen experimentellen Einrichtungen, mit denen unsere Kolleginnen und Kollegen aus der Teilchenphysik Prozesse im frühen Universum nachvollziehen, wären undenkbar ohne die Vorarbeit, welche die kernphysikalische Forschung – der Entstehung der Elemente in den Sternen gewidmet –- unter anderem an dem kleinen van de Graaff Beschleuniger leistete, den Verena Meyer am Physik-Institut in den frühen 50-er Jahren aufzubauen half. Mit dem Aufbau des SIN, dem späteren Paul-Scherrer-Institut, in Villigen verlagerte sich zwar ihr Experimentieren an das dortige Zyklotron, doch führte sie bis zu ihrem Rücktritt noch eine kleine Gruppe, die in Zusammenarbeit mit der Industrie und der ETH die unverändert hochstehenden Qualitäten des zweiten, 1958 installierten van de Graaff-Beschleunigers nutzte, um Materialforschung zu betreiben.

Gerne erinnern wir uns nicht nur an die jährlichen gemeinsamen Ausflüge der Angehörigen des Physik-Instituts, an denen unsere Kollegin regelmässig teilnahm – am letzten vor ihrer Emeritierung durften wir sie sogar ein wenig feiern, etwas was sie sich an ihren Jubiläen immer verbat. Das Preisgeld des ihr 2000 verliehenen Karl-Schmid-Preises übergab sie dem Zürcher Universitätsverein zur Nachwuchsförderung, die ihr bei ihrer Arbeit in allen Gremien ein wichtiges Anliegen war. Auch ihre Festrede anlässlich der Feier zum 150-jährigen Jubiläum der Universität im Grossmünster – hier war am Stiftungstag (29.04.1833) dem ersten Rektor die Stiftungsurkunde überreicht worden - bleibt unvergesslich. Die Wissenschaftspolitik trieb sie auch nach ihrer Emeritierung 1994 noch um, so gehörte sie 2000 dem Expertenrat an, der alle Universitäten in Nordrhein-Westfalen evaluierte. «Kreatives Alter» nennt sich eine der vielen Stiftungen, für die sie als Expertin tätig war, einem Motto, dem sie auch in ihrem neunten Lebensjahrzehnt wahrlich nachlebte, trotz zunehmender Altersbeschwerden, die zum Umzug in eine Alterswohnung zwangen.

Als langjährige Teilnehmerin eines russischen Konversations- und Literaturkurses freute sie sich immer, akademische Gäste aus Russland bei sich in ihrem Witiker Haus zu beherbergen. Auch ihr Bündner Domizil in Tschappina, hier half sie den Nachbarn auch gelegentlich bei der Heuernte, stand Freunden offen.

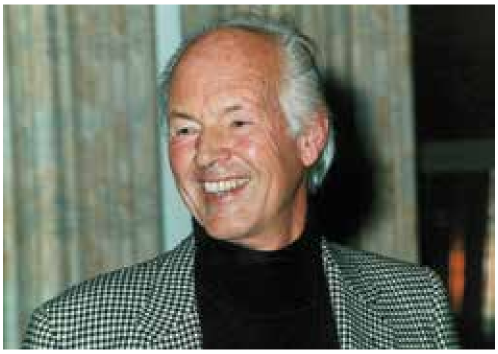
In mehreren ihrer Funktionen war Verena Meyer die erste Frau. In einem längeren Interview, das die Gleichstellungsstelle der Universität Zürich publizierte [1], hat sie diese Rolle eher heruntergespielt, «ich nahm das Leben wie es kam», sie habe auch von einem gewissen Frauenbonus profitiert. Dies werden alle, die ihr in Freundschaft und mit grossem Respekt und Dank verbunden waren bezweifeln. Ihre Familie, ihre Freunde und die Schweizer Wissenschaftsgemeinde betrauern den Tod einer aussergewöhnlichen Persönlichkeit.

Prof. em. Peter Truöl, Universität Zürich

1 http://www.gleichstellung.uzh.ch/de/politik/em-professorinnen/verenameyer.html

In Memoriam Wilfred Hirt (1936 – 2018)

Wilfred Hirt, physicist, sailor, pilot and former vice-director of the Paul Scherrer Institute died on June 13 in Biel. He was 82 years old.



After studying physics at ETH Zürich and doing doctoral research at CERN, Wilfred joined the team of Prof. Jean-Pierre Blaser that was working on the design of a new kind of accelerator. The plans for a meson "factory" based on this novel cyclotron design matured quickly and in 1968 the Swiss Institute for Nuclear Research (SIN) was created, where Wilfred became the head of administration and vice-director. He and the director Blaser led a lean and very efficient team that oversaw the construction of this unique high intensity proton accelerator that until today remains the world's most powerful machine. The proton beam drives not only the spallation neutron source SINQ, but also creates the brightest muon beams used for both fundamental physics experiments and solid state physics research.

A man of clear vision for the Swiss research scene, he was the first to bring up the idea of joining SIN with the neighboring Swiss Federal Institute for Reactor Research (EIR). Not only the synergies, but even more so the new research directions that would open up as a result of the fusion of the two institutes, were on his mind. A larger institute with strong ties to the Swiss universities would be more robust against fluctuations, less dependent on individual research topics of the day and capable of redirecting resources to the new challenges and themes of future research topics.

This idea was met with far from uniform support in both institutes, but thanks to his able handling of what in today's jargon is called "change management", this union became the Paul Scherrer Institute (PSI) and he remained vice-director of PSI until his retirement in 1998.

The first years of the newly created institute were not easy, the politics tried to impose tight control over the research directions. Wilfred fought hard to maintain autonomy of scientific research.

It was in those first years that after the proposal to build a B-factory at PSI did not find the needed support, he seized the idea of the designer team of that project to propose the construction of a very advanced synchrotron radiation source, which was to become the Swiss Light Source (SLS) later on. The first proposal to build such a 3rd generation light source met with strong resistance by significant segments of the Swiss scientific community. Wilfred and the SLS team had to explain to all the major players, and especially to the Universities and the National Science Foundation, the importance and great potential of such a facility. Together with Meinrad Eberle, who took over the directorship of the institute in 1992, they worked hard to convince the community and finally in 1997 obtained the project approval by the Swiss Parliament. The rest, as they say, is history. Swiss Light Source became a great success and paved the way to construction of the next flagship research facility at PSI, the SwissFEL.

PSI is 30 years old and this year's celebration is a fitting tribute to the memory of one of its founders who contributed so much to its success. The Paul Scherrer Institute supports research done by a large national and international user community and is recognized today as one of the world's leading national research laboratories. The fusion of two single-mission institutes into a multidisciplinary laboratory operating large scale research facilities, providing the ETHs and Swiss universities as well as industry with unique instruments that serve a wide spectrum of natural, engineering and life sciences, is indeed a success story.

Martin Jermann and Leonid Rivkin

Progress in Physics (65)

A milestone in the further development of the International System of Units

Beat Jeckelmann, Federal Institute of Metrology METAS

The General Conference on Weights and Measures is expected to adopt a fundamental revision of the International System of Units (SI) on the 16th of November 2018. Newly, a set of seven defining constants with fixed values completely sets the system and forms the basis for defining the units. After more than one hundred years of use, the revision will release the last artifact in the SI, the prototype kilogram, from service and replace it with a mass unit based on natural constants.

In almost all areas of modern society, from science and technology to industrial manufacturing and commerce to daily life, the International System of Units (SI) is used to express the results of measurements in a clear and comparable manner. With the advancement in science and technology, the SI has to evolve and adapt to the needs of users. The revision, to be approved in November 2018, marks a milestone in the further development of the SI. The changes will make measurement results even more consistent, reliable and accurate, enabling new scientific discoveries and innovations.

What distinguishes a system of units?

The choice of a system of units is not a strictly scientific process. It is characterized by historical compatibility conditions, practical considerations, and the knowledge of physical contexts but also some arbitrariness. Thus, the SI introduced worldwide today is the result of a long historical development. Above all, increasing demands on the accuracy of measurements repeatedly led to improvements in the definitions of the units [1]. An important constraint for changes is backward compatibility. Measurement results, such as the climate data should be comparable over a long period. This is only possible if the units used are stable and comparable in time within their uncertainties.

The current SI distinguishes base and derived units. The values of the base units, seven for the moment, are chosen by convention. The derived units are constructed as products of powers of the base units.

1: International prototype of the kilogram. Cylinder made of a platinum-iridium alloy, kept at the International Bureau for Weights and Measures (BIPM) in Sèvres, Paris. (Source: BIPM)

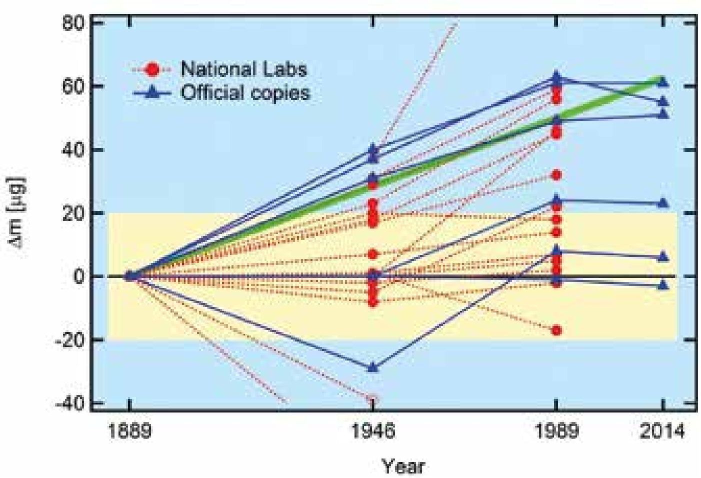
The definitions of the base units, as they have been used over time, can be divided in a simplified manner into different classes:

1.) An appropriate artifact is selected as the unit realization for the desired quantity. Until the upcoming revision, the kilogram is the last SI unit defined in this way: The kilogram is the mass of the International Kilogram Prototype, a cylinder made of a platinum-iridium alloy, which is stored at the International Bureau for Weights and Measures (BIPM) in Paris (Figure 1). This definition obviously has a local character. The unit is only available in one place, the BIPM. The transfer of the unit is done by comparison with the original standard and the accuracy is thus limited by the accuracy of the comparison method. Since the prototype kilogram is a macroscopic body with an unstable surface, the temporal evolution of the unit is not known exactly. This is the biggest disadvantage of the definition.

2.) A unit may also be realized on the basis of a suitable physical state. In this way, the second is defined by the period of the radiation of an atomic transition in the cesium atom. Prior to the revision, the realization of the temperature unit kelvin, makes use of the fact that the thermodynamic temperature of the water at the triple point keeps a stable value independent of environmental influences. The triple point is the state in which all three phases of the water, solid, liquid and gaseous, are in equilibrium. The unit realizations supported in this way have a universal character. This means that the units can be realized everywhere and at any time. All Cs atoms have the same properties that do not change over time. However, the states cannot be described with sufficient accuracy by an analytic model equation. In addition, the accuracy of the unit realization is limited by the characteristics of the chosen physical process itself.

3.) Finally, units can be based on natural constants. These also appear as proportionality constants and quantitative connecting points in the physical theories. Their value cannot be influenced and does not change spatially or temporally. Natural constants are thus the "natural" units and, in an ideal manner serve as the basis for the determination of SI units. Until the revision, the meter and the ampere are examples of this unit class. The meter definition assigns a fixed value to the speed of light in vacuum. In the case of the ampere definition, a fixed value is attributed to the magnetic permeability of the vacuum. Basic units of this type are universal in nature, such as those of type 2. However, they are not bound to specific physical states, which allows for a progressive improvement of the realization with the advancement of physics and technology.

Why a revision of the SI is needed?
Up to the SI revision, the kilogram is the last base unit still represented by an artifact. The kg is defined as the mass of the kilogram prototype. Copies of this standard are preserved by many National Metrology Institutes (NMIs) around the world. Since 1889, these copies have been compared three times to the international prototype. A number of copies were produced later and a comparative measurement with the prototype took place only twice. For both groups, it has been found that the mass of national copies has increased on average compared to the international prototype [2] (see also Figure 2). The mean relative change of about 50 µg in 100 years is very small. However, because the electric units refer to the force and thus to the kilogram through the ampere definition, a drift of the kilogram induces a similar drift in the electrical units.

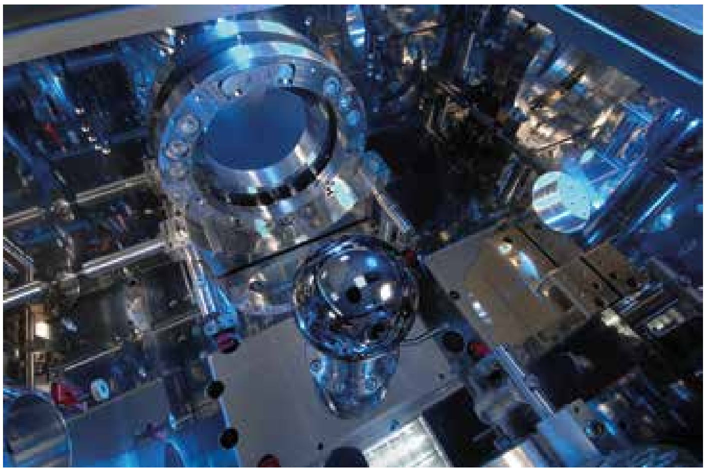


2: Periodic Verification: Comparison of National Copies and Official Copies with the kilogram prototype. The comparisons took place at the time of introduction in 1889, then in 1946 and finally in1989. The comparison of 2014 is not an official "periodic verification" because only one subset of the standards was involved.

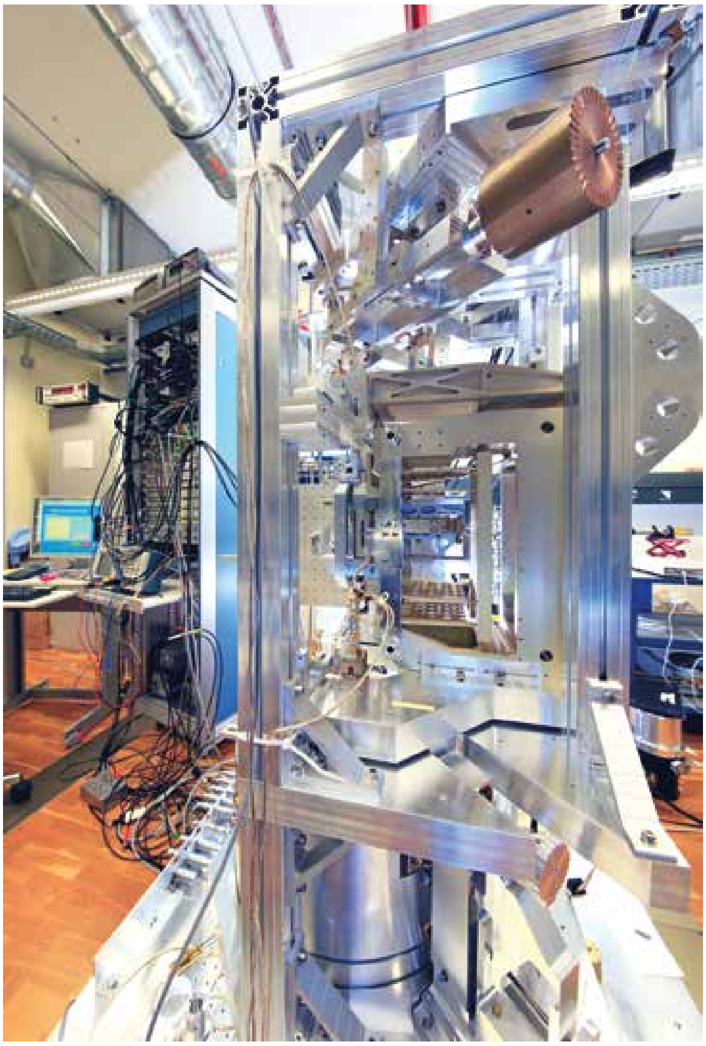
The ampere definition links electrical to mechanical units. For the realization of the electrical units, complicated electro-mechanical experiments are necessary (Kibble balance, calculable capacitor, ...). In modern electrical measurement technology, however, very reproducible voltage and resistance values are realized with the Josephson and quantum Hall effects, which according to the state of knowledge depend only on natural constants [3], [4]. The voltage of a Josephson standard is inversely proportional to the Josephson constant $K_J = 2e/h$. The quantized Hall resistance is proportional to the von Klitzing constant $R_K = h/e^2$. Josephson and quantum Hall standards are, thus, directly traceable to the elementary charge e and the Planck constant h. K_J and R_K could be determined before the SI revision with a relative uncertainty of 10^{-7}. This is about 100 times worse than the reproducibility of quantum effects in the laboratory. As a result, the International Committee of Weight and Measures introduced K_{J-90} and R_{K-90} on 1.1.1990 by convention: K_{J-90} = 483 597.9 GHz V^{-1}, R_{K-90} = 25 812.807 Ω.

This step has dramatically improved the global consistency of electrical measurements. On the other hand, however, it led to a practical subsystem in the SI, which is unsatisfactory from a conceptual point of view.

Also in temperature measurement, the previous definition of the base unit kelvin via the water triple point cell (type 2 according to the classification above) reaches its limits. The realization is sensitive to impurities in the triple point cell and the isotopic composition of the water used. In addition, the realization of the scale from the zero point and the triple point is very time consuming.



3: The sphere interferometer of the German Physikalisch Technische Bundesanstalt (PTB), with which the diameter of the silicon spheres in the XRCD experiment can be measured accurately down to a few nanometers. (Source: PTB)



4: Kibble balance at METAS. The Kibble balance compares mechanical with electrical power. If the electrical quantities are measured in terms of the Josephson and the quantum Hall effect resp., a relation between the test mass and the Planck constant is established.

Experimental precondition for the revision

In order to remedy the identified weaknesses of the system, extensive work was required on two fronts on the experimental side: the establishment of a link between the kg and the Planck constant with a relative uncertainty of ≤ 2 × 10^{-8} as required by the specialists, and the determination of the Boltzmann constant *k* with a relative uncertainty ≤ 10^{-6}. Especially the first problem turned out to be very persistent. Two fundamentally different approaches were pursued:

In the X-Ray Crystal Density (XRCD) experiment, the mass of a silicon atom is measured with high accuracy by "counting" atoms in a nearly perfect Si crystal [5] (Figure 3). The atomic mass in turn can be linked to the Planck constant *h* with very high accuracy. Therefore, the XRCD experiment offers the possibility to refer the kilogram either to an atomic mass or to the Planck constant. Another experimental approach is the so-called "watt balance" (or after its inventor, the "Kibble balance") [6] (Figure 4). The balance compares mechanical and electrical power. If the electrical power is measured with quantum standards, the mass can be related to Planck's constant [5]. Of course, the results of the two different approaches must agree.

There are a number of methods for determining the Boltzmann constant *k* [7]. The most accurate is the acoustic gas thermometer, where *k* is determined from the velocity of sound in a gas as a function of temperature.

The demands on consistency and accuracy in determining the Planck resp. Boltzmann constants and thus the conditions for a revision of the SI were achieved by spring 2017.

A set of constants defines the system

We have seen in the previous sections how the definition of the SI units ranges from a one to one relationship to an artifact (kilogram), through reference to a physical system or state (triple point of water for the kelvin), to the direct use of a natural constant as reference (speed of light for the meter). In the final step, the realization of the unit is conceptually detached from the definition. A unit defined by the fixed value of natural constants can be realized in accordance with the physical laws of science and technology. Improvements in the realization are possible without having to redefine the unit.

With the advances in the experiments, it becomes possible for the first time to base the entire SI on a set of constants with fixed values. In the SI, we have made the choice to select seven base units by convention. For this reason, we also have seven constants to set. The selected set of constants is as follows (see also info box and figure 5):

- *$\Delta\nu$: Frequency of the unperturbed ground-state hyperfine transition of the ^{133}Cs atom*.
  This constant defines the second. The SI revision does not change the practical realization of the unit.
- *c*: *Speed of light in vacuum*.
  With *c* and the second based on $\Delta\nu$, the meter can be realised. Again, the revision does not change anything in the immediate practice.
- *h*: *The Planck-constant,*
  together with *c* and $\Delta\nu$ and the appropriate experiments, linking the microscopic to the macroscopic mass scale, enables the realization of the kg. This is the most important result of the revision.
- *e*: *The elementary charge,*
  together with the second based on $\Delta\nu$ redefines the ampere. The ampere can be realized directly via single-electron circuits. The advantage of the definition of A, however, lies mainly in the fact that when fixing the Planck constant and the elementary charge, the Josephson and the Klitzing constant are also fixed and thus the Josephson and the quantum Hall effect realize the volt and the ohm resp. directly in the revised SI. This eliminates the need for the conventional constants K_{J-90} and R_{K-90}, as well as the practical subsystem.
- *k*: *The Boltzmann constant*,
  together with $\Delta\nu$, *c*, *h* and a suitable primary experiment (e.g., acoustic gas thermometer), realizes the kelvin. Therefore, the temperature of the triple point of water is no longer fixed and is now subject to uncertainty.
- N_A: *Avogadro constant*.
  By fixing the value of the Avogadro constant, the mole is defined as the amount of the substance containing 6.022 140 76 × 10^{23} specified elementary particles. The link to the kg, as it was previously made in the mole definition, is eliminated. Thus, the mass of ^{12}C no longer has a fixed value, but carries an uncertainty.
- K_{cd}: *Luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz.*
  With this definition, the realization of the candela remains unchanged.

5: The revised SI: The inner circle shows the 7 defining constants. They form the building blocks for the realization of units shown on the external circle. The seven base units of the SI are shown. All other units can be derived from combinations of the defining constants. Base and derived units are equivalent.

