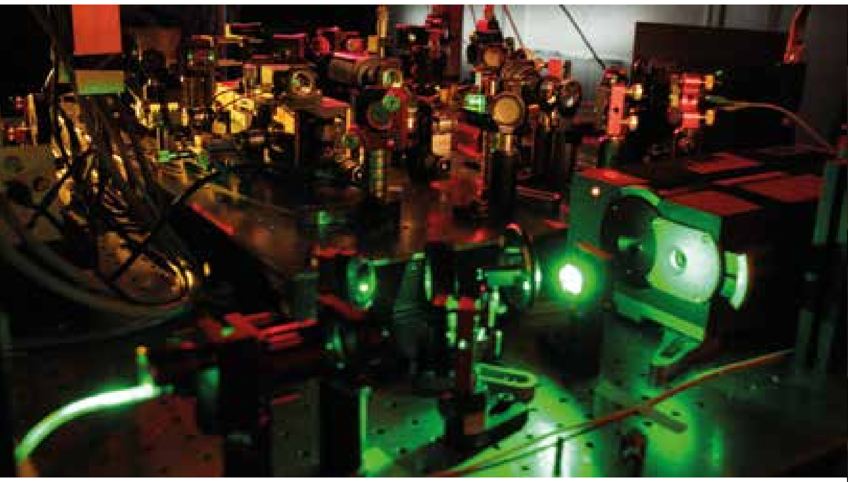
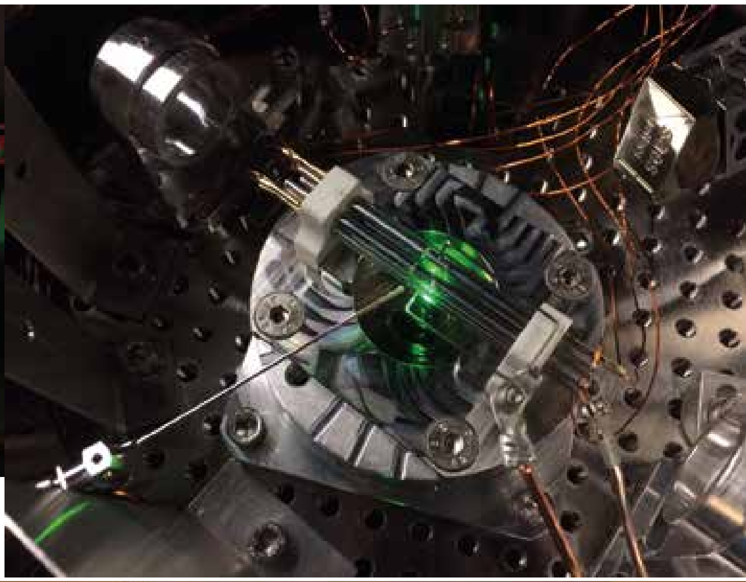
⟨S|P|S⟩
swiss physical society

Nr. 55
Juli 2018

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP





Top: A source of entangled photons that was used to teleport a qubit into a quantum memory. Read more on p. 27.
Right: Ion trap for precision measurements on cold molecular ions (p. 31).

In memoriam of Stephen Hawking we present on p. 37 a summary of his research. This picture shows him trying a zero-g environment during a parabola flight in 2007. *(Credit: Jim Campbell/Aero-News Network, NASA)*

The Swiss team won the International Physicists' Tournament 2018, congratulations ! Read on p. 58 a report of the team leader.
© A.Lomakin (MIPT), supported by MIPT-Union, Abbyy and Pres. Grants Fund.

Annual Meeting of the Swiss Physical Society

28 - 31 August 2018, EPFL

in collaboration with

CHIPP and NCCR MARVEL

General information: p. 12, preliminary program: p. 14

Inhalt - Contenu - Contents

Vorstandsmitglieder der SPG - Membres du Comité de la SSP

Präsident - Président
Dr. Hans Peter Beck, Uni Bern, hans.peter.beck@cern.ch

Vize-Präsident - Vice-Président
Prof. Minh Quang Tran, EPFL, minhquang.tran@epfl.ch

Sekretär - Secrétaire
Dr. MER Antoine Pochelon, antoine.pochelon@epfl.ch

Kassier - Trésorier
Dr. Pascal Ruffieux, EMPA, pascal.ruffieux@empa.ch

Kondensierte Materie - Matière Condensée (KOND)
Prof. Laura Heyderman, PSI & ETHZ, laura.heyderman@psi.ch

Angewandte Physik - Physique Appliquée (ANDO)
Dr. Stephan Brunner, EPFL, stephan.brunner@epfl.ch

Astrophysik, Kern- und Teilchenphysik - Astrophysique, physique nucléaire et corp. (TASK)
Dr. Andreas Schopper, CERN, Andreas.Schopper@cern.ch

Theoretische Physik - Physique Théorique (THEO)
Prof. Gian Michele Graf, ETH Zürich, gmgraf@phys.ethz.ch

Physik in der Industrie - Physique dans l'industrie
Dr. Andreas Fuhrer, IBM Rüschlikon, afu@zurich.ibm.com
Dr. Thilo Stöferle, IBM Rüschlikon, tof@zurich.ibm.com

Atomphysik und Quantenoptik - Physique Atomique et Optique Quantique
Prof. Philipp Treutlein, Uni Basel, philipp.treutlein@unibas.ch

Physikausbildung und -förderung - Education et encouragement à la physique
Dr. Céline Lichtensteiger, Uni Genève, celine.lichtensteiger@unige.ch

Geschichte der Physik - Histoire de la Physique
Prof. Jan Lacki, Uni Genève, jan.lacki@unige.ch

Physik der Erde, Atmosphäre und Umwelt - Physique du globe et de l'environnement
Dr. Stéphane Goyette, Uni Genève, stephane.goyette@unige.ch

Biophysik, Weiche Materie und Medizinische Physik - Biophysique, Matière molle et Physique médicale
Prof. Giovanni Dietler, EPFL, giovanni.dietler@epfl.ch

SPG Administration - Administration de la SSP

Allgemeines Sekretariat - Secrétariat générale
(Mitgliederverwaltung, Webseite, Druck, Versand, Redaktion Bulletin & SPG Mitteilungen) - (Service des membres, internet, impression, envoi, rédaction Bulletin & Communications de la SSP)
S. Albietz, SPG Sekretariat, Departement Physik,
Klingelbergstrasse 82, CH-4056 Basel
Tel. 061 / 207 36 86, Fax 061 / 207 37 84, sps@unibas.ch

Buchhaltung - Service de la comptabilité
sps@unibas.ch

Protokollführerin - Greffière
NN.

Wissenschaftliche Redakteure - Rédacteur scientifique
Dr. Bernhard Braunecker, Braunecker Engineering GmbH, braunecker@bluewin.ch
Dr. MER Antoine Pochelon, antoine.pochelon@epfl.ch

Impressum:

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

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

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

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

Druck:
Werner Druck & Medien AG, Kanonengasse 32, 4001 Basel

sc | nat
Member of the Swiss Academy of Sciences

satw it's all about technology

Editorial

Science for Development

Thierry J.-L. Courvoisier, University of Geneva, President EASAC, the European Academies Science Advisory Council

There is no development without science, whatever the meaning of "development" may be. All what mankind has ever built or constructed rests ultimately on the knowledge we have acquired by observing nature – which may also be a way of responding to the ever recurrent question of the relevance of fundamental science for our societies. This is true for the measurement of time, as it is for biotechnology or semi-conductors, two of the many tools essential in development of human communities worldwide.

But science, like any tool, is used for development, but also for destruction, a triviality that needed no extra emphasis in Viet Nam, where science for development was discussed May 9-11 2018 at the XIVth Rencontres du Viet Nam [1].

Science serves interests of all sorts, some for the benefit of the concerned human communities; we call this development. But science also serves the commercial, industrial, or financial interests of actors very far from the communities involved. These may be large multi-national companies looking for new markets for products, which may or may not be adapted to local conditions. Geopolitical interests of far away nations also influence sometimes the evolution of communities in a way that may not necessarily be to their benefit. The Viet Nam war being a striking example, but by no means the only or last one.

Using science for development therefore requires knowledge, independence and judgement.

Knowledge first. A large number of decisions that need be taken now everywhere and at all levels, be they local, national, continental or global, require a wide body of knowledge. This is true of agriculture and the use of pesticides or genetically modified organisms, but also of mobility and CO_2 emission or adaptation to climate change to name but few examples. It is worth remembering here that climate change is *in fine* a problem of solar radiation transfer in the Earth's atmosphere, continents and oceans that needs be solved to better than 0.05% to understand the Earth energy intake.

Nowadays, the development of local communities must take global issues into considerations. Use of fossil energies at a per capita rate similar to that implied by modern western ways of life everywhere on Earth would indeed be a tremendous problem. Development will therefore have to follow a different path in regions of the world developing now than it typically did in Europe over the last centuries. This is understandably the cause of very significant tensions between different parts of the world.

The knowledge that needs be considered in all aspects of development is not limited to natural sciences, it also encompasses humanities, social and economic sciences. Once the physical, chemical and biological components of a problem are understood, the human, social and political implications of the proposed actions must be considered in order for them to be accepted and implemented, or modified and adapted.

Independence then. Bringing science in society and policy always requires, but probably even more explicitly when dealing with development issues, that the scientists active in informing the decision making processes be free of political interests in the narrow meaning of the word, of industrial, financial or commercial ties be they local or global, or of religious biases. This may be relatively easy to assess as far as economic interests are concerned, it is not when cultural values are concerned. Science is indeed universal in that observations, experiments and the deduced knowledge are valid for all. The scientific questioning, however, depends on the epoch and the culture of the scientists. One does not address the same questions in the same way when sitting in a XXth century western lab or in an oriental surrounding. Following generations look at the world in different ways. These aspects of culture intimate to each of us colour our thinking and our action, the present text included. To mitigate the biases they introduce in science advice, groups including scientists of diverse origin and backgrounds should be formed in order to formulate advice.

With companies eager to access developing markets, or nations pushing geopolitical agendas, both sometimes showing little if any interest for local development issues, think for example of tobacco industries advertising for cigarettes in cultures where smoking is not presently a cultural element, independence of the knowledge brokers is of utmost importance. Science academies are often, rightly I think, considered to be among the knowledge actors most devoid of vested interests. This is the reason for which the interface between science and policy is often entrusted to them, be they national academies or networks like EASAC, the European Academies Science Advisory Council active in supplying scientific advice to the European Union, or its equivalent in Asia, Africa or the Americas.

Judgement finally. What is development? What is sustainable development? What may be the consequences on society or nature of development steps? What is well being for an individual? For a population? All these and more are questions that must be dealt with by society as a whole, including scientists. And answering them must be underpinned by knowledge, be it from natural sciences or from humanities and social sciences.

When discussing development on the planet, be it in a local frame or globally in the coming decade or so, the Sustainable Development Goals, SDGs [2], put together by the United

1 This text is derived from the notes of a talk I gave at this very conference, http://rencontresduvietnam.org/conferences/2018/science_for_development/

2 https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Nations form a frame that is becoming integrated in a number of national policies, including in Switzerland, as well as in the strategic thinking of a number of organisations and associations world wide, also in that of the Swiss academies. The seventeen goals and their 269 targets allow a wide variety of actors to orient their policymaking. They also form a frame that helps define the areas where scientific work must be initiated or pursued in order to achieve the goals and targets and/or to measure progress.

Not only are the sustainable goals an interesting and fruitful tool when discussing development issues everywhere on Earth, but the financial burden of solving the most pressing issues of the planet, namely to tame climate change, is said to be of the order of 1-2% of the world GDP [3]. One would therefore think that with at least one tool likely to bear fruits and a problem for which the solution might cost only a tiny fraction of the world economy, humanity should be on the verge of making very concrete and major progress towards making the planet hospitable for the whole humanity.

3 See for example McCollum, Krey, Rihai, Kolp, Grubler, Makowski and Nakicenovic, Climatic Change 119, 479, 2013 for a discussion of cost and benefit of climate policies.

But somehow it does not work. CO_2 emissions continue to increase worldwide [4], some economies are investing massively in coal plants to produce electricity and worldwide discussions on incentives to decrease carbon and other green house gases emission hinge on arguments related to "productivity" and economic competition between nations, also in Switzerland. Thus the short-term "growth" agenda of our economies seems to systematically win over the long-term harmonious development goal that is essential to preserve an environment in which humanity can live harmoniously.

Short of a major change in the objectives of our society and in the governance that we give ourselves it seems that it will be difficult to modify this state of affairs. To ever produce more in order to sustain "growth" in a finite environment cannot function. We must therefore look at ways that satisfy human well being in terms other than per capita productivity increase to give a meaning to our lives. This probably implies looking at professional careers differently, also in the academic environment where productivity, in terms of number of publications, is still the preferred benchmark.

4 see for example the statistics of the International Energy Agency, https://webstore.iea.org/key-world-energy-statistics-2017

Jahrestagung in Lausanne, 28. - 31. August 2018
Réunion annuelle à Lausanne, 28 - 31 août 2018

Vorwort

Die diesjährige Jahrestagung der SPG, mit Beteiligung von CHIPP und NCCR MARVEL, findet in Lausanne an der EPFL statt.

Neben der bewährten Mischung aus Plenarvorträgen, Fachsitzungen und Händlerausstellung stehen auch zwei öffentliche Vorträge sowie eine Filmvorführung auf dem Programm.
Zusätzlich können sich die Teilnehmer wie gewohnt für das traditionelle Konferenzabendessen anmelden (Teilnehmerzahl beschränkt).

Im Folgenden finden Sie die wichtigsten Tagungsinformationen sowie eine vorläufige Programmübersicht. Das definitive Programm wird in Kürze auf der SPG-Webseite verfügbar sein. In diesem Sinne hoffen wir auf eine rege Beteiligung an der diesjährigen Tagung und freuen uns auf Ihren Besuch.

Avant-propos

La réunion annuelle de la SSP, avec cette année la participation de CHIPP et NCCR MARVEL, aura lieu à Lausanne, à l'EPFL.

En plus de la combinaison de conférences plénières, de sessions par domaines et de la participation d'exposants, nous aurons au programme deux conférences publiques et la présentation d'un film.
En plus, les participants peuvent s'inscrire, comme d'habitude, pour le dîner traditionel de la conférence (nombre de places limité).

Vous trouverez les principales informations sur la conférence ainsi qu'un aperçu du programme préliminaire ci-dessous. Le programme définitif sera disponible prochainement sur le site de la SSP. Nous nous réjouissons de votre visite et espérons avoir une participation soutenue à la conférence avec le programme stimulant de cette année.

Generalversammlung 2018 - Assemblée Générale 2018

Dienstag 28. August 2018, 18:00h - Mardi 28 août 2018, 18:00h
EPFL, Centre Est, CE 6

	Traktanden	Ordre du jour
1.	Protokoll der Generalversammlung vom 22. August 2017	Procès-verbal de l'assemblée générale du 22 août 2017
2.	Bericht des Präsidenten	Rapport du président
3.	Projekte	Projets
4.	Rechnung 2017, Revisorenbericht	Bilan 2017, rapport des vérificateurs des comptes
5.	Wahlen	Elections
6.	Neues Ehrenmitglied	Nouveau Membre d'honneur
7.	Diverses	Divers

Preisverleihungen - Cérémonies de remise des prix

SPG Preise, CHIPP Preis und Charpak-Ritz Preis
Prix de la SSP, CHIPP et prix Charpak-Ritz

Mittwoch 29. August 2018, 10:50h
Mercredi 29 août 2018, 10:50h
EPFL, Centre Est, CE 6

Preise für die besten Poster
Prix pour les meilleurs posters

Freitag 31. August 2018, 10:20h
Vendredi 31 août 2018, 10:20h
EPFL, Centre Est, CE 6

A note from the President

In my role as president of the *Swiss Physical Society*, I sometimes hear a very obvious question: 'What do I gain for being a member of SPS?' The question is definitely relevant and deserves a sincere answer, which I am giving here below.

The *Swiss Physical Society* unites people interested in physics who are active in teaching, didactics, research and development in all branches be these in industry, at schools, in universities, or at research laboratories. Following this paradigm, everyone interested in physics and everyone interested to support physics and the activities of SPS is welcome to become a member. It's not only the *SPG Mitteilungen* and the *Newsletter* that will find their way into your physical and electronic letter box and that may be seen as return of investment. Effectively, it is the uniting of people and it is the annual membership fee that together keep SPS going strong. Paraphrasing a well-known quote, the answer therefore is not so much of what is the Society doing for you, but of what you can do as an individual for the good of the Society, and thus for the good of the activities SPS is running, supporting, and enabling.

Good and effective communication is key for any society, and SPS is of no exception. I am personally very happy of our electronic *Newsletter* that now became fully functional in 2017. With Céline Lichtensteiger from Uni Geneva, we successfully could find the needed effort to regularly send out a new version at ca. one month's interval to SPS members and all interested persons. We hope we match with this *Newsletter* your needs in staying informed and we welcome your proposals for news items to be disseminated this way.

Effective communication within and across the various sections of our society is further assured by the publication of the *SPG Mitteilungen*, and by deferring regularly up-to-date information and news over the SPS web portal. The *SPG Mitteilungen* appear three times per year, disseminating information about the activities of the society and the executive board, giving reports on the on-going projects and reviewing scientific progress in a variety of areas of physics with rubrics like *Progress in Physics, Milestones in Physics, Physics Anecdotes, Plenary Talks, Physics and Society* and *History of Physics*.

A few highlights are worth mentioning from the 2017 activities. In particular, the annual meeting that was held at CERN and at the *Centre International de Congrès* (CICG) in Geneva will stay remembered. With over 520 participants and about 370 contributions, the annual meeting 2017 offered ample opportunity to all participants exchanging ideas within and beyond their own specific fields. These high numbers were possible through the joint organization with the *Austrian Physical Society* (ÖPG) and the fascinating location.

Not only were the invited talks outstanding and offering a broad overview in many hot topics across all fields; it was in particular the parallel session talks that offered an excellent exchange of latest results and activities, driven by invited speakers, young postdocs and students from Switzerland, Austria, and beyond. Two evening lectures, open to the public, gave great insights on fundamental research and their impact in society. Matthew Philipp McCullough presented "A Higgs-Eye View of the Cosmos" at CERN, and Thierry Courvoisier, president of Swiss and European Academies, spoke in French on "De la place de la Science dans la Société" at the CICG, highlighting that knowledge also implies responsibility to the society and the need of communication; a topic very much at the heart of SPS.

The Swiss Physical Society is supporting young physicists via the *Young Physicists Forum* (YPF). With its new president, Ana Roldán, physics student at EPFL, and with little help from SPS, YPF could foster links across all student's associations at Swiss universities. In 2017, YPF organized a topical event on "Computational Physics" at ETHZ and University of Zürich, with participants from all over Switzerland.

The SPS was again involved in the *Swiss Physics Olympiad* SwissPhO by awarding our "Nachwuchsförderpreis" to the two best students. The final round of the SwissPhO took place on 25 and 26 March in Aarau at the Neue Kantonsschule. The five gold medallists formed the Swiss team at the *International Physics Olympiad* 2017 in Yogyakarta, Indonesia.

Another continuous endeavour of the SPS is to improve the contact between teachers and organizers of training courses for secondary school teachers. The *Verein Schweizerischer Mathematik- und Physiklehrkräfte* (VSMP) and SPS have a joint agreement allowing double membership SPS-VSMP at a reduced annual fee. Indeed, we are looking forward for more teachers continuing being members of SPS.

Supporting the very young is achieved with "Physik im Advent", an online physics Advent calendar, presenting 24 small, simple experiments and physics riddles to young pupils and anyone interested during advent period every December. Over 30'000 pupils registered to the competition in 2017 and many more downloaded these simple experiments and riddles for their own curiosity. The SPS is promoting and sponsoring "Physik im Advent" in Switzerland.

Whilst SPS is a member organization of the *Swiss Academy of Science* (SCNAT) and part of the platform *Mathematics, Astronomy and Physics* (MAP), we also maintain strong links with the *Swiss Academy of Engineering Science* (SATW), closing the loop between pure research and our innovation driven economy. At the international level, SPS has tight links to the *European Physical Society* (EPS) and to the *International Union of Pure and Applied Physics* (IUPAP).

At the last General Assembly, I was elected President of our Society. Following the words of our former president, Minh Quang Tran, I would like to concur with him on his and also my firm believe that, in Switzerland, our industry and economy, as in any developed and industrial country, can only progress if both fundamental and applied physics research is vigorously supported. It is fundamental scientific discovery and understanding that make inventions possible, which finally leads to innovation. This is neatly exemplified in many instances of the past and now continues with e.g. quantum-sensoring or quantum-computing that have the full potential of becoming the next drivers.

The Swiss Physical Society, with your help and with your support, will never be tired fostering the importance of science in general and of physics in particular in a modern society.

Hans Peter Beck

Protokoll der Generalversammlung vom 22. August 2017 in Genf
Protocole de l'assemblée générale du 22 août 2017 à Genève

Agenda

1. Approval of the Minutes of the General Assembly held in Lugano on 23 August 2016
2. Brief Report from the President
3. 2016 Finances and Auditors Report
4. Elections
5. Projects
6. Miscellaneous

The President opens the meeting at 15:25.

1. Approval of the Minutes of the General Assembly held in Lugano on 23 August 2016

The protocol of the last General Assembly, published in the *SPG Mitteilungen* Nr. 52 on p. 7 is unanimously approved.

2. Report of the President 2016-2017

The President welcomes the new members to our Society. There is again a slight decrease in the number of members. Please advertise the SPS around you, as you are the best ambassadors of our society.
This year, we have edited our 1st newsletter.
As the first recipient of the *Charpak-Ritz prize*, Carlo Sirtori from France will be honored in the course of the Award Ceremony, which is scheduled a couple of hours after this GA.
EPS Historical site: The inauguration of the "plaque" at the IBM Rüschlikon site will take place on 26 September 2017. This is the 3rd EPS historical site in Switzerland.
We also use for the first time "Indico" for the organisation of our conference, please give us your feedback on this management tool.

3. 2016 Finances and Auditors Report

The 2016 Annual Financial Report is presented by the treasurer, Dr. Pascal Ruffieux, on page 10 of the *SPG Mitteilungen* Nr. 52. Prof. Dr. Philipp Aebi and Dr. Pierangelo Gröning, the auditors of this report, have approved the numbers and their statement can be found on page 11.

A loss of 5'246.47 Swiss Francs is accounted for. The treasurer explains that the benefits or losses depend mostly on the success of our annual meetings. In our 2016 annual meeting in Lugano, we had less exhibitors and less participants than usual, also the number of members has decreased slightly.
The Annual Financial Report is approved unanimously by the General Assembly and gives discharge to the Board.

4. Elections

The president thanks the members of the committee who have arrived at the end of their term, namely Thomas Brunschwiler and Patrick Ruch (Physics in Industry), for their work.
The following committee members are elected or re-elected unanimously by the General Assembly:

- President: PD Dr. Hans Peter Beck (for 2 years)
- Vice-President: Prof. Minh Quang Tran (for 1 year)
- Physics in Industry: Dr. Andreas Fuhrer and Dr. Thilo Stöferle (2 years)
- Applied Physics: Dr. Stefan Brunner (for 1 year)
- Atomic Physics and Quantum Optics: Prof. Philipp Treutlein (for 2 years)

It is sometimes difficult to find replacements for the Board members and all new propositions are welcome.

5. Projects 2017 – 2018 **(This subject is presented by PD Dr. Hans Peter Beck, President elect)**

Open areas: Improve memberships with modernised tools like a new web site and a regular newsletter.
Improve links with SCNAT, SATW (with better links with our Applied Physics Section), EPS, network with other physical societies.
Our commission "Young Physicists Forum" is less and less active. Ideas to make our society more attractive are welcome, like link with the EPS Young Minds, SPS-Day, …

6. Miscellaneous

No other business.

The President closes the meeting at 16:10.

Protocol: Edith Grüter

Statistik - Statistique

Neue Mitglieder 2017 - Nouveaux membres en 2017

An Kyongmo, Banafsheh Mojdeh, Baumberger Felix, Benavides-Riveros Carlos L., Bhat Vinayak, Bruant Gulejova Barbora, Dominguez Ordonez Claribel, Drechsel Carl, Dreyer Hans-Peter, Dumcenco Dumitry, Forrer Yves, Fowlie Jennifer, Frei Marcel, Fuhrer Andreas, Gauthier Nicolas, Gerber Sebastian, Gibert Marta, Glaus Seraina, Heiniger Fritz, Herren Christoph, Hiller Roman, Hruby Lorenz, Käser Jonas, Kubli Martin, Lajkó Miklós, Lançon Diane, Lehnert Kay, Leo Naëmi, Macko Vladimir, Martino Edoardo, Nath-Magnani Ranjana, Nishiyama Ryuichi, Njoh Ekoume Theodore Rodrigue S., Novotny Zbynek, Paniccia Mercedes, Paris Eugenio, Pfeifer Michael, Pizzochero Michele, Produit Thomas, Rauco Giorgia, Renou Marc Olivier, Sahandabadi Ali, Savchenko Tatiana, Scacchi Alberto, Scarfato Alessandro, Schmidt-Wellenburg Philipp, Sfyrla Anna, Sibille Romain, Simutis Gediminas, Souto Gonçalves de Abreu Elsa, Stöferle Thilo, Stucky Adrien, Tamai Anna, Timrov Iurii, Tran Michaël, Türler Marc, Uhrin Martin, Wang Zhe, Würsch Pascal, Xu Pengxiang, Zubiaga Monsalve Asier, Zurin Thomas

Ehrenmitglieder - Membres d'honneur

Prof. Hans Beck (2010)
Dr. J. Georg Bednorz (2011)
Prof. Jean-Pierre Blaser (1990)
Prof. Jean-Pierre Borel (2001)
Prof. Jean-Pierre Eckmann (2011)
Prof. Charles P. Enz (2005)
Prof. Hans Frauenfelder (2001)
Prof. Jürg Fröhlich (2011)
Prof. Hermann Grunder (2001)
Dr. Martin Huber (2011)
Prof. Piero Martinoli (2016)
Prof. Verena Meyer (2001)
Prof. K. Alex Müller (1991)
Prof. Hans Rudolf Ott (2005)
Prof. T. Maurice Rice (2010)
Prof. Louis Schlapbach (2010)
Prof. Herwig Schopper (2015)
Prof. Norbert Straumann (2016)

Assoziierte Mitglieder - Membres associés

A) Firmen

- ABB Schweiz AG, 5405 Baden
- COMSOL Multiphysics GmbH, 8005 Zürich
- IBM Research GmbH, Forschungslabor, 8803 Rüschlikon
- METAS, 3003 Bern-Wabern
- Oerlikon Surface Solutions AG, LI-9496 Balzers

B) Universitäten, Forschungseinrichtungen

- Albert-Einstein-Center for Fundamental Physics, Universität Bern, 3012 Bern
- CERN, 1211 Genève 23
- Swiss Plasma Center (SPC), EPFL, 1015 Lausanne
- Département de Physique, Université de Fribourg, 1700 Fribourg
- Departement Physik, Universität Basel, 4056 Basel
- Departement Physik, ETH Zürich, 8093 Zürich
- EMPA, 8600 Dübendorf
- Lab. de Physique des Hautes Energies (LPHE), EPFL, 1015 Lausanne
- Paul Scherrer Institut, 5332 Villigen PSI
- Physik-Institut, Universität Zürich, 8057 Zürich
- Section de Physique, Université de Genève, 1211 Genève 4
- Section de Physique, EPFL, 1015 Lausanne

C) Studentenfachvereine

- AEP - Association des Etudiant(e)s en Physique, Université de Genève, 1211 Genève 4
- Fachschaft Physik und Astronomie, Universität Bern, 3012 Bern
- Fachschaft Physique, Université de Fribourg, 1700 Fribourg
- Fachverein Physik der Universität Zürich (FPU), 8057 Zürich
- Fachgruppe Physik Universität Basel, 4056 Basel
- Les Irrotationnels, EPFL, 1015 Lausanne
- Verein der Mathematik- und Physikstudierenden an der ETH Zürich (VMP), 8092 Zürich

Verteilung der Mitgliedskategorien - Répartition des catégories de membres (31.12.2017)

Ordentliche Mitglieder	672
Doktoranden	47
Studenten	34
Doppelmitglieder DPG, ÖPG, APS oder VSMP	164
Doppelmitglieder PGZ	60
Mitglieder auf Lebenszeit	121
Assoziierte Mitglieder	24
Bibliotheksmitglieder	2
Ehrenmitglieder	18
Beitragsfreie (Korrespondenz)	6
Total	**1148**

Jahresrechnung 2017 - Bilan annuel 2017

Bilanz per 31.12.2017

	Aktiven	Passiven
Umlaufsvermögen		
Postscheckkonto	90942,21	
Bank - UBS 230-627945.M1U	27130,45	
Debitoren - Mitglieder	1640,00	
Debitoren - SCNAT/SATW u.a.m.	45644,72	
Anlagevermögen		
Beteiligung EP Letters	15840,00	
Mobilien	1,00	
Fremdkapital		
Mobiliar		1,00
Mitglieder Lebenszeit		67278,25
Transitorische Passiven		23295,51
Eigenkapital		
Vefügbares Vermögen		93949,37
Total Aktiven/Passiven	**181198,38**	**184524,13**
Verlust	**3325,75**	
Summe	**184524,13**	**184524,13**
Verfügbares Vermögen per 31.12.17 nach Verlustzuweisung:		90623,62

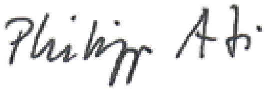
Erfolgsrechnung per 31.12.2017

	Aufwand		Ertrag
Gesellschaftsaufwand		**Ertrag**	
EPS - Membership	12173,48	Mitgliederbeiträge	94941,15
SCNAT - Membership	7749,00	Inserate/Flyerbeilagen SPG Mitteilungen	5190,00
SATW-Mitgliederbeitrag	1750,00	Aussteller	16382,94
		Andere Gesellschaftserträge	51,92
SCNAT Verpflichtungskredite		Zinsertrag	2,85
SPG-Jahrestagung	36809,57	Ertrag aus EP Letters Beteiligung	926,49
Schweizer Physik Olympiade	4000,00		
SPG Young Physicist's Forum	3513,40	**SCNAT Verpflichtungskredite**	
International Physics Tournament	1590,18	SPG-Jahrestagung (SCNAT)	15000,00
Projet Physique et Société	4437,34	Schweizer Physik Olympiade	4000,00
Organisation de la cérémonie "Uni Bastion Genève"	103,80	SPG Young Physicist's Forum	4000,00
SPG Bulletin/Tagungsband (SCNAT)	12210,70	Lehrerfortbildungsevent 2014 ff	5000,00
SCNAT Periodika (SPG Mitteilungen, Druckkosten)	20368,75	International Physics Tournament	4000,00
SCNAT Internationale Zusammenarbeit	2039,20	Projet Physique et Société	5000,00
SCNAT Swiss Young Phys. Tournament	5000,00	Organisation de la cérémonie "Uni Bastion Genève"	2000,00
		SPG Bulletin/Tagungsband (SCNAT)	5000,00
Betriebsaufwand		Periodika (SPG Mitteilungen, Druckkosten) (SCNAT)	5000,00
Löhne	34961,91	Internationale Zusammenarbeit (SCNAT)	2000,00
Sozialleistungen, berufl. Vorsorge, Versicherung	6842,72	SCNAT Swiss Young Phys. Tournament	5000,00
Porti/Telefonspesen/WWW- und PC-Spesen	1305,15		
Versand (Porti Massensendungen)	5817,85		
Unkosten	2029,10		
Büromaterial	1955,57		
Bankspesen	348,10		
Debitorenverluste Mitglieder	1460,00		
Debitorenverlust SCNAT/SATW u.a.m.	10355,28		
Total Aufwand/Ertrag	**176821,10**		**173495,35**
Verlust			**3325,75**
Summe	**176821,10**		**176821,10**

Revisorenbericht zur Jahresrechnung 2017

Die Jahresrechnung 2017 der SPG wurde von den unterzeichneten Revisoren geprüft und mit den Belegen in Übereinstimmung befunden.
Die Revisoren empfehlen der Generalversammlung der SPG, die Jahresrechnung zu genehmigen und den Kassier mit bestem Dank für die gute Rechnungsführung zu entlasten.

Die Revisoren der SPG:



Prof. Dr. Philipp Aebi

Dr. Pierangelo Gröning

Dübendorf, 23. März 2018

SPG Buchhaltung, Departement Physik, Klingelbergstrasse 82, CH-4056 Basel
Email : sps@unibas.ch

Neues Ehrenmitglied - Nouveau membre d'honneur

Der Vorstand hat dieses Jahr einen Vorschlag für ein neues Ehrenmitglied erhalten. Die Ernennung findet im Rahmen der Generalversammlung am 28. August 2018 statt.
Le comité a reçu une proposition pour un nouveau membre d'honneur cette année. La nomination aura lieu le 28 août 2018 lors de l'Assemblée Générale.

Maurice Bourquin

Prof. Maurice Bourquin studied physics at the University of Geneva. In 1971 he moved to Columbia University in New York and worked in the following in experiments at Fermilab in Chicago. He returned back to Geneva in 1974, where his research focused on physics at CERNs accelerators: the Super Proton Synchrotron (SPS) and the Large Electron Positron Collider (LEP) at CERN. He participated in the design and construction of the L3 experiment at LEP – one of the four large experiments at LEP. In 1984 he was promoted to professor of physics at Geneva University.

Maurice Bourquin was also very active in science policy. He served as rector of the University of Geneva in the years 1999 – 2003, at a time, where the Bologna reform was heavily discussed and implemented in Switzerland. He was also one of the founders of the League of European Research Universities (LERU). He served as referee in the Swiss National Science Foundation and until last year he was also member of the jury for the CHIPP prize, which is given each year for the most inventive work as PhD-student in particle physics.

In 2001 he was elected as the first, and so far only, Swiss president of the CERN Council, at a time, when severe financial decisions for the construction of the Large Hadron Collider (LHC) had to be made.

Maurice Bourquin's second research focus was on Astroparticle physics. He played a leading role in the AMS consortium to search for antimatter on the International Space Station (ISS). He was also for several years the Swiss representative in ApPEC, the Astroparticle Physics European Consortium.

Since his retirement, his interest in science and technology continued in several fields. Presently, his most prominent project is on future nuclear reactors based on thorium fuel. Thorium based reactors have the advantages of inherent safe operation, much higher fuel efficiency and consequently much less nuclear waste, more resistant to proliferation. Furthermore, the abundance of thorium is four times higher than uranium.

The proposed laudatio reads as follows:

The Swiss Physical Society awards honorary membership to Professor Maurice Bourquin for his enormous scientific achievements in particle and astroparticle physics, for his extraordinary commitment in the science policy at CERN and at Swiss universities implementing the Bologna Reform, and also for his far-sighted commitment to the promotion of future thorium based nuclear reactors, which have increased efficiency and produce less long-lived waste.

Allgemeine Tagungsinformationen - Informations générales sur la réunion

Konferenzwebseite und Anmeldung

Alle Teilnehmeranmeldungen werden über die Konferenzwebseite vorgenommen.

www.sps.ch

Anmeldeschluß: 1. August 2018

Tagungsort

EPF Lausanne, Gebäude Centre Est (Avenue Piccard)

Tagungssekretariat

Das Tagungssekretariat befindet sich in der Eingangshalle des Centre Est im 1. Stock.

Öffnungszeiten:

Di 28.08	13:00 - 18:00
Mi 29.08 - Do 30.08.	08:00 - 18:00
Fr 31.08.	08:00 - 11:30

Alle Tagungsteilnehmer melden sich bitte vor dem Besuch der ersten Veranstaltung beim Sekretariat an, wo sie ein Namensschild und allfällige weitere Unterlagen erhalten sowie die Tagungsgebühr bezahlen.
Wichtig: Ohne Namensschild ist kein Zutritt zu einer Veranstaltung möglich.

Wir empfehlen Ihnen, wenn möglich den frühen Dienstag Nachmittag für die Anmeldung zu nutzen.

Hörsäle

In allen Hörsälen stehen Beamer zur Verfügung. Bitte bringen Sie Ihre eigenen Mobilrechner und evtl. Adapter und USB Stick/CD mit.

Postersession

Die Postersession findet am Mittwoch Abend sowie am Donnerstag während der Mittagspause in der Halle statt. Bitte bringen Sie Befestigungsmaterial (Reissnägel, Klebestreifen) selbst mit. Die Posterwände sind entsprechend diesem Programm numeriert, sodaß jeder Teilnehmer "seine" Wand leicht finden sollte. Alle Poster sollen an allen beiden Tagen ausgestellt bleiben.
Maximale Postergröße: A0 Hochformat.

Zahlung

Wir bitten Sie, die Tagungsgebühren im Voraus zu bezahlen. Sie verkürzen damit die Wartezeiten am Tagungssekretariat, erleichtern uns die Arbeit und sparen darüber hinaus noch Geld !
Die Angaben zur Zahlung werden während der Anmeldung direkt auf der Webseite angezeigt.

Am Tagungssekretariat kann nur bar bezahlt werden (in CHF). Kreditkarten können vor Ort leider nicht akzeptiert werden.

ACHTUNG: Tagungsgebühren können nicht zurückerstattet werden.

Kaffeepausen, Mittagessen

Kaffeepausen, Apéro und Lunchbuffet (Donnerstag) finden in der Halle und dem "Salle Polyvalente" bei der

Site web de la conférence et inscription

L'inscription des participants se fait sur le site web de la conférence.

www.sps.ch

Délai d'inscription: 1er août 2018

Lieu de la conférence

EPF Lausanne, bâtiment Centre Est (Avenue Piccard)

Secrétariat de la conférence

Le secrétariat de la réunion se trouve dans le hall d'entrée du Centre Est au 1er étage.

Heures d'ouverture:

Mardi 28.8	13:00 - 18:00
Mercredi - Jeudi 23.8 - 24.8	08:00 - 18:00
Vendredi 25.8	08:00 - 11:30

Tous les participants doivent se présenter en premier lieu au secrétariat de la conférence afin de recevoir leur badge et les divers documents ainsi que pour le paiement des frais d'inscription.
Attention: Sans badge, l'accès aux sessions de la manifestation sera refusé.
Nous vous recommandons dans le mesure du possible de vous inscrire déjà le mardi après-midi, le plus tôt possible.

Auditoires

Les auditoires disposent tous d'un projecteur multimédia (beamer). Veuillez apporter votre ordinateur portable ainsi que d'éventuels accessoires tels que clé USB ou CD.

Séance posters

Les posters seront présentés dans le hall le mercredi soir et pendant la pause de midi de jeudi. Veuillez amener vous-même le matériel nécessaire pour fixer les posters (punaises, ruban adhésif). Les panneaux de posters seront numérotés suivant le numéro de l'abstract indiqué dans le programme. Tous les posters doivent rester installés pendant les deux jours.
Dimension maximale: A0, format portrait.

Paiement

Nous vous prions de régler à l'avance vos frais d'inscription. De cette manière vous évitez des files d'attente et facilitez notre travail. De plus, vous réalisez des économies !
Les informations pour le paiement sont indiquées directement sur la page web lors de l'enregistrement.

Les paiements lors de la conférence ne pourront être effectués qu'en espèces (CHF). Les cartes de crédit ne pourront malheureusement pas être acceptées sur place.

ATTENTION: Les frais d'inscription ne sont pas remboursables.

Pauses café, repas de midi

Pauses café, apéro et le buffet de midi (jeudi) se dérouleront dans le hall et le "salle polyvalente" près des

Preise gültig bei Zahlung bis 1. August - Prix valable pour des paiements avant le 1er août	
Kategorie - Catégorie	**CHF**
Mitglieder von SPG, CHIPP - Membres de la SSP, CHIPP	140.-
Doktoranden, die in einer der obigen Gesellschaften Mitglied sind - Doctorants membres d'une des sociétés mentionnées ci-dessus	100.-
Nicht-Mitglieder - Non-membres	180.-
Doktoranden, die NICHT Mitglied sind - Doctorants qui ne sont PAS membres	140.-
Studenten VOR Master/Diplom Abschluß - Etudiants AVANT le degré master/diplôme	80.-
Plenarsprecher, Eingeladene Sprecher, Preisträger - Conférenciers pléniers et invités, lauréats	0.-
Spezialangebot für "Noch nicht Mitglieder" (s.u.) - Offre spéciale pour "Pas-encore-membres" (voir ci-dessous)	190.-
Konferenz Abendessen - Dîner de la conférence	80.-
Zuschlag für Zahlungen nach dem 1. August sowie Barzahler an der Tagung - Supplément pour paiements effectués après le 1er août et pour paiements en espèces à la conférence	**20.-**

Händlerausstellung statt. Diese Leistungen sind in der Konferenzgebühr enthalten.
Für das Mittagessen an den anderen Tagen können die Restaurants auf dem EPFL-Campus genutzt werden.

