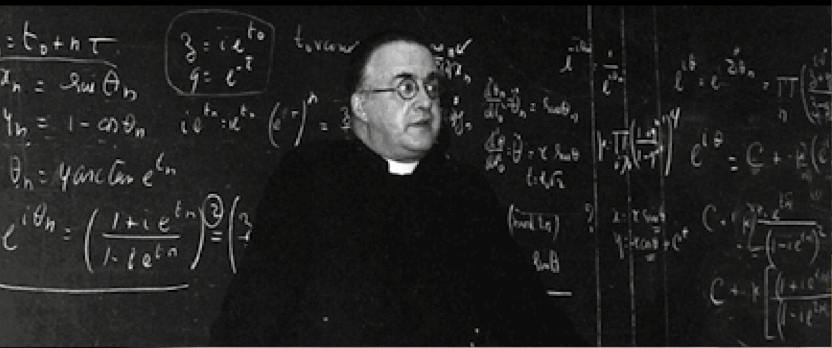
⟨S|P|S⟩ swiss physical society

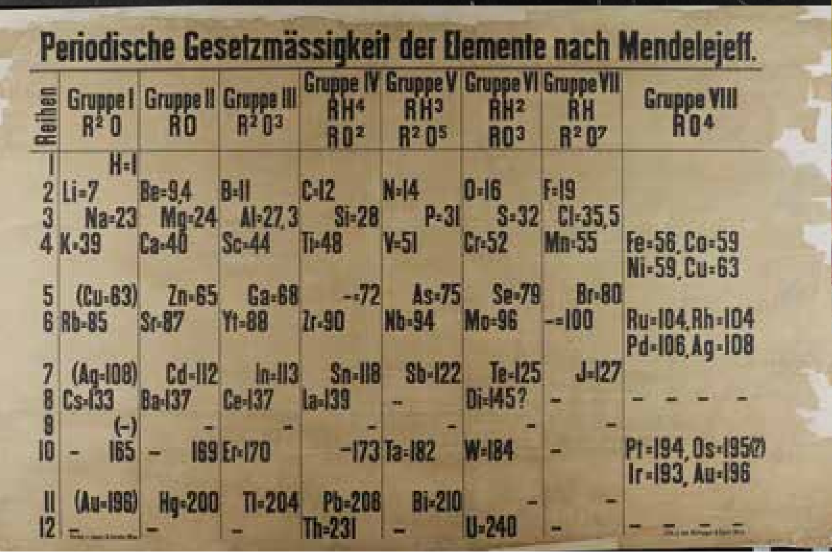
Nr. 58
Juli 2019

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP

Symposium
125th Anniversary of Georges Lemaître

21 November 2019, Kuppelsaal, Hauptgebäude,
Universität Bern, Hochschulstrasse 4, 3012 Bern





Periodische Gesetzmässigkeit der Elemente nach Mendelejeff.

Reihen	Gruppe I R^2O	Gruppe II RO	Gruppe III R^2O^3	Gruppe IV RH^4 RO^2	Gruppe V RH^3 R^2O^5	Gruppe VI RH^2 RO^3	Gruppe VII RH R^2O^7	Gruppe VIII RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	Sc=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	Ga=68	–=72	As=75	Se=79	Br=80	
6	Rb=85	Sr=87	Yt=88	Zr=90	Nb=94	Mo=96	–=100	Ru=104, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	Ce=137	La=139	–	Di=145?	–	– – – –
9	(–)	–	–	–	–	–	–	
10	– 165	– 169	Er=170	–173	Ta=182	W=184	–	Pt=194, Os=195(?) Ir=193, Au=196
11	(Au=196)	Hg=200	Tl=204	Pb=208	Bi=210	–	–	
12	–	–	–	Th=231	–	U=240	–	– – – –

While the PSI celebrated last year its 30th anniversary (p. 44), the SPS commemorates in 2019 two older jubelees: the 125th anniversary of Georges Lemaître with a dedicated symposium (p. 58), and the UNESCO International Year of the Periodic Table of Chemical Elements with a special session at our Joint Annual Meeting (p. 25). The picture on the left shows the presumably oldest periodic table still existent in the world (p. 3). Courtesy of the University of St Andrews Library (ms39012).

Joint Annual Meeting of the
Swiss Physical Society
Austrian Physical Society
26 - 30 August 2019, Universität Zürich

in collaboration with Association MaNEP, NCCR QSIT and SGN

General Information: p. 11, preliminary program p. 14

Inhalt - Contenu - Contents

Vorstandsmitglieder der SPG - Membres du Comité de la SSP

SPG Administration - Administration de la SSP

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

Breakthroughs

Hans Peter Beck, SPS President

The title page of this edition of the *SPG Mitteilungen* features fundamental breakthroughs in the history of science. A periodic table, dated 1885 and found in the University of St. Andrews' School of Chemistry, is thought to be the oldest in the world. This table is representative for the major breakthrough Dmitry Mendeleev achieved, when he presented the *Dependence between the Properties of the Atomic Weights of the Elements* to the Russian Chemical Society in 1869. The United Nations General Assembly and UNESCO therefore proclaim 2019 as the International Year of the Periodic Table of Chemical Elements, the IYPT2019.