The SI is a practical system and in this sense, it is not surprising that the constants listed above do not all have the same significance. The speed of light *c* and the Planck constant *h* are considered as truly fundamental constants in modern physics. They refer to general properties of space, time and physical processes, which apply equally to every kind of particle and interaction. The Boltzmann constant *k* can be considered as a conversion factor between energy and temperature. The ground state hyperfine splitting frequency of the cesium 133 atom $\Delta\nu$ is the property of a particular atom. It cannot be easily expressed in more fundamental terms. The accuracy of the realization of the unit second, associated with this constant, is limited by the natural linewidth of the atomic transition. Considerable efforts are being made to define the unit of time in the foreseeable future through a more fundamental constant. The Avogadro constant N_A and the luminous efficacy K_{cd} are chosen for practical reasons; physicists do usually not consider them "basic".

Definition of the SI:

The International System of Units, SI is defined by fixing the values of 7 constants. The numerical values are taken from CODATA's least square adjustment carried out in the summer of 2017. The SI is the system of units in which:

- the unperturbed ground state hyperfine splitting frequency of the ^{133}Cs atom
  $\Delta\nu = 9\ 192\ 631\ 770\ s^{-1}$
- the speed of light in vacuum
  $c = 299\ 792\ 458\ m\ s^{-1}$
- the Planck constant
  $h = 6.626\ 070\ 15 \times 10^{-34}$ J s (J s = kg m^2 s^{-1})
- the elementary charge
  e = 1.602 176 634 × 10^{-19} C (C = A s)
- the Boltzmann constant
  $k = 1.380\ 649 \times 10^{-23}$ J K^{-1} (J K^{-1} = kg m^2 s^{-2} K^{-1})
- the Avogadro constant
  $N_A = 6.022\ 140\ 76 \times 10^{23}$ mol^{-1}
- the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz
  $K_{cd} = 683$ lm W^{-1}

Using the fixed constants and with the help of the laws of physics all units can be realized in the SI. The constants are the building blocks and set the standard for the entire system. Consequently, it is no longer necessary to distinguish between base and derived units. All units of the SI are derived from the chosen set of seven constants and are, thus, equivalent.

The Committee on Data for Science and Technology Committee (CODATA) periodically provides the scientific and technological community with a self-consistent set of internationally recommended values of natural constants and conversion factors for physics and chemistry through its Task Group on Fundamental Constants. Because of this role, the General Conference for Weights and Measures invited the CODATA Task Group to undertake a special adjustment to determine the values of the defining constants for the revised SI. All relevant data published or accepted for publication before the end of June 2017 have been taken into account in the analysis. The results of this calculation are listed in Box 1 [8], namely the numerical values of h, e, k and N_A, each with a sufficient number of digits to ensure consistency between the previous and the revised SI. The next regular CODATA periodic adjustment of the fundamental constants takes place in 2018. It will be unique as it will be the first one based on the exact fundamental constants of the revised SI.

Beat Jeckelmann graduated in 1986 from the University of Fribourg with a doctoral thesis in the field of experimental physics. He then worked as a post-doc in the Department of Physics at ETH Zurich and at the Massachusetts Institute of Technology. At the end of 1988 he joined the electricity sector of METAS. There his research work was mainly focused on the application of the quantum Hall effect as resistance standard and the associated measurement techniques. From 1997 to August 2015, he headed the electricity sector. Since 2011 he holds the position of Chief Science Officer at METAS.
One of the focal points of his work is the international cooperation in the metrology community, mainly in the framework of the European Association of National Metrology Institutes (EURAMET). He has been the Chair of the Technical Committee for Electricity and Magnetism; he is member of EURAMET's Board of Directors since 2010 and Chair of the association between 2015 and 2018. He is the Swiss representative in the Consultative Committee for Units of the Metre Convention.

What are the changes for the user?
The revised SI will enter into force on 20th May 2019, the World Metrology Day 2019. Although, on this day the most fundamental change since the introduction of SI will be implemented, it will not have any immediate impact on daily life. Despite the new definition, the values of the units kilogram, kelvin and mole remain initially unchanged. Only with the electrical units, small corrections will be necessary. The redefinition of the ampere makes obsolete the practical units defined by the conventional values of the Josephson and Klitzing constants. The "return" to SI means a relative change of 1.07 × 10^{-7} for voltage measurements and 1.78 × 10^{-8} for resistance measurements. These corrections are so small that they are only relevant to a few users outside the NMIs.

Conclusion
Thanks to the revision, the International System of Units is fit for the future. It is designed to allow better realizations of the units over time without being explicitly dictated by the system. Thus, the SI is on a solid basis in the long term and remains the foundation worldwide for measurements with the accuracy required by society, industry and science.

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Milestones in Physics (14)

The centennial of Richard P. Feynman

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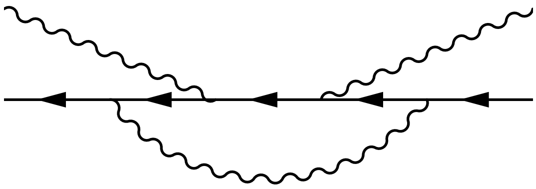
This year the physics community celebrates the centennial of the birth of Richard Feynman. Once one reads a bit about the man, as I had to do for the preparation of this note, it becomes less clear that he would find that much ado appropriate, as he claimed that "ancestor worship" hinders a generation from appreciating its own time. In any event, the writer and the reader have no choice other than worshipping him a bit together. Let us do so by going right to the heart of the matter.



Feynman's name became inseparably linked to Feynman diagrams, like the one seen in the figure. That particular diagram represents a contribution to the amplitude of a photon scattering off an electron (Compton scattering), an experiment simple enough to be shown in class (it was e.g. shown to me by the late Valentine Telegdi). Other, similar diagrams account for the determination of the magnetic moment of the electron, i.e. of its gyromagnetic factor g, in terms of the fine structure constant α. The best experimental value

$$g/2 = 1.00115965218073(28),$$

allows for a determination of α that is ten times better than, but in agreement with, the next best method. It makes Quantum Electrodynamics (QED) the physical theory that is verified to the greatest degree of precision (largest number of significant digits). The expression of "seeing further by standing on the shoulders of giants" can hardly be used more appropriately than in relation with those little drawings. They enabled generations of theoretical physicists to compute testable predictions of QED and of many other field theories, in particle and in condensed matter physics, in an almost automated way.

Such diagrams have two rather different faces. One the one hand they are a means to compute correlation functions of a *quantum field*, in that they organize the perturbative expansion in some coupling parameter, such as α, by taming the combinatorics, and allow to obtain finite results by renormalization. On the other hand, and much more pictorially, they represent *particles*, real and virtual ones, in guise of colliding trajectories with particles and antiparticles being drawn alike, except for running in opposite time directions; this is the case in the figure for electrons and positrons, shown as straight lines, but not photons (wiggly lines), as they are their own antiparticles. That dual reading is common knowledge nowadays (after all particles are asymptotic states of the quantum field), and is largely due to Feynman. His work on QED was rewarded with the Nobel prize in Physics in 1965, which he shared with Sin-Itiro Tomonaga and Julian Schwinger, whose approaches were quite different.

In order to understand how the diagrams came into being, let us backtrack a bit. Feynman was born on May 11, 1918 into a family that was not so well-off. He grew up in Far Rockaway (Queens, New York) and was raised by parents of Belarus and Polish ancestry. Richard's inquisitive attitude was fostered early on by his father, who wanted him to become a scientist. At high school he learnt to become a "real guy" and not a "sissy"; in his own words: "To be a practical man was, to me, always somehow a positive virtue, and to be 'cultured' or 'intellectual' was not". (He later admitted that "The first was right, of course, but the second was crazy.") That included his direct manners and his disrespect for authorities of all kinds. He also taught himself some advanced mathematics from a book by the title *Calculus for the Practical Man*. After high school he went to MIT in 1935 to study mathematics as his major subject. Not before long he went to see the head of the math department to just ask him "What is the use of higher mathematics besides teaching more mathematics?" Upon being told "If you have to ask that, then you don't belong to mathematics", he simply followed the advice and switched to engineering, which he soon found to be too practical to his taste. So he ended up doing physics, which was the real thing. All this, by the way, did not prevent him from taking part in 1939 in the Putnam mathematics competition, open to all undergraduates in the U.S. and Canada, where he ranked among the five (not further ranked) top scorers. But it shows, once again, that he loved math as long as it was problem oriented and led to concrete results.

By 1939, when Feynman arrived in Princeton for graduate studies, he already had set himself the goal of solving the problems with QED. Eventually he got his adviser Wheeler, by a few years his senior, interested in the idea for some time. Before continuing however we have to backtrack once more and briefly review the status of quantum field theory back then. Attempts to understand the theory were under way already for a while. In a sense, it was nothing but obvious from locality (the German word *Nahwirkungsprinzip* is more precise) that quantum theory would have to apply not just to particles, but also to fields, like the electromagnetic one. As early as 1929 Pauli and Heisenberg realized that the theory was plagued with divergences, the origin of which had to be found in the infinitely many degrees of freedom interacting with a point-like particle, not unlike with the self-interaction of a point particle in the classical theory. This did not prevent some significant successes, though all just obtained in leading order of perturbation theory. For instance Weisskopf and Wigner (1930) calculated spontaneous emission and thus the natural line width of spectral lines, as well as Einstein's A,B-coefficients; Bethe and Fermi (1932) understood that the interaction between charged particles is mediated by the exchange of virtual photons (later to be extended to nuclear forces by Yukawa); Bethe and Heitler (1934) treated the electron and the positron as a Dirac particle and were able to calculate effects such as bremsstrahlung of relativistic particles.

Feynman's initial approach to QED was both heretical and radical. First of all he decided that the infinities had to be removed at the classical level first; second, he just denied the existence of the electromagnetic field as a carrier of degrees of freedom, demoting it to nothing more than an auxiliary quantity determined by the particle variables, as we are used to in *electrostatics*. There, the interaction of a particle with itself can be declared to vanish and the mutual ones attributed to an action at a distance (*Fernwirkung*); and so did Feynman for *electrodynamics*. In order to comply with relativity, he would simply replace the action at a distance in *space* by one in *spacetime*. He soon realized that there would be no radiation resistance, but Wheeler (using an observation of Dirac) noticed that it could be rescued by treating emission and absorption of radiation (time-)symmetrically (Wheeler-Feynman electrodynamics). That however made the theory even more heretical because, if one thinks it through, one should no longer talk of emission and absorption, but just of transmission of radiation; in other words any light, that was once emitted by some star and is presently on a journey, is somehow predestined to be absorbed some day. (Crazy as it sounds for real photons, this is however the fate of virtual ones.) Quite importantly the theory also allowed for an action principle: The action is a functional of the worldlines $x^{(i)}(\cdot)$ of the particles i of masses $m^{(i)}$ and charges $e^{(i)}$ (no field variables!) given by

$$S=\sum_i\int m^{(i)}\,ds^{(i)}+\sum_{i\neq j}\iint e^{(i)}e^{(j)}\delta(R_{ij}^2)\,dx_\mu^{(i)}\,dx^{\mu(j)}\;,\qquad(1)$$

where $(ds^{(i)})^2=dx_\mu^{(i)}dx^{(i)\mu}$, $R^2=R_\mu R^\mu$, and $R_{ij}=x^{(i)}-x^{(j)}$. Notice that there is indeed no self-interaction and that mutual interactions occur only at light-like separations, yet time-symmetrically [9].

The next issue was to quantize the theory. Wheeler told Feynman not to pursue it, because he himself knew how to, whereas Pauli, who was skeptical about the whole thing, correctly predicted to him that Wheeler would not succeed. Feynman did not care. He saw the problem as a special case of a much more general one, namely that of quantizing a classical theory directly from its Lagrangian (or its action), i.e. without going through the Hamiltonian, and thus avoiding the approaches of both Schrödinger and Heisenberg. Somewhat fortuitously, Feynman learnt that Dirac had published an idea in this direction and actually even pointed out its worth in obtaining a manifestly relativistically covariant quantization. Feynman turned the idea into the path integral formulation of quantum mechanics. Still somewhat symbolically, it expresses the amplitude for a transition linking configurations q and q' of a systems between times t and t' as

$$\langle q',t'\,|\,q,t\rangle\propto\int_{\text{paths }\gamma}e^{iS(\gamma)}\mathcal{D}\gamma\,,$$

where the integral ranges over all possible paths γ joining (q,t) with (q',t'). (Essentially, Dirac proposed the integrand, but not the integral.) That got Feynman a PhD.

Still in Princeton he then started work with Wilson on the separation of uranium isotopes but soon afterwards he accepted to join the Manhattan project in Los Alamos early in 1943 and under Bethe, for reasons that we shall see. There he attended to all sorts of tasks, such as managerial, theoretical and computational ones, including operating and fixing electromechanical computers, as well as overseeing human ones. His work on QED became intermittent.

In 1945 Feynman went to Cornell as a professor and in 1949 he finally accomplished his goal to quantize QED. He did so in two twin papers by the titles of *The Theory of Positrons* [5] and *Space-Time Approach to Quantum Electrodynamics* [6]. The first one actually did not deal with electrodynamics proper, but with the scattering of a Dirac particle, such as an electron, in an external electromagnetic field $A^\mu(x)$ depending on space and time, $x = (x^\nu)_{\nu=0,\dots3}$. For comparison, scattering of a Schrödinger particle is computed perturbatively by means of the retarded Green's function of the free particle. That is not the only possible choice of Green's function, but a physically convenient one, because the state is usually specified in terms of an incoming state. Feynman noticed that that could not work for a Dirac particle, because the negative energy states are not available to the electron. Those states, which are to be interpreted as positive energy states of the positron, are available not after scattering, which would violate charge conservation, but before it, which describes pair annihilation. The correct Green's function would thus have to be like the retarded one in its positive energy part and like the advanced one in the the negative energy part; more pictorially a positron is an electron running backwards in time. That Green's function became later known as the Feynman propagator for the Dirac field and yields the weight associated to any of the straight electron/positron lines in the figure.

In the second paper Feynman quantized the theory defined by (1). The second term would be viewed as a perturbation of the first one and, in the resulting perturbation expansion, $\delta(R^2)$ would be the Green's function mediating the interaction between spacetime points x and y across their separation $R = x - y$. Feynman realized however that $\delta(s)$ would have to be replaced according to

$$\delta(s)\rightsquigarrow\delta_+(s):=\delta(s)+\frac{1}{i\pi s}=(i\pi)^{-1}(s-i0)^{-1}\,,\qquad(2)$$

which is the positive frequency part of $\delta(s)$. The result is essentially the Feynman propagator of the electromagnetic field, yielding the weight of the wiggly photon lines. That change retains the time symmetry of $\delta(R^2)$ (unlike the retarded or advanced Green's functions of which $\delta(R^2)$ is the half-sum), but now its future part (i.e. for $R^0 > 0$) has a time dependence like $\propto\delta_+(R^0-|\vec{R}|)$ which contains only positive frequencies. That paralleled what he did in the previous paper and embodies the physical fact that the photons mediating the interaction only have positive energies.

The paper contained some guesswork. We may imagine that this could have been the cause for the poor reception, at least in Feynman's own perception, of his ideas at the Pocono conference the year before. He later explained the mishap by saying that "my machines came from too far away".

There was one more change in the paper with respect to. his work with Wheeler. The self-interaction $i = j$ was reinstated in (1) but was now less troublesome, because the δ-singularity got replaced by the milder pole singularity of δ_+. Both changes were acknowledged in two small footnotes, but were described in a much more flowery way years later in his Nobel lecture *The development of the space-time view in quantum electrodynamics*, which ended as follows: *So what happened to the old theory that I fell in love with as a youth? Well, I would say it's become an old lady, that has very little attractive left in her and the young today will not have their hearts pound anymore when they look at her. But, we can say the best we can for any old woman, that she has been a very good mother and she has given birth to some very good children. And, I thank the Swedish Academy of Sciences for complimenting one of them. Thank you.*

As a little aside, these words may prompt some considerations on Feynman's relation to women. It is likely that it would nowadays be frowned upon to use metaphors like the one just mentioned, at least if done by a man of his standing. A likely no-go today would also have been his frequent visits to those places, where anybody can meet lightly dressed women but only he could do physics ("When my calculations didn't work out, I would watch the girls.") One should however not jump to the conclusion that he reduced women to pleasure or motherhood. For instance, he married his first wife Arline Greenbaum at a time it was clear she would provide neither, as she was ill with tuberculosis and he knew she would soon die. He quit his job with Wilson at Princeton and joined the Manhattan project because he thought that the climate in New Mexico would be beneficial to her. (Sure, he also supported the goal of the project, which was then directed against Germany, but his last job in Princeton had the same one.) Arline taught him how to love. In a letter he would have liked to send her a year after her death in 1945, and which was opened after his own in 1988, he wrote "You, dead, are so much better than anyone else alive." On another count he encouraged his younger sister Joan to earn a PhD in physics, which she did. All this considered one should rather conclude that Feynman simply managed to bear life with a lightness perhaps forgotten nowadays.

But let us return to physics, at least briefly. Among the countless contributions across all of physics let us recall a few [1]: (i) On liquid helium, where he went beyond the phenomenological theory of Landau by placing its conclusions on the foundation provided by the many-body Schrödinger equation; (ii) on parity violation, where he and Gell-Mann proposed a modification of the Fermi theory of the weak interaction that would account for its then recent discovery. (The same V-A–theory was independently found by Sudarshan and Marshak); (iii) the parton hypothesis as a general model of composite hadrons. The theory proved successful in describing deep inelastic scattering of leptons by hadrons and is a precursor of the quark model and hence of Quantum Chromodynamics. (iv) Feynman, in a talk by the title *There's Plenty of Room at the Bottom* given in 1959, envisaged the opportunities that miniaturization would provide. He foresaw a lot of what nanotechnology would later accomplish, and ahead of Moore's law. (v) In a talk in 1981 he proposed to simulate quantum systems by universal computers that operate themselves according to the laws of quantum mechanics. While he may not be credited for being the first one to propose a quantum computer, he popularized the idea a lot. Many experiments, in particular with ultracold atoms, are done today in this spirit. However, those simulators are not universal and it remains to be seen whether other implementations are, while still being scalable and quantum.

The human side of Feynman is also well-known, not least thanks to himself, who spread lots of stories now collected in various books [2, 3, 4]. There is no need to recount them here (with one exception below). I just would like to add two anecdotes, not found there, told to me by Christoph Schmid and Klaus Hepp, who were young postdocs when they met him. Feynman took interest in the research of young fellows at Caltech, like Christoph, even if it was not in the line of his own. During discussions with them he expressed his views: To him physics had to have a clear "why", had to be reasonably concrete, and be done by getting one's hands dirty; moreover he liked to play the tough guy. As for Klaus, Feynman barely knew him, but one evening at a conference in Berkeley he entrusted him with safekeeping his office folder full of work in progress, so he could go to a topless bar. In the meantime Klaus had to resist all night the much bigger temptation of opening it.

Let us also spend some words on Feynman's relation to anything "cultured" or "intellectual", which in his youth included poetry ("To me no *real* man ever paid any attention to poetry and such things") but also higher mathematics, as we saw. At least in later years that was no longer always the case. One quite insightful instance, pointed out to me by Arthur Jaffe who witnessed it, is provided by a Rochester meeting in 1967, where Feynman proved to fully appreciate a genuine mathematical issue. Wightman lectured on quantum field theory in mathematical terms. After the lecture, Feynman asked a long question worth to be cited at least in part: ... *I want to get experimental results and I'm not usually worried about general mathematical questions. However there is a mathematical question which I think is very relevant. ... The question is whether this theory [QED] if carried out to the ultimate in all orders will give a satisfactory series (I don't mean in agreement with experiments, but with logic). ... I do not know and I am not at all convinced that ... the limit really does give a logically satisfactory theory; ... The question is, do we have a theory? ... I just don't know whether the whole thing means anything.* Some of the people present, including Hepp, could reassure him that the theory is finite order by order after renormalization, but that did not satisfy him: *I thought that each order could be computed and that the renormalization would work out. I didn't prove it and I am not worried about proving it. I thought it was true. I don't worry about proving something I think is true. I worry about proving something I'm not sure about.* Nobody could answer his real question, though. Reasons to worry (Landau pole, Gell-Mann-Low equation) existed already back then, but they had their basis in perturbation theory itself. Today, by works of Aizenman and Fröhlich, we know that the worries are well-founded on non-perturbative grounds.

In the last twenty-five years deep connections have emerged between Feynman diagrams on the one hand and Hopf algebras, Galois theory, and the Riemann zeta function on the other. One may just wonder how Feynman would have commented those outgrowths of his work into pure mathematics. For a change one might also wonder what poets would have thought about Feynman. It seems to me that Walt Whitman (1819-1892) would have seen in him the fulfillment of his own American dream (*Song of myself*): “Do I contradict myself? Very well then I contradict myself, (I am large, I contain multitudes.)”

We cannot close this note without making some links to Switzerland and specifically to Geneva. The first one simply is that he first met Gweneth Howarth, who would become his wife for the rest of his life, in 1958 in Geneva, where she spent time as an au-pair from the UK and he participated at a UN conference. The second link is a little Feynman story: During that same visit he lodged at a hotel which turned out to be a brothel. He made a reservation well in advance, perhaps still unaware of the kind of location, but was nonetheless delighted by what he then saw. That included the owner’s embarassment as he became aware of the kind of guest once the UN called in. The reassuring thing however was “It’s Switzerland; it was clean!”. The last link is more important and relates to Ernst Stueckelberg, who was professor of theoretical physics in Geneva from 1935 to 1975. Fact is that already in 1934 Stueckelberg realized the importance of a manifestly relativistically covariant perturbation theory, and so is that in 1941 he drew figures in which positrons are represented by worldlines running backwards in time. The latter is acknowledged by Feynman in the abstract of his first paper of 1949. Stueckelberg and his student Rivier even came up with the Feynman propagator, but published it about one month after him. Less documented is the following event, reported by Mehra [7], which purportedly took place in 1965 after a lecture by Feynman: “After the lecture, Stueckelberg was making his way out alone ... from the CERN ampitheatre, when Feynman – surrounded by admirers – made the remark: 'He [Stueckelberg] did the work and walks alone toward the sunset; and, here I [Feynman] am, covered in all the glory, which rightfully should be his!'” Even if true, that would in no way diminish Feynman’s scientific achievements. It would add to the man.