Konferenz-Abendessen

Das Abendessen findet am Donnerstag im "Casino Morges" im Anschluß an die Parallelsessions statt. Der Preis beträgt CHF 80.- pro Person (beinhaltet Bus Transfer, Apéro, 3-Gänge Menü und Getränke). Die Anzahl der Plätze ist limitiert, bitte registrieren Sie sich unbedingt im Voraus, damit wir disponieren können. Eine Anmeldung vor Ort ist nicht möglich !

Spezialangebot für "Noch-Nicht" SPG-Mitglieder

Planen Sie, an unserer Tagung teilzunehmen sowie Mitglied der SPG zu werden ? Sie können nun beides zum äusserst günstigen Preis von nur CHF 190.- (CHF 210.- nach dem 1. August). Dieser Betrag deckt die Konferenzgebühr sowie die Mitgliedschaft für 2018. Verpassen Sie dieses Angebot nicht ! Wählen Sie einfach bei der Online Registrierung die Kategorie "Special Offer", laden Sie das Anmeldeformular (http://www.sps.ch/fileadmin/doc/Formulare/anmeldeformular_d-f-e.pdf) für neue Mitglieder herunter, drucken es aus und schicken oder faxen es ausgefüllt an das SPG-Sekretariat.

(Dieses Angebot gilt nicht für Studenten oder Doktoranden. Diese profitieren sowieso von der Gratis-Mitgliedschaft im ersten Mitgliedsjahr, und zahlen nur die in der Tabelle angegebene Konferenzgebühr.)

Anreise und Unterkunft

Alle Informationen zur Anreise finden Sie auf https://information.epfl.ch/access

Hotel Reservationen können individuell direkt über Lausanne Tourismus (www.lausanne-tourisme.ch) vorgenommen werden.

Vergessen Sie nicht, beim Einchecken nach der "Lausanne Transport Card" zu fragen. Diese erlaubt die freie Benutzung des öffentlichen Verkehrs und weitere Vergünstigungen.

exposants. Ces prestations sont inclues dans les frais d'inscription.
Pour les autres repas de midi, les restaurants du campus de l'EPFL pourront être utilisés.

Dîner de la conférence

Le dîner se tiendra le jeudi soir dans le "Casino Morges", après les séances orales. Le prix est de CHF 80.- par personne (transfert par bus, apéro, menu trois services et boissons inclus). Le nombre des places étant limité, veuillez s.v.p. absolument vous enregistrer à l'avance pour des raisons d'organisation. Il ne sera plus possible de s'inscrire sur place !

Offre spéciale pour les non-membres de la SSP

Voulez-vous participer à la conférence et devenir par la même occasion membre de la SSP ? Profitez de notre offre avantageuse ! Pour la somme de CHF 190.- (CHF 210.- après le 1er août) nous vous offrons l'inscription ainsi que la cotisation de membre de la SSP jusqu'à fin 2018. Ne ratez pas cette occasion! Cochez simplement la case « Special Offer » lors de votre inscription en ligne, téléchargez le formulaire d'admission à la SSP de http://www.sps.ch/fileadmin/doc/Formulare/anmeldeformular_d-f-e.pdf , imprimez-le, et renvoyez-le dûment rempli par courrier ou fax au secrétariat de la SSP.

(Cette offre ne s'applique pas aux étudiants et aux doctorants. Ceux-ci profitent en effet d'une affiliation gratuite à la SSP pendant la première année et ne paient que les frais d'inscription indiqués dans le tableau ci-dessus.)

Arrivée et hébergement

Toutes les informations se trouvent sur https://information.epfl.ch/access.

Les réservations d'hôtel peuvent être effectuées individuellement sur la page web de Lausanne Tourisme (www.lausanne-tourisme.ch).

N'oubliez pas, en vous enregistrant à l'hôtel, de demander la "Lausanne Transport Card". Celle-ci vous permet d'utiliser gratuitement les transports publiques lausannois ainsi que d'avoir accès à d'autres avantages.

Vorläufige Programmübersicht - Aperçu préliminaire du programme

Das vollständige Programm wird allen Teilnehmern am Tagungssekretariat abgegeben sowie auf der Konferenz- und der SPG-Webseite publiziert.
Hinweise:
- Je Beitrag wird nur der präsentierende Autor aufgeführt.
- Die Postersitzung ist am Mittwoch von 18:30 - 20:00 (mit Apéro) sowie am Donnerstag von 12:20 - 14:00 (mit Lunch Buffet).
- (p) = Plenarsprecher, (i) = eingeladener Sprecher

Le programme final complet sera distribué aux participants au stand du secrétariat de la conférence et sera également publié sur le site de la conférence et de la SSP.
Indications:
- seul le nom de l'auteur présentant la contribution a été indiqué.
- la session poster a lieu le mercredi de 18:30 à 20:00 (avec apéro) ainsi que le jeudi de 12:20 à 14:00 (avec buffet de midi).
- (p) = orateur de la session plénière, (i) = orateur invité

Plenary Session

Tuesday, 28.08.2018, CE 6

Time	ID	Plenary Session I
16:20		Official Conference Opening
		Chair: Stéphane Goyette, Uni Genève
16:30	1	**Climate Change: From the Greenhouse Effect to High-Resolution Climate Modeling** *Christoph Schär (p)*
		Chair: Andreas Schopper, CERN
17:15	2	**Hints of New Physics from flavour-changing processes** *Gino Isidori (p)*
18:00		***SPS General Assembly***
19:00		***Apéro Break***
		Public Lecture *Chair: Hans Peter Beck, Uni Bern*
19:30	3	**Thorium-Based Systems – A new concept for nuclear waste elimination and energy production.** *Maurice Bourquin (p)*
20:45		***END***

Wednesday, 29.08.2018, CE 6

Time	ID	Plenary Session II *Chair: Alfredo Pasquarello, EPFL*
09:00	4	**Computational design and discovery of novel materials** *Nicola Marzari (p)*
		Chair: Andreas Fuhrer, IBM Rüschlikon
09:40	5	**The Transformation of the Energy System - Challenges and how to meet them** *Almut Kirchner (p)*
10:20		***Coffee Break***
10:50		***Award Ceremony***
		Chair: Hans Peter Beck, Uni Bern
11:20	6	**Silicon for Beauty and Structure** *Roland Horisberger (i)*
11:50	7	**Half a Century of EPS!** *Christophe Rossel (i)*
12:20		***Lunch***
13:30		***Topical Sessions***
18:30		***Postersession with Apéro***

Time	ID	Public Lecture *Chair: Minh Quang Tran, EPFL*
20:00	8	**Let's Talk About Open Science** *Martin Vetterli (p)*
21:15		***END***

Thursday, 30.08.2018, CE 6

Time	ID	Plenary Session III *Chair: Laura Heyderman, PSI & ETHZ*
09:00	9	**Transient electric-field-driven dynamics in condensed matter: from Terahertz to Petahertz** *Ursula Keller (p)*
		Chair: Philipp Treutlein, Uni Basel
09:40	10	**Rydberg Gases in Thermal Vapor Cells** *Tilman Pfau (p)*
10:20		***Coffee Break***
		Chair: Minh Quang Tran, EPFL
10:50	11	**Facets of Gravity** *Lavinia Heisenberg (i)*
		Chair: Tatsuya Nakada, EPFL
11:20	12	**CHIPP Award Talk** *NN (i)*
		Chair: Hans Peter Beck, Uni Bern
11:50	13	**Presentation Brochure "Physics and Society"** *NN (i)*
12:20		***Postersession with Lunchbuffet***
14:00		***Topical Sessions***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 31.08.2018, CE 6

Time	ID	Plenary Session IV *Chair: Minh Quang Tran, EPFL*
09:00	14	**ITER—An Essential Step Toward Fusion Energy** *Tim Luce (p)*
		Chair: Bernhard Braunecker
09:40	15	**The revised International System of Units: A new foundation for all measures** *Beat Jeckelmann (p)*
10:20		***Poster Award Session***
10:40		***Coffee Break***
11:15		***Topical Sessions***
13:15		

Time	ID	Public Film Presentation *Chair: Antoine Pochelon, EPFL*
13:30	16	**Let there be light** *See p. 23 for details*
14:45		***CONFERENCE END***

Physics beyond University

Wednesday, 29.08.2018, CE 100

Time	ID	Physics beyond University *Chair: Thilo Stöferle, IBM Rüschlikon*
13:30		*Introduction*
13:40	51	**From Quantum Physics to Quantum Geology?** *Lorenz Meier (i)*
14:00	52	**Going astray to Intellectual Property management** *Mirja Richter (i)*
14:20	53	**Electricity, steam and radioisotopes from nuclear power** *Bruno Zimmermann (i)*
14:40	54	**Physics – a teacher's life!** *Sophie Schönenberger (i)*
15:00	55	**From physical chemistry to liability insurance: structural modeling to solve complex problems** *Salomon Billeter (i)*
15:20	56	**Bridging the gap between academia and industry** *Francesca Venturini (i)*
15:40		*Discussion*
16:00		***Coffee Break***
		Chair: Andreas Fuhrer, IBM Rüschlikon
16:30	57	**CSEM - The Swiss Center for Electronics and Microtechnology** *Christian Bosshard (i)*
16:50	58	**High-precision cantilever-based measurement instrumentation for academic and industrial R&D** *Nikola Pascher (i)*
17:10	59	**The Physics of Money** *Eugen Voit (i)*
17:30	60	**The Experience of a Physicist at ABB Corporate Research - Research and Development in the Context of the Energy Transition and in a Corporate Environment** *Stephan Schnez (i)*
17:50		*Discussion*
18:10		***END***
18:30		***Postersession with Apéro***
20:00		***Public Lecture***

History of Physics

Friday, 31.08.2018, Room CE 100

Time	ID	History of Physics *Chair: Jan Lacki, Uni Genève*
11:15	81	**Neither experimental nor theoretical? Computer simulations and the dichotomy between experimental and theoretical physics** *Claus Beisbart (i)*
12:00	82	**Star catalogues: from Hipparchos to Hipparcos (ESA)** *Bernhard Braunecker*
12:45	83	**What history of physics teaches to physics students and working physicists** *Jan Lacki*
13:30		***END***
13:30		***Public Film Presentation***

KOND

Wednesday, 29.08.2018, Room CE 1

Time	ID	KOND I *Chair: Laura Maurel, PSI Villigen*
16:30	101	**Decomposing ultrafast broadband transient spectra with the help of anisotropy** *Bernhard Lang*
16:45	102	**Generation of entangled photon pairs via the cross Feshbach resonance** *Morteza Navadeh Toupchi*
17:00	103	**Simultaneous coherence enhancement of optical and microwave transitions in solid-state electronic spins** *Antonio Ortu*
17:15	104	**Photoemission study of K-doped 1T-$TiSe_2$** *Maxime Rumo*
17:30	105	**Ti K-edge X-ray Linear Dichroism in Anatase TiO_2 single crystal** *Thomas Rossi*
17:45	106	**Robust exciton states above the Mott density in hybrid organic-inorganic perovskites single crystals** *Tania Palmieri*
18:00	107	**Evolution of the spin, orbital and charge degrees of freedom upon tuning the local lattice environment of Sr_2IrO_4** *Eugenio Paris*
18:15	108	**Electronic structure of LAO/STO thin films: artificial control of the two dimensional electron gas properties** *Marco Caputo*
18:30		***Postersession with Apéro***
20:00		***Public Lecture***

Thursday, 30.08.2018, Room CE 1

Time	ID	KOND II: Award Talks *Chair: Laura Heyderman, PSI & ETHZ*
17:00	111	**Hard X-ray tomography of three-dimensional magnetic systems** *Claire Donnelly (i)*
17:30	112	**Understanding Perovskite Solar Cells** *Wolfgang Tress (i)*
18:00	113	**Thermodynamics at the level of a single electron** *Andrea Hofmann (i)*
18:30	114	**2D/3D Hybrid Perovskites for Stable and Efficient Solar Cells** *Giulia Grancini (i)*
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 31.08.2018, Room CE 1

Time	ID	KOND III *Chair: Diane Lançon, PSI Villigen*
11:15	121	**Experimental signatures of emergent quantum electrodynamics in $Pr_2Hf_2O_7$** *Romain Sibille*
11:45	122	**Numerical investigation of comb magnets** *Natalia Chepiga*
12:00	123	**Manipulating the spin and hole dynamics in the spin ladder of Co doped $Sr_{14}Cu_{24}O_{41}$** *Yi Tseng*
12:15	124	**Anisotropic evolution of charge/spin excitations in square-planar cuprates** *Jonathan Pelliciari*
12:30	125	**Superconducting fluctuations in a thin NbN film probed by the Hall effect** *Daniel Destraz*
12:45	126	**Phase mixture and pseudogap behavior in the bismuthate unconventional superconductors** *Muntaser Naamneh*
13:00	127	**Unconventional Order-Disorder Phase Transition in Improper Ferroelectric Hexagonal Manganites** *Sandra Helen Skjaervoe*
13:15		***END***
13:30		***Public Film Presentation***

ID	KOND Poster
131	**Ultra-fast carriers and gap dynamics of Black Phosphorus** *Silvan Roth*
132	**Bottom-up fabrication of graphene nanoribbons: From molecules to devices** *Gabriela Borin Barin*
133	**InteractiveXRDFit: a new tool to simulate and fit X-ray diffractograms of oxide thin films and heterostructures** *Céline Lichtensteiger*
134	**Surface electronic structure of $CsPbBr_3$ perovskite single crystals by Angle-Resolved-Photoelectron-Spectroscopy** *Serhii Polishchuk*
135	**THz Emission Spectroscopy** *Philipp Krauspe*
136	**Dimensional crossover during charge density wave formation in quasi-one-dimensional $NbSe_3$** *Christopher W. Nicholson*
137	**Spin-Orbital Excitations in Ca_2RuO_4 revealed by Resonant Inelastic X-Ray Scattering** *Lakshmi Das*
138	**Charge-carrier cooling in ZnO nanoparticle colloidal solution by femtosecond broadband UV spectroscopy** *Kevin Jablonka*
139	**Comprehensive band structure study of single-layer hole-doped cuprate superconductors** *Kevin Kramer*
140	**A Novel Kagomé-like Cu_2OSO_4 Crystal** *Virgile Favre*
141	**Ultrafast demagnetization dynamics of Ge-doped $CoCr_2O_4$** *Martin Decker*
142	**Preliminary Analysis to Understand the Universal Aspects of Metamagnetic Phase Transitions in $Ca_3Co_2O_6$** *Nagabhushan Ganesh Hegde*
143	**Electron Injection of Metal Oxide Solar Materials Probed by Ultrafast Deep-UV Transient Absorption Spectroscopy** *Lijie Wang*
144	**On-surface synthesis and transfer of aligned graphene nanoribbons** *Rimah Darawish*

Applied Physics & Plasma Physics; Earth, Atmosphere and Environmental Physics (combined session)

Friday, 31.08.2018, Room CE 5

Time	ID	Combined Session *Chair: Stephan Brunner, EPFL*
11:15	201	**Broadband THz source based on thin-disk laser oscillators** *Jakub Drs*
11:30	202	**Particle accelerators for proton therapy: what is so special?** *Marco Schippers*
11:45	203	**Superconducting proton-therapy gantry with a large energy acceptance** *Konrad Pawel Nesteruk*
12:00	204	**Development of Fast Timing Silicon Monolithic Pixel Sensors and Image Reconstruction for Positron Emission Tomography** *Daiki Hayakawa*
12:15	205	**Tracing Atlantic branches entering the Arctic Ocean by means of I129 and U236** *Nuria Casacuberta*
12:30	206	**Investigating the effects of non-thermal plasma treatments on plant seed germination using heat- and oxidative-stress reporters** *Alexandra Waskow*
12:45	207	**Thermal, electromagnetic and structural analysis of gas baffles for the TCV divertor upgrade** *Dario Vaccaro*
13:00	208	**Localised plasma production for plasma dynamics analysis around single null X-point** *Paolo Micheletti*
13:15		***END***
13:30		***Public Film Presentation***

ID	Applied Physics & Earth, Atmosphere and Environmental Physics & Plasma Physics Poster
231	**Reentrant Cavity Resonator for low Intensities Proton Beam Measurements** *Sudharsan Srinivasan*
232	**Detection of FEL based XUV Coherent anti-Stokes Raman signals (CARS)** *Georgio Pamfilidis*
233	**Segmented THz electron manipulator for relativistic electrons** *Csaba Lombosi*
234	**Optical link through fog and clouds: clearing a path with laser filamentation** *Thomas Produit*
235	**Mechanical energy budget and mixing efficiency in an ice-covered and radiatively-forced freshwater basin** *Hugo Ulloa*
236	**Numerical investigation of mid-latitude subgrid-lake effects using a coupled single-column model with an application to Lake Geneva, Switzerland** *Stéphane Goyette*

237	**SOLPS-ITER simulations of the TCV divertor upgrade** *Mirko Wensing*
238	**Scrape-off layer simulations in X-point diverted geometry** *Maurizio Giacomin*
239	**A synthetic tangential phase contrast imaging diagnostic based on nonlinear GENE simulations with TCV geometry** *Aylwin Iantchenko*
240	**The Exposure Hackaton science short-film festival: "Sun in a Box" beautifully presenting nuclear fusion to the public.** *Pedro Molina Cabrera*

Nuclear, Particle and Astrophysics (TASK)

This session has been organised in conjunction with CHIPP.

Tuesday, 28.08.2018, Room CE 3

Time	ID	**CHIPP Plenary Meeting (Non Scientific Topics)** *Chair: Tatsuya Nakada, EPFL*
14:15	31	**Welcome, news from Board and EB** *Tatsuya Nakada*
14:25	32	**CHIPP Elections** *Tatsuya Nakada*
14:40	33	**CHIPP Outreach report** *Katharina Müller*
14:50	34	**TBA - Swiss Education representative at CERN** *Andreas Müller*
15:00	35	**European Committee for Future Accelerators (ECFA) report** *Lenny Rivkin*
15:10	36	**Advisory Committee of CERN Users (ACCU) report** *Michael Dittmar*
15:20	37	**Astroparticle Physics European Consortium (APPEC) report** *Teresa Montaruli*
15:30	38	**Nuclear Physics European Collaboration Committee (NuPECC) report** *Bernd Krusche*
15:35	39	**CHIPP Computing Board report** *Christoph Grab*
15:40	40	**European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) report** *Gilberto Colangelo*
15:50	41	**CERN Council report** *Olivier Schneider*
16:00		***END***

Wednesday, 29.08.2018, Room CE 3

Time	ID	**TASK I: High Energy Physics I** *Chair: Nicola Serra, Uni Zürich*
13:30	301	**Lepton Flavour Violation searches at LHCb** *Guido Andreassi*
13:45	302	**Lepton flavour universality tests in semileptonic b-quark decays** *Annarita Buonaura*
14:00	303	**Tests of Lepton flavour universality in $b \rightarrow s\ell^+\ell^-$ decays at LHCb** *Elena Graverini*
14:15	304	**Anatomy of $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decays and prospects for NP** *Andrea Mauri*
14:30	305	**Flavour anomalies** *Albert Puig Navarro*
15:00	306	**Search for ttH(bb) in the all-hadronic channel** *Korbinian Schweiger*
15:15	307	**Search for direct top squark pair production in events with a Higgs or Z boson, and missing transverse momentum with the ATLAS detector** *Claudia Merlassino*
15:30	308	**Search for Supersymmetry with photonic signatures in LHC run 2 data taken with the ATLAS detector** *Joaquin Hoya*
15:45	309	**A search for bottom squarks in decay chains involving the Higgs boson with the ATLAS Detector** *Thomas Weston*
16:00		***Coffee Break***
		TASK II: High Energy Physics II *Chair: Rainer Wallny, ETH Zürich*
16:30	311	**Evidence for the Higgs boson produced in association with a Z or W boson, where H decays to b-bbar and the Z/W to leptons.** *Gael Ludovic Perrin*
16:45	312	**Combined Time-Dependent CP Violation Measurements by the B factory experiments BaBar and Belle** *Markus Röhrken*
17:00	313	**Search for CP violation in the charm sector through an amplitude analysis of $D^0 \rightarrow K^+K^-\pi^+\pi^-$ decays at LHCb** *Maxime Schubiger*
17:15	314	**Dimensional mismatch theories and confinement** *Joao Barros*
17:30	315	**Hadron Physics from Lattice Simulations** *Wolfgang Bietenholz*
17:45	316	**Overview of very rare decays at LHCb** *Luca Pescatore*
18:00	317	**First steps towards the experimental observation of purely baryonic decay processes using the LHCb detector.** *Vladimir Macko*
18:15	318	**Photon polarisation in radiative b-hadron decays at LHCb** *Violaine Bellee*
18:30		***Postersession with Apéro***
20:00		***Public Lecture***

Thursday, 30.08.2018, Room CE 6

Time	ID	**TASK III: Accelerator Physics & Technology I** *Chair: Lenny Rivkin, EPFL & PSI*
14:00	321	**The Compact Linear Collider (CLIC): High Precision Physics beyond the HL-LHC** *Konrad Elsener (i)*
14:30	322	**The landscape of Future Circular Colliders** *Alain Blondel (i)*
15:00	323	**The PSI Canted-Cosine-Theta Technology Program for FCC** *Bernhard Auchmann*
15:15	324	**Quench Protection of CCT-type High-field Magnets for Accelerators** *Jiani Gao*
15:30	325	**Production of the first 1-m long Canted-Cosine-Theta (CCT) model magnet a PSI** *Giuseppe Montenero*

15:45	326	**Beam-Beam studies for Future Circular Colliders** *Tatiana Pieloni*
16:00	327	**Transverse beam stability and Landau damping at LHC and FCC** *Claudia Tambasco*
16:15	328	**Machine learning applications for Hadron Colliders: LHC lifetime optimization and designing Future Circular Collider** *Loic Thomas Coyle*
16:30		***Coffee Break***
		TASK IV: Accelerator Physics & Technology II *Chair: Lenny Rivkin, EPFL & PSI*
17:00	331	**Linearised dynamical model for electron cloud induced instabilities** *Emmanuel Markus Gottlob*
17:15	332	**Electron-ion dynamics and fast instabilities in the LHC** *Lotta Mether*
17:30	333	**muCool: Development of ultra-cold high-brightness muon beam line** *Ryoto Iwai*
17:45	334	**The development of a high brightness muonium beam** *Narongrit Ritjoho*
18:00		
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Thursday, 30.08.2018, Room CE 3

Time	ID	TASK V: Dark Matter & Astrophysics *Chair: Laura Baudis, Uni Zürich*
14:00	341	**Search for inelastic WIMP-nucleus scattering with XENON1T** *Adam Brown*
14:15	342	**Simulations and Background predictions for DARWIN** *Yanina Biondi*
14:30	343	**Updates from the XENON1T Dark Matter Experiment** *Chiara Capelli*
14:45	344	**DARWIN: the ultimate dark matter detector** *Patricia Sanchez-Lucas*
15:00	345	**The Progress of ArDM Experiment** *Wei Mu*
15:15	346	**Highlights of the FACT TeV monitoring program** *Axel Arbet-Engels*
15:30	347	**FACT - Robotic Monitoring at TeV Energies** *Dominik Neise*
15:45	348	**The SST-1M camera prototype performances and calibration for the CTA SST-1M Project** *Cyril Martin Alispach*
16:00	349	**Gamma-ray Burst Polarization Results from POLAR** *Merlin Reynaard Kole*
16:15	350	**FIT: The Fiber Tracker for the HERD Facility** *Chiara Perrina*
16:30		***Coffee Break***
		TASK IV: Neutrinos & Low Energy Physics *Chair: Klaus Kirch, PSI & ETH Zürich*
17:00	351	**First evidence of a flaring neutrino source and scan of the full sky** *Tessa Lauren Carver*
17:15	352	**Measurement of neutrino interactions in the T2K near detector** *Lucie Violette Maret*
17:30	353	**Search for neutrinoless double beta decay beyond 10^{26} yr of half life sensitivity with GERDA** *Rizalina Mingazheva*
17:45	354	**First results from the 3x1x1 m^3 dual phase Liquid Argon Time Projection Chamber prototype at CERN** *Christoph Alt*
18:00	355	**The proposted SHiP experiment** *Federico Leo Redi*
18:15	356	**Investigating the solid deuterium in the PSI UCN source moderator** *Nicolas Hild*
18:30	357	**Muonic Atom Spectroscopy: Preparations Regarding a Measurement of the Charge Radius of Radium** *Alexander Albert Skawran*
18:45	358	**Laser System for the Measurement of the Ground-State Hyperfine Splitting in Muonic Hydrogen** *Manuel Zeyen*
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 31.08.2018, Room CE 3

Time	ID	TASK VI: Detector & Reconstruction *Chair: NN*
11:15	361	**Performances of the upgraded CMS pixel detector** *Giorgia Rauco*
11:30	362	**Optoboard Development for the Inner Tracker of the High Luminosity ATLAS Detector** *Armin Fehr*
11:45	363	**Deep neural network based simultaneous b-jet energy correction and resolution estimator** *Nadezda Chernyavskaya*
12:00	364	**Real-time track reconstruction for the ATLAS HL-LHC** *Riccardo Poggi*
12:15	365	**Deep Neural Networks for signal/background classification in associated Higgs production with a vector boson decaying into a b-bbar quark** *Pirmin Berger*
12:30	366	**CMS detector simulation tuning through machine learning** *Thomas Reitenspiess*
12:45	367	**Reconstruction improvements and model extensions of the ATLAS SUSY search in multijet plus missing transverse momentum final state.** *Marco Valente*
13:00	368	**Tuning the simulated response of the CMS detector to b-jets using Machine learning algorithms.** *Krunal Bipin Gedia*
13:15		***END***
13:30		***Public Film Presentation***

ID	TASK Poster
371	**Johnson-Nyquist Noise Studies for the n2EDM Experiment** *Pin-Jung Chiu*
372	**Measuring Silicon Nuclei in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station** *Yao Chen*
373	**Measuring the Beryllium Isotopic Composition in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station** *Jiahui Wei*
374	**Measuring the Al/Mg ratio in cosmic rays with the Alpha Magnetic Spectrometer on the International Space Station** *Zhen Liu*

375	**Characterisations of the MALTA Monolithic Active Pixel Sensor for the Phase II upgrade of the ATLAS Inner Tracker.** *Abhishek Sharma*
376	**Monte Carlo Simulations for the Mott Calibrations of the MEGII Spectrometer** *Patrick Schwendimann*
377	**Development of a Caesium Magnetometer Array for the n2EDM experiment** *Duarte Pais*
378	**Angular analysis of $B^0 \rightarrow K^{*0}e^+e^-$ decays at LHCb** *Zhenzi Wang*
379	**Time-of-flight Ramsey Experiment with a Chopped Neutron Beam** *Estelle Chanel*
380	**The principle and detection system for the measurement of the hyperfine splitting in muonic hydrogen** *Laura Sinkunaite*
381	**Status of the Pulsed Neutron Beam EDM Experiment** *Marc Solar*
382	**Time-dependent studies with IceCube** *Stephanie Bron*
383	**Characterisation of a monolythic silicon sensor with 30 ps timing resolution** *Yves Bandi*
384	**Analysis and implications of the magnetic environment for n2EDM** *Solange Emmenegger*
385	**A novel approach to Landau damping of transverse collective instabilities in hadron colliders** *Michael Schenk*
386	**Temperature and Pressure Dependence of the Gain Achieved in an Argon Dual Phase LEM Time Projection Chamber** *Caspar Maria Schlösser*
387	**Performance of the 3x1x1 m³ dual phase Liquid Argon Time Projection Chamber prototype at CERN.** *Kevin Fusshoeller*
388	**The Geant4 Simulation of HERD Fiber Tracker** *Junjing Wang*
389	**Towards establishing LFU-breaking in $\bar{B}^0 \rightarrow \bar{K}^* \ell\ell$ decays** *Michele Atzeni*

Atomic Physics and Quantum Optics

Thursday, 30.08.2018, Room CE 5

Time	ID	**I: Quantum Science** *Chair: Philipp Treutlein, Uni Basel*
14:00	401	**Quantum Computation and Many-Body Physics with Trapped Ions** *Petar Jurcevic (i)*
14:30	402	**Einstein-Podolsky-Rosen steering between spatially separated regions in Bose-Einstein condensates** *Boris Décamps*
14:45	403	**Tunable nanoscale defect cavities for exciton-polariton condensates at room temperature** *Darius Urbonas*
15:00	404	**Optically probed phonon-Fock state dynamics** *Christophe Galland*
15:15	405	**Motional Sideband Asymmetry in Quantum Optomechanics in the Presence of Kerr-type Nonlinearities** *Liu Qiu*
15:30	406	**Backaction evasion measurement of mechanical motion in the optical domain** *Liu Qiu*
15:45		
16:30		***Coffee Break***
		II: Quantum Metrology *Chair: Boris Décamps, Uni Basel*
17:00	411	**MEMS Atomic Vapor Cells for Quantum Technologies** *Gilles Buchs*
17:30	412	**High-performance Rb atomic clock demonstration using additive manufactured microwave cavity** *Christoph Affolderbach*
17:45	413	**Generation of pure amplitude and frequency modulation in a quantum cascade laser using an integrated heater** *Atif Shehzad*
18:00	414	**Time-resolved two color X-ray pump/X-ray probe photoelectron spectroscopy at XFELs** *Andre Al Haddad*
18:15		***END***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

ID	Atomic Physics and Quantum Optics Poster
431	**Towards non-destructive transport measurements of interacting fermions** *Hideki Konishi*
432	**Quantum-Logic Spectroscopy of Molecular Ions** *Mudit Sinhal*

Advanced Electronic-Structure Developments and Applications

This session has been organised by the **NCCR MARVEL.**

Wednesday, 29.08.2018, Room CE 2

Time	ID	**Advanced Electronic-Structure Developments and Applications I** *Chair: Giacomo Miceli, EPFL*
16:30	501	**Electronic structures through *GW* and hybrid functionals: from defect levels to band gaps** *Wei Chen (i)*
17:00	502	**Koopmans-compliant functionals: A reliable and efficient tool for the prediction of spectroscopic properties** *Nicola Colonna*
17:15	503	**Electronic structure and excitonic effects in the photoanode β-$Cu_2V_2O_7$** *Julia Wiktor*
17:30	504	**pH-dependent surface chemistry and catalytic reaction pathway from first-principles** *Francesco Ambrosio*
17:45	505	**Transition-metal compounds from extended Hubbard functionals** *Matteo Cococcioni*
18:00	506	**Hubbard interactions from density-functional perturbation theory** *Iurii Timrov*
18:15		
18:30		***Postersession with Apéro***

20:00		*Public Lecture*

Thursday, 30.08.2018, Room CE 2

Time	ID	ADVANCED ELECTRONIC-STRUCTURE DEVELOPMENTS AND APPLICATIONS II *Chair: Wei Chen, Université de Louvain*
17:00	511	**Nonempirical hybrid functionals unravel the intricate mechanisms of self-compensation in Mg-doped GaN** *Giacomo Miceli (i)*
17:30	512	**Quantitative modelling of Pt(111)/water interface under bias potential through constant Fermi-level molecular dynamics** *Assil Bouzid*
17:45	513	**Surface Polarons Reducing the Overpotentials in the Oxygen Evolution Reaction** *Patrick Gono*
18:00	514	**First-principles-based prediction of yield strength in the RhIrNiPdPtCu high entropy alloy** *Yin Binglun*
18:15	515	**Silicon liquid structure and crystal nucleation from ab-initio deep metadynamics** *Luigi Bonati*
18:30	516	**Ordering at the Ga/GaAs interface. Combining first-principles and machine-learning simulations** *Giulio Imbalzano*
18:45		*END*
19:00		*Transfer to Dinner*
19:30		*Conference Dinner*

ID	ADVANCED ELECTRONIC-STRUCTURE DEVELOPMENTS AND APPLICATIONS POSTER
531	**Hole diffusion across leaky amorphous TiO_2 coating layers for catalytic water splitting at photoanodes** *Zhendong Guo*
532	**Revealing chemical patterns by combining sketch-map with the density overlap region indicator** *Benjamin Meyer*
533	**How Do London Dispersion Interactions Impact the Photochemical Processes of Molecular Switches?** *Alberto Fabrizio*
534	**Operando Spectroscopies in Electrochemical Environments from First-Principles** *Francesco Nattino*
535	**Ab-initio heat transport in ordered/disordered systems** *Michele Simoncelli*
536	**Homogeneous Electron Gas Beyond GW** *Tommaso Chiarotti*
537	**Band structure of semiconductors and insulators from Koopmans-compliant functionals** *Riccardo De Gennaro*

Advances in Topological Materials

THIS SESSION HAS BEEN ORGANISED BY THE NCCR MARVEL.

Thursday, 30.08.2018, Room CE 2

Time	ID	ADVANCES IN TOPOLOGICAL MATERIALS I *Chair: NN*
14:00	601	**Topology-driven thermoelectricity and non-abelian statistics in momentum space** *Alexey Soluyanov (i)*
14:30	602	**Observation of Weyl nodes in robust type-II Weyl semimetal WP_2** *Mengyu Yao*
14:45	603	**Topological quantum phases in graphene nanoribbons** *Pascal Ruffieux*
15:00	604	**Observation of a phononic quadrupole topological insulator** *Marc Serra Garcia*
15:15	605	**Axial field induced chiral channels in an acoustic Weyl system** *Valerio Peri*
15:30	606	**Type-I and type-II classification of composite Weyl nodes** *Daniel Gosalbez Martinez*
15:45	607	**Signatures of the 6D Quantum Hall effect in 3D topological pumps** *Ioannis Petrides*
16:00	608	**Non-trivial band topology in high pressure structure of $Ba_3CaIr_2O_9$** *Vamshi Mohan Katukuri*
16:15	609	**High-pressure phases of Kitaev Materials** *Gediminas Simutis*
16:30		*Coffee Break*
19:00		*Transfer to Dinner*
19:30		*Conference Dinner*

Friday, 31.08.2018, Room CE 2

Time	ID	ADVANCES IN TOPOLOGICAL MATERIALS II *Chair: NN*
11:15	611	**Emergence of massless Dirac and Weyl fermions in Semi-metals with broken PT symmetry** *Ming Shi (i)*
11:45	612	**Novel topological semimetals predicted from first-principles** *Quansheng Wu*
12:00	613	**Reinvestigating the surface and bulk electronic properties of Cd_3As_2** *Alberto Crepaldi*
12:15	614	**Prediction of a large-gap and switchable Kane-Mele quantum spin Hall insulators from first-principles simulations** *Antimo Marrazzo*
12:30	615	**Magnetoresistance from Fermi surface topology** *Shengnan Zhang*
12:45	616	**Electronic and spin structure of the nodal-line semimetals ZrSiX (X=Se,Te)** *Gianmarco Gatti*
13:00	617	**Experimental evidence of proximity induced odd-frequency superconductivity in a topological insulator** *Jonas Krieger*
13:15		*END*
13:30		*Public Film Presentation*

ID	Advances in Topological Materials Poster
631	**Ultrafast light-spin phenomena in topological insulators** *Davide Bugini*
632	**Deep insight into the electonic structure of ternary topological insulators: A comparative study of $PbBi_4Te_7$ and $PbBi_6Te_{10}$** *Ilenia Grimaldi*
633	**Substrate-induced topological mini-bands in Dirac materials** *Tobias Wolf*
634	**From a 4D Dirac model to the boundary physics of 2D lattices** *Ioannis Petrides*
635	**Measurement of the entanglement spectrum of a symmetry-protected topological state using the IBM quantum computer** *Kenny Choo*

SwissFEL- recent advances and future opportunities

Thursday, 30.08.2018, Room CE 4

Time	ID	SwissFEL- recent advances and future opportunities I *Chair: NN*
14:00	701	**New insights into condensed matter functions by ultrafast Free Electron Laser science** *Henrik Till Lemke (i)*
14:30	702	**Structural Dynamics of Ti_3O_5 nanocrystals** *Marco Cammarata (i)*
15:00	703	**Ultrafast dynamics of electronic and crystal structure in correlated materials** *Urs Staub (i)*
15:30	704	**Femtosecond electron-phonon lock-in in FeSe via ultrafast x-ray scattering and photoemission** *Simon Gerber*
15:45	705	**Exploring photoswitching pathways in photomagnetic materials with ultrafast optical and X-ray spectroscopies** *Serhane Zerdane*
16:00	706	**THz/x-ray pump-probe experiments on metal catalyst surfaces** *Luca Castiglioni*
16:15	707	**X-ray detection of ultrashort spin current pulses in magnetic multilayers** *Christian Stamm*
16:30		***Coffee Break***
		SwissFEL- recent advances and future opportunities II *Chair: NN*
17:00	711	**The next free electron laser line of SwissFEL: Athos** *Romain Ganter*
17:15	712	**Time-resolved Resonant Inelastic X-ray Scattering on Quantum Materials** *Claude Monney (i), Thorsten Schmitt (i)*
17:45	713	**X-ray Diffraction under Extreme Conditions** *Johan Chang (i)*
18:15	714	**Nonlinear XUV-optical transient grating spectroscopy at the Si L2,3 – edge** *Rok Bohinc*
18:30	715	**SwissFEL photon diagnostics: current situation and future outlook** *Christopher Arrell*
18:45	716	**ACHIP experiments at PSI** *Eugenio Ferrari*
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 31.08.2018, Room CE 4

Time	ID	SwissFEL- recent advances and future opportunities III *Chair: NN*
11:15	721	**First results from the SwissFEL Alvra experimental station** *Jakub Szlachetko (i)*
11:45	722	**Ultrafast X-ray spectroscopy and scattering of photo-excited systems at X-ray Free Electron Lasers** *Giulia Fulvia Mancini (i)*
12:15	723	**Correlated spin and structural dynamics in the recombination of nitric oxide (NO) to deoxy-Myoglobin in physiological media** *Dominik Kinschel*
12:30	744	**Tracing the nuclear and electronic structure of excited molecules using femtosecond XUV and X-ray pulses** *Kirsten Schnorr (i)*
13:00	725	**Single-shot imaging of nanoparticles with FEL pulses** *Christoph Bostedt*
13:15		***END***
13:30		***Public Film Presentation***

ID	SwissFEL Poster
731	**SwissFEL Event Timing System** *Tomaž Šuštar*

Magnetism and Spintronics at the Nanoscale

Wednesday, 29.08.2018, Room CE 1

Time	ID	Magnetism and Spintronics at the Nanoscale I *Chair: Claire Donnelly, PSI Villigen*
13:30	801	**Single Atom Magnets at Surfaces** *Harald Brune (i)*
14:00	802	**Chemically selective reorganization of molecular Bi-layers films driven by molecule-substrate interactions** *Mehdi Heydari*
14:15	803	**Antiferromagnetic properties of individual goethite nanoparticles studied by temperature and orientation-dependent X-ray spectromicroscopy** *David M. Bracher*
14:30	804	**Imaging scale-invariant antiferromagnetic textures in a nickel oxide** *Jonathan Pelliciari*
14:45	805	**Imaging the magnetization reversal in strongly exchange-coupled bilayers** *Andrada-Oana Mandru*
15:00	806	**Damping Modulation in Magnetic Thin Films** *Susmita Saha*
15:15	807	**Skyrmion formation in SRO-SIO epitaxial bilayer** *Mirko Bacani*

15:30	808	**Asymmetric domain wall nucleation in DMI coupled in-plane and out-of-plane magnetic wires** *Phuong Dao*
15:45	809	**Edge states in graphene: spin polarization and how to protect them** *Amogh Kinikar*
16:00		***Coffee Break***
18:30		***Postersession with Apéro***
20:00		***Public Lecture***

Thursday, 30.08.2018, Room CE 1

Time	ID	Magnetism and Spintronics at the Nanoscale II *Chair: Jizhai Cui, PSI Villigen*
14:00	811	**Magnetic domain walls – from basics to applications** *Rolf Allenspach (i)*
14:30	812	**Velocity enhancement by synchronization of magnetic domain walls** *Ales Hrabec*
14:45	813	**Chiral coupling between in-plane and out-of-plane nanomagnetic patterns induced by interfacial Dzyaloshinskii-Moriya interaction** *Zhaochu Luo*
15:00	814	**Spin-orbit torque induced domain switching in antiferromagnet/ferromagnet heterostructures** *Gunasheel Krishnaswamy*
15:15	815	**Effects of oxidation on the spin-orbit torques and topological domain textures in ultrathin Pt/Co/AlO_x layers** *Junxiao Feng*
15:30	816	**Emergent Dynamic Chirality in a Thermally Driven Artificial Spin Ratchet** *Sebastian Gliga*
15:45	817	**Exploration of Topological Defects in Kagome Artificial Spin Ice via Magnetic Force Microscopy and Brillouin Light Scattering Spectroscopy** *Vinayak Shantaram Bhat*
16:00	818	**Nanoscale Magnetic Imaging of Artificial Spin Ices Using Single Spins in Diamond** *Natascha Hedrich*
16:15	819	**Phase diagram of dipolar-coupled XY moments on disordered square lattices** *Dominik Schildknecht*
16:30		***END; Coffee Break***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

ID	Magnetism and Spintronics Poster
831	**Magneto-mechanical material** *Paolo Testa*
832	**Anomalous Nernst effect in $Ir_{22}Mn_{78}/Co_{20}Fe_{60}B_{20}/MgO$ layers with perpendicular magnetic anisotropy** *Junfeng Hu*
833	**Broadband spin-wave spectroscopy on artificial ferromagnetic quasicrystals identifying characteristic mode motifs** *Sho Watanabe*
834	**All electrical method for detecting parametrically pumped spin waves in a magnetic insulator** *Kyongmo An*
835	**Direct observation of a tunable spin wave phase shift at a magnetic defect in a one-dimensional magnonic crystal** *Korbinian Baumgaertl*
836	**Electroless Deposition of Magnetic Materials on Three-Dimensional Nanostructures** *Petai Pip*
837	**Direct correlation of atomic structure and magnetic properties of individual cobalt nanoparticles: experiment vs. simulation** *Tatiana Savchenko*
838	**Broadband spin wave spectroscopy of yttrium iron garnet decorated with ferrimagnetic nanoparticles** *Andrea Mucchietto*
839	**Confined spin waves in ferromagnetic nanotubes detected by Brillouin light-scattering spectroscopy** *Maria Carmen Giordano*
840	**Presence of Neel Skyrmions in magnetic thin film with in-plane anisotropy** *Jaianth Vijayakumar*
841	**Spatial correlations in artificial XY spin systems** *Kevin Hofhuis*
842	**Spin Wave Nonreciprocity in Bi-component Magnonic Crystals** *Jingyuan Zhou*
843	**Numerical Studies of Skyrmion Lattices** *Thomas Schönenberger*
844	**EPR Study of Spin Dependent Charge Transfer Processes at Functionalized Electrodes** *Felix Blumenschein*
845	**Zero-field switching of Pt/Co/AlO_x nano-dots induced by inhomogeneous current density** *Giacomo Sala*

Biophysics and Medical Physics

Wednesday, 29.08.2018, Room CE 5

Time	ID	Biophysics and Medical Physics I *Chair: Paolo de los Rios, EPFL*
13:30	901	**Statistical physics of river networks (statics, dynamics, ecological complexity)** *Andrea Rinaldo (i)*
14:00	902	**Oscillatory stimuli differentiate adapting circuit topologies** *Sahand Jamal Rahi (i)*
14:30	903	**Traction Forces Mediate Cell Activity During Cell Polarization** *Zeno Messi*
14:45	904	**Non-Additive Model for Wetting of Heterogeneous Structures** *Anna Murello*
15:00	905	**Photonic Crystal supported surface electromagnetic waves and their use for ultrasensitive label-free biosensing and generation of long propagating surface plasmon - polaritons** *P. O. Kapralov*
15:15	906	**Revealling the mechanism of protein aggregation and fibrillization by atomic force microscopy** *Jiangtao Zhou*
15:30	907	**Coevolution based inference of allosteric architectures** *Barbara Bravi*
15:45		
16:00		***Coffee Break***

Time	ID	**Biophysics and Medical Physics II** *Chair: Paolo de los Rios, EPFL*
16:30	911	**Integrative modeling at the protein-membrane interface** *Matteo Dal Peraro (i)*
17:00	912	**Scaling Morphogenesis** *Marcos Gonzales-Gaitan (i)*
17:30	913	**Exciton dynamics in DNA oligomers studied by broadband deep-UV transient absorption spectroscopy** *Benjamin Bauer*
17:45	914	**Single-Shot Broadband Femtosecond Circular Dichroism in the Deep-UV** *Malte Oppermann*
18:00	915	**Implementation of cylindrical PET scanners with block detector geometry in STIR** *Parisa Khateri*
18:15	916	**The SAFIR Readout Prototype** *Christian Edwin Ritzer*
18:30		***END; Postersession with Apéro***
20:00		***Public Lecture***

ID	**Biophysics and Medical Physics Poster**
931	**Modelling the Relationship Between Cell Geometry and Traction Force Distribution** *Zeno Messi*
932	**Fast drug susceptibility testing with nanomechanical sensors** *Petar Stupar*
933	**Long-life plastic optical fiber probes for Scanning Near-field Optical Microscope** *Emilie Laetitia Haizmann*
934	**Microfabricated nanomotion detectors for ultra-rapid bacterial sensitivity tests** *Anton Malovichko*
935	**Ultrasensitive NMR and MRI with hyperpolarised radionuclei** *Jared Croese*

Public Presentation: *Let there be light*, a film on the quest for fusion energy

This time, for once, the conference will be closed by a film on Friday 31 August, 13:30h.

