⟨S|P|S⟩
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Communications de la SSP

Annual Meeting of the Swiss Physical Society

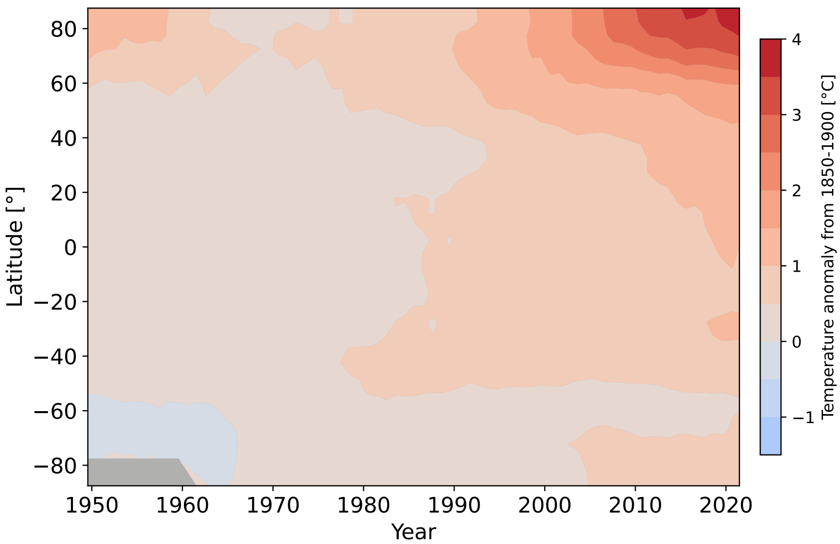
27 - 30 June 2022, Université de Fribourg

in collaboration with

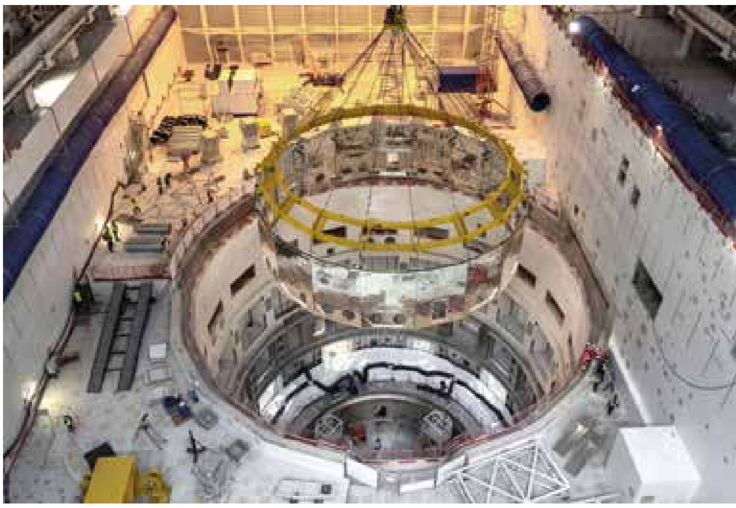
CHIPP, NCCR Bioinspired Materials, SGN, Département de Physique - Université de Fribourg

Call for Abstracts: Submission Deadline 15 March 2022

More information on page 4.



Observed evolution of zonal mean surface temperature change since 1950, relative to 1850 - 1900. For more information see article on p. 22.
(Figure by C. Wirths, Physics Institute, University of Bern)



A joint SPS - EPS delegation had been invited for an amazing visit to the ITER construction site (p. 28). This image shows the lower cryostat thermal shield being successfully lowered in the tokamak pit and inserted into the cryostat base, begin of 2021. © ITER

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Editorial

Themes, activities and challenges in 2022

Johan Chang, SPS President

Last year's opening editorial, by Hans Peter Beck, expressed hopes to shake-off the pandemic grip. Now one year later, vaccines have given some control and more opened societies. Yet, many of the hopes for 2021 can be carried into 2022. Certainly, we hope that seminars, symposia, and our annual meeting in Fribourg can be held in person.

This coming year has a number of important themes. It is the centenary of Albert Einsteins Nobel Prize for his explanation of the photoelectric effect. On p. 13 we have a very interesting article covering modern electron spectroscopy based on this effect. Moritz Hoesch, Claude Monney and Felix Baumberger illustrate how, over the last three decades, angle resolved photo emission has developed into a powerful condensed matter technique.

The centenary of Einstein's Nobel Prize is also celebrated by a symposium held in Bern on 9 April (p. 41, reserve the date). This event, initiated and organized by Claus Beisbart and Hans Rudolf Ott, is supported by the SPS, the Einstein Society and SCNAT.

Another centenary is that of the *International Union of Pure and Applied Physics*, IUPAP. Switzerland is a founding member of IUPAP. The mission was from the beginning to foster international cooperation in physics and to help application of physics towards solving problems of concern to humanity.

The United Nations decided in their most recent general assembly to make 2022 the **International Year of Basic Sciences for Sustainable Development** (IYBSSD - *https://www.iybssd2022.org*). With "climate action" being one of the 17 declared sustainable development goals (*https://sdgs.un.org/goals*), this also signals that climate change is a major concern to humanity. IUPAP's starting mission thus remains valid and to which we as physicists must contribute to – basic science and applying its findings is key when the sustainable development goals of the United Nations shall be met.

The importance of this problem is also highlighted by the 2021 Nobel Prize which is given "*for groundbreaking contributions to our understanding of complex systems*" jointly to Syukuro Manabe, Klaus Hasselmann and Giorgio Parisi. One half of the prize went to Syukuro Manabe and Klaus Hasselmann "*for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming*". This topic is covered on p. 22 in an article by Thomas Stocker. The other half of the Nobel Prize given to Giorgio Parisi "*for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales*" is covered in two articles by Jürg Fröhlich & Daniel Wyler (p. 25) and Yi-Cheng Zhang (p. 27).

To this end, let me stress that the Swiss Physical Society still seeks to fill an empty chair in the section of *Earth, Atmosphere and Environmental Physics*. Candidate suggestions are very welcome.

The first ***SPS Focus*** issue published by the SPS in 2021 contributes to another UN sustainable development goal on "affordable and clean energy" and is adding to the debate of energy and climate. By choosing the topic of nuclear energy, it reopens the sensitive debate about risk/safety and CO_2 neutral energy sources. The release of the ***SPS Focus*** triggered many positive comments. Hans Peter was invited to discuss the topic in the magazine of the Italian Physical Society. More recently RAI Südtirol brought a 10 minutes interview with Hans Peter on this topic. The visit to ITER (p. 28) is another recent activity within in SPS on the topic of energy. Most recently, the talk at PSI by Maurice Bourquin, one of the ***Focus*** authors, about the Thoriumtechnology attracted also scientists from Germany, USA, and India.

In 2022, our second ***SPS Focus*** issue will be concerned with physics and innovation in the private sector. The message aims to illustrate how physics knowledge and education is important for technology driven medium and small sized companies to stay competitive over time.

As closing remark, I would like to stress the 2020 Bonn declaration that perhaps has gone under the radar during the pandemic. It defines the freedom of research as a central pillar of democratic societies. Freedom of research is a principle to be defended. Another characteristics of democratic societies is the ideal to provide equal opportunities across ethnicity and gender. In physics, we have come far but there still exists a gender imbalance especially on professorial level. This means that we can still improve on gender balanced talent development. SCNAT has initiated a monthly profiling of female role-model scientists, see p. 21. On this note, the annual meeting in Fribourg will feature a satellite event entitled "Women in Physics Career Symposium". This event has been inspired by similar meetings organized by the American and German Physical Societies. See p. 7 for more info.

Wish you all a successful 2022 – stay healthy and safe.

SPS Annual Meeting in Fribourg, 27 - 30 June 2022

The next annual meeting will take place from 27 - 30 June 2022 at the Université de Fribourg on the Campus Pérolles.

Renowned invited speakers will give talks in the plenary session, parallel sessions will allow in depth discussions in several topical fields, and a poster exhibition will complement the scientific program.

This program is further enriched by the direct contributions of the *Swiss Institute for Particle Physics* (CHIPP), the *NCCR Bio-Inspired Materials*, and the *Swiss Neutron Science Society* (SGN). Thanks to all these collaborations, our annual meeting will offer again an exciting program, covering latest advancements of physics in a wide range of fields at its best.

Special thanks go to the Physics Department of UniFR, in particular to Prof. Claude Monney, Dr. Baptiste Hildebrand and their team, for their generous help and support with the organisation.

Important note: The conference is planned to take place, as in 2021, as *in person* event. We will inform in time on our web page on special restrictions or in case the pandemic situation should prevent the modus operandi.

Scientific Program

Plenary Session

Nine plenary talks will adress latest advancements in different research fields:

- **Christof Aegerter,** Universität Zürich:
  Physics & Education – Perspectives from Solid State Physics
- **Hatice Altug,** EPFL:
  Frontiers in Nanophotonics: Enabling Technology for Optical Biosensing and Bioimaging.
- **Dominik Brunner,** Empa:
  Monitoring and tracking carbon dioxide emissions from satellites
- **Atac Imamoglu,** ETH Zürich:
  Optical spectroscopy of strongly correlated electrons in two-dimensional materials.
- **Frank Jenko,** IPP Garching:
  Towards predicting plasma confinement in fusion devices
- **Teodoro Laino,** IBM Research Rüschlikon:
  Are Language Models better than Physics based models for Chemical and Materials Industries ?
- **Teresa Montaruli,** Université de Genève:
  The Cherenkov Telescope Array Observatory
- **Hans Rudolf Ott,** ETH Zürich:
  Large Research Infrastructures in Switzerland; History, Results and Opportunities
- **Pedro Reis,** EPFL:
  Untangling the mechanics of knots: from shoelaces to surgical knots

Furthermore, a public lecture is scheduled in the evening of Monday 27 June:

- **Thomas Stocker,** Universität Bern:
  Climate models: Early warning system of the climate crisis

A *Women in Physics Career Symposium* as a satellite event will complete the conference.

Topical Sessions

The following parallel sessions will be scheduled from Monday to Thursday:

- Applied Physics and Plasma Physics
- Atomic Physics and Quantum Photonics
- Biologically inspired assembly of ordered and disordered optical materials *
- Biophysics, Medical Physics and Soft Matter
- Condensed Matter Physics
- History and Philosophy of Physics
- New prospects in ARPES for quantum materials
- Nonequilibrium properties of quantum materials
- Nuclear, Particle- & Astrophysics **
- Physics at work in Industry
- Swiss Neutron Science on the European Scale ***

* in collaboration with NCCR Bio-Inspired Materials; ** in collaboation with CHIPP; *** in collaboation with the Swiss Neutron Science Society (SGN)

Depending on the number and contents of the contributed papers, each topical session may be split into special thematic subsessions.

Poster Session

The poster session will start on 28 June evening with an apéro and will continue on 29 June with a lunch buffet.
All posters are presented on both session days.

The three most outstanding posters will be awarded with a "Best Poster Prize". It is required that at least the first author of the poster is personally present at the conference in order to be eligible for the award.

The maximum poster size is A0 (portrait).

Award Ceremony

As in every year, outstanding scientific work will be honoured with the SPS awards in the fields of General Physics (sponsored by ABB Research Center), Condensed Matter Physics (sponsored by IBM Zürich Research Laboratory), Applied Physics (sponsored by Oerlikon), Metrology (sponsored by METAS), Computational Physics (sponsored by COMSOL) and Energy Technology (sponsored by Hitachi Energy). Each award is granted with CHF 5000.-.

Furthermore the winners of the Charpak-Ritz award and the CHIPP award will also be honored.

The award ceremony will be held on 28 June at 11:00h.

General Assembly

The general assembly is scheduled for 27 June in the afternoon. The agenda will be published in the next issue of the *SPG Mitteilungen*. We encourage all members to actively participate and contact the committee if special points of interest should be discussed at the assembly.

Conference Dinner

A conference dinner is scheduled for the evening of 29 June. Information on the location and more details will be available on our web site soon.

Vendors Exhibition

A vendors exhibition will be organized in parallel to the sessions. An invitation letter will be mailed within the next weeks to interested companies. If your company would like to join the exhibition, but did not receive the invitation letter, please contact: *sps@unibas.ch*

Abstract Submission:
Deadline 15 March 2022

You can submit abstracts to all topical sessions. The choice between an oral or a poster presentation of your contribution is possible. Due to the limited number of time slots the session organizers might however be forced to change oral presentations into posters. If possible, please mark both options in your submission, indicating that you are flexible regarding the presentation mode. Abstracts shall not be longer than ca. 100 words, and pictures are not allowed.

The submission of abstracts must be done online. Visit our webpage *www.sps.ch* and follow the link to the submission form. Further explanations are available there. The submission form will be activated shortly.
The conference program will be available in May 2022 on *www.sps.ch*. Please check the web regularly for further information and updates.

Conference Fees, Registration and Payment

The conference fees cover the participation to all sessions, including coffee breaks (all days), poster-apéro (Tuesday) and lunch buffet (Wednesday). The conference dinner on Wednesday evening will be charged separately.

Pay your conference fee in time and save money !

The regular fees, as shown in the table below, hold for payments reaching us before 1 June 2022.

Category:	*CHF*
Members of SPS, CHIPP	140.-
Ph.D. Students who are members (*)	100.-
Ph.D. Students who are not members (*)	140.-
Students before Master/Diploma degree (*)	80.-
Plenary speakers, invited speakers, awardees	0.-
Other persons	180.-
Conference Dinner	80.-

(*) Students licence required

For payments done later than 1 June a surcharge of CHF 20.- will be added. This applies also for participants paying cash at the conference.
For registration just follow the link on *www.sps.ch*. Payment information is available directly during the registration process. Please make sure that your name and the purpose of the payment are indicated.

Attention: Fees are not refundable in case of individual cancellation. In the case the entire conference needs to be cancelled, we will contact participants who have already paid for the refunding process.

Registration Deadline: 1 June 2022

Special offer for non-members:

Do you plan to participate in our meeting and want to become a member of the SPS ? Take advantage of our special offer of CHF 190.- covering the conference fees and the membership for 2022. (CHF 210.- after 1 June) !
Fill out the online-registration form, choose the option "Special offer", then download, print, fill and sign the admission form for new members, and return it as soon as possible to the SPS Secretariat.
The membership admission form is available on *www.sps.ch/fileadmin/doc/Formulare/anmeldeformular_d-f-e.pdf* .

(This offer does not apply for students and Ph.D. students. They still profit from the free membership in the first year and have only to pay the conference fee shown above.)

Additional information for selected sessions

Physics at work in Industry

Technology companies are often either driven by physicists or a physical effect or device lies at the heart of their main product. In this year's *Physics in Industry* session, we want to bring together presentations from a broad range of companies that span the full width of this spectrum. We specifically also welcome presentations from companies where the role of physics or physicists is maybe not immediately obvious to the outside observer but has played an important role in the success or founding process of the company.
If you are interested in presenting a talk in this session please contact the section heads.

Contact: Thilo Stöferle (tof@zurich.ibm.com), Andreas Fuhrer (afu@zurich.ibm.com).

Theoretical Physics

As in the previous years, theoretical contributions are highly encouraged and will be included directly in a corresponding topical session. This way, the sessions will profit from a broad range of experimental, phenomenological, and theoretical advancements that are relevant in the specific topical field and thus can engage in broader and deeper discussions.
Please submit your abstract to the session which best matches your topic. You can optionally mark your contribution as "theoretical" in the submission interface.

Contact: Philippe Jetzer (jetzer@physik.uzh.ch)

Condensed Matter (KOND)

The condensed matter program welcomes contributions from all topics within Condensed Matter Physics, including magnetism, superconductivity, semiconductors and more. Where relevant, we encourage participants to submit their abstracts to the respective focus sessions described below.

Contact: Henrik M. Rønnow (henrik.ronnow@epfl.ch), Ilaria Zardo (ilaria.zardo@unibas.ch)

Biologically inspired assembly of ordered and disordered optical materials

The brilliant colors found in plants, insects, birds, and mammals are the most exciting and appealing examples of how nature creates complex materials. Colored coatings and pigments play an important role in material science and applications in paints, displays, packing, and optical filters. The design targets for an industrial application are often like the challenges faced by nature: high purity of the color, optical density, bleaching stability, and long lifetime. Recently, disordered but structurally correlated materials, such as hyperuniform dielectric assemblies and networks, have led to a paradigm shift in the field. The session discusses and presents cutting-edge research that leverages nature's inspiration and aims to understand better and exploit ordered and disordered materials' optical physics and assembly.
Invited speakers are Prof. Diederik Wiersma, LENS, Univ. Florence, INRIM, Italy, and Dr. Ahmet Faik Demirörs, ETH Zürich. Contributed talks and posters are welcome.

Contact: Frank Scheffold (frank.scheffold@unifr.ch), Guillermo Pedro Acuna (guillermo.acuna@unifr.ch), Ullrich Steiner (ullrich.steiner@unifr.ch)

New prospects in ARPES for quantum materials

Angle-resolved photoemission spectroscopy (ARPES) is one of the most powerful techniques to measure the momentum-resolved electronic structure of materials. In the recent years, the development of high brilliance synchrotron facilities, as well as stable laser technology, have allowed new possibilities like micro- and nano-ARPES, in-operando ARPES on tiny devices, as well as versatile time-resolved ARPES to cite a few of them.
This special session is dedicated to review the recent ARPES developments and highlight the most advanced achievements in systems ranging from quantum materials, correlated systems and complex devices. The session will bring together the ARPES research groups and serve to elaborate novel perspectives and collaborative development.

Contact: Claude Monney (claude.monney@unifr.ch), Luc Patthey (luc.patthey@psi.ch), Felix Baumberger (felix.baumberger@unige.ch)

Nonequilibrium properties of quantum materials

The development of ultrafast laser techniques and pump-probe experiments has enabled studies of the nonequilibrium properties of materials on the intrinsic timescales of the charge, spin, orbital and lattice degrees of freedom. Such experiments allow to disentangle competing or cooperative effects along the time axis, and to access metastable states with novel properties. Also, on the theory side, this research field is currently very active with the development of theoretical concepts and computational techniques which enable a description of nonequilibrium phenomena in interacting lattice systems. The ultimate goal in the field is the control of material properties on ultrafast timescales, and the realization of new devices which exploit nonequilibrium states of matter.
This session will bring together experts from the experimental and theoretical sides to stimulate discussions and an exchange of recent insights and ideas. The invited speakers will provide an overview of recent achievements and emerging techniques, while the contributed talks will present recent activities of the respective research groups.

Contact: Claude Monney (claude.monney@unifr.ch), Philipp Werner (philipp.werner@unifr.ch)

Swiss Neutron Science on the European Scale

The Swiss spallation neutron source SINQ at Paul Scherrer Institute (PSI) is celebrating 25 years of user operation, and recently underwent a major upgrade program. PSI’s ultra-cold neutron (UCN) source remains the most-powerful UCN source. Together, they enable a growing number of leading experiments in fields ranging from particle physics to quantum matter science, to applied and functional materials. In addition, Switzerland, and the Swiss neutron science community are deeply engaged on the European neutron landscape with investments at the world-wide most powerful reactor-based neutron source at the Institute Laue Langevin (ILL) in Grenoble and the European Spallation Source (ESS) under construction in Lund, which will become Europe’s new flagship facility. The Swiss Neutron Science Society invites abstracts from the growing user-base of these facilities to share their research. Abstract submissions are welcome from all topics where neutron experiments have contributed, or may contribute in the future.

Contact: Fundamental Physics: Florian Piegsa (florian.piegsa@lhep.unibe.ch), Hard Condensed Matter and Quantum Materials: Daniel Mazzone (daniel.mazzone@psi.ch), Applied and Functional Materials: Markus Strobl (markus.strobl@psi.ch), General requests: Marc Janoschek (Marc.janoschek@psi.ch)

Satellite Event: Women in Physics Career Symposium

The goal of this symposium is to boost women in the early career stage starting from undergraduate up to postdoctoral studies in building a professional and mentoring network in physics. The event will feature a series of career talks, which will provide information on navigating a career in physics from the personal perspective of invited speakers covering several career levels. This will be complemented by a podium discussion, in which participants can ask questions and share experiences, advice, and ideas. The event will feature several networking opportunities such as extended coffee breaks and a dinner during which participants can get to know each other with the aim of forming a growing mentoring network.

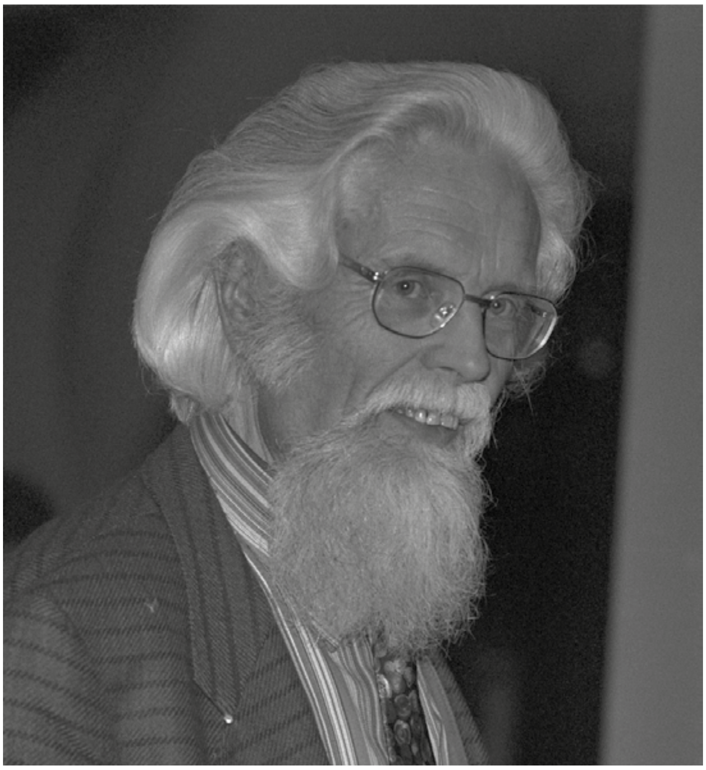
We invite female participants from all career levels to register for this event. Suggestions for desired mentors can be made during registration. In addition, we are asking interested colleagues willing to act as mentors to register, where we also encourage male colleagues to contribute. The event is sponsored by the University of Zurich and the Paul Scherrer Institute. Further contributions are most welcome. More details will be made available soon.

Contact: Lea Caminada (lea.caminada@psi.ch), Ellen Fogh (ellen.fogh@epfl.ch), Marc Janoschek (marc.janoschek@psi.ch), Christine Klauser (christine.klauser@psi.ch)

In Memoriam Roland Engfer

5. Dezember 1934 - 18. Oktober 2021

Wir trauern um unseren Kollegen, Freund und Mentor Roland Engfer, der am 18. Oktober im Alter von 86 Jahren verstorben ist.



Roland Engfer war von 1975 bis zu seiner Emeritierung 2001 Professor für Experimentalphysik am Physik-Institut der Universität Zürich.

Roland Engfer studierte, promovierte und habilitierte sich an der Technischen Universität Darmstadt bei Professor Peter Brix. Sein Interesse galt myonischen Atomen. Das sind exotische Atome, bei denen ein negativ geladenes Myon mit dem Kern ein wasserstoffähnliches System bildet. Mit Hilfe von Spektroskopie exotischer Atome lernt man, wie im Atomkern Ladungen und magnetische Momente verteilt sind. Danach forschte er am CERN in Genf und am Paul Scherrer Institut (PSI, früher Schweizerisches Institut für Nuklearforschung SIN) und lehrte als Privatdozent an der ETH Zürich. 1975 wurde Roland Engfer als Nachfolger von Hans H. Staub zum ordentlichen Professor für Experimentalphysik an die Universität Zürich berufen. Diese Position behielt er bis zu seiner Emeritierung im Jahr 2001.

Seine Forschungsgruppe in Zürich experimentierte am Paul Scherrer Institut. Die Gruppe konzentrierte sich zunächst auf die Teilchenemission nach dem Einfang von negativen Pionen in Kernen, ging aber bald dazu über, seltene und verbotene Myonenzerfälle als führendes Mitglied der SINDRUM I und II Kollaborationen zu untersuchen. Die meisten der damals beobachteten Grenzwerte für die Verletzung der Lepton Flavours bestehen auch noch heute.