Acknowledgments. I thank Klaus Hepp, Arthur Jaffe, and Christoph Schmid for sharing their memories about Feynman with me, as well as Jürg Fröhlich and Jan Lacki for discussions.

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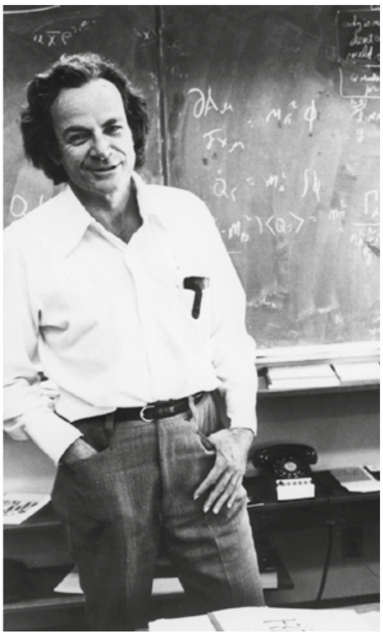
Symposium: Richard Feyman's centennial celebration

30 November 2018, 10:00h - 17:00h

University of Geneva - Sciences II - 30, quai Ernest Ansermet, Auditorium A100

Organizers of the symposium: Jan Lacki and Hans Peter Beck.



The SPS celebrates Richard P. Feynman in his 100th year of birth twice, first by the excellent article above and second, by organizing a joint symposium together with the *History and Philosophy of Science Unit* of the University of Geneva. The celebration, gathering physicists and historians of modern physics, intends to review Richard Feynman’s contributions to 20th century physics in a morning session and aims at presenting some examples of contemporary research that has followed upon his pioneering work in the afternoon session of the celebration event.

Five international well-known experts will remind us on Feynman or will tell us where Feynman’s legacy is an ongoing fertilizer in pioneering efforts of contemporary fundamental physics research:

- **Olivier Darrigol** (CNRS and Paris-Diderot University): *The magic of Feynman's QED*
- **Charalampos (Babis) Anastasiou** (ETH Zürich): *Feynman diagrams and modern collider physics*
- **Gabriele Veneziano** (CERN and Collège de France): *Feynman’s strong interaction side*
- **Uwe-Jens Wiese** (Bern University): *Quantum Simulation: from Feynman's Vision to Today's Reality and into the Future*
- **Adrian Wüthrich** (TU Berlin): *Putting Feynman’s style in context*

The SPS welcomes everybody to learn more about this extraordinary scientist, whose many outstanding physical visions are expected to be realized in the near future like Quantum Computing. Feynman supposed already 1982 that it could simulate quantum mechanical systems with much greater accuracy than classical computers.

History of Physics (21)

SOHO – the ESA / NASA Solar and Heliospheric Observatory
I. Overview, a Window into the Solar Interior, and SOHO's Instruments

Martin C. E. Huber

The Solar and Heliospheric Observatory *SOHO* is a space observatory that studies the Sun from its deep core to the outer corona and beyond – into the Heliosphere [1]. *SOHO* is observing from a halo orbit around the first Lagrange point, L1, in the Sun-Earth system – about five light-seconds away from Earth toward the Sun (cf. Fig. 1). Launched in December 1995, *SOHO* is still operating today [2]. Remarkably, it is the first joint ESA/NASA mission that is led by the European Space Agency [3].

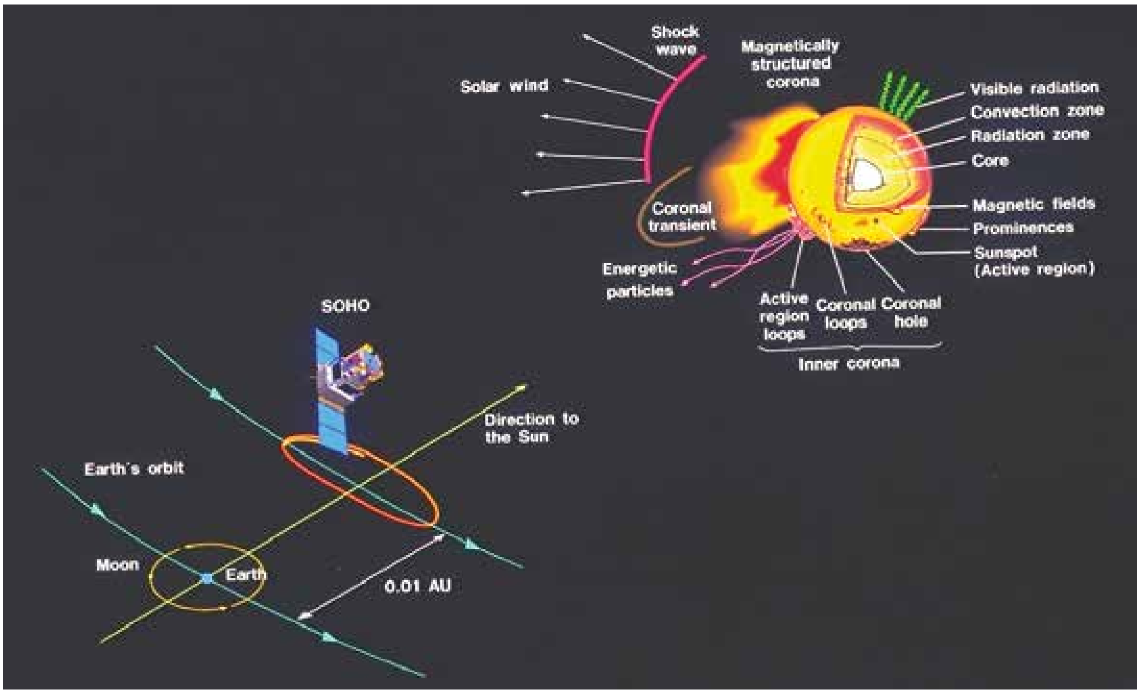


Figure 1: The location of SOHO in a halo orbit around the first Lagrange point, L1, in the Sun-Earth system, with a sketch of solar phenomena that can be studied from this orbit.

From its vantage point at L1 *SOHO* observes the rich palette of solar phenomena depicted in Fig. 1. The internal structure of the Sun is shown in its cut out octant: fusion generates a temperature of ≈ 15 MK in the core of the Sun; this energy-producing region extends to about the first quarter of the solar radius (0.25 $R_\odot$). Heat then migrates through the radiation zone to about 0.75 $R_\odot$, where convection sets in and becomes the dominant mode of energy transport to the 'surface'. The outermost atmospheric layer is the 300 km thick photosphere, which has a temperature of about 5800 K and radiates off most of the Sun's energy. A small part of the energy, in non-thermal form, is used to maintain the corona – an extended, tenuous atmosphere above the photosphere with a temperature reaching millions of kelvin –, and to accelerate the solar wind that sustains the Heliosphere.

The scientific goals of *SOHO* can be summarised by three questions, namely

- what are the structure and dynamics of the solar interior?
- why does the solar corona exist, and how is it heated to a temperature of millions of kelvin?
- where and how is the solar wind accelerated?

In this first part of an article on *SOHO*, we present an overview of the mission, address the first above question, and sketch *SOHO*'s scientific payload. The still mysterious temperature increase above the relatively cool photosphere as well as the acceleration of solar wind will be the topic of the second part of this article in the next issue of the *SPG Mitteilungen*.

Helioseismology

At first sight, the aim implied by the first question above, namely looking into the solar interior to investigate its structure and dynamics, sounds rather extravagant. But exploring the solar interior did become feasible in 1975, after Deubner [1] had demonstrated that the five-minute oscillations, which had been discovered and extensively explored by Leighton, Noyes and Simon [2], are in fact a manifestation of global oscillations propagating throughout the Sun. This offered the prospect of probing the solar interior by helioseismology – a method analogous to geoseismology, where waves generated by an earthquake, for example, propagate inside the

1 The Heliosphere is a bubble-like region in space that is dominated by the Sun. Plasma 'blown out' by the Sun – the solar wind – maintains this bubble against the outside pressure of the interstellar medium, i.e. the gas that permeates the Milky Way Galaxy (cf. *https://en.wikipedia.org/wiki/Heliosphere*).

2 This article is published under the rubric 'History of Physics', because it was originally expected that the *SOHO* mission would end this year. However, given the excellent current state of spacecraft and experiments and the prospective contributions of *SOHO* to NASA's recently launched *Parker Solar Probe*, an extension of the mission is now considered.

3 European industry built the *SOHO* spacecraft with ESA funding under ESA project management. NASA provided the launch by an Atlas II-AS rocket and ESA's Space Operations Centre (ESOC) in Darmstadt handled the navigation to L1. A joint ESA/NASA team, located at NASA's Goddard Space Flight Center (GSFC) in Greenbelt MD/USA, then took over the science operations, i.e. planning and verifying of the observing programme, while NASA controlled the spacecraft. The European experiments on *SOHO* have been designed, built and tested with national resources in laboratories of European Universities and research institutes. Across the Atlantic, the same applied to the NASA-provided instruments, except that they received their funding from NASA. Some instruments were actually the result of trans-Atlantic collaborations.

Earth and are measured as a time-dependent deformation of the surface. From such measurements on the surface of the Earth it is possible to gain information on the interior structure of the Globe.

In the case of the Sun the oscillations are persistent. Their most easily detected form of appearance – the pressure modes – are standing acoustic waves. They manifest themselves in spherical harmonics. As an example, we show a single spherical harmonic in Fig. 2.

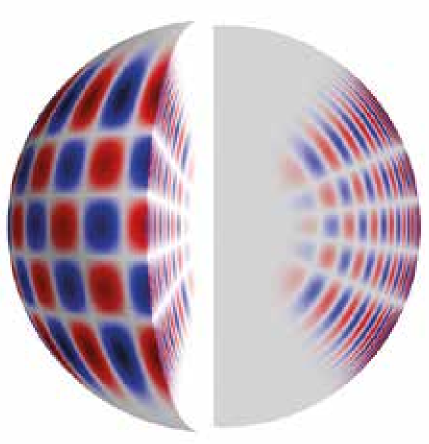


Figure 2: Representation of a single mode of solar oscillations – the pressure mode with radial order n = 14, angular degree l = 20 and azimuthal order m = 16. The corresponding spherical harmonic is marked on the surface (with opposite motion, or displacement, indicated by red and blue). The interior shows the radial displacement computed using a standard solar model. Note that the increase in the speed of sound, as waves approach the centre of the Sun, causes a corresponding increase in the acoustic wavelength [after 3].

The frequency of such a mode depends on the course of the sound speed in the solar interior, and can be determined by observing the time-dependent deformation of the areas shown on the surface of the sphere of Fig. 2. On the Sun this can be done by observing either the periodic Doppler shift of a corresponding area on the photosphere [4], or by recording the periodic intensity changes of such areas that are associated with the oscillations. Since the local speed of sound in the solar interior depends on the progression of density and temperature with depth, an inversion procedure by use of a large number of modes and their frequencies is able to determine this course.

Such measurements are not trivial, however, since each radial order, *n*, of the spherical harmonics appears with up to hundreds of angular degrees, *l*, that have slightly different frequencies [5]. The frequencies of the modes must be found from a Fourier analysis of the observed time series. At the frequencies observed for pressure modes (i.e., approximately 1 mHz to 5 mHz), this requires long, uninterrupted observing periods.

Early in the 1980s the first long, uninterrupted helioseismology observation was obtained during the southern summer by a telescope set up near the South Pole [4]. Later, networks of telescopes located around the globe have been set up to overcome the day-night cycle at fixed observing sites at low-latitudes [6]. As of early 1996 *SOHO* is also providing uninterrupted time series for helioseismology from L1 [7].

Today, helioseismology is a wide, very active field. It uses observational and mathematical methods that are much more numerous and complex than what we can describe here: there is global and local helioseismology; and beyond the pressure modes discussed above, there exist gravity modes that are confined to the convectively stable interior of the Sun [8] as well as surface gravity modes. Moreover, helioseismology has spawned asteroseismology – seismology on stars [9].

The helioseismology payload of *SOHO* at L1 has produced several «Firsts» in solar physics. The use of the relevant instruments [10] has led to

- the first images ever taken of a star's turbulent outer shell, i.e. of its convection zone,
- revealing the structure of sunspots below the solar 'surface' [11].

In addition, *SOHO* has

- provided the most detailed and precise measurements of
  - the internal temperature structure of the Sun (cf. Fig. 3),
  - the rotation of the solar interior, and
  - of gas flows in the solar interior.

Spacecraft and Science Payload

Fig. 4. shows the spacecraft with its twelve scientific instruments that enable the investigation of the palette of solar phenomena symbolised in Fig. 1. The scientific instruments are mounted on the upper part of the spacecraft, on the so-called payload module. A service module with equipment for power and communications, as well as propellants and thrusters for attitude and orbit control is located in the lower part of the spacecraft. The total mass of *SOHO* at launch was 1850 kg, its length along the Sun-pointing axis (its height in Fig. 4) is 4.3 m; the solar panels – the blue panels facing the technicians – are unfurled in space to a span of 9.5 m. Propellants, which were needed to guide *SOHO* from Earth to its halo orbit around L1 following the launch were part of the weight; the remainder of these propellants is now used to keep the spacecraft on its halo orbit, and to control the spacecraft's attitude [12].

4 Reminder: the photosphere is the atmospheric layer that we perceive to be the solar 'surface'.

5 Modes with angular degrees *l* from zero (corresponding to purely radial motion) to several hundred are observed. Moreover, the rotation of the Sun breaks the degeneracy of the modes with different azimuthal orders *m*. As a consequence, the observed mode frequencies differ by *rotational splittings* that are weighted averages of the rotation rate throughout the Sun. (They are weighted, because the overall power of a given mode has different contributions at different radii inside the Sun.)

6 GONG (the Global Oscillation Network Group) and BiSON (Birmingham Solar Oscillations Network), set up by the US National Solar Observatory and by Birmingham University, respectively, are still operating today.

7 In 2010, NASA launched the Solar Dynamics Observatory (SDO) with an advanced helioseismology payload into an inclined geosynchronous orbit, where the spacecraft is also in permanent sunlight.

8 Refer to Fig. 1 for the internal structure of the Sun.

9 A general, albeit very concise description, of the principles and the history of helioseismology (and asteroseismology) is available in the Wikipedia article: https://en.wikipedia.org/wiki/Helioseismology#Global_helioseismology.

10 *SOHO*'s instruments used for helioseismology observations are described, in the context of the entire scientific payload below.

11 Note that both these accomplishments have used the method of local helioseismology.

12 The halo orbit around L1 is not gravitationally bound; *SOHO* therefore needs propellants to follow its trajectory. A halo orbit, rather than station at L1 was chosen, because it uses less propellant than keeping the spacecraft in the metastable Lagrange point. Seen from Earth, *SOHO*'s orbit keeps

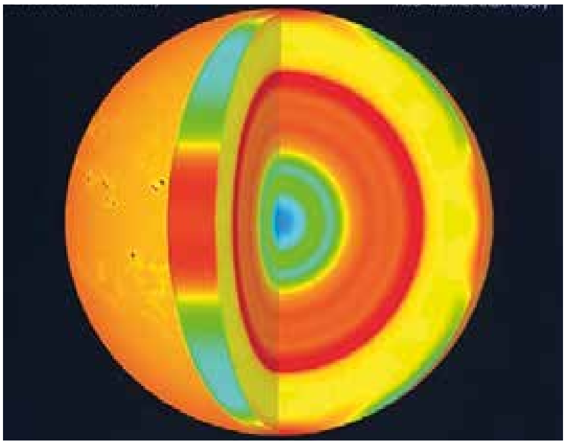


Figure 3: SOHO data revealed oddities in the speed of sound in the solar interior: measured and theoretically predicted sound speeds differ. Differences in sound speed are shown here as the related temperature differences – with 'green' to 'blue' indicating cooler than theory, and 'red' warmer than theory. The conspicuous darker shell at the transition between the stable inner radiation zone and the turbulent outer convection zone suggests unexpectedly high temperatures. This shear layer (where a rapid change in the speed of rotation has been measured as well) may generate the solar magnetism.
(Credit: SOHO (ESA & NASA), MDI/SOI and VIRGO data, image by A. Kosovichev, Stanford Univ.)

SOHO's Science Payload consists of three parts:

the *Helioseismology Experiments*, which take full advantage of the continuous sunlight at L1 to record the long time series needed for high-resolution Fourier transforms; the imaging helioseismology instruments also take advantage of the spacecraft's stabilisation to one arc second,

the *Solar Wind and Particle Payload*, which benefits from the fact that L1 is far away from the Earth's magnetosphere and offers full access to the solar wind, and

the *Coronal Payload*, which is used to investigate the solar phenomena depicted in Fig. 1 with high spatial and spectral resolution over a wavelength range extending from the visible to X-rays. In addition, three coronagraphs with fields of view extending to 30 $R_{\odot}$ permit observations of the lively extended corona – and have led to unexpected discoveries of numerous comets.

The three helioseismology experiments and the institutions of their Principal Investigators are

MDI/SOI – the **Michelson Doppler Imager/Solar Oscillations Investigation**, Stanford University CA/USA,

GOLF – **Global Oscillations at Low Frequencies**, Institut d'Astronomie Spatiale, Orsay/F and

VIRGO – **Variability of Solar Irradiance and Gravity Oscillations**, Physikalisch-Meteorologisches Observatorium Davos/CH.

They provide measurements of both intensity and Doppler-shift oscillations with spatial resolutions ranging from very high to modest, i.e. from 10^6 to a few data points or even to a single element, namely the solar disk. This, together with the wide frequency range covered, yields a comprehensive insight into the structure and dynamics of the solar interior (cf. Fig. 3). Measurements of the line-of sight component of the magnetic field are also provided; and accurate measurements are taken to quantify the variability of the total solar irradiance (still paradoxically known as '*solar constant*') over periods of days to the duration of the *SOHO* mission.

The four instruments of the solar-wind and particle payload and their PI institutions are:

CELIAS – the **Charge, Element and Isotope Analysis System**, Max-Planck-Institut für Extraterrestrische Physik, Garching/D

COSTEP – the **Comprehensive Suprathermal and Energetic Particle Analyzer**, University of Kiel/D

ERNE – the **Energetic and Relativistic Nuclei and Electron experiment**, University of Turku/FIN and

SWAN – **Solar Wind Anisotropies**, Service d'Aéronomie du CNRS, Verrières-le-Buisson/F

These experiments continuously sample the solar wind as well as more energetic ions that are not only of solar, but also of interplanetary and interstellar origin. The latter measurements permit a classification of the wide range of energetic particle populations of solar, interplanetary and galactic origin. The SWAN experiment – the only instrument on *SOHO* that doesn't look at the Sun – studies the interaction between the solar wind and hydrogen atoms from interstellar space that intrude into the Solar System. SWAN thus determines how the solar wind is distributed within the Heliosphere.

The five experiments of the coronal payload and their PI institutions are:

EIT – the **Extreme ultraviolet Imaging Telescope**, Institut d'Astronomie Spatiale, Orsay/F

Figure 4: The SOHO spacecraft photographed during its laboratory tests. In its halo orbit, SOHO is three-axis stabilised and points continuously at the Sun.

the spacecraft about 45° off the Sun. The antennas of the NASA Deep Space Network thus receive the pure data stream, free of a background of solar radio emissions.

CDS – the **Coronal Diagnostics Spectrometer**, Rutherford Appleton Laboratory, Chilton/UK

SUMER – **Solar Ultraviolet Measurement of Emitted Radiation**, Max-Planck-Institut für Sonnensystemforschung, Göttingen/D

LASCO – the **Large Angle and Spectrometric Coronagraph**, Naval Research Laboratory, Washington DC/USA and

UVCS – the **UltraViolet Coronagraph Spectrometer**, Smithsonian Astrophysical Observatory, Cambridge MA/USA

EIT, the 'eyes' of *SOHO*, provides full-disk images of the Sun in the extreme ultraviolet that map the plasma in the low corona at temperatures between 80 kK and 2.5 MK. The two imaging spectrometers CDS and SUMER provide diagnostics of solar plasma, and enable the determination of the temperature and density, as well as of flows of the solar plasma over a temperature range from 10 kK to 2 MK. LASCO creates a permanent artificial solar eclipse that reveals the solar corona from near the limb to a distance of 30 $R_\odot$ or ca. 21 Gm, i.e. about a seventh of the distance between the Sun and the Earth; LASCO unexpectedly turned out to be a fertile comet finder (see info box). UVCS also creates an artificial eclipse with a field of view ranging from 1.3 to 12 solar radii and permits analysing the microscopic and macroscopic behaviour by observing the less intense far-ultraviolet emission of the highly ionised plasma in the corona.

Planning the Observing Programme

Parts of the science payload are complementary, as demonstrated by Fig. 2, which is based on data obtained by both the MDI/SOI and the VIRGO instruments. The complementarity of experiments helped significantly in addressing the complex solar processes under investigation. But this required a close coordination of *SOHO*'s observing programme. For several years after launch, representatives of the groups that had contributed payload instruments, were present at the Science Operations Centre (located at the Goddard Space Flight Center, GSFC, in Greenbelt MD/USA) to jointly develop, and agree on the daily – and longer-term – observing programmes. Observing planning also was guided by daily data on solar activity provided by ground-based solar observatories; in turn *SOHO* also performed space observations that were coordinated with observatories located around the globe.