This documentary on fusion energy research uses the form of interviews of physicists and engineers, either from the large international project ITER at the halfway pint of its construction in the south of France and involving many partner countries, or other smaller projects mainly in North America. Directed by two Canadian filmmakers, Mila Aungh-Thwin and Van Royko, it follows researchers in their daily lives. Thus, not only does it show us large experimental facilities while recalling the important milestones in the history of fusion, but it also leads us to the heart of what motivates researchers to dedicate their lives to see the realization of fusion energy. There is a good balance between the scientific and the social aspects in this film, which was one of the top 10 Canadian films in 2017. This film represents a solid introduction to the subject and a useful update on the state of the art for those already familiar with the subject, but it is primarily intended for a large non-scientific audience.

Mark Henderson, responsible for Electron Cyclotron Wave Heating and Current Drive at ITER and at the same time one of the main protagonists of the film, sharing motivations with workers constructing ITER bioshield. © Let there be Light.

One of ITER superconducting toroidal field coil built in Italy, ready to ship to ITER. © Let there be Light.

After “ITER, An essential step towards fusion energy”, the plenary talk by Tim Luce depicting in all its scientific rigor the implementation of ITER scientific program to realize and to study burning plasmas, ***Let there be Light*** describes with the means of a documentary film the research on fusion in the wider context of the search for a sustainable, clean, safe and inexhaustible source of energy with low carbon emission.

By way of introduction, a 3-minutes film resulting from a long weekend training course on *how to communicate science* and made by students, “Sun in a box” (see *SPG Mitteilungen* Nr. 54, p. 36), gives us a peek at a poetic approach of communicating science.

Aussteller - Exposants

COMSOL Multiphysics GmbH, 8005 Zürich
www.comsol.com

Coyslab Switzerland GmbH, 5303 Würenlingen
www.cosylab.com

Dyneos AG, CH-8307 Effretikon
www.dyneos.ch

Handelsvertretung Technische Produkte für Forschung und Industrie, DE-44623 Herne
www.vacgen.com

Keyence International (Belgium) NV/SA, BE-2800 Mechelen
www.keyence.eu

MaTeck GmbH, DE-52428 Jülich
mateck.com

PINK GmbH Vakuumtechnik, DE-97877 Wertheim
www.pink-vak.de

teltec systems AG, 5620 Bremgarten
www.teltec.ch

TOPTICA Photonics AG, DE-82166 Gräfelfing
www.toptica.com

X-Tronix AG, CH-1027 Lonay & CAEN Electronic Instrumentation
www.xtronix.ch

Zurich Instruments, CH-8005 Zürich
www.zhinst.com

#Wescientists Research Culture workshops: let's co-construct the future of research at the Annual Meeting of the Swiss Physical Society at EPFL!

Pre-conference workshop, 28 August 2018, 13:30 - 16:00, Room CE 101

Research culture is the culture within the research ecosystem that influences the environment, the people and utlimately ultimately, the quality of work that is being done. Research culture stems from the values, norms and expectations of researchers and it influences aspects such as research integrity, openness, inclusivity, academic career trajectories, the peer review system and attitude towards public engagement.

At the **We Scientists Shape Science** (*https://naturalsciences.ch/topics/wescientists*) meeting in January 2017, 200 researchers and key players from the Swiss research landscape met to discuss the issues relating to research culture in Switzerland. As part of its ongoing commitment to improving research culture, SCNAT is adapting the Royal Society UK's workshops « Visions of 2035 ». We are offering the workshop to up to 12 participants of this year's SPS Annual Meeting at EPFL. The workshop uses speculative design scenarios to encourage novel thinking about what an idealised research culture would look like in 27 years time, with the aim to start with small changes today.

In the first part of the workshop, participants will explore two alternate future research culture scenarios. They will discuss what they like and dislike about them and what they would do differently. The group will then co-construct their ideal future research culture. In the second part of the workshop, the participants will plan the first steps required to achieve their ideal. The goal is that after the workshop, participants will feel empowered to implement small changes in their research environments and to make the outcome a source of inspiration for others.

This workshop is open to researchers from all career stages but is limited to 12 participants. It is available on a first come, first served basis via the SPS conference registration system. If you have any questions regarding the content of the workshop, please contact Tania Jenkins (*tania.jenkins@scnat.ch*).

Le Référentiel, selon Ferdinand Gonseth

Colloque du 1er septembre 2018, organisé par l'Association Ferdinand Gonseth, sous le patronage des Sociétés, française et suisse, de physique (SFP, SSP), à l'Ecole Polytechnique Fédérale de Lausanne (EPFL), sur le thème du référentiel de la recherche scientifique.

Dans les dernières années de son long itinéraire scientifique et philosophique, Ferdinand Gonseth a élaboré le concept de référentiel, qui mesure la part du sujet dans les connaissances objectives. Grâce au référentiel, ce qui est du sujet humain et ce qui n'est pas de lui apparaissent irréductiblement distincts et irréductiblement complémentaires. Leur rencontre s'effectue toujours dans cet *horizon intermédiaire* et *mixte* de la subjectivité et de l'objectivité. Ce faisant, il met en situation notre projet d'exister [1], inhérent à l'être vivant que nous sommes. Le sort de nos vies dépend de la nature idoine ou non du référentiel par lequel nous nous projetons dans le monde et le laissons venir à nous. Le référentiel se définit comme *un instrument de médiation des pôles de la subjectivité et de l'objectivité, qui intervient à tous les niveaux de l'activité humaine*.

Le but du colloque vise à éclairer le pouvoir d'intervention du référentiel dans la recherche scientifique et ses répercussions décisives sur la destinée humaine. L'enjeu est aujourd'hui crucial.

Ce référentiel est collectif, mais il n'existe et ne se renouvelle que dans les référentiels individuels qui y prennent part. Il opère la médiation de la conscience méthodologique des chercheurs et de leur conscience éthique qui les confronte à la responsabilité envers notre projet d'exister, inséparable de celui de tous les êtres vivants qui constituent la biodiversité. Mais il permet aussi d'articuler la vision de l'homme que nous offrent les sciences de la nature et celle que nous fournissent les sciences humaines, d'en faire deux miroirs dans lesquels nous pouvons tour à tour nous regarder dialectiquement [2], sans pouvoir ni les réduire à l'identique ni les séparer par une ligne de démarcation tranchée. Un humanisme engagé dans l'expérience pourrait alors se développer. Il valoriserait surtout le choix d'assumer notre responsabilité envers notre projet d'exister et, dans cette mesure, nous donnerait le droit d'espérer la poursuite de l'aventure humaine à travers les générations futures.

Des scientifiques de haut niveau ont accepté de traiter les différents sujets de ce colloque. Michel Spiro parlera de la question du *référentiel de la recherche scientifique dans la coopération internationale*. Alexei Grinbaum abordera la question : *Observateur et contextualité dans la mécanique quantique*. Gilles Cohen-Tannoudji interviendra sur le rôle du *référentiel en physique théorique*. Blaise Jeanneret fera un exposé sur *Le référentiel et le système métrologique dans les sciences*. Pierre-Marie Pouget présentera, en guise d'introduction au colloque, l'idée du *référentiel dans l'itinéraire scientifique et philosophique de Ferdinand Gonseth*. Estefania de Mirandès, secrétaire exécutive du Comité Consultatif des Unités (CCU) du Bureau des Poids et Mesures, et Vincent Bontems, philosophe des techniques au Laboratoire de Recherches sur les Sciences de la Matière (Larsim) du Commissariat à l'Énergie atomique et aux Énergies alternatives (CEA), sont deux personnalités invitées pour *soulever les questions et les critiques susceptibles de mettre les interventions en perspective*.

Le programme du colloque et l'ouverture des inscriptions sont en ligne. Internet : http://csph-2018.sciencesconf.org. Le site web de l'association donne des informations plus complètes sur la vie et les œuvres de Ferdinand Gonseth : http://afg.logma.ch

Pierre-Marie Pouget

1 Le projet d'exister n'est pas intentionnel. Il est une propriété de l'invariance reproductive des êtres vivants. Des perturbations au hasard surviennent dans cette invariance, qui les conserve et qui peuvent être ainsi soumises à la sélection naturelle. De la sorte, l'être vivant que nous sommes, à l'instar de tous les êtres vivants, est porteur d'un projet d'exister, qui l'adapte à sa survie.

2 Nous regarder dialectiquement, c'est-à-dire sous la pression de l'expérience croisée des sciences de la nature et des sciences humaines, qui enrichit notre situation ou l'ébranle plus ou moins, nous obligeant à la réviser en conséquence.

Ferdinand Gonseth, né à Sonvilier (Jura bernois) en 1890 et mort en 1975, a enseigné les mathématiques à l'Université de Berne, puis à l'École Polytechnique Fédérale de Zurich. Mais dès le début de sa carrière, il s'est intéressé aux fondements des mathématiques, à la philosophie des sciences et à la théorie de la connaissance. Ses principaux ouvrages sont :

Les fondements des mathématiques (1926/1974)
Les mathématiques et la réalité (1936/1974)
Déterminisme et libre arbitre (1944)
La géométrie et le problème de l'espace (1945-1956)
Le problème du temps (1964)

auxquels il faut ajouter des manuels d'enseignement des mathématiques ainsi que de nombreux articles et conférences. Il a ainsi constitué une pensée originale, appelée idonéisme ou aussi méthodologie ouverte, pensée qui refuse de se laisser enfermer dans des a priori dogmatiques et exige une totale ouverture à l'expérience. Cependant, ses préoccupations ne se sont pas cantonnées dans ce cadre relativement restreint. À la fin de sa vie, Gonseth s'est tourné vers les sciences humaines; il a tenté d'appliquer à un domaine plus vaste, en particulier en linguistique et en morale, une méthodologie rigoureuse qui a fait ses preuves dans le domaine des sciences dites exactes.

Source: http://afg.logma.ch/fg.htm

Dr. sc. nat. ETH Karl Knop

(12. Dezember 1943 – 19. März 2018)

Das langjährige SPG-Mitglied Karl Knop starb am 19. März 2018 während einer Reise nach Norwegen, als er sich den lang gehegten Wunsch erfüllte, die Faszination des Polarlichtes zu erleben. Mit ihm verliert die Schweiz einen ihrer bekanntesten Physiker an der Schnittstelle zwischen Hochschule und Industrie. Als Leiter des ehemaligen RCA Zurich Labs, später als Leiter der CSEM-Division „Photonics" und als Mitinitiator der Schweizer Nanoconvention hat er viele Grundlagenphänomene der modernen Optik, der Photonik und speziell der Nano-Photonik frühzeitig erkannt und so weit entwickelt, dass sie heutzutage von der Industrie produktmässig eingesetzt werden können.

Um diesen Prozess zu beschleunigen, setzte er sich stets für Kooperationen von Wissenschaftlern und Technikern ein. Das geschah auf vielfältige Weise, wie z.B. als Präsident der damaligen SGOEM (Schweizerische Gesellschaft für Optik und Elektronenmikroskopie; heute SSOM, Swiss Society for Optics and Microscopy) und als Leiter der Sektion Optik, als er die EOS Topical Meetings und die SSOM Engelberg Lectures im Stile von Gordon-Konferenzen mitinitialisierte und dann regelmässig auch bei deren Durchführung aktiv mitwirkte (siehe Bild 3). Dazu gehörte auch sein Engagement bei den Grundlagenprogrammen des ETH-Rats Ende der 90er Jahre wie Optique I / II, welche damals die einschlägige Schweizer Industrie so nachhaltig weiterbrachten, dass man heute über ihre Wiedereinführung nachdenkt. Schliesslich sein starkes Engagement für die Nanotechnik und hier speziell für die Nanophotonik, als er den Wechsel von der Mikro- in die Nanophysik frühzeitig erkannte.

Der Wissenschaftliche Beirat der SATW hatte bis 2011 mehrere Fachkommissionen und Karl leitete damals diejenige für Nanotechnologie. Als Physiker war er nicht nur an deren physikalisch-chemischen Aspekten interessiert, sondern zeigte auch ein äusserst grosses Interesse an der Rolle, die Nanopartikel im Menschen, d.h. für dessen Gesundheit und in der Umwelt spielen.

Die SATW faszinierte er über viele Jahre hinweg mit eigenen Beiträgen und initiierte unter anderem die SATW Tec-Days, um Jugendliche für Wissenschaft und Technik zu begeistern. Selten hat ein Programm eine solch flächendeckende positive Wirkung erzielt und für die richtige Weichenstellung in der Schweiz gesorgt, um als HighTech-Nation weltweit mithalten zu können. Mittlerweile konnten laut SATW bereits rund 50'000 Schülerinnen und Schüler sowie etwa 5'000 Lehrpersonen von seiner Idee profitieren.

Karl war seit 1968 SPG-Mitglied, und er wirkte von 1993 - 94 als Kassier und von 1995 - 96 als Revisor.

Es war das grosse Interesse von Karl als Physiker über die Physik hinaus, das begeisterte. Er war fachlich äusserst kompetent und dachte immer interdisziplinär. Er war dynamisch und immer wieder an Neuem interessiert und zu neuen Taten bereit. Auf gemeinsamen Reisen oder bei gemeinsamen Essen konnte man mit ihm über Gott und die Welt diskutieren. Es war diese Offenheit und dieses sehr breite Interesse allem und allen gegenüber, das faszinierte. Zudem war Karl ein fantastischer Mensch, offen und ehrlich, liebenswürdig und verständnisvoll, der sich allen zuwendete und alle und alles zu verstehen versuchte. Verstehen, selber herleiten, erklären war seine Motivation, nicht anhäufen von Wissen.
Unsere tiefe Anteilnahme gilt seiner Frau Heidi und seiner Familie.

Bernhard Braunecker (der die Beiträge vieler Kolleginnen und Kollegen zu diesem Nachruf zusammenfasste)

Beide Bilder im Text wurden 2006 in Side/Türkei aufgenommen, als Karl mit vielen Physikkollegen aus aller Welt die totale Sonnenfinsternis in all ihren optischen Feinheiten erlebte. Das dritte Bild zeigt die Teilnehmer der SSOM Engelberg Lecture 2007 „Photonics in Space" mit Karl links in der ersten Reihe.

Progress in Physics (63)

The challenge of long-distance quantum communication: From quantum repeaters to a quantum internet.

Mikael Afzelius, Department of Applied Physics, University of Geneva

When most people connect to the internet through their tablets and smartphones, they might not know exactly what kind of technology makes the internet possible. But most physicists would know that at the physical network layer, internet data is composed of trains of short laser pulses zipping through optical fibres. The technologies underpinning the internet were developed during the second half of the 20th century, such as lasers, single-mode optical fibres, erbium-doped fibre amplifiers (EDFAs), electro-optic modulators and semiconductors, just to mention a few. As numerous technologies that are important for our society rely on the understanding of quantum mechanics, many refer to this as the first quantum revolution.

While the discovery of quantum mechanics was essential for the invention of lasers, transistors and other devices, in applications they do not explicitly exploit quantum effects such as superposition or entanglement. Across the internet, for example, classical bits of information are encoded using the amplitude or phase of the laser pulses consisting of large number of photons, where quantum effects are too weak and subtle to detect.

Today physicists work on novel quantum technologies that explicitly use quantum superposition and entanglement for their applications, with the goal of building devices that can outperform classical devices for secure communication, sensing, simulation and computation. Many therefore argue that we are in the beginning of a second quantum revolution, which might define many of the technologies to come in the 21st century. In Switzerland many research groups realized the potential of quantum technologies early on and the SNSF supports the NCCR "QSIT - Quantum Science and Technology" since 2011. On the European level a Flagship on Quantum Technologies is in the processes of being launched in 2018. At the same time large IT enterprises (Google, Intel, IBM, Microsoft) have started investing in quantum technologies. Here in Switzerland we recently saw ID Quantique, a spin-off company of our Department of Applied Physics at the University of Geneva that has commercially pioneered quantum cryptography, joining forces with SK Telecom, the largest telecom operator in Korea. Clearly the recent gain in momentum for quantum technologies provides many exciting opportunities for researchers, students and engineers interested in quantum physics. The challenges are many as these new technologies are pushed upwards on the technological readiness ladder.

In this report I will focus on quantum communication over long distances, which has been identified as one of the key challenges for the coming decade. Today's systems for quantum cryptography, such as those from ID Quantique, are based on technologies that are fundamentally limited to distances up to maybe 500 km, while continental distances of 1000 km or more definitely will be out of range. To overcome this limit quantum repeaters have been proposed, in analogy to the classical repeater stations used in optical fibre communication. However, straightforward amplification of signals does not work in quantum communication, so quantum repeaters rely on entirely different principles. In fact, a quantum repeater will need a whole set of new technologies, such as quantum memories for single photons, sources of entangled photons, and very efficient single photon counters. Among these the most difficult part is often considered to be the quantum memory, which is the focus of my own research at the Department of Applied Physics at the University of Geneva. Future quantum repeaters will allow the distribution of quantum resources such as entanglement, with applications that go beyond quantum cryptography, e.g. for distributed computing or sensing applications, which lay at the heart of the vision of a quantum internet [1].

Quantum Key Distribution

The very first idea of a quantum communication protocol was published by Bennett and Brassard already in 1984 [2], who proposed a way to distribute a secret key between two parties where security can be guaranteed by the laws of quantum physics. So-called public key distribution is of even more importance now than back in 1984, as any secure communication over the internet (e.g. financial transactions) is based on public key distribution. The security of today's

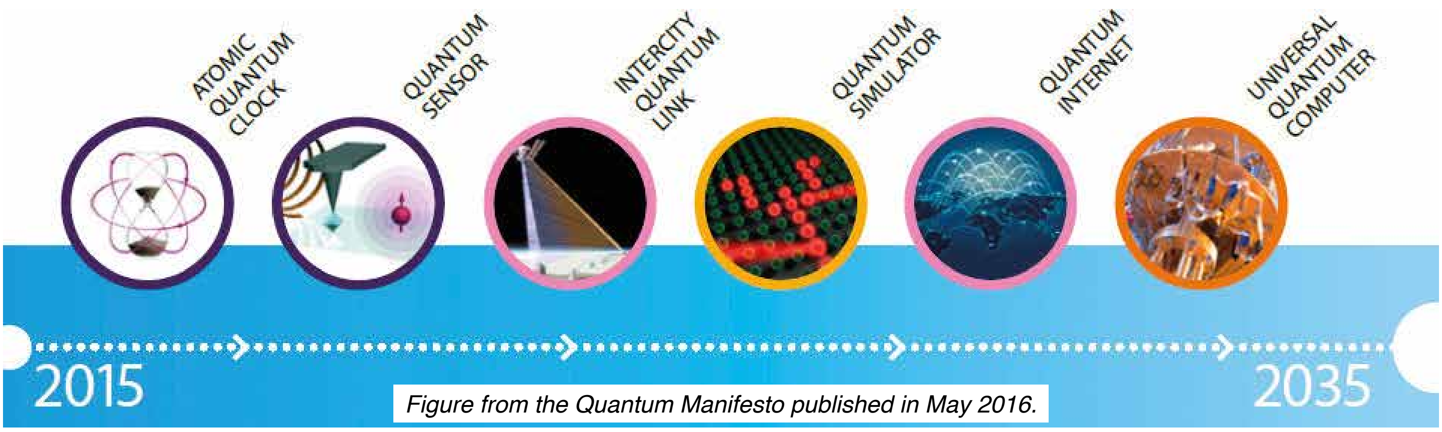


Figure from the Quantum Manifesto published in May 2016.

methods relies on mathematical problems that cannot be solved efficiently using known algorithms, but there is no guaranteed security with these methods. Also, a powerful quantum computer could break encrypted data in the future, meaning that very sensitive data communicated today might not be entirely secure in the future (we might want some secrets, such as medical records, to be hack-proofed also for the next decades!). Quantum key distribution (QKD) schemes provide a new paradigm, where security is guaranteed by the laws of quantum physics, whether it is now or decades in the future.

In classical communication, the information is encoded into bits, 0s or 1s, which can be represented by laser pulses with different amplitudes, for instance. In quantum communication, the information is encoded as qubits, which can be arbitrary superposition states $\alpha|0\rangle+\beta|1\rangle$ of some basis states $|0\rangle$ and $|1\rangle$. In short, the security of QKD is based on the fact that non-orthogonal qubit states, for instance $|0\rangle$ and $\frac{1}{\sqrt{2}}(|0\rangle+|1\rangle)$, cannot be measured simultaneously. In a QKD scheme, the sender (Alice) and the receiver (Bob) randomly switch between non-orthogonal qubit states and measurement bases. Any adversary (Eve) that tries to spy on the communication, for instance by measuring some qubits, will necessarily modify some qubit states and introduce errors that are detectable by Alice and Bob. By measuring the so-called quantum bit error rate (QBER), Alice and Bob can guarantee that a provable secret key can be extracted from the measurement outcomes.

So how does one realize a QKD scheme in practice? On Alice's side the qubit is ideally encoded onto a single photon, because photons can travel far before losses become a problem. The qubit can be encoded into any degree of freedom, such as polarization, position or time(-bin). If the photon qubit will be sent through optical fibres then time-bin qubits are often used as they are more resilient to polarization rotation in fibres. In practice one can also replace the single-photon source on Alice's side by a laser pulse containing less than a photon in average (0.1 photons is commonly used), which is more practical than a true single-photon source. On Bob's side there is a qubit measurement device and a single-photon counter.

The challenges of current QKD research is to increase the quantum key rate and the maximal usable distance, which are very important for real-life applications. These two aspects are linked together, as the exponential losses of any channel, such as an optical fibre, implies that the photon detection rate is decreasing as the distance is increased. For both objectives, the performance of the detectors is determining. In the state-of-the-art QKD systems developed in the group of Prof. Hugo Zbinden at the University of Geneva, see Figure 1, the source qubit rate is 2.5 GHz and secret key rates of more than 1 kbit/s over 200 km of fibre can be achieved using simple semi-conductor detectors [3]. In order to further improve these performances, the Geneva group develops, in collaboration with colleagues from the University of Basel (Prof. Richard Warburton), superconducting single-photon detectors featuring more than 80% of detection efficiency and almost arbitrarily low noise [4]. With these detectors and ultra-low loss fibres, transmission distances of more than 400 km are expected, as well as maximum secret key rates (over short distances) of up to 100Mb/s.

The long-distance problem in QKD

The question is then how far one can transmit qubits with today's QKD systems ? The photon transmission probability of any optical channel is exponentially decreasing with the distance. Commercial ultra-low loss optical fibres have loss coefficients of about 0.17 dB/km. If we assume a QKD system with an optimistic 10 GHz qubit rate, then the detection rate after 500 km is 31 Hz, which is still quite realistic for applications. But for a distance of 1000 km one would need to wait about 4 months to get a single photon detection!

In today's optical fibre networks, the loss problem is solved by inserting optical amplifiers at appropriate intervals, which amplify the laser pulses carrying the classical bits. In quantum communication this is not possible due to the no-cloning theorem [5], which says that an unknown quantum state cannot be amplified (cloned) without introducing errors. So, without the possibility to faithfully amplify qubits, it would look like QKD, or any other quantum communication scheme relying on sending qubits, is limited to about 500 km. But this is where quantum repeaters come in, as these can provide a solution to long-distance quantum communication in general, and specifically to long-distance QKD.

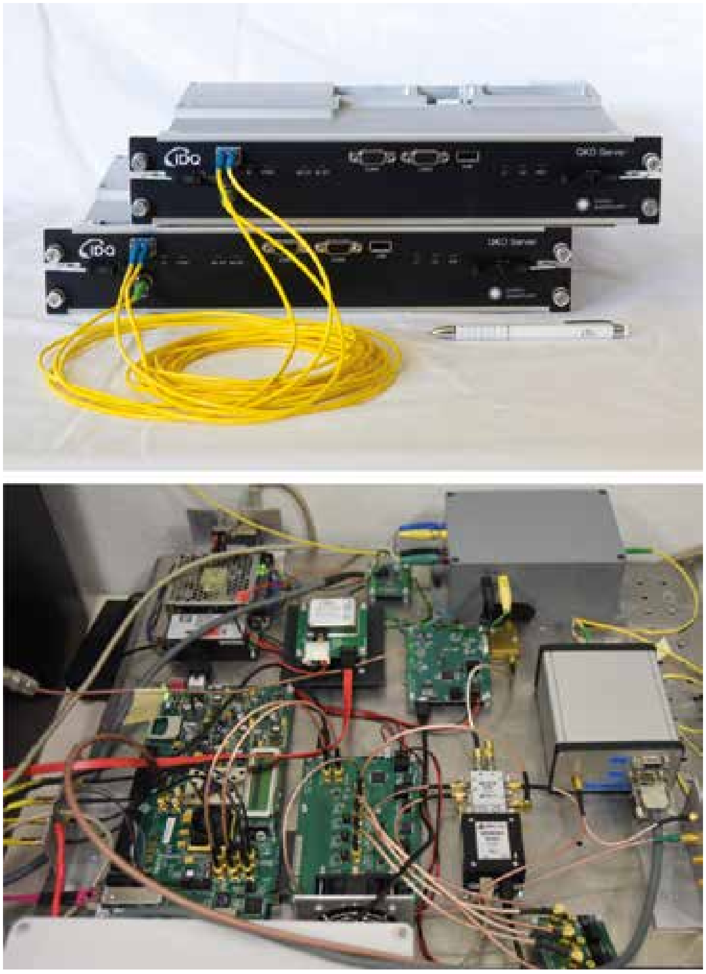


Figure 1. (Top) Commercial QKD system from ID Quantique based on a 2nd generation research prototype from University of Geneva. (Bottom) 3rd generation QKD prototype under development in the group of Prof. Hugo Zbinden at University of Geneva (courtesy Alberto Boaron).

But before describing the basic principles of quantum repeaters, I would like to mention the use of satellites for long-distance quantum communication. In 2016 China launched "Micius", the first satellite dedicated to quantum science experiments. With "Micius" the group of Jian-Wei Pan demonstrated satellite-to-ground QKD up to distances of 1200 km [6]. These amazing experiments represent a real break-through for satellite-based QKD, but also reveal some of the limitations using satellites. The QKD downlink was only possible at night under good atmospheric conditions, and the low-altitude orbit implied that the satellite only briefly passed over the ground station during each orbit. But satellite communication could be the only option for some geographical situations, as crossing an ocean or a large mountain range. In my opinion future quantum networks will probably rely on both satellites and fibre-optic networks on the ground, as is the case for classical communication networks.

Quantum Repeaters and Memories

The quantum repeater was first suggested by H.-J. Briegel et al. in 1998 [7], which is a method for overcoming the exponential loss-problem of point-to-point quantum communication. To understand how it works we need to have a basic notion of quantum entanglement, and the process of entanglement swapping. Let's consider two photons *A* and *B* in an entangled state $|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}(|1\rangle_A|1\rangle_B + |0\rangle_A|0\rangle_B)$. If Alice measures photon *A*, she would randomly obtain either the result 0 or 1, and so would Bob if he measured photon *B*. However, if they compare the measurement results they would make the astonishing discovery that their results are perfectly correlated, for some choices of measurement bases, although they could be space-like separated such that no signal traveling with the speed-of-light could explain this weird correlation (we say that the correlations are non-local). Entanglement, and the non-local correlations that it can produce, was for a long time considered as only interesting for the foundations of quantum mechanics, but has since then entered the realm of applied physics through the invention of quantum technologies.

In quantum communications the correlated measurement results obtained with entangled states can be used for quantum key distribution, as first proposed by Eckert in 1991 [8]. Shortly afterwards, in 1993, Bennet et al. realized that entanglement can also be used to perform so-called quantum teleportation [9], by which a qubit can be teleported from one place to another provided that an entangled state has been created between the two places. This discovery led others to propose a way to "connect" two entangled states through a process known as entanglement swapping. Let's say we have two independent pairs of photons *AB* and *CD*, both in entangled states $|\psi\rangle_{AB}$ and $|\psi\rangle_{CD}$. In entanglement swapping we perform a joint measurement on the photons *B* and *C*, a so-called Bell-state measurement (BSM), which projects photons *A* and *D* onto an entangled state $|\psi\rangle_{AD}$ without them ever having interacted directly [10]! In fact, photons *A* and *D* could be 100s of km apart, as long as photons *B* and *C* are brought together to some measurement station where the BSM is performed.

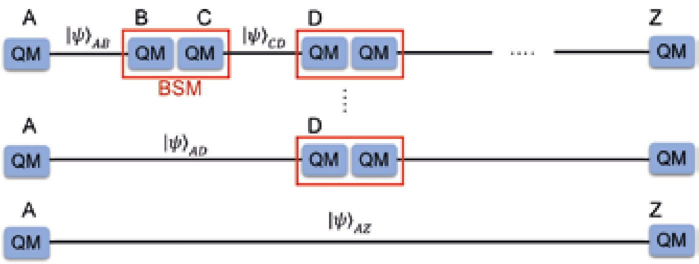


Figure 2. A quantum repeater breaks up the total distance between points A and Z into shorter elementary links. Entanglement between quantum memories (QM) in each node (A to Z) is established independently using entangled photons. Entanglement swappings using Bell-state measurements (BSMs) then extend the entanglement to points A and Z.

This is the central concept behind quantum repeaters, as illustrated in Figure 2. If we want to entangle two systems (e.g. photons) over a very large distance, then we divide the total distance into shorter segments (elementary links) over which the losses are sufficiently low to be able to distribute entanglement (let's say between 50 and 100 km). Once this step is done, one can perform BSMs on neighbouring entangled particles to swap the teleportation over ever larger distances, to end up with one final entangled state over let's say 1000 km. Now, when using entangled photons the great difficulty is to succeed in the BSM. The photons have to travel large distances before reaching the BSM, meaning there is a significant probability of losing at least one of the photons, if not both. This is why we need quantum memories.

A quantum memory is a device that can store a single photon, effectively stopping it inside the memory, without destroying the quantum state that it carries. In most memories this is achieved by coherently mapping the quantum state carried by the photon onto a highly coherent atomic system, using some specifically engineered light-matter interaction. When we want to use the photon, we should be able to "push a button" to release it and use it, which usually means time-reversing the interaction process, as illustrated in Figure 3.

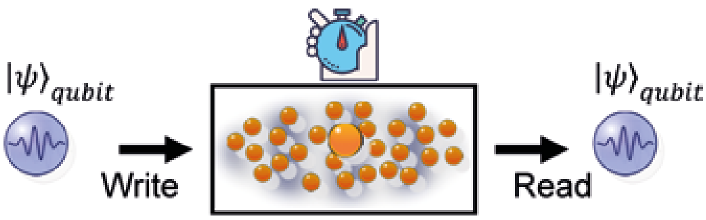


Figure 3. A quantum memory allows to write the qubit carried by a photon onto some material, here an ensemble of atoms or ions. After some variable time the memory can be read out, thereby creating an output photon carrying the same qubit state.

In the repeater, a quantum memory allows us to wait until two memories are charged with photons, before releasing both of them for the BSM. This ability is absolutely crucial in order for quantum repeaters to work over large distances. Please note that one doesn't necessarily need to store the photon for very long durations, as in a classical memory (e.g. a hard drive). It is more like a buffer memory that allows us to temporarily store a photon. A quantum memory with a lifetime of about 1 seconds would already be very useful, but this is extremely challenging as the memory must then be able to preserve the quantum coherence during this time.

Several different physical system have been considered as quantum memories for repeaters. In Switzerland a few groups work on these, including quantum dots [11] (Prof. Ataç İmamoğlu at ETH), atomic vapours [12] (Prof. Philipp Treutlein in Basel) and rare-earth (RE) ion doped crystals (our group at the University of Geneva) [13,14]. It would be out of the scope of this report to discuss them all, I will therefore only mention a few important results that we have achieved recently using RE crystals.

Figure 4. A quantum memory based on a Europium-doped crystal. The crystal is mounted inside a closed-cycle cryostat that cools it to about 3 K. Multiple photonic qubit can be stored inside this crystal for durations of up to one milliseconds.

Quantum memories based on RE crystals, see Figure 4, have several appealing properties for quantum memories, of which maybe two stands out; long coherence times (i.e. long memory times) and the ability to store many photonic qubits in one device (multiplexing). Just as in classical networks multiplexing means higher rates, and it has been shown that multiplexing is crucial for long-distance quantum repeaters. However, it has proven very challenging to store more than one qubit in any quantum memory. In 2008 colleagues and I proposed a new quantum memory scheme that has the highest multiplexing capability [13], specifically when used in conjunction with RE crystals. Using this scheme we were able to store five polarization qubits inside a RE crystal for up to about 1 ms [14], see Figure 5, a significant improvement for quantum memories based on solid-state materials. In a more recent experiment we could show that the memory can store quantum correlations on the same time scale [15], which is a key requirement for repeaters. But many challenges remain, such as improving the memory efficiency, and further increasing the memory lifetime and multiplexing ability. In particular these key properties must be improved simultaneously in one memory device, which is a challenge for all the different approaches to quantum memories. For readers especially interested in quantum memories I refer to the following Physic Today feature article that colleagues and I wrote in 2015 [16].

The Quantum Internet

A quantum repeater uses entanglement as its key resource, meaning that it can be used for much more than conventional QKD. Entanglement-based quantum communication allows so-called device independent schemes, for QKD, random-number generation and other applications, where security can be guaranteed by the user without even trusting the device manufacturer. A repeater could also be used to teleport a quantum state over a very large distance. In a proof-of-principle experiment we recently demonstrated this by teleporting a polarization qubit from a telecom photon into a quantum memory [17]. Building on such experiments one could imagine to connect smaller quantum computers using repeater links, to realize a larger, more powerful, distributed quantum computer [1]. It could also allow a user to connect to a powerful quantum computer and perform the computation without its owner having any knowledge about the results (blind quantum computing). The possibilities of a network of quantum processers connected through a repeater network are many, and some of them we probably can't even imagine now. It is therefore important to get a larger part of the society involved in this endeavour, if we truly are to unlock the potential of quantum technologies.

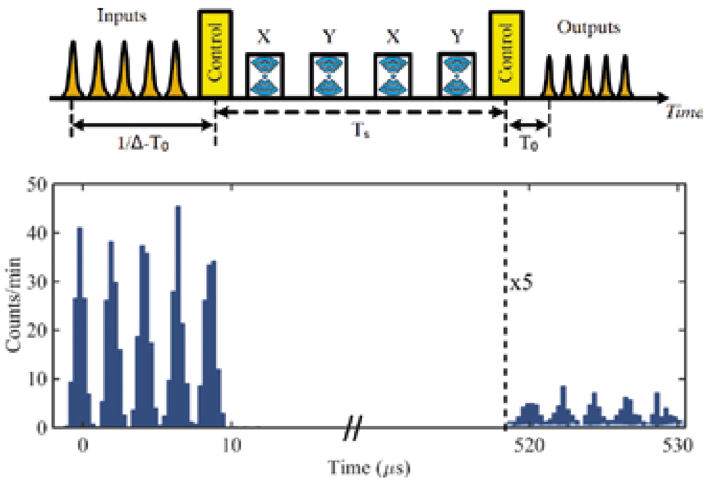


Figure 5. (Top) Illustration of the sequence of input and output pulses (orange), optical (yellow) and radio-frequency (blue) control pulses used in a quantum memory experiment. The intense control pulses coherently maps the input pulses into the memory, and assures the mapping back into the output pulses. (Bottom) Experimental photon counting histogram showing five input and output pulses, which are stored for about 0.5 ms. Each input pulse contains about two photons in average.