Viele Jahre lang unterrichtete Roland Engfer mit Begeisterung klassische und moderne Physik für Universitätsstudenten. Als mitreissender Dozent begeisterte er die Studenten mit seinen spannenden und inspirierenden Vorlesungen und originellen Experimenten. Dabei gelang es ihm, dem Publikum die Fähigkeit zum Staunen und seine Faszination für die Erforschung fundamentaler physikalischer Fragen zu vermitteln. Roland Engfer war leidenschaftlicher Radfahrer, fuhr täglich mit dem Velo zum Campus Irchel, demonstrierte mit dem Mountainbike auf der Hörsaaltreppe Biomechanik und kämpfte als Vorsitzender der Betriebskommission der Universität Zürich erfolgreich für mehr Veloständer. Auch seine Erfahrungen als Bergsteiger flossen direkt in den Unterricht ein; beim Abseilen im Hörsaal konnten Reibung, Energieerhaltung und Wärmeentwicklung sehr anschaulich erklärt werden.

Roland Engfer leitete von 1993 bis 1999 als Direktor das Physik-Institut der Universität Zürich.

Die Universität Zürich, die Kolleginnen und Kollegen und die ehemaligen Studierenden verlieren in Roland Engfer einen inspirierenden Menschen und Lehrer, dem wir viel zu verdanken haben.

Katharina Müller

Progress in Physics (87)

X-ray Lasers using a Plasma Medium: Tabletop Beams Got Brighter than Synchrotrons

Davide Bleiner, Federal Laboratories for Materials Science & Technology (Empa), Überlandstrasse 129, CH-8600 Dübendorf, davide.bleiner@empa.ch

The use of hot and dense microplasmas as gain media powered a renaissance of X-ray lasers on a tabletop. The research was boosted forty years ago in the Star Wars era for military applications. In the last decade, however the number of scientific and industrial applications has grown. Stimulated emission from a highly ionized shell is a transient process that is difficult to accomplish. Still both laser-produced plasma as well as discharge-produced plasmas have tacked the challenge. Switzerland is at the forefront in this unique field.

1. Introduction

The generation of laser light at wavelengths shorter than ultraviolet is a virtually impossible task. As dictated by the scaling of spontaneous versus stimulated emission at shorter wavelengths, the ratio between the Einstein coefficients A and B shows a power of 3 dependence with the wavelength. Since X-rays are 4 - 5 orders of magnitude shorter in wavelength than the UV-Vis, spontaneous emission dominates over stimulated emission by much more than 10^{12}-fold.

Indeed the "short wavelength range" comprises spectral different spectral domains with specific names and characteristics. Ranges such as extreme ultraviolet (EUV), soft X-rays (SXR), and hard X-rays (HXR) have been often confused. The physical boundary is defined using the refractive index jump between a strongly absorbing (e.g. EUV and SXR) to a notoriously penetrating (i.e. HXR) behavior while irradiating matter.

The accomplishment of "Light Amplification by Stimulated Emission of Radiation" (LASER) presumes a so-called population inversion. In a population inversion, there is a shift of the bound electron distribution toward upper energy levels, with transient vacancies at lower or ground levels. Such core excitation lifetime is all the shorter, the larger the energy gap. At energies of hundreds of eV's and more, as found in the short wavelength domain, the corresponding lifetime is too short for stimulated emission to be an active gain process.

A further challenge to make a X-ray laser happen, is the availability of a suitable gain medium. The need to extract high energies will inevitably cause the destruction of any gain material. Therefore, both liquids and solids are to be ruled out as X-ray gain media. Gas lasers are well-known even in the deep UV (exciplexes), but no ordinary substance would permit X-ray amplification. It needs an exotic one such as a plasma.

It must be clarified that so-called X-ray Free-Electron Lasers (XFEL's) are coherent short wavelength sources that do not work on the mechanism of stimulated emission on bound transitions. Such accelerators extract radiation from the oscillatory motion of charged particles, whereas the coherence can be increased by means of radiative feedback to the emitting particle bunch. Hence, not all coherent sources are, strictly speaking, "lasers" i.e. based on stimulated emission. Fig. 1 shows that all the available short-wavelength sources cover a wide range in brightness.

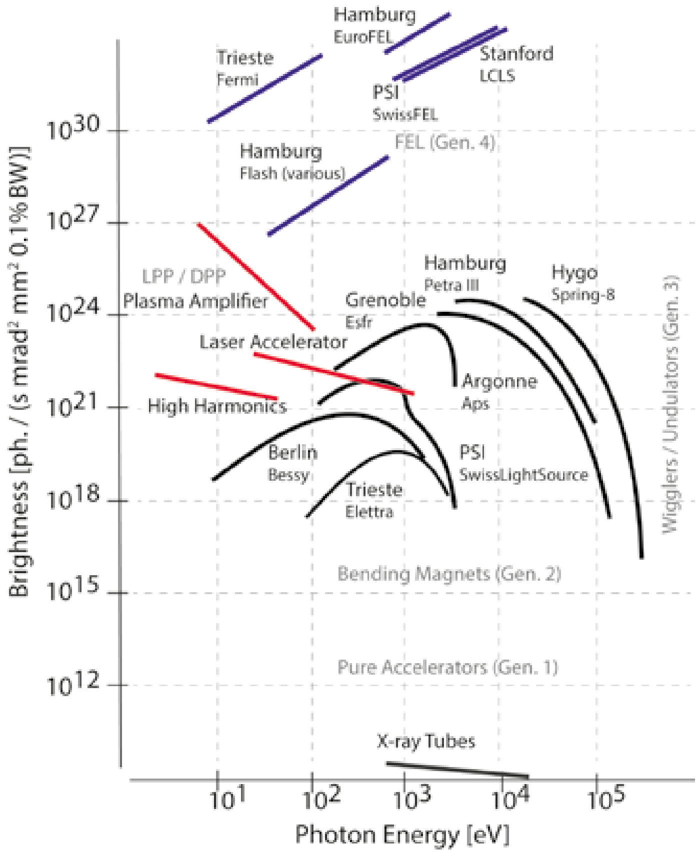


Fig. 1. Comparison of brightness for coherent short wavelength sources.

2. Basic Underlying Physics

2.1. Plasma Gain Medium

A viable option to stimulate the emission of EUV/SXR photons (20 - 500 eV) is using a gain medium with such large energy transitions, i.e. based on highly ionized atoms of a plasma [1]. The concurrence of such ions and a bath of free electrons, as it is in a plasma, is important. Highly ionized atoms of several charge units can be produced on a tabletop as a transient state in electrical discharges or alternatively by focusing a high peak power laser onto a solid target. Such expanding plasmas are very hot-and-dense at the birth moment while rarefy rapidly. The electron temperature and electron density characterize the medium (Fig. 2). For the sake of X-ray lasing across a plasma medium, the electron density is important to sustain an optimum number of excitation collisions between the free and the bound electrons [2]. This collisional excitation should bring the ion into a population inversion. If the collision rate is insufficient, the laser amplification is hindered. If the collision rate is too extensive, deexcitation or local thermalization also hinder

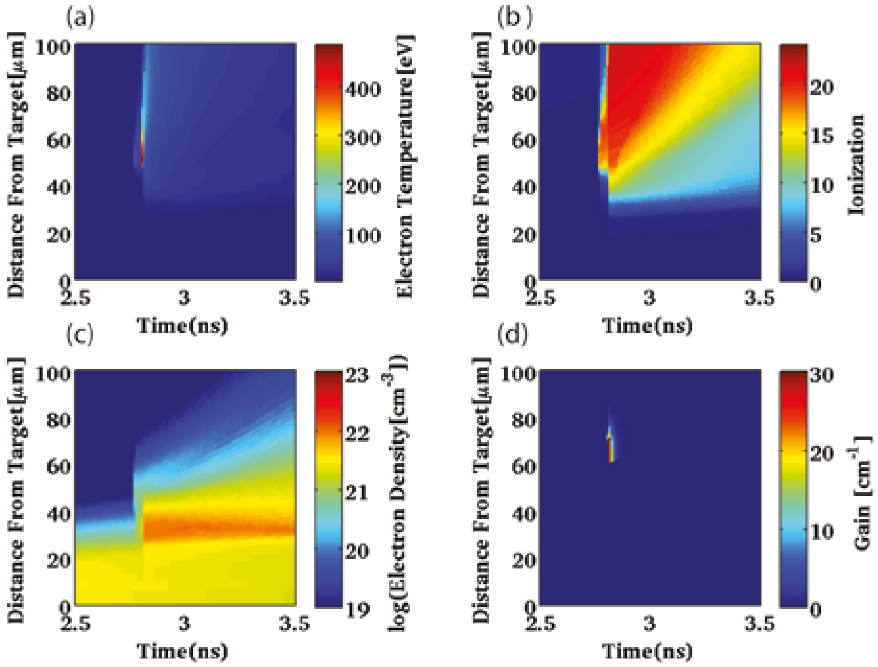


Fig. 2. Hydrodynamics as a function of time and expansion distance of a laser-produced plasma generated by irradiation of a Sn target with a pre-pulse (t = 0) and a main pulse (t = 2.7 ns). a) Electron temperature: one notes the short transient window for hot plasma lasing at the instant of main pulse delivery (see also d.); b) Ionization degree: at the hot condition a +22 ionization (Ni-like Sn) is accomplished, which due to plasma rarefaction does not recombine; c) Electron density; d) Calculated laser gain. From: Masoudnia & Bleiner [3].

population inversion. Obviously, the energy exchanged in the collision should be effective to promote the bound electron to the upper laser level, which demands the temperature of the plasma to be at a hot optimum. In previous publications, we have analyzed in detail the exact values of optimum conditions [2-5]. Such hot-and-dense plasma may support amplified spontaneous emission (ASE) across the plasma length. The requirements are strict and discussed in the next section.

2.2 Lasing by means of "Ionization Locking"

As the temperature does fluctuate across the plasma volume, also as a function of time, one needs to "lock" the related impact on the population inversion for a period long enough for the gain to establish. The gain relies on metastable levels in closed-shell ions working as upper laser level. Metastable levels are populated by means of collisional interaction (monopole excitation). These are between free electrons and bound ones in the ground level, where the selection rules do not allow a dipole transition. Henceforth, if the transition cannot be accessed radiatively (Fig. 3), the upper laser level state cannot relax spontaneously. The only ways to relax are either by stimulated emission, or by collisional de-excitation. The former contributes to gain, while the latter is realized at high electron densities.

As said, one needs to stabilize the ionization stage, otherwise the metastable state can be destroyed by means of ionization and/or recombination. This is done by means of ionization locking. Fig. 2.b shows the fractional abundance of ion stages for Sn calculated by means of coupling collisional and radiative rate equations (so-called non-local thermic equilibrium) for the hot and dense plasma core as well as for the corona. The plot shows that for closed shell configurations, i.e. +22, the specific ion stage is stable over a larger range than non-closed shell configurations.

For instance, a closed shell is the $^1S_0$ term of neon-like ions, i.e. with 10 residual electrons. Indeed, Ne-like argon (atomic number 18) giving soft X-ray lasing in a capillary Z-pinch discharge is eight-fold ionized Ar^{8+} (Ar-IX). Ne-like ions support lasing at modest energies of tens of eV that are possible on a tabletop. In order to extend the lasing to shorter wavelengths, higher atomic numbers are necessary. So far, Nickel-like ($^3F_4$), Zn-like ($^1S_0$) or Pd-like ($^1S_0$) ions have demonstrated lasing at energy as high as several hundreds of eV.

An alternative approach to population inversion, instead of collisional excitation, relies on free electron recombination. While the collisional approach discussed above is easier to realize and scale, it is less Stokes efficient. The use of a hydrogen-like C^{5+} ion that produced lasing by recombination at λ = 13.50 nm (n = 4 to n = 2) and 18.22 nm (n = 3 to n = 2) has remained promising for long time to be scaled up. The underlying difficulty is that one needs a strong temperature contrast interface: a hot core where to breed high ionization radiators, directly in contact with a cold shell to induce massive recombination.

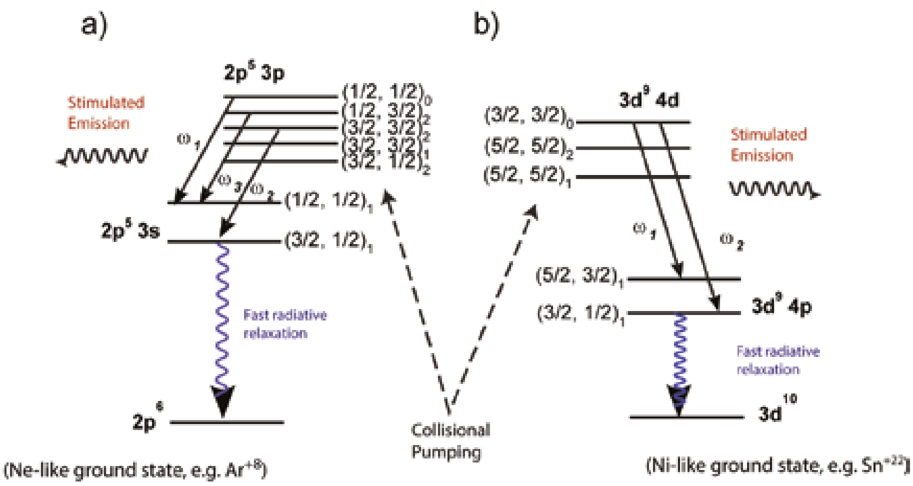


Fig. 3. Comparison of Grotrian schemes for the Ne-like and the Ni-like shells that are used to generate amplification across the 3p-3s and 4d-4p transition respectively. The upper laser level is metastable since it can be only populated by means of collisional excitation. The lower laser level is rapidly emptied thanks to dipole-allowed relaxation, which gives the upper-to-lower level population inversion.

2.3 Advantage of the Plasma X-ray Laser

The accomplishment of amplified spontaneous emission (ASE) is based on fluorescence that stimulates emission in population-inverted ions. The sweep of this process across the plasma-column length gives an active gain. As the process occurs, the natural linewidth experiences gain narrowing. Henceforth, the plasma X-ray laser is extremely monochromatic, with linewidths much narrower than the natural width, in the range of $\Delta\lambda/\lambda$ < 0.001 % or < 1 meV. This spectral purity is at the base of the enhancement of the peak brightness (Fig. 1), and permits high-resolution applications such as spectroscopy and/or lithography.

Furthermore, this is the only X-ray laser able to concomitantly emit two coherent lines at a significant energy span for interest in applications, as we demonstrated a few years ago [5]. While these lasers are extremely coherent in time, they are not so in the transverse direction. This means that the wavefront flatness is rather limited to approx 15 - 20 % of the pulse diameter, as it was shown before [6].

As the ASE is primed by fluorescence, the poor spatial coherence is not surprising. In order to improve the wavefront quality, and enhance collimation, a technique known as injection seeding has been used. This implies to prime the lasing using a good quality external pulse. One has to distinguish between self-seeding and external seeding. The former is accomplished with the concomitant (slightly delayed) generation of two plasma lasers, one injected into the other. In the case of external seeding, high-harmonic generation (HHG) is used which however makes the system grow in complexity.

3. Experimental Realization on a Tabletop Setup

The physics of laser action across a plasma is rich and dominated by unsteadiness and local transient processes. From an experimental standpoint, the overall process relies on specific critical steps to drive the amplification across a microplasma. To begin with, a pre-plasma has to be generated, a weakly ionized plasma that is suitable to prepare the main process of a hot-and-dense plasma gain-medium. A single-pass (no cavity possible) gain process can grow above a lasing threshold, if the plasma width-to-length is within an optimum aspect ratio. We derived the exact relation in a previous publication [7], which would explain why in some case the output is modest while in some other is at saturation. The drive-laser line-focusing (discussed below in sect. 3.1) or discharge confinement capillary geometry are thus crucial.

As the electron density is thicker in the core of the plasma and thinner at the margins, the opacity is also inhomogeneous. While the opacity of a medium determines its refractive index, one experiences larger refraction at the boundary of the plasma column. With that, the ASE tends to give a diverging X-ray laser pulse, as wide as 5 mrad at the output, with a donut profile. We have showed a solution to this issue, using a telecentric normal-incidence collector, fabricated with a multilayer coating [8]. Multilayers working as Bragg reflectors [9] permit to realize reflective optics for this wavelength range, to overcome the limitations of grazing incidence optics. State-of-the-art experimental concepts have been reviewed recently [10]. Here a short synopsis is given about plasma-based X-ray lasers. In general one distinguishes between two architectures (Tab. I): (i) optically-pumped, and (ii) electrically pumped.

Pumping	Optical	Electrical
Plasma Medium	Ne, Ni-like Ions	Ne-like Ions
Drive Power / Energy	0.2 - 20 TW / 0.3 - 30 J	1.5 GW / 2 J
Conversion Yield	< 10^{-5}	~ 10^{-5}
X-ray Pulse Energy	~ 10 - 30 μJ	~ 20 - 50 μJ
Number of Photons	~ 10^{11}	~ 10^{11}
Wavelength	3.56 - 42.10 nm	46.87 nm
Linewidth	< 1 meV	< 1 meV
Pulse Duration	< 1.5 ps	~ 1 ns
Repetition Rate	< 10 Hz	1 - 100 Hz

Tab. I: Main characteristics of the alternative methods for plasma lasing.

3.1 Optically-Pumped X-ray Laser

One approach to generate hot-and-dense plasma gain-media is line-focusing a high peak power laser on a target [11]. Line focusing is important to produce high aspect ratio plasma columns by means of laser ablation [12]. Line focuses can be realized using tilted mirrors: the related astigmatism stretches the focal spot over a thin oval. Alternatively one could illuminate a spherical mirror parallel to the optical axis, such that the focal spot is affected by spherical aberration. Obviously, one could also obtain a line focus using a cylindrical lens: this practice is however disadvantageous because for high pulse intensities is hard staying below the damage threshold.

In fact, the drive-laser should have a pulse duration in the range of ps, leading to high peak powers. Shorter pulse duration of fs, although enhance the peak power, can deposit the energy in a time-scale too fast to exploit the full gain buildup time [4]. Obviously, long pulse durations of ns are too slow to pump the population inversion and ASE gain. The drive laser wavelength is typically in the infrared (IR), although visible pulses can penetrate deeper into the expanding opaque plasma.

A pre-pulse of 5 - 20 % the energy of the main pulse enhances the efficiency. The delivery of the main pulse with a few ns delay permits the pre-plasma to expand and relax the opacity and high-density gradients. The main pulse is thus advantageously coupled. Our group has also introduced a double pre-pulse technique to improve the control and alignment [6]. The pre-pulse was traditionally delivered from a separate laser than the main pulse: while the pre-pulse was a long pulse on-axis to the target, the main pulse was a ps-pulse at grazing incidence. The alignment of these two completely independent pulses, both in time and space, is crucial and critical. Jitter effects or minimal optics tilt would cause a detrimental mismatch of the two pulses on the target. Therefore, our group introduced the use of a dog-leg beam-splitter to generate a pre-pulse from the same laser used for the main pulse.

The pumping requirement (Fig. 4) to realize X-ray plasma lasing have substantially relaxed over the decades. If in the

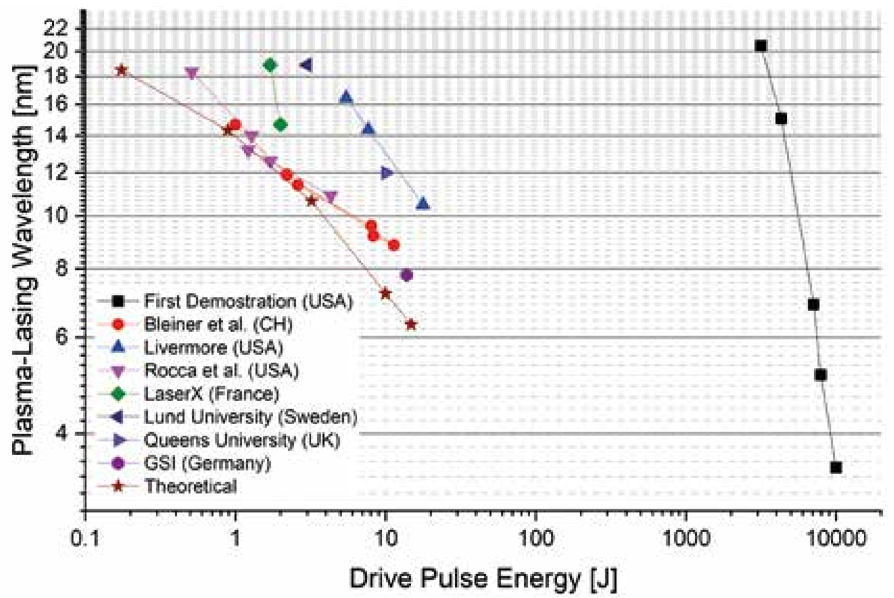


Fig. 4. Progress of the drive pulse requirement to accomplish tabletop X-ray lasers, from the first demonstration at the LLNL Laboratories forty years ago [13].

early times a multi-kJ laser was mandatory (which is an immense facility, with just a few pulses per day), nowadays a few hundreds of mJ can do the job.

3.2 Electrically-pumped X-ray Laser

While a kJ laser is a gigantic facility, a kV generator is a handy device. Henceforth, plasmas produced as electrical discharges have proven a suitable alternative to reduce the footprint and increase the average power (pulse repetition rate). The discharge in a capillary of approx. 20 cm produces the above-discussed plasma column. The pre-plasma is produced with a RF coil and a DC lead. The work gas is mainly Ar as other gases did not prove as effective. Ne-like Ar gives a strong lasing at 46.9 nm wavelength. The main pulse is delivered as a pulse-forming network drives a 40 kV / 40 kA signal, switched in 1 ns by a hydrogen thyratron.

The forward power transfer to the plasma column as load must be optimized by matching the impedance, using a so-called matching box.

4. Alternative Concepts for Short Wavelength Coherent Light

The focus of this update is tabletop X-ray lasers, based on plasma as a gain medium. There are however alternative concepts to realize tabletop high-photon-energy coherent light pulses. For completeness, we briefly mention them, pointing at the main differences with plasma-driven lasers. Coherent light is indeed a wider category than "lasers": the latter strictly implies energy extraction across a gain medium by stimulated emission.

A popular approach is that of utilizing parametric processes. In this case, there is no energy extraction from a medium. A non-linear medium is used for energy conversion involving a quadratic (or higher order) response of the polarization to a driving electric field. The non-linearity requires high amplitudes of the drive fields, i.e. as high as ~ GV/m (or > 0.1 TW/cm^2 in pulse peak intensity). The interaction happens instantaneously through a virtual state: energy and momentum are obviously conserved, making so-called phase-matching critical. High-Harmonic Generation (HHG) is the most popular of these parametric techniques. A high intensity pump beam across a non-linear medium, e.g. noble gas, will generate a comb of odd harmonics of the fundamental wavelength. The conversion yield drops after a cut-off harmonic order, such that at soft X-rays the photon budget is at best 10^7 photons. The details of HHG are beyond the scope of this article, see for instance [14-19].

A further approach to obtain coherent short wavelength light on a tabletop is that to develop scaled-down particle accelerators, in order to obtain synchrotron radiation in a similar fashion as it happens in the full-scale accelerators. We are involved in one such EU project within the Eupraxia consortium (http://www.eupraxia-project.eu/).

Let's consider the undulator equation which gives the wavelength of the n-th harmonic as a function of the period of the undulator poles (λ_u), the relativistic Lorentz factor γ and the deflection parameter K (function of the magnetic field) and the deflection angle θ:

$$\lambda_n \approx \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K}{2}+\gamma^2\theta^2\right) \quad (1)$$

One realizes that if λ_u is substantially scaled down, a comparable output wavelength λ_n is obtained at much lower γ. If a relativistic electron is driven by the oscillating field of a laser, instead of an accelerator of hudreds of meters, this condition is accomplished, such as in so-called betatron or inverse Compton setups. Similarly, the oscillatory drive field that can be realized on the crest of an array of nano-structures, to accomplish an accelerator on a chip. A few recommended papers go into the details of this interesting concept [10, 20-22].