Preview: Part II addressing *SOHO*'s findings in coronal and solar wind physics will appear in the next issue of the *SPG Mitteilungen*. We will also discuss the challenges of radiometric stability, particularly of instruments designed for observing extreme-ultraviolet radiation and the stringent cleanliness requirements to be applied to all work on the ground. We will also mention the accidental loss of the spacecraft in June of 1998 and particularly its successful recommissioning of all the instruments by November of that year.

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SOHO the Comet Finder

SOHO – conceived as a solar flagship mission – turned out to be a very productive comet finder as well. Over 3000 such objects passed through the wide field of view of the Large Angle and Spectrometric Coronagraph LASCO. Most of these objects were unknown 'Sun-grazing' comets; some of them survived their perihelion, but others burned up during a fiery encounter with our daystar [1].

Comet 2012/S1 (ISON, cf. Fig. 5) was a peculiar case. After its discovery in the autumn of 2012 its perihelion was predicted for November 28, 2013 with a distance of only 1.2 Gm (or ca. 1.7 $R_\odot$ above the solar surface). Early on ISON was rather bright and some astronomers hoped that it might become a "comet of the century" after perihelion – "a stunning celestial phenomenon" in the weeks preceding Christmas 2013. But as the comet appeared in LASCO's field of view, its tail became increasingly faint. A detailed analysis of the encounter that also included observations by SUMER showed that the comet broke up or disintegrated shortly before its perihelion [2].

1 The movie https://soho.nascom.nasa.gov/hotshots/2015_09_15/G2015-069_3000SOHOcometsV2-H264_Good_1080_29.97.mov shows the trajectories and describes the categories of the comets observed by LASCO.

2 An in-depth data analysis, which also made use of SUMER observations, has revealed that comet 2012/S1 (ISON) stopped producing dust and gas shortly before it raced past the Sun and disintegrated (cf. http://sci.esa.int/soho/54344-comet-ison-dramatic-final-hours/.

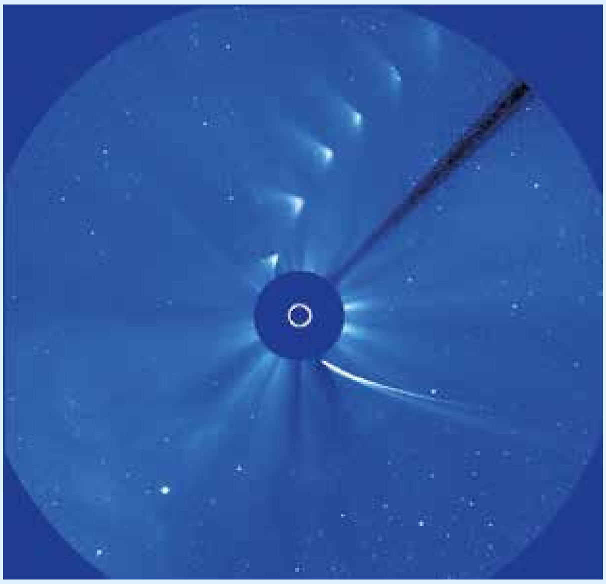

Figure 5: Observations by the wide-angle LASCO coronagraph on SOHO. The small white circle indicates the size and location of the solar disk, whose bright radiation is blocked by an occulting system mounted on the beam sticking into the image. (The bright star to the lower left is the red supergiant Antares.) This composite, spanning three days, shows how the comet had entered the field of view of LASCO on the lower right, brightened dramatically; but gradually evaporated after perihelion. A movie of the encounter with further details is found on http://sci.esa.int/science-e-media/video/4a/496_SOHO_LASCO_comet_ISON_27-30Nov2013.mov .

History of Physics (22)

Joseph Fourier and Sadi Carnot: a counterpoint in 19th century study of heat

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I take the opportunity of this year celebration of the two hundred and fiftieth anniversary of Joseph Fourier to discuss his major achievement, the treatise *Analytic Theory of Heat* (published in 1822), in the context of early nineteenth century conceptions of heat. As an interesting comparison, I shall pay also attention to an almost contemporary work of another hero of modern theory of heat, Sadi Carnot's *Reflexions on the motive power of heat*, which appeared in 1824. As the title of my paper makes it explicit, I intent to present both men and their science using the metaphor of a counterpoint which suggests that I shall emphasize the differences. However, according to definitions, a counterpoint is "the combination of two or more independent melodies into a single harmonic texture in which each retains its linear character". Thus, I shall also put forth how both men realized genuine breakthroughs because their approaches embodied the same attitude with respect to the nature of heat. But first things first, let us introduce our main characters.

Joseph Fourier, born in 1768 in the burgundy town of Auxerre and died in 1830 in Paris, is a perfect case of a supremely gifted young man of humble origin whose achievements became a highlight of 19th century science and who reached the top of the scientific establishment. Son of a tailor, he lost both his parents at an early age and his ensuing education was taken care of by the clergy. After establishing local reputation, he moved in 1794 to Paris where he was taught by such scientific authorities as Gaspard Monge, Joseph Louis Lagrange or Pierre Simon de Laplace. Because of his rising scientific reputation he was proposed in 1898 to take part in the famed Egypt expedition led by the future emperor Bonaparte. He proved there that beside his scientific skills, he was also an able organizer and administrator. After his return to France following the French defeat in 1801 he planned to come back to scholarly activities but Napoleon decided otherwise when he "asked" Fourier to become the prefect of the Isère department. This was a heavy burden but Fourier did not disappoint Napoleon confirming his administrative skills. More surprisingly, he did not give up his research interests either. Quite to the contrary, as it is in this period that he did most of his investigations paving the way to his *Analytical Theory of Heat*. After Napoleon's defeat and the restoration of the monarchy Fourier came back to Paris but initially did not fare well because of his Bonapartist past; he went however eventually elected to the French Academy and became in 1822 its secretary, a position he held until his death.

While initially criticized (more on this soon), *The Analytical Theory of Heat* became eventually widely acclaimed and a model to follow in any positivistic-mathematical approach to the investigation of nature. Also, because of its remarkable use of revolutionary mathematics, Fourier's treatise contributed much to define the field of mathematical physics.

Sadi Carnot was born in 1796 in Paris where he died in 1832. He was, in contrast with Fourier's modest origins, the son of one of the most famous men of his time, the general Lazare Carnot, known both as a gifted scientist and a brilliant revolutionary leader. Sadi enlisted at 16, the minimum age possible, in the *Ecole Polytechnique* where he obtained a first rate scientific and military training. After two more years spent at the *Ecole du Génie* at Metz, he served as military engineer in the French army. Frustrated by his situation, he managed to join, in 1819, the General Staff Corps in Paris but soon asked for a leave. Except for a short return to military duties followed by definitive retirement (1828), Carnot spent the rest of his short life studying while living from a rather modest rent. In 1821, on the occasion of a stay with his father and brother exiled in Germany, Carnot turned his attention to steam engines. The result of his pondering on heat was published in 1824 and went almost unnoticed. It received due attention only after Carnot's death, when Emile Clapeyron, William Thomson and especially Rudolf Clausius saved it from oblivion and explained to the community Carnot's merits. Carnot's treatise contains, as we shall see, indeed much of the founding material for the second principle of Thermodynamics.

To properly appreciate Fourier's and Carnot's contributions to the theory of heat, one needs to recall the context and the situation, at the time, of the French science and its institutions. Flourishing all over the 18th century, French science reached its apogee at the turn of the 19th century. Benefiting of Napoleon's keen interest in science, it was endowed in the last decade of the century with prestigious institutions such as the *Ecole Normale Supérieure* (created in 1794) and the *Ecole Polytechnique* (1795). Together with the *Académie Royale des Sciences*, reorganized and renamed the 1st class (*classe des sciences physiques et mathématiques*) of the *Institut National* during the French Revolution, these institutions had the lead in French scientific education and research. The positions offered there represented consequently sure steps to the pinnacle of scientific careers. Because of the tightly centralized organization of the French empire, control over these institutions, the nominations boards, the themes of prizes, enabled, as a matter of fact, almost full control over scientific beliefs and paradigms. In the time period of interest to us, the dominant science was what historians have since aptly named *Laplacian science*. Its most distinguished dignitaries were men many of them still remembered for first rate contributions: Pierre Simon de Laplace of course, but also Claude-Louis Berthollet, the French chief chemist, and their brilliant "protégés", Jean Baptiste Biot, Siméon Denis Poisson, Etienne Malus, François Arago, to name only a few.

The dominant paradigm: Laplacian science

To understand what Laplacian science was, one must first recall the success of Newton's mechanics and of his theory of universal attraction (exposed in Newton's *Mathematical Principles of natural Philosophy*, 1787) which greatly impressed the natural philosophers of the time. When Newton's physics eventually overcame on the continent the rival system of Descartes, many thought that the keys to an understanding of all of natural phenomena, not only mechanical but optical, electrical and magnetic, etc. were at last in sight. Indeed, Newton's theory of attraction but also his (rather wild) speculations exposed in the rhetoric form of questions (Queries) at the end of his treatise *Opticks* first published in 1704 suggested that all of phenomena resulted from the mutual actions of minute particles composing matter and possibly some (imponderable) subtle fluids. This inherently corpuscular, mechanistic worldview, with dynamics derived from inter-corpuscular forces, truly blossomed at the end of the 18th century. It was much helped by the development of analysis and its expert handling by some of the most brilliant minds of the time.

Among the latter, one finds Pierre Simon de Laplace, most gifted mathematician, astronomer and physicist, the author of many treatises proposing sweeping perspectives over natural phenomena at the astronomic, terrestrial, macroscopic or microscopic scale. His friend's Berthollet's summer residence in Arcueil (near Paris) gave the name to an informal circle of scholars, the *cercle d'Arcueil*, sharing Laplace's views over the proper conduct of natural inquiry and fully dedicated to the cause. Laplacian science is characterized first by its basic reliance on Newtonian mechanics and the explanatory scheme offered by Newton's theory of universal attraction. More precisely, the Laplacians believed (to various degrees), within a corpuscular conception of matter, that its constituents repel or attract themselves because of, besides gravity, of other (possibly short range) forces. Moreover, some "fluids" composed of minute corpuscles were postulated which, interacting, always with central forces, were held responsible for electrical, magnetic, optic, etc. phenomena. In Laplace's best supporter Jean-Baptiste Biot's words:

> *In order to explain [the respective phenomena of electricity, magnetism, and heat] physicists have imagined certain elastic fluids endowed with attractive or repulsive properties... that are named electric fluid, magnetic fluid, and the principle of heat, or caloric. By means of these suppositions most of the phenomena are able to be represented up to a certain point.*

(from his article « Sur l'esprit du système » in *Melanges scientifiques et litteraires*, Paris, 1858)

The "Laplacian" touch to this neo-newtonian world-view consisted in the sheer mathematical virtuosity in which excelled Laplace and many of his supporters such as Poisson or Biot: to reach an explanation of macroscopic effects, the Laplacians summed over the minute microscopic actions using integration with maestria.

This paradigm was quite powerful to tackle a surprising range of phenomena (so that one can consider it as an example of what Thomas Kuhn defined as "normal science"). Not only did it lead to spectacular results in celestial mechanics (which is no surprise given that this was the defining field of the paradigm): Laplacian physics could bring as well some insights on such diverse topics as capillarity or optics. Among many phenomena investigated, there was also heat.

Early heat phenomenology: contributors and milestone

Let us then review briefly what was known about heat at the turn of the 19th century. The first thermometers appeared at the very end of the 16th century and it took a long time before an understanding of what temperature is and how it relates to heat content. Two key observations/assumptions should be quoted here, the so-called "Newton's law of cooling" (1701) which loosely states that the rate of temperature change is proportional to the difference of temperature of the relevant bodies, and the even more basic statement of the Dutch Herman Boerhaave that temperatures tend spontaneously to equalize, called the law of the "equilibrium of heat" (1720). In the 1760's the Scot Joseph Black contributed further his very important observations on the different capacities of bodies to stock or release heat which brought him to the definition of specific heat. He also drew attention to the phenomenon of latent heat: because there was no temperature change observed during evaporation while heat was added to the body, the later was described as "conceiled" or "latent" (an understandable characterization in the framework of a substantialist theory of heat, to be discussed next). Specific heats were later investigated by Laplace and Lavoisier in the framework of their calorimetric experiences (1789).

The "substantialist" conception of heat

In the framework of Laplacian science taken at face value, heat was thought of as the manifestation of an imponderable fluid aptly named by Lavoisier as "Caloric". As already hinted at, the (minute) particles of this fluid repel from each other but are instead attracted by those of matter and tend to agglutinate around the latter. This is what heating bodies is all about. As a result, molecules of matter are spread apart which can account in a simple way for thermal dilation. In this substantialist conception, thermometers are to be understood as genuine gauges measuring the level of the caloric within bodies. This does not go without paradoxes. Besides the phenomenon of latent heat, it was also observed that bodies do not gain weight while heated so that one had to assume that caloric was weightless hence "imponderable".

The "dynamical" conception of heat

There were other paradoxical aspects of the caloric: The simple phenomenon of friction appeared quite puzzling too: the amount of heat one could "extract" from a rubbed body seemed unlimited so that either the latter had an infinite content of heat (then necessarily caused by a brusque variation of its specific heat) or heat could be created at will "out of blue",which was judged a strange conclusion indeed. Benjamin Thompson (better known as count Rumford) concluded an account of his famous observations of the prodigious amount of heat friction could generate (the boring of bronze artillery guns) with the following words:

> *in reasoning on this subject, we must not forget to consider that most remarkable circumstance, that the source of the heat generated by friction, in these experiments, appeared evidently to be inexhaustible. It is hardly necessary to add, that anything which any insulated body, or system of bodies, can continue to furnish without limitation, cannot possibly be a material substance: and it appears to me to be extremely difficult, if not quite impossi-*

ble, to form any distinct idea of anything, capable of being excited, and communicated, in the manner the heat was excited and communicated in these experiments, except it be Motion.

(An Inquiry concerning the Source of the Heat which is excited by Friction, *Phil. Trans. R. Soc. Lond.*, vol. 88, 80-102, 1798)

Rumford did not venture to speculate on the kind of motion that was involved and how the phenomena of heat were related to it. He was not the first to relate heat to motion and to promote thus a "dynamical" conception of heat but it still took some decades before the substantialist theory gave way to the dynamical one and even more to see heat identified with the energy of thermal motion in the early kinetic models of gases of Joule, Clausius, Kelvin, and mature investigations of Maxwell and Boltzmann. Clearly, this shift in favor of the dynamical theory occurred in tight relation with the recognition of the principle of conservation of energy discovered around mid-century.

Between commitment and agnosticism as to the nature of heat

I hinted at the dominant character of the substantialist, caloric, theory of heat at the turn of the 19th century. However, it would be wrong to assume that those who put it to work in their speculations were unconditionally committed to its reality. One finds at the end of the 18th century a fair amount of statements where the caloric is presented merely as a handy model to think of heat phenomena while an agnostic attitude is expressed in what concerns heat's true nature. To witness, the following lines from Lavoisier's celebrated *Traité élémentaire de chimie*, 1789, who yet identified the caloric among the 33 elements of his new chemistry:

Wherefore, we have distinguished the cause of heat, or that exquisitely elastic fluid which produces it, by the term caloric. Be sides, that this expression fulfills our object in the system which we have adopted, it possesses this further advantage, that it accords with every species of opinion, since, strictly speaking, we are not obliged to suppose this to be a real substance; it being sufficient, as will more clearly appear in the sequel of this work that it be considered as the repulsive cause, whatever that may be, which separates the particles of matter from each other; so that we are still at liberty to investigate its effects in an abstract and mathematical manner.

Or, this time quoting from R. Haüy's *Traité élémentaire de physique* (1803):

Without any thing to decide between [the caloric and the dynamic theories], we adopt the language which is consistent with the [caloric fluid one], while regarding it solely as an hypothesis more suitable to assist the understanding ()

And, from the already quoted article by Biot:

Also true physicists acknowledge the consideration of fluids [the electric, magnetic, caloric] uniquely as a convenient hypothesis, to which they rightly refrain from attaching ideas of reality, and that they are given to modifying or entirely abandoning when facts will prove them to be inconsistent

A crucial break in the study of heat: giving up ontological questions

Even if there was thus a fair amount of agnosticism when true nature of heat was considered, in practical studies of heat effects, and especially in attempts at quantitative results, it was the caloric model that was used. I am now in position to explicit the counterpoint established by Fourier's *Théorie analytique*… and Carnot's *Réflexions*… But first, what is the common "harmonic structure" this counterpoint is built upon ? Both works share the same attitude with respect to the ontological question of the nature of heat: they just do not care and introduce instead new deductive schemes, independent of what heat truly is, as they rely only on heat effects. Indeed, Fourier is interested in the laws and mathematical expressions of heat exchanges between bodies causing changes in temperature, and Carnot in heat engines producing motive power. But, just because of this, their works build a counterpoint: in modern terms, Fourier considers in effect pure dissipation while Carnot is interested in the production of motive power which, as he will recognize, necessitates, to be optimal, to avoid spontaneous passages of heat between concomitant parts of the engine. So, here we have it: dissipation without work on one hand, and work without dissipation on the other, a beautiful counterpoint indeed.

Fourier's motivations

What were Fourier's motivations underlying his interest in heat? A folk account suggests that because of a disease contracted in Egypt that made him extremely sensitive to cold, problems related to temperature changes came naturally under his scrutiny. There is a more documented and compelling explanation. It has to do with Fourier's ambition to challenge Laplace's universal mechanistic worldview. Indeed, while heat is as universal as gravitation, its phenomenology is not addressed in Laplace's monumental *Système du monde*. Obtaining a theory of heat exchanges and ensuing temperature changes meant consequently to Fourier to equal in scope and universality the physical vista of his main scientific opponent Laplace. The ambition of Fourier is clear since page one of his treatise:

PRIMARY causes are unknown to us; but are subject to simple and constant laws, which may be discovered by observation, the study of them being the object of natural philosophy.

Heat, like gravity, penetrates every substance of the universe, its rays occupy all parts of space. The object of our work is to set forth the mathematical laws which this element obeys. The theory of heat will hereafter form one of the most important branches of general physics.

(*Théorie analytique*, Discours préliminaire, p. 1)

Fourier emphasizes further in the long *Discours préliminaire* how heat escapes the laws of mechanics and is hence in need of new physics and mathematics. To witness the following quotes:

[Archimedes] explained the mathematical principles of the equilibrium of solids and fluids. About eighteen centuries elapsed before Galileo, the originator of dynamical theories, discovered the laws of motion of heavy bodies. Within this new science Newton comprised the whole system of the universe. The successors of these philos-

ophers have extended these theories, and given them an admirable perfection […] But, whatever might be the scope of mechanical theories, they do not apply to the effects of heat. The latter encompass a special order of phenomena which cannot be explained with the help of the laws of motion and equilibrium

And further:

[…] a very extensive class of phenomena exists, not produced by mechanical forces, but resulting simply from the presence and accumulation of heat. This part of natural philosophy cannot be connected with dynamical theories, it has principles peculiar to itself, and is founded on a method similar to that of other exact sciences. The solar heat, for example, which penetrates the interior of the globe, distributes itself therein according to a regular law which does not depend on the laws of motion, and cannot be determined by the principles of mechanics. The dilatations which the repulsive force of heat produces, observation of which serves to measure temperatures, are in truth dynamical effects; but it is not these dilatations which we calculate, when we investigate the laws of the propagation of heat.

(Chapter I, section 17, p. 23)

Finally, Fourier makes plain how only mathematical analysis of the kind foreign to mechanics, can make the investigation of the *Théorie analytique* reach its aim:

The effects of heat are subject to constant laws which cannot be discovered without the aid of mathematical analysis. The object of the theory which we are about to explain is to demonstrate these laws ; it reduces all physical researches on the propagation of heat, to problems of the integral calculus whose elements are given by experiment. No subject has more extensive relations with the progress of industry and the natural sciences ; for the action of heat is always present, it penetrates all bodies and spaces, it influences the processes of the arts, and occurs in all the phenomena of the universe

(Chapter I, Introduction, p. 14)

Carnot's motivations

It is tempting, given the lack of recognition his work suffered, to fancy Carnot's *Réflexions* as an outcome of a solitary quest, as a work of in isolated visionary much in advance of his time. But this would be neglecting Sadi's father Lazare's most important work in theoretical engineering. In 1783, in a context where applied science and engineering gains notably in importance Lazare Carnot publishes a remarkable essay on machines, his *Essai sur les machines en general*. This is a close examination of the principles that govern the efficient transmission of motive power in mechanical engines. Lazare recognizes in particular the fatal effects of impacts between connecting rods, teeths of cogwheels, etc., when the later are not "matched motionwise". Sadi's declared intent, namely to found a general theory of heat machines, bypassing in scope and generality the purely empirical results obtained from the practice of steam engines appears a logical continuation of his father's interest in founding a general theory of mechanical engines. Also, the impairments (leading to losses of live force) that the father recognized as the main obstacle to the efficiency of mechanical engines is in perfect analogy to dissipation (irreversibility) that prevents maximal efficiency of heat engines according to the son's *Réflexions*.

A fundamental input to Fourier's theory: Prévost "theory of exchanges"

Fourier bases his theory on what is dubbed at the time the "theory of exchanges" due to the Geneva professor Pierre Prévost and exposed in his "Memoire sur l'équilibre du feu" (*Journal de Physique*, 38 ,1791). Fourier clearly pays his dues to Prévost declaring:

[…] bodies mutually transmit heat […] It is in this exchange of [heat] rays that the hypothesis proposed by Professor Prevost of Geneva principally consists. This hypothesis furnishes clear explanations of all the known phenomena. It lends itself more easily than any other [hypothesis] to the applications of calculations: it therefore appears useful to us to choose it, and it can even be employed with profit to represent the manner of propagation of heat within solid bodies.