[1] H. J. Kimble, Nature **453**, 1023 (2008).
[2] C. H. Bennett and G. Brassard, Proceedings of the IEEE International Conference on Computers, Systems, and Signal Processing, **175** (Dec. 1984).
[3] A. Boaron, B. Korzh, R. Houlmann, G. Boso, D. Rusca, S. Gray, M.-J. Li, D. Nolan, A. Martin and H. Zbinden, Appl. Phys. Lett. **112**, 171108 (2018).
[4] M. Caloz, M. Perrenoud, C. Autebert, B. Korzh, M. Weiss, C. Schnenberger, R. J. Warburton, H. Zbinden and F. Bussires, Appl. Phys. Lett. **112**, 061103 (2018).
[5] W. K. Wootters and W. H. Zurek, Nature **299**, 802 (1982)
[6] S.-K. Liao et al., Nature **549**, 43 (2017).
[7] H.-J. Briegel, W. Dür, J. I. Cirac and P. Zoller, Phys. Rev. Lett. **81**, 5932 (1998).
[8] A. K. Ekert, Phys. Rev. Lett. **67**, 661 (1991).
[9] C. H. Bennett, G. Brassard, C. Crepeau, R. Jozsa, A. Peres and W. K. Wootters, Phys. Rev. Lett. **70**, 1895 (1993).
[10] M. Halder, A. Beveratos, N. Gisin, V. Scarani, C. Simon and H. Zbinden, Nat. Phys. **3**, 692 (2007).
[11] A. Delteil, Z. Sun, W.-B. Gao, E. Togan, S. Faelt and A. Imamoğlu, Nat. Physics **12**, 218 (2016)
[12] J. Wolters, G. Buser, A. Horsley, L. Béguin, A. Jöckel, J.-P. Jahn, R. J. Warburton and P. Treutlein, Phys. Rev. Lett. **119**, 060502 (2017)
[13] M. Afzelius, C. Simon, H. de Riedmatten and N. Gisin, Phys. Rev. A **79**, 052329 (2009).
[14] P. Jobez, C. Laplane, N. Timoney, N. Gisin, A. Ferrier, P. Goldner and M. Afzelius, Phys. Rev. Lett. **114**, 230502 (2015).
[15] C. Laplane, P. Jobez, J. Etesse, N. Gisin and M. Afzelius, Phys. Rev. Lett. **118**, 210501 (2017).
[16] M. Afzelius, H. de Riedmatten and N. Gisin, Physics Today **68**, 12, 42 (2015).
[17] F. Bussières, C. Clausen, A. Tiranov, B. Korzh, V. B. Verma, S. W. Nam, F. Marsili, A. Ferrier, P. Goldner, H. Herrmann, C. Silberhorn, W. Sohler, M. Afzelius and N. Gisin, Nat. Photon. **8**, 775 (2014).

Progress in Physics (64)

Cold molecules: techniques and applications

Ziv Meir, Dongdong Zhang and Stefan Willitsch
Department of Chemistry, University of Basel, Klingelbergstrasse 80, 4056 Basel, Switzerland

Introduction

Over the past decades, the development of experimental techniques for the cooling and trapping of atoms down to nanokelvin temperatures has revolutionized atomic physics [1]. These advancements have opened up a range of new applications for both neutral atoms and atomic ions in the realms of quantum computation, collision physics and precision measurements. A similar revolution is currently underway in molecular and chemical physics, fueled by new methods for the cooling and motional control of molecules [2–4]. In the present article, we highlight techniques and applications of "cold molecules" with examples from our own work.

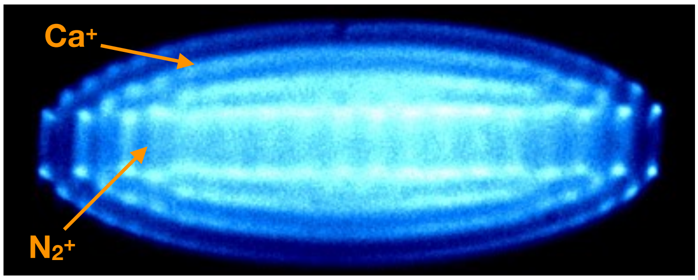


Fig. 1: False-colour fluorescence image of a Coulomb crystal of laser-cooled Ca^+ and sympathetically cooled molecular N_2^+ ions. The non-fluorescing molecular ions are intercalated into the Ca^+ crystal and appear as a non-fluorescing region in the centre of the image.

Cooling techniques

For atomic systems, both neutral and ionic, the starting point of a typical experiment is Doppler laser cooling [1] which allows the preparation of samples at temperatures in the millikelvin regime or slightly lower. The atoms are usually confined in magnetooptic, magnetic or optical-dipole traps in the case of neutrals and radiofrequency electrodynamic (Paul) or combined electric and magnetic (Penning) traps in the case of ions [1, 5]. Advanced techniques like evaporative cooling for atoms and resolved-sideband cooling for ions eventually allow to reach quantum degeneracy in neutrals and the quantum-mechanical motional ground state of the trap in the case of the more tightly confined ions. For molecules, however, laser cooling, the work horse technique of atomic physics, is only applicable to a small class of systems and even then only with limited efficacy. The reason for this lies in the complexity of molecules. In addition to the electronic and spin degrees of freedom present in atoms, molecules exhibit rotational and in particular vibrational motions which render the implementation of closed optical cycles required for Doppler laser cooling experimentally very challenging. Although laser cooling and even magnetooptical and magnetic trapping has by now been achieved for a few selected molecular systems [6, 7], the vast majority of cold-molecules experiments relies on alternative methods for the preparation of cold samples.

In the case of molecular ions, sympathetic cooling by the interaction with trapped, laser-cooled atomic ions has proven to be a highly versatile approach which is applicable to a wide variety of systems ranging from diatomic molecules to proteins [8]. The cold trapped ions form ordered structures in the trap, usually referred to as "Coulomb crystals", which can be imaged by collecting the fluorescence of the laser-cooled atomic ions. An example of a mixed-species Coulomb crystal consisting of laser-cooled Ca^+ and sympathetically-cooled N_2^+ ions is shown in Fig. 1.

For neutral molecules, one of the most widely used methods is Stark deceleration of molecular beams [9]. The principle of the method is illustrated in Fig. 2. A beam of dipolar molecules is coupled into an assembly of dipole electrodes to which time-varying electric potentials are applied. The time-varying inhomogeneous electric fields produce Stark potential energy barriers which successively slow down the dipolar molecules traversing the assembly. The slow beam of molecules exiting the decelerator can then be trapped in a magnetic or electrostatic trap.

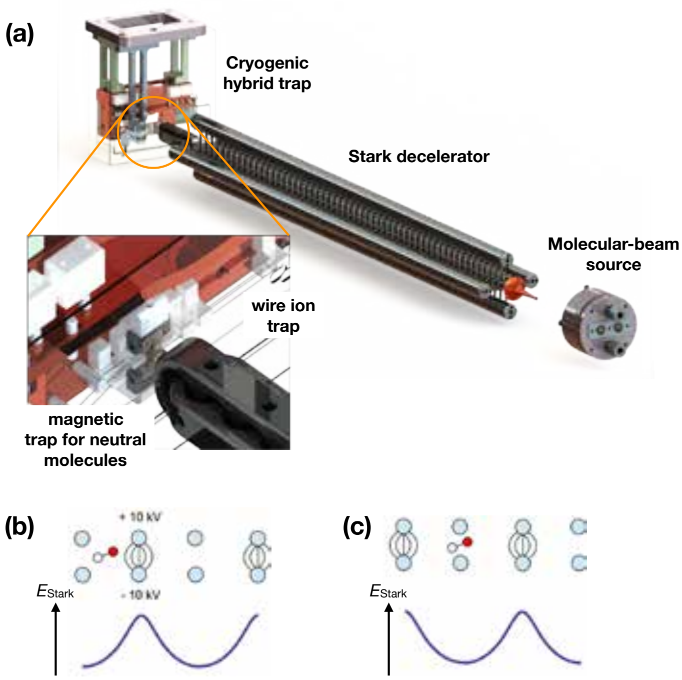


Fig. 2: (a) Schematic of an experimental setup for the hybrid trapping of cold molecules and cold molecular ions consisting of a molecular-beam source, a Stark decelerator for the slowing of the molecular beam and a combined magnetic/ion trap. (b,c) Principle of Stark deceleration (from Ref. [4]). (b) A molecular beam of dipolar molecules traverses an array of dipole electrodes alternately charged to high voltage. The inhomogeneous electric fields produce potential-energy barriers for molecules in low-field seeking Stark states. A packet of molecules is slightly slowed down as it approaches a barrier. (c) Before the molecules are re-accelerated at the other side of the barrier, the fields are switched to the subsequent pair of electrodes to initiate the next deceleration stage. This scheme is continued until the packet of molecules has almost come to a standstill.

Cold interactions: Ion-neutral hybrid systems

For a long time, the fields of cold neutrals and cold ions have developed in parallel. However, about a decade ago a new generation of experiments emerged in which neutrals and ions were simultaneously trapped in the same region of space [10–12]. This development enabled the study of ion-neutral interactions at very low temperatures, accessing a regime of intermediate strength between weak neutral-neutral and strong ion-ion interactions. The first generation of experiments combined cold neutral atoms with cold atomic and molecular ions, as illustrated with the setup in operation in our laboratory in Basel shown in Fig. 3. Such "hybrid" experiments provide an ideal platform for studies of ion-neutral collisions at very low temperatures. Over the past years, it became clear that even seemingly simple atomic collision systems exhibit a rich variety of processes comprising elastic, inelastic and reactive collision processes [13– 16]. These include sympathetic cooling of the ions by the ultracold atoms [17–19], non-equilibrium dynamics of the ion motion [20–22], unusual light-driven chemical processes leading to the formation of cold molecules and subtle effects of intermolecular interactions driving the collision dynamics which are usually obscured at higher temperatures [4, 23, 24].

In a next generation of experiments currently coming online, the cold atoms are replaced with cold molecules produced by, e.g., Stark deceleration (see Fig. 2 (a)). These developments will push hybrid trapping technology to a new level and enable for the first time the simultaneous trapping of neutral molecules and molecular ions at very low temperatures. These experiments aim at the exploration of distinctly molecular effects in ion-neutral interactions in the cold regime. This opens up perspectives to study molecular energy transfer and chemical dynamics under precisely controlled conditions and ultimately to unravel the detailed properties of even very large polyatomic molecules [26].

Keeping track of time with a single molecule

Another exciting, currently emerging application of cold molecules lies in the field of metrology. Presently, optical atomic clocks are the most precise man-made measurement tools, capable of keeping time with 10^{-18} fractional uncertainty which is equivalent to loosing or gaining less than one second over the age of the universe [27–29]. Commercialization of atomic clocks leads to many applications such as satellite navigation, geodesy and global time keeping [27]. Atomic clocks have allowed for precision spectroscopic measurements testing fundamental physics theories. For example, an atomic clock was used to detect the time dilation due to a gravitational field over only 30 cm height difference [30].

Current atomic clocks utilize the precise measurement of an electronic transition in an atom in the visible or ultraviolet spectral range for the purpose of time keeping. In our laboratory, we are in the process of building a variant of an atomic clock which will exploit a vibrational transition in a molecule instead. Molecular vibrational frequencies typically lie in the infrared spectral domain thus enabling clocks in a different spectral regime than the ones presently used. Moreover, precise spectroscopic measurements of molecular vibration transitions will allow tests of fundamental physical concepts including a possible time variation of fundamental constants like the ratio of the electron and proton masses or the hypothetical existence of a fifth fundamental force [31, 32]. In our experiment, we use molecular nitrogen (N_2^+) ions which possess many advantageous systematic characteristics for these purposes [33, 34].

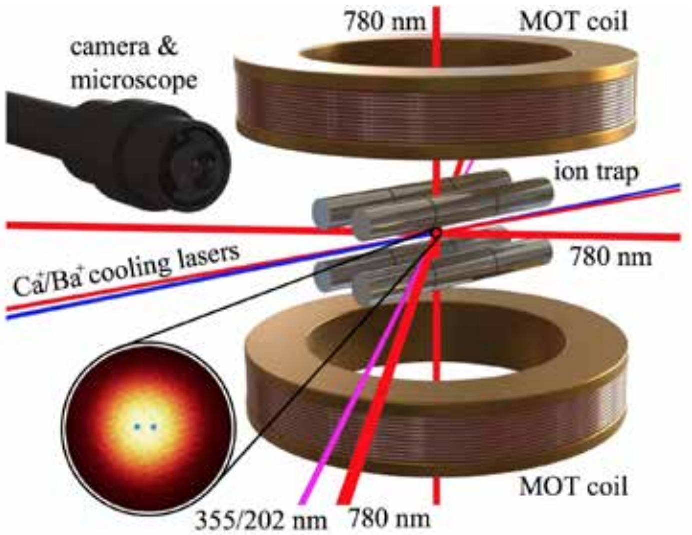


Fig. 3: Schematic of the ion-neutral hybrid trapping experiment in Basel consisting of a radiofrequency trap for atomic and molecular ions combined with a magneto-optical trap (MOT) for neutral Rb atoms (from Ref. [25]). The inset shows superposed false-colour fluorescence images of two laser cooled Ca^+ ions (blue) immersed in cloud of ultracold Rb atoms (yellow-red).

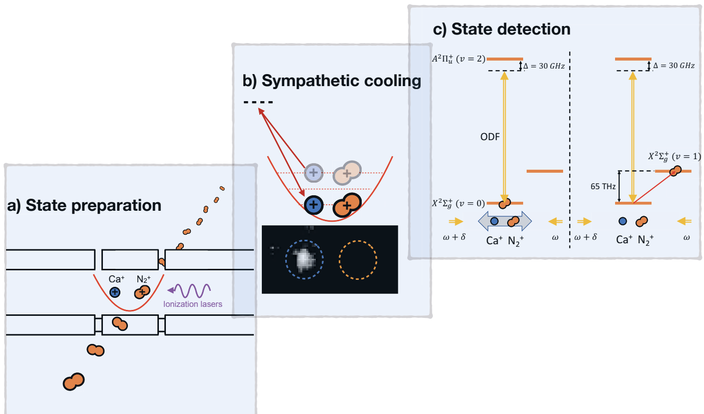


Fig. 4: Quantum techniques for the spectroscopy of single molecules. a) State preparation. A beam of neutral N_2 molecules (orange) passes through the trap center where a single atomic Ca^+ ion (blue) is trapped and Doppler cooled. Pulsed lasers (magenta) ionize a single molecule into the desired molecular state. Immediately after ionization, the molecule is trapped by the electric trapping fields which create a confining harmonic potential (red line). b) Sympathetic cooling. The positively charged atom and molecule form a Coulomb crystal due to their mutual repulsion and the harmonic confinement. Lasers that scatter photons only from the atom (red arrows) are used to dissipate energy of the atom-molecule crystal until it is cooled to the motional ground state of the trap (dashed lines). Image of a Ca^+-N_2^+ crystal taken in our laboratory (bottom). Only the atom scatters photons and is therefore visible. c) State detection. Left: Two counter-propagating laser beams (frequencies ω and $\omega+\delta$) create an optical-dipole force (ODF) modulated at the a motional frequency δ of the ion crystal. The ODF lasers are detuned closely ($\Delta \approx 30$ GHz) to a transition between the initial state of the molecule (here $X^2\Sigma_g^+$ (v=0)) and an auxiliary state ($A^2\Pi_u^+$ (v=2)). The ODF coherently drives the motion of the atom-molecule crystal if the molecule is in its initial state. Right: Spectroscopic interrogation (red line) excites the molecule to a different state (here it is the $X^2\Sigma_g^+$ (v=1) first vibrationally excited state). Due to the increased detuning (here 65 THz), the ODF lasers do not excite the motion in the crystal anymore thus indicating the spectroscopic excitation of the molecule.

An atomic clock requires the ability of preparing the atom in a specific quantum state, of freezing its translational motion and of detecting the atomic state with high fidelity. The complex energy-level structure of molecules, however, renders the implementation of a molecular clock extremely challenging. To overcome these challenges, we combined techniques from ion-trap quantum computing and precision molecular spectroscopy.

First, we use a resonance-enhanced multi-photon ionization (REMPI) technique pioneered in our group [35] to produce single molecular ions in a well-defined quantum state (see Fig. 4a).

Second, the single state selected molecular ions are sympathetically cooled by the strong Coulomb interaction with a single Ca^+ ion in an ion trap. By addressing individual energy levels of their combined motion in the quantum regime, the ions are cooled down to the quantum-mechanical motional ground state (see Fig. 4b).

Third, a method to read out the quantum state of the molecule needs to be implemented [36, 37]. Direct non-destructive detection of the molecular state is not possible due to its complex energy-level structure and detection methods based on chemical reactions [33, 35] are inherently slow due to their destructive nature. Instead, we use quantum-logic spectroscopy (QLS), an indirect technique originally invented in the realm of atomic-ion clocks and ion-based quantum technologies [38]. In our experiments, we apply a state-dependent optical-dipole force (ODF) on the molecule using a modulated laser beam. The laser modulation frequency matches the harmonic frequency of the atom-molecule crystal in the trap such that it excites coherent motion in the crystal (denoted as $|\bar{n}\rangle_{\text{crys.}}$), similar to the way one rocks a swing. We tune the laser frequency to interact only with a specific state of the molecule (denoted as $|\downarrow\rangle_{\text{mol.}}$). Other molecular states (denoted $|\uparrow\rangle_{\text{mol.}}$) do not interact with the laser field and hence no motion is induced on the crystal ($|0\rangle_{\text{crys.}}$). The force depends on the molecular state and entangles the motion of the atom-molecule crystal with the molecular state,

$$|\Psi\rangle = \alpha|\downarrow\rangle_{\text{mol.}} \otimes |\bar{n}\rangle_{\text{crys.}} + \beta|\uparrow\rangle_{\text{mol.}} \otimes |0\rangle_{\text{crys.}}.$$

Here, α and β are the initial coherent-superposition amplitudes of the molecular state. Detecting the coherent motion of the crystal collapses the wave function into one of the molecular states with probability $|\alpha|^2$ and $|\beta|^2$ respectively (see Fig. 4c). Since the coherent motion is common to both the atomic ion and the molecule, detection is most easily performed on the atomic ion by fluorescence methods. In this way, a non-destructive (in a chemical sense) detection of the molecular state is achieved, enabling precision-spectroscopic measurements on vibrational transitions of N_2^+ as a prerequisite for its application as a clock.

Acknowledgements

We thank Alexander Dörfler, Pascal Eberle, Dominik Haas, Gregor Hegi, Christian Mengeng, Kaveh Najafian, Claudio von Planta and Mudit Sinhal for their contributions to the work summarized here. Financial support by the Swiss National Science Foundation under grant nr. 200020 175533 and as part of the National Centre of Competence in Research, Quantum Science & Technology (NCCR-QSIT) is acknowledged.

[1] H. J. Metcalf and P. van der Straten, *Laser Cooling and Trapping* (Springer, New York, 1999).
[2] L. D. Carr, D. DeMille, R. V. Krems and J. Ye, New J. Phys. **11**, 055049 (2009).
[3] M. Lemeshko, R. V. Krems, J. M. Doyle and S. Kais, Mol. Phys. **111**, 1648 (2013).
[4] S. Willitsch, Adv. Chem. Phys. **162**, 307 (2017).
[5] F. G. Major, V. N. Gheorghe and G. Werth, *Charged Particle Traps* (Springer, Berlin and Heidelberg, 2005).
[6] J. Barry, D. McCarron, E. Norrgard, M. Steinecker and D. DeMille, Nature **512**, 286 (2014).
[7] H. J. Williams, L. Caldwell, N. J. Fitch, S. Truppe, J. Rodewald, E. A. Hinds, B. E. Sauer and M. R. Tarbutt, Phys. Rev. Lett. **120**, 163201 (2018).
[8] S. Willitsch, Int. Rev. Phys. Chem. **31**, 175 (2012).
[9] S. Y. T. van de Meerakker, H. L. Bethlem, N. Vanhaecke and G. Meijer, Chem. Rev. **112**, 4828 (2012).
[10] A. T. Grier, M.Cetina, F. Oručević and V. Vuletić, Phys. Rev. Lett. **102**, 223201 (2009).
[11] S. Schmid, A. Härter and J. Hecker Denschlag, Phys. Rev. Lett. **105**, 133202 (2010).
[12] C. Zipkes, S. Palzer, L. Ratschbacher, C. Sias and M. Köhl, Phys. Rev. Lett. **105**, 133201 (2010).
[13] W. G. Rellergert, S. T. Sullivan, S. Kotochigova, A. Petrov, K. Chen, S. J. Schowalter and E. R. Hudson, Phys. Rev. Lett. **107**, 243201 (2011).
[14] F. H. J. Hall, M. Aymar, N. Bouloufa-Maafa, O. Dulieu and S. Willitsch, Phys. Rev. Lett. **107**, 243202 (2011).
[15] J. Joger, H. Fürst, N. Ewald, T. Feldker, M. Tomza and R. Gerritsma, Phys. Rev. A **96**, 030703 (2017).
[16] T. Sikorsky, Z. Meir, R. Ben-shlomi, N. Akerman and R. Ozeri, Nature communications **9**, 920 (2018).
[17] I. Sivarajah, D. S. Goodman, J. E. Wells, F. A. Narducci and W. W. Smith, Phys. Rev. A **86**, 063419 (2012).
[18] K. Ravi, S. Lee, A. Sharma, G. Werth and S. A. Rangwala, Nat. Commun. **3**, 1126 (2012).
[19] S. Haze, M. Sasakawa, R. Saito, R. Nakai and T. Mukaiyama, Phys. Rev. Lett. **120**, 043401 (2018).
[20] Z. Meir, T. Sikorsky, R. Ben-shlomi, N. Akerman, Y. Dallal and R. Ozeri, Phys. Rev. Lett. **117**, 243401 (2016).
[21] I. Rouse and S. Willitsch, Phys. Rev. Lett. **118**, 143401 (2017).
[22] Z. Meir, M. Pinkas, T. Sikorsky, R. Ben-shlomi, N. Akerman and R. Ozeri, arXiv preprint arXiv:1801.06839 (2018).
[23] A. Härter and J. Hecker Denschlag, Contemp. Phys. **55**, 33 (2014).
[24] M. Tomza, K. Jachymski, R. Gerritsma, A. Negretti, T. Calarco, Z. Idziaszek and P. S. Julienne, arXiv preprint arXiv:1708.07832 (2017).
[25] F. H. J. Hall, P. Eberle, G. Hegi, M. Raoult, M. Aymar, O. Dulieu and S. Willitsch, Mol. Phys. **111**, 2020 (2013).
[26] Y.-P. Chang, K. Dlugolecki, J. Küpper, D. Rösch, D. Wild and S. Willitsch, Science **342**, 98 (2013).
[27] A. D. Ludlow, M. M. Boyd, J. Ye, E. Peik and P. O. Schmidt, Rev. Mod. Phys. **87**, 637 (2015).
[28] N. Huntemann, C. Sanner, B. Lipphardt, Chr. Tamm and E. Peik, Phys. Rev. Lett. **116**, 063001 (2016).
[29] T. Nicholson, S. Campbell, R. Hutson, G. Marti, B. Bloom, R. McNally, W. Zhang, M. Barrett, M. Safronova, G. Strouse, W. Tew and J. Ye, Nature Commun. **6**, 6896 (2015).
[30] C. W. Chou, D. B. Hume, T. Rosenband and D. J. Wineland, Science **329**, 1630 (2010).
[31] S. Schiller and V. Korobov, Phys. Rev. A **71**, 032505 (2005).
[32] E. J. Salumbides, J. C. J. Koelemeij, J. Komasa, K. Pachucki, K. S. E. Eikema and W. Ubachs, Phys. Rev. D **87**, 112008 (2013).
[33] M. Germann, X. Tong and S. Willitsch, Nat. Phys. **10**, 820 (2014).
[34] M. Kajita, Phys. Rev. A **92**, 043423 (2015).
[35] X. Tong, A. H. Winney and S. Willitsch, Phys. Rev. Lett. **105**, 143001 (2010).
[36] F. Wolf, Y. Wan, J. C. Heip, F. Gebert, C. Shi and P. O. Schmidt, Nature **530**, 457 (2016).
[37] C.-W. Chou, C. Kurz, D. B. Hume, P. N. Plessow, D. R. Leibrandt and D. Leibfried, Nature **545**, 203 (2017).
[38] P. O. Schmidt, T. Rosenbrand, C. Langer, W. M. Itano, J. C. Bergquist and D. J. Wineland, Science **309**, 749 (2005).

Why should you be interested in Thorium Power? (Part 2)

Maurice Bourquin, iThEC, international Thorium Energy Committee, Geneva, Switzerland

A subcritical system driven by an accelerator

An accelerator-driven system (ADS) is a subcritical approach to energy production and nuclear waste destruction, where a high-energy particle accelerator provides an external neutron source through a spallation reaction, coupled with a core in which both spallation neutrons and fission neutrons are at work, with a moderator allowing for a fast neutron spectrum. Figure 1 represents a sketch of this approach.

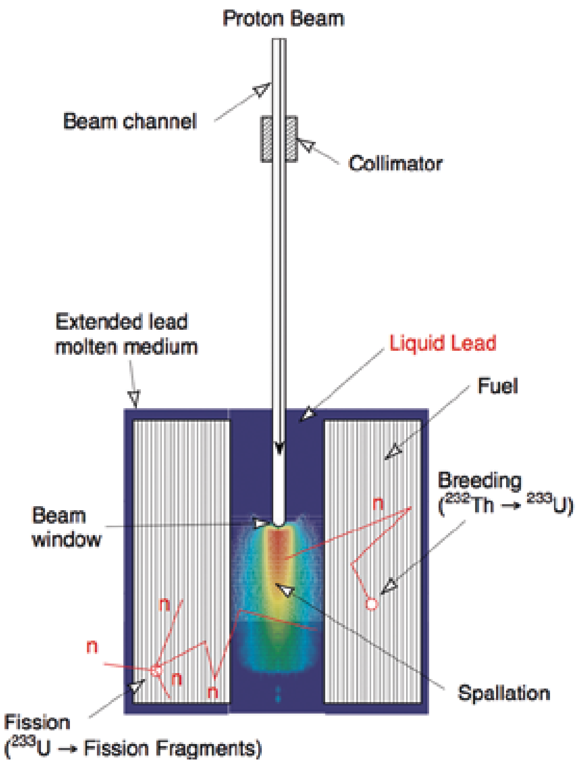


Figure 1. Sketch of an accelerator-driven system [1]

Some basic ADS concepts were developed in Switzerland:

- the FEAT experiment at the CERN PS was the first "Energy Amplifier" test, whose purpose was to verify the simulation studies for an accelerator-driven thermal subcritical system (with an effective multiplication factor k of about 0.9), at very low power level, coupled to a spallation source [1];
- the TARC experiment at the CERN PS, whose purpose was to demonstrate the possibility of using adiabatic resonance crossing for nuclear transmutation by spallation neutrons slowing down in lead [2];
- the MEGAPIE project at the Paul Scherrer Institute (PSI), the goal of which was to produce neutrons from a liquid metal lead-bismuth target when hit by a 1 MW proton beam [3].

The ADS development is pursued in several research institutes worldwide [4]. Three major projects, all driven by proton linear accelerators (linac's), are presently at the forefront of the field:

- MYRRHA [5], at SCK•CEN, in Mol, Belgium, which should be the flagship of accelerator-driven systems, with a proton linac (600 MeV, 2.5 mA) driving a subcritical core cooled with a eutectic lead–bismuth mixture, designed to produce a thermal power of 50 to 100 MW;
- ADANES [6] developed by the Chinese Academy of Sciences, both at the Institute of High Energy Physics in Beijing and at the Institute of Modern Physics in Lanzhou. The project includes notable innovations in target design and the goal is to reach 1000 MW of electrical power by 2032. A site for the first prototype was recently chosen by the Chinese Government at the city of Huizhou, in the Guangdong Province;
- HISPA [7] at the Bhabha Atomic Research Centre in India, concentrating on the development of a high-power proton linac, with as first stage a 30 mA, 20 MeV injector, and the goal of reaching 30 MW of beam power with 1 GeV protons. This project is carried out in cooperation with the USA.

In the United States, the Argonne National Laboratory (ANL) has designed and constructed an ADS facility using a 100 kW, 100 MeV electron accelerator [8] for the Kharkov Institute of Physics & Technology (KIPT) in Ukraine. The facility is in the start-up phase. This activity is supported by the Russian Research Reactor Fuel Return (RRRFR) program of the United States Department of Energy. The facility is planned to produce medical isotopes, train young nuclear professionals, support the Ukraine nuclear industry, and provide capability for performing reactor physics, material research, and basic science experiments. It is suitable for studying accelerator-driven systems and performing basic neutron research, including a cold neutron source. Other USA R&D activities are being carried out to study and investigate various aspects of ADS including monitoring and controlling the system subcriticality. The development of ADS for disposing of US spent nuclear fuel inventory is being carried out by different institutes and private corporations. Among the other countries involved in ADS-related activities, are Japan at J-PARK, the Japan Accelerator Research Complex, where ADS research was restarted as a consequence of the Fukushima accident, Russia, at INR Troitsk (see below), and South Korea with the HYPER project, (Hybrid Power Extraction Reactor: a system for clean nuclear energy), to name only the most significant activities. Europe, including Switzerland, is building the most powerful spallation neutron source, the European Spallation Source (ESS), at Lund, in Sweden, also based on a linac [9]. The ESS proton beam power will reach 5 MW. This project will provide Europe with the most advanced expertise on target technology for ADS. The overarching goal of those projects is to demonstrate the feasibility of energy generation, radioactive waste incineration and medical isotope production with ADS.

A technological breakthrough: the thorium-fueled accelerator-driven system

An ADS will have safety features which rely on physical properties of the system as opposed to active control in critical reactors. It eliminates the possibility of criticality accidents by keeping the system subcritical. Indeed, stopping the proton beam from the accelerator instantly stops the fission reaction and the low-pressure liquid metal, which remains well below the boiling point, allows natural circulation to provide the decay heat removal. Unlike water, the chemically inert liquid metal coolant carries no danger of formation of hydrogen as in Fukushima Daiichi's reactors. Natural circulation is independent of pumps and does not require a power supply. Furthermore, the combination of fast neutrons from the spallation source, and recycling of long-lived transuranic elements reduces long-lived waste. With an ADS fueled with natural thorium instead of uranium (see part I in the *SPG Mitteilungen* Nr 54), plutonium and high-level wastes such as minor actinides, namely neptunium, americium and curium, are produced in much lower quantities. In the envisaged system, the waste mainly consists of fission fragments. Their radioactivity is intense, but limited to a few hundred years compared with the one-million-year lifetime of the long-term waste in the present uranium fuel cycle.

It is even possible to eliminate much of the waste resulting from the operation of existing conventional plants, thus reducing the size and complexity of long-term nuclear waste storage sites. The key to this unique characteristic is the ability of the ADS to accept fuels incorporating minor actinides and excess plutonium without compromising safety, as the ADS does not depend on the so-called beta factor, the proportion of delayed neutrons, for control of reactivity. In addition the destruction of minor actinides and plutonium by fission releases energy that can be used to produce electricity, thereby minimizing the cost of the operation. The resulting fission energy can be collected in a classical manner by a liquid heat carrier such as gaseous helium or molten metal (lead for example) via an exchanger and turbine.

The creation of a new, appropriate end-of-cycle fuel reprocessing is still a necessity for the practical realization of any closed thorium cycle. However, for the spent nuclear fuel in a fast neutron ADS, it is not necessary to separate out plutonium as is done in PUREX. Therefore, the pyro-electrolysis method can be used to extract the entire transuranic actinide mixture to manufacture fresh thorium-based fuel.

What are the main requirements for an ADS accelerator? In practice, for industrial applications, there are many requirements which make the accelerator challenging. The proton beam energy should ideally be above 900 MeV, but a lower energy can be compensated by a higher current. The beam power should reach a value between a few MW to about 10 MW, depending on the required application. A large operational range is desirable to adapt the beam power to the operation of the reactor and the fluctuating electric power demand associated with the network, when renewable sources are used on a large scale. The size of the beam spot at the target entrance window has a large impact. Beam losses have to be tightly controlled to minimize irradiation of the accelerator and of the environment: a figure of merit for linac's is less than 1 W/m, while for cyclotrons losses are mainly localized at injection and extraction.

The issue of reliability requiring minimizing beam trips is a significant challenge: the limitation mainly comes from thermal stresses inducing fatigue in the beam window, fuel claddings and vessel structures. Solutions include making the accelerator more reliable, adding redundancy (several sources, several accelerators, etc.), improvements in materials, maintenance and operation, relaxing the demands from reactors with the fuel in a liquid molten salt mixture, etc. At the ThEC13 conference, an innovative concept for a high power superconducting cyclotron, in principle adoptable as a driver for an accelerator-driven system, was presented. A design study is in progress, including partners at PSI, INFN, CERN, ENEA, and in private companies [10].

Resistance to military diversion

The resistance to proliferation of thorium-fueled ADS requires a careful analysis, but one can already conclude on a high degree of resistance by the following arguments.

Thorium-based fuels breed significantly less plutonium than current uranium fuel cycles, which we recall is one of the reasons why, between 1950 and 1980, the uranium-plutonium fuel cycle necessarily was established first (in order to start breeding reactions) and once the infrastructure was in place the thorium fuel cycle was disadvantaged.

The production of protactinium-233 in the thorium portion of the reactor could constitute a proliferation objection to thorium fuel. If it could be extracted chemically, it would decay quickly into pure U-233, a weapons-grade isotope. The solution would be to denature any bred U-233 by mixing it with U-238. But some discount altogether this risk, because the U-233 in the reactor would be mixed with U-232, whose decay products produce high energy gamma radiation that renders it lethal to handle. And furthermore the long presence of the fuel in the reactor (five to ten years) minimizes access to extract protactinium-233.

The proliferation concerns which are presently raised by the IAEA about ADS can be answered in a straightforward way. Diverting an ADS for producing macroscopic quantities of tritium to manufacture a fission-fusion bomb can be avoided by control, as tritium is unstable and production has to continue on a regular basis. Thus, tritium production would be relatively easy to spot, as it requires very high power accelerators running continuously for long time periods without producing energy.

An ADS experiment at the Institute for Nuclear Research (INR) in Troitsk

An experimental facility of significant power would today be needed in order to validate technological solutions for thorium-fueled ADS. At the ThEC13 conference, a proposal was presented for an ADS experiment at INR Troitsk in Rus-

Proliferation resistance of thorium-fueled ADS

- Negligible production of plutonium
- Hard gamma radiation from U-232 rendering fuel completely unsuitable for weapons material
- Simple controls avoiding diverting production of macroscopic quantities of tritium
- Long burnup cycles reducing access to nuclear fuel

sia using the Moscow Meson Factory [11]. At this facility it would be possible to couple the proton beam to a subcritical core for the first time at significant power (≥ 1 MW thermal) to characterize the properties of ADS, demonstrate safety and learn how to operate such a system. This would provide invaluable input for designing and constructing an industrial prototype, as well as for developing a future thorium fuel cycle.

Thanks to the availability of the facility, the experiment would be faster and cheaper than other current projects. The pit to be used for the target and the core already exists, with the reflector already in place (Fig. 2). The main features of the core concept are: a fast neutron flux similar to a fast reactor flux (10^{14} n/cm^2/s), a minimum inventory of fuel, a fast driver zone, a simplified cooling system and control of reactivity, which should result in a significant cost reduction.

Figure 2. The INR core facility at Troitsk, Moscow.

The technical specifications include a beam power of 30 kW to 90 kW for 300 MeV protons on a water-cooled tungsten target. The maximum thermal power reached, 1 to 2 MW, will depend on the investment in the accelerator refurbishment, while the effective multiplication factor k must not exceed 0.98, in order to ease the licensing requirements. During the experiment, k can be varied up to this maximum value to characterize the core-to-accelerator coupling over the largest k range.

Other expected benefits of ADS

When the feasibility studies have proven the ADS concept at a significant power, business will have to adapt it to the market and plants will be constructed. I believe that capital will also be invested to capture incremental value through diversified applications. For example, nuclear reactors generate heat. That heat can be converted partially into electric energy or used as process heat. Future nuclear reactors will provide much higher temperatures, thereby enabling technologies with high efficiencies that can also produce hydrogen through water-splitting. And perhaps even the path for carbon dioxide sequestration is to use CO_2 as a carbon source for making liquid fuels, such as methanol, using nuclear energy at high temperatures, a prospect that could recycle CO_2 emissions.

Radiopharmaceutical production and material irradiation testing offer other significant potentials of incremental profits. Those additional sources of revenue would drive down direct costs, while securing margins and balancing global risks, using similar or even identical plants.

Conclusions

It is difficult to imagine how the “decarbonization challenge” discussed at the UN Climate Change Conferences would work globally without energy from nuclear power. Large-scale growth in much of the developing world will have to be powered by nuclear energy. Innovative thorium-fueled ADS can ensure the long-term societal acceptance of this energy source, and thus contribute to protecting climate and reducing pollution from fossil fuels. Most importantly, they have the potential of reducing the inventory of long-lived nuclear wastes produced in reactors.

In parallel with the technical feasibility studies of this application of particle accelerators, its socio-economic value should be demonstrated, so that industry can prepare the entry of such technologies into the market. We should be interested in thorium.

Acknowledgments

The author would like to thank the colleagues of iThEC who have helped in the preparation of this article.

References

[1] C. Rubbia et al., Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier, CERN/AT/95--44 (ET).
[2] A. Abánades et al.: Nucl. Instrum. Methods Phys. Res. A 478, 577–730 (2002)
[3] Ch. Latge et al., MEGAPIE: *The World’s First High-Power Liquid Metal Spallation Neutron Source*, in Thorium Energy for the World, ThEC13 Proc., CERN Globe of Science and Innovation, Geneva, Switzerland (October 27–31, 2013), Springer, (2016), DOI 10.1007/978-3-319-26542-1_41.
[4] Y. Kadi and J.-P. Revol, *https://indico.cern.ch/event/564485/contributions/2464348/attachments/1410062/2387792/ADSeffortsworldwide.pdf*.
[5] Didier De Bruyn, Hamid Aït Abderrahim, Peter Baeten and Paul Leysen, *The MYRRHA ADS Project in Belgium Enters the Front End Engineering Phase*, Physics Procedia 66 (2015) 75 – 84.
[6] P. Luo, S.-C. Wang, Z.-G. Hu, H.-S. Xu, W.-L. Zhan, *Accelerator-Driven Subcritical Systems - A Promising Solution for Cycling Nuclear Fuel*, Physics, 45(9), 569–577 (2016), DOI: 10.7693/wl20160903.
[7] P. Singh, *India ADS Programme*, EuCARD2 Workshop on Status of Accelerator Driven Systems Research and Technology Developments, CERN, 7-9 February 2017, *https://indico.cern.ch/event/564485/contributions/2379331/*.
[8] A. Y. Zelinsky et al., *NSC KIPT Neutron Source on the Base of Subcritical Assembly Driven with Electron Linear Accelerator*, Proc. of IPAC2013, Shanghai, China, THPFI080 (January 2013).
[9] ESS, Technical Design Report, April 23, 2013, ESS-doc-274 *http://eval.esss.lu.se/cgi-bin/public/DocDB/ShowDocument?docid=274*.
[10] M. Conjat and P. Mandrillon, *Single Stage Cyclotron for an ADS Demonstrator*, Proceedings of the 21st International Conference on Cyclotrons and their Applications, Zurich, September 2016.
[11] S. F. Sidorkin et al., Proposal of the ADS Research Stand Based on the Linac of the Institute for Nuclear Research of the Russian Academy of Sciences, in Thorium Energy for the World, ThEC13 Proc., CERN Globe of Science and Innovation, Geneva, Switzerland (October 27–31, 2013), Springer, (2016), DOI 10.1007/978-3-319-26542-1_41.

Milestones in Physics (12)

Stephen Hawking

Domenico Giulini, ZARM Bremen, Institute for Theoretical Physics Leibniz University of Hannover, Germany

On Wednesday, March 14th 2018, Stephen Hawking died at the age of 76 in Cambridge. He has been an outstanding theoretical physicist whose scientific work not only advanced, but reshaped the fields of gravitational physics and cosmology in a lasting fashion. This note is intended as a short sightseeing tour that highlights some of his scientific achievements and tries to explain the ideas behind them.

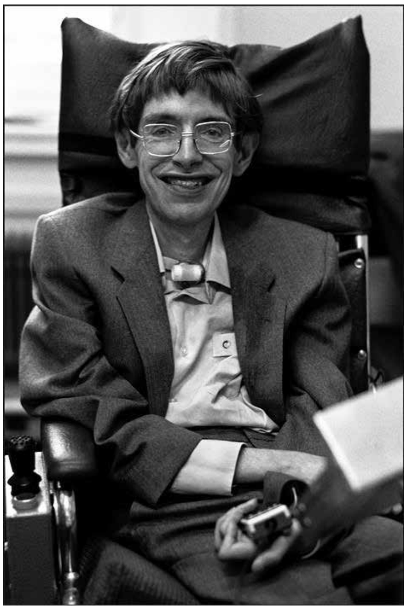


Figure 1: Stephen Hawking 1986. (Picture credit: Ian Berry)

Introduction

Stephen William Hawking was born on 8th January 1942 (exactly 300 years after the death of Galileo) in Oxford, England. His research career began when he entered the Department of Applied Mathematics and Theoretical Physics (DAMTP) at the University of Cambridge to do research in cosmology. Only a few month later, just after his 21st birthday, he was diagnosed with ALS (amyotrophic lateral sclerosis), a common form of so-called motor neurone diseases, of which no cure is known.