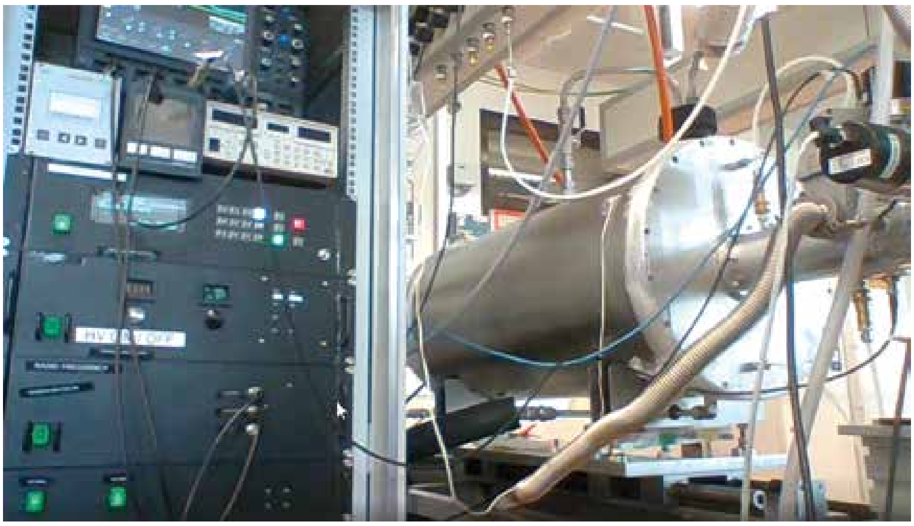


Fig. 5 The self-developed X-ray laser based on a electrical plasma discharge across a capillary.

5. Applications of tabletop X-ray lasers

There is a number of scientific and technical uses of EUV and/or SXR which become accessible on a tabletop [8]. The main strengths of such spectral range are the following three: (a) strong absorption, (b) nano-scale sensitivity, (c) efficient photolysis [23].

Defect inspection of nano-lithography masks is a technological application with huge economic impact [24]. The special physico-chemical processes that occur under the action of ionizing photons (radiolysis) are found also in nature in astrochemistry. Laboratory astrochemistry thus benefits for the possibility to produce and reproduce the quite exotic chemistry and radicals found in the extraterrestrial context. On the other hand , the wavelength range between the C_K edge (282 eV) and the O_K edge (533 eV) offers a strong contrast between organic and aqueous matter. This "water window" is thus attractive to perform in-vivo bio-microscopy.

The short wavelength favors the enhancement of the diffraction limit. As the latter scales as $\lambda/2$, a wavelength in the 10 - 100 nm means a substatial improvement of the spatial resolution. Nano-scale microscopy is thus possible without the use of electrons, but with similar advantages, and without sample preparation [25]. While illuminating the region of interest, chemical visualization in either pixel-scanning mode (mapping) or full-field snapshots (imaging) are possible [26, 27].

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Progress in Physics (88)

Photoemission from Solids

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I. Introduction

Photoemission spectroscopy analyses the energy and momentum distribution of photoelectrons from samples under illumination by ionising radiation. The theoretical description, involving quanta of energy $h\nu$ famously gave rise to Einstein's nobel prize (see the historical summary by H. R. Ott [1]). In modern notation, this energy conservation is written as

$$E_k = h\nu - \Phi - E_B, \quad (1)$$

where E_k is the kinetic energy of the photoelectron, ν is the frequency of the radiation, Φ is the work function of the surface under study and E_B is the binding energy of the electron's initial state. A spectrum of photocurrent as a function of E_k thus readily reveals the occupied states in a material. In addition to this energy conservation, also the momentum is conserved, although effects of the inevitably broken symmetry of the surface allow for strict momentum conservation only for the component parallel to the surface. The electron spin is conserved, too. The combination of energy and momentum conservation is the basis for plotting the data as maps against energy and momentum or against two momentum components. These intensity maps correspond to the band structure diagrams used in the theoretical description the electronic structure of solids. If a momentum map of the photoelectrons with the highest E_k is plotted, its high intensity lines directly correspond to the Fermi surface of the material [2], the fundamentally important part of the electronic structure, where transport occurs, thermal excitations are possible and magnetic as well as charge order phenomena can be linked to the movement patterns of the electrons in the material.

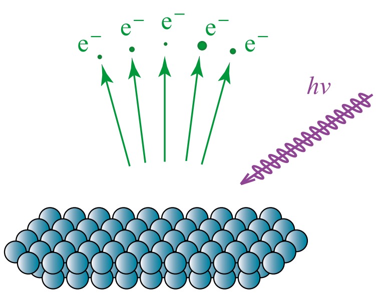

FIG. 1: Schematic view of photoemission. Photoelectrons are ejected from the sample upon irradiation with monochromatic ionising radiation. Different directions of emission with respect to the crystal lattice as well as to the polarisation and propagation of the light are recorded as spectra.

The technique goes by the name angle-resolved photoemission spectroscopy (ARPES) when such combined data sets are analysed. The potential of ARPES for the study of quantum materials has been recognised early on. Discussing Cuprate superconductors, P. W. Anderson famously wrote in 1992 in Physics Today "*Angle resolved photoemission is, for this problem, the experiment that will play the role that tunneling played for BCS superconductivity*". Capitalizing on this potential, however, required numerous instrumental advances to push the energy resolution of ARPES to the natural energy scale k_BT of superconductivity and other low-temperature quantum phases of matter.

II. High Resolution ARPES

Early key contributions to the understanding of the electronic structure of solids were realised solely due to high energy resolution [3]. These allowed for a distinction between Fermi liquid like electronic structures, with a characteristic high energy Fermi cut off and unusual non-Fermi-liquid-like metallic states. Also the direct measurement of the excitation gap of superconductors became possible in this way [4, 5] (see Fig. 2). When the momentum of the photoelectron excitation is analysed, too, the coupling of the itinerant electronic states to all other degrees of freedom of the solid, vibrational, magnetic and correlation-driven excitations becomes accessible [6]. In addition to mapping the Fermi surface and occupied bands of the electronic structure, the photoemission experiment can thus measure the full spectral function of the electronic system, including all excitations that interact with the charges, and it can do this at any temperature and on any crystalline material, provided the conductivity is high enough that the overall removal of electrons does not distort the spectra due to macroscopic charging of the sample.

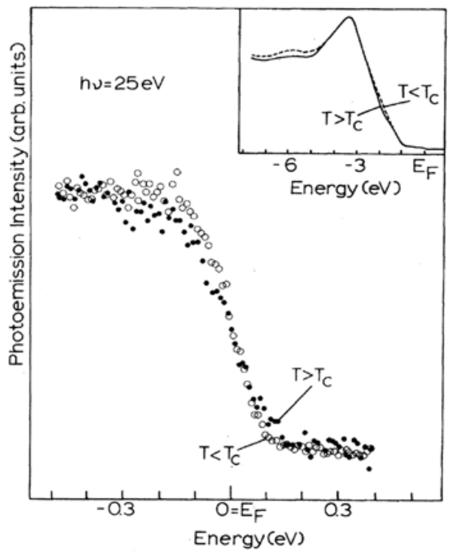

FIG. 2: Measurement of the superconducting gap of $Bi_4Ca_3Sr_3Cu_4O_{16+x}$ in 1989. From this data, Chang et al. [4] estimated a gap of 15 – 45 meV. The inset shows spectra over a larger energy range (reprinted from Ref. [4] with permission by the publisher).

On the technical side, every photoemission instrument consists of three components: a light source, a sample holder for positioning and orientation, and an electron spectrometer that analyses or selects the photoemission by kinetic energy and angle. These components are shown in Fig. 3. The technology of all three has developed over the years. The key light source of the turn of the century was the

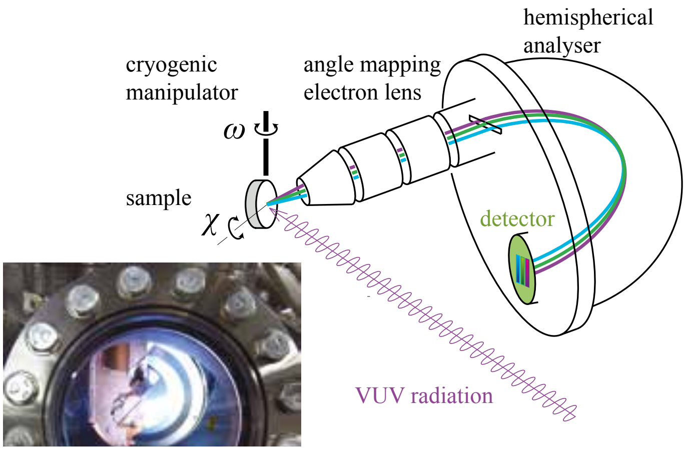

FIG. 3: Components of a photoemission instrument: the hemispherical analyser with pre-lens selects angles in one direction and projects the other, as well as a segment of kinetic energy onto the detector. The manipulator aligns the sample and is used to scan an angle. The light source provides monochromatic, polarised radiation.

He discharge lamp. When operated at optimised He gas pressure this yields spectroscopically sharp radiation at $h\nu$ = 21.221 eV among a few other emission lines. When combined with a monochromator to select this line, radiation of the highest purity at high intensity is obtained. The sample environment of photoemission is ultrahigh vacuum (UHV) with a low magnetic field background. Specialised cryogenic sample manipulators with temperatures down to few K nowadays allow for easy temperature changes and accurate positioning, all with minimised degassing. Equal progress has been made in the technology of photoemission spectrometers. The standard instrument is an electrostatic hemispherical analyser with a pre-lens that can either select a specific sampling area or, as shown in Fig. 3, project the angular distribution of photoelectrons onto the entrance slit area of the energy analyser and thus on the detector in one direction.

The use of synchrotron radiation for photoemission is particularly attractive due to its tuneable photon energy and polarisation. The technology of monochromators has also evolved, and an energy resolution that is quite comparable to the He lamp is routinely available, at any photon energy. This is particularly important for the use of the momentum resolution in photoemission. The momentum component parallel to the surface is fully conserved in photoemission. The only way to vary all components and map all of momentum space is by varying the excitation energy $h\nu$. A dedicated photoemission beamline is thus found in the instrument portfolio of almost every synchrotron radiation facility, including the Swiss Light Source.

These instruments are available to provide insight into the electronic structure of materials and electronically driven phenomena of solid state physics. Recent reviews summarise the most significant successes [7, 8], and here below we cite a few scientific cases that illustrate well recent progress. The largest number of publications of the last years relates to materials with nontrivial topological symmetries. Their rich phenomenology of momentum structures is routinely verified in relation to theoretical band structure calculations [9]. Among all iron based unconventional superconductors, FeSe has received the strongest attention from the ARPES community. It can be considerered the simplest, due to its simple stoichiometry, yet it shows the catching electronic stucture features that are common to all members of this family. A refined, although still controversial view on the mechanism of the 90 K phase transition, termed nematic order, has been derived from such data [10]. The rather low superconducting temperature and corresponding low gap value then made full use of the high performance of modern instruments [11] and important conclusions were drawn on the relationship with the orbital character in the nematic state and the gap isotropy [12]. Also the continuously intriguing properties of doped Cuprate high T_c superconductors continue to be further clarified by numerous ARPES studies [13]. Apart from superconductivity, the study of electron phonon coupling has enabled the distinction of fundamentally important model cases, including the unambiguous visualisation of the spectral signatures of the Fröhlich model in a 2D electron gas in $SrTiO_3$ [14]. The intricate temperature dependent re-arrangements of electronic states in Kondo lattice materials have been clarified in combinations of careful ARPES studies with other techniques [15, 16].

III. ARPES Using Lasers

The introduction of deep UV laser sources, pioneered by the group of S. Shin at the University of Tokyo marked an important step to improving the energy resolution of ARPES. As for other spectroscopies, high energy resolution in ARPES comes at the expense of low count rates. Light sources for ARPES should thus combine a narrow bandwidth with a high photon flux. This is natural strength of lasers. What proved more difficult is to maintain this combination deep into the UV range, which is reached by successive frequency conversion in non-linear crystals or gas cells. Efficient frequency conversion requires high peak power, which competes directly with the necessity of long pulses ($\gtrsim$ 10 ps) to maintain a narrow line width and a high repetition rate to avoid a loss of resolution from space charge, the inelastic scattering of photoelectrons in vacuum. Initially, narrow bandwidth laser-sources could only be achieved with non-linear crystals for $\lambda > 177$ nm ($h\nu < 7$ eV). This is sufficient to overcome the work function barrier but the low kinetic energy of photoelectrons emitted with such light sources restricts the accessible momentum range. Recent developments have now expanded the photon energy range of high-resolution laser-ARPES

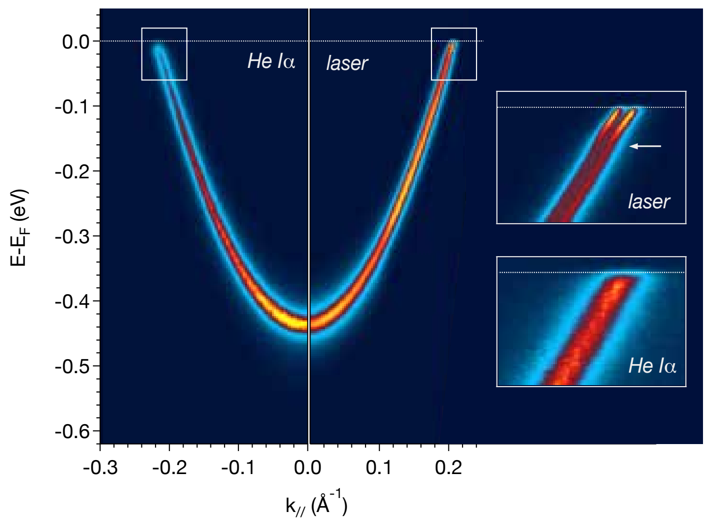

FIG. 4: Laser ARPES data from the Cu(111) surface state detecting a previously unresolved minute Rashba-type spin-splitting (adapted from Ref. [17] with permission by the publisher).

up to 11 eV - sufficient to map the entire Brillouin zone of most materials - while maintaining a bandwidth and photon flux that is superior to even the very best synchrotron beamlines [18, 19].

The improvement in resolution and cleanliness of ARPES data enabled by UV laser systems is illustrated in Fig. 4. Reinvestigating a well-known surface state on Cu by laser-ARPES, Tamai *et al.* reported a minute, previously unresolved Rashba-type spin splitting. The same data also shows a faint 'kink' in the dispersion near the chemical potential. This arises from the mass enhancement of low-energy quasiparticles interacting with phonons. The clear evidence for such a kink in Cu, which has an exceptionally low electron-phonon coupling strength, illustrates the remarkable sensitivity of modern ARPES experiments.

Laser-ARPES also evolved into a powerful tool for the study of topological insulators and semimetals. A particularly remarkable example is the detection of a Dirac cone topological surface state on the iron based superconductor $FeTe_{0.55}Se_{0.45}$ [20]. This surface state connects across a small spin-orbit induced band gap of a few 10 meV and its detection would have been out of reach only a few years earlier.

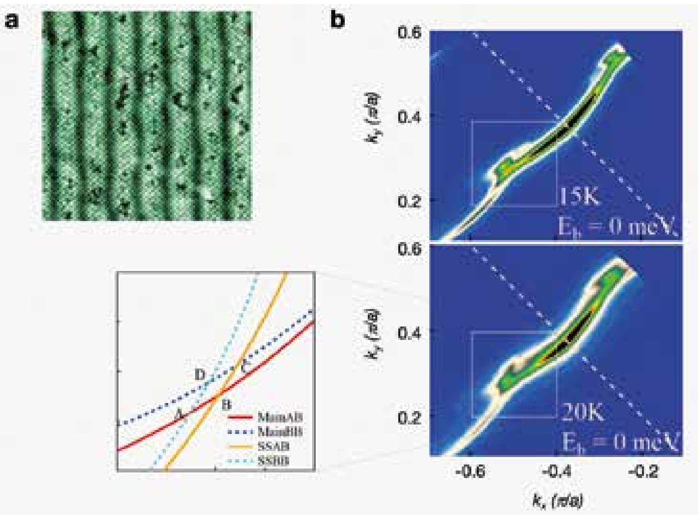

FIG. 5: Laser-ARPES data from Bi2212. (a) shows an STM topography with the characteristic superstructure (adapted from Ref. [21]). (b) laser-ARPES Fermi surfaces of optimally doped and overdoped Bi2212. The bottom right panel shows a schematic of the main and backfolded bands (adapted from Ref. [22] with permission by the publisher).

Fig. 5 shows an example for the application of laser-ARPES to cuprate superconductors. $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212), the most widely studied cuprate in ARPES has a periodic unidirectional superstructure, well known from diffraction and STM experiments. This additional periodicity leads to diffraction replicas of the electronic bands, evident in numerous conventional ARPES studies. Using a 7 eV laser source, Gao *et al.* could now show for the first time that these diffraction replicas open small hybridization gaps at the (avoided) crossings with the main bands [22]. This identifies the replica bands as an initial state effect modifying the intrinsic electronic structure of Bi2212 (as opposed to diffraction of the outgoing photoelectron final state).

IV. Time-Resolved ARPES

By using the pump-probe technique, ARPES can be extended to the time-domain to study the out-of-equilibrium dynamics of materials. In this approach, an intense pulse of low photon energy, the pump, excites the material under investigation and a subsequent weak pulse of light probes it by ejecting a photoelectron. By precisely tuning the time delay between the two pulses, one acquires a series of spectra to reconstruct the time-evolution of particular spectral features typically on the sub-picosecond timescale.

First pioneering time-resolved photoemission experiments were performed well before the year 2000, as for instance in the work of Fann and coworkers setting up the basis for the study of the thermalization of excited electrons in metals [25]. However, it was mainly after the turn of the century, notably thanks to technological advances made possible by commercial Ti:sapphire lasers, that time-resolved PES was used to look at the ultrafast dynamics of complex materials. The goal was typically to suppress an ordered phase and to identify the mechanism of its origin by comparing the relevant timescales for its suppression and subsequent recovery. One of the prominent cases was the study of the Mott-Insulator transition in the transition metal dichalcogenides (TMDC) TaS_2 by Perfetti and coworkers in 2006 [26] (see Fig. 6(A)).

Following this early success on correlated material, time-resolved ARPES studies looking at complex electronic dispersions came soon after with a study of the collapse of the charge density wave (CDW) phase in the tritelluride $TbTe_3$ [23]. A direct correlation between the collapse of the CDW band gap and the coherent oscillation of the related phonon mode allowed to identify the electron-phonon interaction as the origin of the CDW phase.

At that time, the probe photon energy was about 6 eV, close to the highest possible photon energy reachable using non-linear crystals. However, such low photon energies allow only to probe band dispersions close to the center of Brillouin zones. A breakthrough beyond this limitation occurred a few years later thanks to the process of high-harmonics generation (HHG) in gases. In 2011, Rohwer and coworkers made the tour de force of using 43 eV probe photon pulses generated by HHG to probe the CDW phase in the TMDC $TiSe_2$ [27]. By looking at the ultrafast collapse of the CDW band occurring in this material at high momenta (at the border of the Brillouin zone), they evidenced a surprisingly fast response that was attributed to the disputed excitonic insulator phase.

However, during the time the pump pulse is present and in interaction with the material, coherent interaction between the field of the pulse and the electronic system can lead to a new state of matter that can be optically manipulated. The work of Mahmood and coworkers on $Bi2Se_3$ opens the way to the observation of so-called Floquet-Bloch states, i.e. hybrid electronic states dressed by the photon field, with ARPES in 2016 [28].

The photoexcitation generated by the pump pulse can also be tuned to bring a material in an out-of-equilibrium state that displays an electronic structure or physical properties

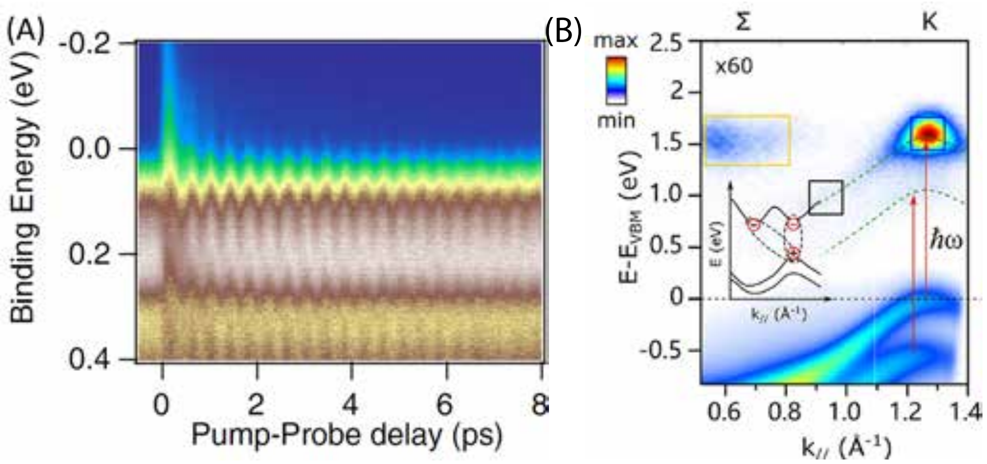

FIG. 6: (A) Time-resolved ARPES measurements on TaS_2 on a few ps timescale, showing the quasi-instantaneous closure of the Mott gap, concomitant with a coherent phonon oscillation (adapted from Ref. [26] with permission by the publisher). (B) Transient photoemission signal of the resonantly excited exciton appearing in the band gap of the semiconductor WSe_2 (adapted from Ref. [24] with permission by Prof. Ralph Ernstorfer).

that are never encountered at equilibrium. Optical manipulation of a semiconductor band gap was for instance evidenced in the layered material Ta_2NiSe_5 in 2017 [29].

Recently, time-resolved ARPES was taken to the next level with the realization of high repetition rate HHG sources. Indeed, previously, sources were typically operating at a few kHz, limiting the achievable quality of the signal, especially for states above the Fermi level and compromising on the energy resolution. In 2018, using HHG driven at 500 kHz as a pulsed photon source, Nicholson and coworkers uncovered the mechanism of the photoinduced phase transition in In nanowires by mapping their transient electronic structure [30]. More recently, Dong and coworkers presented a remarkable mapping of the unoccupied states in the semiconductor WSe_2, highlighting the ultrafast dynamics of excitons with time-resolved ARPES (see Fig. 6 (B)) [24].

V. Experiments in Operando

ARPES with few-micrometer or even sub-micrometer spatial resolution opens the way to study in-operando electronic devices. In micro- or nano-ARPES experiments, a conventional electron spectrometer is combined with a scanning sample manipulator and a tightly focused UV beam defining the spatial resolution. The main application of this variant of ARPES to date are 2D materials and in particular mechanically exfoliated van der Waals crystals and heterostructures thereof. This is a very active field of quantum matter physics where remarkable progress was achieved within a few years only. By now dozens of 2D materials including wide gap insulators, direct gap semiconductors, superconductors, magnets and topological materials have been exfoliated to monolayer or few-layer thickness. Combining such crystals into vertical heterostructures offers virtually unlimited possibilities to design artificial quantum matter with tailored properties. However, the typical lateral dimensions of a few microns of such van der Waals heterostructures pose a challenge for many traditional experimental methods of condensed matter physics. In ARPES this challenge has by now largely been overcome and successful experiments on exfoliated 2D crystals were performed at multiple specialized synchrotron nano-ARPES beamlines as well as with focused UV laser sources. Recent examples including different 2D semiconductors, the 2D topological insulator WTe_2 or magic angle twisted bilayer graphene are reviewed in Ref. [32].

The properties of 2D materials can often be tuned by electrostatic gating. Nano-ARPES experiments allow to image the effects of gating on the band structure. One of the first successful such experiments is shown in Fig. 7. Using a van der Waals heterostructure consisting of monolayer WSe_2 with a graphene contact, a graphite back gate and a boron nitride gate dielectric, Nguyen *et al.* showed that they can tune the chemical potential across the band gap of WSe_2 and populate the conduction band [31]. These experiments confirmed the direct band gap at the K-point in monolayer WSe_2 and showed that the Q-valley of the conduction band is only populated at slightly higher gate voltage corresponding to carrier densities around 10^{13} cm^{-2}. Recent proof-of-principle experiments of the Hofmann group on monolayer graphene also demonstrated local ARPES experiments on a current carrying device [33]. Extending such measurements to imaging the low-energy manybody physics of more complex systems such as magic angle twisted bilayer graphene will be a formidable challenge for the next decade.