(Fourier, from a paper he submitted as an entry to the 1811 Institut's prize devoted to the study of heat propagation.)

Prévost proposed his hypothesis as a solution to the riddle of the apparent transmission of "cold" that could be observed in a "reverse" of the experiment of "radiant" heat reflected and focused on a distant thermometer with the help of parabolic mirrors. By the end of the century, another famed Geneva scholar, Marc-August Pictet replaced the incandescent coal bricks in the focal point of the mirror by a recipient full of ice. The distant thermometer recorded a temperature decrease. Some of the contemporaries did not hesitate to fancy that this experiment proved the existence of rays of cold! Prévost explained instead that because all bodies radiated heat whatever their temperature, the correct explanation of the thermometer fall was that the latter was sending more than it was receiving.

Another ingredient of Fourier's theory of heat is Newton's law of cooling, or rather Fourier's analytical expression of the latter that states the proportionality of heat flux between contiguous portions of matter to the gradient of temperature. This was enough for Fourier and his mathematical expertise to immediately obtain the celebrated equation of heat propagation.

Most of the rest of his treatise is devoted to apply the theory to various cases with specific boundary conditions, and of course to the discussion of the general technique to obtain solutions that he derived using trigonometric series. Because my primary concern is the physical theory of heat, I shall leave aside this remarkable mathematical discovery and all that it prompted in 19^{th} century mathematics to turn now to Carnot's *Réflexions*.

A fundamental input to Carnot's theory: the watermill as a model for the heat production of motive power

Taking the *Réflexions* at face value, Carnot assumes the substantialist theory of heat. However, a closer scrutiny shows that it is not really material to his reasoning, at least as far as one focuses on the essential results obtained in his memoire. Indeed, the originality of Carnot's deductions resides in the fact that they dispense with any hypothesis about heat's very nature. First, to obtain motive power using heat, Carnot emphasizes that one needs a difference of temperature. Then, it is the transfer of heat from hot (furnace) to cold (condenser) that generates motive power: according to Carnot, heat "falling in temperature" generates work in perfect similarity to (gravitationally) falling water. Hence, the production of motive power in a heat engine is obtained as if a variation of a kind of "thermic potential" was compensated by a gain of mechanic energy. This is of course wrong from the point of view of the principles of thermodynamics. However, the elegant reasoning of Carnot on "his" ideal cycles, linking efficiency to irreversibility, and his recognition of the fundamental need, in the production of motive power, of a heat transfer across a temperature difference (again, insights independent of any hypothesis on the nature of heat) will prove, once properly understood, crucial for future progress.

A second counterpoint: the contrasted receptions of Fourier's and Carnot's works and their later fate

In 1807, Fourier sent a paper devoted to heat propagation to the First class of the Institute. In spite (or rather because) of the revolutionary character of its content, the paper was (to make it short) rejected, mainly due to the hostility of the Laplacians and Lagrange's frustration with the lack of proper justification for Fourier's innovative mathematics. Fourier did not give up and over the consecutive years kept trying to make his theory respectable. In particular in 1811 he won the Institute's prize for heat propagation but his theory remained unpublished until 1822. Benefiting from a weakening of the Laplacian grip over French science, Fourier's physics went finally hailed as a model for a successful account of natural phenomena. What the Laplacians considered its major flaw, its dispensing with any mechanistic model, went recognized as its essential virtue. It avoided any unnecessary speculation on the very causes of heat and was a potential manifesto for a positivistic investigation of nature. Fourier's mathematical techniques and the assumptions behind nourished, on the other hand, a great deal of 19th century progress in mathematics. Fourier enjoyed lastly a deserved fame and respect which is certainly witnessed by his election as secretary of the restored Royal Academy once his role in Napoleon's empire went forgiven.

It took Fourier's work several years to prevail and set the standards for a new approach to phenomena, but it is nothing in comparison to the neglect which hampered Carnot's *Réflexions* until they were rediscovered by men able to understand their scope and value. At the time of its publication the *Réflexions* went ignored, presumably because it appeared too theoretical and abstract to some, while too odd and remote from contemporary physics to others. Indeed, practitioners of steam engines looking for ready-made solutions to improve their machines failed to find any in the general theory of Carnot. The scientific establishment, on the other hand, if it read Carnot at all, must have been rebutted by Carnot's highly original style of reasoning totally at odds with the contemporary ways of mechanistic-analytical schemes of proof. There is only one known exception to this neglect: in 1834 the engineer Emile Clapeyron reformulated Carnot's theory in mathematical terms (we owe him for instance the expression of Carnot's cycles in terms of pressure-volume diagrams), but did not contribute any insight of his own and, most of all, failed to see Carnot's theory true potential and meaning. Carnot did not live up to see his theory finally arise the interest it deserved: by the time Clapeyron reformulated his work, he was already dead. The seeds of future progress were however planted and ready to grow. The young William Thomson learned of the work of Carnot while reading Clapeyron during his Parisian sojourn in 1847. In turn, Rudolf Clausius learned of Carnot reading Thomson. Both, and especially Clausius, took the work seriously enough to bring it back to the forefront of science. In 1850 Clausius showed how to make Carnot's conceptions easily compatible with the just accepted principle of the conservation of energy. In a rather generous move, Clausius further granted to Carnot most of the merits in the discovery of the facts leading to the second principle of thermodynamics. Indeed, he emphasized how crucial was Carnot's observation that there is no conversion of heat into work without a portion of heat transferred across a difference of temperature.

A posteriori, Carnot went eventually vindicated. But this is not all: at the end of his life, Carnot actually corrected his initial views on the production of work without consumption of heat! His brother Hippolyte who assisted Sadi in the publication of the *Réflexions* and who later brought order to the unpublished notes of his defunct brother transmitted some to the Academy. These documents show beyond doubt that Carnot had understood, in the years consecutive to the writing of his *Réflexions*, that not all the heat taken from the hot source was given back to the cold one if work was obtained. Thus, to many historians of the first principle (most notably Thomas Kuhn) Carnot appears an unsung hero of the conservation of energy and thus, even more a founder of Thermodynamics.

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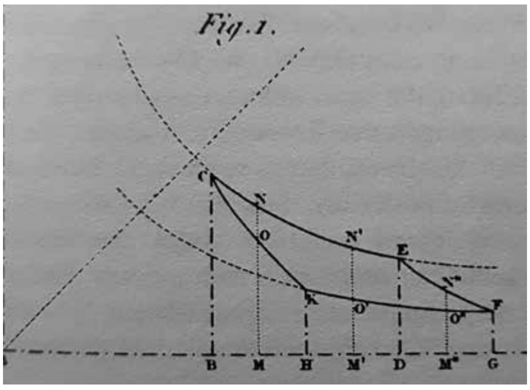

Carnot circle-process for a gas, from a treatise of Emile Clapeyron (Journal de l'Ecole Polytechnique XXIII: 190, 1834).

Nobel Award 2018 in Physics

Strickland and Mourou recognized for invention of chirped-pulse amplification

Lukas Gallmann, ETH Zürich

Ultrashort laser pulses of femtosecond duration offer very high peak power, intensity and electric field strengths by concentrating moderate amounts of energy into very short bursts of light. At the same time it is precisely this property that severely limited progress of this field for a long time. The reason for this is that as peak field strengths get high enough to break chemical bonds in materials, damage of optical components and amplifier crystals occurs. Even before this regime, the beams of ultrashort laser pulses experience unwanted distortions in space and time due to the onset of optical nonlinearities.

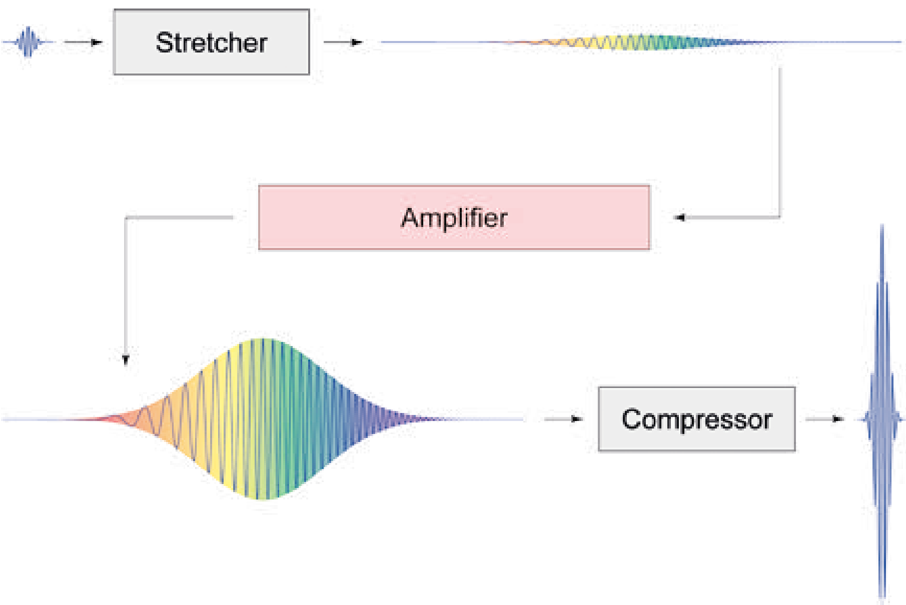

Illustration of chirped pulse amplification: a short pulse with little energy is stretched in time before amplification. The energetic amplified pulse is recompressed close to its original duration but with orders of magnitude higher peak power.

Chirped-pulse amplification (CPA, [1]) invented by Donna Strickland and Gérard Mourou and recognized by this year's Nobel Prize in Physics elegantly overcomes this technical limitation and enabled an increase in peak power and intensity by many orders of magnitude compared to prior approaches. A high-intensity laser system consists of a low-energy (~nJ) seed oscillator followed by one or more power amplification stages. The principle of CPA is to stretch the duration of the seed pulses by many orders of magnitude (i.e., from femtoseconds to nanoseconds) before they're amplified to high energy (typically mJ to J). As a result of their increased duration, peak power and intensity remains below the threshold of nonlinearities or damage even after amplification. In a final step, the pulses are recompressed to their original femtosecond duration. The final recompression can happen in vacuum, which means that not even the optical nonlinearity or laser-induced ionization of air becomes a limitation.

Modern state-of-the-art laser systems, such as the ones presently being constructed for the European Extreme Light Infrastructure (ELI, [2]), can reach a peak power of 10 PW and focused intensities of 10^{23} W/cm^2. At such high intensities, the motion of free electrons in vacuum that are accelerated by the electric field underlying the optical pulse becomes highly relativistic. The high fields enable the acceleration of protons to tens of MeV and electrons to GeV energies on micrometer to millimeter length scales. The energy density in the focused beam becomes so high than one expects to observe electron-positron pair production with the latest generation of lasers systems.

Aside from these extreme regimes, CPA enabled the design of comparably compact high-intensity laser systems that gave rise to a vast range of applications. These sources laid the technical foundation to new research fields such as attosecond science, as well as commercial applications such as in refractive eye surgery for vision correction.

This year's Nobel Prize in Physics marks the third Nobel Prize awarded for achievements related to ultrashort laser pulses following the 1999 Nobel Prize in Chemistry (A. Zewail, for the application of ultrafast lasers for studying chemical dynamics) and the 2005 Nobel Prize in Physics (J. Hall and T. W. Hänsch, for the use of ultrafast lasers in precision frequency metrology). While the previous two prizes recognized the foundation of specific fields of research enabled by the availability of ultrashort laser pulses, the 2018 prize is different in that it was awarded for a specific technological development that gave rise to a broad range of applications from the commercial domain to fundamental science. CPA is now an indispensable ingredient of intense sources of femtosecond optical pulses and is expected to create more exciting research opportunities by yielding access to new regimes of fundamental laser-matter interaction for the foreseeable future.

[1] D. Strickland and G. Mourou, "Compression of amplified chirped optical pulses," *Opt. Commun.* **56**(3), 219 (1985)
[2] https://eli-laser.eu

Peeking and poking at particles with light

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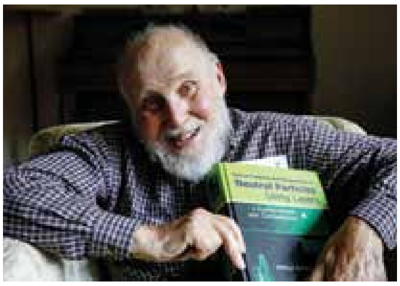
Nature is made of discrete building blocks - atoms and molecules in the physical world, large biomolecules and cells in living systems. To precisely manipulate these building blocks, to study their function one at a time and to assemble them into larger systems has been a long-standing dream of science. With the invention of the optical tweezer and related laser trapping and manipulation tools, this dream has come true. One half of this year's Nobel prize in physics goes to Arthur Ashkin, who pioneered these techniques since the early 1970s.



The fact that light can exert forces on matter had been known for a long time, postulated by Kepler to explain comet tails and finally observed in the lab in delicate precision experiments in the early 1900s. However, the optical forces were much too weak to be of practical use. This changed with the invention of the laser in 1960, which provided an intense and coherent source of light that can be tightly focused and precisely aligned. Soon after the first lasers became available, researchers began to study optical forces as a tool to manipulate small particles.

Arthur Ashkin at Bell Laboratories in New Jersey reported a first success in 1970, demonstrating radiation pressure forces on small particles in water and air [1], followed soon by the demonstration of optical levitation with a gravito-optical trap [2]. In 1986, Ashkin and his co-workers reported the first all-optical single-beam trap [3], which soon became known as "optical tweezers".

Two different types of forces can be distinguished in optical trapping: the scattering force, which is proportional to the light intensity and directed along the beam's propagation direction, and the gradient force, which is proportional to the intensity gradient and points along this gradient. It is the latter force which is employed in optical tweezers to confine polarizable particles to the intensity maximum of a tightly focused laser beam.

The optical trapping techniques developed by Arthur Ashkin kick-started two entire fields of research in different domains of science. In atomic physics, laser traps and related laser cooling schemes were soon used to trap clouds of atoms and to cool them to microkelvin temperatures. Experiments with such ultracold atoms in laser traps made it possible to study quantum physics with unprecedented control and precision. This led, among other things, to the observation of novel states of matter, such as Bose-Einstein condensation, and to the development of the most accurate atomic clocks and other atomic precision measurement devices. The optical trapping techniques for ultracold atoms have been continuously refined, and it is now possible to use computer-controlled arrays of optical tweezers to arrange individual atoms in nearly defect-free three-dimensional patterns of arbitrary shape. These techniques currently play an important role in the development of quantum technologies.

Optical tweezers have also enabled an entirely new set of precision experiments in the life sciences, which has revolutionized the field of single-molecule biophysics. Already in 1987, Arthur Ashkin used optical tweezers to trap living bacteria without harming them [4]. For the first time it became possible to perform controlled mechanical manipulations of individual living cells, benefitting from the fact that the optical forces can be applied to these objects in their natural environment under ambient conditions. Ashkin noticed that even structures within the cell could be moved and manipulated by the optical force. A major breakthrough came in the 1990s, when scientists realized that optical tweezers can reveal the mechanical properties of individual motor proteins, which are macromolecules that move and transport cargos along the skeleton of a cell. When an individual motor protein is attached to a dielectric bead held in an optical trap, the motor's movement can be measured through the forces it exerts on the bead. In this way, the 8 nm steps of the motor protein kinesin along its track could be measured for the first time. Since these first studies, the resolution of optical tweezers has dramatically improved such that it is even possible to observe the 3.4 Å steps that the RNA polymerase takes as it reads the genetic code.

About 50 years after it started, optical trapping of particles continues to be a dynamic and exciting field of research. Most recently, techniques for optical levitation have been used in the new field of optomechanics to trap dielectric nanospheres in vacuum and cool them close to the quantum mechanical ground state. Such experiments could lead to novel tests of quantum physics with massive, mesoscopic objects and find applications in precision force sensors operating at the nanometer scale. In the life sciences, optical tweezers have become a widely used tool for interrogating and manipulating individual biomolecules and subcellular structures. Recent advances include the application of optical holography to simultaneously use thousands of optical traps in high-throughput experiments and the integration of optical tweezers with super-resolution microscopy to simultaneously and correlatively visualize and manipulate molecular interactions with sub-piconewton and sub-nanometer resolution. This shows that the work of Arthur Ashkin, which has now been honored with the Nobel Prize in physics, continues to have significant impact even today.

[1] A. Ashkin, Acceleration and trapping of particles by radiation pressure, Phys. Rev. Lett. **24**, 156 (1970).
[2] A. Ashkin and J.M. Dziedzic, Optical levitation by radiation pressure, Appl. Phys. Lett. **19**, 283 (1971).
[3] A. Ashkin, J.M. Dziedzic, J.E. Bjorkholm and S. Chu, Observation of a single-beam gradient force optical trap for dielectric particles, Opt. Lett. **11**, 288 (1986).
[4] A. Ashkin and J.M. Dziedzic, Optical trapping and manipulation of viruses and bacteria, Science **235**, 1517 (1987).

Physicists in Industry (7)

Physics as Driver of Innovation

Bernhard Braunecker, Leica Research Fellow (ret.)

Innovation pipeline and knowledge transfer

The success of Switzerland's High-Tech industries is based to a large extend on their profound physical understanding of the technologies. This capability must be maintained in the future in order to further compete internationally as a leading economic nation. Only an innovation pipeline *permanently filled with proved physical concepts* leads to a continuous technology stream that can be transformed sustainably into products and services. The technology value added chain begins with basic research performed at universities and research institutes such as PSI or CERN, continues with applied research and development carried out at the ETHs and universities of applied sciences and finally flows into the pre- and product development activities of industry.

In the following we restrict ourselves to the knowledge transfer between universities and industry. It must take place in *both directions* in order to inform industry about technical progress on the one hand, and to make universities aware of developing markets on the other. This last information allows universities to redefine or fine tune their teaching programs, which also ensures their international attractiveness, being reflected in good ranking results.

National top/down programs for physics-based cross sectional technologies

If there are strong indications of so-called disruptive technologies [1] in the research pipeline, and if at the same time industry expects that their implementation in products would find positive market acceptance, then maximum attention has to be given on both sides. If it can also be seen that an arising technology could be a *cross sectional technology* affecting many industrial sectors such as mechanical engineering, chemistry, pharmacy, food, mobility, etc., then the cooperation between universities and industry should be best organized as national top/down programs.

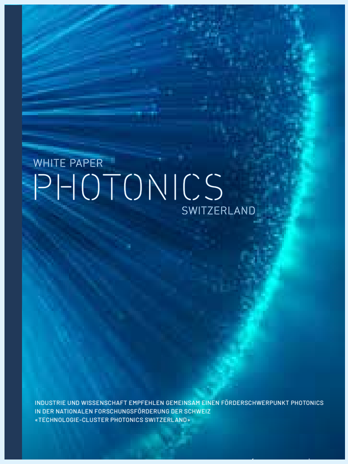
Examples of today's cross sectional technologies are digitization, algorithms, data security, advanced manufacturing, smart sensors and robots, while applied quantum physics, functional materials, modern photonics and above all the interaction of physics with life science, i.e. biology, chemistry, pharmacy and medicine are candidates for the near future. They offer best business opportunities for start-ups but also for existing smaller industries.

The aim of the top/down programs is to jointly develop technology approaches to such an extent that they can be transferred seamlessly to industry from a certain degree of maturity onwards. The participating industries do not compete but cooperate during this phase as development partners. The scientific goals are defined on an equal eye-to-eye level by the universities and the industry. The funding of the academic partners is done by the state, while the other half of the programs' costs is covered by the industry itself. However, to encourage small and medium sized enterprises (SMEs) to participation more flexible financial conditions than in the past need to be set up.

This concept was successfully implemented at the end of the 1990s in the basic programs of the ETH Board such as *Optique I/II*, *LESIT*, *TopNano21*, where physicists from universities and industry were the main drivers [2]. A similar Swissmem initiative is currently under way to establish the cross-sectional technology *Photonics* as a national priority program (see infobox).

White Paper *Photonics Switzerland*

A group of experts led by Swissmem's photonics group wrote a white paper describing photonics as both, an independent and a cross sectional technology. It shows that in Switzerland the mutual coordination and exchange of information between universities and industry must be improved to remain at the fore front of technology application. SME in particular, which contribute significantly to Switzerland's economic strength, are at risk in view of the increasing complexity of modern photonic technologies and consequently must be better included in all activities. As an effective approach the experts recommend a national top-down program, which is jointly defined and implemented by universities and industries. A first presentation of the white paper at Federal Councillor Johann Schneider-Ammann, the State Secretariat of Education, Research and Innovation SERI and and the Swiss Innovation Agency *Innosuisse* found very positive resonance.
https://www.swissmem.ch/en/organization-members/specialist-groups/photonics.html



Role of physics as a driver of progress

Today physical concepts are not only the base of engineering science and chemistry, but also of biology and even medicine. They all benefit from the quantitative understanding of the dynamic processes on a molecular level. It is e.g. impressive how Physics can support the more empirically acquired knowledge in medicine. Similarly, geotechnics,

1 The technologies show the potential to substitute traditional approaches almost overnight after having reached a certain degree of maturity. And it is foreseeable that this might happen within the next 1 to 3 years.

2 *https://www.sps.ch/artikel/physik-und-gesellschaft/nationale-foerderinitiativen-zur-staerkung-des-wissenstransfers-zwischen-hochschule-und-industrie-10/*

climatology research and energy technology, even modern traffic engineering, would not be so successful in their statements without physical modelling of the involved processes. This makes it possible to exceed the current limits and thus to generate new application possibilities.

Comments of industrial physicists

This discernible trend prompted us to ask some colleagues from the physics industry (see info box) for their opinion on the role of physics in their company today and in the future.

Question 1: How important are concepts from physics in your field of work?

UC: Concepts of applied physics and a good understanding of electrodynamics, thermodynamics and mechanics are prerequisites for innovation in electric motors.

RC: Nothing new can be developed in our space sector without physics.