As SPS, we have enough reason to celebrate the IYPT2019, which we will do with a physicists' perspective on the origin and abundances of the elements in the Universe, the Solar System and on Earth, where the structure of atomic nuclei, and the inner structure of the protons and neutrons that make up the nuclei, come into play. In a special dedicated session at its annual meeting in Zürich, *On the Origin of the Elements*, jointly organized by SPS and SCNAT, the IYPT2019 will be celebrated with three overview talks covering historical remarks, Big Bang nucleosynthesis, and the creation of heavy elements in stellar explosions. Details can all be found on page 25.

The notion of Big Bang nucleosynthesis brings us seamlessly to the 2nd breakthrough featured on the title page. Georges Lemaître, who was born 125 years ago, was first to recognize in 1927 that the Universe expands when rigorously applying Einsteins' general relativity and derived what became known as Hubble's law two years before Hubble published his landmark article. Rightfully, this law is now called the Hubble-Lemaître law. Breakthroughs are important landmarks in the history of science and we like celebrating them in Symposia, Colloquia, and with public talks. A dedicated Lemaître Symposium, again jointly organized by SPS and SCNAT, will take place on 21 November at the University of Bern. All details on this special Symposium can be found on page 58.

The remaining title pictures show impressions from the Paul Scherrer Institute, which celebrated last year its 30th anniversary. Breakthroughs and other highlights achieved at PSI in these last 30 years are detailed on p. 44.

Breakthroughs are not only important when looking back in history. Breakthroughs, small or big ones, are what we all active in research, or simply as interested observers, long for. We do so when trying to shape out our next steps in research and development, writing funding proposals, talking to stake holders, or to the public at large. Breakthroughs cannot be planned easily, but resilience and persistency will finally lead to success. Sometimes a breakthrough may even come from an unforeseen and unplanned direction.

Oldest known Periodic Table

The periodic table shown on the front page is owned by the University of St Andrews' School of Chemistry in Scotland and is thought to be the oldest known periodic table chart in the world. It was discovered by Dr Alan Aitken during a clear out of a storage area in 2014 in the School of Chemistry.
The chart has strong similarity to Dmitri Mendeleev's second version of 1871 and is dated by several international experts to be created between 1879 and 1886, but most probably to 1885. Their analysis is based on the chemicals like Gallium and Scandium, which were discovered in 1875 and 1879 respectively and which are included on the table, whereas Germanium, which was discovered in February 1886, is not. Further technical arguments are the German inscriptions which identify a scientific printer who lived in Vienna between 1875 and 1888, and the lithographer who died in 1890. Financial records confirm that the table was produced in Vienna in 1885 and purchased by Professor Thomas Purdie in 1888 for the School of Chemistry. The periodic table has been confirmed by Guinness World Records to be the world's oldest.

For details please look at
https://www.thesaint-online.com/2019/01/worlds-oldest-surviving-periodic-table-found-in-st-andrews/

The SPS is grateful to the Special Collections Division of the University of St Andrews for giving permission to print a reproduction of this unique document.

Photo © Bernd Braunecker

Gemeinsame Jahrestagung in Zürich, 26. - 30. August 2019
Réunion annuelle commune à Zürich, 26 - 30 août 2019

Vorwort

Die diesjährige gemeinsame Jahrestagung von SPG und ÖPG, mit Beteiligung von MaNEP, NCCR QSIT und SGN, findet an der Universität Zürich auf dem Irchel-Campus statt.

Neben der bewährten Mischung aus Plenarvorträgen, Fachsitzungen und Händlerausstellung steht auch ein öffentlicher Vortrag sowie zwei Pre-conference Workshops auf dem Programm.
Zusätzlich können sich die Teilnehmer wie gewohnt für das traditionelle Konferenzabendessen anmelden (Teilnehmerzahl beschränkt).

Im Folgenden finden Sie die Informationen für die SPG Mitglieder, 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 commune de la SSP et de l'ÖPG, avec cette année la participation de MaNEP, NCCR QSIT et SSSN, aura lieu sur le campus Irchel de l'université de Zürich.

En plus de la combinaison de conférences plénières, de sessions par domaines et de la participation d'exposants, nous aurons au programme une conférence publique ainsi que deux "pre-conference workshops".
En plus, les participants peuvent s'inscrire, comme à l'habitude, pour le traditionel dîner de la conférence (nombre de places limité).

Vous trouverez les informations s'adressant aux membres de la SSP et les principales informations sur la conférence de même 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.

Generalversammlung 2019 - Assemblée Générale 2019

Dienstag 27. August 2019, 11:30h - Mardi 27 août 2019, 11:30h
Hörsaal G 30 - Auditoire G 30

	Traktanden	Ordre du jour
1.	Protokoll der Generalversammlung vom 28. August 2018	Procès-verbal de l'assemblée générale du 28 août 2018
2.	Bericht des Präsidenten	Rapport du président
3.	Projekte	Projets
4.	Rechnung 2018, Revisorenbericht	Bilan 2018, rapport des vérificateurs des comptes
5.	Wahlen	Elections
6.	Diverses	Divers

Preisverleihungen - Cérémonies de remise des prix

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

Mittwoch 28. August 2019, 10:50h
Mercredi 28 août 2019, 10:50h
Hörsaal G 30 - Auditoire G 30

Preise für die besten Poster
Prix des meilleurs posters

Freitag 30. August 2019, 10:20h
Vendredi 30 août 2019, 10:20h
Hörsaal G 30 - Auditoire G 30

A note from the President

Once a year, I am asked to write a note to all members of the Swiss Physical Society, to reflect on the past year, and to give an outlook on the coming year. With the role of SPS to promote physics in research, development and education throughout Switzerland and not to stop at its borders, there is a special responsibility not only for physicists, but for society as a whole. Physics has a crucial role to play in the increasingly heated discussions about climate change and its severe effects on life and ecosystems at the global scale. Climate science is multi-disciplinary, with many experts from various fields working together. However, physics is at the centre of climate science. It is thermodynamics and quantum mechanics that provide insight into the absorption and emission of radiation of molecules in the atmosphere consisting of two atoms, like oxygen O_2 and nitrogen N_2, with respect to molecules with more than two atoms, like carbon dioxide CO_2, water vapour H_2O, or methane CH_4.