Hawking's scientific œvre can be very roughly divided into three parts, headed respectively by: 1) Singularities, Gravitational Waves, and Black Holes; 2) Gravity and Quantum Theory; and 3) Quantum Cosmology. The first part comprises his early work on Einstein's Theory of General Relativity, whereas the second and third parts contain his attempts to transcend this theory into the realm of Quantum Theory.

Singularities, Gravitational Waves, and Black Holes

After a long period of neglect, renewed interest in General Relativity (henceforth abbreviated by GR) set in during the 2nd half of the1950s, a period that today is refereed to as the *renaissance of GR*. This renaissance had many origins which I cannot possibly list here (see [3] for more information and references), but one of the hot topics then was cosmology. It was known for long that GR could model universes of time dependent geometry in which the observed redshifts of distant sources could find a natural explanation in terms of "expanding universes". However, these models also implied initial singularities in the dynamical variables, which effectively cut-off the possibility to understand, in any reasonable theoretical terms, how the universe began (if at all). A widely held belief was that this singular behaviour is possibly an artefact of the overly idealising assumption of exact homogeneity and isotropy, that was imposed on the models as a mathematical implementation of the so-called Copernican Principle, according to which no place and no direction in the universe should be preferred – at least on the largest scales. It was the Russian school formed by Evgeny Lifshitz and Isaak Khalatnikov who in the early 1960s started a systematic analytical investigation of the question whether the initial singularity is a generic feature of cosmological solutions to Einstein's equations. In 1963 they wrote a long summary [17] of their investigations, which supported the belief that singularities may well be just artefacts of the special conditions imposed on the models and hence not generic. Clearly this paper soon attracted much attention in the cosmology group at Cambridge University.

Hawking's first published paper [7] appeared in October 1965 in the prestigious journal *Physical Review Letters*. In it he referred to [17] and showed that the belief expressed there was unfounded. This he achieved by adopting a completely novel approach that Roger Penrose initiated with a similar paper in the same journal a few months earlier [18]. I remember that during a seminar at Heidelberg University in the late 1980s, Khalatnikov told the audience that initially they did not know what to make of the Penrose-Hawking arguments, for the global mathematical techniques from geometry and topology they employed seemed outlandish and incomprehensible to them.

Penrose's paper was concerned with the singularity inside a collapsing star (see Fig. 2), that also had been predicted by GR and that also had been suspected to possibly be just an artefact of exact spherical symmetry. Penrose gave sufficient conditions under which a star must inevitably undergo a gravitational collapse, leading to a singularity, independent of the equations of state of the matter the star was made of, as long as this matter obeyed some condition of "non-negativeness of local energy". The novel approach he invented consisted in the employment of mathematical techniques from differential geometry and differential topology that had so far not been seen in physics. Hawking reformulated Penrose's considerations in a way so as to make them applicable to cosmological solutions. Quite generally, these novel techniques allowed to extract the most far reaching conclusions from the otherwise forbiddingly difficult equations of GR in the form of proper mathematical theorems. For that to be possible the notion of "singularity" had to be properly phrased such that it applied to the most general of circumstances. Just saying that a dynamical variable becomes infinite in finite time is not sufficient, for that behaviour could merely be an artefact of a bad choice of coordinates. It was not at all an easy task to come up with a geometrically

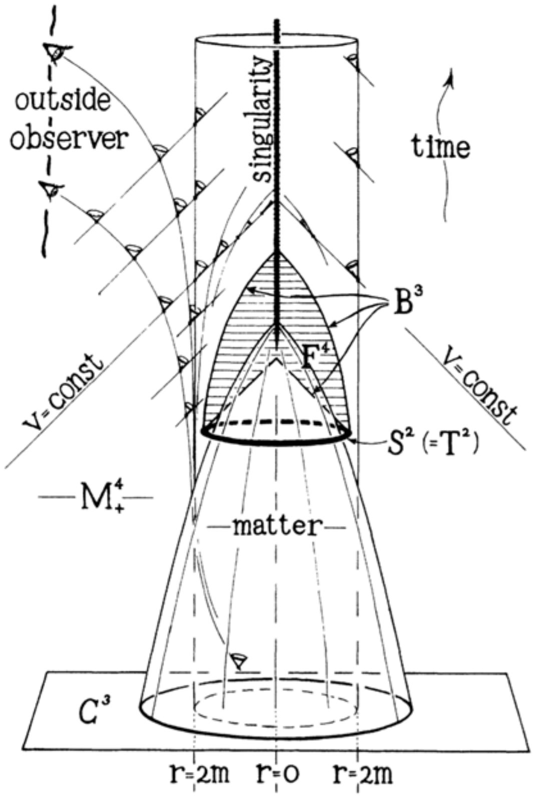


Figure 2: Sketch by Roger Penrose showing the spacetime diagram of a collapsing star. Once the mass is sufficiently compact a trapped surface exists and a horizon forms with a singularity inside it. The horizon prevents the singularity from being seen by an outside observer, as indicated by the tilted light-cones. Here T^2 denotes the trapped surface, which is a topological 2-sphere S^2. See below and Fig. 3 for an explanation of "trapped surface". (Picture credit: [18])

meaningful definition that at the same time concurred with physical intuition and expectation. After some discussions [4] it was agreed that the best compromise is that of geodesic incompleteness. Following that notion a spacetime is now called *singular* if, firstly, it is inextendible, in the sense that no point or portion of it has been artificially removed (so that it can be restored), and, secondly, it contains timelike geodesics, i.e. spacetime curves describing freely falling observers that come to an end (without the possibility of being extended) in finite proper time. This notion can also be suitably extended to also capture lightlike geodesics, describing light rays.

In 1966 Penrose and Hawking independently wrote longer essays in which they explained their results and further ideas in the context of the new techniques. They both submitted these essays to be considered for the Adams Prize (so named after the 19th century Cambridge mathematician John Couch Adams who was actively involved in the discovery of the planet Neptune). They both won the prize for the year 1966. Hawking's prize-winning essay has only recently been published [12] and it is fascinating to see how many more seminal ideas it contains. Penrose and Hawking then joined forces and together they published a paper in 1970 [15] that considerably generalised their previous work and contained a collection of theorems based on minimal assumptions on the existence of singularities inside collapsing stars or at the initial (Bing Bang) and final (Big Crunch) phases in cosmological evolution. These theorems were completely independent of any symmetry requirements and thus showed that the development of singularities were an irreversible and generic prediction of any gravitational system in a state of sufficiently progressed gravitational contraction, given that their evolution follows Einstein's equations.

Regarding the notion of "sufficiently progressed", we remark that already in his first paper [18], Penrose characterised it by the existence of "trapped surfaces". These are orientable (i.e. two sided) embedded surfaces in space such that their two neighbouring wavefronts, which are the two envelopes to the spheres of light flashes emerging from each point of the surface, *both* have a smaller area than the original surface. This geometric definition clearly captures the physical idea of a gravitational field that refocusses the light in both directions normal to the surface; see Fig. 3.

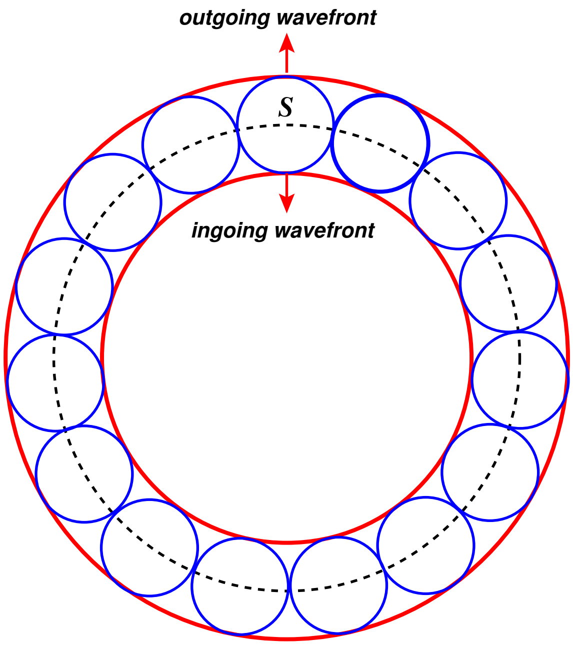


Figure 3: At each point of a closed orientable surface S (depicted by the dotted line) simultaneous light flashes develop into small spheres (blue) after a short and fixed time. The envelopes of this family of spheres are the outgoing (in the direction away from the centre) and ingoing (towards the centre) wave fronts. Usually the outgoing wave front has a bigger, the ingoing a smaller area than S. However, the condition for S to be a trapped surface is that both nearby wavefronts are of smaller area. (Picture credit: Author)

Coming back to the general theorems, we stress that they hold *irrespectively* of the precise dynamical laws that govern evolution of the matter degrees of freedom, as long as the matter always obeyed some local conditions on energy positivity. These investigations then came to a certain close with the publication of two books, a smaller one of about 70 pages by Penrose [19], containing a written up lecture given at Pittsburgh University in June 1970, in which the novel techniques from differential topology where explained in detail, and a far more extensive one of almost 400 pages by Hawking and George Ellis [14], that is now considered to be *the* classic on the mathematical theory of GR, containing not only singularity theorems, but also all about the geometric and topological aspects of Black Holes and cosmological solutions, as well as a comprehensive discussion of the Cauchy problem for Einstein's equations. It is a truly outstanding book, both in its mathematical rigour, skilful argumentation, and physical foresight. Still today, if an eager student asks a profound question concerning the foundations of GR, we always tend to reply automatically: "Did you check Hawking-Ellis"?

As an interlude let me mention an amusing story that seems not to be widely known.[1] Hawking's first graduate student was Gary Gibbons (who changed supervisors from Dennis Sciama, who left Cambridge for Oxford). Soon they published a paper [5] in which they proposed a redesigned bar detector for gravitational waves that could improve on that used in the pioneering experiment by Joseph Weber, who at that time had been believed to have very likely detected gravitational waves [20]. Gibbons and Hawking applied for funding to actually build their own detector in the basement of their department (DAMTP), which was then located a stone's throw away from the vibrant city-centre of Cambridge. But the funding was given to Ronald Drever's group at Glasgow University, who became then one of the leading pioneers in gravitational-wave detection. However, all people involved in this early endeavour of gravitational-wave detection agree that the 1971 paper by Gibbons and Hawking had a major impact on their research.

Thinking about gravitational waves, Hawking immediately realised that the new mathematical techniques used in the context of singularity theorems could be employed to gain significant insight into the otherwise forbiddingly complicated and extremely violent processes of their generation, for which he, for the first time I believe, envisioned the collision of two Black Holes. As had also been shown by Penrose and Hawking, such objects must be surrounded by an event horizon, except in extreme cases that were conjectured not to occur in nature. The surface area of the event horizon is a quadratic measure for the mass it contains. In a paper of 1972, entitled "Gravitational Radiation from Colliding Black Holes", Hawking proved what is now famously known as "area theorem".

According to this theorem, the sum of the horizon areas of (any finite number) of Black Holes cannot decrease in the future *irrespectively* of the details of the collision and merging process and of the types of matter components that may accompany it, as long as Einstein's equations hold and

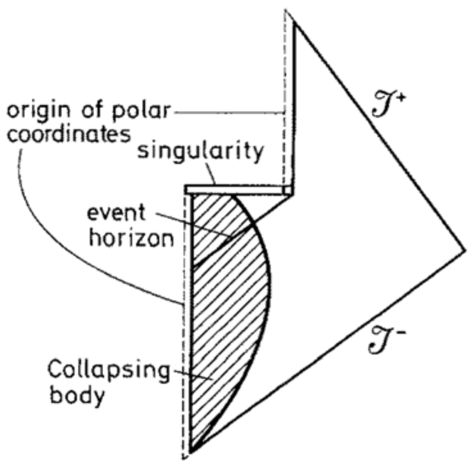


Figure 4: A so-called Penrose diagram for a gravitational collapse followed by the slow evaporation and eventual disappearance of the Black Hole, leaving empty space with no singularity at the origin. (Picture and caption credit: [9])

1 The story was told by Bruce Allen on the occasion of Hawking's 75. birthday; see the programme at *www.ctc.cam.ac.uk/activities/stephen75*

the matter satisfies the so-called "weak energy condition", saying that the energy density of the matter is never negative. Again a result of tremendous generality was derived by choosing an appropriate technique that allowed to insert just the right input from the basic equations without any need to enter the almost hopeless game to actually solve them for the strongly time-dependent processes considered. As the area is proportional to the square of the mass, an immediate consequence for the collision of two Black Holes of equal-mass m into a final back hole of mass M is that $M^2 \geq 2m^2$ or $M \geq \sqrt{2}\,m$. Hence the relative energy extraction $(2m–M)/2m$ cannot exceed $1 - 1/\sqrt{2} \approx 0.293$, corresponding to an upper bound of 29 percent of the initial rest energy $2mc^2$.

Gravity and Quantum Theory

The area theorem was considered reminiscent of the second law of thermodynamics by Jakob Bekenstein, who proposed the hope that perhaps the physics of Black Holes and their interactions could be understood in a similar way to that of thermodynamic systems [2]. Hawking and collaborators immediately showed how this analogy could be put into proper mathematical terms and, in fact, generalised to the *four* laws of "black-hole mechanics" [1]. Entropy would then be proportional to the horizon area (squared mass) and the temperature to the inverse mass.

But, clearly, the analogy remained so far a purely formal one. In particular the zeroth law, ensuring the existence of a temperature function, made clear that the thermodynamic analogy required a non-zero temperature to be assigned to a Black Hole. But then, how can it be that an object at non-zero temperature is completely black and never radiates? This conundrum left Hawking sceptical regarding the physical relevance of the whole idea, until he himself came up with a daring and ingenious solution: Black Holes *can*, in fact *must*, radiate, as he showed by applying the rules of Quantum-Field Theory to fields that propagate in the background geometry of Black Holes. [8, 9]. Although this conclusion was based on an approximation in which the spacetime structure did not receive any back-reaction from the quantum field, which is certainly unjustified during the late and violent stage of an evaporation process, the derivation was otherwise based on well established concepts which left no doubt that "Hawking radiation", as it is now called, is a genuine prediction (still to be understood better) of Quantum-Field Theory in the presence of objects surrounded by an event horizon.

Having solved one conundrum, Hawking radiation immediately poses another, apparently even more fundamental one: If a Black Hole radiates energy it should loose mass due to energy conservation. As the temperature at which it radiates is inversely proportional to its mass, the luminosity steadily increases and - presumably - ends in an explosion (compare the title of [8]). So the Black Hole disappears into thermal black-body radiation and - presumably - nothing else (see Fig. 4). If this were true then the complete evolution of a star that underwent gravitational contraction into a Black Hole and that subsequently disappeared into thermal radiation could not be described by the familiar dynamical rules of Quantum Mechanics, according to which a pure state remains pure, or, in other words: no information gets lost in the evolution. But if an initial star eventually turns into thermal blackbody radiation without any other remnant left, there clearly is a lot of information in the initial (low entropy) state that cannot be found anymore in the final (high entropy) state. So where is it? This puzzle was again immediately recognised by Hawking [10], who pointed out that once the evolution of quantum systems is considered in the presence of event horizons we face a new "ignorance principle" (as he then called it) that prevents information conservation or, in technical terms, unitary evolution. The so-called scattering matrix, familiar from elementary-particle theory, will cease to be unitary (information preserving). This observation led to a lively debate in the community, which is still ongoing, and to one of the famous bets between Hawking and his scientific friends and colleagues. This time it was Hawking and Kip Thorne (one of the three Physics Nobel-Prize winners 2017 for the detection of gravitational waves) on one side, and John Preskill, a theoretical particle physicist at Caltech, on the other. They disagreed on whether information is really irretrievably lost (Hawking-Thorne), in which case the existence of horizons will force physicists to give up fundamental structural properties of Quantum Mechanics, or whether a (hypothetical) full theory of Quantum Gravity will eventually restore unitarity by properly applying quantum rules also to the gravitational field (Preskill).

Later these questions were also discussed between Hawking and his former mentor and collaborator Roger Penrose, who did not agree with Hawking's gradual withdrawal from his original position in becoming more inclined to give Quantum Theory the pride of place in its proposed union with GR. In an open debate, published in [16], that took place at the Isaac Newton Institute in Cambridge in 1994, they both laid down their views and essentially agreed to disagree on essential points concerning the interpretation and role of Quantum Theory. In 2004 Hawking announced that he was conceding the bet with Preskill, but discussions on what is now known as "information-loss paradox" went on until this day. In fact, Hawkings last scientific paper [13], submitted to the preprint-archive "ArXiv" at Cornell University Library on September 3. 2015, carries the title: "The Information Paradox for Black Holes". The abstract reads as follows:

> "I propose that the information loss paradox can be resolved by considering the supertranslation of the horizon caused by the ingoing particles. Information can be recovered in principle, but it is lost for all practical purposes."

Here the word "supertranslations" refers to certain symmetries which will give rise to conserved charges and which, in turn, are suggested to encode the missing information.

Quantum Cosmology

The discovery and debate surrounding the information-loss paradox naturally led Hawking deeply into issues concerning the possibility to formulate a unifying theory of Quantum Gravity in which both, Quantum Theory and General Relativity, could coexist (as appropriate limits) in a logically coherent fashion. A natural playing ground for ideas how to achieve such a formidable task was cosmology, since here the standard mathematical models only considered finitely many gravitational and matter degrees of freedom due to the assumption of (approximate) overall homogeneity and isotropy. Hence known methods of quantisation could be tried on these models and consequences derived. All this was extremely speculative, of course, but the primary purpose was to try ideas in kind of mathematical laboratory. One of the typically daring ideas was the "no-boundary proposal", that Hawking developed together with his colleague James Hartle [6] in a paper which they called – with a twinkle in their eyes, I am sure – "Wave Function of the Universe". They employed the path-integral formulation of Quantum Mechanics which generally allows to calculate the probability amplitude for a final configuration, given the initial configuration. They asked how this could possibly be applied to a universe that emerged from a Big Bang. Since we do not know - and never will know - what the initial condition at the Big Bang might be, they came up with an idea that is familiar from Quantum Mechanics and Quantum-Field Theory, but totally foreign to GR, namely to continue spacetime, which is modelled over the real numbers, into the field of complex numbers. In Quantum Mechanics this trick is usually applied to calculate so-called tunnel-amplitudes for quantum transitions that cannot occur in the classical theory. Applied to GR an unexpected possibility to think of the Big Bang, together with a beautiful picture emerged (see Fig. 5): The observable Universe, which is four-dimensional with one dimension being geometrically distinguished as time, is connected to another Universe without further boundary, which is also four-dimensional, but where all four dimensions are now equal in their geometric role and interpretation, hence where no notion of time exists. In technical terms: Our observable Universe corresponds to a Lorentzian manifold $\mathcal{M}_L$ (one time-, three space dimensions), the other, replacing the Big Bang in a now regular (not singular!) fashion, is an Euclidean (or Riemannian) manifold $\mathcal{M}_E$ (four space dimensions) which has the geometry of a hemisphere in four dimensions. The two geometrically different manifolds are glued together along a 3-sphere, which forms the equator of $\mathcal{M}_E$ and which fits in between $\mathcal{M}_E$ and $\mathcal{M}_L$ in a geometric fashion that makes the join as smooth as possible (called totally geodesic).

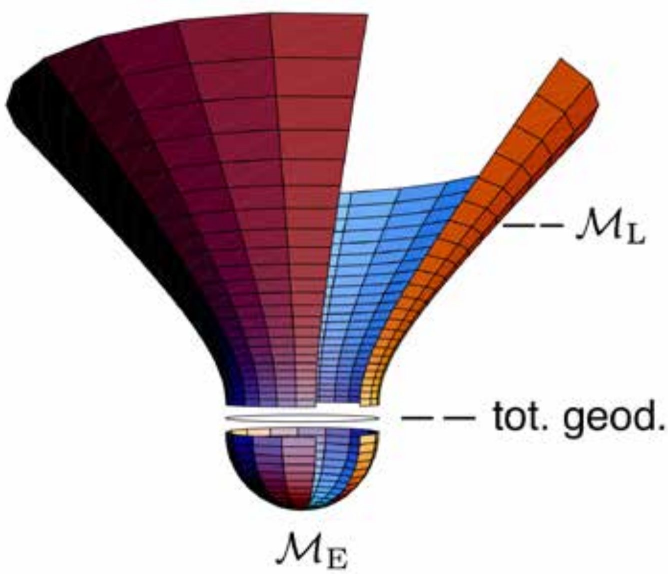


Figure 5: The universe-model according to Hartle and Hawking [6]. (Picture credit: Author)

This last condition is imposed by Einstein's equations, which can be applied to this type of "matched solutions", in exactly the same way in which Maxwell's equations can be applied in the presence of two different materials touching along a common boundary. If the material properties change discontinuously across that boundary, one needs to impose the well known junction conditions in order for Maxwell's equations to be solved in an integrated form. This also works in GR, where the junction conditions between Lorentzian und Euclidean geometries turn out to require precisely that the common boundary be totally geodesic.

This opens up the possibility to think completely differently about the apparently meaningful question of what happened before the Big Bang. The answer is most simple: "nothing!" The big bang is replaced by a nowhere singular spacetime $\mathcal{M}_E$, that "rounds off" the universe $\mathcal{M}_L$ such that on the "other side", i.e. within $\mathcal{M}_E$, time simply does not exist and nothing "happens" – in the sense of "becoming in time". There is no boundary at which the universe began and hence this suggestion by Hartle and Hawking was called "the no-boundary proposal".

Epilogue

This ends my little tour through the scientific work of Stephen Hawking, who in his later years became more and more involved with making his insights available to the public. His first popular book [11] is now a classic. It sold more than 25 million times and became translated into about 40 languages. Other books were to follow, partially with the help of his daughter Lucy. He received many public and scientific honours. In 1982 he was awarded CBE (Commander of the Most Excellent Order of the British Empire), in 1989 Companion of Honour to Her Majesty, and in 2009 the Presidential Medal of Freedom. The scientific prizes included the Fundamental Physics Prize (2013), the Copley Medal (2006) and the Wolf Foundation Prize (1988). He was a Fellow of the Royal Society, which he became at the exceptionally young age of 32, and a member of the US National Academy of Sciences and the Pontifical Academy of Sciences.

Last not least, Stephen Hawking was an extraordinary human being, whose wit, sense of humour, optimism, and, above all, courage, left an unforgettable impression with anyone who had the privilege to meet him.

References

[1] James M. Bardeen, Brandon Carter, and Stephen W. Hawking. The four laws of black hole mechanics. *Communications in Mathematical Physics*, 31(2):161–170, 1973.
[2] Jacob D. Bekenstein. Black holes and entropy. *Physical Review D*, 7(8):2333–2346, 1973.
[3] Alexander Blum, Domenico Giulini, Roberto Lalli, and Jürgen Renn. Editorial introduction to the special issue "The renaissance of Einstein's theory of gravitation". *The European Physics Journal H*, 42(2):1667–1685, 2017.
[4] Robert Geroch. What is a singularity in general relativity? *Annals of Physics*, 48(3):526– 540, 1968.
[5] Gary W. Gibbons and Stephen W. Hawking. Theory of the detection of short bursts of gravitational waves. *Physical Review D*, 4(8):2191–2197, 1971.
[6] James Hartle and Stephen W. Hawking. Wave function of the universe. *Physical Review D*, 28(12):2960–2975, 1983.
[7] Stephen W. Hawking. Occurence of singularities in open universes. *Physical Review Letters*, 15(7):689–690, 1965.
[8] Stephen W. Hawking. Black hole exlosions? *Nature*, 248:30–31, 1974.
[9] Stephen W. Hawking. Pair creation by black holes. *Communications in Mathematical Physics*, 43(3):199–220, 1975.
[10] Stephen W. Hawking. Breakdown of predictability in gravitational collapse. *Physical Review D*, 14(10):2460–2473, 1976.
[11] Stephen W. Hawking. *A Brief History of Time*. Bantam Press, London, 1988.
[12] Stephen W. Hawking. Singularities and the geometry of spacetime. *The European Physical Journal H*, 39(4):413–503, 2014.
[13] Stephen W. Hawking. The information paradox for black holes. *arxiv:1509.01147*, 2015. Talk given on August 28. 2015 at "Hawking Radiation", a conference held at Royal Institute of Technology, Stockholm.
[14] Stephen W. Hawking and George F. R. Ellis. *The Large Scale Structure of Spacetime*. Cambridge University Press, Cambridge, 1973.
[15] Stephen W. Hawking and Roger Penrose. The singularities of gravitational collapse and cosmology. *Proceedings of the Royal Society A* (London), 314:529–548, 1970.
[16] Stephen W. Hawking and Roger Penrose. *The Nature of Space and Time*. Princeton University Press, Princeton, New Jersey, 1996.
[17] Evgeny M. Lifshitz and Isaak M. Khalatnikov. Investigations in relativistic cosmology. *Advances in Physics*, 12(46):185–249, 1963.
[18] Roger Penrose. Gravitational collapse and space-time singularities. *Physical Review Letters*, 14(3):57–59, 1965.
[19] Roger Penrose. *Techniques of Differential Topology in Relativity*. Regional Conference Series in Applied Mathematics. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, Pennsylvania, 1972.
[20] Joseph Weber. Evidence for discovery of gravitational radiation. *Physical Review Letters*, 22(24):1320–1324, 1969.

Domenico Giulini was born in Heidelberg (Germany) where he also began his university studies in physics and mathematics. After taking part in a one-year exchange programme to Cambridge after his 3rd semester in Heidelberg, he decided to not return home but rather stay at Cambridge to take up a Ph.D. programme at the Department of Applied Mathematics and Theoretical Physics (DAMTP) in the group led by Stephen Hawking under the supervision of Gary Gibbons. The subject of the thesis had to do with certain mathematical aspects of multi-black-hole initial data sets for Einstein's equations. After finishing the Ph.D. in 1990 Giulini returned to Germany and became a university assistant at Freiburg (Breisgau), where he obtained the habilitation and venia legendi. After that he worked for several years as a scholar of the SNF in Norbert Straumann's group at Zürich University and then became a researcher at the Max-Planck-Institute for Gravitational Physics at Golm near Potsdam in Germany. Currently he is a Professor for Theoretical Physics at the Leibniz University of Hannover and also a member of the Center of Space Technology and Microgravity (ZARM) at the city Bremen.
His research mostly concentrates on theoretical and conceptual aspects of gravitational physics and General Relativity. Recent research has to do with a novel type of proposed experiments for more accurate tests of Einstein's Equivalence Principle - which underlies GR - using matter in entangled states. The theoretical task here is to understand to a sufficient degree how classical gravitational fields interact with quantum matter. Other current interests concern theoretical cosmology, in particular the development of a systematic method for the construction of initial data sets for Einstein's equations that are inhomogeneous to any prescribed degree and at any scale.

Milestones in Physics (13)

Ground States of Metals

Hans Rudolf Ott, Laboratorium für Festkörperphysik, ETH Hönggerberg, Otto-Stern-Weg 1, 8093 Zürich

I. Setting the stage

One of the most fruitful areas of condensed matter physics started with the seemingly simple problem of understanding the behaviour of dilute solutions of magnetic moments in an electrically conducting matrix, i.e., a metal. As I hope to show below, this endeavour developed into one of the major fields of research for discovering and understanding the ground states of matter in the solid state, thereby touching upon fundamental questions regarding many-body physics and its consequences on the behaviour of metals at low temperatures.

In retrospect, 1957 was an important year with respect to the setting of milestones in the physics of metals. First of all, Landau introduced his ^{3}He-inspired Fermi-liquid model which, for years to come, also served as *the* model for describing the behaviour of itinerant yet interacting electrons in normal metals [1]. Even more spectacular was the solution of one of the long-standing problems of condensed matter physics, the understanding of the occurrence of superconductivity, solved by Bardeen, Cooper and Schrieffer (BCS) [2]. Their theory, based on an effective attractive interaction between electrons mediated by phonons, turned out to explain a number of experimental observations related to the onset of superconductivity in simple metals.

Around the same time, early theoretical treatments [3] of the problem mentioned above, claimed to provide a sufficient understanding of the situation, emphasizing the special role of d-transition metal moments such as Fe. However, subsequent experiments, mainly by Matthias, Suhl and Clogston [4-6], probing the influence of dilute magnetic moments in both the superconducting and the normal phase of various types metals, revealed unexpected complications. This prompted Phil Anderson to consider an extension of the existing models which resulted in the now famous Anderson Hamiltonian [7], aiming at explaining why Fe ions in certain metallic environments retain their magnetic moments and in others are quenched.

The detrimental effect of stable, i.e., unquenched moments on superconductivity was clarified by Abrikosov and Gor'kov [8] by introducing the concept of pair breaking and by Anderson [9], based on the breaking of time-reversal symmetry by magnetic moments and -fields, thus disturbing the formation of Cooper pairs that are formed by electronic states that are related by the time-reversal operation.

Very shortly afterwards, another long-standing puzzle, the experimental observation of minima in the resistance ρ(T) in a variety of metals [10] was theoretically explained by Kondo. In his work [11] he showed that localized moments can be shielded by nearby conduction electrons whose spin moments compensate the local moment. In this situation the electronic excitation spectrum is altered, eventually leading to an enhancement of ρ with decreasing temperature below a characteristic temperature T_K, setting the relevant energy scale.

II. Stability of Magnetic Moments in Metals

All the above happened while I still attended the Gymnasium and later during my studies of physics at ETH. While working on my doctoral thesis my research was dedicated to investigating volume effects at superconducting transitions of simple metals. For some of those I studied, the effects were rather small and therefore technically challenging to observe. At any rate, although of no real relevance in our context, it may be mentioned that the same instrument that allowed to measure relative length changes of the order of 10^{-10} much later served to calibrate (during a holiday-season vacation) an early version of the scanning tunneling microscope (STM) of Heini Rohrer and Gerd Binnig that provided their first results monitoring the surfaces of Si single crystals.

After the completion of my thesis my interests turned to metallic materials where ions carrying magnetic moments occupy regular lattice sites in corresponding rare-earth compounds. To some extent, this was inspired by activities in the group of Prof. Busch, then the head of the laboratory for solid state physics at ETH, where Fritz Hulliger's expertise in synthesizing such compounds was of great help and a close collaboration with him over many years emerged. At the same time I had the opportunity to collaborate with former students of Jørgen Olsen, my thesis adviser. These were Bruno Lüthi, then at Rutgers University and Klaus Andres at Bell Labs. The topic of the day was „Valence Fluctuations". It had turned out that for some compounds of elements at the beginning, the middle and the end of the rare-earth (RE) series, i.e., Ce, Sm, Eu, Tm and Yb, did often not order magnetically at low temperatures, although the temperature dependence of the magnetic susceptibility χ(T) at elevated temperatures indicated stable moments of considerable magnitude (> 1 μ_B) to reside on the rare-earth ions, depending on the valence of these ions. The latter may vary from 2+ up to 4+, depending on the location within the series. The problem, the stability of magnetic moments due to localized 4f electrons of rare-earth ions in metals, was to understand the interaction between the itinerant electron states and the localized electron orbitals of the 4f shell and its consequences. It turned out to be a real challenge for theorists. At the end of the first conference on the topic, Anderson compared the situation with that of seven blind men, trying to figure out an elephant by simply touching its body at different places.

In a collaboration with John Graebner and Klaus we studied some of the physical properties of one of these compounds, $CeAl_3$, down to very low temperatures, i.e., to much below 1K [12]. Although a metal, ρ(T) increases monotonously with decreasing temperature below 300 K, passing through a maximum around 35 K and then dropping rapidly by more than two orders of magnitude and reaching a residual resistance at 0 K of less than a 1 $\mu\Omega$cm. Close to T = 0 K, $\rho(T) \sim AT^2$, with a huge prefactor A of 35 $\mu\Omega cm/K^2$ (see Fig. 1). The magnetic susceptibility $\chi(T)$ above 2 K is compatible with an effective moment per Ce ion of 2.5 μ_B. It turns into a temperature-independent Pauli-type susceptibility but much larger in magnitude than found for simple metals. A large negative thermal expansion coefficient below 1 K indicates

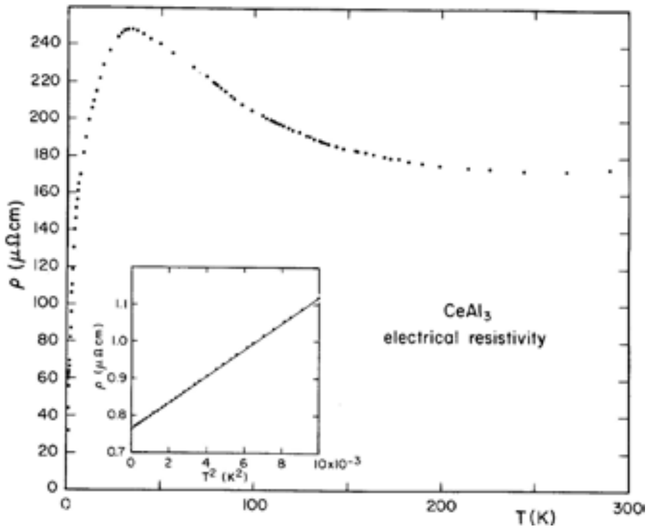


Fig. 1: Electrical resistivity of $CeAl_3$ between 0.015 and 300 K. Note the T^2 dependence below 0.1 K.

a very narrow density of electronic states $D(E_F)$ at the Fermi energy, very much in agreement with the specific heat vanishing linearly with T below 0.1 K, with an enormous slope γ of 1.62 J/moleK^2, about 400 times the value of Al. These data, never observed in this manner in a metal before, is compatible with the conduction electrons forming a strongly renormalized Fermi liquid of quasiparticles adopting a very large effective mass $m^* >> m_e$. The data of later experiments probing both the electrical and the thermal conductivity confirmed this view [13]. Thermodynamically argued it appears that the entropy due to magnetic degrees of freedom are, at very low temperatures, transferred to the ensemble of itinerant electrons. The large effective mass implies a very low Fermi energy E_F of the order of 1 meV, i.e., lower than the Debye energy $k_B\theta_D$, synonimus with a low Fermi velocity v_F, lower than the speed of sound of the corresponding material. As usual, this discovery of very heavy electronic quasiparticles in a metal was largely ignored for a while but in retrospect it was the beginning of a new era in the physics of metals.

III. Interlude: Unconventional Superconductivity

The emerging topic got a strong boost in 1979 with the discovery of superconductivity in $CeCu_2Si_2$, a compound with similar low-temperature electronic properties dominated by heavy quasiparticles [14]. The experimental results showed very clearly that the superconducting state was due to the pairing of these heavy quasiparticles, on this occasion termed heavy fermions. Also this discovery by Frank Steglich and collaborators was quite unexpected because the unusually strong Pauli-type paramagnetic background was thought to inhibit such a transition and at first, the community reacted again with reservations.

Meanwhile the instability of magnetic moments of RE compounds was, in some cases, traced back to crystal-field effects, responsible for the splitting of the Hund's rule multiplet of the 4f electron configuration. These may result in singlet- or non-magnetic doublet ground states and magnetic order is therefore not expected in these cases. At the time I studied materials of this type, again in collaboration with Bruno and Klaus. Our major contributions were the first experimental demonstrations of (i) a Schottky anomaly in thermal expansion coefficient and (ii) together with Jørgen Kjems at Risø in Denmark, an induced Jahn-Teller distortion in $PrCu_2$, respectively. Along the way it occurred to me that earlier work of Ernst Bucher, a former student of Georg Busch and, at the time, active at Bell Labs, reported on low-temperature properties of UBe_{13}, an actinide compound [15]. In this case, of course, it is the 5f-electron orbitals which may combine to a local moment on the respective ions. Bucher and collaborators noted the absence of magnetic order above 0.45 K and a sharp diamagnetic shift in $\chi(T)$ at 0.97 K, usually an indication of an onset of superconductivity, which, for various reasons, the authors didn't consider as an intrinsic property of this compound.

Being aware of the case of $CeCu_2Si_2$ I thought it might be worth to measure the resistivity $\rho(T)$ and the specific heat $C_p(T)$ of UBe_{13} to below 1 K. Since both U and Be are considered as bad actors in various ways, I contacted Zach Fisk and Jim Smith, both colleagues and friends at Los Alamos National Laboratory (LANL). They were ready to try to grow single-crystalline samples and make them available for our intended measurements which, at ETH, involved my graduate student Helmut Rudigier. Monitoring the resistive transition to superconductivity just below 1 K was the easy part. The electronic component of the specific heat $C_p^{el}(T)$ data down to 1 K showed a gradual but strong increase of the ratio C_p^{el}/T with decreasing temperature, indicating a strong increase of the electronic effective mass and therefore the rather unexpected formation of a heavy-electron state in a U-based compound. To our satisfaction, the transition to the superconducting state was accompanied by the expected large anomaly of the specific heat, proving that it was the heavy quasiparticles that take part in the pairing and $CeCu_2Si_2$ was not a singularity [16].

The conditions for superconductivity in UBe_{13} are, conventionally viewed, extremely unfavourable. As in $CeAl_3$, $\partial\rho / \partial T$ is negative below room temperature and, at the onset of superconductivity of UBe_{13}, the electrical resistivity is unusually high, of the order of 200 $\mu\Omega$cm. The magnetic susceptibility $\chi(T)$ at temperatures above 100 K indicates an effective moment of 3.1 μ_B/U-ion and the magnetization M(H) at 4 K varies linearly with increasing magnetic field H up to 10 T. These macroscopic properties, together with the fact that $E_F < k_B\Theta_D$ (the characteristic energy of the lattice) and considering that the degrees of freedom of the heavy quasiparticles are of magnetic origin, suggested that the superconducting state was not of the conventional BCS variety. Indeed, as shown in Fig. 2, the variation of the normalized electronic specific heat $C_s^{el}(T)/C_n^{el}(T_c)$ below T_c deviates strongly from the calculated version based on the original BCS theory. Calculations of Maurice Rice and his postdoc Kazuo Ueda indicated that the data were con-

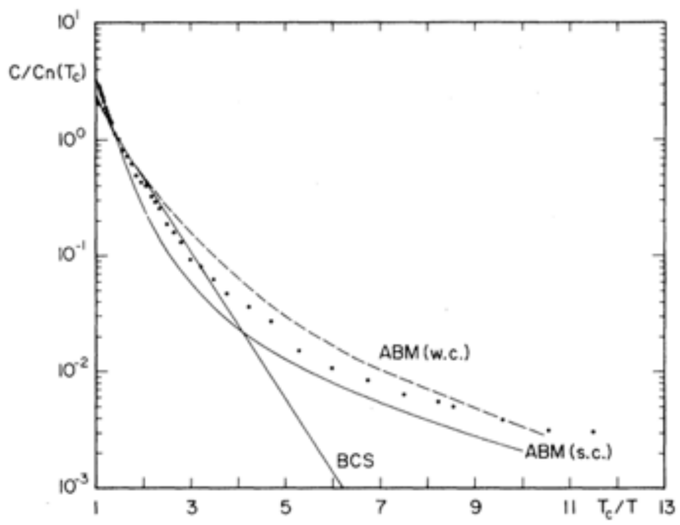


Fig. 2: $C_s/C_n(T_c)$ for superconducting UBe_{13}. Dashed line: weak-coupling triplet (ABM) state; solid lines: BCS and strong-coupling ABM state. For details see [17].