VI. Summary and Outlook

ARPES, in its many flavours shown above will continue to be a key player in the exploration of solids. The photon energies used for these experiments span from the barely

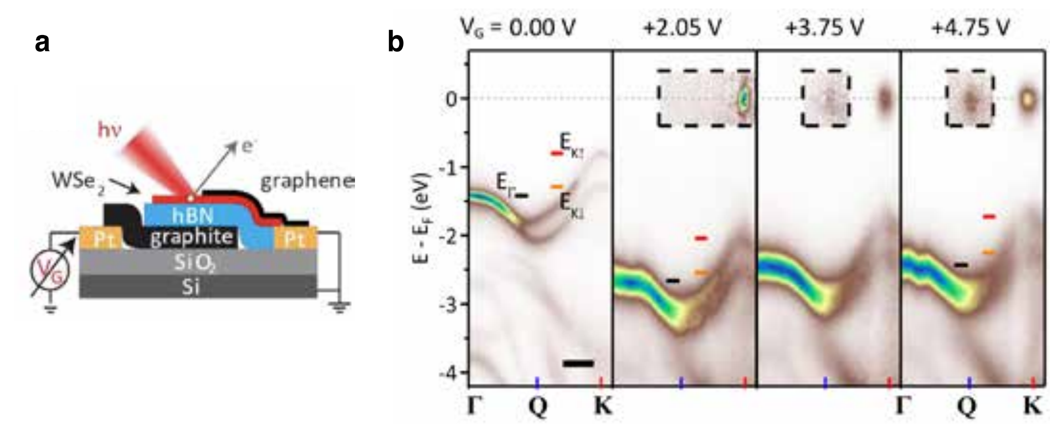

FIG. 7: ARPES measurements on gated monolayer WSe_2. (a) shows a schematic of the heterostructure with a graphite bottom gate, a hexagonal boron nitride dielectric and the monolayer WSe_2 contacted by monolayer graphene. (b) Gate voltage dependent ARPES data showing the bottom of the conduction band at the K point. At high gate voltage a second valley at Q becomes populated (adapted from http://arxiv.org with kind permission of Prof. Neil R. Wilson).

ionising 6 eV to approx. 0.6 keV where declining photoionisation yield marks the border beyond which the photon-hungry experiment starts to be unfeasible. ARPES requires a narrow photon bandwidth, but also gains hugely in precision and reliability when the photon energy is tunable. In this way the key development prospect continues to be on the side of photon sources, with interesting challenges for laser developers, as well as further optimisations of synchrotron radiation beam lines, the latter also on ultrashort pulse free electron lasers. All these highly coherent beams allow for ultimately diffraction limited focussing, thus the instruments can be equipped for in operando studies that will continue to yield entirely novel insight. Even the regime of fully coherent photoemission, where electron's coherence length of the state under study is larger than illumination beam spot will become accessible in the foreseeable future. The key benefit of ARPES to the progress of research is, however, its accessibility by researchers who focus on the questions and have the right materials for the studies. This benefit is best tapped into by further developments into reliable and robust detectors, sample manipulators and efficient protocols in their use.

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Progress in Physics (89)

Hydrodynamics of fish swimming and mechanical regulation of regeneration

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1 Introduction

In development, organisms have to grow organs that are well adapted for their respective function, while at the same time being robust enough to cope with environmental variations [1 - 4]. Thus there are robust and stable genetic programs that are followed during development that lead to very similarly shaped organs even in the presence of changes in temperature or other such factors [5]. On the other hand functionally relevant environmental factors [6, 7] can have a profound influence on organ size and shape, such as in the liver or the bones of land animals, therefore necessitating a certain amount of plasticity in growth [8] and development [9, 10].

One such functionally relevant environmental factor is mechanical stress, which has long been known to lead to the development of bone shapes ideally suited for the incurred loads [11, 12]. This is known as Wolff's law in anatomy and for instance explains the different skeleton shapes observed in differently sized animals in the absence of a direct genetic prescription of bone shape. On another level, this law is used in Anthropology to infer the behavior of our ancestors from the found skeletons. In spite of its common application however, the biomechanical and genetic mechanisms behind Wolff's law remain mostly unknown.

Here we describe to use the zebrafish caudal fin as a model system to study the interplay between the environment and genetic regulation in the formation of shape and size in bone and organ development [6, 13]. This model system has several advantages that make a detailed study of the influence of mechanical forces on shape and size amenable. Being one of the modern model organisms, many genetic regulatory factors in growth control are known and genetic and biochemical tools for the manipulation of growth and development are available [5]. Furthermore, the fin is one of the very few vertebrate organs, which can fully regenerate. Therefore, the growth of the fin can be studied in two very distinct settings: as part of an organism that increases in size over time as well as part of a fully grown organism, where in both cases the overall function of propulsion is conserved. However, due to the change in Reynolds number in the two different settings, the type of swimming and therefore the ideal shape for propulsion, changes in the two situations [14, 15]. This indicates a second interest into the zebrafish fin, since its function and interaction with the environment is governed by hydrodynamics at intermediate Reynolds numbers, which is also a challenge experimentally as well as computationally. Here, I will describe experiments on three dimensional particle tracking velocimetry to study the spatio-temporally acting forces on fins during swimming. In particular, I will discuss the experimental setup and validation of the system as well as some findings in terms of fish propulsion as well as fin regeneration that we have been able to obtain in collaboration with biologists studying the process from a molecular point of view.

2 Experimental Setup and Data Analysis

In order to study the flow field around a deformable, flapping fin, we use three dimensional particle tracking velocimetry based on stereo imaging using three cameras [16, 17]. For an accurate determination of the flow speeds of the tracer particles, we use a double pulsed laser system for illumination, where the pulse separation δt between two adjacent pulses corresponds to the temporal distance between two snap shot of the three dimensional particle positions, hence giving rise to a determination of the velocity. By the combination of the three cameras, each frame consists effectively of triplets of particles forming a triangle, whose size and orientation determine the position in the depth of the field of view, which is defined as the *z*-direction below. Due to the shortness of the time interval δt, the separation of the par-

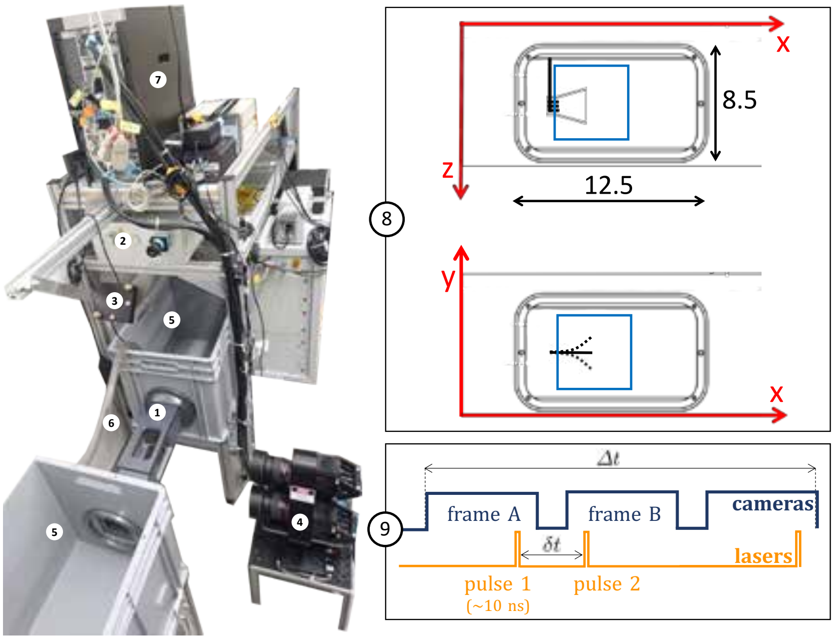

Figure 1: Experimental setup for 3D-3C PTV. (1) Flow chamber with transparent windows on three sides and a fixation wall on one side for inserting the synthetic fin. (2) Dual-head pulsed Nd:YAG laser with wave-length of 532 nm and maximal energy of 120 mJ/pulse, equipped with a pair of cylindrical lenses to expand the beam. (3) Mirror to deflect the laser beam. (4) Three cameras (resolution 4 MP, 85 mm lenses, sensor size 11.3 × 11.3 mm², magnification 0.3, maximal frequency of capture 180 Hz) mounted on a triangular plate parallel to the front wall of the flow chamber (x – y plane). The distance between the cameras plate and the center of the water tunnel is ≃ 465 mm. (5) Water tanks for the recirculating system. (6) Pipe and pump to control the flow. (7) V3V software and synchronizer. (8) Close-up of the flow chamber with inner dimensions (in cm), PTV-interrogation volume in blue (≃ 50 × 50 × 20 mm³) and sketch of the trapezoidal fin. Frontal view (x – y plane) and top view (x – z plane). (9) Frame straddling method with δt between the particle images and Δt between the velocity fields. Adapted from [18].

ticles has been small enough for a distinction of neighbour pairs to determine the velocity of the tracer particle in 3D. With a camera frame rate of 120 Hz, we thus obtain a full 3D flow field of the illuminated volume of 50 × 50 × 20 mm^3 at a time resolution of up to 60 Hz. With a spatial resolution of the particle positions of 3.6 *μ*m in the *x*- and *y*-direction and 32 *μ*m in the *z*-direction, the flow field is determined with an accuracy of 2 mm/s in the *x*- and *y*-directions and 18 mm/s in the *z*-direction [18]. From these velocity-fields we can then determine the hydrodynamic stresses via differentiation for the viscous stresses:

$$\tau_{ij} = \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \quad (1)$$

where μ is the dynamic viscosity and by integrating the pressure gradient given by the Navier-Stokes equation in terms of derivatives of the flow field by [19, 20]

$$\frac{\partial p}{\partial x_i} = -\rho\left(\frac{\partial u_i}{\partial t} + u_i\frac{\partial u_i}{\partial x_i} + u_j\frac{\partial u_i}{\partial x_j} + u_k\frac{\partial u_i}{\partial x_k}\right) + \mu\left(\frac{\partial u_i^2}{\partial x_i^2} + \frac{\partial u_i^2}{\partial x_j^2} + \frac{\partial u_i^2}{\partial x_k^2}\right), \quad (2)$$

where ρ is the density of the fluid. For this purpose, we use the queen2 algorithm, which is available at http://dabirilab.com/software/ [21].

Thus we are able to determine the full hydrodynamic stress tensor $\sigma_{ij} = -p\delta_{ij} + \tau_{ij}$ dependent on space and time. In addition, we are able to determine the position of the flapping fin from the absence of identified tracking particles, such that we can project the stress tensor onto the surfaces of the flapping fin and thus create spatio-temporally dependent force maps on the flapping fins. As a control of the accuracy of these force maps, integrating them along the width of the fin directly yields the force per unit length along the flexible fin, which is bent by these hydrodynamic forces. In addition, the shape of the bent fin is known from the experiment and its bending stiffness can be determined experimentally [22]. From this it is then possible to calculate the force per unit length acting on the fin based on the bending state using Euler-Bernoulli beam theory in order to calibrate the force determination from the hydrodynamic flows.

3 Calibration of the Method Using Euler-Bernoulli Beam Theory

Given a time dependent force acting on a flexible beam, its bending can be calculated using [23]

$$f_n(x,t) = m(x)\frac{\partial^2 h(x)}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI(x)\frac{\partial^2 h(x)}{\partial x^2}\right). \quad (3)$$

Here, *h(x)* is the midline position along the y-direction, f_n is the force per unit length along the x-direction varying temporally and $m(x) = \rho_f w(x) d$ and $EI(x) = E\frac{w(x)d^3}{12}$ are the mass per unit length and the bending stiffness respectively, where *w(x)* is the width of the fin. In the equation above, the first term on the right hand side describes the inertial force needed to displace the water surrounding the bent fin. The second term corresponds to the elastic force needed to bend the fin into the observe shape. In the most general case, one would also introduce viscous damping forces for both of these processes, however for the flapping frequencies and size of the fin we are studying here, these are negligible. In order to obtain a continuous description of the midline positions with only a few parameters, we fit the solution to a freely vibrating beam clamped at one end to the observed midlines.

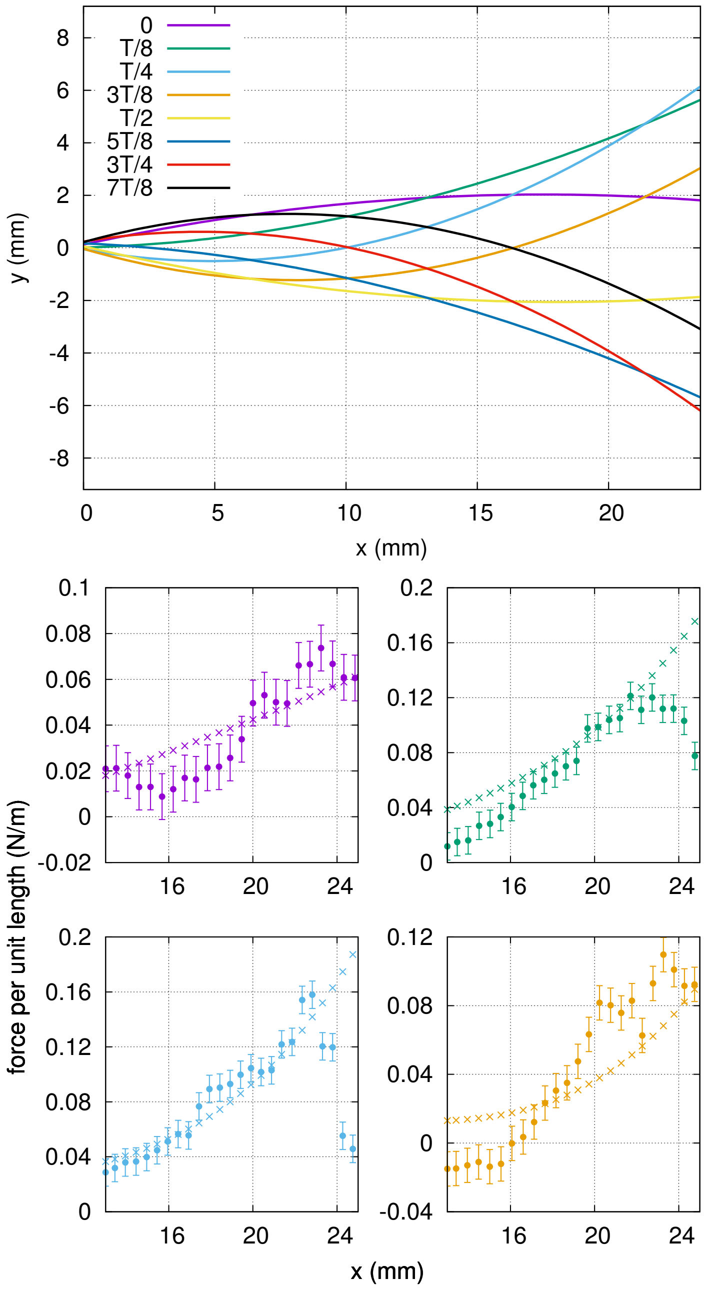

Figure 2: A: Foil midline positions at different time points during the oscillatory flapping. B: Force per unit length along the proximo-distal axis of the fin, from the PTV-based stress distributions (full circles) and the Euler-Bernoulli load calculation (crosses), at t0, t1/8, t1/4 and t3/8 from top left to bottom right, respectively. Adapted from [18].

The comparison of the results is shown in Fig. 2, which demonstrates that the determined forces per unit length capture the behaviour of the forces determined from beam theory quite well, except for the end tips of the fin, where the force drop is not reproduced by beam theory. At these positions however, fit capturing the curvature of the fins is not very accurate, such that the observed deviations are not surprising and we are confident that the hydrodynamic force maps present a more accurate physical picture. In addition, a control volume analysis [18] and a study of the vorticity in the fluid volume [24, 25] show that the forces determined from the hydrodynamic flows can be used with an accuracy of about 0.01 to 0.02 N/m. Similarly, the viscous stresses are determined to an accuracy of a few mPa and the normal stresses to below 1 Pa. With such accurate measurements of force distributions on flapping fins, we can then study the effect of these forces during regeneration of zebrafish fins.

4 Hydrodynamic Forces during Fin Regeneration

In order to study the influence of hydrodynamic forces on fin regeneration, we have determined the influence of shape changes on growth rates in regeneration experiments in actual zebrafish fins [26]. Subsequently, we have determined the force maps on differently sized and shaped fins using particle tracking velocimetry as described above. Comparing the forces acting at different shapes and sizes with the growth rates of regenerating fins, we were then able to correlate the growth with certain components of the forces acting on the fin. Given that the growth takes place at the tip of the fin, we expected the forces at the outer edge of the fin to be the most promising candidates, which in a complete study of the stress tensor has shown to be the case, with only one component of the stress correlating with all the observational data on growth rates as a function of shape and size.

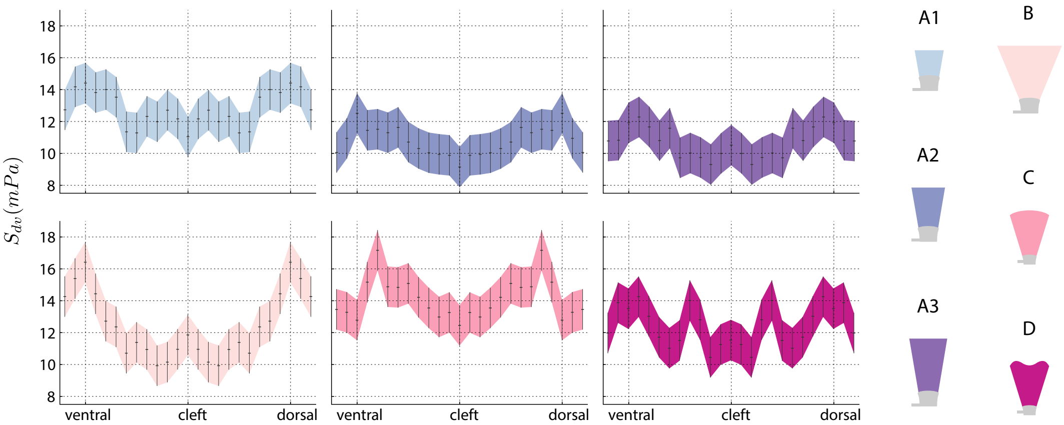

Figure 3: Spatial distribution of dorso-ventral shear stress at the tip of hydrofoils, $|S'_{dv}|$. Shown is the dependence along the dorsoventral direction of the absolute value, averaged over a flapping period for differently sized and shaped fins. A growth promoting effect of this stress is consistent with growth termination at the correct size, different growth rates for fins of different width as well as the dependence of the depth of the cleft of the fin in fins of different width. Adapted from [26].

This candidate stress for growth control that we have been able to thus identify, consists of the shear stress along the dorsoventral direction in a fish fin. This corresponds to the *z*-direction of the experimental setup shown in Fig. 1. The period averages of the absolute values of this stress component are shown in Fig. 3 along the tip for six different fin shapes and sizes. Comparing fins A1 to A3 corresponding to an increase in length and hence mirroring growth of the fin, the results are consistent with a growth promotion of such a mechanical stress, leading to a deceleration of growth with increased length. In addition, experimental regeneration studies have shown that changing the width of the regrown fin by constant ablation leads to (i) decreased size with decreased width and (ii) decreased depth of the cleft of the fin (the indentation in the middle) with decreased width of the fin. Both of these structural features are also borne out by the force distributions shown in Fig. 3 for the differently shaped fins [26].

5 Conclusions and Outlook

Using three dimensional tracking of particles, it is possible to determine the full hydrodynamic forces acting on a flapping fin dependent on both space and time [18, 27–29]. Using proper control measurements and calibrations, we have shown that the thus determined values are a good representation of the forces acting on the fin.

The applications of such measurements of hydrodynamic forces can be used to study swimming efficiencies and propulsion mechanisms [30]. With these detailed measurements of forces acting on flapping fins, propulsion mechanisms and efficiencies for differently shaped fins can be weighed against each other. For instance, flapping frequency can counteract deficiencies in shape and thus lead to increased propulsion efficiency [24].

In addition, for small fish, where the flow regime is at intermediate Reynolds numbers [14], it is possible study the influence of boundary layer flows [19]. These can be important where spatial structures like ray bifurcations lead to different boundary layer flows and hence mixing of surface flows along the fish fin [31]. This can be sensed by the fish and leads to a more dense distribution of sensory cells in the tissue between bifurcated rays.

Above we have used this to study the influence of mechanical forces on the regeneration of zebrafish fins, where it is possible to find candidate stresses that act as growth regulators [26]. Hence, the regeneration can show phenotypic plasticity where the re-grown fin is adapted to the swimming forces acting on it, indicating a direct example of Wolff's law in a functional biological context. This information can now be used to guide studies of mechanisms of biological growth regulation on a molecular or genetic level and hence be used in the future for a mechanistic understanding of Wolff's law.

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Kurzmitteilungen - Short Communications

Wie sich Wissenschaftlerinnen etablieren

Märta Tschudin, Physikdoktorandin in Basel, untersucht extrem dünne Magnete und geht in ihrer Freizeit gerne bouldern [1]. Kathryn Hess, Mathematikprofessorin in Lausanne, beschäftigt sich mit Topologien und hat vier Kinder. Beide sind Teil der Serie: "Wissenschaftlerinnen im MAP-Bereich (Mathematik, Astronomie, Physik)", der Plattform MAP, die zur SCNAT gehört. Jeden Monat porträtiert die Plattform während eines Jahres eine erfolgreiche Wissenschaftlerin auf der Website [2]. Von der Doktorandin bis zur Professorin zeigen Frauen, wie sie ihre Karriere verfolgen, an welchen Themen sie arbeiten und was sie neben der Wissenschaft beschäftigt. Die Porträtserie soll junge Frauen in ihrer Absicht bestärken, eine akademische Karriere einzuschlagen.

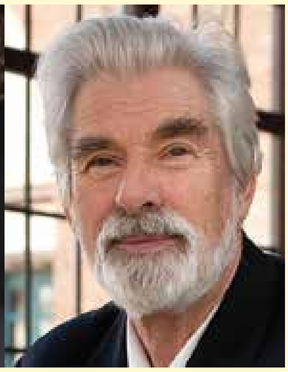
Die Porträts zeigen, dass es mit den unterschiedlichsten Interessen und Hintergründen möglich ist, eine wissenschaftliche Karriere zu gestalten, und welche bereichernden Erfahrungen dieser Weg mit sich bringt. Doch die Porträts zeigen auch – es gibt einige Baustellen, weshalb Frauen in den oberen Karrierestufen im MAP Bereich untervertreten sind: es fehlen in der Schweiz oft weibliche Vorbilder und ein Umfeld, das Studentinnen Lust auf eine wissenschaftliche Karriere macht. Und sobald Kinder da sind, erbringen Frauen eine extrem grosse Leistung, um Forschung und Familie gerecht zu werden. Die klassische wissenschaftliche Karriere richtet sich an Menschen, die sich ausschliesslich auf sich und ihre Forschung konzentrieren können. Wer das nicht kann, muss mit einigen Herausforderungen umgehen. Wenn wir die vielen Ideen, die Begeisterung und Errungenschaften der Porträtierten sehen, können wir etwas erahnen, wieviel wissenschaftliches Potential durch diese Einseitigkeit verloren geht. Die Porträts wurden vom Wissenschaftsjournalisten Benedikt Vogel im Auftrag der Plattform MAP erstellt.

Anina Steinlin, Plattform MAP, https://map.scnat.ch/ ;
Kontakt Benedikt Vogel: https://www.vogel-komm.ch/

1 Bouldern ist das Klettern ohne Kletterseil und Klettergurt an Felsblöcken, Felswänden oder an künstlichen Kletterwänden.

2 https://map.scnat.ch/de/activities/women_scientists

Nobel Prize in Physics 2021

The citation of the Nobel committee

The Nobel Prize in Physics 2021 was awarded ***for groundbreaking contributions to our understanding of complex systems*** with one half jointly to Syukuro Manabe and Klaus Hasselmann ***for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming*** and the other half to Giorgio Parisi ***for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales***.

The Swiss Physical Society expresses its sincere congratulations and best wishes to these colleagues and 2021 Nobel Laureates.

Syukuro Manabe and Klaus Hasselmann

Thomas Stocker, Climate and Environmental Physics, Physics Institute,
and Oeschger Centre for Climate Change Research, University of Bern, stocker@climate.unibe.ch

It came as a surprise to most of us that the 2021 Nobel Prize in Physics was awarded to Giorgio Parisi, Syukuro Manabe, and Klaus Hasselmann, for their groundbreaking contributions to our understanding of complex physical systems. Nobel Prizes for environmental science are rare: In 1995 the Nobel Prize in Chemistry was awarded for the understanding of the observed ozone depletion in the stratosphere over Antarctica and the demonstration that this is due to the complex chemical reactions triggered by the massive emissions of chlorofluorocarbons from industrial activity. It took the Nobel Prize Committee a full 26 years to acknowledge that also Physics has played a crucial role in providing the tools to understand the complex climate system. The fundamental contribution of Giorgio Parisi to enable generalized predictions of complex systems, on scales from molecular to galactic, will be discussed in a separate article. Here I focus on the area of physical climate modelling, where the two colleagues Syukuro Manabe and Klaus Hasselmann have made foundational contributions that are now timely acknowledged by the Nobel Prize in Physics 2021.