The larger degrees of freedom to vibrate and oscillate of molecules with three or more atoms are at the core of how these molecules are transparent to light in the visible spectrum and opaque to light in the infrared. The scientific debate has concluded on the core principals long time ago. Climate models make it possible to draw up timelines for the effects and scenarios associated with the increase in CO_2 emissions in the atmosphere. By nature, this is a more difficult task, but no model can be built that would predict no or only little impact without gross ignorance or violation of the physics at the core of any such model.

SPS takes seriously the climate debate and thus the problems that arise when striding forward in a future where the energy demand will need to be covered free of emission of CO_2 from fossil sources. Indeed, at the last SPS annual meeting, which took place from 28 to 31 August 2018 at the EPFL in Lausanne, with the participation of CHIPP, the Swiss Institute for Particle Physics, and MARVEL, the NCCR for Computational Design and Discovery of Novel Materials, special emphasis was placed on energy and climate.

In the plenary talks, the focus was on the transition in energy production and use that Switzerland must make with the Energy Strategy 2050 that was voted by the Swiss population. The progress with the international large fusion machine ITER was presented and the current state of art in climate modelling was discussed. It was obvious in that context to also give an outlook into a possible and promising scenario of an accelerator driven Thorium burning plant in an evening talk by Maurice Bourquin, which is also of high interest for the reduction of already existing nuclear waste. This specific commitment was indeed a key-driver for awarding Maurice Bourquin honorary membership in SPS for his enormous scientific achievements "… *and for his far-sighted commitment to the promotion of future thorium based nuclear reactors, which have increased efficiency and produce less long-lived waste.*" About 360 physicists and students gathered in this 2018 Annual Meeting, with a total of 283 contributions (208 orals and 75 posters).

Research in physics, either fundamental or applied, in industry, universities, or at highly specialized research laboratories, are at the forefront of new developments, that often lead to new tools and products interesting for industry, SMEs and potentially leading to new start-up companies. The Swiss Academy of Engineering Sciences (SATW) is aware of this chain from early R&D to final engineering solutions, and invited SPS to contribute to the discussions that have led to the actual version of the *Technology Outlook Report* by SATW (see p. 49). Quantum developments in many specific areas lead to new products and new markets, where new opportunities are opening up for Switzerland. Examples are quantum-based photonics, quantum-sensing devices, quantum cryptography, quantum electronics, and quantum computing. Given the complexity of the matter and the sometimes early-phase in view of developing market-ready products, pre-recognition is indeed crucial for Switzerland.

Planning the future is impossible without taking care of the next generation of young talents who will soon have important challenges to master and who will be exploring new unpaved routes to give answers to the questions of tomorrow.

SPS is supporting young physicists via the *Young Physicists Forum* (YPF). YPF fosters links across all students' associations at Swiss universities and is organizing a yearly young physicists forum event. In 2018, the topic chosen was 'Particle Physics' and was organized 4-6 May at CERN, with participants from all over Switzerland and the help of SPS. The SPS was again involved in the Swiss Physics Olympiad, SwissPhO and in the International Physics Tournament, IPT. The Swiss team was winning the final of the IPT 2018, at the Moscow Institute of Physics and Technology (MIPT), competing against teams from fifteen countries.

For the very young, *Physik im Advent*, has been taken on board by SPS. It is an online physics Advent calendar, presenting 24 small, simple experiments and physics riddles to young pupils and anyone interested during the advent period every December. The SPS is promoting and sponsoring Physik im Advent in Switzerland and is offering special prices for participants from Swiss schools. Such prizes include visits to CERN and to the Technorama Winterthur, as well as book prizes and physics gadgets to puzzle the mind.

With what we can do today, and with what an educated and savvy next generation of talents will be able doing, climate change, energy strategy 2050, artificial intelligence, quantum computing, and many more challenges can all be tackled. It needs, however, an environment which allows these talents to flourish. SPS is taking its share in contributing exactly here, with your help of being a Member, an Associate Member or a SPS Prize sponsor.

Hans Peter Beck

Protokoll der Generalversammlung vom 28. August 2018 in Lausanne
Protocole de l'assemblée générale du 28 août 2018 à Lausanne

Agenda

1. Approval of the Minutes of the General Assembly held at CERN, Geneva on 22 August 2017
2. Brief Report from the President
3. Projects
4. 2017 Finances and Auditors Report
5. Elections
6. New honorary member
7. Miscellaneous

The president opens the general assembly at 18:00.

1. Approval of the Minutes of the General Assembly held at CERN, Geneva on 22 August 2017

The protocol of the last General Assembly, published in the *SPG Mitteilungen* Nr. 55 on p. 7 is unanimously approved.