BGH: Overall, it should be noted that the continuing trend towards smaller physical structures requires the application of new processes in the respective manufacturing context (e.g. plasmas and particle-surface interactions in different speed ranges for structuring and changing surfaces).

RH: Very important, especially concepts for energy conversion, photonic, thermodynamics are necessary.

RL: The Comet Group manufactures high-tech products in which physics plays a decisive and fundamental role: Vacuum capacitors, electron beam tubes, X-ray sources/ tubes and complete X-ray systems.

MR: AMS develops various types of sensors for consumer and industrial applications. The basis for most products are located in the area of semiconductor, material and micro/nanotechnologies, or in their sciences.

RV: Optics & Photonics are an essential part of industrial physics. Photonics has grown very strongly in the last 25 years and has changed our daily lives massively. Innovative concepts of photonics, such as new lasers, optical data transmission, nanophotonics, meta-lenses, 3D printing etc. can only be developed with the means of physics.

Question 2: Do you observe that the complexity of physical technology approaches is generally increasing?

UC: Yes, the power density of the drives is constantly increasing, and the analysis of the phenomena that occur is becoming more complex. Simple engineering approaches reach their limits.

RC: Yes, an increase can be observed, which is being accelerated by the development of new materials and electronics in particular.

BGH: The individual technology approaches are not necessarily more complex in themselves, but overall complexity is increasing due to increasing diversity.

RL: The complexity of the technology approaches remains more or less the same, however the requirements tend to increase, but not fundamentally. We are constantly trying to improve quality, yield and reliability, which increases the complexity of production and other processes. The integration in higher-level systems and the digitization of measurement data and parameters are becoming increasingly important. Of course, we are also looking at completely different physical approaches to achieve the same results as with traditional technologies.

RH: Yes, fast. Our company is active in the field of CO_2-neutral energy supply based on methanol. The number of published scientific articles explodes in practically all areas such as the extraction of CO_2 from the air, photovoltaics, optimization of Si-based PV cells, electro-catalytic, electro-enzymatic and photocatalytic methanol production.

MR: Products are continuously becoming more integrated and complex. Physics as a basic knowledge enables the combination of different technologies.

RV: No! The technology relevant for industry today and in the next 5 years is usually based on physical concepts which are well understood. The physical approaches to technology, which will only become relevant for industry in 15 to 20 years' time, are just as complex as physics has always been.

Question 3: How much do you differentiate yourself from the competitors through physical/technical innovation?

UC: Technical innovation is at the heart of business success in a high-wage country.

RC: We try to realize innovations faster than the competition in our products and physical innovations play the decisive role.

BGH: The question is less whether physical/technical innovations permit quantitative differentiation or whether differentiation offers a competitive advantage. For Swiss companies, technological leadership is usually indispensable, not least because of the reputation generally attached to them. Thus, there is already an expectation that the solutions are

Contact persons

UC: Ulrich Claessen, R&D Manager of *Maxon Motors* AG in Sachseln / OW, which produces electric motors in numerous variants. (*https://www.maxonmotor.ch*)

RC: Reinhard Czichy, President of *Synopta GmbH* in Eggersriet / SG, which produces optical terminals for satellite communication. (*https://www.synopta.ch*)

BGH: Bernd-Günther Harmann, Patent Attorney of *Kaminski, Harmann Patentanwälte AG* in St. Gallen. (*https://www.khp-law.ch*)

RH: Reto Holzner, Chief Scientific Officer of *Silent Power AG* in Cham / ZG, dealing with innovative energy storage concepts. (*https://silent-power.com*)

RL: René Lenggenhager, CEO of *Comet Group AG* in Flamatt / FR, specializing in industrial X-ray, high-frequency and electron beam equipment. (*https://www.comet-group.com*)

MR: Markus Rossi, Vice President of *Heptagon-AMS AG* in Rüschlikon / ZH, who supply Mems-based photonic subsystems for international mobile phone manufacturers. (*https://www.hptg.com*)

RV: Reinhard Völkel, CEO of *SUSS MicroOptics SA* in Neuchâtel / NE, which manufacture micro-optics for a wide range of sensor applications. (*https://www.suss-microoptics.com*) in any case at the forefront of technical development, and it is less the extent of differentiation or its additional effect that comes to the fore. Rather, the decisive criterion seems to be the continued membership in the group of technically leading suppliers, rather than the increase in a technical "distance".

RH: Very strong. Thanks to the innovative use of physical properties, we want to develop and sell low-noise, low-maintenance, lightweight, environmentally friendly and reasonably priced products.

RL: We differentiate ourselves strongly from our competitors because we master the technical and physical processes to such a high degree that there is little competition. Innovation is a fundamental driver of our business. Our physicists and engineers understand excellently what we do, be it the excellent basic understanding of physics and the physical and technical processes or more and more the simulation of them. This allows us to understand physics and its applications in our products even better. Simulation not only provides a better understanding, but also a higher speed and lower costs in development, since fewer functional samples/prototypes are required and/or these are used later.

MR: Our competition is mainly in Asia, and we have to achieve the same manufacturing costs. This is only possible if we see technical innovation as the main differentiator.

RV: Not much! We have a total of four PhD students in the field of photonics, but they come from engineering and mechanical engineering. A pure physicist not only has to deal with technical questions, but we need him to address new kinds of questions.

Question 4: How important is a profound physical understanding of the technologies used in order to develop them further and implement them reliably in industry?

UC: Very important. The understanding must be tested in practice ("working knowledge").

RC: This understanding is essential.

BGH: Essential.

RH: Very important. The vast majority of our employees have a profound education in physics or electrical engineering.

RL: Since all our components "work" at the limits of physics, it is essential to have a broad and very deep understanding of the technologies used. As mentioned above, simulation is very important, but also the analytical understanding of physical processes and technologies. When working at the limits of physics (surfaces, purity, high voltage).

MR: For sensors of all kinds (optics, electronics, environment, acoustics) a comprehensive understanding of the physical basics is absolutely necessary: from the first concept to implementation in products and their manufacture in mass production.

RV: The important key technologies of photonics are essentially based on the basic principles of mathematics, physics, chemistry, mechanical engineering and computer science. Even though a large number of courses, some of which are very specific, are offered today, these can be traced back to the six important pillars. A profound understanding of physics is just as necessary as good knowledge in mathematics, chemistry, mechanical engineering and computer science.

How to solve apparent cultural differences?

It is important in top/down programs to minimize the impact of inherent cultural differences: while at the universities 'Time to Maturity' is considered as success criterion, which usually corresponds to the duration of a doctoral thesis of four years, its equivalent in industry is 'Time to Market' with typical durations of a maximum of two years. A time conflict? Since, however the doctoral or master theses are also supervised by industrial physicists in the basic state programs, the transfer of knowledge is 'adiabatic' avoiding wrong decisions and a resilient trust between individuals and institutions is formed.

Question 5: At what intervals do you expect technology changes in your field in the future, and how important is the discipline of physics?

UC: The time intervals for technology changes in motors are long (> 10 years), in controller technology and sensors shorter (new processors, new control methods, new sensor principles e.g. Giant Magnetic Resonance). Additive manufacturing of motors would be a disruptive manufacturing technology.

RC: In our space division, technology changes are often implemented rather late in products because these first have to prove themselves. In other ground-based activities (astronomy, metrology), technology progress can be used more quickly. However, we do not expect anything revolutionary new in our areas in the next 5 years. But physics is essential for us to be able to assess and understand these changes.

RH: Technology improvements are already underway at an annual rate, and even faster in some areas. A good physics education helps enormously, just to separate the wheat from the chaff within a useful period of time, not to mention to familiarize oneself with the innovations.

BGH: This question cannot be answered in general. On the one hand, the definition of a technology is difficult in itself, and on the other hand, the determination of whether and when a change has taken place is problematic. Moreover, not every technical discontinuity necessarily leads to significant changes in the market or disruptive business models. Nevertheless the future will be marked by technology changes, where most of which may need the solution of physical problems, see e.g. Quantum Computing.

RL: I expect fundamental technology changes in a period of 3 to 5 years, where physics and semiconductor technology (which is also physics) will play a decisive role here. However, fast and intelligent data processing combined with sensor technology are also becoming increasingly important. They allow to increase the physical performance of components like a better noise suppression by physical modelling.

MR: Individual product categories change every 1-2 years; the technologies on which they are based can change significantly every 3-5 years. Many innovations are not evolutionary, i.e. require fundamental developments, not engineering.

RV: In 10 years robots will invent, develop, assemble, program, and control/monitor other robots. Half of all current subjects and many technical professions will disappear. But physics will always remain and Out-of-the-box thinking, creativity and abstraction must come from physics.

Conclusions

The answers of our colleagues from industry show that the results of applied physics are indispensable for the future development of technologies, products and services in Swiss industries. But applied physics depends on the results of fundamental research. The complete knowledge transfer chain must therefore be kept at the highest level. In Asian countries, state agencies set the standards for universities and industry, monitor and control their implementation. In Switzerland, however, with its liberal tradition, the freedom of research and industrial self-responsibility must remain the cornerstones of success. We can only counter the state dirigism of big Asian countries with better cooperations, for which the top/down basic programs would be well suited managing instruments with proven efficiency. More than until now SMEs must be better involved, but they themselves must also learn that in addition to engineering skills a profound knowledge of physics will be required in order to stay ahead in the future.

Neue Studie der SATW: Schweizer Industrie verliert an Innovationskraft
Nouvelle étude de la SATW: L'industrie suisse perd de sa force d'innovation

Béatrice Huber, SATW

Die Schweiz belegt regelmässig Spitzenplätze in Rankings, welche die Innovationsfähigkeit von Ländern bewerten. Trotz dieser positiven Beurteilung mehren sich Stimmen, die eine bedenkliche Abnahme der Innovationskraft der Schweizer Industrie wahrnehmen. Wo liegt nun die Wahrheit?

Die SATW hat genauer hingeschaut und präsentiert eine neue Studie zu "Innovationskraft der Schweizer Industrie 1997–2014: Neu bewertet". Die in den Innovationsumfragen der Konjunkturforschungsstelle (KOF) an der ETH Zürich erhobenen Daten bilden die Basis für diese detaillierte Analyse. Aufgrund der analysierten Daten lassen sich einige Trends erkennen.

- In der Schweizer Industrie gibt es immer weniger Firmen.
- Viele KMU in der Schweizer Industrie reduzieren ihre F&E-Anstrengungen sowohl im In- als auch im Ausland. Besonders betroffen sind die Klassen Chemie, Maschinen, Metallerzeugnisse, Textil/Bekleidung und Uhren.
- KMU der Klassen Elektrotechnik und Metallherstellung sowie Grossunternehmen der Klassen Chemie, Elektronik/Instrumente und Nahrungsmittel verlagern ihr F&E-Aktivitäten stark ins Ausland.
- Die Konzentration der Forschungsausgaben [1] ist bei KMU der Klasse Elektrotechnik sowie bei Grossfirmen

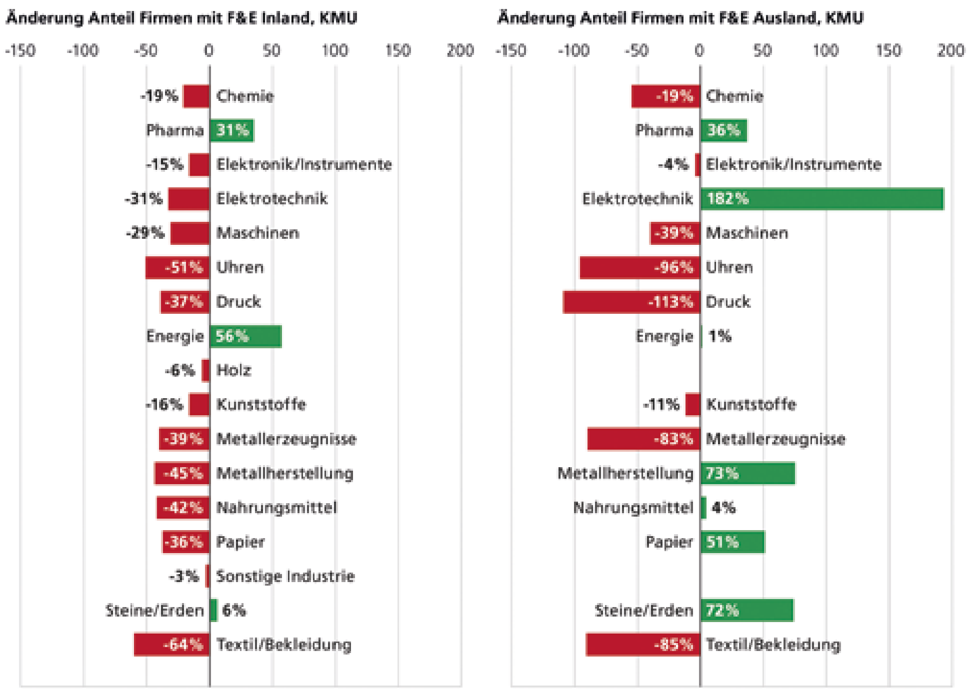
1 Unter "Forschung" wird hier mehr die Technologieentwicklung, das heisst die Vorentwicklung für industrielle Produkte und Prozesse verstanden.

La Suisse occupe régulièrement les premières places dans des classements mesurant la capacité d'innovation des pays. Malgré cette évaluation positive, de plus en plus de voix indiquent percevoir une diminution de la force d'innovation de l'industrie suisse. Qu'en est-il réellement?

Les données récoltées par le KOF, le centre de recherches conjoncturelles de l'EPF de Zurich, constituent la base d'une analyse détaillée de la force d'innovation de l'industrie suisse. L'étude se conforme à la «Nomenclature générale des activités économique» (NOGA) de l'Office fédéral de la statistique. Aucunes nouvelles données n'étant disponibles au moment de la publication, les chiffres des années 1997 à 2014 ont été utilisés. Les chiffres analysés permettent de dégager quelques tendances.

- Le nombre d'industries diminue en Suisse.
- De nombreuses PME réduisent leurs efforts en matière de R&D tant dans le pays qu'à l'étranger. Les divisions chimie, machines, métallurgie, textile/habillement et horlogerie sont particulièrement touchées.
- Les PME des divisions électrotechnique et fabrication de produits métalliques, de même que les grandes entreprises des divisions chimie, électronique/instruments et industries alimentaires déplacent à large échelle leurs activités de R&D à l'étranger.
- La concentration des dépenses liées à la recherche est particulièrement marquée dans les PME de la division électrotechnique et dans les grandes entreprises des di-

Entwicklungstrends des Anteils von Schweizer KMU verschiedener NOGA-Klassen mit F&E in der Schweiz und im Ausland 1997–2014. Angegeben ist die Änderung in Prozent des Ausgangswerts. Zunahme ist mit einem grünen, Abnahme mit einem roten Balken dargestellt. Die Skala ist für beide Abbildungen identisch. «Allgemeine Systematik der Wirtschaftszweige» bzw. «Nomenclature Générale des Activités économiques» (NOGA), Bundesamt für Statistik



Tendances d'évolution de la part des PME suisses de diverses divisions NOGA menant des activités de R&D en Suisse et à l'étranger entre 1997 et 2014. La variation est exprimée en pourcentage de la valeur initiale. Une barre de couleur verte représente une augmentation, une barre de couleur rouge une diminution.*
** «Nomenclature Générale des Activités économiques» (NOGA) de l'Office fédéral de la statistique*

der Klassen Metallherstellung und Nahrungsmittel am stärksten ausgeprägt.

- Der Umsatz mit Firmenneuheiten in Bezug zum Gesamtumsatz nimmt bei KMU und Grossunternehmen aller Industrieklassen zu. Besonders ausgeprägt sind die Zunahmen bei KMU der Klassen Druck, Kunststoffe, Metallerzeugnisse und Pharma.
- Der Umsatz mit Marktneuheiten in Bezug zum Gesamtumsatz sinkt bei KMU und Grossunternehmen aller Industrieklassen.
- Einzig KMU der Klasse Pharma verzeichnen steigenden Umsatz mit Marktneuheiten.

Die Studie zeigt, dass sich die Innovationskraft der Schweizer Firmen sehr heterogen entwickelt. Besorgniserregend ist insbesondere die zunehmende Öffnung der Schere zwischen Unternehmen, die F&E betreiben und dafür wachsende Mittel aufwenden, und solchen, die auf F&E verzichten. Die Tatsache, dass Schweizer Unternehmen immer weniger echte Marktinnovationen entwickeln, sowie der Rückgang der Forschungsaktivitäten bei vielen KMU geben zu denken.

visions métallurgie et industries alimentaires.

- Le chiffre d'affaires des produits innovants par rapport au chiffre d'affaires total augmente dans les PME et les grandes entreprises dans toutes les divisions industrielles. Cette augmentation est particulièrement marquée dans les PME des divisions imprimerie, plastiques, fabrication de produits métalliques et pharma.
- En revanche, le chiffre d'affaires des innovations de marché par rapport au chiffre d'affaires total baisse dans les PME et les grandes entreprises de toutes les divisions industrielles.
- Seules des PME de la division pharma présentent une augmentation du chiffre d'affaires avec des innovations de marché.

L'étude montre que la force d'innovation des entreprises suisses se développe de manière très hétérogène. L'élargissement du fossé entre les entreprises actives dans la R&D et qui y consacrent des ressources croissantes, et celles qui y renoncent, est particulièrement inquiétant. Le fait que les entreprises suisses développent toujours moins de réelles innovations de marché, de même que le recul des activités de recherche dans de nombreuses PME, sont préoccupants.

Der SATW Bericht sollte als Weckruf hauptsächlich für KMU verstanden werden, die Zeichen der Zeit zu erkennen. Die zunehmende Komplexität neuer Technologien wie z.B. im Quantenbereich könnte sie in Zukunft schnell in eine wirtschaftliche Schieflage bringen, wenn es an einem soliden Physikverständnis mangelt. Die technisch-ingenieurmässige Kompetenz würde dann allein nicht mehr ausreichen, wie auch die Antworten der Fachleute im voranstehenden Artikel zeigen. Unsere Fachhochschulen mit ihrer ausgewiesenen Nähe zu den KMU sind deshalb gut beraten, vermehrt auch Fragestellungen und Lösungsmethoden aus der angewandten Physik in ihr Ausbildungsangebot mit aufzunehmen. Die in den SPG-Fachsektionen vorhandene Kompetenz sollte hierzu abgerufen werden.

BB

The physics of the greenhouse effect

Stéphane Goyette, Nonlinearity and Climate group, University of Geneva, stephane.goyette@unige.ch

Introduction

Global warming is arguably one of the most pressing scientific issues of the last decades since it impinges directly on societal, economic, and environmental aspects of the world we live in. The fundamentals of the science underlying the forecasting of climate, and anthropogenic climate change, have been published and debated long before making headlines. In fact, the foundation of our understanding about the so-called "greenhouse effect" in relation to the earth's surface temperature is almost two centuries old. The greenhouse effect refers to the radiative process by which a planet's atmosphere warms the surface to a temperature above what it would be without it. The sensitivity of the earth's climate system to changes in atmospheric carbon dioxide (CO_2) was estimated at the end of the nineteenth century with an earlier allusion to a greenhouse effect credited to the French physicist Fourier. The rise of the atmospheric CO_2 concentration was discovered about fifty years ago and the compelling evidence of anthropogenic climate change to global warming stated in the IPCC (2014) report.

The purpose of this short communication is to briefly overview some of the fundamentals behind the natural and anthropogenic greenhouse effect. Some values to quantify the magnitude of the natural and anthropogenic forcings using a simple but physically-based climate model are provided, and conclude with a short acknowledgement of the contributions of the first scientists whose pioneering and seminal works aspired to develop comprehensive numerical models to understand and forecast global warming and its consequences.

The greenhouse effect

The existence of the greenhouse effect was hypothesised by Joseph Fourier in his "*Mémoire sur la température du globe terrestre et des espaces planétaires*" in 1827. Fourier is often considered as one of the scientists behind the discovery of the greenhouse effect, an expression that he did not use but was introduced later. However, his work, even qualitative, shows that he grasped the essential principles of this effect. The evidence was further strengthened by John Tyndall in 1859 who measured the radiative properties of specific gases. The effect was more fully quantified by Svante Arrhenius in 1896 who made the first quantitative prediction of global warming due to a doubling of atmospheric CO_2.

The greenhouse effect refers to the complex phenomena starting with the passage of the sun radiation, referred here to as "short-waves" ($0.1\ \mu m < \lambda < 4\ \mu m$; λ being the wavelength) and the absorption by the surface of the earth, since the troposphere [1] interacts weakly with short-waves. As the surface warms it emits thermal infrared energy, referred here to as "long-waves" ($4\ \mu m < \lambda < 100\ \mu m$) that would reach space if some radiatively active gases, also called greenhouse gases (GHG), were not present to trap the heat and therefore warm the surface.

According to the Stefan-Boltzmann law developed in 1879, based on experimental measurements made by Tyndall, the total energy radiated per unit surface area of a black body across all wavelengths per unit time is directly proportional to the fourth power of its temperature. Also, the Wien displacement law (formulated around 1893) states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional its temperature. Therefore, the sun maximum energy emission wavelength peaks at around 0.5 μm, whereas all components of the climate system emit radiant energy in the long-wave of the electromagnetic spectrum, at around 10 μm.

All real bodies emit and absorb less radiant energy than the theoretical black body at the same temperature and wavelength. The ratio between radiant energy between a real and a black body defines its emissivity, ϵ, and therefore, its absorptivity. In the heat transfer field of study, Kirchhoff's law (circa 1860) of thermal radiation states that both properties are less than 1 and vary with wavelength. The range of variation of emissivity with wavelength is large for gases. Monoatomic gases absorb and emit radiant energy in very distinct spectral absorption lines resulting from quantized changes in electronic states. But, molecular gases produce spectral absorption and emission bands formed by a large number of very close lines. The location and strength of these bands depend on the molecular structure of the gas. Therefore, atmospheric absorptivity varies greatly with wavelength and has highly irregular and discontinuous patterns.