To physically describe the climate system one needs to solve the complete Navier-Stokes equations on a rotating sphere, for both the ocean and the atmosphere. These momentum equations are supplemented by conservation equations for mass of air and water in the atmosphere, water and salt in the ocean, and energy in both domains. Equations of state for moist air and saline water, as well as a set of parameterizations that describe the effects of smaller-scale motions in the atmosphere and ocean are implemented in the climate model. Moreover, the coupling of ocean and atmosphere requires formulations of mass, momentum and energy fluxes at the atmosphere-ocean interface. This also includes physical descriptions of sea ice, snow cover, and land surface processes. It is evident that this is a formidable problem that involves a large range of time and space scales, about 14 orders of magnitude in each. A large body of experience, in particular regarding the numerical solution of the partial differential equations of geophysical fluid dynamics, stems from numerical weather prediction that was made possible by the advent of the first electronic computers in the 1940ies. It is in this environment, that the development of three-dimensional coupled climate models began in the early 1960ies.

Manabe's work started in one dimension only: To simulate the vertical temperature structure in the Earth's atmosphere, he considered radiative transfer and convective adjustment in an atmosphere that also contained the major greenhouse gases H_2O, CO_2 and O_3 and their effect on the vertical fluxes of energy. In this paper [1] Manabe and his colleague were explicit about about their scientific agenda. In the acknowledgement they wrote: "*This work constitutes part of an effort to construct an advanced general circulation model …*", and they published such a model only a year later [2]. Manabe was early in recognizing the problem of increasing CO_2 concentrations in the atmosphere. Their one-dimensional model simulated the response of the atmosphere to a doubling of CO_2: global surface warming of 2°C and concomitant stratospheric cooling [3]. This is a remarkable fingerprint of anthropogenic global warming that is observed today and is due to the effect of the rapidly increasing CO_2 concentration caused by the burning of fossil fuels.

Suki, as called by his friends and colleagues, spent his entire career at the Geophysical Fluid Dynamics Laboratory, a government institution next to Princeton University. In the same lab, Kirk Bryan lead the equivalent effort to build a numerical model of the ocean circulation [4]. The two scientists teamed up and constructed the first coupled climate model [5]. They boldly chose a very idealized domain for their model: a 120°-slice of the planet, half of which was land from 66.5°S to 66.5°N, the rest ocean and periodic boundary conditions in the atmosphere. This configuration captured the essential elements of the global climate system while still being computationally feasible with the computer and storage infrastructure available at the time. The work was more than a proof-of-concept: It marked the beginning of a rapid evolution in climate model development that continues till today. Manabe has always been interested in the applica-

tion of the ever imperfect models to global problems. He had a keen eye for tractable problems and entertained intensive scientific contacts with geochemists and paleoclimate scientists in search of challenging problems.
One example with a Swiss connection concerns rapid climate change. Hans Oeschger (1927 - 1998), physicist at the University of Bern, and Willy Dansgaard (1922 - 2011), from Copenhagen University, found evidence in their isotopic analyses of lake sediments in Gerzensee, and of ice cores from Greenland, that during the last ice age, climate could change rapidly between a warm and a cold state, resembling a physical flip-flop system [6]. This hypothesis motivated a test with the comprehensive climate model that Manabe and colleagues had developed. They showed, that indeed their model could simulate two different equilibrium states [7]. One state was characterized by a strong overturning circulation in the Atlantic Ocean transporting heat northward and warming Greenland. In the second state, this circulation was substantially weaker and caused a relative cooling in Greenland, qualitatively in agreement with the findings of Oeschger and Dansgaard. Multiple equilibria were well known from the analysis of non-linear dynamical systems. Although the climate system engenders many strong damping feedbacks — for example planetary grey body radiation (the Planck feedback) — it is evidently non-linear and exhibits many of the characteristics of non-linear dynamical systems such as limited predictability, chaotic behavior, or multiple equilibria.

The cessation of this Atlantic circulation, an elegant physical mechanism for abrupt climate change, captured the attention of many researchers, e.g., [8, 9]. Manabe and his colleague Ron Stouffer were interested in the consequence of this finding for the ongoing global warming. They showed that the non-linear atmosphere-ocean system could undergo a bifurcation of the Atlantic overturning circulation depending on the warming caused by the continuing increase of the atmospheric CO_2 concentration [10]. This early work is at the start of simulating critical transitions and irreversibility in the climate system.

The work of Klaus Hasselmann was equally foundational. His interest in the global climate system departed from a more theoretical point. Originally concerned with the dynamics of ocean surface waves and their statistical analysis, he proposed that climate variability could be understood as the action of stochastic weather fluctuations on a slow-responding ocean-land- cryosphere component [11]. In this radically reduced description of the climate system he could invoke scale separation and found that the time evolution of the probability distribution of variability of the slow component can be described by a Fokker-Planck equation. This also allowed basic inferences regarding predictability under stochastic forcing, a deep insight into the complexity of the Earth's climate system. The work opened up a new avenue to utilize methods of theoretical physics, classically applied to problems such as Brownian motion, turbulence and plasma dynamics. Thereby, Hasselmann recognized a link between fundamental physics and climate science.

In order to describe the slow component more realistically, Hasselmann laid out a plan for an efficient ocean model [12], which could be used to simulate climate processes on time scales of centuries to millennia. This ocean model became the early workhorse of the scientific activity of the Max-Planck-Institute of Meteorology in Hamburg, of which Hasselmann was the founding director. It was the first three-dimensional model that also simulated the global carbon cycle and a series of tracers in the world ocean [13]. This opened up new avenues of coupled climate-carbon cycle simulations which today form the core of the latest climate change projections of the Intergovernmental Panel on Climate Change [14, 15]. Both Hasselmann and Manabe, with their collaborators, used coupled models to predict climate change expected for a doubling of the CO_2 concentration in the atmosphere [16] (see Figure 1 and Figure on the cover). These results informed the first assessment report in 1990 [17] which was the scientific basis for the UN Framework Convention on Climate Change of 1992.

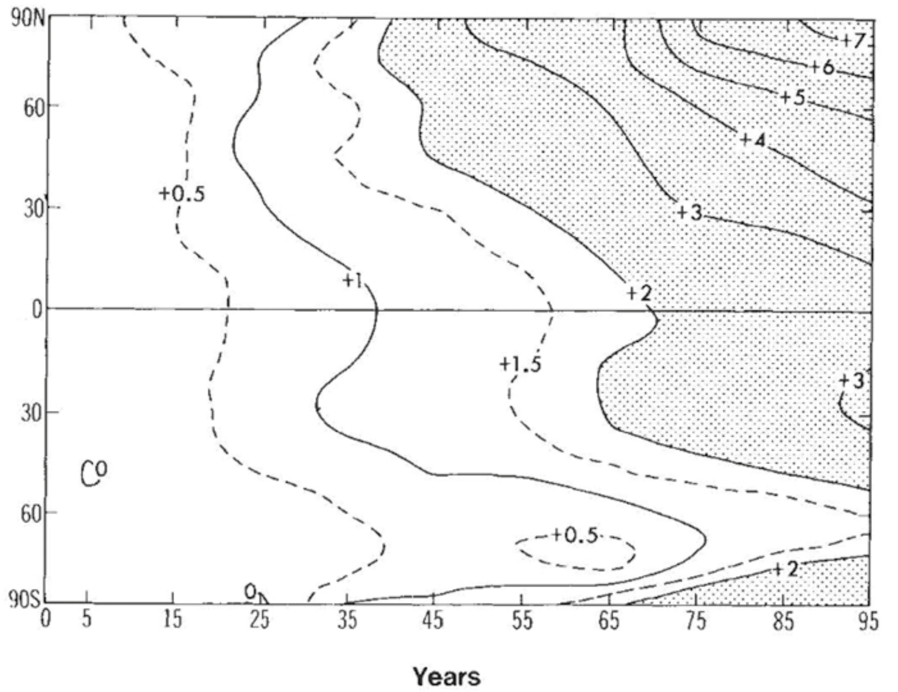


Figure 1: Latitude-time diagram showing the simulated zonal-mean surface warming in a 100-year integration of one of the first coupled atmosphere-ocean models, published in 1989 [16]. In this idealized simulation the CO_2 concentration was gradually increased by 1% per year. See Figure on the cover page for an analysis based on observations.

It is worth to reflect on the realism of this early simulation and its usefulness to estimate the future. Figure 1 emphasizes two salient features of global warming induced by a gradual increase in the greenhouse gas concentration in the atmosphere. First, the model simulates a substantial polar amplification of warming in the northern hemisphere from about 45° to 90°N. This is due to the positive snow-albedo feedback: warmer temperatures melt snow and sea ice and allow the surface to absorb more heat. Second, there is a strongly delayed warming in the southern hemisphere between about 40° to 75°S. This is caused by efficient uptake of heat into the Southern Ocean. In consequence, the coupled model predicts a strongly asymmetric response of the global climate system to the increase in CO_2. More than

30 years after this projection, this characteristic spatial distribution of the warming is unequivocally observed. The Figure on the cover of this issue shows observed zonal mean surface temperatures (HadCRUT5.0 data set), relative to 1850-1900 in decadal running means, as functions of time and latitude. Both the more rapidly evolving heating in the northern high latitudes and the polar area, and the delayed warming in the southern mid- to high-latitudes, are clear patterns of the observed surface temperature changes. In spite of the idealized CO_2 scenario used in 1989, this early model predicted the patterns of warming remarkably well [18].

This realism is also a prerequisite for a further key contribution in climate science. Building on the early statistical work, Hasselmann and colleagues developed new statistical techniques to detect observed climate change and attribute it to different drivers. The approach uses pattern analysis — empirical orthogonal functions, and variants thereof — on fields of observed climate variables such as temperature, precipitation, etc., and their twins in climate model simulations. This fingerprinting method permitted them to individually estimate the contributions of greenhouse gases, aerosols and solar variations to the observed global mean surface warming [19]. Today, detection and attribution has evolved into a new and vigorous field in climate research. Through the combination of the latest satellite and in situ observations with climate model simulations, observed changes in the three-dimensional structure of temperature in the atmosphere, precipitation, sea ice extent, ocean heat content, heat wave occurrence, sea level, and many more, can be quantitatively attributed to the increase in greenhouse gas concentrations and therefore to human activity. Most recently, these techniques have been applied to single extreme events. This event attribution [20] could have serious legal implications regarding liability for loss and damage caused by climate extreme events exacerbated or triggered by climate change.

It is remarkable to see the convergence of the work of these two climate scientists: Syukuro Manabe starting from the radiative fluxes in the atmosphere, and Klaus Hasselmann from the effect of random weather fluctuations on global climate. Both have laid the foundation for the development of comprehensive climate models that have been used to investigate and understand the physical processes that shape the Earth's climate. Since the early 1990ies, significant progress has been made by incorporating the carbon cycle in the ocean and on land, dynamical formulations of vegetation types, the chemistry of the atmosphere and polar ice sheets. This made coupled climate models also attractive tools for interdisciplinary research. Today coupled models include modules of chemistry to investigate tropospheric and stratospheric chemical reactions determining the composition of the atmosphere, modules of biogeochemistry to study the ocean's role in influencing the atmospheric CO_2 concentration both in the past and the future, or modules of biology when questions regarding changes in land vegetation or in marine organisms are addressed.

With the ever growing computer power, the currently most advanced coupled climate models have a grid resolution of 1 km globally, more than 500 times finer than in their infancy. They are now able to simulate local weather systems and impact of climate change with an unprecedented degree of realism. Manabe and Hasselmann, together with countless colleagues, have given us the tools for a physical understanding of our planet. These tools are now available for decisions regarding the future of our Earth system. The significance of their contributions is most appropriately recognized by the Nobel Prize in Physics 2021.

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The work of Giorgio Parisi

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1 Introduction

In the following we aim to describe some of the very many contributions of Giorgio Parisi to theoretical and computational physics in a research career of half a century. As the somewhat hazy citation of the Nobel Committee indicates, it is impossible to do justice to Parisi's accomplishments in a single sentence. Even a few pages won't suffice! His substantial and influential accomplishments in almost all areas of theoretical physics, computational physics and in the development of special-purpose computers make Parisi a modern incorporation of a Renaissance scholar with universal interests in the Natural Sciences.

2 Remarks on Parisi's career

Giorgio Parisi was born in Rome on the fourth of August, 1948. He studied physics at the University of Rome "La Sapienza," completing his education under the supervision of Nicola Cabibbo in 1970. His first appointment as a research theorist was at the National Laboratories of Frascati (1971 - 1981). During this period he held visiting appointments at academic institutions abroad, including Columbia University, New York (1973 - 1974), the Institut des Hautes Études Scientifiques, and the École Normale Supérieure in Paris (1977 - 1978). These visits led to long-lasting, intense and very fruitful interactions with French colleagues. In 1981, he was appointed full professor at the University of Rome 'La Sapienza' where he is now professor emeritus. In June 2018 he was elected President of the "Accademia dei Lincei" in Rome. Parisi has published about eight hundred articles and contributions to conference proceedings and is the (co-) author of four books. His work has had considerable impact on all fields he turned his mind to. In the Google scholar database more than 88'000 citations are listed; Parisi's h-index reaches the astronomical value of 124.

3 A brief survey of Parisi's work

In the 1960's and 70's scientific culture in Italy and the personalities of Nicola Cabibbo (1935 - 2010) and Raoul Gatto (1930 - 2017) led to the creation of a strong school of excellent young physicists who would shape many further developments in particle physics. Cabibbo was deeply interested in quantum field theory, such as Quantum Chromodynamics (QCD), at a time when S-matrix bootstrap models were still promoted by many physicists. In this free and collaborative atmosphere, Parisi thrived. His results, with Guido Altarelli, on the so-called *Altarelli-Parisi equations* [1], for the Q^2-dependence of the quark and gluon densities became very influential; they are described in more detail in the last section. He then went on to work on lattice gauge theory, among other topics in quantum field theory. He made contributions to a heuristic understanding of quark confinement derived from conjectural properties of the chromo-electric flux tubes, and he worked on properties of lattice gauge- and random surface theories in very high dimensions (with Jean-Michel Drouffe and Nicolas Sourlas). They discovered a connection between the mean-field theory of lattice gauge- and random surface theoy on one side and the theory of branched polymers on the other side. Branched polymers had just been studied by Lubensky and Isaakson, using the so-called replica method, which consists in considering n independent replicas of a disordered physical system and, after averaging over the disorder, taking the limit $n \to 0$. In a nearly incomprehensible paper, these authors had argued that the upper critical dimension of branched polymers was 8 and the lower critical dimension was 4. Their paper triggered Parisi's interest in the replica method, and he suggested that the lower critical dimension of gauge theories ought to be 4, which would imply that quarks are permanently confined in a 4D non-abelian gauge theory. Alas, while this is highly plausible, it still remains mysterious mathematically!

Between 1984 and 1994, Parisi worked in a team headed by Cabibbo that developed and implemented APE (Array Processor Experiment), a massively parallel supercomputer project [2] designed to calculate, for example, mass spectra of strongly interacting particles in lattice QCD.

With Sourlas, Parisi introduced ideas and methods from supersymmetry into statistical mechanics [3] that led to a mechanism of dimensional reduction suggesting, for example, a connection between spin systems in a random external magnetic field in D+2 dimensions and spin systems in the absence of an external field in D dimensions, as well as a connection between branched polymers in D+2 dimensions and the Lee-Yang edge singularity of the D-dimensional Ising model. These findings opened the way to the discovery (made precise by Brydges and Imbrie) of connections between branched polymers in D+2 dimensions and a classical hard-core gas at negative chemical potential in D dimensions, which led to the exact calculation of critical exponents for branched polymers in 2, 3 and 4 dimensions.

Once familiar with the replica method mentioned above, Parisi extracted from the literature the idea that the obvious permutation symmetry between replicas could be broken when the number of replicas tends to 0. He speculated that the permutation group of 0 elements has the permutation groups of m elements as subgroups, for all m = 1, 2, 3, ..., and hence is an infinite group. He applied such mathematically shaky, but ultimately fruitful intuitions to the problem of understanding the low-temperature phase structure of the Sherrington-Kirkpatrick mean-field model of (Ising) spin glasses, discovering the exact solution [4], which is since called "*Parisi solution*." Parisi's highly imaginative, but mathematically "unorthodox" work made the Stanford mathematician Persi Diakonis say that Parisi is a "torturer of mathematicians." Well, the torture had a pay-off: The Parisi solution was proven to be exact in major efforts by Guerra and Toninelli, Talagrand and Panchenko. Parisi went on to explore new ways to understand his solution. In joint work with Mézard he invented the "*cavity method*." In work with Mézard, Sourlas and Virasoro, the ultrametric structure of the low-temperature phases of the Sherrington-Kirkpatrick model and the failure of self-averaging of order parameters in models of spin glasses were discovered [5].

As emphasized, e.g., by Fu and Anderson, these efforts have given rise to a new paradigm in the theory of phase transitions enabling one to analyze systems that do *not* have a local order parameter, as in Landau theory, and *cannot* be reformulated as gases of topological defects such as vortices, as, e.g., the XY model of superfluid ^{4}He.

The ideas and methods Parisi and his co-workers devloped for the analysis of the Sherrington-Kirkpatrick model turned out to have numerous interesting applications to problems in combinatorial optimisation, neural networks, etc. They have triggered an industry of work by very many followers.

The breadth of Parisi's work is overwhelming indeed! To quote the late Freeman Dyson: "*Scientists come in two varieties, hedgehogs and foxes. I borrow this terminology from Isaiah Berlin, ... Foxes know many tricks, hedgehogs only one. Foxes are broad, while hedgehogs are deep. Foxes are interested in everything and move easily from one problem to another. Hedgehogs are only interested in a few problems that they consider fundamental, ... Some periods in the history of science are good times for hedgehogs, while other periods are good times for foxes. ... In the middle of the 20th century, the foundations* [of modern theoretical physics] *were firm and the universe was wide open for foxes to explore.*" Dyson described himself as being a typical fox, and he never won a Nobel Prize. Well, times have changed. Parisi is the ultimate fox. This becomes glaringly evident when we look at some of his further endeavors in theoretical physics, among which are: Stochastic quantization of quantum field theory (Parisi-Wu; lately very popular among mathematicians); spin glasses and glasses; general theory of disordered systems; supersymmetry methods in statistical mechanics; interface dynamics (Kardar-Parisi-Zhang equations; now very popular among probabilists); graph theory (e.g., counting of diagrams with a fixed genus, such as planar diagrams; work by Brézin, Itzykson and Parisi); stochastic resonances in climate physics (Benzi, Parisi and others); turbulence and chaos (Parisi-Vulpiani and others; the well known French mathematician Yves Meyer claims that Parisi's injection of new ideas involving multi-fractality into the field of fully developed turbulence has shed new light on the subject); computer science (APE); shape of bird flocks; and so on, and so on.

4 The Altarelli-Parisi (AP) equations

The early 1960's had seen the development of the quark model. While at first mostly used to count building blocks of protons, neutrons, etc. the model eventually gave rise to a heuristic method, the quark-parton model (Feynman 1969, Bjorken 1969), to be applied to high energy experiments with hadrons. At the beginning of the 1970s, the rise of QCD, a non-abelian gauge field theory of the strong interactions, promised to put the quark model on solid grounds; especially after the discovery of asymptotic freedom (Nobel prize in Physics 2004 – Gross, Wilczek and Politzer), which made QCD a powerful tool for systematic calculations. An important problem was then to combine the heuristic quark-parton model with QCD.

The observation of (approximate) scaling and its violations in deep inelastic (very high energy-) scattering processes (Bjorken 1969) together with QCD laid the foundations of the AP paper of 1977 [1]. Scaling, the notion that observables depend naively on powers of dimensionful quantities, such as energy (as an example, in units where the velocity of light and Planck's constant constant are set to one, a cross section with the dimension of cm^2 goes like E^{-2}, where E is a typical energy for the process considered) led to the notion that high-energy hadron interactions could be thought of as the scattering of almost free 'partons' (quarks) inside a hadron. The decisive step of Altarelli and Parisi was to establish the connection of the quark-parton picture with QCD. They found that the scaling violation observed earlier could find an explanation in QCD. In fact, their knowledge of field theory had made them acquainted with the (logarithmic) scale violations typical of field theory. By using renormalization group techniques incorporating asymptotic freedom they were able to provide solid, reliable (perturbation-theory based) predictions for high energy processes involving hadrons. The central element of their work consists in the evolution equations for the quark (gluon) densities, the AP equations, which describe their energy dependence. These equations are the basis for understanding and interpreting results at past and present accelerators, such as the LHC.

One has since become aware of the fact that similar ideas had been entertained earlier by researchers around the eminent soviet physicist Vladimir Gribov, an early proponent of QCD. The paper by Gribov and Lipatov 1972 [6] already contains several elements of the AP paper. Yu. Dokshitzer, also in 1977 [7], published independently the complete set of evolution equations. These articles were unknown to Altarelli and Parisi. They came to light once HERA at Desy (Hamburg) produced an abundance of data on the physics of the AP equations, and the large international collaborations facilitated the world-wide flow of scientific information. Nowadays, the AP equations are often referred to as DGLAP equations.

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My PhD advisor - A personal recollection on the occasion of the 2021 Nobel Award to Giorgio Parisi

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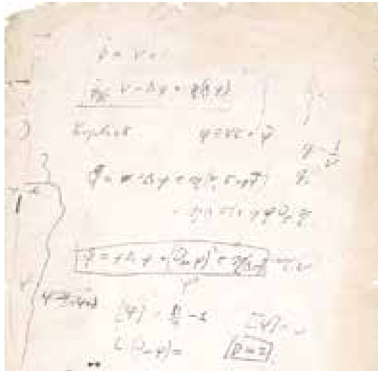
As a former doctoral student, the Nobel award to Giorgio brings back fond memories working with him which I would like to share here. Many physicists have been expecting the prize going to Giorgio, but the award still comes as a surprise. Typically, the Prize would be given for specific, experimentally verifiable discoveries; the recognition of Giorgio instead is seen by many as the coronation of his illustrious scientific career, for his many pivotal contributions in a field that we might call the Complexity that he pioneered. That is the encouraging surprise for many, especially for his former students and coworkers and for the thousands of scientists working on many branches of complexity sciences.

Though Giorgio has had some students before me, like Enzo Marinari et al., I was his first doctoral student because there was not yet a Ph.D. program at Rome and I managed to register as a PhD student at SISSA, Trieste, which agreed to continue supporting me in Rome and the SISSA director appointed Giorgio as my PhD advisor. Hence, I was privileged to witness the burst of intellectual sparks of Giorgio during the 1981-1984 period.

I must admit that it was not easy to be his student because he treated me as a peer rather than an eager student trying to learn the state-of-art of theoretical physics. So, on my first morning he presented to me on the blackboard what he was doing that morning, renormalization group computations of Lattice Gauge theory. Of course, I immediately plunged into the subject but the week after he started telling me how 0 × 0 matrices can finally tackle Spin Glasses. There was an amazing array of creative sparks thrown at me from which I could catch only a fraction at best. I remember one day he came to me saying "let's try to use 2D geometry suggested by John Wheeler to model cosmology" (2D tori spanning 4D space), then another week later he sent me to Nordita in Denmark to attend a superstring workshop…. Well, it was like throwing babies into the ocean, some may manage to survive! When I myself became professor in Switzerland I adopted a similar approach in guiding my own Ph.D. students: don't teach them, just inspire.

In the early 1980's, particle physics was very popular and I also did "routine" research on lattice gauge theory but conversations with Giorgio almost always led beyond the hardcore physics, only many years later when I visited Santa Fe I realized he was really initiating an interdisciplinary field that would be called *Complexity Sciences*.

Another sign that Giorgio treated students and everybody else as equals was that we shared his small office (about 8 m^2). On the other hand, Giorgio rarely came to the office, interacting with Giorgio happened often on casual events such as lunches and walks. Below I attach a "casual" lunch note that eventually led to KPZ equation.



In summer 1984 I got the degree after publishing about 10 papers (half with Giorgio) primarily on particle physics, then went on to Brookhaven Lab for a stint of two-year postdoc. In July 1985, I went back to Rome for a visit, and had a lunch with Giorgio and a few colleagues. As a typical occurrence, Giorgio grabbed a napkin and started to draw what he was interested in: the oil-water interface problem from a paper of Schlumberger Lab. I teared a blank page from my notebook asking him to write more clearly of what he started on the napkin. As the yellowish page shows (drawing on the left margin), when an interface is moving through quenched disorders, the advancing interface encounters a noise term with the interface position in it, a hard problem to treat. However, he said, if we do perturbation on the stochastic equation, then to the one-loop approximation the expansion would generate a nonlinear term (the famous term magically appeared for the first time!).