2. Brief Report from the President

The President welcomes the 63 new members to the Society, which now counts 1148 members, thereof 18 honorary members and 24 associate members. With 68 members leaving, this marks again a slight decrease with respect to last year's count. The President states that the Society is healthy and active with many projects and activities going on. However, the Society can do more and be more effective with broader support and with more members participating.

3. Projects

The President then reports on the main goals of the Society and the activities organized and/or supported in 2017. Besides the organization of the main annual event, the Society is organizing smaller, regional seminars and symposia, often together with the help of regionally embedded associations. Examples are the Joseph Fourier Symposium (together with PGZ) or the Jost Bürgi Symposium (together with the Jost Bürgi foundation, VSMP and SAG).

Promoting the youth is important for the Society, which it does via sponsoring various events targeted to young talents like the *Swiss Physics Olympiad*, the *Swiss Young Physicists' Tournament*, the *International Physicists' Tournament*, etc. Further by supporting the Swiss *Young Physicists Forum*, the EPS *Young Minds*, and without forgetting the very young where the *Physics in Advent* is exemplary for inspiring and raising interest of the next generation.

The Society is further promoting individual physicists by giving awards to young and gifted minds. Six young physicists are awarded this year with SPS Prizes sponsored by ABB, IBM, Oerlikon Surface Solutions, METAS, and COMSOL, respectively.

Confirmed physicists are awarded with the *Charpak-Ritz Prize* which is bestowed jointly by the French Physical Society and the Swiss Physical Society. In 2018, the Charpak-Ritz award was given to Roland Horisberger.

IBM Rüschlikon has been selected as EPS Historical site. The inauguration and the unveiling of the commemorative plaque took place on 26 September 2017, which is reported on page 53 of the *SPG Mitteilungen* Nr. 53. A fourth EPS historical site in Switzerland has been announced to be the High Altitude Research Station Jungfraujoch, where the ceremony will take place on February 8, 2019.

The Physics and Society brochure, reporting on the importance of physics to the Swiss economy, innovation and society is a study that is sponsored by SCNAT and commissioned by the Swiss Physical Society. The study is well underway and results shall be published by the end of the year.

The Society is informing its members with its journal, with three issues annually and the monthly newsletter, which has become well-established within only one year of its existence.

4. 2017 Finances and Auditors Report
The 2017 annual financial report is presented by the treasurer, Dr. Pascal Ruffieux (see page 9 of the *SPG Mitteilungen* Nr. 55). 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 10.

A loss of 3'325.75 Swiss Francs is accounted for. The treasurer explains that the benefits or losses depend mostly on the success of our annual meetings. In our 2017 annual meeting at CERN and Geneva, we had higher costs that could not easily be recovered without asking for higher participation fees. We wanted to avoid a raising of the fee as much as possible.
The annual financial report is approved unanimously by the General Assembly which gives discharge to the Board.

5. Elections
The President thanks the members of the committee who have reached the end of their term and, according to our statutes, cannot be re-elected, namely: Minh Quang Tran (Vice-president), Antoine Pochelon (Secretary), Pascal Ruffieux (Treasurer), Jan Lacki (History of Physics), Gian Michele Graf (Theoretical Physics), Stéphane Goyette (Earth, Atmosphere and Environmental physics), Stephan Brunner (Applied Physics).
P. Paruch (KOND) resigned already on 6 September 2017.

The following committee members have reached the end of their current mandate, can be re-elected for a further term according to our statutes, and are re-elected unanimously by the General Assembly:
- Giovanni Dietler (Biophysics, Medical Physics and Soft Matter)
- Laura Heyderman (KOND)
- Céline Lichtensteiger (Education and Promotion of Physics)
- Andreas Schopper (TASK)
- Pierangelo Gröning (Auditor)

With Prof. Dr. Claus Beisbart being proposed to chair the section 'History of Physics' it is also proposed that the section shall undergo a broadening of its scope and will from now on be named '*History and Philosophy of Physics*'. This new section name is unanimously endorsed by the General Assembly.

The following persons are elected unanimously by the General Assembly (* = 1 vote against):
- Vice-president: Dr. Bernhard Braunecker (for 1 year)
- Secretary: Dr. Lukas Gallmann (for 2 years)
- Treasurer: Dr. Dirk Hegemann (for 2 years)
- KOND: Prof. Dr. Henrik Rønnow (for 2 years)
- Applied Physics: Prof. Dr. Lenny Rivkin (for 2 years) and Dr. Laurie Porte (for 2 years)
- Theoretical Physics: Prof. Dr. Philippe Jetzer (for 2 years)
- Education and Promotion of Physics: Prof. Dr. Andreas Müller (for 2 years)
- History and Philosophy of Physics: Prof. Dr. Claus Beisbart * (for 2 years)

No successor could be identified for Stephane Goyette, who is chairing the Earth, Atmosphere and Environmental Physics section. Experts in the field have been contacted at ETHZ, EPFL, University of Bern, etc., but have been reluctant to commit themselves. The main reason is that these people are engaging already in many associations, expert bodies, discussion groups, or in other more interdisciplinary learned societies, e.g. ProClim, etc.

The General Assembly agrees to prolongate Stephane Goyette's mandate for one year allowing to find a successor.

6. New honorary member
The General Assembly agrees unanimously to bestow Prof. Maurice Bourquin the title of Honorary Member of the SPS in recognition of 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.