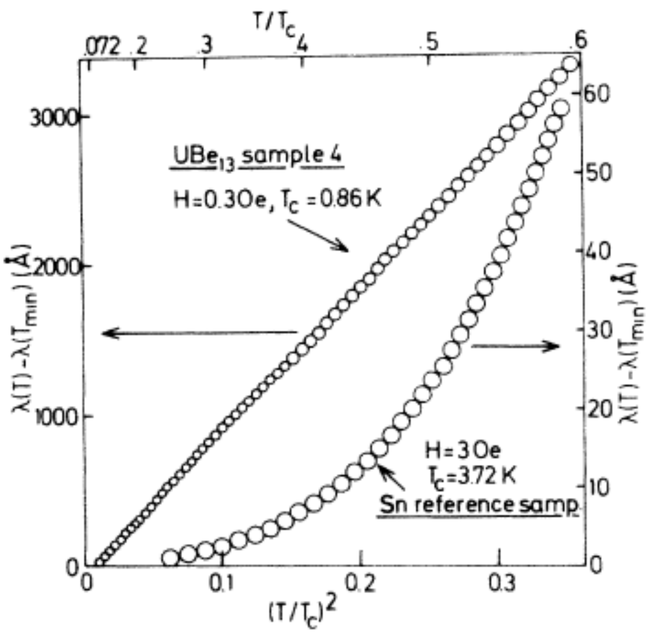


Fig. 3: Direct comparison of the incremental London penetration depth of UBe_{13} and Sn in the same reduced temperature scale T/T_c (see [20]).

sistent with an unconventional pairing symmetry [17]. Soon thereafter also Phil Anderson argued on general grounds that superconductivity in these heavy-electron materials was not due to the usual electron-phonon interaction [18]. These and results of subsequent experiments in collaboration with partners in the USA and Germany probing the temperature dependences of the nuclear magnetic (NMR) relaxation rate $T_1^{-1}(T)$ of ^{9}Be nuclei [19], the London penetration depth $\lambda_L(T)$ [20] (see Fig. 3) and the ultrasound attenuation [21] supported this view. The BCS theory predicts an exponential decrease of these quantities below T_c, reflecting the opening of an energy gap Δ in the quasiparticle excitation spectrum. Instead, the observation of respective power laws indicates the formation of gap nodes, i.e., regions of remnant non-zero density of states, a feature of unconventional superconducting states. Since then, the observation of power laws instead of exponential temperature dependencies of the above mentioned parameters below T_c is one of the predominant arguments for claiming unconventional superconductivity in new materials. Another unusual feature of the superconducting state of UBe_{13} is its surprising stability versus external magnetic fields, exemplified by an enormous slope of $\partial H_{c2}/\partial T$ of about 50 T/K at T_c. Also $H_{c2}(T=0)$ exceeding 10 T, considering that $T_c < 1$ K, is remarkable. First results were due to Brian Maple and collaborators at UCSD [22], later complemented and interpreted by groups and colleagues at Darmstadt and Grenoble [23].

In metal-physics research and particularly in studies of superconductivity, an often chosen approach to characterize a material is to vary, if possible, its chemical composition. This route was also chosen for UBe_{13}, resulting in a really surprising observation. The original aim was to study the variation of the onset of superconductivity by replacing U with a selection of elements, including alkaline-earth, rare-earth and actinide elements, at a low at% level. All these „impurities“ reduce T_c and, surprisingly, the strongest reduction per at% is observed for Lutethium, the end member of the rare-earth series with a fully occupied 4f shell [24]. By far the most surprising observation was made for $U_{1-x}Th_xBe_{13}$ for which a non-monotonic reduction of T_c was established for $0 < x < 0.06$. Subsequent measurements of the specific heat of a number of samples with varying x revealed a multi-domain phase diagram of the superconducting state, indicated by two consecutive anomalies in $C_s^{el}(T)$ at and below T_c for $0.019 < x < 0.04$ [25]. A subsequent study of this phase diagram under external pressure revealed two superconducting states, separated by a narrow region of x with normal-state features above 1 GPa [26]. Again, these experimental observations confirmed the „exotic“ nature of superconductivity in UBe_{13}. Manfred Sigrist, then a PhD student with Maurice Rice succeeded, via a phenomenological analysis on the basis of Ginzburg-Landau expansions involving symmetries and representation crossings, to reproduce the experimental phase diagram [27], shown in Fig. 4, quite accurately [28]. Somewhat later, Manfred and Kazuo presented a very complete discussion of the symmetry of possible superconducting states and their interplay [29].

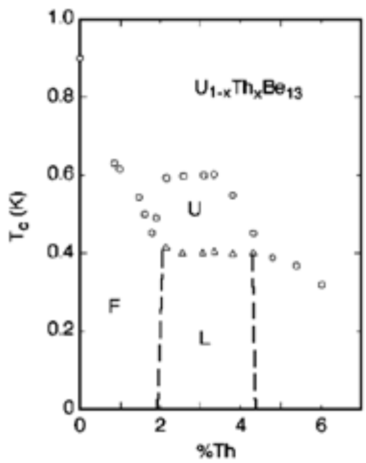


Fig. 4: (x,T) phase diagram of superconducting $U_{1-x}Th_xBe_{13}$ as derived from specific heat data. The letters denote three different superconducting phases.

IV. Heavy Electrons (HE), Magnetic Order and Superconductivity

In the wake of the described studies on $CeAl_3$, $CeCu_2Si_2$ and UBe_{13}, many new similar materials, mainly Ce and U compounds were synthesized and their ground states, revealed by their physical properties at low temperatures, investigated. Many conferences and workshops since then have been dedicated to this topic which also has kept its place in numerous meeting- and workshop sessions during the last 35 years. In the following I shall discuss a few cases that were part of our involvement in this development with partners in Europe and the USA. It turned out that the situation was not as straightforward as originally thought.

Together with colleagues at LANL, $CeCu_6$ was soon identified as another heavy-electron compound without magnetic ordering above 0.04 K and $C_p^{el} = \gamma T$ below 0.5 K and γ = 1.53 J/moleK^2 [30]. Rather intriguing, however, is the temperature variation $\rho(T)$ which changes from approximately T^2 below 0.1 K to linear in T above 0.6 K. In retrospect this indicated what was later found in experiments by Hilbert von Löhneysen and collaborators, to be discussed further below.

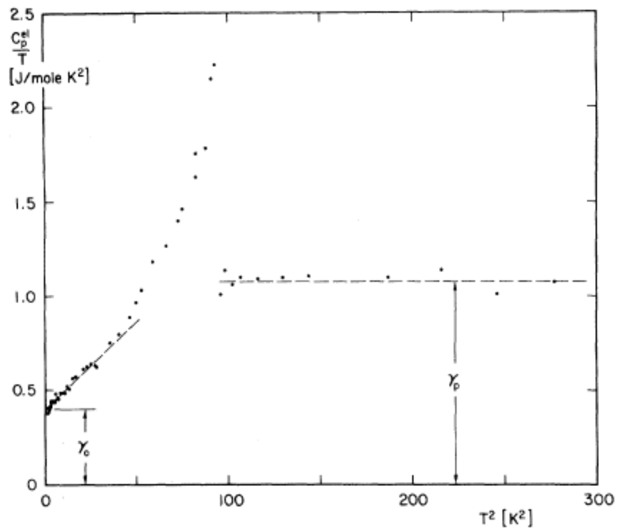
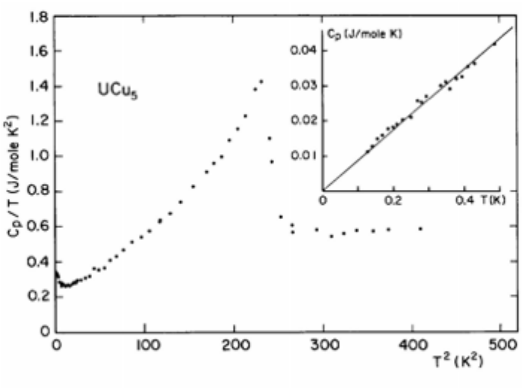


Fig. 5: Electronic specific heat of U_2Zn_{17} at low temperatures. Note the substantial residual $C_p^{el}(T)$ in the magnetically ordered phase.

By investigating selected compounds, again in collaboration with colleagues from LANL, Risø, and Bell Labs, it was found that the formation of heavy quasiparticles did not necessarily imply the absence of magnetic order. Based on results of measurements probing $\chi(T)$, $C_p(T)$ and $\rho(T)$, the compound U_2Zn_{17} was found to order antiferromagnetically out of a HE state. The $C_p(T)$ data below the ordering temperature T_N revealed the survival of about 40% of the heavy quasiparticles down to T = 0 K [31] (see Fig. 5). The analysis of later results obtained from neutron-scattering experiments suggested that the onset of order was due to the temperature dependence of the effective interaction parameter rather than the result of a diverging single-ion susceptibiity [32]. UCu_5 was known to order magnetically at 15 K [33]. Our measurements of the specific heat in the ordered phase revealed an upturn of the C_p/T ratio below 4 K to a value of about 320 mJ/moleK^2 at 1.5 K (see Fig. 6). Preliminary C_p data for T ≤ 0.6 K indicated a considerably lower value for this ratio, suggestive for an instability of the HE phase in between. Indeed, the corresponding transition was prominently manifested by an anomaly in $C_p(T)$ around 1 K [34] (see Fig. 6). The clear hysteresis of the anomaly, depending on the mode of the measurement of either heating or cooling, demonstrated the first order character of the transition. These data, combined with a detailed analysis of results obtained from electronic-transport measurements [35], suggest that the electronic structure of UCu_5 is highly anisotropic in k-space, i.e., different parts of the Fermi surface are unstable at different temperatures. The nature of the lower transition is still not really understood but the coexistence of conventional antiferromagnetic order and a renormalized Fermi-liquid type electronic background seems to be established.

The first investigation of $CeAl_3$ employing a microscopic probe in the form of muon spin rotation (μSR) experiments was carried out in collaboration with Alex Schenck at PSI and Stefan Barth, our PhD student. The detailed study, sponsored by a special fund of the directorate of the ETH domain (Schulratsmillion) revealed a new feature of the low-temperature properties of this compound. The collected data indicated the onset of magnetic correlations below 2 K. By combining data from measurements in zero-, transverse- and longitudinal field configurations it was concluded that, with decreasing temperature, these correlations develop, in a spatially inhomogeneous and frustrated way. Below 0.7 K they are partly static. This sluggish onset of magnetic correlations was tentatively ascribed to a temperature-dependent variation of competing interactions rather than a divergence of a single-ion susceptibility for which there is no experimental evidence [36]. Later, results of measurements monitoring NMR spectra of ^{27}Al nuclei and the corresponding spin-lattice relaxation rates $T_1^{-1}(T)$ at very low temperatures [37] confirmed this magnetically and spatially inhomogenous ground state of $CeAl_3$, later shown to turn into a moderately enhanced paramagnetic state under external pressure (see below). Considering these results, the ground state of $CeAl_3$ at ambient pressure cannot be regarded as a simple strongly renormalized Fermi liquid. Later, to be discussed below, it turned out that such complications and new features were more numerous than expected.



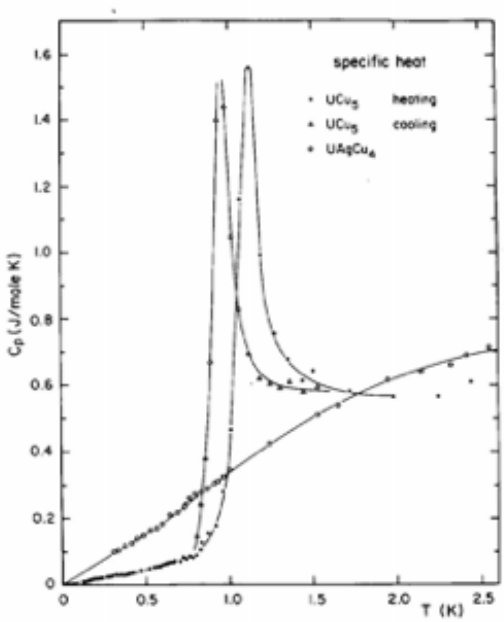


Fig.6: $C_p(T)$ of UCu_5, emphasizing the magnetic transition at 15.5 K and the formation of the heavy-electron state below 4 K (upper panel) and the lower transition and its suppression by replacing one Cu atom per formula unit with Au.

Returning to the topic of superconductivity, during the following years the harvest of finding new superconductors with unusual physical properties turned out to be rather rich and I apologize for not mentioning them all here. The next in the series, UPt_3, had been studied before and its normal-state electronic properties reflected features of a Fermi liquid whose quasiparticles interacted with incoherent spin fluctuations [38]. However, it turned out that the really interesting features appeared only at temperatures below 1 K offering a rich playground for studying possible features of an unconventional superconductor. The onset of superconductivity at 0.54 K was first reported by Greg Stewart and colleagues at LANL [39]. As described above for UBe_{13}, the temperature dependencies of a number of properties indicated again the formation of nodes in the superconducting energy gap of UPt_3 [40-43]. On the basis of various experimental data, including results of measurements of $C_p(T)$, ultrasound and torsional-oscillator responses [44-48] it soon turned out that the [H,T] phase diagram exhibits three different phases (A, B and C), separated by distinct boundaries, their location partly depending on the orientation of the external magnetic field with respect to the hexagonal crystal-lattice (see Fig. 7). The phase just below T_c and in low fields (A phase) may be quenched by application of moderate external magnetic fields and pressure [47-49]. A specially designed experiment probing the local induction in UPt_3 with a 2D electron-gas Hall probe confirmed the time-reversal symmetry breaking in the B phase [50]. A fairly complete discussion of the obviously unconventional superconductivity of UPt_3 is given in [51] by Robert Joynt and Louis Taillefer. Incidentally UPt_3 was the first compound for which the mass enhancement of the electronic quasiparticles was confirmed on the basis of results of de Haas-van Alphen experiments by Taillefer and Gil Lonzarich [52]. The subsequent development of superconductivity in f-electron materials up to 2008 is well documented in the review of Christian Pfleiderer in [53]. This development brought a number of additional surprises such as examples of superconducting ferromagnets which, according to folklore, was believed to be impossible.

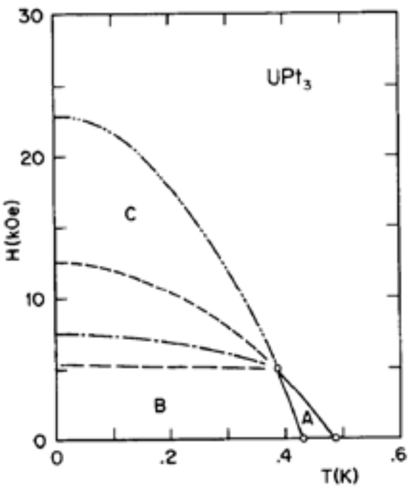


Fig. 7: Schematic (H,T) phase diagram of superconducting UPt_3. The location of the boundary separating B and C depends on the field orientation with respect to the crystal lattice. The broken line with 2 dots represents the upper critical field $H_{c2}(T)$.

V. Non-Fermi-Liquid features and Quantum Criticality in Metals

Meanwhile, new insights had been gained through studies of intentionally disturbed heavy-electron ground states, e.g., by external pressure or magnetic field as well as chemical variations of the compounds. Specific heat data of Brodale and collaborators [54] revealed an extreme influence of external pressure on the low-temperature properties of $CeAl_3$, previously suggested by an anomalously large negative thermal expansion coefficient below 1 K [12]. With a rather moderate pressure of 0.82 GPa, the parameter γ is reduced to roughly a third of its ambient-pressure value and the region of $C \sim T$ is extended from 0.1 K to 1 K above T = 0. The results of later measurements employing NMR techniques probing ^{27}Al nuclei under external pressure revealed more details in the sense that the intrinsic magnetic and electronic inhomogeneities at ambient pressure are completely removed by a pressure of the order of 0.1 GPa [55] (see Fig. 8). The resulting simple paramagnetic state is stable above 65 mK, i.e., no magnetic order is observed. Altogether these results suggest that $CeAl_3$ at ambient pressure is on the brink of magnetic ordering but is driven away from such a state upon applying external pressure.

An early example of the effect of replacing a small amount of an element on the regular sublattice of a compound was found in comparing UPt_5 and $UAuPt_4$ [56]. The parent compound is a metallic compound without showing any obvious anomalous features above 1 K. However, $C_p^{el}(T)$ of $UAuPt_4$ indicates the formation of a heavy-electron state below 5 K without any sign of magnetic ordering above 0.15 K, i.e., the C_p/T ratio increases steadily with decreasing temperature towards T = 0 K without a trend to saturation and thus doesn't reach the Fermi-liquid limit in the covered range of temperatures. In UCu_5 this typical feature, shown in the upper panel of Fig. 6 is suppressed by replacing Cu with Ni at the few at% level.

Subsequent studies finally revealed more quantitatively a new interesting aspect of these low-temperature features. Seaman and collaborators reported the observation that for $U_{0.2}Y_{0.8}Pd_3$ $C_p^{el}(T)/T \sim -\ln(\alpha T)$ and $\rho(T) \sim T$, both between 0.6 and 16 K [57]. Essentially the same result was simultaneously reported by Andraka and Tsvelik [58]. The difference between the two articles was the theoretical interpretation of the data. In reference [58] the non-analytic behaviour of $C_p^{el}(T)$ was suggested to reflect a second-order phase transition at T = 0 K, a Quantum Phase Transition (QPT). The consequence is a non-Fermi-liquid (NFL)-type $\rho(T) \sim T$ at low non-zero temperatures above the QCP. In our own

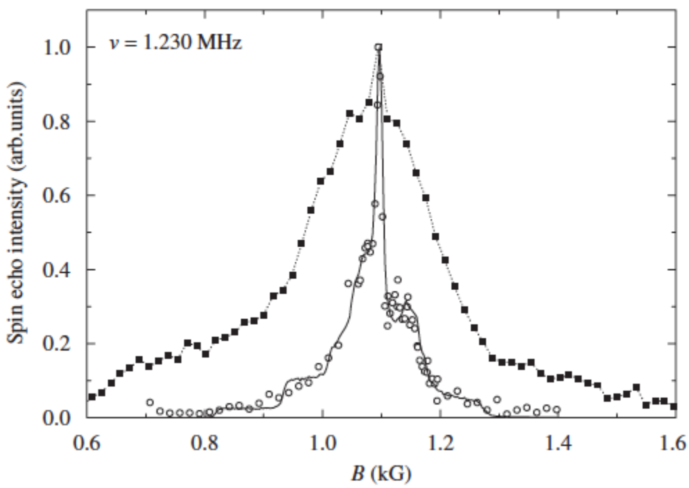


Fig. 8: Compaison of ^{27}Al NMR spectra of $CeAl_3$ measured at 64 mK at ambient pressure (black squares) and 0.125 GPa (open circles), respectively. The solid line is a simulated spectrum and the dotted line serves to guide the eye.

subsequent work [59] we extended the experimental temperature regime to below 0.1 K and confirmed the previous data but noted a substantial additional divergence of C_p^{el}/T below 0.1 K (see Fig. 9). In addition, the $\rho(T)$ data down to 0.02 K did not confirm the 2-channel Kondo-effect scenario put forward in [57]. These early experiments started a new series of studies hunting for NFL behaviour and QCP.

A particularly intriguing example resulted from a study of effects due to partially replacing Cu by Au in $CeCu_6$. The related experiments of Hilbert von Löhneysen and collaborators involved experiments probing the specific heat and resistivity in $CeCu_{6-x}Au_x$ [60]. Replacing Cu with Au at the few at% level first leads to the described logarithmic increase of C_p^{el}/T with decreasing temperature and, with further increasing x, to the onset of antiferromagnetic order below 1 K. Results of subsequent experiments at fixed values of x but variations of external pressure and/or magnetic fields that resulted in the same kind of variations of low-temperature properties are summarized in [61]. These detailed studies strengthened the view that in these cases, zero-temperature transitions from a paramagnetic state to magnetic order or vice versa may be tuned to occur at a QCP. At the same time they triggered a new track of research on that topic. A first review on these activities by Greg Stewart appeared in [62], followed by an update a few years later [63].

VI. Superconductivity of Cuprates

Research on the type of novel superconductivity as sketched above was in full swing in 1986 when another major milestone of condensed-matter physics was set with the discovery of superconductivity of copper oxide materials by Georg Bednorz and Karl Alex Müller at the IBM laboratories in Rüschlikon, published in October 1986 [64]. It was not only the completely unexpected appearance of superconductivity in a compound containing La, Ba, Cu and O, nota bene, not surprisingly, discovered by following up a new idea, but much more so its really amazing onset at temperatures between 30 and 40 K, distinctly higher than ever observed before in metals and alloys, which shook the community. Its initial skepticism was soon put to rest by rather quick confirmations of the fact in reports of a number of laboratories around the globe [65] and an amazingly fast raising of the

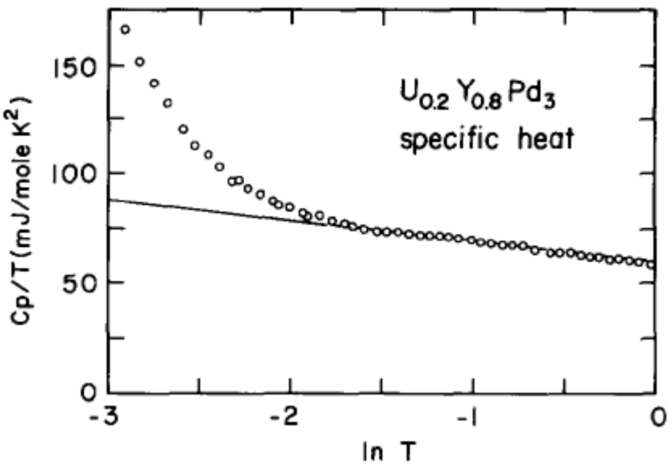


Fig. 9: Specific heat of $U_{0.2}Y_{0.8}Pd_3$ plotted as C_p/T between 0.05 and 1 K. The upturn below ln T ~ -2 is orders of magnitude larger than a possible contribution due to nuclear degrees of freedom.

critical temperature T_c of another cuprate, i.e., $YBa_2Cu_3O_{7-\delta}$ (YBCO), to above the boiling point of liquid nitrogen [66] already a few months after the publication of the original report. It was at the Conference on Valence Fluctuations and Heavy Fermions at Bangalore in early January 1987, where Phil Anderson, more or less ad hoc, proposed a new concept for superconductivity in hole-doped La_2CuO_4 [67]. This meant that the discovery was now considered as a new and important component with respect to ground states of solids, thus deserving full attention. An early puzzle related to those Cu-oxides that are eventually superconducting was set by the temperature dependence of the resistivity $\rho(T)$ which, for these oxides, varies linearly with T in the normal state up to room temperature and even beyond.

I shall not enter a detailed narrative of the development of high-T_c superconductivity. This has been done in different versions before and interested readers may consult a fairly complete coverage of superconductivity in cuprates and other oxides in [68]. Please also note that competent presentations of the development of high-T_c superconductivity from a personal point of view have recently been presented by Alex Müller as well as Maurice Rice in this series of the *SPG Mitteilungen* [69,70]. Instead I'll try to give a brief sketch of our engagement in the field.

Naturally, this important discovery meant that in parallel to our activities described above, we could not let this field of research completely unattended. Based on our background, together with Fritz Hulliger, we concentrated on investigating a series of YBCO compounds where Y was replaced by rare-earth elements [71]. In our and other authors' studies it turned out that the presence of rare-earth ions carrying considerable magnetic moments had no significant influence on the value of T_c indicating that the conventional view of a strong reduction of T_c caused by magnetic moments of dilute or regular constituents of compounds does not apply in this case. It appears that it is mainly the appropriate size of trivalent ions occupying the Y site that sustains the superconducting properties.

Our data of magnetization M(H) curves of YBCO up to 10 T revealed the very strong type II character of the superconducting state, thus implying pairing with very short coherence lengths [71]. This latter fact and the specific structural property of these cuprates in the form of the stacking of Cu-O planes along the c-axis of the quasi-orthorhombic crystal structure with inserted „neutral“ planes as stabilizers but also weakening the 3-dimensional character of the lattice, triggered an enhanced interest for studying the properties of the mixed state. At ETH Zürich, Gianni Blatter and his collaborators were particularly interested in the theoretical aspects related to this state and with time their work developed into the field of „vortex matter“, finally summarized in an extended and often cited article in Reviews of Modern Physics [72]. In our group, Andreas Schilling, after completion of his PhD thesis dedicated to studies of thermal and magnetic properties of cuprates, got interested in some experimental aspects of this topic, particularly in establishing the difference between the upper critical field $H_{c2}(T)$ and the so-called irreversibility line, reflecting the melting of the vortex-lattice in the [H,T] phase diagram, a new important parameter which was, so far, not considered as essential in studies of conventional type II superconductors. Details of this melting line $B_m(T)$ depend on the effective dimensionality of the system and Andreas, with the help of Rong-Yin Jin, a new PhD student and J. D. Guo, an expert in materials synthesis, also grew single-crystalline samples that suited his purposes [73].

The acquired expertise in synthesizing cuprate materials was decisive for a contribution to the global efforts to enhance T_c. After YBCO it was mainly Bi- and Tl-based Cu-oxides that made the headlines in this sector and T_c values up to the range of 120 K were reported [68]. Early in 1993 we got aware of an article describing a new superconducting cuprate, namely $HgBa_2CuO_4$, a compound with only one Cu-O plane per unit cell, but with a surprisingly high value of T_c of 94 K [74]. Previous experience suggested that by inserting additional Cu-O planes might lead to an enhancement of T_c. The tricks to do this were known and in a relatively short time, we succeeded in confirming the conjecture by observing the onset of superconductivity in $HgBa_2Ca_2Cu_3O_8$ distinctly above 130 K [75]. Later efforts revealed that inserting additional Cu-O planes did not lead to a further enhancement of T_c [76] but by applying external pressure, unusually large initial enhancements of up to 1.8 K/GPa were observed [77]. Within the covered pressure range of up to 30 GPa, the claims of the highest achieved T_c values in different reports varied substantially. Possible reasons for this are discussed at the end of [78].

As mentioned above, the onset of superconductivity in these materials was really surprising and it didn't take long that speculations and discussions with respect to unconventional characteristics of this type of superconductivity appeared in the literature. An early example is the result of numerical model calculations of Claudio Gros in the group of Maurice, which suggested an instability of the normal state with respect to a superconducting state with a d-wave gap symmetry and respective gap nodes [79]. Results of analogous experiments as those described above involving heavy-electron superconductors backed these suspicions, mainly by monitoring the temperature dependence of parameters such as the penetration depth, the NMR spin lattice relaxation and Knight shift [68].

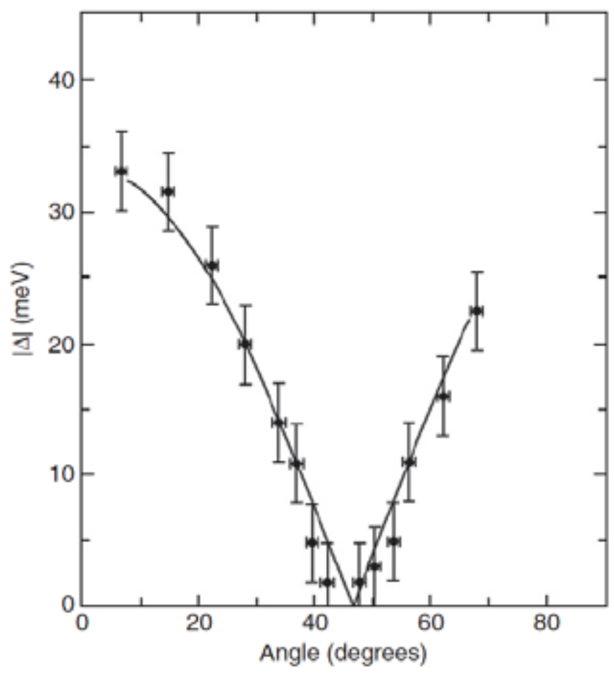


Fig. 10: The leading-edge shift of ARPES spectra of Bi-2212 relative to the position of the Fermi edge of Pt as a function of the average emission angle. The solid line is calculated assuming a d-wave symmetry of the gap function (see [80]).

At that time, a really new possibility due to substantial technological progress in photoelectron spectroscopy (PES) at synchrotrons, was the mapping of the energy gap Δ(k) and its symmetry via angle-resolved PES, i.e., ARPES. In this way, gap nodes could be identified directly [80] (see Fig.10). Based on ideas of Dima Geshkenbein and Anatoli Larkin [81], Manfred and Maurice [82], suggested a new type of experiments probing the phase coherence of a closed superconducting loop combining a common superconductor and the unconventional superconductor to be tested. Experiments of this type in various configurations were made within a year, including our own experimental approach. The technically most elegant solution was due to Tsuei, Kirtley and collaborators at the IBM laboratory in Yorktown Heights [83]. All experiments, confirmed the d-wave symmetry of the gap of YBCO (T_c ~ 90 K) in the basal plane. For tunneling perpendicular to that plane, the situation was not so straightforward. Later we confirmed that also underdoped YBCO with a T_c of only 60 K exhibits the same gap configuration and we also showed that another oxide superconductor, $Ba_{1-x}K_xBiO_3$, with a fairly high T_c of approximately 23 K, adopts a gap with spherical symmetry, i.e. no nodes. Summaries of these activities may be consulted in [68, 84 and 85].

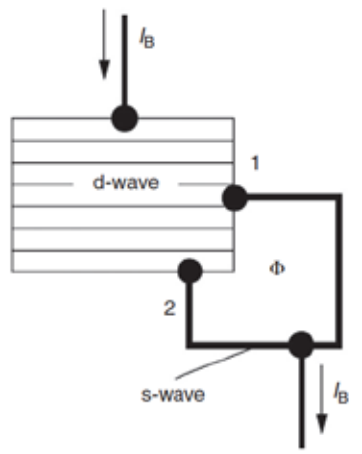


Fig. 11: Schematic layout of a superconducting loop for phase-sensitive tests of the order-parameter symmetry of cuprate superconductors (see [82]).

VII. Epilogue

The upshot of this story is the extraordinary development of the research on the physics of metals, here covered in selected parts from 1960 up to 2010. In this development there were a few milestones in the form of unexpected discoveries that inspired a broad range of experimental and theoretical work worldwide, lasting up to present. At this point I have to apologize for not having covered the topic of organic metals which also revealed a number of unusual features at low temperatures in the years before 2000. This, however, is done excellently by Denis Jérome in [86].

References

[1] L. D. Landau, Zh. Eksp.Teor. Fiz. **30**, 1058 (1956) [Sov. Phys.JETP **3**, 920 (1957)].
[2] J. Bardeen, L. N. Cooper and J. R. Schrieffer, Phys. Rev. **108**, 1175 (1957).
[3] J. Friedel, J. Phys.Radium **19**, 573 (1958).

[4] B. T. Matthias, H. Suhl and E. Corenzwit, Phys. Rev. Lett. **1**, 92 (1958).
[5] B. T. Matthias, M. Peter, H. J. Williams, A. M. Clogston, E. Corenzwit and R. C. Sherwood, Phys. Rev. Lett. **5**, 542 (1960).
[6] A. M. Clogston, B. T. Matthias, M. Peter, H. J. Williams, E. Corenzwit and R. C. Sherwood, Phys. Rev. **125**, 541 (1962).
[7] P. W. Anderson, Phys. Rev. **124**, 41 (1961)
[8] A. A. Abrikosov and L. P. Gor'kov, Zh, Eksp. Teor. Fiz. **39**, 1781 (1960) [Soviet Physics JETP **12**, 1243 (1961)].
[9] P. W. Anderson, J. Phys. Chem. Phys. **11**, 26 (1959).
[10] G. J. van den Berg, in *Progress in Low-Temperature Physics*, Vol. IV, ed. G: J. Gorter, (North-Holland, Amsterdam 1964) p. 194, and references therein.
[11] J. Kondo, Progr. Theoret. Phys. (Kyoto) **32**, 37 (1964).
[12] K. Andres, J. E. Graebner and H. R. Ott, Phys. Rev. Lett. **35**, 1780 (1975).
[13] H. R. Ott, O. Marti and F. Hulliger, Solid State Commun. **49**, 1129 (1984).
[14] F. Steglich, J. Aarts, C. D. Bredl, W. Lieke, D. Meschede, W. Franz and H. Schäfer, Phys. Rev. Lett. **43**, 1892 (1979).
[15] E. Bucher, J. P. Maita, G. W. Hull, R. C. Fulton and A. S. Cooper, Phys. Rev. B **11**, 440 (1975).
[16] H. R. Ott, H. Rudigier, Z. Fisk and J. L. Smith, Phys. Rev. Lett. **50**, 1595 (1983).
[17] H. R. Ott, H. Rudigier, T. M. Rice, K. Ueda, Z. Fisk, and J. L. Smith, Phys. Rev. Lett. **52**, 1915 (1984).
[18] P. W. Anderson, Phys. Rev. B **30**, 1549 (1984).
[19] D. E. Mac Laughlin, C. Tien, W. G. Clark, M. D. Lan, Z. Fisk, J. L. Smith and H. R. Ott, Phys. Rev. Lett. **53**, 1833 (1984).
[20] D. Einzel, P. J. Hirschfeld, F. Gross, B. S. Chandrasekhar, K. Andres, H. R. Ott, J. Beuers, Z. Fisk and J. L. Smith, Phys. Rev. Lett. **56**, 2513 (1986).
[21] B. Golding, D. J. Bishop, B. Batlogg, W. H. Haemmerle, Z. Fisk, J. L. Smith and H. R. Ott, Phys. Rev. Lett. **55**, 2479 (1987).
[22] M. B. Maple, J. W. Chen, S. E. Lambert, Z. Fisk, J. L. Smith, H. R. Ott, J. S. Brooks and M. J. Naughton, Phys. Rev. Lett. **54**, 477 (1985).
[23] F. Thomas, B. Wand, T. Lühmann, P. Gegenwart, G. R. Stewart, F. Steglich, J. P. Brison, A. Buzdin, L. Glémot and J. Flouquet, J. Low Temp. Phys. **102**, 117 (1996).
[24] J. L. Smith, Z. Fisk, J. O. Willis, A. L. Giorgi, R. B. Roof, H. R. Ott, H. Rudigier and E. Felder, Physica **135 B**, 3 (1985).
[25] H. R. Ott, H. Rudigier, Z. Fisk and J. L.Smith, Phys. Rev. B **31**, R1651 (1985).
[26] S. E. Lambert, Y. Dalichaouch, M. B. Maple, J. L. Smith and Z. Fisk, Phys. Rev. Lett. **37**, 1619 (1986).
[27] see, e.g., H. R. Ott, Physica B **171**, 212, 1991.
[28] M. Sigrist and T. M. Rice, Phys. Rev. B **39**, 2200 (1989).
[29] M. Sigrist and K. Ueda, Reviews of Modern Physics **63**, 239 (1991).
[30] H. R. Ott, H. Rudigier, Z. Fisk, J. O. Willis and G. R. Stewart, Solid State Comm. **53**, 235 (1985).
[31] H. R. Ott, H. Rudigier, P. Delsing and Z. Fisk, Phys. Rev. Lett. **52**, 1551 (1984).
[32] C. J. Broholm, J. K. Kjems, G. Aeppli, Z. Fisk, J. L. Smith, S. M. Shapiro, G. Shirane and H. R. Ott, Phys. Rev. Lett. **58**, 917 (1987).
[33] A. Murasik, S. Ligenza and A. Zygmunt, phys. status solidi (a) **23**, K163 (1974).
[34] H. R. Ott, H. Rudigier, E. Felder, Z. Fisk and B. Batlogg, Phys. Rev. Lett. **55**, 1595 (1985).
[35] A. Bernasconi, M. Mombelli, Z. Fisk and H. R. Ott, Z. Phys. B **94**, 423 (1994).
[36] S. Barth, H. R. Ott, F. N. Gygax, B. Hitti, E. Lippelt, A. Schenck and C. Baines, Phys. Rev. B **39**, 11695 (1089).
[37] J. L. Gavilano, J. Hunziker and H.R. Ott, Phys. Rev. B **52**, R13106 (1995).
[38] P. H. Frings, J. J. M. Franse, F. R. de Boer and A. Menovsky, J. Mag. Magn. Mater. **31-34**, 240 (1983).
[39] G. R. Stewart, Z. Fisk, J. O. Willis and J. L. Smith, Phys. Rev. Lett. **52**, 679 (1984).
[40] D. J. Bishop, C. M. Varma, B. Batlogg, E. Bucher, Z. Fisk and J. L. Smith, Phys. Rev. Lett. **53**, 1009 (1984).
[41] A. Sulpice, P. Gandit, J. Chaussy, J. Flouquet, D. Jaccard, P. Lejay, and J. L. Tholence, J. Low Temp. Phys. **62**, 39 (1986).
[42] B. S. Shivaram, Y. H. Yeong, T. F. Rosenbaum and D. G. Hinks, Phys. Rev. Lett. **56**, 1078 (1986).
[43] V. Müller, Ch. Roth, D. Maurer, E. W. Scheidt, K. Lüders, E. Bucher and H. E. Bömmel, Phys. Rev. Lett. **58**, 1224 (1987).
[44] R. A. Fisher, S. Kim, B. F. Woodfield, N. E. Philips, L. Taillefer, K. Hasselbach, J. Flouquet, A. L. Giorgi and J. L. Smith, Phys. Rev. Lett. **62**, 1411 (1989).
[45] R. N. Kleiman, P. L.Gammel, E. Bucher and D. J. Bishop, Phys. Rev. Lett. **62**, 328 (1989).
[46] A. Schenstrom, M.-F. Xu, Y. Hong, D. Bein, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, T. Tokuyasu, D. W. Hess, J. B. Ketterson, J. A. Sauls and D. G. Hinks, Phys. Rev. Lett. **62**, 332 (1989).
[47] K. Hasselbach, L. Taillefer and J. Flouquet, Phys. Rev. Lett. **63**, 93 (1989).
[48] S. Adenwalla, S. V. Lin, Q. Z. Ran, Z. Zhao, J. B. Ketterson, J. A. Sauls, L. Taillefer, D. G. Hinks, M. Levy and B. K. Sarma, Phys. Rev. Lett. **65**, 2298 (1990).
[49] T. Trappmann, H. v. Löhneysen and L. Taillefer, Phys. Rev. B **43**, R13714 (1991).
[50] D. A. Brawner, H. R. Ott and Z. Fisk, Physica B **230-232**, 338 (1997).
[51] R. Joynt and L.Taillefer, Rev. Mod. Phys. **74**, 235 (2002).
[52] L. Taillefer and G. Lonzarich, Phys. Rev. Lett. **60**, 1570 (1988).
[53] Ch. Pfleiderer, Rev. Mod. Phys. **81**, 1551 (2009).
[54] G. E. Brodale, R. A. Fisher, N. E. Phillips and J. Flouquet, Phys. Rev. Lett. **56**, 390 (1986).
[55] M. Weller, J. L. Gavilano, A. Sacchetti and H. R. Ott, Phys. Rev. B **77**, 132402 (2008).
[56] H. R. Ott, H. Rudigier, E. Felder, Z. Fisk and J. D. Thompson, Phys. Rev. B **35**, R1452 (1987).
[57] C. L. Seaman, M. B. Maple, B. W. Lee, S. Gamathy, M. S. Torikachvili, J.-S. Kang, L. Z. Liu, J. W. Allen and D. L. Cox, Phys. Rev. Lett. **67**, 2882 (1991).
[58] B. Andraka and A. M. Tsvelik, Phys. Rev. Lett. **67**, 2886 (1991).
[59] H. R. Ott, E. Felder and A. Bernasconi, Physica B **186-188**, 207 (1993).
[60] H. v. Löhneysen, T. Pietrus, G. Portisch, H. G. Schlager, A. Schröder, M. Sieck and T. Trappman, Phys. Rev. Lett. **72**, 3262 (1994).
[61] H. v. Löhneysen, J. Phys.: Condens. Matter **8**, 9689 (1996).
[62] G.Stewart, Rev. Mod. Phys. **73**, 797 (2001).
[63] G. Stewart, Rev. Mod. Phys. **78**, 743 (2006).
[64] J. G. Bednorz and K. A. Müller, Z. Phys. B **64**, 189 (1986).
[65] see, e.g., H. Takagi, S. Uchida, K. Kitazawa and S. Tanaka, Jap. J. Appl. Phys. **26**, L123 (1987).
[66] M. K. Wu, J. R. Ashburn, C. J. Torng, P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, Y. Q. Wang and C. W. Chu, Phys. Rev. Lett. **58**, 908 (1987).
[67] P. W. Anderson, in *Theoretical and Experimental Aspects of Valence Fluctuations and Heavy Fermions*, ed. by L. C. Gupta, S.K. Malik (Plenum Press, New York, 1987) p. 9.
[68] H. R. Ott, in *Superconductivity*, vol.2, eds. K. H. Bennemann and J. B. Ketterson, (Springer, Berlin 2008) p. 765.
[69] K. A. Müller, *SPG Mitteilungen* Nr. 46, 34 (2015).
[70] T. M. Rice, *SPG Mitteilungen* Nr. 48, 17 (2016).
[71] F. Hulliger and H. R. Ott, Z. Phys. B **67**, 291 (1987).
[72] G. Blatter, M. V. Feigel'man, V. B. Geshkenbein, , A. I. Larkin and V. M. Vinokur, Rev. Mod. Phys. **66**, 1125 (1994).
[73] A. Schilling, R. Jin, J. D. Guo and H. R. Ott, Phys. Rev. Lett. **71**, 1899 (1993).
[74] S. N. Putilin, E. V. Antipov, O. Chmaissem and M. Marezio, Nature **362**, 226 (1993).
[75] A. Schilling, M. Cantoni, J. D. Guo and H. R. Ott, Nature **363**, 56 (1993).
[76] B. A. Scott, E. Y. Suard, C. C. Tsuei, D. B. Mitzi, T. R. McGuire, B.-H. Chen and D. Walker, Physica C **230**, 239 (1994).
[77] L. Gao, Z. J. Huang, R. L. Meng, J. G. Lin, F. Chen, L. Beauvais, Y. Y. Sun, Y. Y. Xue and C. W. Chu, Physica C **213**, 261 (1993).
[78] D. Tristan Jover, R. J. Wijngaarden, H. Wilhelm, R. Griessen, S.M. Loureiro, J.-J. Capponi, A. Schilling and H. R. Ott, Phys. Rev. B **54**, 4265 (1996).
[79] C. Gros, R. Joynt and T. M. Rice, Z. Phys. B **68**, 425 (1987).
[80] J. C. Campuzano, M. Randeria, M. Norman and H. Ding, in *The Gap Symmetry and Fluctuations in High-T_c Superconductors*, eds. J. Bok, G. Deutscher; D. Pavuna, S.A. Wolf, NATO-ASI series B, vol. 371 (Plenum, New York 1998) p. 229.
[81] V. B. Geshkenbein and A. I. Larkin, JETP Lett. **43**, 395 (1987).
[82] M. Sigrist and T. M. Rice, J. Phys. Soc. Jpn. **61**, 4283 (1992).
[83] C. C. Tsuei, J. R. Kirtley, C. C. Chi, L. S. Yu-Jahnes, A. Gupta, T. Shaw, J. Z. Sun and M. B. Ketchen, Phys. Rev. Lett. **73**, 593 (1994).
[84] D. J. van Harlingen, Rev. Mod. Phys. **67**, 515 (1995).
[85] C. C. Tsuei and J. R. Kirtley, Rev. Mod. Phys. **72**, 969 (2000).
[86] D. Jérome, in *Superconductivity in New Materials*, eds. Z. Fisk and H. R. Ott, *Contemporary Concepts of Condensed Matter Science*, Vol.4 (Elsevier, 2011) p. 149.