Coming back to Brookhaven, I started to tell visitors to Per Bak's cafe room (a famous hangout for brainstorming initiated by Per) about it. One day I thought that Giorgio's problem is too hard; maybe I should first study the easier equation just with the nonlinear term. Talking to Per and his visitors we simply called it "modified EW equation" (Edwards and Wilkinson equation is similar without the nonlinear term). One visitor, Tom Witten if I remember correctly, said "you can't study an equation just because it's nice like mathematicians do, you should justify what physics it can describe". Having in hand an intriguing equation first, then look for what it may represent, is quite contrary to the normal scientific logic! Next day I realized that Witten's objection can be lifted because the modified EW equation in fact describes the Eden surface growth problem that Giorgio asked me to study about two years earlier!

Giorgio actually gave two key pieces of the puzzle on two separate "casual" occasions. It dawned on me that putting two hints of Giorgio we'd have a simple physics as well as a nice equation perfectly fitting to each other! Mehran Kardar was a frequent visitor of Per, and we immediately struck a mutual understanding. Upon seeing the equation, he taught me the new renormalization group methods he learned from Harvard school (D. Nelson and D. Fisher et al.), and quickly turned his powerful tools to the equation and we wrote a draft within weeks. Then I sent an airmail (those days emails were of limited use) to Rome, asking Giorgio apologetically that if it's OK we first attack the simpler problem, maybe later we'd return to the full interface problem? Without a reply, a few months later we assumed that Giorgio wouldn't object, and we submitted to PRL. Mehran kindly offered me the first author place but I declined, and since the whole idea was initiated by Giorgio, so we opted to put our names in the alphabetic order.

Among Giorgio achievements (medals and prizes before the Nobel) often the merits cited were Spin Glasses, Altarelli-Parisi equation (quarks asymptotic freedom) and sometimes also KPZ. I recently asked Giorgio by noting that in his many speeches most often topics were about Spin Glasses, not even once about KPZ. Was it too simple or did he never explicitly approve what Mehran and I did or wrote? (We'd never know the answer.)

But KPZ related work lived on also in Switzerland. For example, Martin Hairer, a Ph.D. student of Jean-Pierre Eckmann, won the Fields Medal [1] for doing mathematical research on the 1+1 dimension KPZ, and there is also a strong following in both physics and mathematics still working on KPZ related subjects.

I hope that Giorgio should be glad that even one of his side interests, expressed "casually", could give us the enduring excitement. What I have seen in him must only be glimpses of his genius for which the scientific community finally gave him due recognition. I'm sure that his impacts to physics and beyond can still go much farther, I feel really fortunate to be able to follow him on a tiny part of his path-breaking endeavor.

1 https://www.sps.ch/artikel/diverse-artikel/martin-hairer-got-the-fields-medal-for-his-study-of-the-kpz-equation

A visit to the ITER construction site by a joint EPS and SPS delegation

Antoine Pochelon, Christophe Rossel

The visit to ITER by part of the SPS board follows the distribution of the first issue of the ***SPS Focus*** [1] on *Nuclear Energy Generation, Progress in Fission, Breeding and Fusion Technology*, which prompted ITER Directeur General Bernard Bigot to invite the SPS for a visit to ITER. The chapter on fusion, "ITER – An Essential Step Towards Fusion Energy" provides an insight into the ITER project and objectives. However, nothing replaces a real visit on the construction site to get a sense of the scale of the undertaking.

Independently, the EPS Technology and Innovation group (TIG) organized a visit to ITER on the 23 November 2021. The smart idea was to merge the two societies for the visit, which started with a nice joint meal in a good restaurant in Aix-en-Provence, at the invitation of the EPS. Eighteen physicists in total signed up for the visit in Saint Paul-lez-Durance, a place near Cadarache in south of France.

Our group in front of a sector mounted on the assembling tool. One can see a D-shaped TF coil surrounding the vacuum vessel sector. © ITER

Inside the tokamak pit, assembling the tokamak components. © AP

The visit itself was scheduled for the following morning. A pleasant drive through the provençal countryside brought us to St-Paul-Lez-Durance. At a distance, the cranes rising above the horizon mark the landscape, and as we approach, the main experimental building, consisting of the assembly and tokamak hall, appears gigantic on the platform. A prominent banner on the building proudly announces "We have delivered", accompanied by the flags of the seven partners, China, EU, India, Japan, Russia, Korea, USA, in total 35 countries, sets the tone of the multinational endeavor, thus supported by more than 50% of humanity. Many parts of the machine are built and delivered by the different partners as in-kind contributions.

Moving upright a 440 t sector of the vacuum vessel, to bring it to the assembling tool on the left of the image (Korean sector, 11.12.2021). © ITER.

The visitors were welcomed by Alain Bécoulet, Head of Engineering Domain, replacing Bernard Bigot at short notice. In a comprehensive presentation of this most ambitious energy project, the construction of the world's largest tokamak was explained to the audience. ITER is designed to demonstrate the feasibility of fusion at a large scale, with a reactor device, whose plasma is capable of producing a positive net energy for long periods. ITER will be the first burning plasma with largely dominating fraction of fusion power, (factor Q) representing ten times the heating power injected into the plasma, $Q \equiv P_{fus}/P_{heating} = 10$, with $P_{fus} = 500$ MW.

But ITER is not intended to produce any electricity, although the fusion reactions will provide a lot of power that will have to be dissipated in cooling towers.

75 % of the "total construction work scope through First Plasma" is now reached, according to the organisation. About 80% of the installation's civil works is now completed and the manufacturing of the reactor's parts is in good progress. Some delays are now occuring due to supply shortage and the Covid-19 pandemic, so that the first plasma is scheduled earliest in 2027. But the full-power operation objective (2035) is maintained. The huge components, the toroidal field coils (TF), the central solenoid (CS), all superconductors, the vacuum chamber sectors, the cryostat elements come from the different partners. The largest poloidal field (PF) coils, too large to be transported (up to 24 meter in diameter), are built on ITER site, in the PF coil winding facility, an interesting and impressive part of the tour.

Building the World's Most Powerful Pulsed Superconducting Magnet

The General Atomics Magnet Technologies Center has successfully completed and tested the first module of the ITER Central Solenoid [1], which was shipped in June 2021. When fully assembled, the six-module Central Solenoid [2] and associated structures will be 13 meters tall, weigh 1,000 tons, and be capable of producing a magnetic field of 13 Tesla, making it the largest pulsed superconducting magnet ever constructed. The Central Solenoid is often referred to as the heart of ITER and will drive 15 million amperes of electrical current.
General Atomics is a defense and diversified technologies company, founded in 1955 as a Division of General Dynamics, operating with its affiliated companies on the five continents with over 15,000 employees.

A pdf copy of the *ITER CS Photo* booklet is available for download: *https://www.ga.com/images/products/energy/iter/ITER-booklet-2021.pdf*

1 https://www.ga.com/magnetic-fusion/iter-solenoid-celebration

2 https://www.ga.com/magnetic-fusion/iter-manufacturing

Using fusion - the strong interaction that holds the nucleus together - instead of chemical reactions releases huge amounts of energy: 1 g of fusion fuel is equivalent to 8 tons of oil.

The fusion reaction occurs in a plasma of deuterium and tritium $^2H + ^3H + 0.7\ MeV \rightarrow ^4He + 3.5\ MeV + n + 14.1\ MeV$ heated to over 150 million °C. Deuterium is very abundant, while tritium is regenerated using the fast neutron via ^6Li, the actual fuel. To achieve fusion the hot plasma is shaped in the form of a torus and confined by strong magnetic fields. The helium nuclei sustain the burning plasma whereas the emitted neutrons transfer their energy to the blanket. The generated heat is transformed into electricity via a conventional steam generator, turbine and alternator.

The first sector of the vacuum vessel (out of 9, 440 t) mounted on the assembly tool, surrounded by its 2 TF coils (2 x 320 t). © ITER

Briefly, the interesting points of fusion are:
- Massive, predictable baseload power complementary to renewable energies
- Intrinsically safe
- Nearly unlimited supply of fuel for millions of years
- No greenhouse gases emission; no impact on climate
- No long-lasting high-activity radioactive waste

The birth of the ITER project, or how ITER was decided

The Reagan-Gorbatchev Geneva summit in 1985 was a key moment in the decision to launch an international collaboration in the field of fusion "for the benefit of all mankind". Recognizing the rapid progress obtained by tokamaks, in particular JET in the EU and TFTR in the US, the summit suggested to start the joint conception of a reactor called ITER capable of power generation. This was not the first activity of this kind: an international team, under the auspices of the IAEA was working on the INTOR (International Torus) project, in which the EU was involved, while also working in parallel on their own burning plasma project NET (Next European Tokamak). The EU and Japan decided to join the ITER project in 1988 thus replacing the previous studies and strengthening considerably the collaboration.

The conceptual design activities for ITER were initiated first in Garching bei München. Then in 1991 a new treaty under the auspices of IAEA, unparalleled in the history of science, was formalized: placed on a strictly equal footing, Americans, Europeans, Japanese and Soviets agreed to share the intellectual property of their joint work. Three ITER teams were established: in the US in San Diego, in Japan in Naka and in Germany in Garching. An ambitious fusion reactor project (with plasma properties: 1000 s, 1.5 GW, 1000 m^3, Q = 30) was conceived. Aware of the high cost of the venture, the ITER Council requested to reduce it with a less ambitious scope. Another turmoil was the withdrawal of the US participation in 1997, preferring laser-based inertial confinement fusion (ICF), which mainly serves military interest, at the expense of slowing down magnetic confinement fusion (MCF) in the US.

For the three remaining partners, the request for reducing the scope led in 2001 to the design of ITER-FEAT (Fusion Energy Advanced Reactor), a machine with a lower power gain of Q = 10 less demanding in high-tech materials and neutronic fluence, but sufficient to test dominant alpha particle heating. Symbolically and officially, the meaning of the acronym ITER changed, from "International Thermonuclear Experimental Reactor" to the Latin word *Iter*, meaning "the way". The *Iter Final Design Report*, a bible of many thousand pages, result of 8 years of work, was formally accepted by the partners. In the meantime, China and South Korea joined the Project in 2003, followed by India in 2005 just after the choice of the construction site was made.

An obvious issue became urgent at the beginning of 2000: where to place the device? The selection of a location for ITER was to be a lengthy and sensitive procedure. No partner had made a firm proposal although the question was central for its economical and structuring effects. France, in the mid-90s, had started studying implementing ITER in Cadarache, a large nuclear centre located 40 km north east of Aix en Provence. In 2001 the French fusion lab working within the European framework resumed vigorously qualification studies of the Cadarache site. Canada proposed the site of Clarington, located east of Toronto. In 2002, the French site team obtained a strong political and financial support from the local communities of Provence. At the same time, the US, revaluating their participation to a reduced size ITER, proposed in 2003 to re-join the partnership.

Spain, was proposing Vandellòs, south of Tarragona and Japan proposed Rokkasho-Mura in northern Japan. Finally, the high quality Cadarache site, was chosen after discussions at the European level, giving to Spain the headquarter of the European Domestic Agency, Fusion for Energy (F4E).

After the Canadian site withdrawal, a final choice had to be made between Cadarache and Rokkasho-Mura. This led to intense discussions from 2003 to 2005 with the strong will that there should be no looser in the competition. After many inconclusive meetings, an encounter between the French President Chirac and the Japan Prime Minister Koizumi paved the way to a win-win solution, the so-called "Broader Approach", in June 2005. Europe, was chosen as the host, for the construction of ITER in Cadarache. Japan received substantial compensation in the form of a satellite machine to ITER (JT60-SA), studies for a material test stand, IFMIF (International Fusion Material Irradiation Facility) and a large calculation center dedicated to fusion. More and better than a single machine, the "Broader Approach" now provided a solid and coherent foundation so that ITER and associated activities are truly global undertakings and reflect the profound nature of the challenges of fusion.

Following the site decision for Cadarache on 28 June 2005, the creation of "ITER International Organization" was signed in Paris on 21 November 2006 by the seven members. The "Broader approach" was signed in February 2007 between EU (Euratom) and Japan, and the "ITER Treaty", signed by the seven partners came into force on 24 October 2007 with site activities starting before the end of 2007.

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We would like to thank Jean Jacquinot for his careful checking of this section.

Winding and insulating a 24 m diameter PF coil at the ITER PF coils winding facility. © AP

Excerpts from the QA session:

- The machine planned after ITER, called DEMO should provide 500 MW_{elec}, with 1200 MW_{therm}. Different partners are already outlining their own DEMO design and roadmap.
- The material issues are important for the design of the first wall, which must withstand high neutron fluence and heat flux. The control or suppression of edge plasma instabilities releasing high energy fluxes is mandatory. This could be achieved by using a liquid metal wall, like lithium, or other innovations, so that the future reactor could be different from ITER [2].
- There is a strong interest for fusion by private, non-governmental companies. About 36 of them have raised some 2 billion USD, an amount increasing rapidly. This aggressive fundraising pitch reflects probably shorter-term interests in the fusion race. In fact we are witnessing the progressive industrialization of fusion, as it is more perceived as an achievable technology.

  At the end of November, Commonwealth Fusion System (CFS), a MIT spin-off with its project SPARC, received a gigantic contribution of 1.8 billion USD from Bill Gates, bringing private investments in fusion soon to 4 billion USD. The SPARC project – a high field tokamak with HTS magnets - appears as a serious and visible enterprise, with 7 open access articles published in 2020 in a recognized journal, providing a full description of the project [3]. ENI, the Italian oil - or energy - company was one of the early investor in CFS.

The challenges regarding the physical process itself, the material science and the integrated technologies are enormous. Evidently an impressive logistic is required for the construction of the buildings and the whole infrastructure. After the excellent presentation and the active QA discussion, the participants were invited to tour the whole worksite, including the Poloidal Magnetic Field Coils facility, the Assembly Hall, and the Tokamak itself. Needless to say, the construction site and the large scale of the tokamak components and assembly tools highly impressed the visitors, who were able to ask all their questions to a team of very competent guides.

Our general enthusiasm can be well summarized by a few impressions of a young PhD student, Hana, who had joined us *"I must admit that by the end of the ITER visit...I wished I could remain there much longer, begin working immediately as an active member into the details, challenges and contribute to this important project, which aims at delivering clean, and much needed energy to our planet"*.

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See also: Timothy C. Luce, ITER, an essential step towards fusion energy, *SPG Mitteilungen* Nr. 56, Oktober 2018, 22-23. https://www.sps.ch/fileadmin/articles-pdf/2018/Mitteilungen_PT032018.pdf

[2] Different from ITER could mean: 1) the D-shaped plasma cross-section - as in ITER tokamak - could be changed to a tokamak with inverse-D shape plasma cross-section, also called negative triangularity, or 2) move to the stellarator line, a helical twisted toroidal device. See e.g. L. Porte, A. Pochelon, It's All in the Shape: Triangularity on TCV, *SPG Mitteilungen* Nr. 59, Oktober 2019. https://www.sps.ch/fileadmin/articles-pdf/2019/Mitteilungen_Progress_69.pdf

[3] Martin Greenwald, Status of the SPARC Physics Basis, *J. Plasma Phys.* (2020), vol. **86**, 861860501, 2020. doi: 10.1017/S0022377820001063, and following articles.

Switzerland and EURATOM

As a member of EURATOM, Switzerland used to participate in ITER with several mandates. The Swiss Plasma Center of EPFL operates the TCV tokamak (Tokamak à Configuration Variable) as an EU facility and the test installation SULTAN, the largest worldwide magnet facility to test forced flow, high current superconductors up to 11 T, is used as the reference facility for ITER superconductors. However, due to the failure of the framework agreement with the EU, Switzerland's participation (as well as the UK) in ITER and other Horizon projects has been suspended. Both countries - at least for the moment - are not part of the Euratom treaty which governs access to EUROfusion. A recent workaround has been found, not totally satisfactory, but offering at least a partial solution. It is not ideal, because for instance now these members do not have a vote in EUROfusion's decision making body. But researchers can still contribute to EUROfusion's research activities: the work can go on. (https://actu.epfl.ch/news/how-switzerland-and-the-uk-stayed-part-of-eurofusi/)

Physik Anekdoten und persönliche Erinnerungen (24)

Datenverschlüsselung: Von Bürgis Logarithmus zur digitalen Enigma

Bernhard Braunecker

Die SPG beteiligt sich alljährlich organisatorisch an den Jost Bürgi Symposien in Lichtensteig im Kanton St. Gallen, dem Geburtsort Bürgis (1552 – 1632). Man entdeckt im Laufe der Jahre immer mehr erstaunliche Eigenschaften dieses Zeitgenossen von Johannes Kepler und Tycho Brahe, mit denen Bürgi um 1600 herum in Prag zusammenarbeitete [1]. Im Gegensatz zu ihnen erlangte Bürgi nicht die historische Aufmerksamkeit, die er nach heutigem Wissen verdient hätte. So ist auch eine seiner Grosserfindungen, der Logarithmus, der heutigen Jugend kaum mehr geläufig; dies ganz anders als früher, als der Gebrauch von Rechenschiebern noch alltäglich war. In einem Referat am JB Symposium 2021 zeigten wir, dass dabei der Logarithmus höchst aktuell ist, da er sich bestens zur Verschlüsselung grosser Datenströme eignet. Allerdings muss man ihn mit Konzepten der Restklassenmathematik vereinen. Dann kann man das geniale Konzept der legendären Codiermaschine Enigma, bekannt aus dem 2. Weltkrieg, in neuer, nunmehr rein digitaler Form für schnelle und sichere Datencodierung im Alltag einsetzen [2].

Bei der mechanischen Ausführung der historischen Enigma zur Verschlüsselung von Texten aus einem Alphabet von 26 Grossbuchstaben wurden drei bis vier Codescheiben hintereinander auf einer gemeinsamen Drehachse eingebaut, wobei jede Scheibe an ihrer Vorder- und Hinterseite 26 im Uhrzeigersinn angeordnete Stromkontakte trug. Diese Kontakte waren in scheinbar zufälliger und geheim zu haltender Weise paarweise elektrisch miteinander verbunden. Drückte man eine der 26 Eingabetasten, wurde ein elektrisches Signal durch die Codescheibenanordnung geschickt und brachte eine der 26 Anzeigelampen zum Aufleuchten. Der Einbau und die Voreinstellung der Drehscheiben waren zeitraubend und gerade in kritischen Situationen fehleranfällig, hingegen erfolgte die eigentliche Verschlüsselung eines Zeichens sehr schnell und sehr sicher. Die allerdings grosse inhärente Schwäche, dass die mechanischen Einstellparameter der zu synchronisierenden Enigmas auf beiden Seiten in unverschlüsselter Papierform mitgeführt werden mussten, führte in der Folge jedoch zur Abkehr von der an und für sich leistungsstarken Verschlüsselungsmethode.

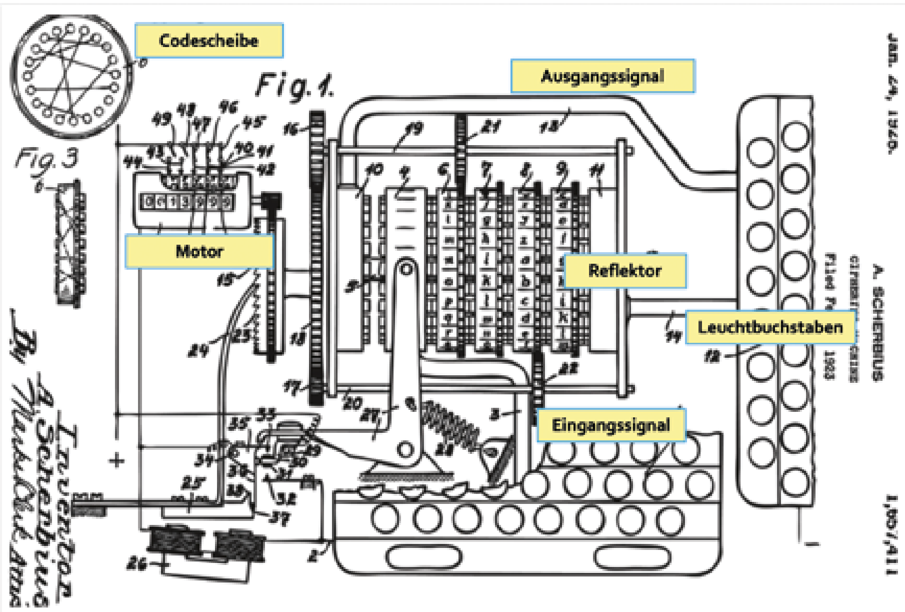
In digitaler Form ersetzt man die Drehscheibenverdrahtung durch Permutationsvektoren des gewählten Alphabets, und die nach jeder Zeicheneingabe vorzunehmenden Codescheibendrehungen durch entsprechende mathematische Shift-Operationen. Die sich ergebenden Permutationsvektoren der Gesamtanordnung kann man nun für eine gewisse Anzahl an Zeicheneingaben vorausberechnen und in einer Look-Up Tabelle LUT ablegen, so dass die anschliessend vorzunehmende eigentliche Verschlüsselung eines Textes oder einer Datenmenge ohne grossen Rechenaufwand sehr schnell, also mit der Taktfrequenz des Prozessors innerhalb von Bruchteilen von Mikrosekunden ablaufen kann.

Das erwähnte Risiko bei der Synchronisierung der Einstellparameter kann man in der digitalen Form eliminieren, indem für jeden Einstellparameter jede Seite eine zufällige und nur ihr allein bekannte Geheimzahl wählt. Diese Geheimzahlen werden mit Hilfe der Restklassenmathematik in neue Zahlen umgewandelt, die öffentlich übertragen werden können. Beide Parteien können aus ihnen mittels ihrer Geheimzahlen dieselbe Einstellzahl extrahieren, während dies für den unbefugten Lauscher praktisch unmöglich ist. Sie wissen also vorab bei der Wahl ihrer spontanen Geheimzahlen nicht, welche Einstellwerte sich ergeben werden; sie wissen nur, dass sie beide dieselben Werte erhalten werden. Das wird im zitierten Bericht ausführlich erläutert und mit Beispielen belegt.

Man kann also parallel zur momentanen Datenübertragung in Bruchteilen von Sekunden die nächste virtuelle Einstellung beider Enigmas, also die Anzahl der Codescheiben, deren Codierung, ihre Drehwinkelvoreinstellungen und die Grösse der Winkelschritte durch Austausch von nur wenigen und spontan gewählten Geheimzahlen ändern, und kann somit bereits die Look-Up Tabelle für das nächste Datenpaket vorbereiten. Vor diesem Feuerwerk an permanenten Änderungen wird im Alltag der genervte Lauscher schnell kapitulieren.

Beispiel einer digitalen Enigma

Sie soll Texte aus einem Alphabet von 127 alphanumerischen Zeichen verschlüsseln. Die Enigma bestehe aus



Enigma Patent 1923. Bild: Gemeinfrei

1 siehe den Artikel von Peter Ullrich in den *SPG Mitteilungen* Nr. 65, Seite 14.

2 https://www.jostbuergi.com/bibliothek/mathematik/

10 virtuellen Drehscheiben und einer Reflektorscheibe. Die Textcodierung erfolgt somit im doppelten Durchgang wie bei der klassischen Enigma. Man benötigt zur Erzeugung des Permutationsvektors einer Drehscheibe in unserem Fall 7 Geheimzahlen. Hinzu kommen zwei weitere Zahlen für die Drehwinkelvoreinstellung und die Winkelschrittweite. Bei 10 Scheiben inklusive des nicht-rotierenden Reflektors müssten somit lediglich 97 Geheimzahlen auf jeder Seite generiert und öffentlich übertragen werden. Damit wird der erste Permutationsvektor der Länge 127 der LUT erzeugt. Die weiteren LUT Zeilen ergeben sich durch die individuell verschiedenen, aber beiden Seiten bekannten Rotationen der 10 Codescheiben. Die Spaltenlänge der LUT ist frei wählbar.