7. Varia
The President states that the Swiss Physical Society is a 'learned society' with goals and interests to link and interlink physicists in Switzerland and beyond. He stresses that physicists are: professionals, teachers, undergraduate and graduate students, postdocs who are directly active in physics in academia, at research institutes, in industry, at schools, or anyone with a deeper interest in physics.

The President also repeats a statement he made in the *SPG Mitteilungen* Nr. 55:

> *The strength of the Society 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.*

The President closes the meeting at 18:55.

Statistik - Statistique

Neue Mitglieder 2018 - Nouveaux membres en 2018

Achermann Marc, Bebié Pascal Laurent, Beisbart Claus, Benelli Angela, Berruto Gabriele, Bourquin Maurice, Bracher David M., Campi Davide, Chernyavskaya Nadezda, Courret Gilles, De Gennaro Riccardo, Drs Jakub, Frison Ruggero, Galland Christophe, Gallmann Lukas, Gambardella Pietro, Hayakawa Daiki, Hegemann Dirk, Heydari Mehdi, Hildebrand Baptiste, Jucker Stefanie, Kirsebom Veronica Sølund, Konishi Hideki, Marschall Raphael, Materzanini Giuliana, Micheletti Paolo, Murello Anna, Nattino Francesco, Nicholson Christopher, Ortu Antonio, Patthey Luc, Peri Valerio, Perrin Gaël, Poggi Riccardo, Porta Sergio, Porte Laurie, Pospisil Christina, Psaroudaki Christina, Rahi Sahand Jamal, Rieger Carla, Rienäcker Ingo, Röhrken Markus, Romero Imelda, Ronetti Flavio, Rossi Markus, Rossi Thomas, Shehzad Atif, Simoncelli Michele, Skjaervoe Sandra Helen, Spoor Humphrey Louis, Stocker Francesca, Tal Aleksei, Testa Paolo, Vecsei Pascal Marc, Weber Manuel, Wenger Quentin, Wittmann Angela, Wüthrich Johannes, Zagozdzinska-Bochenek Agnieszka Anna

Ehrenmitglieder - Membres d'honneur

Prof. Hans Beck (2010)
Dr. J. Georg Bednorz (2011)
Prof. Jean-Pierre Blaser (1990)
Prof. Jean-Pierre Borel (2001)
Prof. Maurice Bourquin (2018)
Prof. Jean-Pierre Eckmann (2011)
Prof. Charles P. Enz (2005)
Prof. Hans Frauenfelder (2001)
Prof. Jürg Fröhlich (2011)
Prof. Hermann Grunder (2001)
Prof. Martin C. E. Huber (2011)
Prof. Piero Martinoli (2016)
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 (31.12.2018)

Ordentliche Mitglieder	658
Doktoranden	59
Studenten	35
Doppelmitglieder DPG, ÖPG, APS oder VSMP	164
Doppelmitglieder PGZ	58
Mitglieder auf Lebenszeit	117
Assoziierte Mitglieder	24
Bibliotheksmitglieder	2
Ehrenmitglieder	18
Beitragsfreie (Korrespondenz)	6
Total	**1141**

Jahresrechnung 2018 - Bilan annuel 2018

Bilanz per 31.12.2018		
	Aktiven	**Passiven**
Umlaufsvermögen		
Postscheckkonto	19594,44	
Bank - UBS 230-627945.M1U	32692,94	
Debitoren - Mitglieder	2907,50	
Debitoren - SCNAT/SATW u.a.m.	123424,60	
Anlagevermögen		
Beteiligung EP Letters	15840,00	
Mobilien	1,00	
Fremdkapital		
Mobiliar		1,00
Mitglieder Lebenszeit		69958,25
Transitorische Passiven		15568,92
Eigenkapital		
Vefügbares Vermögen		90623,62
Total Aktiven/Passiven	**194460,48**	**176151,79**
Gewinn		**18308,69**
Summe	**194460,48**	**194460,48**
Verfügbares Vermögen per 31.12.18 nach Gewinnzuweisung:		108932,31

Erfolgsrechnung per 31.12.2018			
	Aufwand		**Ertrag**
Gesellschaftsaufwand		**Ertrag**	
EPS - Membership	13558,64	Mitgliederbeiträge	95425,24
SCNAT - Membership	7686,00	Sponsorbeiträge	150,00
SPG Preise	85,15	Inserate/Flyerbeilagen SPG Mitteilungen	5334,90
SATW-Mitgliederbeitrag	1750,00	Aussteller	13720,95
		Verkauf Broschüren	28,00
SCNAT Verpflichtungskredite		Zinsertrag	3,10
SPG Jahrestagung	19201,35	Ertrag aus EP Letters Beteiligung	11436,55
Schweizer Physik Olympiade	4000,00		
SPG Young Physicist's Forum	5903,44	**SCNAT Verpflichtungskredite**	
Lehrerfortbildungsevent	1268,35	SPG-Jahrestagung (SCNAT)	15000,00
International Physics Tournament	1810,18	Schweizer Physik Olympiade	3500,00
Projet Physique et Société	2154,00	SPG Young Physicist's Forum	3500,00
SPG Bulletin/Tagungsband (SCNAT)	10395,10	Lehrerfortbildungsevent 2014 ff	5000,00
SCNAT Periodika (SPG Mitteilungen, Druckkosten)	19580,66	SPG Defizitgarantie Jahrestagung	10000,00
SCNAT Internationale Zusammenarbeit	2502,10	SPG/APS FECS Studentenaustausch	4000,00
SCNAT Swiss Young Phys. Tournament	5500,00	International Physics Tournament	4000,00
MAP Brochure "Physics and the Swiss Society"	25201,78	Projet Physique et Société	2000,00
MAP "Physics for Public"; Newsletter	6200,00	SPG Bulletin/Tagungsband (SCNAT)	5000,00
		Periodika (SPG-Mitteilungen, Druckkosten) (SCNAT)	5000,00
Betriebsaufwand		Internationale Zusammenarbeit (SCNAT)	2000,00
Löhne	26422,43	SCNAT Swiss Young Phys. Tournament	4000,00
Sozialleistungen, berufl. Vorsorge, Versicherung	16138,95	MAP Brochure "Physics and the Swiss Society"	23000,00
Porti/Telefonspesen/WWW- und PC-Spesen	918,75	MAP "Physics for Public"; Newsletter	6000,00
Versand (Porti Massensendungen)	5271,19		
Unkosten	3446,13		
Büromaterial	4766,40		
Bankspesen	336,33		
Debitorenverluste Mitglieder	1473,00		
Debitorenverlust SCNAT/SATW u.a.m.	14220,12		
Total Aufwand/Ertrag	**199790,05**		**218098,74**
Gewinn	**18308,69**		
Summe	**218098,74**		**218098,74**