Physik und Gesellschaft

Wechselspiele der Welterklärung
Das neue Weltbild der Physik und seine Rezeption in der modernen Literatur

Mario Andreotti, Universität St. Gallen, mario.andreotti@hispeed.ch

Seit dem Einstein-Jahr 2005 ist der naturwissenschaftliche Diskurs stärker denn je in die deutsche Literatur eingedrungen. Romane wie Daniel Kehlmanns "Vermessung der Welt" und Lyrik wie die von Ulrike Draesner und Durs Grünbein zeugen vom Ende der Trennung der Wissenskulturen und von einer neuen Annäherung der Disziplinen.

Die Literatur und ihre Wissenschaftsskepsis

Das war nicht immer so. Über Jahrhunderte sind Literatur und Naturwissenschaft getrennte Wege gegangen, sind sie einander mit gegenseitiger Ignoranz begegnet. Noch um 1800 trennte eine tiefe Wissenschaftsskepsis den literarischen Kosmos von der naturwissenschaftlich-technischen Welt. Goethe war einer der wenigen, die neben ihrer literarischen Betätigung vielfältige naturwissenschaftliche Studien in Geologie, Physik und Botanik betrieben, wobei er Empirie mit Spekulation verband und so zu einem organischen Naturbegriff gelangte. Davon zeugen vor allem zwei seiner Werke: "Faust" und die "Wahlverwandtschaften". Erst die Naturalisten gegen Ende des 19. Jahrhunderts begannen sich konsequent mit der naturwissenschaftlich-technischen Revolution auseinanderzusetzen und vollzogen dadurch einen gewaltigen Traditionsbruch. Ähnlich wie die Naturwissenschaften das beobachtende Subjekt völlig dem Objekt unterwerfen, um die reinen, objektiven Gesetze der Erscheinungen sichtbar zu machen, wollten sie die Wirklichkeit detailgetreu und vor allem nackt, d.h. durch keine Zutat des Autors beschönigt, wiedergeben. Die Naturalisten entnahmen dabei der klassischen Physik das deterministische Denken und machten es zur Grundlage ihrer literarischen Texte, vor allem des sozialen Dramas.

Die epochale Wende um 1900: der Sturz der klassischen Physik

Ende des 19.Jahrhunderts war man in der wissenschaftlichen Welt allgemein der Ansicht, die Entwicklung von Physik und Chemie sei zu einem Abschluss gelangt, die beiden Disziplinen seien kaum noch ausbaufähig. Doch man hatte sich getäuscht. Innerhalb weniger Jahre wurden Physik und Chemie auf völlig neue Grundlagen gestellt, wodurch sich auch unser ganzes Weltbild wandelte.

Nachdem Wilhelm Conrad Röntgen, der 1901 als Erster den Nobelpreis für Physik erhielt, die nach ihm benannten Strahlungsarten festgestellt und ärztlichen Zwecken nutzbar gemacht und das Ehepaar Curie 1898 die Strahlen des Elementes Radium beschrieben hatten, entdeckte der englische Physiker Ernest Rutherford 1902 die Teilbarkeit der Atome - eine Entdeckung, die mit einem Schlag die ganze klassische Physik, in der man die Atome für unteilbar gehalten hatte, umstürzte. Nach Rutherford setzt sich das Atom aus Protonen und Elektronen zusammen, wobei die Elektronen den aus Protonen bestehenden Kern umkreisen. 1919 gelang ihm die erste Kernreaktion durch den Beschuss von Stickstoffatomen mit α-Teilchen, 1938 dem deutschen Chemiker Otto Hahn gar die Zertrümmerung des Atomkerns. Damit war das Zeitalter der Kernenergie, aber auch der Atombombe angebrochen.

Die Frage nach der Verantwortung der Naturwissenschaft in der modernen Literatur

Mit der Kernenergie ist der Menschheit eine unvorstellbare Kraft in die Hände gegeben, die ihre Lebensbedingungen gewaltig verändert, die sie aber auch vernichten kann, wenn sie diese nicht sittlich zu beherrschen lernt. In der modernen Literatur, vor allem im modernen Theater, führt das zur Frage nach der moralischen Verantwortung der Naturwissenschaftler, d.h. konkret zur Warnung vor der Vorstellung einer ‘wertfreien’ Wissenschaft. So beispielsweise in Bertolt Brechts Lehrstück "Leben des Galilei", in Max Frischs Farce "Die Chinesische Mauer", in Friedrich Dürrenmatts Tragikomödie "Die Physiker" und in Heinar Kipphardts Dokumentartheater "In der Sache J. Robert Oppenheimer". Was Dürrenmatt betrifft, so hat sich dieser Autor einerseits kritisch mit den technischen Umsetzungen der modernen Naturwissenschaften auseinandergesetzt, z.B. mit der Bedrohung durch die Atombombe und die Verführung durch den Medienspektakel um die Raumschifffahrt, andererseits sich aber intensiv interessiert für die theoretischen Inhalte der modernen Physik selbst und vor allem für deren erkenntnistheoretische Implikationen.

Max Plancks Quantentheorie und ihr Einfluss auf die literarische Moderne

Der deutsche Physiker Max Planck stellte Ende 1900 die These auf, die Strahlungsenergie werde nicht kontinuierlich abgegeben, sie bestehe vielmehr aus Teilchen, sog. "Lichtquanten oder Photonen", die von der Materie unkontinuierlich, in Stössen ausgestrahlt würden. Entsprechend gebe es ein kleinstes Wirkungsquantum h als absolute, invariable Grösse, die multipliziert mit der Strahlungsfrequenz ν des Lichtes die Photonenenergie $E = h\,\nu$ angibt.

Mit Max Plancks Entdeckung des nach ihm benannten Wirkungsquantums begann das Zeitalter der modernen Physik, das durch die Entwicklung einer Reihe neuer Theorien gekennzeichnet ist, die weit über die klassischen Gesetze hinausgehen. 1913 verknüpfte der erst achtundzwanzigjährige Däne Niels Bohr Plancks Quantentheorie mit der Atomlehre Rutherfords. Wie dieser dachte sich auch Bohr den Atomaufbau als ein mikrokosmisches Planetensystem, bei dem die Elektronen um den aus Protonen gebildeten Kern kreisen. Die klassische Physik lehrt jedoch, dass das Planetenmodell der Elektronen infolge der Strahlungsdämpfung nicht stabil sein kann. Bohr erzwingt die Stabilität, indem er fordert, dass die Wirkung, also das Produkt aus Elektronenimpuls und Bahnlänge ein ganzzahliges Vielfaches n des Wirkungsquantums h sein muss. Dadurch hängt auch die

Bahnenergie des Elektrons von *h* und der Quantenzahl *n* ab. Ein Quantensprung erfolgt, wenn ein Elektron in eine energetisch höher oder tiefer liegende Bahn gelangt. Dies geschieht durch Absorption oder Emission eines Lichtquants, wobei die Differenz der Bahnenergien der Energie des Lichtquants entsprechen muss.

Max Plancks Quantentheorie hatte, wenn auch nicht unmittelbar, einen nachweisbaren Einfluss auf die Entstehung einer literarischen Moderne. Seine Preisgabe des Determinismus, des Kausalitätsprinzips der klassischen Physik, also ihrer Grundüberzeugung, wonach die Natur keine "Sprünge" macht, hat im modernen Roman mit seiner Auflösung eines linearen, chronologischen Erzählens, seinem Übergang zu einer diskontinuierlichen Erzählweise ihr Pendant gefunden. Deutlichstes Beispiel dafür sind wohl die Romane Alfred Döblins, der als einer der Wegbereiter der literarischen Moderne sich neben medizinischen und literaturtheoretischen auch mit naturwissenschaftlichen Fragen intensiv befasste und sich am kühnen Vorstoss der Physiker in völliges Neuland äusserst interessiert zeigte. In seinem Grossstadtroman "Berlin Alexanderplatz" von 1929, einem Schlüsselwerk der modernen Erzählprosa, durchbricht Döblin den chronologischen Handlungsverlauf immer wieder jäh, indem er Montagen, collageartige Zitate, Rückblenden usf. einbaut, kurz, indem er diskontinuierlich erzählt.

Albert Einsteins Relativitätstheorie und das Zeitproblem in der modernen Literatur

Noch aufregender als Max Plancks Quantentheorie war Albert Einsteins Spezielle Relativitätstheorie aus dem Jahr 1905, das deshalb häufig auch als "annus mirabilis" der Physik bezeichnet wird. Einstein wies unter anderem nach, dass Raum und Zeit keine absoluten Grössen, sondern "relativ" sind, dass sich die Masse mit ihrer Geschwindigkeit verändert, dass die Materie folglich "nur" eine besondere Form der Energie ist. Daraus ergibt sich Einsteins berühmte Äquivalenzformel für Energie und Masse $E = mc^2$, die später Geschichte machen sollte. Mit ihr schränkte Einstein den Geltungsbereich der klassischen Mechanik ein. 1915 baute Einstein seine Theorie zur Allgemeinen Relativitätstheorie aus.

"Diskontinuität", "Sprünge", "Relativität" - all das erschütterte das bisherige Weltbild, das zwar als ergänzbar, aber doch als gesichert gegolten hatte. Anstelle bestimmter, für unumstösslich gehaltener Gesetze traten nur noch Hypothesen, Modelle. War das Weltbild der klassischen Physik (Galilei, Newton, Laplace) streng deterministisch gewesen, so musste dieser Determinismus nun aufgegeben werden. So besagt etwa Werner Heisenbergs 1927 formulierte Theorie der Unschärferelation, dass in der Quantenphysik keine deterministischen, genauen Voraussagen, sondern nur noch Wahrscheinlichkeitsaussagen möglich sind.

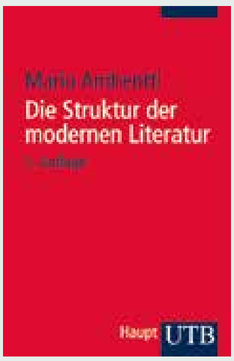
Es ist schwer zu sagen, wie weit Einsteins Relativitätstheorie die Entstehung einer literarischen Moderne beeinflusst hat, zumal damals noch wenig Laien von dieser physikalischen Revolution Kenntnis nahmen und selbst den Gelehrten die Bildungsgrundlage dazu fehlte. Trotzdem lassen sich auffallende Parallelen zwischen Einsteins Theorie und der neuen, avantgardistischen Literatur ausmachen. So zeigt sich in der Aufhebung der Chronologie und der Problematisierung der Zeit überhaupt, wie sie zur modernen Erzählprosa gehört, eine gewisse Anlehnung an Vorstellungen der Relativitätstheorie, etwa an die Vorstellung von der Relativität von Raum und Zeit. Gerade die für moderne Autoren, etwa für Proust, Joyce, Schnitzler und Döblin, typische Subjektivierung der Zeit in der Technik des Bewusstseinsstroms und der Simultantechnik erinnert in mancherlei Hinsicht an Einsteins Lehre über Zeit und Raum.

Eine unmittelbare Wirkung der Relativitätstheorie, aber auch von Heisenbergs Theorie der Unschärferelation lässt sich bei Friedrich Dürrenmatt im Hinblick auf die Rolle des Zufalls in seinen Komödien nachweisen. Es sei hier nur an Dürrenmatts Einstein-Vortrag von 1979 erinnert, wo er unter anderem sagte. "Ich habe Einstein und seine Welt am einfachen Beispiel des Schachspiels klarzumachen versucht: dass sich nun herausstellt, dass die alten Gesetze des Schachspiels auf eine geheimnisvolle Art nicht mehr stimmen, dass also plötzlich der weisse Läufer vom weissen Feld auf ein schwarzes Feld gerät."

Der Beschränkung der modernen Physik auf Hypothesen und Modelle entspricht in der modernen Literatur die Vorliebe für Modellsituationen, wie sich das in ihrem parabolischen Grundzug zeigt. Eine solche Modellsituation findet sich beispielsweise in Kafkas Romanen, wo die Welt immer wieder im Modell eines Gerichtes oder einer unüberschaubaren Bürokratie erscheint, aber auch in den Parabelstücken Brechts, Dürrenmatts und Max Frischs, am deutlichsten wohl in Frischs Lehrstück "Andorra".

Mario Andreotti, Prof. Dr., geb. 1947, Studium der Germanistik und Geschichte in Zürich. Danach Gymnasiallehrer für Deutsch und Geschichte an der Kantonsschule St. Gallen. Heute Lehrbeauftragter für Sprach- und Literaturwissenschaft an der Universität St. Gallen und Gastdozent an den Pädagogischen Hochschulen Luzern und Vorarlberg. Von seinen Beiträgen und Publikationen, vor allem zur literarischen Moderne, ist der folgende Band, der seit September 2014 bereits in 5., stark erweiterter und aktualisierter Auflage vorliegt und der längst als Standardwerk der literarischen Moderne gilt, am bekanntesten geworden:

Die Struktur der modernen Literatur. Neue Formen und Techniken des Schreibens: Erzählprosa und Lyrik. Mit einem Glossar zu literarischen, linguistischen und philosophischen Grundbegriffen. UTB Band 1127. Haupt Verlag Bern, Stuttgart, Wien.



Ernst Mach und der literarische Impressionismus

Als illustres Beispiel, wie Physiker ganze Literaturströmungen beeinflussen können, sei der Österreicher Ernst Mach (1838-1916) genannt. Sein wissenschaftliches Schaffen war ungemein breit gefächert und reichte von der experimentellen und theoretischen Physik über Sinnesphysiologie und Psychologie bis hin zur Wissenschaftsgeschichte und zur Philosophie. Ernst Mach befasste sich gegen Ende des 19. Jahrhunderts unter anderem mit der kritischen Analyse der Grundlagen der Newtonschen Mechanik. Eines seiner wichtigsten Werke ist die "Mechanik in ihrer Entwicklung", die eine Untersuchung des damaligen physikalischen Kenntnisstandes beinhaltet. Mit dem Namen dieses Physikers verbinden wir heute in erster Linie die sogenannte Machzahl, die in der Flugzeugtechnik Bedeutung erlangte. Ernst Mach gilt hauptsächlich als heuristischer Wegbereiter der Allgemeinen Relativitätstheorie; Einstein selbst bezeichnete sich in diesem Zusammenhang als "Schüler" Machs.

Einem breiteren Publikum fast noch bekannter denn als Physiker ist Ernst Mach als Philosoph geworden. Er gilt, wenn auch nicht als Begründer, so doch als einflussreichster Vertreter des *Empiriokritizismus*, in dem das Ich als "Komplex von Erinnerungen, Stimmungen, Gefühlen" erscheint. Damit leugnet Mach die von Descartes, Kant und Hegel postulierte Einheit des Bewusstseins. Nach ihm gibt es kein Ich, das wie bei Descartes einer Welt der Objekte autonom gegenübersteht, denn "Nicht das Ich ist das Primäre, sondern die Elemente [Empfindungen] bilden das Ich." Mit dieser *Preisgabe des Glaubens an das Ich als Urrealität* weist Mach in die Nähe von Nietzsches und Freuds Subjektkritik.

Von Ernst Mach, der um 1900 dem Kreis der "Wiener Moderne" angehörte, gingen im Hinblick auf die Entstehung einer avantgardistischen Literatur entscheidende Impulse aus. Die Impressionisten (Lilienkron, Dehmel, der junge Hofmannsthal, der junge Rilke, Bahr, Schnitzler u.a.) feierten Machs Weltanschauung als die "Philosophie des Impressionismus". Allen voran war es Arthur Schnitzler, der in seiner Novelle "Leutnant Gustl" (1900) erstmals den *inneren Monolog* verwendete, der mit seiner Auflösung des Ich in eine Vielheit von Kräften von Ernst Machs Subjektkritik unmittelbar beeinflusst ist. Das folgende Textbeispiel aus der besagten Novelle mag diesen inneren Monolog illustrieren, bei dem Gedanken, Wünsche, Erinnerungen in der Ich-Form ohne erzählerische Vermittlung, so wie sie sich im Augenblick vollziehen, wiedergegeben werden:

Leutnant Gustl wird nach einem Konzert von einem "satisfaktionsunfähigen" Bäcker beleidigt. Die ganze Nacht reflektiert er über seine Situation, ehe er am Morgen erfährt, dass sein Beleidiger am Schlagfluss gestorben ist.

"Was, ich bin schon auf der Strasse? Wie bin ich denn da herausgekommen? - So kühl ist es … ah, der Wind, der ist gut … Wer ist denn das da drüben? Warum schau'n denn die zu mir herüber? Am Ende haben die was gehört … Nein, es kann niemand was gehört haben … ich weiss ja, ich hab' mich gleich nachher umgeschaut! Keiner hat sich um mich gekümmert, niemand hat was gehört …

Der Umbruch um 1900 in einer Gesamtschau

Der geistige Wende zu Beginn des 20. Jahrhunderts muss als Ganzes gesehen werden. Gerade auf dem Höhepunkt der technischen, wirtschaftlichen und politischen Geltung des Abendlandes verstärkte sich ein Gefühl des Unbehagens. Die ungeheure Wirkung, die etwa Friedrich Nietzsche mit seiner Forderung nach der "Umwertung aller Werte" ausübte, die Auflösung der überkommenen Formen in Literatur und bildender Kunst, Freuds Tiefenpsychologie, in der die idealistische Vorstellung eines Ich, das im Bewusstsein, in der Ratio gründet und so Herr seiner selbst ist, preisgegeben wird - all diese Erscheinungen und nicht zuletzt die revolutionären Entdeckungen der Physiker sind letztlich Ausdruck des Suchens nach einem neuen Halt in einer als brüchig empfundenen Welt.

Wiener Kreis

1895 wurde der zuvor in Prag dozierende Physiker *Ernst Mach* auf die Lehrkanzel für Philosophie der Universität Wien berufen, eine Aufsehen erregende und in philosophischen Kreisen nicht unumstrittene Berufung. Mach selber musste seine Vorlesungen aus gesundheitlichen Gründen ab 1902 *Ludwig Boltzmann* überlassen, der den Lehrstuhl für Theoretische Physik bis zu seinem Freitod 1906 innehatte. Dennoch gelang es Mach in den nur wenigen Jahren, über Wien hinaus viele literarische und naturwissenschaftliche Talente anzusprechen und zu fördern. So befasste sich 1908 in Berlin der später grosse Bedeutung als Schriftsteller erlangende *Robert Musil* (Roman: ‚Der Mann ohne Eigenschaften') in seiner Dissertation mit der Beurteilung der Lehren Machs, die er mit der Bemerkung einleitete: *„Das Wort des Naturforschers wiegt schwer, wo immer heute erkenntnistheoretische oder metaphysische Fragen von einer exakten Philosophie geprüft werden. Die Zeiten sind vorbei, wo das Bild der Welt in Urzeugung dem Haupte des Philosophen entsprang.*" [S. 65 *]

Auf Machs Nachfolger Adolph Stöhr folgte dann ab 1922 der Erkenntnistheoretiker *Moritz Schlick*, den man zum Gründer des Wiener Kreises rechnet, dem bedeutende Persönlichkeiten wie Rudolf Carnap und Kurt Gödel angehörten, der aber auch Kontakte zu Ludwig Wittgenstein und Karl Popper pflegte.
Wie weit der Einfluss Machs ausstrahlte, kann man den Worten von Karl Popper entnehmen: *„Nur wenige Männer haben auf die geistige Entwicklung des 20.Jahrhunderts einen ähnlich grossen Einfluss gehabt wie Ernst Mach. Er beeinflusste die Physik, die Physiologie, die Psychologie und die reine (oder spekulative) Philosophie. Er beeinflusste Albert Einstein, Niels Bohr, Werner Heisenberg, William James und Bertrand Russell – um nur einige zu nennen.*" [S. 19 *]

Zitate aus Karl Sigmund "Sie nannten sich Der Wiener Kreis, Exaktes Denken am Rand des Untergangs", Springer Spektrum 2015, (ISBN 978-3-658-08534-6)

BB

La cosmologie et la relativité générale par les mathématiques et la physique du lycée

Exemple d'une séquence sur l'effet de lentille gravitationnelle

Alicia Gasparini, Université de Genève

Le Cadre

À l'occasion du centenaire de la relativité générale (novembre 2015), le pôle national de recherche SwissMAP (« The Mathematics of Physics ») a lancé un projet pédagogique visant à introduire auprès des élèves des écoles secondaires (collèges, gymnases, lycées) les notions de base de la relativité générale et de la cosmologie. Ce projet a abouti à un cours et un livre [1] sur ces sujets, dont l'originalité est celle d'avoir un niveau de transposition se situant entre le « zéro équations » adressé au large public et la géométrie tensorielle réservée aux spécialistes universitaires : il se base uniquement sur les notions de mathématiques et physique enseignées au secondaire post obligatoire. Le but de ce projet n'est donc pas de remplacer les contenus traditionnellement enseignés dans les lycées, mais plutôt de les consolider tout en traitant des contenus motivants pour les élèves.

La création de ce cours a eu la chance de s'étendre sur trois années exceptionnelles pour la cosmologie moderne avec la première détection historique des ondes gravitationnelles, et a abouti à un livre édité aux Presses Polytechniques et Universitaires Romandes. Ce manuel comprend 9 chapitres, allant de l'introduction à l'astrophysique jusqu'aux ondes gravitationnelles, en passant par l'effet de lentille gravitationnelle, les trous noirs et les équations cosmologiques. Sept annexes complètent le cours afin d'intégrer et/ou d'approfondir les notions complémentaires dont l'élève pourrait avoir besoin pour une compréhension aisée du cours principal. Chaque chapitre possède une série d'exercices y relatifs avec leur correctif, ces documents sont librement disponibles sur le site SwissMAP.

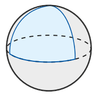
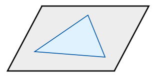
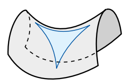
Ce cours peut être dispensé dans sa version intégrale sur deux semestres à raison de 2 périodes par semaine, par exemple dans le cadre d'un cours à option complémentaire. Mais il constitue également une « boite à outils », où les contenus et/ou les exercices peuvent être choisis de manière ponctuelle, et insérés selon le niveau dans un cours « traditionnel » de physique et application des mathématiques.
De plus, les sujets traités constituent une base idéale pour le développement de travaux de maturité ou simplement une lecture pour toute personne ayant les bases en physique et mathématiques et une curiosité pour les sujets traités.

Exemple de parcours thématique : Effet de lentille gravitationnelle

Nous présentons ici une proposition de séquence sur l'effet de lentille gravitationnelle, sujet introduit dans le chapitre 5, en tant qu'exemple d'application remarquable des idées à la base de la relativité générale.

Le chapitre 4 introduit les notions de courbure de Gauss en un point et de courbure totale d'une surface [2] à deux dimensions et vise à se familiariser avec propriétés des surfaces courbes, en particulier avec le comportement des géodésiques parallèles.

Tableau récapitulatif des propriétés des espaces courbes

Courbure	positive	nulle	négative
Exemple d'espace 2D	sphère 	plan 	selle 
Propriété	fermé	euclidien	ouvert
Géodésiques parallèles	convergent	ne se croisent jamais	divergent
Périmètre du cercle de rayon r	$< 2\pi r$	$= 2\pi r$	$> 2\pi r$
Surface de la sphère de rayon r	$< 4\pi r^2$	$= 4\pi r^2$	$> 4\pi r^2$
Volume de la sphère de rayon r	$< \frac{4}{3}\pi r^3$	$= \frac{4}{3}\pi r^3$	$> \frac{4}{3}\pi r^3$
Somme des angles du triangle	$> 180°$	$= 180°$	$< 180°$

Une attention particulière est prêtée à la surface représentant le potentiel gravitationnel d'une concentration de masse/énergie à symétrie sphérique, où la courbure est positive dans la partie centrale (en jaune dans la figure ci-dessous) et négative dans la zone périphérique (verte dans la figure ci-dessous). Nous pouvons constater cette propriété à l'aide d'un plastique représentant la forme du potentiel et d'un ruban coloré : deux géodésiques parallèles divergent si elles passent dans la zone à courbure négative, elles convergent si elles passent dans la zone à courbure positive.

La relativité générale de Einstein a introduit l'idée que la présence de masse/énergie déforme l'espace-temps et dévie

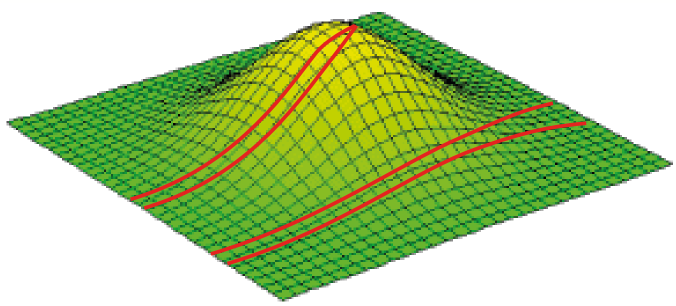


Figure 1 : Le potentiel gravitationnel d'une concentration de masse/énergie à symétrie sphérique dans une espace bidimensionnel. Les géodésiques parallèles divergent là où la courbure est négative, convergent là où elle est positive.

1 A. Gasparini, *Cosmologie & relativité générale, Une première approche*, PPUR (2018).
http://www.ppur.org/produit/876/9782889152094/Cosmologie%20%20relativite%20generale%20
A. Gasparini & A. Müller, *Cosmologie & relativité générale, Activités pour les élèves du Secondaire II*, SwissMAP, Université de Genève (2017).
http://nccr-swissmap.ch/education/highschool/GRcourse

2 En relativité générale, la notion de *surface* s'étend à tout espace de dimension supérieure à deux.

la lumière. Par analogie avec l'effet des lentilles optiques, on nomme « lentille gravitationnelle » une concentration de masse (par exemple une galaxie, un trou noir ou un étoile massive) qui a pour effet de dévier la lumière. Dans le chapitre sur l'effet de lentille gravitationnelle, la question est donc de trouver l'expression de l'angle de déviation α de la trajectoire d'un rayon de lumière passant près d'une masse *grave*.

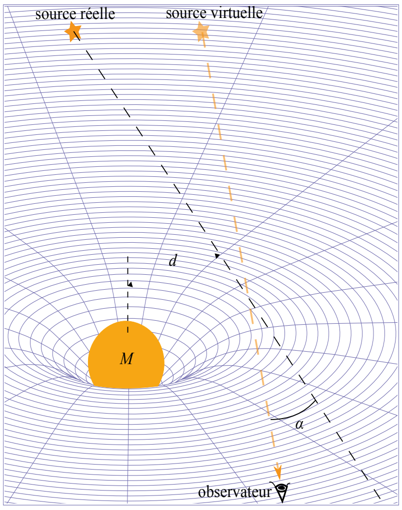


Figure 2 : La trajectoire d'un rayon de lumière provenant d'une source lointaine suit la déformation de l'espace-temps par une masse M.

Approches simplifiées

Ce problème peut être abordé de plusieurs manières. Le premier exercice de la série 5 utilise l'analyse dimensionnelle et permet de trouver la formule de α de manière simple, sans facteur numérique. Pour résoudre l'exercice, nous pouvons schématiser la situation : un rayon de lumière provenant d'une source lointaine s'approche d'une masse *M*, sa trajectoire est déviée par la présence de la masse (figure 2). De quels paramètres peut dépendre cette déviation ?

On peut aisément citer l'accélération de la gravité $g = GM/d^2$ (*G* étant la constante de la gravitation), la vitesse de la lumière *c*, et la « distance » de passage *d*, soit la distance entre la masse *M* et la droite représentant la direction de provenance du rayon. Autrement dit le « *paramètre d'impact* », concept très important en physique car tout autant central que transversal.

Pour trouver l'angle de déviation, on cherche une combinaison de puissances entières de ces paramètres (*p*, *q* et *r*), telle que les unités se compensent car l'unité des angles est adimensionnelle

$$\alpha_g \propto g^p \cdot d^q \cdot c^r$$

$$[\mathrm{m}\cdot\mathrm{s}^{-2}]^p \cdot [\mathrm{m}]^q \cdot [\mathrm{m}\cdot\mathrm{s}^{-1}]^r = 1$$

$$\Rightarrow \mathrm{m}^p \cdot \mathrm{s}^{-2p} \cdot \mathrm{m}^q \cdot \mathrm{m}^r \cdot \mathrm{s}^{-r} = 1^0 \quad \Rightarrow \mathrm{m}^{p+q+r} \cdot \mathrm{s}^{-2p-r} = 1^0$$

$$\Rightarrow \begin{cases} p+q+r=0 \\ -2p-r=0 \end{cases} \Rightarrow \begin{cases} r=-2p \\ p+q-2p=0 \end{cases} \Rightarrow \begin{cases} r=-2p \\ q=p \end{cases}.$$

La solution la plus simple non nulle est donnée par *p* = 1, *q* = 1 et *r* = -2 :

$$\alpha_g \propto g^1 \cdot d^1 \cdot c^{-2} = \frac{GM}{d^2} d \cdot c^{-2} = \frac{GM}{c^2 d}.$$

Cette formule diffère d'un facteur 4 de celle obtenue en utilisant les équations tensorielles d'Einstein $\alpha_{gE} = 4GM/c^2 d$, mais elle est beaucoup plus accessible. Une dérivation de la formule de l'angle de déviation à partir de la physique newtonienne se trouve dans la section 5.1 du livre : cette démonstration est plus avancée car elle demande une connaissance aisée du formalisme vectoriel, de la dérivation et de l'intégration des fonctions, et elle donne une formule de l'angle de déviation : $\alpha_{gN} = 2GM/c^2 d$, qui diffère d'un facteur 2 par rapport à celle relativiste. Ce facteur 2 a une importance historique, notamment dans les mesures de l'angle de déviation de la lumière faites par Eddington lors de l'éclipse totale solaire de 1919. Bien que peu précise, ce fut cette expérience qui rendit Einstein célèbre.

L'analogie optique

Ainsi, la simple dérivation dimensionnelle permet d'inférer la dépendance *inverse* $\alpha_g \propto 1/d$, qui constitue la clé pour comprendre le phénomène de lentille gravitationnelle. Il est utile d'analyser la situation analogue d'une lentille optique convergente, où la dépendance linéaire de la distance entre le rayon incident et l'axe optique $\alpha_o \propto d$ mène à la présence d'un foyer optique, comme illustré dans la figure ci-dessous.

D'autre part, puisque dans le chapitre 4 nous avons pu constater que la courbure est négative autour d'une masse avec un potentiel gravitationnel à symétrie sphérique (figure 1), nous avons les éléments pour comprendre que la déviation en 1/*d* traduit le comportement divergent des géodésiques parallèles.

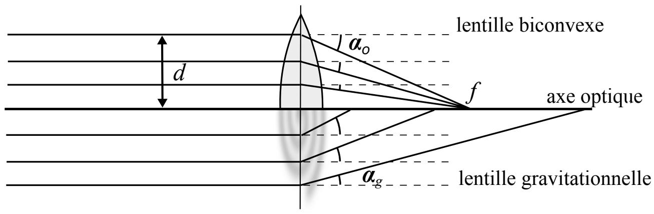


Figure 3 : Comparaison de l'effet d'une lentille gravitationnelle avec celui d'une lentille optique convergente, sur des rayons parallèles.

La question de savoir s'il existe une forme de lentille optique capable de reproduire cette déviation en 1/d surgit spontanément, et la réponse se trouve dans l'exercice 7 de la série 5, où les lois de la réfraction et une intégration sont déployées pour obtenir cette dépendance : un profil d'allure logarithmique, semblable à celui d'un « pied de verre à vin » est celui recherché.

L'idée est que, en supposant l'approximation des « petits angles » ($\sin\alpha \cong \alpha$), si l'angle de réfraction *r* est proportionnel à l'angle d'incidence *i*, et si l'on veut qu'en s'approchant de l'axe optique (l'axe *y* dans la figure 4) la déviation augmente (*r* augmente) comme on le voit dans la figure 3, on doit avoir un profil qui forme un angle toujours plus grand avec le rayon incident (direction de l'axe *y*).

L'expérience permettant de visualiser l'image d'une source ponctuelle à travers la reproduction optique d'une lentille

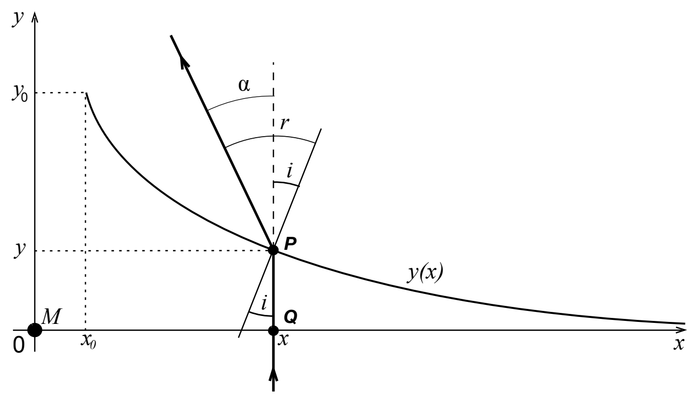


Figure 4 : Trajectoire d'un rayon de lumière passant au travers d'une lentille optique avec un profil de « pied de verre à vin ».

gravitationnelle est une activité qui peut facilement être pratiquée.

Ainsi, il est possible de « tester » les conditions pour l'observation d'un anneau, d'une croix d'Einstein ou d'arcs gravitationnels (ces derniers comme dans la figure 5).

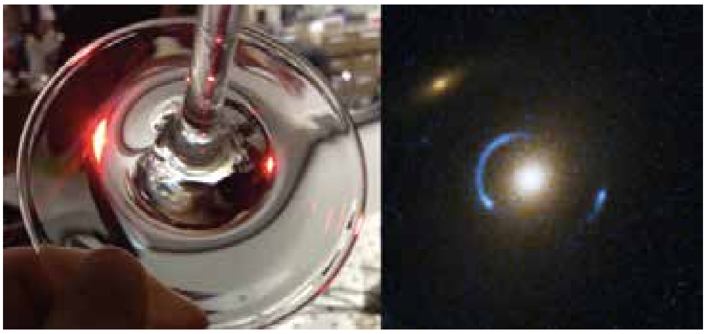


Figure 5 : À gauche, une image de source ponctuelle vue au travers d'un pied de verre à vin. A droite, la l'image de lentille gravitationnelle SDSS J120540.43+491029.3. [Crédit: Hubble, NASA.] La similitude entre les images lumineuses de la source est clairement visible.

Dans le cas d'alignement entre observateur O, lentille L et source S, la formule donnant le rayon d'Einstein θ (il s'agit bien d'un angle même s'il est appelé « rayon ») en fonction de la masse de la lentille et des distances entre la source et la lentille s'obtient à partir de celle de l'angle de déviation, en utilisant la loi des sinus et l'approximation des petits angles.

$$\theta \cong \sqrt{\frac{4GM \cdot D_{SL}}{c^2 D_{SO} \cdot D_{LO}}}$$

La formule ci-dessus est démontrée dans la section 5.3 du livre et utilisée par les astronomes pour estimer la masse

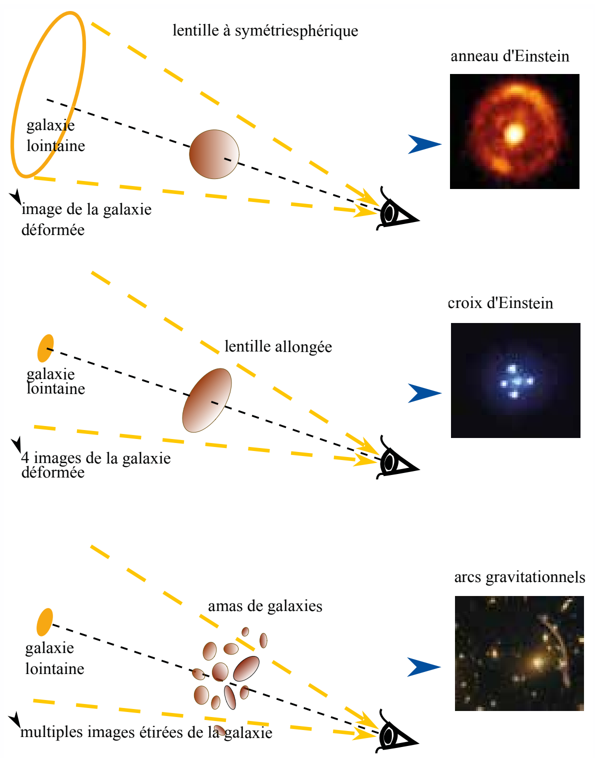


Figure 6 : Schématisation des trois types de strong lensing, permettant d'observer des images d'anneaux, croix d'Einstein, ou d'arcs gravitationnels. Crédit: Hubble, NASA.

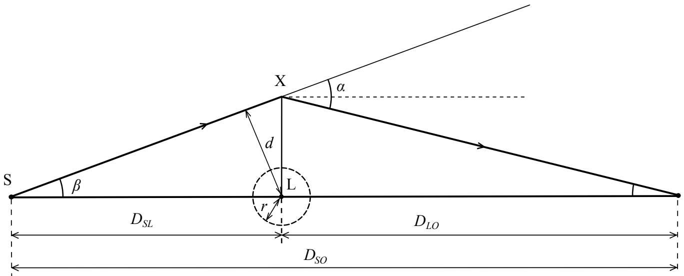


Figure 7 : Schématisation du parcours d'un rayon de lumière dans une situation de strong lensing donnant lieu à un anneau ou une croix d'Einstein : le point S représente la source de lumière (une galaxie lointaine), le point O l'observateur et L est la lentille (une galaxie ou un amas de galaxies). La révolution de 360° autour de l'axe OS du point X représente l'image virtuelle de la source S, sous forme d'anneau. L'angle d'observation θ est nommé « rayon d'Einstein ».

de la lentille, y compris celle de la matière noire, puisque c'est la masse grave de la lentille qui cause le phénomène. En effet, les distances peuvent être estimées à partir des redshifts de la source et de la lentille et le rayon d'Einstein est une quantité mesurable, normalement inferieure à la seconde d'arc. Des exercices d'applications de cette formule se trouvent dans la série rélative au capitre 6.