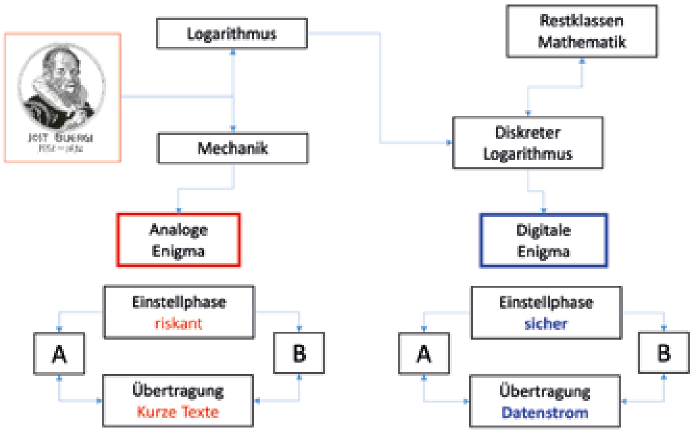
Es soll folgender Probetext verschlüsselt werden: ABC:0123456789?XYZ! In unserem Beispiel ergab sich als erste Zeile der LUT der Permutationsvektor als

22	3	2	64	51	93	16	41	92	40
100	105	74	84	82	7	121	57	115	101
43	1	68	76	45	69	107	116	98	65
49	62	96	114	113	53	77	94	124	10
8	104	21	50	25	81	56	97	31	44
5	125	36	70	95	47	18	120	80	110
75	32	123	4	30	117	111	23	26	54
109	118	78	13	61	24	37	73	106	59
46	15	90	14	89	119	103	112	85	83
126	9	6	38	55	33	48	29	99	11
20	127	87	42	12	79	27	122	71	60
67	88	35	34	19	28	66	72	86	58
17	108	63	39	52	91	102			

Das erste Zeichen im Probetext, der Buchstabe A ist in unserem Alphabet als Nr. 34 indiziert und man entnimmt dem Vektor an dieser Stelle den Index 114, also das Zeichen '. Wegen des Reflektors muss an der Stelle 114 der Index 34 stehen. Die zweite Zeile der LUT ergab sich als

5	61	25	110	1	84	72	23	48	26
16	82	88	41	34	11	117	69	121	68
106	118	8	78	3	10	105	38	58	115
32	31	55	15	119	57	104	28	50	59
14	98	53	124	101	97	108	9	116	39
90	66	43	103	33	123	36	29	40	81
2	112	86	127	74	52	70	20	18	67
71	7	125	65	122	93	109	24	111	95
60	12	92	6	126	63	99	13	102	51
96	83	76	120	80	91	46	42	87	114
45	89	54	37	27	21	113	47	77	4
79	62	107	100	30	49	17	22	35	94
19	75	56	44	73	85	64			

Für das zweite Zeichen im Probetext, den Buchstaben B, der im Alphabet als Nr. 35 indiziert ist, findet man den Index 119, also das Zeichen - und umgekehrt.



Für die 19 Zeichen des Probetextes ergaben sich dann aus den ersten 19 Zeilenvektoren der LUT die Verschlüsselungsindizes

114	119	117	32	74	120	115	106	82	66
97	35	20	91	85	120	13	79	54	

was der zu übertragenden Buchstabenfolge '-"?i–'‰qa€B3zt–,nU entspräche. Es mag verwirren, dass das Zeichen – (Alphabet Index 120) zweimal im codierten Text vorkommt (an den Stellen 6 und 16), einmal als Verschlüsselung des Zeichens 1 und dann des Zeichens X. Dies ist eine Folge der Drehscheibenrotation. Es wäre sogar denkbar, wenn auch unwahrscheinlich, dass die codierte Botschaft nur aus lauter gleichen Symbolen bestehen würde.

Das Gebiet der modernen Datenverschlüsselung dürfte junge Leute sehr interessieren, da sie nicht nur wie bislang defensiv, also zum Schutz von Informationen eingesetzt werden kann, sondern sie sich auch proaktiv für neue Geschäftsmodelle wie *Geo-Fencing* anbietet [3]. Die Enigma Grundidee der intelligenten Voreinstellung, der permanenten Codeveränderung und der schnellen eigentlichen Datenverschlüsselung wird auch bei der digitalen Version beibehalten. Der Ersatz der Mechanik durch Mikroprozessoren erlaubt problemlos eine nach Belieben wählbare Verschlüsselungssicherheit, so dass sich in der Alltagspraxis der Aufwand zur Entschlüsselung meist nicht lohnt.

Hervorzuheben sei noch das soziale Moment dieser Art der Verschlüsselung, denn sie erfordert den permanenten Informationsaustausch und Datenabgleich zwischen beiden Parteien im gegenseitigen Benehmen. Dieser moralische Aspekt zusammen mit der technischen Herausforderung bei der Programmierung macht das Thema einer digitalen Enigma ideal für Maturaarbeiten.

3 *Geo-Fencing*: Der Betrieb einer geleasten Bau- oder Landwirtschaftsmaschine erfolgt innerhalb eines Areals, dessen Grenzkoordinaten mittels Satellitennavigation bestimmt und der online verbundenen Zentrale übermittelt werden. Diese schätzt die zu erwartenden Betriebskosten ab und schaltet die Software frei, wenn der Kunde den Betrag akzeptiert. Es ist verständlich, dass der subtile Datenaustausch zwischen der Zentrale und den Maschinen vor Missbrauch geschützt werden muss.

Physik Anekdoten und persönliche Erinnerungen (25)

Erinnerungen an die Villa Vesta in Zürich 1963 – 1970

Claudio Palmy, Igis-Landquart

Die Villa Vesta an der Physikstrasse 7 stand unmittelbar hinter dem ab 1953 benutzten Paul-Scherrer Hörsaal an der Gloriastrasse 35. Die ETH war bestrebt, Bauland in der Nähe ihrer Liegenschaften zu kaufen und erwarb deshalb unter anderen auch die Villa Vesta. Das Haus wurde zunächst dem Laboratorium für Kalorische Apparate und Kältetechnik zugeteilt (Prof. Peter Grassmann (1907-1994)). Später kam auch die Forschungsgruppe von Prof. Georg Busch (1908 - 2000) dazu. Im Keller der Villa Vesta hat 1952 der damals als wissenschaftlicher Mitarbeiter angestellte Dr. Jörgen Lykke Olsen (1923 - 2006) erstmals Helium verflüssigt. Damit wurde Supraleitungsphysik in Zürich möglich [1, 2].

Nachdem der theoretische Physiker Heinz Fröhlich (1907 - 1970) die Supraleitung als Folge der Wechselwirkung zwischen Elektronen und Gitterschwingungen vermutete, schlugen er und Wolfgang Pauli (1900 - 1958) Experimente vor, die Volumeneffekte beim Phasenübergang zum supraleitenden Zustand zeigen müssten.

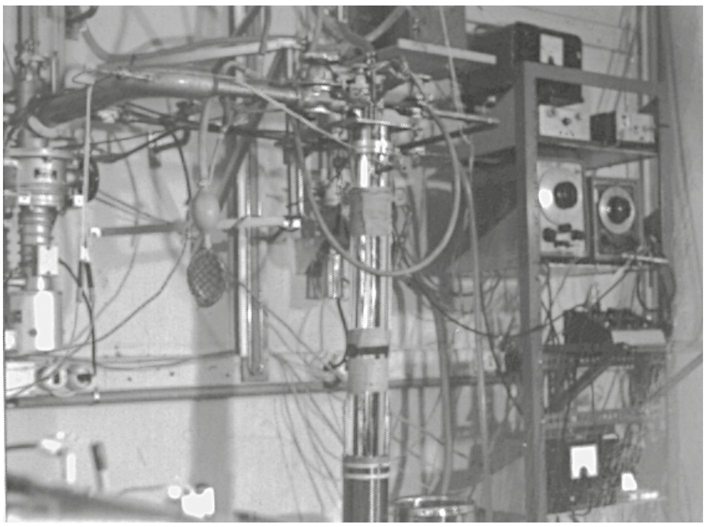
Die Villa Vesta, das „ Heliumlabor", kurz bevor es 1970 abgerissen wurde. Davor stand der um 1965 erbaute Physik-Pavillon, damals auch „Baracke" genannt.

Ich kam erstmals Ende 1963 in die Villa Vesta. Zu meiner grossen Freude erhielt ich einen Arbeitsplatz in der Tieftemperaturgruppe von J. L. Olsen. Mein Auftrag war, einen He-3 Kryostaten zu bauen, um damit Druckeffekte an Supraleitern zu untersuchen. Die Aufgabe faszinierte mich, obschon praktisches Können und theoretisches Wissen erst erworben werden mussten. Die Anstellung als Praktikumsassistent erlaubte aber eine langjährige Promotionszeit.

Einer von Olsens ersten Doktoranden war Heinrich Rohrer (1933 - 2013). Er hatte eine sehr empfindliche Apparatur gebaut und konnte Längenunterschiede zwischen normal- und supraleitenden Stäbchen der Grössenordnung $\Delta l/l = 10^{-6}$ messen [3]. Tagsüber waren die Messungen nicht möglich, weil die terrestrischen Erschütterungen des Trams in der Gloriastrasse zu heftig waren. Also blieb nur die Nacht nach 24.00 Uhr. Dann war die Längenänderung sichtbar, aber der ganze Messvorgang mit einem Spiegelgalvanometer zeigte eine merkwürdig überlagerte Schwingung von 0.3 - 1 Hz. Nach weiteren Nächten und Diskussionen in der morgendlichen Kaffeerunde wurde der Effekt geklärt: Die vom Wind bewegte Tanne vor dem Haus führte zur Schwingung der Villa und damit auch der Messanordnung. Nach seiner Promotion über „Druck- und Volumeneffekte in der Supraleitung" verliess H. Rohrer die ETHZ in Richtung Rutgers University. Was aber in der Gruppe weiterlebte, waren Geschichten zur Messtechnik, zur Vertrauenswürdigkeit der beobachteten Effekte und ihrer Interpretation.

Anfänglich war die Villa nicht im ganzen Umfang für die Physiker zugänglich. Die Besitzerin, eine ältere Dame, hat die Villa Vesta an die ETH verkauft, mit der Bedingung, die oberste Wohnung weiterhin bewohnen zu dürfen. Als sie dann das Rattern des He-Verflüssigers im Keller wahrnahm, fragte sie die in den unteren Stockwerken arbeitenden Physiker, ob diese Maschine gefährlich sei. Die Antwort lautete: Ja, sie kann jederzeit explodieren. Daraufhin verliess die Dame das Haus. Fortan beherbergte es in allen Räumen physikalische Apparaturen.

Im Keller stand der Collins He-Verflüssiger und eine mechanische Werkstatt. Im Parterre arbeiteten Jean Müller (1929 - 2012), später Professor in Genf und Ernst Bucher (*1934), später Ordinarius für Festkörperphysik an der Universität Konstanz. Im ersten Stock hatte J. L. Olsen sein Büro und sein Labor. Daneben war ein Zimmer mit Platz für zwei Doktoranden, nämlich für René Fasel und für mich. Im zweiten Stock hatten Peter Wyder (*1934), später Ordinarius an der Radboud University in Nijmegen und Piero Cotti (1931 - 2015) ihre Dissertationen eben abgeschlossen.



Der He-3 Kryostat (ohne Dewargefässe) ermöglichte Druckexperimente im Temperaturbereich bis zu 0.4 K.

Um 1963 wurden in der Villa Vesta die ersten Druckexperimente an Supraleitern mit einer Druckbombe (Klammer-Technik) möglich. Die dabei benutzten Berylliumbronze und Wolframcarbide erzeugten Drücke von bis zu 3×10^9 Pascal (30 kbar). Damit wurden Druckexperimente an diversen Elementen und an einem α-Uran Einkristall gemessen. Beim α-Uran wurde ein Anstieg von T_c unter moderatem Druck von 0.4 K auf 1.7 K beobachtet [4].

Olsen erzeugte mit dieser Technik 1964 eine supraleitende Phase des Halbleiters Tellur [5]. Zum ersten Mal wurde ein Element der 6. Spalte des Periodensystems supraleitend. Er notierte damals: Diese Beobachtung unterstützt die Ansicht, wonach Supraleitung ein generelles Phänomen ist.

Prof. J. L. Olsen und seine Frau Marianne, am Abschiedsfest der „Baracke".

Dieser Vorschlag, nennen wir es die "Olsen Regel", wurde ungefähr 20 Jahre später bestätigt, als J. Georg Bednoz (*1950) und K. Alex Müller (*1927) im Jahr 1986 den ersten Hochtemperatursupraleiter im IBM Forschungslabor in Rüschlikon entdeckten [6]. Die Entdeckung wurde 1987 mit dem Nobelpreis in Physik geehrt.

Alex Müller war einer der ersten Abnehmer von flüssigem Helium in der Villa Vesta, als er noch an der Gloriastrasse 35 experimentierte. Das keramische Material $La_{2-x}Ba_xCuO_4$ zeigte eine Übergangstemperatur von ungefähr 30 K, eine spektakuläre Steigerung und ein Meilenstein zur damaligen Zeit. Dies war besonders der Fall, weil Keramiken im Wesentlichen Isolatoren sind, obwohl einige wenige Oxide als gute Leiter bekannt sind, z.B. Bleioxid, Rutheniumdioxid, Wismutruthenat, oder das transparente Indium-Zinnoxid ITO. Einige stellten sich sogar bei niedrigen Temperaturen als supraleitend heraus, wie unter anderem das Spinel LTO, das in den frühen 1970ern mit T_c = 11 K [7] entdeckt wurde.

Das Tieftemperatur-Labor Villa Vesta war attraktiv für junge Physiker und das Haus wurde abermals zu eng. Deshalb wurde für die Übergangszeit bis zum Bezug der Hönggerberg-Laboratorien um 1965, ein Provisorium (Pavillon) gebaut. Wir nannten es die „Baracke". Sie wurde 1970 entfernt. Es gab ein feierliches Abschiedsfest, die Bilder auf dieser Seite stammen von diesem Anlass.

Rückblickend entsprangen damals auch in Zürich wissenschaftliche Wurzeln, die in späteren Jahren als Spuren einer spektakulären Entwicklung im Bereich der Hochtemperatur-Supraleitung, bis hin zur Zimmertemperatur-Supraleitung, geortet werden können. Die Schweizer Supraleiterphysik gründet ausschliesslich auf ehemaligen Mitarbeitern der Villa Vesta. Hans Rudolf Ott (*1940), emeritierter ordentlicher Professor für Physik an der ETHZ, sowie Piero Martinoli (*1941), Physikprofessor in Neuchâtel und emeritierter Direttore dell' Università della Svizzera Italiana in Lugano, haben dort erstmals mit Supraleitung experimentiert.

Piero Martinoli und seine Frau Carla.

Einer der Schritte zu höheren Übergangstemperaturen T_c wurde 1993 von Andreas Schilling et al. [8] am Institut für Festkörperphysik der ETH auf dem Hönggerberg gemacht. Das Quecksilber-, Barium- und Kalzium-basierte Kuprat $HgBa_2Ca_2Cu_3O_{8+x}$ (Hg-1223) ist immer noch eines der Materialen mit der höchsten Übergangstemperatur bei Umgebungsdruck von etwa 133 K. Neuere Entwicklungen wurden 2021 in einem Artikel in den *SPG Mitteilungen* beschrieben [9]. Im Jahr 2015 wurde Hochtemperatursupraleitung in Hydridverbindungen bei Anwendung eines hohen hydrostatischen Drucks entdeckt. Dies führte zu zahlreichen neuen Studien. Kürzlich wurden an der University of Rochester, New York von einem Team um Elliot Snider et al. [11] erfolgreich Experimente mit einem photochemisch umgewandelten kohlenstoffhaltigen Schwefelhydrid-System realisiert, welche zu Supraleitung bei Raumtemperatur (ca. 15°C) in einer Diamantamboss-Zelle bei über 220 GPa führten.

Das Sprichwort sagt: "Erfolg hat viele Väter", es ist jedoch ebenfalls wahr, dass Erfolg die Summe kleiner Anstrengungen ist. In diesem Sinn war die ursprüngliche Grundlagenforschung zur Supraleitung in Zürich ein kleiner Beitrag zu einem wissenschaftlichen Ziel, welches zu jener Zeit für unerreichbar gehalten wurde.

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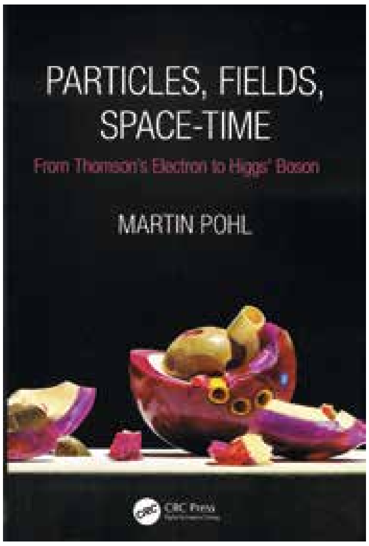
Bücherecke - Le coin aux livres - Book Corner

Martin Pohl

Particles, fields, space-time: From Thomson's electron to Higgs' boson

CRC Press, ISBN 978-0-367-34723-9



Target readership

This book is neither a popular account of particle physics, nor it is a textbook in the field. Rather, the intended readership is defined by the author as “someone who has a background in physics, at least in classical physics”, maybe “has not followed particle physics for a while” and “is looking for input in his or her own teaching at whatever level, or just for intellectual stimulus”. Much of this is true for many colleagues and students in physics (the author of this review fulfils every criterion of the target readership).

Another key feature of the book emphasized by the author is that it strongly takes historical background into account, due to his shared experience that this may increase “student interest by giving a human touch to an otherwise rather abstract matter”. In fact, there is more to say about this historical stance, to which I will return below.

To begin with...

To start with a conclusion, the book has fulfilled its objectives in an impressive way, both by breadth (scope) and by depth.

As for breadth, “From Thomson's electron to Higgs' boson” in the book’s title already gives a good hint – the incredible development that our understanding of the microscopic structure of matter has seen in little more than a century. Ten chapters lead the reader from “The first particles” to “Pushing the boundaries” (about particle astrophysics), including background in classical physics, relativity, quantum physics, atoms and nuclei, quantum fields, and chapter 9 on the standard model, the main piece of the book. This is completed by chapters on “War time physics” and on “Enabling technologies”. For the reader’s convenience, this wealth of knowledge is made accessible by a 14-page index.

Regarding depth, or quality of insight, the book has a twofold structure with a mainly conceptual and historical main text, and almost 80 focus boxes providing more “technical” background, most often on a more advanced mathematical level. Throughout the book, Martin Pohl succeeds in providing deep insight also on the conceptual level, a main achievement of his book in particular in view of an interested, but non-specialist readership, or of colleagues in search of insightful explanations for their teaching. He quotes one of his academic teachers who said that “*the truth is in the formulae, not in the blabla*”. Others would maintain that his teacher was not completely right, e.g. Werner Heisenberg, saying that “*even for the physicist the description in plain language will be a criterion of the degree of understanding that has been reached*” [1], or P. W. Andersons statement that “*even in theoretical physics most of the great advances have been conceptual rather than mathematical*” [2]. Luckily for his readers, Martin Pohl has not followed his teacher’s advice on that matter.

Some highlights

In the following, I give some examples of the topics I found particularly interesting or illuminating in the different parts of the book:

- In the introductory and background chapters, the “tree diagram” of a “reductionist view of the development of particle physics”, as Martin Pohl calls his position, or the many cases he discusses where advances in craftsmanship and technology laid the ground for discoveries in physics (e.g. glass blowing and vacuum pumps for cathode ray tubes in the second half of the 19th century).
- In chapter 9 on the standard model, the very clear and, at the same time, short account of the development of electroweak theory, in particular of the Wu parity violation experiment and more generally of the symmetry violations by the weak interaction (indeed useful for teaching purposes), as well as a mainly conceptual but thorough treatment of the main elements of strong interaction theory (self-interaction, running coupling constant, asymptotic freedom, confinement, hadronization, etc.).
- In the “outlook” chapter 10, e.g. the discussion of the Hillas diagram for classifying sources of high-energy cosmic rays according to their size *R* and magnetic field *B* (based on the Larmor radius, making accessible a topic of current particle astrophysics even at a high-school level), and in general the fascinating extension of accelerator particle physics to cosmic ray observatories and the Alpha Magnetic Spectrometer (AMS) on the ISS.
- Many interesting historical considerations and excursions within the individual chapters, e.g. about Bruno Pontecorvo, his contributions to neutrino physics, and his “somewhat mysterious” life as a communist and spy for the Soviet Union. Another interesting example concerns the Gargamelle experiment, which in 1973 provided evidence for neutrino elastic scattering of the type $\nu_\mu e^- \rightarrow \nu_\mu e^-$, as predicted by electroweak theory. Pohl emphasizes that “[t]o filter such rare events out of the many thousand (mostly empty!) bubble chamber pictures is an impressive achievement” and gives the names of the all-female team who achieved this feat (which the original publication doesn’t). The acknowledgement of the too long neglected work of women in science, at this and other places in the book, makes with its sober matter-of-factness a quite convincing impact.
- To the historical perspective the entire chapter devoted to “War time physics” adds the description of a kind of historical turning point, which was scientifically extremely prolific – whether you want it or not – and politically decisive for today’s world.
- Last but not least, the entire chapter on “Enabling technologies”, putting the focus on their interplay with dis-

covery and progress in physics as mentioned above, starting from pioneering work on cosmic rays, through extended and insightful treatment of detector and accelerator physics, to failed projects, which are also historically most interesting.

Of course, the above perspective is completely personal, and tainted by not being a specialist (as intended by the author). Moreover, I am working in physics education and physics teacher education, and thus in some way responsible for the "next generation" of physics students and – hopefully – interested laypeople. This has clearly had some influence on the perspective I have taken towards the book and the selection of smaller and larger "gems" I found within it. Analogously, this applies also to the next paragraph.

Some points to discuss, minor improvements, and 1½ points of gentle disagreement

A few points that might merit re-consideration are to be mentioned. A minor question is why the term 'confinement' appears nowhere; if there is a reason for this, it would be interesting to know it. Then, the very clear focus box 9.17 on the cross section of the e^-e^+ annihilation into hadrons could be completed by the famous graph showing the "jumps" of the cross-section at the thresholds given by the quark masses, a graph that has several educational merits: a reasoning accessible to high school students, but going right to the heart of the standard model; an example of a "precision test" of the model; and an example of the impressive collective gathering of data in the international community of physicists [3; fig. 52.2]. The following point might help to better follow the book's line of thought: The notions of decay width, peaks and resonances appear as early as on p. 139, then at several other places, but are only properly introduced in box 9.12 on p. 204; this box should be moved to sect. 7.3 (alongside box 7.7 on decay widths), where cross-sections and decay widths are introduced as main observables for the square of the invariant amplitude.

I turn to my very few points of disagreement with the book. The first ½ point concerns the author's view on the history of science, which he says has often bored him, as "who exactly published what detail first" is not really interesting. Truly so, but I think this perception does not really do justice to the history of science as it is practised today. Rather, it is about the evolution, revolutions and interactions of scientific thought and their driving forces, in some sense the "dynamics", not just the "kinematic record" of the history of science, exactly in the way of the historical aspects treated in Martin Pohl's book, and this *is* interesting. In fact, it is also illuminating and can be helpful for the understanding of scientific content, not only for motivation (see e.g. [4]). If researchers in this field base their conclusions on meticulous validation of historical data and facts, this should appear to physicists as being rather akin to their own approach.

The other point of respectful disagreement is on the use of the so-called "natural units" $\hbar = c = 1$ etc. While it is clear that this is very convenient for experts, there are three objections to this: First, an expository text should be oriented towards the convenience of the reader (learner), not the convenience of the author (expert). Second, learners lose a powerful method of error checking and of order-of-magnitude reasoning [5], as illustrated e.g. in the marvellous "Search for Simplicity" series by Victor Weisskopf [6]. These faculties are even more important in a new, unfamiliar field. It is difficult enough to train students for them, so an educational text should support rather than hamper their development. Third, the educational potential of dimensional considerations is replaced by an opaque assertion. A physical quantity is given by the product of a number and a unit [7]; changing the unit changes the number but does not make the whole product disappear. So, what the so-called "choice of natural units" in terms of natural constants actually does is to set the numbers to 1 *and* supress the units, which amounts to suppressing the constants altogether [8,9].

By way of conclusion

Beyond its depth, breadth and inclusion of historical aspects, there is another key feature of the book I found very interesting: the very close treatment of experiments, alongside with the theory *and* the technology behind them. This reminds me of the great "classic" by a E. Bodenstedt on "Experiments in nuclear (and particle) physics and their interpretation" [10], a reference work in the area during the studies of this reader; in some sense the book by Martin Pohl is a modern exemplar in the same insightful style on "Experiments in Particle Physics and their Interpretation *and* Technology".