Revisorenbericht zur Jahresrechnung 2018

Die Jahresrechnung 2018 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, 15.03.2019

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

Allgemeine Tagungsinformationen - Informations générales sur la réunion

Konferenzwebseite und Anmeldung

Alle Teilnehmeranmeldungen werden über die Konferenzwebseite vorgenommen.

www.sps.ch

Anmeldeschluß: 1. August 2019

Tagungsort

Universität Zürich, Winterthurerstr. 190, Hörsaalgebäude Geschoss G ("Lichthof")

Tagungssekretariat

Das Tagungssekretariat befindet sich in der Lichthof-Halle beim Durchgang zur Mensa, direkt gegenüber des Hörsaals G 30.

Öffnungszeiten:

Mo 26.08.	13:00 - 17:00
Di 27.08 - Do 29.08.	08:00 - 18:00
Fr 30.08.	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 Montag Nachmittag für die Anmeldung zu nutzen. So können Sie am Dienstag direkt ohne Wartezeiten die Vorträge besuchen.

Hörsäle

In allen Hörsälen stehen Projektoren und MacOS Rechner zur Verfügung. Sie können auch Ihre eigenen Mobilrechner anschließen. Bringen Sie ggf. Adapter und USB Stick mit.

Postersession

Die Postersession findet am Mittwoch Abend sowie am Donnerstag während der Mittagspause in der Lichthof-Halle statt. Bitte bringen Sie Befestigungsmaterial (nur Reissnägel) 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.

Die 3 besten Poster werden am Freitag um 10:20h in einer kleinen Zeremonie ausgezeichnet.

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 leider nicht akzeptiert werden.

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 2019

Lieu de la conférence

Universität Zürich, Winterthurerstr. 190, bâtiment des auditoires, étage G ("Lichthof")

Secrétariat de la conférence

Le secrétariat de la réunion se trouve dans le hall du Lichthof, près du couloir vers la mensa, vis-à-vis de l'auditoire G 30.

Heures d'ouverture:

Lundi 26.8	13:00 - 17:00
Mardi - Jeudi 27.8 - 29.8	08:00 - 18:00
Vendredi 30.8	08:00 - 11:30

Tous les participants doivent en premier lieu se présenter 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 lundi après-midi afin d'éviter des temps d'attente inutiles le mardi matin.

Auditoires

Les auditoires disposent tous d'un projecteur multimédia (beamer) et d'un ordinateur MacOS. Il est aussi possible de connecter votre ordinateur portable.Veuillez apporter les éventuels accessoires tels qu'adapteurs ou clé USB.

Séance posters

Les posters seront présentés dans la halle du Lichthof le mercredi soir et pendant la pause de midi du jeudi. Veuillez amener vous-même le matériel nécessaire pour fixer les posters (seulement des punaises). Les panneaux de posters seront numérotés selon le numéro de l'abstract indiqué dans le programme. Tous les posters doivent rester installés pendant les deux jours.

Dimension maximale: A0, format portrait.

Les 3 meilleurs posters seront récompensés au cours d'une petite cérémonie le vendredi à 10:20h.

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 peuvent malheureusement pas être acceptées.

Preise gültig bei Zahlung bis 1. August - Prix valable pour des paiements avant le 1er août	
Kategorie - Catégorie	**CHF**
Mitglieder von SPG, ÖPG - Membres de la SSP, ÖPG	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.-**

ACHTUNG: Tagungsgebühren können nicht zurückerstattet werden.

Kaffeepausen, Mittagessen

Kaffeepausen, Apéro und Lunchbuffet (Donnerstag) finden in der Halle bei der Händlerausstellung statt. Diese Leistungen sind in der Konferenzgebühr enthalten.
Für das Mittagessen an den anderen Tagen können die die Mensa sowie umliegende Restaurants genutzt werden.

Konferenz-Abendessen

Das Abendessen findet am Donnerstag im "Zunfthaus zur Meisen" im Anschluß an die Parallelsessions statt. Der Preis beträgt CHF 80.- pro Person (beinhaltet 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 2019. 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, und schicken es ausgefüllt an das SPG-Sekretariat zurück.