At the ground level, the variety of surface types has different broadband emissivities ϵ, e.g. 0.97 for open waters and 0.98 for vegetation. The net effect of the absorption and emission spectrum for long-wave terrestrial radiation in the troposphere results from the superposition of the absorption spectra for the entire vertical column of individual constituents of the atmosphere. Thermal vibrations and rotations of the molecules produce emission and absorption spectra with emissivity less than 1. The spectral distributions are explained by the fundamental principles of atomic physics and quantum mechanics, involving quantum-mechanical selection rules whose details is beyond the scope of this communication. The emission spectra of molecules are far more complex than those of atoms because they have more degrees of freedom. Diatomic molecules such as N_2 and O_2, composing more than 99% of the air, have no electric dipoles and therefore no vibrational or rotational spectra, but mainly electronic transition with emission and absorption spectra in the ultraviolet and visible bands of the solar spectrum. The principal atmospheric gases that are radiatively active in the long-waves are "greenhouse gases".

The basic quantitative information on absorption spectra comes from laboratory experiments. To represent the effects of GHG in numerical models for weather prediction and climate simulation, knowledge of infrared absorption spectra for each gas is required. The most abundant greenhouse gas in the atmosphere is water vapour (H_2O) having rotational and vibrational states leading to complex and irregular absorption. It has a rotational band starting at 14

1 Troposphere: the lowest layer of the atmosphere where almost all weather phenomena take place. It contains approximately 75% of the atmosphere's mass and 99% of the total mass of water vapour and aerosols. The average depths of the troposphere are 17 km (~100 hPa) in the Tropics to 10 km (~250 hPa) in Polar regions. The tropopause meanwhile is the boundary between the troposphere and the stratosphere.

μm and centered at 65 μm, and several vibrational-rotational in the 1 μm - 8 μm band. Carbon dioxide (CO_2), which is naturally present in Earth's atmosphere but its concentration rose from pre-industrial levels of 280 ppmv to about 410 ppmv (July 2018; NOAA); with the increase mainly due to the use of fossil fuels and deforestation. Because CO_2 is a linear and symmetric molecule it only has vibrational bands causing absorption showing maxima at 2 μm, 3 μm and 4 μm, and in the 13 μm - 17 μm region. Ozone (O_3), which is abundant in the stratosphere, contributes to the absorption of long-wave radiation through vibrational-rotational states centered at 9.6 μm. Methane (CH_4) is another important greenhouse gas. Since it has even more atoms, its vibrations are complicated and centered around 7 μm. We should also mention that nitrous oxides (N_2O), plus a collection of man-made gases with more than 2 atoms also play a role. In the 8 μm - 12 μm region the atmosphere is almost transparent for long-wave terrestrial radiation in the absence of clouds, with the exception of the absorption by ozone. Interestingly enough, through absorption in this region, small increases of GHG may have a large impact on the climate.

Equilibrium of the global climatic system is achieved in the long term, so the short-wave radiation absorbed by the Earth and the atmosphere is returned back to space as long-wave radiation because practically all the energy exchange between the earth and outer space is achieved through radiative transfer. Therefore, in order to better understand the greenhouse effect, we first examine the global Earth's radiation balance at the top of the atmosphere (TOA) [2].

Radiation balance of the earth: a simple model

Meteorological satellites made significant scientific contributions to the measurements of the radiation budget in both the short-wave input and the long-wave output at TOA. Measurements of the planetary albedo [3], i.e. a mixture effect of surface and atmospheric reflection at TOA, combined with incoming solar radiation at TOA form the first component of the radiation budget. These indicate that the solar constant I_o is about 1370 Wm^{-2} and a planetary broadband albedo α of 30%, with contributions of about 26% from the atmosphere (air, clouds, and aerosols) and 4% from the surface. Long-wave radiation coming from outer space is not significant so only the emission by the earth-atmosphere system $R_L^{\uparrow}$ is considered. The earth is in radiative equilibrium so that the integration of the short-wave input minus that of the long-wave output at TOA approximately vanishes on the long term to produce a global all wave net radiation budget R_n close to zero, consequently

$$R_n = \frac{I_o}{4}(1-\alpha) - R_L^{\uparrow} \approx 0 \qquad (1)$$

with the factor one quarter coming from the integration over a disk for the short-wave and over a sphere for the long-wave radiation. If $R_n \neq 0$, the global Earth-atmosphere system would be subject to cooling or heating. With the accuracy of actual measurements this does not seem to be the case. The first term on the left hand side of ≈ in Eq. (1) is about 239.8 Wm^{-2}, a useful reference value for the study of the energetics of the global climate system. If we suppose that the global Earth-atmosphere system behaves like a black body, then T_e defines the effective radiating temperature computed using the Stefan-Boltzmann law as $R_L^{\uparrow} = \sigma T_e^4 = 239.8\ Wm^{-2}$, where σ is the Stefan-Boltzmann constant equal to 5.67×10^{-8} Wm^{-2}K^{-4}, so that T_e = 255 K or about -18°C, and that is the temperature at which satellites see the top of the atmosphere emitting long-wave radiation to space. Because the atmosphere emits in specific wavelength bands, the emission departs significantly from that of a black body.

An appraisal of the global greenhouse effect

Due to the existence of an atmosphere with greenhouse gases that absorb and emit in the long-wave spectrum, the global average surface temperature, T_{sfc}, is greater than it would be if the atmosphere were transparent with regards to the long-wave radiation, formally:

2 Top of the atmosphere: the actual altitude used for calculations varies depending on what parameter or specification is being analysed. For example, in radiation budget, TOA is considered ~20 km because above that altitude the optical mass of the atmosphere is negligible.

3 Albedo: the measure of the diffuse reflection of solar radiation out of the total solar radiation received by the Earth.

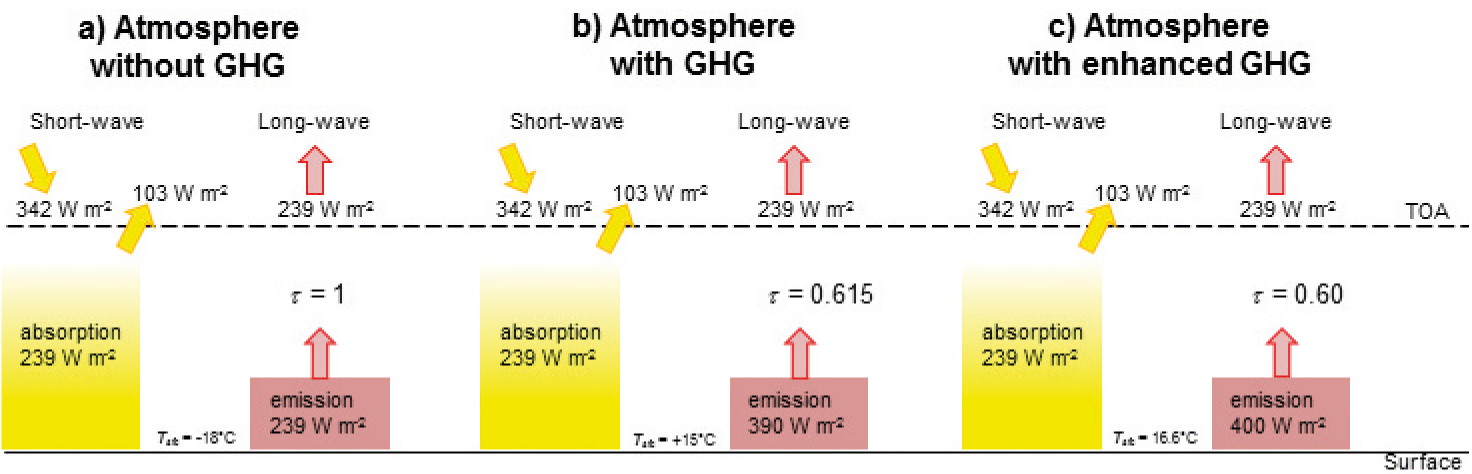


Figure 1. Schematic comparing short-wave and long-wave fluxes, atmospheric transmissivity in the long-wave, τ, and the global average surface temperature, T_{sfc}, at equilibrium for : a) an hypothetic earth's atmosphere without GHG, τ = 1 and T_{sfc} = -18°C; b) an atmosphere with GHG representative to that of the second half of the 20th century, τ = 0.615 and T_{sfc} = +15°C; c) an atmosphere with enhanced man-made GHG, τ = 0.60 and T_{sfc} = +16.6°C. The assumption made to estimate the magnitude of the greenhouse effect and its enhancement is that the same amount of short-wave is absorbed at the global earth-atmosphere system in each case based on Eq. (3).

$$T_{sfc} = T_e + \Delta T \qquad (2)$$

Long term meteorological observations indicate that the global average surface temperature is about 15°C. The value ΔT of 33°C in Eq. 2 is attributed to the greenhouse effect. At a temperature of 15°C, the surface emits 390 Wm^{-2} on the global average, whereas satellite measurements indicate that only 239.8 Wm^{-2} escape to space (see Fig 1b). The difference, termed G, between the surface emission and the total energy loss of about 150 Wm^{-2} is a metric for the greenhouse effect. The energy budget at TOA can also be characterised by an effective transmissivity factor of the atmosphere in the long-wave spectrum, τ, by connecting the absorbed solar radiation to the Earth's surface temperature using the following model

$$R_n = \frac{I_o}{4}(1-\alpha) - \varepsilon\tau\sigma T_{sfc}^4 = 0 \qquad (3)$$

therefore $\epsilon\tau = 0.61$. Thus more efficient heat trapping in the long-wave, i.e. lower τ, produces higher T_{sfc} for given I_o and α. The contributions to the greenhouse effect on Earth are about 50% due to water vapour, 25% due to clouds, 19% due to CO_2, and 7% due to other GHG. From Eq. (3), one can easily note that if the earth's atmosphere is devoid of GHG as shown in Fig 1a, $\tau \rightarrow 1$ and the surface temperature tends to T_e. One may also show using a simple 2- layer radiative model that with an absorbing atmosphere in the long-wave, the surface temperature would be much higher than that of the atmosphere and the resulting temperature profile would be unstable. Thus, air parcels disturbed from a location close to the surface would be turbulent and carry energy upwards through sensible and latent heat fluxes. These turbulent fluxes mix the lower atmosphere and produce a lapse rate such as that observed on the global average.

The anthropogenic contribution to the greenhouse effect

Charles Keeling set up an infrared spectroscope measuring atmospheric CO_2 at the Mauna Loa Observatory and later published his results (Keeling et al., 1976); this paper revealed for the first time the measurable increase in the atmospheric CO_2 as a result of the combustion of fossil fuels.

If the atmospheric concentration of CO_2 increases, the global mean direct radiative forcing of the surface-atmosphere system first results in the reduction of the TOA long-wave flux causing stronger infrared trapping holding all the other climate parameters fixed, such as I_o and α in Eq. (3). This is strictly an enhanced greenhouse effect above that occurring due to natural GHG concentrations as the atmosphere is more opaque in the long-waves.

Due to its major role in the global warming, let's focus on the CO_2 forcing [4]. Radiative calculations lead to an evaluation of perturbation in the long-wave emission to outer space with a change in the CO_2 concentration and yield a value of about -4 Wm^{-2} for a doubling of the atmospheric concentration of CO_2 (e.g. Dickinson and Cicerone, 1986). In other words, if the CO_2 is abruptly doubled, the long-wave flux would decrease by about 4 Wm^{-2} at the tropopause with heating increasing by the equivalent radiative forcing of 4 Wm^{-2}. According to the simple model (Eq. (3)), the climate system will re-establish a radiation balance by warming up the surface and the troposphere until it re-emits to space the excess 4 Wm^{-2}. The increase in long-wave emission induced by higher temperature balances its decrease caused by the lower value of τ, or likewise by the increase in atmospheric emissivity. Figure 2 shows the variation of the global average temperature as a function of the long-wave transmissivity using Eq. (3) and shows warming with increasing CO_2 (also shown in Fig. 1c). This simple analysis ignores the stratosphere which in fact will cool because of the increased CO_2 infrared emission. Although this does not alter the overall results described above and therefore will not be addressed here.

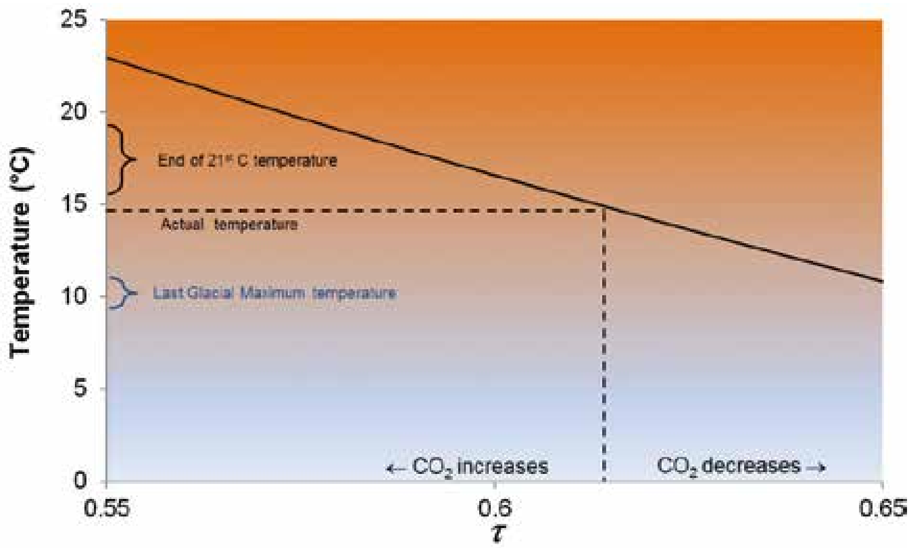


Figure 2. Global mean surface temperature as a function of atmospheric long-wave transmissivity τ. Actual conditions are depicted by the black dashed lines. As the CO_2 increases, long-wave opacity increases, i.e. transmissivity decreases and the surface warms up. By the end of the 21st century, the temperature will depend much on the emission scenario (e.g. IPCC 2014) but the CO_2 concentration will presumably be much more than twice the amount of pre-industrial period. Also shown, the last Glacial Maximum temperature for comparison.

Feedback effects ensuing from the anthropogenic greenhouse effect

The global mean earth's surface temperature may be regarded as one of the responses of the climate system to forcings taking into consideration possible internal feedbacks. In fact, there are a large number of non-linear mechanisms operating within the various components of the climate system and subsystems. Actually, there are many positive and negative feedback mechanisms and there is compensation between them in the mean to prevent from a runaway situation such as that which presumably happened on Venus. There are some approaches published in the scientific literature to get some insight into the complex feedback mechanisms (Schlesinger 1988). Without going into the details, only a few examples can be given in this com-

4 Forcing: the change in net (down minus up) irradiance (solar plus longwave; in Wm^{-2}) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values. Radiative forcing is used to assess and compare the anthropogenic and natural drivers of climate change IPCC (2014).

munication to provide for some hints as to how the climate system reacts to a given perturbation. As described above, the infrared loss at TOA depends on the CO_2 concentration and the atmospheric temperature, but also on water vapour content because of the evaporation feedback with the inclusion of other known non-linear effects such as the temperature-albedo feedback. The simple model described above (Eq. 3) does not include feedback mechanisms and the direct radiative response is clearly positive with a sensitivity of 0.3 $KW^{-1}m^2$ at 288 K (15°C). The increase of GHG induces a positive feedback. The water vapour-greenhouse effect induces a positive feedback contribution due to the non-linear relation of the air moisture and temperature through the Clausius-Clapeyron equation which is a non-linear equation describing the rate of increase in vapour pressure per unit increase in temperature. An increase in temperature causes a melting of sea ice and snow cover that lowers the albedo and thereby increases the absorbed short-wave radiation, the whole process amplifying the surface warming, and thus producing positive feedback. On the other hand, the temperature long-wave radiation coupling in the atmosphere produces a negative feedback; as the temperature increases the atmosphere will loose more long-wave radiation to space thus reducing the temperature and thus weakening the initial perturbation. One should mention that cloud feedback is one of the largest sources of uncertainty in the theory of climate change. Clouds and aerosols reflect the incoming short-waves (parasol effect through the modulation of the planetary albedo) and absorb the long-waves emitted by the surface and emit energy to space from colder cloud tops (greenhouse effect). Therefore, while this greenhouse effect of clouds warms the planet, the albedo effect cools it. Modern three-dimensional numerical global climate models predict global warming of more than 2°C by the end of the XXI century depending on the GHG emission scenario (IPCC, 2014). Therefore, the climate system sensitivity with regards to GHG would be more than 0.3 $KW^{-1}m^2$, presumably in the range of 0.4 – 1.25 $KW^{-1}m^2$ due to numerous feedback processes. This shows the complexity of what might be an initial CO_2 forcing on the subtle energy balance of the earth-atmosphere system.

Conclusions

The physical processes of the greenhouse effect may be synthesised as follows: the incoming solar energy warms the surface, which in response to short-wave absorption emits long-wave energy that is then partially trapped by GHG primarily composed of water vapour and CO_2, with a smaller (< 5%) contribution from O_3, N_2O and CH_4, due to the interaction with the long-wave emission originating from the surface. Clouds also contribute significantly to the natural greenhouse effect. Several anthropogenic gases, however, such as the halocarbons also contribute. Tropospheric temperatures decrease with height, so that the GHG absorb more upward radiative flux than they emit upwards, consequently the metric *G* is positive. The net result of these absorption and emission processes is that part of the infrared radiation emitted by the surface is trapped, forces increased convection, and acts to warm the troposphere and surface until the long-wave emission to space balances the net incoming short-wave.

Following the seminal works undertaken more than a century ago, the development of the greenhouse theory reached higher rungs in the knowledge ladder. But as is often the case, many early works have been only valued in hindsight. Callendar in 1938 linked the increase in CO_2 concentration over the previous fifty years to rising temperatures. Plass (1956) calculated that the mean global surface temperature would increase by approx. 3.6°C if atmospheric carbon dioxide were to double. Möller (1963) provided the first model attempt and advocated that water vapour might also act as a positive climate feedback mechanism. The pioneering effort by Manabe and Wetherald (1967) provided quantitative results for carbon dioxide induced warming on the basis of a numerical one-dimensional radiative-convective model. One of the most significant advances in the CO_2 warming was the pioneering development by Manabe and Wetherald in early 1970s of a three-dimensional global climatic model. Since then, these models have increased the complexity and the reliability of their simulations allowing for the analysis of the impacts of global warming at a fine spatial resolution in order to address the most pressing issues for the decades to come, as presented in the numerous IPCC reports. The history of this sensational journey in research is presented by Weart (2008) and in a collection of papers in Archer and Pierrehumbert (2011).

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Bücherecke - Le coin aux livres

Otto Sager

Debatten zur Kulturgeschichte der Physik

Verlag Books on Demand, ISBN-13: 9 783752 850512

Das langjährige SPG-Mitglied, der Industriephysiker im Ruhestand Dr. Otto Sager hat eine flüssig lesbare Abhandlung über die Diskussionskultur in der Physik verfasst. Sein Buch *Debatten zur Kulturgeschichte der Physik, von Demokrit zu Dürrenmatt* beschreibt in 32 Episoden, dass epochale Fortschritte in der Physik immer von teils heftigen Auseinandersetzungen begleitet wurden. Selbst wenn sich letztlich eine Auffassung dann als Lehrmeinung durchsetzte, blieben die Argumente der Gegenseite in vielen Fällen erhalten und harren einer Neubetrachtung. In 32 fiktiven Debatten wird dieser Aspekt der Physikgeschichte aufgezeigt, wobei der Autor das jeweilige Streitthema mit den Namen zweier illustrer Physikpersönlichkeiten verknüpft.

Das Buch ist in fünf Hauptkapitel gegliedert

- Physik als Teilgebiet der Philosophie (Beispiel: Die Thomas von Aquin-William von Ockham-Debatte über Realismus oder Nominalismus)
- Debatten auf dem Weg zur klassischen Physik (Beispiel: Die Boltzmann-Ostwald-Debatte über statistische oder phänomenologische Physik)
- Debatten zur Physik des 20. Jahrhunderts (Beispiel: Die Pauli-Scherrer-Debatte über theoretische oder experimentelle Physik)
- Physik als Basis für andere Fachgebiete (Beispiel: Die Millikan-Pauling-Debatte über Physik und Chemie)
- Physik und Gesellschaft (Beispiel: die Popper-Kuhn-Debatte über Wissenschaftstheorie und Physik)

Der Autor hat kein wissenschaftliches Geschichtsbuch verfasst, sondern zieht sein Wissen aus der gängigen Literatur. Das, was das Buch lesenswert macht, ist, wie er die Sachverhalte auf nur wenigen Seiten feuilletonhaft-elegant erläutert, verknüpft mit den Kurzbiographien der Kombattanten, und so dem Leser ein erfrischendes Déjà-vu Erlebnis beschert.

Bernhard Braunecker

Jeunes physiciens suisses médaillés de bronze au IYPT

Emilie Hertig, EPFL

Des gymnasiens passionnés de physique, venus de 32 pays différents d'Europe, d'Asie, d'Amérique et d'Océanie, se sont rassemblés en juillet dernier à Pékin lors du 31ème IYPT (*International Young Physicists' Tournament*). Cette compétition internationale, fondée en 1988, vise à donner aux jeunes scientifiques un bref aperçu du monde de la recherche : les participants sont amenés à réaliser des petits projets dont la préparation s'étend sur plusieurs mois, puis à présenter leurs résultats en anglais et à les défendre face aux critiques des autres équipes. A l'issue de cinq étapes de débats passionnés, des recherches théoriques avancées, des résultats expérimentaux variés et des performances convaincantes sur scène ont valu à la délégation helvétique une belle 10ème place.