Plusieurs parcours thématiques

En conclusion, la séquence que nous avons parcourue montre comment, en s'appuyant d'une part sur l'intérêt du lecteur pour l'astrophysique et la cosmologie, d'autre part sur ses connaissances mathématiques de base, il est possible d'expérimenter un chapitre de la physique moderne. Elle n'est qu'un exemple des nombreux parcours possibles à partir du matériel disponible dans le cours. En effet, l'ordre et le choix des activités concernant un thème spécifique (ici l'effet de lentille gravitationnelle) est flexible et peut s'adapter aux contraintes liées à l'enseignement et/ou au niveau du public : le cours contient un choix d'exercices à développer au travers des chapitres sur le principe d'équivalence, sur la courbure et sur l'effet de lentille gravitationnelle, y compris les aspects historiques. En outre, des thèmes parcourent de manière transversale l'ensemble du cours et constituent un « fil rouge » qui aide le lecteur à s'approprier des contenus tout au long de différents chapitres, en consolidant leurs notions de base en mathématiques et en physique. Par exemple le thème « comparaison entre l'interaction gravitationnelle et électrique » débute au premier chapitre en introduisant les ordres de grandeurs en jeu dans les deux interactions, il est ensuite repris dans les chapitres sur le principe d'équivalence (pour introduire les notions de base de la relativité générale) et sur la chronologie du Big Bang (en comparant gravitation à et électromagnétisme à l'interaction nucléaire forte) puis ultérieurement développé dans le chapitre sur les ondes gravitationnelles. Ou encore le thème « expansion de l'univers » introduit dans les premiers deux chapitres les découvertes observationnelles de l'expansion, du fond diffus cosmologique, et celle plus récente de l'accélération cosmique : en avançant dans le chapitres, la modélisation mathématique permet de décrire la dynamique de l'univers et les implications théoriques des observations, jusqu'à l'introduction récente de modèles encore hypothétiques qui essaient de résoudre les problèmes observationnels actuels (inflation, gravité modifiée).

Stromproduktion: Erneuerbare sind spitze

Eine neue Studie der SATW ermittelt eine sehr gute Gesamtenergiebilanz für die Wasserkraft sowie die neuen erneuerbaren Energien in der Schweiz.

Im Auftrag der Schweizerischen Akademie der Technischen Wissenschaften SATW haben Fachleute der Professur für Energiepolitik an der ETH Zürich erstmals die Gesamtenergiebilanz der wichtigsten Formen der Stromproduktion in der Schweiz nach einer einheitlichen Methodik analysiert. Dafür wurden zwei Kennzahlen berechnet:

- **Gesamtenergiebedarf (nicht erneuerbar)** bzw. «Non-Renewable Cumulative Energy Demand»: kumulierter Bedarf an nicht erneuerbarer Energie für den Bau und die Entsorgung einer Anlage sowie für die eigentliche Stromproduktion. Bei fossilen Produktionsverfahren ist dies in erster Linie die Energie im jeweiligen Brennstoff (Gas, Kohle, Uran).
- **Erntefaktor** bzw. «Energy Return on Energy Investment» (EROI): beschreibt das Verhältnis des produzierten Stroms zur investierten («grauen») Energie über die gesamte Lebensdauer einer Anlage und sollte immer grösser als 1 sein.

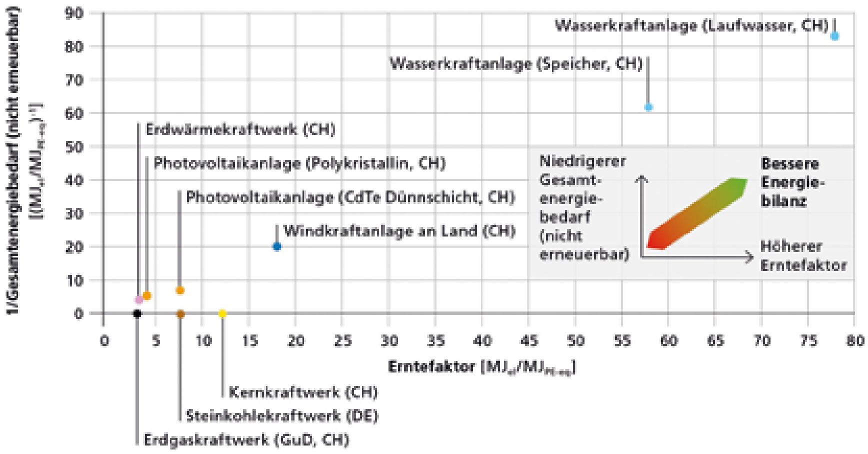


Abbildung 1: Die Gesamtenergiebilanz, ermittelt aus den Kennzahlen "Gesamtenergiebedarf (nicht erneuerbar)" und "Erntefaktor (EROI)", zeigt ein deutliches Bild: Die Wasserkraft schlägt alle übrigen Arten der Stromerzeugung um Längen. Doch auch Photovoltaik und Windkraft schneiden gut ab.

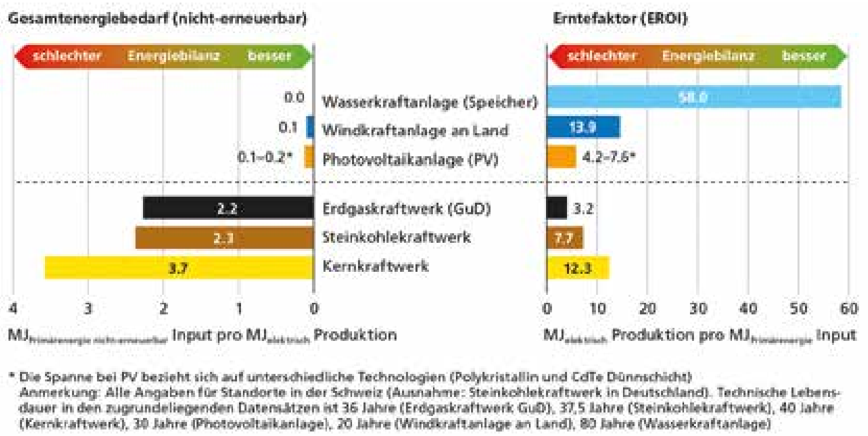


Abbildung 2: Die Resultate bzgl. Gesamtenergiebedarf und Erntefaktor zeigen deutlich die grosse Überlegenheit der Wasserkraft.

Anhand dieser Kennzahlen lassen sich Aussagen zur **Gesamtenergiebilanz** machen:

- Die Gesamtenergiebilanz der Wasserkraft ist herausragend.
- Die Analyse bekräftigt das Argument, die Wasserkraft als wichtigsten Pfeiler der Schweizerischen Stromversorgung unbedingt zu erhalten.
- Auch neue erneuerbare Energien schneiden gut ab.
- Aufgrund der technologischen Lernkurve hat sich der Erntefaktor neuer erneuerbarer Energien in den letzten zehn Jahren stark erhöht und wird künftig weiter steigen.
- Der vom Bund in der Energiestrategie 2050 vorgesehene Schweizer Strommix dürfte zu einer weiteren Verbesserung der Gesamtenergiebilanz führen.
- Öffentliche Förderprogramme tragen massgeblich zur positiven Entwicklung der neuen erneuerbaren Energien (und anderer Technologien) bei, auch bezüglich Gesamtenergiebilanz.

Bestandsaufnahme der Gesamtenergiebilanz

Unter den in der Schweiz eingesetzten Verfahren zur Stromproduktion schneidet die Wasserkraft bezüglich Gesamtenergiebilanz deutlich am besten ab, wobei Laufwasserkraftwerke bessere Werte erreichen als Speicherkraftwerke. Sie verfügen über den niedrigsten nicht-erneuerbaren Gesamtenergiebedarf sowie den mit Abstand höchsten Erntefaktor. In Anbetracht des Schweizer Strommix mit rund 60 Prozent Wasserkraft ist das ein erfreuliches Resultat. Die nächstbeste Gesamtenergiebilanz hat die Windkraft, selbst unter hiesigen Bedingungen. Bei fossilen Technologien ist der nicht-erneuerbare Gesamtenergiebedarf aufgrund des verwendeten Brennstoffs naturgemäss höher als bei erneuerbaren, womit sie auch punkto Gesamtenergiebilanz schlechter abschneiden. Den höchsten Erntefaktor weist dort die Kernenergie auf, gefolgt von Steinkohlekraftwerken. Doch beide liegen bereits klar hinter der Windkraft zurück.

Erntefaktor: Wind und Photovoltaik legten dank Lerneffekten deutlich zu

Die Effizienz einer Technologie verbessert sich mit zunehmender Verbreitung und Erfahrung. Entsprechende Effekte von Lernkurven konnten für den Energiesektor in diversen Studien nachgewiesen werden. Dadurch haben in der Vergangenheit Photovoltaik und Windkraft grosse Fortschritte in Bezug auf Kosten, aber auch den Erntefaktor erzielt. Um Voraussagen über die künftige Entwicklung machen zu können, haben die Autoren einen dynamischen Erntefaktor entwickelt. Dafür wurden historische Lernkurven für typische mitteleuropäische Standorte analysiert und in die Zukunft extrapoliert, wobei grössere Unsicherheiten bezüglich der künftig installierten Leistung und Lerneffekten berücksichtigt wurden, nicht jedoch disruptive technologische Entwicklungen. Vier Verfahren der Stromerzeugung wurden

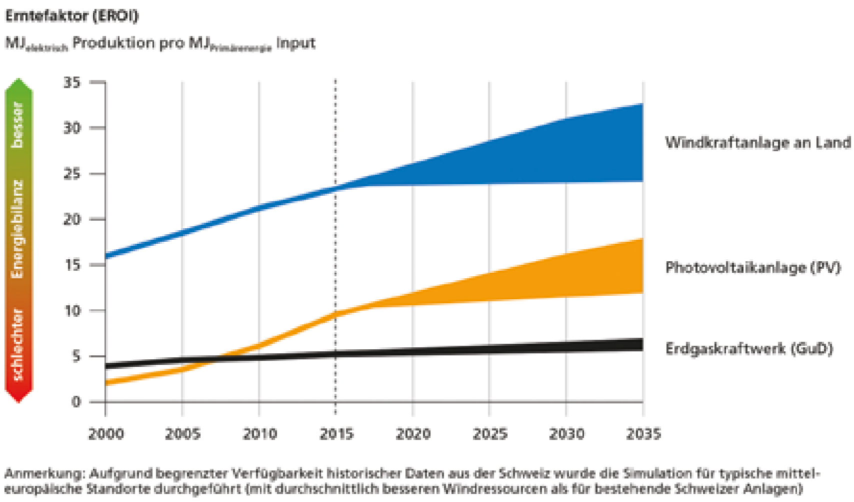


Abbildung 3: Bisherige und erwartete Entwicklungen des Erntefaktors von Windkraft an Land, Photovoltaik sowie Gaskombikraftwerk. Während die Prognosen bei allen Szenarien eng beieinanderliegen, zeigt das Zielband als Fächer eine relativ grosse Varianz. An der grundlegenden Reihenfolge und den Trends ändert die Wahrscheinlichkeitssimulation aber kaum etwas.

untersucht: Erdgas (Gaskombikraftwerke), Photovoltaik, Windkraft und Steinkohle. Da Steinkohlekraftwerke für die Schweiz allerdings nicht relevant sind, wurden sie hier nicht weiter berücksichtigt.
Aufgrund mangelnder Daten und grosser Varianzen im nuklearen Brennstoffkreislauf (insbesondere Abbau und Anreicherung von Uran) sowie der sehr unterschiedlichen, standortabhängigen Energieaufwendungen beim Bau von Wasserspeicherkraftwerken konnte kein dynamischer Erntefaktor für die beiden in der Schweiz wichtigsten Arten der Stromerzeugung berechnet werden. Da der Ausstieg aus der Kernenergie jedoch politisch beschlossen ist und das Ausbaupotenzial der Wasserkraft beschränkt ist, zeigt die Studie gut auf, welches aus energetischer Sicht die lohnendsten Alternativen sein können, um die wegfallende Kernenergie künftig zu kompensieren und eine allfällige Zunahme des Strombedarfs zu decken.

Basierend auf den Berechnungen wird bei der Windkraft an Land bis 2035 eine Verbesserung des Erntefaktors auf 25 bis 30 erwartet, je nach betrachtetem Szenario. Gründe dafür sind grössere Anlagen mit höherer Leistung und Energieausbeute, neue Materialien sowie Verbesserungen bei standardisierten Komponenten (z.B. Transformatoren und Spannungswandler). Der Erntefaktor der Photovoltaik dürfte sich aufgrund effizienterer Module, besserer Produktionsmethoden sowie Skaleneffekten bei der Herstellung in höheren Stückzahlen auf 12 bis 17 verbessern. Demgegenüber fallen die untersuchten Arten der brennstoffbasierten Stromerzeugung ab. Gaskombikraftwerke – die für die Schweiz relevanteste Technologie – dürften 2035 einen Erntefaktor in der heutigen Grössenordnung von 5 bis 6 haben. Naturgemäss sind solche Prognosen mit grossen Unsicherheiten behaftet. Unter Berücksichtigung verschiedener Szenarien verändert sich aber weder die Reihenfolge der Technologien noch der Umfang der zu erwartenden Effizienzgewinne grundsätzlich.

Datengrundlage

Grundlage der Analyse waren primär die Zahlen von «ecoinvent» (*www.ecoinvent.ch*), der weltweit führenden Datenbank für Lebenszyklusanalysen. Dabei wurde der Energiebedarf über die gesamte Lebensdauer der Produktionsanlagen berücksichtigt, also inklusive Bau, Abriss und Entsorgung. Für Formen der Energieerzeugung, die hierzulande nicht existieren, wurden Zahlen aus anderen europäischen Ländern verwendet, wie Deutschland (Steinkohle) oder Dänemark (Offshore-Windenergie). Wo ecoinvent keine Daten liefern konnte, wurde auf andere Quellen zurückgegriffen, wie die Internationale Energieagentur (IEA) oder die Internationale Organisation für erneuerbare Energien (IRENA).

Beurteilung der Speichertechnologien

Ein weiterer Teil der Studie beschäftigt sich mit verschiedenen Möglichkeiten der Stromspeicherung. Dazu verwenden die Autoren die Kennzahl «Energy Stored on Energy Investment (ESOI)», welche die Gesamtmenge der über die Lebensdauer gespeicherten Energie ins Verhältnis setzt zur investierten Energie für die Produktion des Speichermediums. Besonders schlecht schneiden Bleiakkumulatoren ab. Ihr ESOI-Wert liegt bei 1. Sie speichern über ihre Lebensdauer also insgesamt nur so viel Energie, wie für ihre eigene Produktion benötigt wird. Bereits deutlich höher liegt der Wert bei Lithium-Ionen-Batterien (Faktor 7) oder Power-to-Gas-to-Power-Verfahren (Faktor 23). Mit einem ESOI von 186 sind aber Wasserspeicherkraftwerke klare Spitzenreiter der Speichertechnologie. Die Wasserkraft hat also auch hier die Nase vorn. Viele Speichertechnologien befinden sich aber noch am Anfang ihrer Lernkurve, sodass dort noch grosse Verbesserungen erwartet werden dürfen.

Ziel der Studie

Die Schweizerische Akademie der Technischen Wissenschaften SATW ist bestrebt, die wichtige Diskussion um die künftige Stromerzeugung zu versachlichen und die Grundlagen für eine offene, faktenbasierte und zukunftsgerichtete Diskussion in Gesellschaft, Politik und Wirtschaft zu liefern. Zu diesem Zweck wurde die Professur für Energiepolitik der ETH Zürich beauftragt, die Gesamtenergiebilanz verschiedener Anlagen der Stromerzeugung zu ermitteln und vergleichbar darzustellen. Zudem sollten Aussagen über die zukünftige Entwicklung der entsprechenden Technologien gemacht werden. Da es sich bei Investitionen in die Stromerzeugung um langfristige Entscheidungen handelt, ist nicht nur der Status quo entscheidend, sondern auch die Erwartung, wie sich entsprechende Technologien mittelfristig entwickeln werden. Die Studie soll periodisch aktualisiert werden.

Hintergrund

Die Anstrengungen zur Reduktion der CO_2-Emissionen führen weltweit zu grundlegenden Umwälzungen bei der Stromproduktion. Neue erneuerbare Formen der Stromproduktion sind weltweit die grossen Hoffnungsträger, um den steigenden Strombedarf bei gleichzeitigem Ersatz fossiler Brennstoffe zu decken. Auch in der Schweiz können neue erneuerbare Formen eine entscheidende Rolle spielen. Im Vorfeld der Abstimmung über das neue Energiegesetz am

21. Mai 2017 hat sich jedoch einmal mehr gezeigt, dass grosse Unsicherheiten über die Eignung der verschiedenen Formen der Energiegewinnung bestehen und bisweilen nicht hinreichend faktenbasiert argumentiert wird. Eine neue Studie zu Kosten und Lebenszyklusemissionen [1] hilft, die Debatte zu versachlichen, indem sie für den Zeitraum bis 2050 u.a. Kosten- und Treibhausgassenkungspotenziale (z.B. für Photovoltaik) aufzeigt. Die Gesamtenergiebilanz verschiedener Technologien war jedoch bis jetzt nicht klar dargelegt.

Kernaussagen der Studie

- Die Studie belegt eindrücklich die positive Gesamtenergiebilanz der Wasserkraft. Doch auch Photovoltaik und vor allem Windkraft zeigen positive Werte. Beeindruckend ist aber, wie deutlich die Wasserkraft andere Formen der Stromerzeugung beim Erntefaktor überflügelt.
- Die Effizienz von Photovoltaik und Windkraft ist in den vergangenen Jahren deutlich gestiegen und weitere Verbesserungen sind künftig zu erwarten. Der Ausstieg aus der Kernenergie hat das Potenzial, die Gesamtenergiebilanz und damit die Nachhaltigkeit der Stromproduktion in der Schweiz zu verbessern und nicht umgekehrt, wie bisweilen postuliert.
- Der Umbau des Schweizer Energieversorgungssystems führt dazu, dass der Anteil stochastischer – also schwankender – Stromproduktion aus Photovoltaik und Windkraft weiter steigt. Die Speichertechnologie wird also künftig eine immer wichtigere Rolle als Regelenergie einnehmen.
- Bei Stromspeicher-Technologien sind Wasserspeicherkraftwerke gegenüber Power-to-Gas-to-Power-Verfahren und Batterien klar im Vorteil. Trotz der aktuell schwierigen ökonomischen Situation der Wasserkraft sollte die Schweiz also aus Sicht der Gesamtenergiebilanz auch künftig an ihr als wichtigste Säule der Stromversorgung festhalten.
- Obwohl umstritten, waren staatliche Förderprogramme wie die kostendeckende Einspeisevergütung (KEV) wichtige Impulsgeber für Innovationen im Energiesektor. Sie schaffen Anreize für die Installation entsprechender Kapazitäten, was die technologische Entwicklung entlang der Lernkurve beschleunigt.
- Andere nicht-stochastische erneuerbare Energieformen, wie die Geothermie, können künftig ebenso eine wichtige Rolle einnehmen. Deshalb sollte die Politik prüfen, ob auch für diese Technologien ein Fördermechanismus anzustreben ist.
- Schliesslich stützen die Erkenntnisse der Studie den von Bundesrat und Parlament mit der Energiestrategie 2050 eingeschlagenen Weg, der einen starken Zubau neuer erneuerbaren Energien in der Schweiz vorsieht, auch aus Sicht der Gesamtenergiebilanz.

Beatrice Huber und Adrian Sulzer (SATW)

Autoren der Studie: Bjarne Steffen, Dominique Hischier und Tobias S. Schmidt (Professur für Energiepolitik an der ETH Zürich)
Begleitgruppe: Willy R. Gehrer, Rolf Hügli und Ulrich W. Suter (SATW)

1 Bauer, C., et al (2017), Potentials, costs and environmental assessment of electricity generation technologies, Bundesamt für Energie BFE, Ittigen, 01.11.2017

Great success at the International Physicists' Tournament

Evgenii Glushkov, EPFL, Laboratory of Nanoscale Biology

It was a very intense Easter break in the life of six 3rd year physics students from EPFL. And a very successful one! They were representing Switzerland in the final of the International Physicists' Tournament (IPT 2018, http://2018.iptnet.info/) and competing against teams from fifteen other countries. And they did it so well, that Switzerland won the tournament for the first time in 5 years!

Here are the names of our heroes: Alberto Rolandi (captain), Laurent Michaud, Noémie Planat, Virginie Solans, Mathieu Suter and Marion von Allmen. They also had two very experienced helpers from last year's team – Quentin Dubey, who helped the students dive much deeper into the physics of the problems than they could have ever imagined, and Arthur Parmentier, who taught the team to present their solutions in a clear, structured and appealing way. Those two helpers made my role as a team leader quite easy – just bring the team to Moscow and let them win the tournament.

Now, a couple of words about the IPT itself, which celebrated this year its 10th edition. It originated from a physics tournament held in Ukraine in the 2000s, then moved to Russia in 2011 and became truly international a couple of years later. IPT has been extensively growing in the last several years and by now is the world's biggest competition in physics for university students. The tournament plays an important role in letting undergraduate students get hands-on research experience early in their scientific career. And in contrast to the standard lab exercises, which they have in their curriculum, it provides the students with the unique freedom to choose their own way of tackling an open physics problem – from literature study to the data analysis – much like any research is carried out in the scientific world. And most problems don't require complex scientific equipment to be solved, so the students can work on them even at home!

The range of problems they can choose from is quite wide as well. Each August the teams all around the world receive a list of 17 physics problems, carefully selected and assembled specifically for the tournament by the International Organizing Committee of the IPT. The topics of the problems can vary from hydrodynamics and optics to black hole formation. Many of the problems require building a simple experimental setup and optimizing it to fulfil a specific task. For example, one problem from the IPT 2017 asked the students to make a device that can most quickly and efficiently dilute a spoon of honey in a teacup. And some teams went so far as building a real piece of engineering art with servos to turn the spoon and lasers to check how well the honey was mixed with tea!

Several months after the list of problems is published, the teams from different universities within each country meet for the National Selection, the winner of which will be representing the country in the International Final. The IPT final is traditionally held each year in April and each edition is hosted by a different university from one of the participating countries. As I mentioned earlier, the international final usually lasts for one week, during which the teams have several qualifying physics fights and the grand finale with the top three teams.

Those of you who have never heard of a physics fight might be a little disappointed, as there is no fighting at all! Instead, the whole concept is focused on discussing physics at the deepest level possible! Though, I must confess, sometimes the discussion might become quite hot, but our well-educated students can still hold their temper. And, naturally, the professional tone of the discussion and the respectful behaviour during the fight are influencing the grades the teams get from the jurors, so it all creates a very friendly and constructive environment for the students.

It is quite hard to tell where the structure of the physics fights originally came from, but it was definitely inspired by the International Young Physicists' Tournament – a widely known competition for the high-school students. There are three roles in a physics fight: a Reporter, who during 10 minutes presents the solution to one of the IPT problems, an Opponent, who analyses the presented solution, shows its strengths and weaknesses and suggests how it might be improved, and a Reviewer, who gives an overview of both Reporter's and Opponent's performances and moderates the discussion between them. At some point the teams can also join the discussion and at the end the players are given marks by a respectful panel of juries followed by valuable comments. This constitutes one round of a physics fight. Logically, the whole fight consists of three rounds, which gives each of the three teams in the fight an opportunity to try on the role of Reporters, Opponents and Reviewers.

Of course during the IPT the students not only enjoy the physics fights, but also have a unique opportunity to interact with each other in an informal setting, learn various traditions of physics education in different countries and explore the culture of the hosting country! So the very fact of being part of the IPT final is a great reward to the students for all the months of hard work spent on preparation for the tournament! And this is how the participants themselves, who just cannot forget this wonderful experience they had at the IPT, pass the spirit of the tournament from year to year! This happened to me as well. After playing in the IPT 2015 I couldn't grow apart from the tournament and, while continuing my studies and becoming a PhD student, I also adopted the role of a team leader and the IPT representative in Switzerland.

If you got excited as you were reading this – it's just the right moment to get involved! Just send an e-mail to *switzerland@iptnet.info* or directly to *evgenii.glushkov@epfl.ch* and express your interest! If you are a professor at one of the Swiss universities – you can tell your students about the IPT and see if they can form a team. Likewise, if you are a student – talk to your friends and see if they like the idea of the tournament! This is how most of the IPT teams were started and we do hope to see more of them appearing in Switzerland! And of course we are happy to share our experience on preparing for the tournament, playing in physics fights, getting credits, etc., so you won't have to start from scratch!

Also, for the National Selection, which in Switzerland will happen during a weekend in early December, 2018, you just need to prepare solutions for a couple of problems from the list, which won't be that time-consuming. So my message is – why don't you come to EPFL next December to try to beat the winners of the IPT 2018? And, who knows, maybe in a year you'll be holding the trophy of the IPT 2019?!

Last, but not least, I would like to thank the EPFL Vice Presidency for Education for sponsoring the team's plane tickets, the Swiss Physical Society for covering the registration fee and promoting the IPT in Switzerland, itself supported by the platform MAP of the Academy SCNAT, and EPFL Physics Section for fully supporting the team throughout months of preparation for the tournament! Special thanks also go to Ms. Martine Truan, administrative assistant of LBEN, for making the travel arrangements for the whole team.

Picture Credits: p. 58: Alberto Rolandi, p. 59: A.Lomakin (MIPT), supported by MIPT-Union, Abbyy and Pres. Grants Fund.

Physik Olympiaden 2018

Die Schweiz hat auf Gymnasialebene zwei Physikwettbewerbe: die Schweizerische Physikolympiade (SwissPhO) und das Swiss Young Physicists' Tournament (SYPT), welche jeweils zu ihren internationalen Pendants weiterleiten. Relativ neu gibt es auf dieser Ebene auch eine Europäische Physikolympiade (EuPhO). Nachfolgend berichten wir über SwissPhO und EuPhO, in der nächsten Ausgabe folgen Informationen und Ergebnisse zu den internationalen Wettbewerben.

The Swiss Physics Olympiad: a competition for gymnasial students leading to International (IPhO) and European (EuPhO) Olympiads

Rafael Winkler, SwissPhO and ETH Zürich

This year, as organizers of the Swiss Physics Olympiad, we introduced an additional round to our competition. This new first round was held in August and September 2017, with the goal of reaching more students by enabling teachers to take the test with their class either as a paper version or online. Additionally, the students could also participate by themselves online. In terms of student numbers, the result was a big success with 647 participants, which was almost eight times as many participants as in the previous years. The level of the students was pretty high. We also hope that by this new way of doing, we can motivate a lot more teachers to regularly take the test with their students.

The best 80 students from Switzerland and Liechtenstein qualified for the second round. In order to prepare these students for this second round there was a preparation camp, where, during one week, they learned a lot of physics and practised solving former Olympiad problems. Besides the training, the preparation camp was also a good occasion for the students to meet other students with the same passion. In the evening, they often played cards or other games.

After the relaxed nature of the preparation camp, the next event on the Physics Olympiad calendar promised a more serious atmosphere. On the 17th of January, the students gathered in Lugano, Lausanne, Bern and Zurich for a second round of examinations. After being greeted by cheerful volunteers, they sat down for an hour of multiple-choice questions. In the afternoon, three written problems awaited the students. After the exhausting two-hour exam, they were rewarded with a pleasant buffet of snacks. Finally, they headed home, impatiently awaiting the e-mail announcing their results.

The students, who qualified for the final round, were invited to an experimental training camp at EPFL in Lausanne. After a theoretical introduction to AC circuits, the students went to the lab where they had to build a low pass filter and examine its properties. Additionally, they also examined an electrical black box containing different linear elements. On the second day of the experimental training the students received an introduction to statistics and were then able to apply their newly learned knowledge to different former Physics Olympiad experiments. The whole training was rounded off on the third day with a lecture about relativity.

On 24th /25th of March, the final round of the Physics Olympiad took place at the Neue Kantonsschule Aarau. The students had a total of 3.5 hours for solving different theoretical problems and 2.5 hours for the experimental one. In this experimental task, they had to investigate different optical and electrical properties of a light bulb. On Sunday morning the ranking and the teams for the two international competitions were announced in the final ceremony. This year Switzerland does not only take part in the International Physics Olympiad, which takes place in Lisbon, July 21-29, but for the first time, we will also participate in the European Physics Olympiad in Moscow, May 28 to June 1. The final ranking of the SwissPhO 2018 is given at www.swisspho.ch, including also the participation to the two international Olympiads to come.

The two best performing students have been rewarded with the "SPG Nachwuchförderpreis" / "Prix de la Relève de la SSP", given with the support of the Academy SCNAT.

Gold medal winners (from left to right): Julius Vering ("SPG Nachwuchförderpreis"), Arthur Jaques ("Prix de la Relève de la SSP"), Ciril Humbel, Tim Mosimann and Hiro Josep Kaga.

Pictures: left column © R. Winkler , right column © M. Meier

Die Europäische Physikolympiade EuPhO 2018 in Moskau

Alfredo Mastrocola, SwissPhO (alfredo@mastrocola.ch)

Die Schweiz nimmt heuer zum ersten Mal an der zweiten Auflage dieses neuen Wettbewerbs für Gymnasiasten teil. Neben der internationalen IPhO fanden bis 2017 noch Regionalolympiaden für Asiatische und für Iberosprachige Länder statt. Dabei sind diese Wettbewerbe nicht als Vorausscheidungen für die IPhO, sondern als unabhängige und andersartige Anlässe gedacht.

Schon 2008 hatten sich Olympiadendelegierte von 9 kleineren europäischen Ländern, nämlich von Bosnien Herzegowina, Estland, Island, Liechtenstein, Norwegen, Serbien, Slowenien, Österreich und der Schweiz in Aarau zu einer Arbeitstagung getroffen, um über eine EuPhO zu beraten. Sie wollten einen einfacheren, moderneren Wettbewerb und einigten sich auf neue, kreativere Formen. Leider verhinderte aber die darauf folgende Wirtschaftskrise vorerst die Realisierung.

Die Delegierten von 2008 in Aarau. Foto © A. Mastrocola

Prof. Jaan Kalda (links oben im Bild) aus Estland gelang es letztes Jahr die erste EuPhO mit 19 Teilnehmerstaaten durchzuführen und verwirklichte die schon 2008 angestrebten Ziele u.a.:

- eine halb so grosse Dauer von nur 5 Tagen,
- ein weniger pompöser Rahmen,
- schlankere und modernere Aufgaben und eine
- straffe, einfachere Bewertung.

Der kleinere Aufwand ermutigt zukünftige Organisatoren und die niedrigeren Kosten ermutigen zur Teilnahme zusätzlich zur IPhO. So erhöhte sich die Anzahl der teilnehmenden Teams 2018 in Moskau auf 25. Auch die Schweiz konnte ohne namhaften Mehraufwand neben dem Team für die IPhO in Portugal ein solches für die EuPhO aufstellen. Die experimentellen Trainings wurden zusammengelegt und das EuPhO-Team kam in den Genuss eines Trainingswochenendes in Theorie am PSI.

Am 27. Mai sind fünf hoffnungsvolle physikbegeisterte nach Moskau geflogen, und ob es gelingt, Medaillen zu gewinnen oder nicht, so werden sie aber sicher noch physikbegeisterter als vorher zurück kommen.
Die SPG als Förderin der Physikolympiaden leistet so einen willkommenen Beitrag zur Sicherung des Physikernachwuchses in der Schweiz.

http://eupho2018.mipt.ru/
http://eupho.ut.ee/

Kurzmitteilungen

Anton Paar Forschungspreis für instrumentelle Analytik & Charakterisierung

Anton Paar, der österreichische Spezialist für Analyselösungen und Messgeräte, schreibt den ersten "Anton Paar Forschungspreis für instrumentelle Analytik & Charakterisierung" aus. Mögliche Einreichungen umfassen neue Methoden und/oder Anwendungen der instrumentellen chemischen Analyse oder der physikalischen Charakterisierung von Materialien und dürfen nicht älter als zwei Jahre sein. Darüber hinaus sollen die eingereichten Projekte idealerweise als Produkt oder Anwendung realisierbar sein.

Diese Ausschreibung ist offen für alle, die sich für chemische Analyse oder physikalische Charakterisierung interessieren. Der Schwerpunkt soll auf neuen Methoden oder Anwendungen liegen. Zur Einreichung sind auch Projekte zugelassen, die nicht publiziert sind, solange sie den Vorgaben entsprechen.

Der Anton Paar Forschungspreis ist mit 20.000 Euro dotiert und wird von Anton Paar finanziert. Die Preisträger werden von einer Jury bewertet und ausgewählt, die aus renommierten, universitären Forschern und Spezialisten von Anton Paar besteht. Bei der Beurteilung geht es primär darum, ob die Einreichung letztendlich das Potenzial hat, als neues Produkt oder neue Methode umgesetzt zu werden oder zu einer neuen oder verbesserten Messtechnik oder Messmethodik zu führen. Der Preis wird im November 2018 in der Zentrale von Anton Paar in Graz oder einer internationalen Unternehmenstochter verliehen.

Weitere Informationen:
https://www.anton-paar.com/at-de/research-award/

Rückblick 2. Internationales Jost-Bürgi Symposium

Bernhard Braunecker

Das 2. Jost Bürgi Symposium im Toggenburger Lichtensteig, dem Geburtsort Bürgis, lockte am diesjährigen 14. April, einem schönen Samstagmorgen, gut 250 Zuhörer an, die erwartungsvoll den Ausführungen der sieben Referenten folgten.

Die Veranstaltung galt der Erinnerung an dieses Renaissancegenie, das stets im Schatten von Johannes Kepler und Tycho Brahe, sowie von Galilei in Florenz stand und auch heute noch steht, obwohl diese von Bürgis Instrumenten und Rechenmethoden durchaus mehr profitierten als man bislang wusste. Unter den Zuhörern war viel Prominenz vertreten, u.a. der SPG Präsident Hans Peter Beck und der Regierungspräsident des Kantons St. Gallen Fredy Fässler (Bild 1).

Der erste Teil wurde von Historikern gestaltet mit Ausführungen über den heute im Zürcher Landesmuseum ausgestellten Himmelsglobus (Bernard A. Schüle), dann über den Nachbau eines mechanischen Himmelmodells von Bürgis Freund Ursus (Günther Oestmann) und über die Neuentdeckung einer bis jetzt unbeachteten Schrift, die Bürgi als kenntnisreichen Metallurgen ausweist (Jürgen Hamel). Interessant war eine von Fritz Staudacher vorgebrachte Vermutung, dass Bürgis Scheu beim Publizieren, die ihn durch das Raster der Geschichte fallen liess, in seinem angespannten Verhältnis zu Tycho Brahe liegen könnte.

Der zweite Teil galt den Auswirkungen Bürgis, Keplers und Brahes bis in unsere heutige Zeit, wobei der Fokus auf Messtechnik, Astronomie und Raumfahrt lag. Im ersten Vortrag schilderte ich, dass ohne die Bürgischen Winkel- und Zeitsekunden, die er als verlässliche Messgrössen in der Astronomie eingeführt hatte, heutzutage keine ‚Point-to-Point' Verbindungen von mittels Laserstrahlen kommunizierenden Satelliten möglich wären.

Im zweiten Vortrag beschrieb die Astrophysikerin Aurora Sicilia-Aguilar von der Universität Dundee / UK neuere Erkenntnisse über die Bildung von Sternen und Planeten (Bild 2). Sie zeigte, dass eine geschickte Verknüpfung der Messdaten aus dem gesamten Wellenlängenbereich von Gammastrahlen bis zu Radiowellen erlaubt, Details über die Stern- und Planetenentstehung aufzulösen, die Einzelmessungen wegen ihres eingeschränkten Messbereichs verborgen bleiben. Ermöglicht wird dies durch den bemerkenswerten Fortschritt in der Instrumentation und der physikalischen Modellbildung in den letzten Jahren, sodass Messdaten von Grossteleskopen mit denen von kleineren Teleskopen kombiniert werden können. Da letztere vermehrt zur Verfügung stehen, besteht dadurch auch die Möglichkeit, die Dynamik von protoplanetaren Scheiben und jungen Sternen mit wiederholten Messungen über mehrere Jahre hinweg einzufangen. Ebenso lassen sich Datensätze aus den letzen 40 Jahren in die neuartige Auswertung aufnehmen. Die erhaltenen kurz-, mittel- und langfristigen Veränderungen von Form, Symmetrie und Lage hochaufgelöster Spektrallinien geben Aufschluss über kleine, normalerweise nicht detektierbare Strukturen und Bewegungen in der Stern- und Planetenentstehung.

Im anschliessenden und letzten Vortrag erinnerte Claude Nicollier mit spektakulären Bildern an seine vier Raumfahrtmissionen zur ISS mit den Space Shuttles Columbia, Discovery, Atlantis und Endeavour in den Jahren 1992 bis 1999. Seine extrem schwierigen Einsätze zur Korrektur des Hubble-Teleskops im Orbit werden angesichts der Bedeutung des Teleskops für die Astrophysik als bedeutende Meilensteine in die Annalen der Raumfahrt eingehen.

Die SPG trat als Mitorganisator auf und engagierte sich vornehmlich im zweiten Teil bei den Auswirkungen in die Neuzeit. Die Gründe sind zweierlei: zum einen wird die von Kepler und Galilei geprägte Zeit als Wiege der modernen Physik gesehen, und neue Erkenntnisse über das Werk Bürgis sind somit von unmittelbarer Wichtigkeit für die Geschichte der Physik. Zum anderen kann sie das grosse öffentliche Interesse an historisch-naturwissenschaftlichen Themen, wie es durch den Erfolg der Bürgi-Biographie von F. Staudacher geweckt wurde, nutzen, um auf neuzeitliche Fragestellungen zu verweisen. Allerdings verlangt die Kombination aus publikumswirksamer feuilletonhafter Darstellung, historisch-wissenschaftlicher Objektivität und neuzeitlich-technologischer Umsetzung klare Regeln, um möglichen Irritationen vorzubeugen.

Die Zusammenfassungen der sieben Vorträge können von der Webseite *https://www.jostbuergi.com/symposium/* herunter geladen werden. Das Symposium soll regelmässig wiederholt werden, wobei der nächste Fokus die Zeit und die Uhren sein könnten.

Prix Schläfli since 1866

Rewarding the best Swiss PhDs in the natural sciences

Call 2019

The Prix Schläfli, one of the oldest science prizes in Switzerland (since 1866), is awarded by the Swiss Academy of Sciences (SCNAT) to young scientists for excellent articles resulting from PhDs in each one of the following natural sciences disciplines:

- Biology
- Chemistry
- Geosciences
- Physics

Eligible are young researchers who did their doctoral thesis at a Swiss University or Swiss nationals who did their PhD thesis abroad. Candidates must have defended their doctoral thesis between 1 November 2015 and 31 October 2018. Nominations can be submitted by the supervisor of the candidate or by a SCNAT member society.

A jury is established for each of the four disciplines in order to evaluate the nominations. Prize consists of CHF 5000 and support for a conference participation in each of the scientific fields.

Nominations are submitted via an online form before 31 October 2018 (scnat.ch/prixschlaefli).
Please consult the guidelines before applying: scnat.ch/prixschlaefli

sc | nat

Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
Académie des sciences naturelles

Contact details:
Swiss Academy of Sciences · House of Academies · Laupenstrasse 7 · P.O. Box · 3001 Bern
Dr Anne Jacob · Phone +41 31 306 93 05 · anne.jacob@scnat.ch

Wir haben interessante Jobs für Physiker: Entwicklung und Marketing & Sales

Bereit für den nächsten Schritt?

AWGs

bereits ab **CHF 5 680.–** pro Kanal

- → 2.4 GSa/s, 16 bit, 750 MHz
- → 4, 8 und mehr Kanäle
- → <50 ns Triggerlatenz

Typische Anwendungen
Halbleiter-Test, Quanten-Computer, phasedarray Radar Design und Test, Lidar, Spektroskopie, NMR

Impedanz-Analysator

bereits ab **CHF 10 695.–**

- → DC bis 5 MHz, 1 mΩ bis 1 TΩ
- → 0.05% Grundgenauigkeit
- → Compensation Advisor und Confidence Indicators

Typische Anwendungen
High-Q Dielektrika, kapazitive Sensoren, PV Materialien, Superkondensatoren, Komponenten-Charakterisierung

Lock-in-Verstärker

bereits ab **CHF 5 980.–**

- → Bis zu 600 MHz
- → Oszilloskop, FFT, FRA, Sweeper, Imaging-Modul
- → Optional: AWG, PID, PLL, Boxcar, Counter, AM & FM

Typische Anwendungen
AFM, LVP, CARS, SRS, SNOM, Graphen, optische PLL, THz, Pump-Probe, RFID, MEMS, NEMS, Gyroskope, NDT, MRFM

Gerätesoftware

Alle Geräte sind mit LabOne® ausgestattet. Die Kontrollsoftware von Zurich Instruments bietet einen grossen Funktionsumfang, einfache Benutzung und damit effiziente Arbeitsabläufe. Greifen Sie mittels Webbrowser auf Ihr Gerät zu und integrieren es direkt in Ihre LabVIEW, MATLAB, Python, C und .NET Experimentsteuerung.

Zurich Instruments

www.zhinst.com info@zhinst.com Intl. +41 44 515 0410 Sprechen Sie uns an