(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 und Zimmerreservation aus unserem Tagungskontingent finden Sie auf unserer Webseite
https://www.sps.ch/events/gemeinsame-jahrestagung-2019/anreise-und-unterkunft/

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

Pauses café, repas de midi

Pauses café, apéro ainsi que le buffet de midi (jeudi) se dérouleront dans le hall près des exposants. Ces prestations sont inclues dans les frais d'inscription.
Pour les autres repas de midi, les mensas du campus ainsi que les restaurants situés aux alentours pourront être utilisés.

Dîner de la conférence

Le dîner se tiendra le jeudi soir dans le "Zunfthaus zur Meisen", après les séances orales. Le prix est de CHF 80.- par personne (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 2019. 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* , et renvoyez-le dûment rempli 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 sur l'arrivée et la réservation des chambres du contingent de notre réunion se trouvent sur
https://www.sps.ch/en/events/joint-annual-meeting-2019/arrival-and-accommodation/

Aussteller - Exposants

Allectra GmbH, DE-16587 Schönfliess
www.allectra.com

COMSOL Multiphysics GmbH, 8005 Zürich
www.comsol.com

Dr. Eberl MBE-Komponenten GmbH,
DE-71263 Weil der Stadt
www.mbe-komponenten.de

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

GMP SA, CH-1020 Renens
www.gmp.ch

Hiden Analytical Ltd., UK-Warrington, WA5 7UN
www.hidenanalytical.com

Lumibird, FR-22300 Lannion
www.lumibird.com

MaTeck GmbH, DE-52428 Jülich
mateck.com

mechOnics AG, DE-81825 München
www.mechOnics.de

Scienta Omicron GmbH, DE-65232 Taunusstein
www.scientaomicron.com

Springer Verlag GmbH, DE-69121 Heidelberg
www.springer.com

teltec systems AG, 5620 Bremgarten
www.teltec.ch

VacGen Ltd., UK-Hailsham, BN27 4EL
www.vacgen.com

VACOM, DE-07751 Großlöbichau
www.vacom.de

Vaqtec-Scientific, DE-13189 Berlin
www.vaqtec-scientific.com

World Scientific Publishing Co Pte Ltd.,
DE-80333 München
www.worldscientific.com

Übersichtsplan Campus Irchel Zürich

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 19:00 - 20:30 (mit Apéro) sowie am Donnerstag von 12:30 - 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 19:00 à 20:30 (avec apéro) ainsi que le jeudi de 12:30 à 14:00 (avec buffet de midi).
- (p) = orateur de la session plénière, (i) = orateur invité

Plenary Session

Tuesday, 27.08.2019, Room G 30

Time	ID	PLENARY SESSION I
10:00		OFFICIAL CONFERENCE OPENING
		Chair: NN
10:10	1	**Artificial intelligence in materials science - hype or revolution?** *Claudia Draxl (p)*
		Chair: Philippe Jetzer, Uni Zürich
10:50	2	**Understanding Giant Planets** *Ravid Helled (p)*
11:30		***General Assemblies of SPS and ÖPG ****
12:30		***Lunch***
14:00		***Topical Sessions***
		PUBLIC LECTURE *Chair: Andreas Fuhrer, IBM Rüschlikon*
19:30	3	**The Quantum Way of Doing Computations (New Technologies for the Information Age)** *Rainer Blatt (p)*
20:45		***END***

Wednesday, 28.08.2019, Room G 30

Time	ID	PLENARY SESSION II *Chair: Peter Korczak*
09:00	4	**The Future of Computing** *Heike Riel (p)*
		Chair: Emmerich Kneringer, Uni Innsbruck
09:40	5	**Galactic High-Energy Particle Accelerators** *Olaf Reimer (p)*
10:20		***Coffee Break***
10:50		***Award Ceremony***
		Chair: Hans Peter Beck, Uni Bern
11:50	6	**The Einstein-Podolsky-Rosen paradox in a many-body system** *Matteo Fadel (i)*
		Chair: Gottfried Strasser, TU Wien
12:20	7	**Many-body localization, thermalization, and entanglement** *Maksym Serbyn (i)*
12:50		***Lunch***
14:00		***Topical Sessions***
19:00		***Postersession with Apéro***
20:30		***END***

Thursday, 29.08.2019, Room G 30

Time	ID	PLENARY SESSION III *Chair: Philipp Treutlein, Uni Basel*
09:00	8	**Probing nanoscale magnetism using single spin magnetometry** *Patrick Maletinsky (p)*
		Chair: NN
09:40	9	**Synthetic holography with spatial light modulators for biophotonics applications** *Monika Ritsch-Marte (p)*
10:20		***Coffee Break***
		Chair: Andreas Schopper, CERN
10:50	10	**First electron acceleration in AWAKE, the proton driven plasma wakefield acceleration experiment** *Edda Gschwendtner (p)*
		Chair: Minh Quang Tran, EPFL
11:30	11	**A brief history of polariton quantum fluids** *Benoît Deveaud (i)*
		Chair: Henrik M. Rønnow, EPFL
12:00	12	**Guest dynamics in methane and hydrogen clathrate hydrates under high pressure** *Umbertoluca Ranieri (i)*
12:30		***Postersession with Lunchbuffet***
14:00		***Topical Sessions***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 30.08.2019, Room G 30

Time	ID	PLENARY SESSION IV *Chair: NN*
09:00	13	**Compound semiconductor nanowires for next generation solar cells and quantum technologies** *Anna Fontcuberta i Morral (p)*
		Chair: Bernhard Braunecker
09:40	14	**Economic Materials Design for Clean Energy** *Greta R. Patzke (p)*
10:20		***Poster Award Session***
10:40		***Coffee Break***
11:15		***Topical Sessions***
13:45		***CONFERENCE END***

** in Room G 91*

On the Origin of the Elements - 150 Years of the Periodic Table

This session has been organised together with SCNAT. Further details on page 25.