Coming back to its broad scope, "Particles, fields, spacetime: From Thomson's electron to Higgs' boson" contains a very stimulating bibliography of almost 700 references, including pioneering papers, reviews, popular, historical, philosophical and political accounts, and more – one sees how a lifetime of thought has gone into the book.

And finally, a figure of thought I liked very much: the large parenthesis between the reductionist credo in ch. 1 and a pensive quote by Freeman Dyson with which the book ends: "*A reductionist philosophy, arbitrarily proclaiming that the growth of understanding must go only in one direction, makes no scientific sense. Indeed, dogmatic philosophical beliefs of any kind have no place in science.*"

Andreas Müller, Université de Genève

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[8] Desloge, E. A. (1984). Suppression and restoration of constants in physical equations," *Am. J. Phys.* **52**(4), 312-315.
[9] In fact, what is really behind "$\hbar = c = 1$" can be put in clear terms, and it is something *different* from a mere choice of units [8]; interestingly the underlying mathematical structure is that of a vector space which can even be used to turn an opaque, ill-formulated procedure into an interesting exercise for students; Maksymowicz, A. (1976). Natural units via linear algebra. *Am. J. Physics* **44**(3), 295-297; Ansmann, G. (2015). Natural units and the vector space of physical values. *Eur. J. Physics*, **36**(3), 035008.
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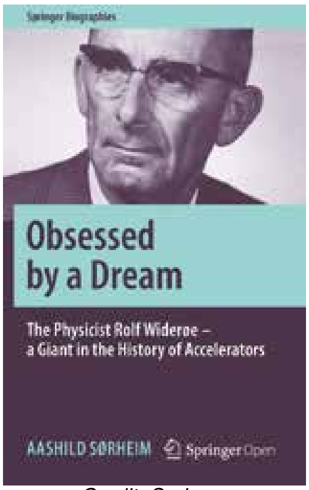
Aashild Sørheim

Obsessed by a Dream: The Physicist Rolf Widerøe – A Giant in the History of Accelerators

Springer, ISBN 978-3-030-26340-9

The betatron is an early type of MeV-range electron accelerator which uses the electric field induced by a varying magnetic field to accelerate electrons, or beta particles. It operates like a transformer with the secondary winding replaced by a beam of electrons circulating in a vacuum tube. It was invented by pioneering Norwegian accelerator physicist Rolf Widerøe when a student in 1925. Since the construction failed at the time, he had to find another theme for his thesis, and so in 1927 he constructed the first linear accelerator (50 keV), before later proposing the principle of colliding beams to fully exploit the energy of accelerated particles. Through these innovations, Rolf Widerøe decisively influenced the course of high-energy physics, with betatrons shaping the landscape in the early days, and linear accelerators and colliding beams becoming indispensable tools today.



Credit: Springer

Aashild Sørheim, a professional writer, now presents a new biography of this visionary engineer, who had a seminal impact on accelerator physics. Her book covers Widerøe's whole life, from 1902 to 1996, and from his childhood in a well-to-do family in Oslo to his retirement in Switzerland. Certainly, many who read Pedro Waloscheck's 1994 biography, *The Infancy of Particle Accelerators: Life and Work of Rolf Widerøe*, will be curious how this new book will complement the former. Sørheim's new offering is based on new documentary evidence, the result of painstaking sifting through archives, and a large number of interviews. She has opened new perspectives through her interviews, and the access she has gained in several countries to hitherto restricted archives has provided a wealth of new material and insights, in particular in relation to the second world war. Sørheim's book focuses not on physics or technology, but on Widerøe himself, and the social and political environment in which he had to find his way. In particular, it gravitates to the question of his motivation to work in Germany in the troubled years from 1943 to 1945, when he constructed a betatron, the accelerator he had invented two decades earlier while a student in Karlsruhe.

Occupied Oslo

In the most interesting parts, the book provides background information about the entanglement of science, industrial interests and armament, and in particular the possible reasons for the "recruitment" of Rolf Widerøe in occupied Oslo in the spring of 1943 by three German physicists mandated by the German air force. They insinuated that willingness to cooperate might well help to improve the conditions of his brother Viggo, who was in prison in Germany for helping Norwegians escape to England. The apparent motivation was that a powerful betatron could produce strong enough X-rays to neutralise allied bomber pilots. Though leading German scientists quickly discovered this to be nonsense, the betatron project was not interrupted. The book describes the difficult working conditions in Hamburg, and the progress towards a 15 MeV betatron. Among the key players was Widerøe's assistant Bruno Touschek, who was finally arrested by the Gestapo in 1945 as his mother was Jewish. It was during this time that Widerøe patented his idea to use colliding beams to maximise the energy available, against the advice of Touschek, who found the idea too trivial to publish. It was the Touschek though, who in 1961 first used this principle in ADA, the e^+e^- ring in Frascati which was the first collider of the world.

Post-war Period

After Widerøe's return to Oslo in March 1945, when the betatron was operational and the advancing English army made a study of a 200 MeV betatron illusionary, he faced official prosecution on the ludicrous main charge of having helped develop V2 rockets, explains Sørheim. Released from prison after 47 days, he got away without trial, but had to pay a substantial fine. Unemployed, seeing no basis for pursuing his dream of further developing betatrons in his home country, and with the stigma of a collaborator in the understandably overheated atmosphere of the time, he moved his family to Switzerland in 1946. One chapter, strangely put near the beginning of the book, describes how Widerøe then became a successful leader of the betatron production at Brown-Boveri in Switzerland, a respected lecturer at the ETH in Zurich and a promoter of radiation therapy until late into his retirement. He was a CERN consultant in the early days, and worked with Odd Dahl and Frank Goward in Brookhaven 1952 where they became acquainted with the alternating-gradient focusing principle which was then boldly proposed to the CERN Council as basis for the design of the 25 GeV Proton Synchrotron.

The book leaves the reader somehow overwhelmed by the amount of material presented, the non-chronological presentation, and the many repetitions of the same facts, conveying the impression that the author had difficulty in putting the information in a coherent order. However, the many interviews and new documentary evidence, including a hitherto unknown letter from his brother Viggo, open novel perspectives on this extraordinary engineer and scientist who, besides receiving many honours abroad, finally also received recognition in his home country, after a lengthy reconciliation process.

Kurt Hübner, formerly of CERN (now retired)

This text has been published first in the CERN Courier Volume 60 Number 3, May / June 2020, p. 53. We are thankful for the reprint permission.

An article on Widerøe appeared in the SPG Mitteilungen Nr. 35: https://www.sps.ch/artikel/physik-anekdoten/rolf-wideroee-und-das-betatron-13

Maison d’Ampère - EPS Historic Site 2021 in France with a Swiss connection

Hans Peter Beck

The **Maison d'Ampère** (*http://amperemusee.fr*) in Poleymieux-au-Mont-d'Or received on 9 October 2021 the "EPS Historic Site" award from the European Physical Society (Figure 1). With this recognition, France and Switzerland have now each five distinct sites, showing significant places for the development of modern physics.

Figure 1: Aerial view of the Maison d’Ampère in Poleymieux-au-Mont-d'Or. (© Wikipedia)

André-Marie Ampère was born in Lyon on 20 January 1775 and spent his youth in Poleymieux-au-Mont-d'Or, 13 km outside Lyon, which houses today the Ampère museum.
Ampère, founder of electrodynamics, who also coined the term ‘solenoid’ and was first formulating the well-known right-hand rule, did not work in isolation but exchanged a lot with physicists of his time. From an entirely Swiss point of view, Gaspard de la Rive and his son August de la Rive, who were both professors at the University of Geneva are to mention here. Ampère visited Geneva several times and experimental setups have resulted out of these exchanges of which some can now be seen at the Ampère museum (Figure 2).

Figure 2: Experimental setup where an electric current flows through a conductor. The magnetic field lines were measured using magnetized needles at various distances to the non-uniform conductor. (Donation of the University of Geneva) (© HP Beck)

The award ceremony, to which the President of our Society was kindly invited to assist, started first in the morning at the Claude Bernard University in Lyon, where Serge Haroche (Nobel Prize 2012) fascinated a large audience of about 200 participants with a talk in French on «La lumière révélée, de la lunette de Galilée à l’étrangeté quantique» (Light revealed, from Galileo's telescope to quantum strangeness). After a served three-course lunch at the University, the ceremony continued in Poleymieux-au-Mont-d'Or, with a guided tour through the museum, showing life and work of Ampère. The exhibition doesn’t stop there and shows how the understanding of electrodynamics immediately was leading to applications, from early inventions to more modern devices.

The formal event of the unveiling of the plaque, where the mayor of Poleymieux-au-Mont-d'Or, Corinne Cardona, the director of the museum and president of the society of friends of André-Marie Ampère, Alfonso San Miguel, the president of the French physical society, Guy Wormser, and Serge Haroche assisted, and where all gave their short or long speeches, was a festive event, where about 80 persons were invited to.

It would not be French art of living if the event would not have been concluded with a catering service from a nearby traiteur, with good wine, cheeses of all kind and variations, charcuterie, and desserts.

Throughout the day, the European, the French and the Swiss collaborative and friendly spirit could be sensed, showing clearly that science advances then best when an open exchange of ideas, people and equipment is granted – unfortunately, this is not always a given.

Figure 3: The plaque was unveiled on 6 October by EPS President Luc Bergé (right) and Serge Haroche (Nobel Prize 2012).

6. Internationales Jost Bürgi Symposium

Das kommende Bürgi Symposium findet vom **29. bis 30. April 2022** in Lichtensteig im Kanton St. Gallen statt, dem Geburtsort Jost Bürgis (1552-1632).

Schwerpunkt des **Workshops** am Freitag ist diesmal eine Serie von Referaten zum Thema ***Historische Kartographie / Globenkunde***, organisiert von Jost Schmid-Lanter, Leiter Abteilung Karten und Panoramen der Zentralbibliothek Zürich und von Raoul DuBois, Universität Zürich.

Der Kartograf und Globenhersteller Gerhard Mercator (1512-1594) im Alter von 62 Jahren; Kupferstich von Frans Hogenberg. Bild: Gemeinfrei

Das 16. Jahrhundert war eine Zeit grosser wissenschaftlicher Veränderungen. Berichte über neu entdeckte geographische Räume, aber auch neue Erkenntnisse und Entdeckungen in den Naturwissenschaften, namentlich in der Astronomie, stellten althergebrachte Vorstellungen und das bisherige Weltbild in Frage. Ebenso wurden die Messungen und Methoden immer besser, infolgedessen entstanden im 16. Jahrhunderts die ersten modernen Weltkarten und Atlanten.

Beim **Zukunftsforum** am Samstag steht aus aktuellem Anlass der Umgang mit Krisen im Mittelpunkt. Ein Vortrag beschäftigt sich mit den Fragen: Wie entstehen Krisen und wie kann man die Schwierigkeiten bei der politischen Umsetzung vermindern, um nachhaltig Veränderungen zu erreichen? Ein zweiter Vortrag geht der Frage nach, wie man die jüngere Generation bereits in der Schule so vorbereiten kann, dass sie später mit Krisen besser zurechtkommen werden.

Anschliessend wird gezeigt, wie man aktuelle Krisen technisch lösen, beziehungsweise physikalisch so weit verstehen kann, dass sich Lösungsmöglichkeiten abzeichnen. Im ersten Fall wird von Dejan Šeatović (FHS OST, Rapperswil, SG) der kombinierte Einsatz von Drohnen, Bildverarbeitung und Robotern in der Landwirtschaft zur Reduzierung der Umweltbelastung bei der Unkrautbekämpfung beschrieben und auch demonstriert. Im zweiten Fall spricht Dominik Brunner (Empa) über CO_2 in der Atmosphäre als Treibhausgas, wie die Konzentration von der Erde aber auch von Satelliten aus gemessen werden kann, und wie schnell wir CO_2 reduzieren müssen, um die Ziele des Pariser Klimaabkommens zu erreichen.

Prototyp des Robotiksystems zur Bekämpfung von Unkraut auf landwirtschaftlichen Nutzflächen.

Sie finden auf der JB Webpage in den kommenden Wochen mehr Informationen zu den beiden Veranstaltungen.
https://www.jostbuergi.com/symposium/

B. Braunecker

Announcement EPS Forum 2022 – Save The Date

The European Physical Society organizes a first EPS Forum on the **2 - 4 June 2022** at the Sorbonne University International Conference Center in Paris. This is an international meeting of interest for all European researchers, PhD students and Post Docs who wish to be introduced to exciting research opportunities in large companies and start-ups and engage in a dialogue with representatives of the industry sector.

The EPS Forum will take place essentially on two days and include a series of conferences, roundtables and workshops on the following topics:

- Condensed matter physics: from quantum materials to additive manufacturing
- Energy and sustainability, transportation and technology
- Accelerators, high-energy particle physics, nuclear physics
- Quantum technologies and photonics
- Machine learning and artificial intelligence
- Biophysics, technological sequencing of proteins, pandemic, cancer treatments

Day 1 titled *Physics meets Industry*, will be dedicated to the employment of young physicists in Europe and favour direct exchanges with CEOs, managers and engineers of major industrial companies in these fields. Day 2 will address *scientific and societal challenges* facing the physics community, including latest achievements in physics presented by the most outstanding physicists, among them 3 Nobel laureates.

You can find more information on the programme and how to register to the event under https://epsforum.org/

Symposium

100 Years Nobel Prize for Albert Einstein

Saturday, 9 April 2022; 10:15 – 17:15

Universität Bern, Gebäude UniS, Lecture Hall S003
Schanzeneckstrasse 1, 3012 Bern

10:15 – 11:00	***Hans Rudolf Ott,*** ETH Zürich **100 Years ago: Nobel Prize for Physics goes to Albert Einstein**
11:00 – 11:30	***Jürg Osterwalder,*** Universität Zürich **From Einstein's explanation of the photoeffect to high-resolution spectroscopy of matter**
11:30 – 12:00	***Rachel Grange,*** ETH Zürich **Integrated devices for controlling light by electrons**
12:00 – 13:00	**Lunch**
13:00 – 13:45	***Klaus Hentschel,*** Universität Stuttgart **„Light quanta" – how was this concept & mental model understood since 1905?**
13:45 – 14:30	***Nicolas Gisin,*** Université de Genève **Single photons, entangled photon pairs and optimal cloning of Qubits**
14:30 – 15:15	***Ursula Keller,*** ETH Zürich **New frontier in physics: time in quantum mechanics**
15:15 – 15:45	**Coffee Break**
15:45 – 16:15	***Natalie Banerji,*** Universität Bern **From light to electricity: New materials in electronics**
16:15 – 16:45	***Thomas Feurer,*** Universität Bern **When the photoeffect becomes destructive: Lasers as tools in materials processing**
16:45 – 17:15	***Aldo Antognini,*** ETH Zürich und PSI Villigen **High-precision tests of QED**

Albert Einstein Gesellschaft

⟨S|P|S⟩ swiss physical society

scnat swiss academy of sciences

Free entrance, no registration needed *. Further information:
www.einstein-bern.ch, *www.sps.ch*, *www.scnat.ch*

* If a registration should be required due to COVID regulations, information will be availabe in due time on the web.

Time	SYMPOSIUM 100 YEARS NOBEL PRIZE FOR ALBERT EINSTEIN ABSTRACTS
10.15 – 11.00	**100 years ago: Nobel Prize for Physics goes to Albert Einstein** *Hans Rudolf Ott, ETH Zürich* Within a few months in the first half of the *annus mirabilis* 1905, Einstein submitted 3 articles to the Annalen der Physik. In retrospect each one of them had the quality to justify a nomination for the Nobel Prize in Physics, annually awarded by the Royal Swedish Academy since 1901. For various reasons it took more than 15 years until Einstein was chosen to be a recipient of this prestigious award. First, the scientific background of his light quantum hypothesis that resulted in the formulation of the *law of the photoelectric effect* for which he actually was honoured, is briefly reviewed. It is followed by remembering some of the highlights of his scientific career up to 1921. Considering the current flawless procedure of the prize reception, the circumstances under which he eventually received the insignia of the prize were quite unusual and deserve to be recalled. Finally some insight concerning the financial aspects of the prize and their impact on Einstein's private life will be provided.
11:00 – 11:30	**From Einstein's explanation of the photoeffect to high-resolution spectroscopy of matter** *Jürg Osterwalder, Universität Zürich* Experiments at the end of the 19th century showed that UV light can eject electrons from solid surfaces into vacuum. A puzzling observation was that the intensity of the light determines the number of emitted electrons but not their velocity. Einstein's revolutionary concept of light quanta solved this problem and allowed him to make predictions about the kinetic energy of the emitted electrons that were later confirmed experimentally by Millikan. While the first electron spectrometer was demonstrated as early as 1914, applications of photoelectron spectroscopy for studying electronic properties of matter began only in the second half of the 20th century. They evolved separately along two lines, x-ray photoelectron spectroscopy (XPS) for the study of core levels and ultraviolet photoelectron spectroscopy (UPS) for valence band studies. The former has developed into a widely used method for chemical surface analysis, while the latter has been extended into a most powerful method for the mapping of energy bands and the study of manybody effects in solids. The availability of new types of light sources and vast improvements of electron spectrometers have brought amazing progress in recent years. An overview will be given about the latest developments, including several variants of these spectroscopies.
11:30 - 12:00	**Integrated devices for controlling light by electrons** *Rachel Grange, ETH Zürich* Nonlinear and electro-optic devices are present in our daily life with many applications: light sources for eye surgery, green laser pointers, or modulators for telecommunication. They mainly use bulk materials such as glass fibres or crystals, hardly integrable due to low signal and difficult fabrication. Here I will show several strategies to enhance optical signals by engineering metal-oxides at the nanoscale with the goal of developing nonlinear and electro-optic photonics devices for a broad spectral range and over large surface area. We use metal-oxides such as barium titanate and lithium niobate as a platform for integrated photonics. I will present innovative fabrication approaches of metal-oxides materials that are very different from standard semiconductors or metals. Recently, we developed a waveguide Fourier transform spectrometer. We achieved a much broader bandwidth than typical commercial systems by using the electro-optic effect in lithium niobate. This concept of compact, broadband spectrometer without any moving parts is of interest for applications where flexibility and versatility are key, like in spaceborne spectroscopy, remote sensing or integration in mobile devices.
12:00 – 13:00	LUNCH
13:00 – 13:45	**"Light quanta" – how was this concept & mental model understood since 1905?** *Klaus Hentschel, Universität Stuttgart* What happened after Einstein published his paper on the photoelectric effect (the only one he ever called "revolutionary") in 1905? The early reception of his new concept of "light quanta" was highly critical, even from those who normally supported Einstein. For example, Planck who tried everything to minimize the conflict with classical electrodynamics, v. Laue or Lorentz who opposed light quanta with reference to interference phenomena indicating an extended, non-pointlike structure of light. Experimentalists such as Millikan or Compton had their own, misleadingly naïve understanding of light quanta as "light atoms" or "bullets" and the only supporter early on was Johannes Stark who later became Einstein's severest antisemitic critic. Einstein himself intensely searched for a clear understanding of what light quanta are. In 1951 he admitted that fifty years of searching had not brought him any closer to any deeper understanding. I will compare different mental models of light quanta since 1905, or "photons" as they have been usually called since 1926.
13:45 – 14:30	**Single photons, entangled photon pairs and optimal cloning of qubits** *Nicolas Gisin, Université de Genève* Single photons and entangled photon pairs are todays routinely produced in many labs all around the world. Both single-photons and entangled photon pairs can be used to violate some Bell inequality, thus demonstrating the non-local character of quantum physics that Einstein accused of "spooky action at a distance". Einstein was worried that quantum non-locality was, on the one hand side, reintroducing Newton's gravitation non-locality into physics, and, on the other side, allowing for arbitrarily fast signaling, hence violating his beloved relativity theory. Today, the quantum information community understands that these legitimate worries are circumvented by, first, the randomness of the outcomes of quantum measurements, i.e. by non-local randomness, and, secondly, by the impossibility of perfectly cloning quantum states. Interestingly, optimal quantum cloning lies precisely at the limit imposed by no signaling, i.e. no spooky action at a distance. Moreover, optimal quantum cloning relates exactly to Einstein's A and B coefficients of spontaneous and stimulated emissions. It would be fascinating to ask Einstein what he thinks of today's understanding of his worries and whether he would, today, accept quantum non-locality?

14:30 – 15:15	**New frontier in physics: time in quantum mechanics** *Ursula Keller, ETH Zürich* With progress towards ever shorter laser pulses we have developed many different pump-probe techniques to access fast dynamics with the time resolution approximately given by the duration of the laser pulse. With the discovery and understanding of high-harmonic generation (HHG) we were able to move into the attosecond domain. The orbital period of an electron in ground-state hydrogen in Bohr's model amounts to 150 as. The attosecond is therefore the typical time scale for electronic motion on an atomic scale in quantum mechanics. We have invented the attoclock as an alternative measurement technique with attosecond time resolution to address very fundamental questions in quantum mechanics such as tunneling time, time delays between electrons in double ionization, and momentum transfer to photoelectron in multi-photon ionization. For example quantum tunneling time is a highly debated topic – we explain why. We discuss the attoclock technique to extract tunneling delays with regards to the typical approximations such as the dipole approximation, non-adiabatic effects, photoelectron momenta at the tunnel exit, electron correlation and exit coordinate. We can confirm that the He attoclock measurement is in agreement with two theoretical predictions: the Larmor time, and the probability distribution of tunneling times constructed using a Feynman Path Integral (FPI) formulation. Still there is an ongoing debate and we are in the process of building up an attoclock experiment with atomic hydrogen.
15:15 – 15:45	**Coffee Break**
15:45 – 16:15	**From light to electricity: New materials in electronics** *Natalie Banerji, Universität Bern* Organic conjugated materials have many favourable properties that make them interesting for a variety of electronic applications. The aim of my group is to understand the fundamental processes underlying their functionality. We use ultrafast spectroscopic techniques, such as transient absorption (TA) and time-domain terahertz (TD-THz) spectroscopies, to investigate charge carriers in organic semiconductors. While femtosecond TA measurements bring insights to the nature and evolution of the photoexcited species, we use TD-THz spectroscopy to gain information about the charge transport properties on the nanoscale. After presenting an overview of our experimental techniques, I will show results about charge generation in highly efficient solar cell materials based on organic polymer:non-fullerene blends. The photophysical properties of doped organic semiconductors are then discussed, as well as their applications to bioelectronic devices such as organic electrochemical transistors (OECTs). Finally, ways to explore ultrafast spectroscopy to study such devices in situ are presented.
16:15 – 16:45	**When the photoeffect becomes destructive: Lasers as tools in material processing** *Thomas Feurer, Universität Bern* When light is incident on a metal surface, electrons are emitted from (or within) the material. This phenomenon is called external (or internal) photoelectric effect. The internal photoelectric effect is relevant for the working of solar panels, but in case of high power photon sources can become destructive and is used for material processing. The physical processes associated to the redistribution of the energy added to the material via the internal photoelectric effect are diverse and strongly correlated. For instance, light-matter interaction becomes nonlinear, heat conduction competes with a sequence of phase transitions, ultimately resulting in material ejection, and hydrodynamic instabilities in the liquid phase of the material strongly influence the quality of material processing. All of these processes happen on similar time scales and make a formal description difficult. During the talk I will elaborate on these phenomena and show that a clever combination of analytical and numerical models can correctly describe such processes, is in agreement with experiments, is accurate enough to guide process and machine design, and can be used to train machine learning algorithms.
16:45 – 17:15	**High precision tests of QED** *Aldo Antognini, ETH Zürich und PSI Villigen* Laser spectroscopy is a powerful technique that allows precise measurements of atomic transitions. In this talk we focus on laser spectroscopy of muonic atoms, hydrogen-like atomic systems formed by a negative muon and a nucleus. Because the muon mass is 200 times larger than the electron mass, the atomic wave-functions of muonic atoms are strongly overlapping with the nucleus. The resulting sensitivity of the 2S-2P energy splitting in muonic atoms to nuclear structure effects has been recently exploited to extract precise values of the proton, deuteron and He-nucleus charge radii. These radii serve as benchmarks for modern approaches to the internal structure of these nuclei that still remains challenging despite the several decades of investigations. Moreover, the precise values of these radii open the way for highly accurate comparison between theory and experiments in the most simple "atomic" system such as H, He, HD^+ and He^+ leading to bound-state QED (quantum-electrodynamics) tests to an unprecedented level of accuracy. Because QED is the relativistic quantum field theory of electrodynamics, a precisions test of bound-state QED automatically implies a precision test of relativity and a precision test of photon-charged-particles interaction, both at the core of Einstein's legacy.
17:15	***END***