Les récompenses sont attribuées selon la règle suivante : les trois ou quatre équipes les mieux classées reçoivent une médaille d'or et s'affrontent devant tous les autres participants lors de la finale, où elles ont la possibilité de présenter leur projet le plus convaincant. Les cinq équipes suivantes reçoivent une médaille d'argent, et le reste des équipes dans la première moitié du classement obtiennent le bronze. Cette année, la finale a été disputée entre la Chine, la Corée du Sud, l'Allemagne et Singapour, qui a atteint la première place et remporté le trophée pour la sixième année consécutive. Les concurrents suisses, David Tschan (capitaine), Daniel Gotsmann, Daniil Lozner, Piotr Salustowicz et Jakob Storp, encadrés par les *Teamleaders* Emilie Hertig et Eric Schertenleib, ont eu la joie d'ajouter une nouvelle médaille de bronze à un palmarès helvétique

Les cinq membres de l'équipe sur le campus de l'Université Renmin. De gauche à droite: Daniil Lozner, Jakob Storp, Daniel Gotsmann, David Tschan et Piotr Salustowicz.

déjà bien fourni. En effet, la Suisse avait déjà remporté cinq fois le bronze, une fois l'argent et deux fois l'or, et continue de viser haut pour l'édition 2019 !

Le IYPT représente une opportunité formidable pour les étudiants enthousiasmés par la science : il leur permet notamment de rencontrer des jeunes du même âge, originaires des quatre coins du globe et partageant leur passion. De plus, les 17 problèmes ouverts sur lesquels les participants travaillent en vue du concours sont l'occasion de se familiariser avec des notions théoriques et des méthodes expérimentales dépassant largement le cadre de l'enseignement gymnasial ; une solution détaillée à l'un ce ces problèmes peut parfois aller jusqu'à être présentée à *La Science appelle les Jeunes*, ou même faire l'objet d'une publication. Ces questions de la recherche actuelle touchent à tous les domaines de la physique, de la mécanique à la thermodynamique, en passant par les fluides, l'optique et l'électricité. Quelques exemples de problèmes abordés par l'équipe 2018 : analyser la stabilité de trajectoires d'un pendule chaotique, inventer et construire un sismographe, faire léviter des particules sur des ondes sonores, ou encore expliquer les rais de lumières apparaissant lorsque l'on photographie une lanterne.

S'attaquer à de telles questions est un véritable défi pour un gymnasien, et implique un investissement personnel conséquent, autant d'un point de vue scientifique que du côté organisationnel et pratique. Le capitaine de l'équipe, habitant à Bâle, ainsi qu'un de ses coéquipiers scolarisé à Zuoz (Grisons), faisaient ainsi le déplacement jusqu'à Zurich (où se déroulent les séances de préparation) presque tous les week-ends pendant les semaines précédent le départ en Chine ; deux autres membres de l'équipe ont aussi dû équilibrer le temps consacré au IYPT par rapport à celui consacré à leurs examens de maturité. Bien que les projets de recherche soient individuels, le IYPT reste une compétition par équipe et le travail de groupe est indispensable lors des débats et interactions avec les autres équipes. Apprendre à gérer une collaboration et à composer avec les différences de niveau et de caractère au sein de l'équipe constitue donc un défi supplémentaire pour les participants. Le IYPT est ainsi l'occasion pour des élèves motivés d'être confrontés un environnement similaire à celui d'une équipe de recherche, ce qui en fait une expérience très instructive. Les cinq physiciens en herbe ont saisi cette occasion, fait preuve d'intelligence et de détermination tout au long du tournoi, pour finalement obtenir une médaille bien méritée et profiter de quelques jours de tourisme à Pékin et dans les environs. Faire quelques pas sur la Grande Muraille de Chine en compagnie des équipes de Suède et de Russie a permis de clore en beauté cette expérience inoubliable !

L'équipe et les deux Teamleaders sur scène lors de la cérémonie de remise des médailles.

SYPT / IYPT, comment est-ce organisé?

Le IYPT, *International Young Physicists' Tournament*, est une compétition internationale de physique ayant lieu chaque année dans une ville différente, et à laquelle participent plus de 30 pays. Chaque pays y envoie une équipe de 5 gymnasiens, qui sont amenés à travailler de manière autonome sur 17 problèmes ouverts dans les mois précédent le concours. Les équipes s'affrontent trois par trois devant un jury d'experts lors de *physics fights*, au cours desquels les élèves prennent tour à tour les rôles de *reporter* (présente sa solution à l'un des problèmes), *opponent* (analyse les points forts et faibles d'une présentation adverse et débat avec le reporter) et *reviewer* (synthétise la présentation et la discussion et donne son avis sur les points abordés). Les membres de l'équipe suisse sont choisis sur la base de deux étapes de sélection. La première est le SYPT, *Swiss Young Physicists' Tournament*, qui a lieu en mars et se déroule à l'échelle nationale de manière similaire au IYPT. Les 9 concurrents les mieux classés à l'issue du SYPT sont invités à travailler sur un nouveau problème en vue de la qualification de l'équipe, quelques semaines plus tard, consistant en un examen écrit suivi de plusieurs *physics fights*.

Joseph Fourier
Moderne Wissenschaft in seinem 250ten Geburtsjahr

David Müller, PGZ

Unter diesem Motto haben die SPG und die Physikalische Gesellschaft Zürich (PGZ) am 24. Mai 2018 ein gemeinsames Mini-Symposium veranstaltet. Es wurde von SPG-Präsident Hans Peter Beck eröffnet, während PGZ-Präsident Jürg Osterwalder die Schlussworte sprach.

Während die drei physikalisch-technischen Vorträge Aspekte um die Fouriertransformation zum Inhalt hatten, ging ***Jan Lacki*** von der Université de Genève in seinem historischen Überblick auf das bewegte Leben von Fourier ein und schilderte insbesondere die politischen Umstände um die Entwicklung der Theorie der Wärmeleitung.

Fouriers Leben und die Wärmeleitungstheorie

1768 in bescheidenen Familienverhältnissen geboren, ist Fourier bereits in seinem neunten Lebensjahr verwaist. Seine grosse mathematische Begabung, verbunden mit einem ausserordentlichen Organisationstalent, fiel früh auf, so dass er 1797 die Professur für Analysis und Mechanik in der Nachfolge von Lagrange übernehmen konnte. 1798 folgte er Napoleon als wissenschaftlicher Begleiter auf den Ägyptenfeldzug. In dieser Periode erstellte er seine ersten Arbeiten zur Theorie der Wärmeleitung. Nach den Wirren durch die englische Eroberung Ägyptens wollte Fourier die wissenschaftliche Arbeit in Paris fortführen, wurde aber von Napoleon als Präfekt ins Departement de l'Isère beordert; seine Fähigkeiten und die Unterstützung für den Kaiser verhalfen ihm für kurze Zeit zu Position und Einkommen.

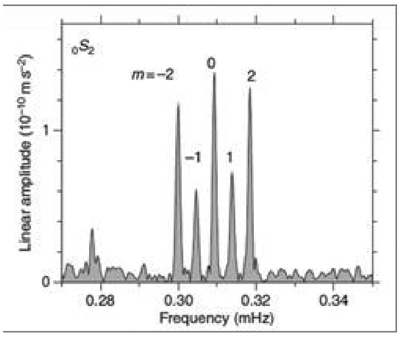
Mit der Restauration der Monarchie 1815 verlor er zwar diese Privilegien, wurde aber aufgrund seiner Leistungen 1817 trotzdem in die Académie des Sciences gewählt. Politische Kämpfe prägten das wissenschaftliche Leben Frankreichs in dieser Zeit. Laplace und Berthollet dominierten die Vergabe von Preisen und Positionen.
Hinsichtlich der Natur der Wärme herrschte damals die Vorstellung eines stofflichen „Calor" vor. Diese früher auch von Newton vertretene These wurde jedoch durch experimentelle Resultate zunehmend bedrängt. Eine anschauliche Erklärung auf der Basis der inneren Energie lag hingegen noch in weiter Ferne. Fouriers Verdienst ist es, mit seiner Wärmeleitungsgleichung eine umfassende mathematische Beschreibung der Phänomene geliefert zu haben, ohne bei der Frage hängen zu bleiben, wie man sich Wärme denn vorzustellen habe. Damit hat er den grossen Schritt hin zu den mathematisch beschreibenden Wissenschaften mitgeprägt.

Fourier für Erleuchtete

Moderne Optiken, welche nur dank unseres Verständnisses der Fouriertransformation gebaut werden können, hat ***Markus Rossi*** von der Firma Heptagon/AMS erläutert. Jedes optische Abbildungssystem ist dual aufgebaut: während die räumlichen Strukturen der Objektebene vom Objektiv in bekannter Weise in die Bildebene abgebildet werden, gibt es stets eine ähnliche Abbildung der Eintritts- in die Austrittspupille. In die Pupillen setzt man zum Beispiel physische Blenden ein und oft bildet man auch die Lichtquelle dorthin ab. Der mathematische Zusammenhang zwischen beiden Abbildungssubsystemen ist die Fouriertransformation. Das kann man technisch nutzen, indem man in einer der Pupillenebenen speziell strukturierte Hologramme als Diffractive Optical Elements (DOE) einbringt, um so das räumliche Frequenzspektrum des abzubildenden Objekts zu beschneiden oder in gewünschter Weise zu verändern.
Eine in höchstem Mass miniaturisierte und auf Kosteneffizienz optimierte Anwendung dieses Phänomens wird von AMS zur Erzeugung von strukturiertem Licht mit pseudo-randomisiert verteilten Lichtpunkten verwendet. Dabei wird als DOE ein computergeneriertes Hologramm (CGH) mit geeigneter Mikrostruktur eingesetzt, so dass die optisch durchgeführte Fouriertransformation in der Bildebene die gewünschte Punktverteilung erzeugt. Auf diese Weise lassen sich kostengünstig miniaturisierte Infrarot-Lichtpunkt-Projektoren bauen. Wozu das Ganze? Projiziert man das bekannte Punktemuster auf ein Objekt wie zum Beispiel auf ein menschliches Gesicht, dessen dreidimensionale Oberfläche man vermessen möchte, und bildet dieses wiederum mit einer Kamera auf einen normalen 2D Sensor ab, so kann man aus der Verzerrung des abgebildeten Punktemusters zurück auf die 3D-Struktur schliessen. Eine so aufgebaute 3D-Kamera, bestehend aus integrierter Projektions- und Abbildungsoptik, wird in Mobiltelefonen zur Gesichtserkennung eingesetzt.

Das Spektrum der Erde

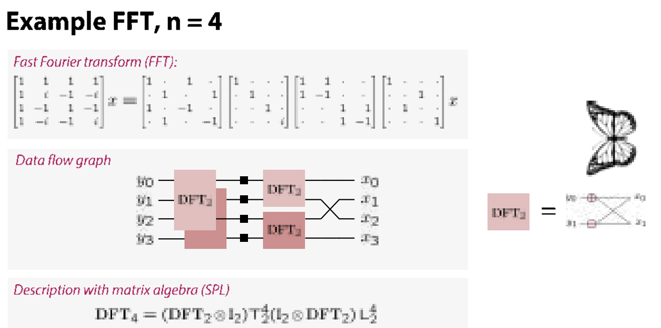
Einen Resonator von ganz besonderer Bedeutung für die Menschen – nämlich unseren Erdball – hat ***Andreas Fichtner*** vom Departement Erdwissenschaften der ETH äusserst anschaulich vorgestellt.
Lord Kelvin hatte 1863 die längste Eigenperiode der Erde mit 69 min. abgeschätzt. Knapp hundert Jahre später ist diese Periode in der Auswertung eines schweren Erdbebens in Chile mit 57 min. gemessen worden. Darüber hinaus ist eine Vielzahl von höheren Eigenfrequenzen bis in den Bereich von 1 Hz bekannt. In Analogie zur Aufspaltung der Energieniveaus in der Atomphysik entsteht auch bei seismischen Wellen eine „Feinstruktur". Die Differenzierung geschieht aufgrund der Erdrotation.
Genaue, zeitsynchrone seismographische Messungen an verschiedenen Punkten der Erde erlauben detaillierte Rückschlüsse auf den Aufbau des Planeten. Jedes grosse Beben wird in dieser Weise zu einer Quelle neuer Kenntnisse. So können die Ausbreitungsgeschwindigkeiten für Longitudinal- und - falls vorhanden - Transversalwellen aus verschiedenen Tiefen aus den verschiedenen Eigenmodi bestimmt werden. Daraus wird die Druck-, Temperatur- und Dichteverteilung abgeleitet. Aufgrund der heute verfügbaren Daten kann ein 3D-Modell der Erde erstellt werden, wobei beispielsweise Abweichungen der Ausbreitungsgeschwindigkeit von Transversalwellen von weniger als einem Prozent in einer Tiefe von 500 km genau angegeben werden können. Diese Daten sind in hervorragender Übereinstimmung mit den plattentektonischen Modellen der Erde.



Schnelle Fourier-Transformation: Algorithmen, Implementierungen, Anwendungen

Markus Püschel vom Departement Informatik der ETH hat die praktische Bedeutung der Fouriertransformation, respektive der diskreten Fouriertransformation (DFT) und ihrer Umsetzung in Rechnersystemen ins Zentrum seines Referats gestellt. Egal ob in der digitalen Signalverarbeitung (DSP), Echounterdrückung in Telefongesprächen, drahtlosen Kommunikation, Bildkompression oder für die Mustererkennung, stets werden im Hintergrund intensiv Fouriertransformationen gerechnet.
Bei einer „naiven" Umsetzung der DFT in Software muss für jedes Element des Resultatvektors direkt über jeden Punkt des Eingangsvektors summiert werden. Der Rechenaufwand steigt damit quadratisch zur Länge des zu transformierenden Vektors an. Darüber hinaus führen die Zugriffe des Algorithmus auf den gesamten Eingangsvektor zu massiven Leistungseinbussen, falls dieser Datenbereich nicht vollständig im innersten Speicherbereich des Prozessors (L1-Cache) gehalten werden kann. Seit den frühen Zeiten der Informatik wird an schnellen und besser skalierenden Algorithmen zur Umsetzung geforscht (Fast Fourier Transform, FFT). 1965 wurde ein FFT-Algorithmus mit einem Rechenaufwand proportional zu (5n × log(n)) publiziert, der damit den Anfang der digitalen Signalverarbeitung einläutete. Seitdem wurden viele Varianten für verschiedene Zwecke entwickelt.

Sämtliche FFT Algorithmen basieren auf einer Aufteilung der Berechnung auf kleinere Sub-Blöcke, welche mehrfach durchlaufen werden, jeweils mit einem Austausch von Zwischenresultaten. Damit zerfällt die Aufgabe in kleinere Teilaufgaben. Die Grösse der Sub-Blöcke kann variiert werden – wobei kleinere Blöcke zu einer grösseren Anzahl zu durchlaufender Schritte führen. Die schnellste Umsetzung hängt von der Grösse des Vektors, aber auch von verschiedenen Parametern der Rechnerplattform ab, wie Prozessorgeschwindigkeit, Grösse des L1-Cache, Speicherbandbreite, etc. Der Programmgenerator Spiral erlaubt, die beste Variante zu finden und erzeugt den dazu notwendigen Code automatisch. Werden anstelle von Prozessoren hoch parallele Elektronikschaltungen verwendet, so wird deren Struktur in einer Hardware-Beschreibungssprache festgelegt, welche durch denselben Programmgenerator erzeugt werden kann.



Fazit

250 Jahre nach der Geburt von Joseph Fourier ist die von ihm geschaffene Transformation aus dem Orts- oder Zeitraum in den räumlichen oder zeitlichen Frequenzraum zu einem der wichtigsten „Arbeitstiere" von Forschern und Ingenieuren geworden. Ihre schnelle Umsetzung FFT wird in Hörgeräten und Mobiltelefonen permanent durchgeführt.
Diffraktive Optikelemente sind sozusagen die "Programmierung" der Analogoptik. Hier wird die Fouriertransformation vom Licht direkt ausgeführt.

Ausschreibung der SPG Preise für 2019
Annonce des prix de la SSP pour 2019

Auch im Jahr 2019 sollen wieder SPG Preise, die mit je CHF 5000.- dotiert sind, vergeben werden.

- SPG Preis gestiftet vom Forschungszentrum ABB Schweiz AG für eine hervorragende Forschungsarbeit auf allen Gebieten der Physik
- SPG Preis gestiftet von der Firma IBM für eine hervorragende Forschungsarbeit auf dem Gebiet der Kondensierten Materie
- SPG Preis gestiftet von der Firma Oerlikon Surface Solutions für eine hervorragende Forschungsarbeit auf dem Gebiet der Angewandten Physik
- SPG Preis gestiftet vom METAS für eine hervorragende Forschungsarbeit mit Bezug zur Metrologie
- SPG Preis gestiftet von der Firma COMSOL für eine hervorragende Forschungsarbeit auf dem Gebiet der computergestützten Physik

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)):

En 2019, la SSP attribuera à nouveau des prix de CHF 5000.- chacun, à savoir:

- Le prix SSP offert par le centre de recherche 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 pour un travail de recherche d'une qualité exceptionnelle en physique de la matière condensée
- Le prix SSP offert par l'entreprise Oerlikon Surface Solutions pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique appliquée
- Le prix SSP offert par 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 pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique numérique

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 des fichiers très grands (zip):

awards@sps.ch

Einsendeschluss: 28. Februar 2019

Délai: 28 février 2019

Die Preise werden an der Jahrestagung der SPG 2019 in Zürich überreicht. Das Preisreglement befindet sich auf den Webseiten der SPG: *www.sps.ch*

Les prix seront attribués à la réunion annuelle de la SSP qui se tiendra en 2019 à Zürich. Le règlement des prix se trouve sur les pages Web de la SSP: *www.sps.ch* swiss physical society

Société Française de Physique

Call for nominations for the Charpak-Ritz Prize 2020

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 2020** 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 2020".

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

The award will be given at the annual meeting of the *French Physical Society* in 2020.

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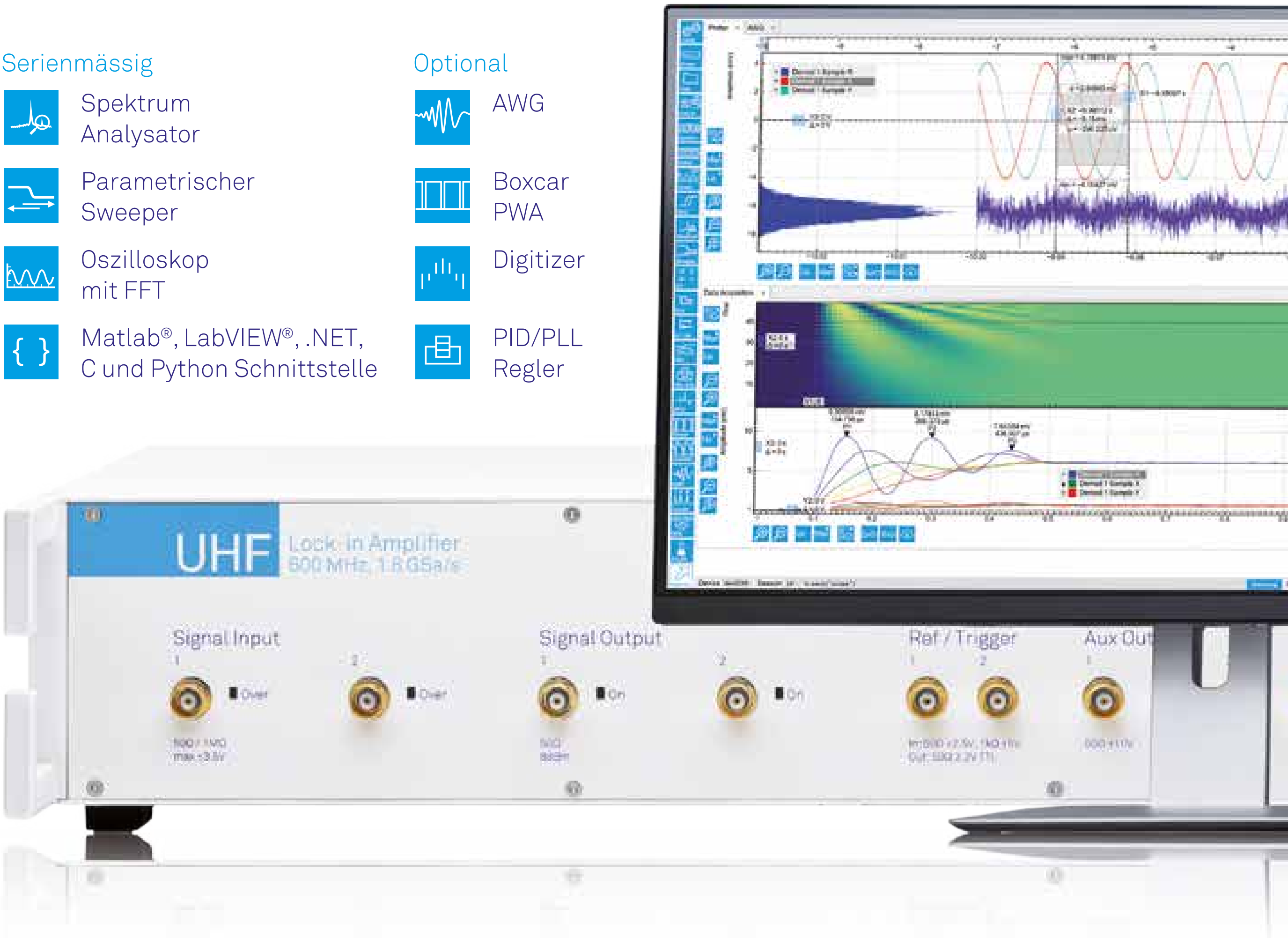

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