Friday, 30.08.2019, Room G 30

Time	ID	On the Origin of the Elements - 150 Years of the Periodic Table *Chair: Claus Beisbart, Uni Bern*
11:15	31	**Celebrating 150 years Periodic Table, historical remarks and current situation** *Heinz W. Gäggeler (i)*
12:00	32	**Big Bang and stars, two hot environments for making elements** *Georges Meynet (i)*
12:45	33	**Stellar Explosions and the Heavy Elements** *Friedrich-Karl Thielemann (i)*
13:30		***END***

Quantum and Artificial Intelligence: New Jobs for Physicists in Emergent Industries

Thursday, 29.08.2019, Room G 60

Time	ID	Quantum and Artificial Intelligence: New Jobs for Physicists in Emergent Industries *Chair: Thilo Stöferle, IBM Rüschlikon*
14:00	51	**Introduction** *Thilo Stöferle*
14:10	52	**Benchmarking next-generation ion-trap quantum computers** *Thomas Monz (i)*
14:30	53	**Can AI pass the exam for human pilots?** *Luuk van Dijk (i)*
14:50	54	**Quantum Computing at Microsoft** *Damian Steiger (i)*
15:10	55	**AI assisted Scalable Knowledge Ingestion for Automated Discoveries** *Peter W. J. Staar (i)*
15:30	56	**Applying Quantum Computing to Quantum Chemistry** *Jan Reiner (i)*
15:50	57	**Industrial AI at work: Cyber Physical Production Systems and Cognitive Services for Power Line Systems at Siemens Austria** *Herwig Schreiner (i)*
16:10	58	**Sensing with Diamonds** *Gabriel Puebla-Hellmann (i)*
16:30		***Coffee Break***
		Chair: Andreas Fuhrer, IBM Rüschlikon
17:00	59	**Zurich Instruments and the Race for the Quantum Computer** *Sadik Hafizovic (i)*
17:20	60	**Quantum and AI research: challenges for physicists at Bosch** *David Reeb (i)*
17:40	61	**Quantum Technologies: from basic research to industry** *Stephan Ritter (i)*
18:00	62	**Quantum meets AI @ Google** *Frank Ruess (i)*
18:20		***END***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

KOND

Tuesday, 27.08.2019, Room G 95

Time	ID	KOND I: Magnetism *Chair: NN*
14:00	101	**Spin fluctuation induced Weyl semimetal state in the paramagnetic phase of $EuCd_2As_2$** *Junzhang Ma*
14:15	102	**Spin wave modes in Permalloy micro stripes using time-resolved scanning transmission X-ray microscopy** *Andreas Ney*
14:30	103	**Spin-orbitronics of wurtzite semiconductors** *Margherita Matzer*
14:45	104	**Combining high-resolution Atomic Force Microscopy with Scanning Tunneling Microscopy induced light emission on single molecules** *Katharina Kaiser*
15:00	105	**Reduced Density Matrix Functional Theory for Superconductors** *Carlos L. Benavides-Riveros*
15:15	106	**Multiple Coulomb Phase in the Fluoride Pyrochlore $CsNiCrF_6$** *Tom Fennell*
15:30	107	**Spatially resolved thermoelectric effects in semiconductor-metal heterostructures** *Nadine Gächter*
15:45	108	**Signatures of event horizon physics in a condensed matter system** *Maxime Jacquet*
16:00	109	**Spin Hamiltonian and Dimensional Reduction in $(Ba,Sr)CuSi_2O_6$** *Stephan Allenspach*
16:15	110	**Progressive lifting of the ground-state degeneracy of the long-range kagome Ising antiferromagnet** *Jeanne Colbois*
16:30		***Coffee Break***
19:30		***Public Lecture***

Wednesday, 28.08.2019, Room G 95

Time	ID	KOND II: Low-dimensional systems *Chair: NN*
17:00	111	**Spin-Orbital Excitations in Ca_2RuO_4 revealed by Resonant Inelastic X-Ray Scattering** *Lakshmi Das*
17:15	112	**Disentangling charge and spin excitations and their evolution in the phase diagram of $Bi_2Sr_2CaCu_2O_{8+x}$ superconducting cuprate** *Wenliang Zhang*
17:30	113	**High-speed domain wall racetracks in a magnetic insulator** *Saül Vélez*
17:45	114	**Static and dynamic magnetic coupling in $Co_xZn_{1-x}O$–Permalloy heterostructures** *Verena Ney*
18:00	115	**La_2NiMnO_6 thin films grown by off-axis RF magnetron sputtering** *Gabriele de Luca*

18:15	116	**Tuning the electronic structure of $LaNiO_3$ thin films** *Jasmin Jandke*
18:30	117	**Electron-lattice interaction boost on the verge of metal-insulator transition in oxides** *Vladimir Strocov*
18:45	118	**Giant Magnetoelectric Response and Cross-Caloric Effect Around a Tetracritical Point in Multiferroic $SrMnO_3$** *Alexander Edström*
19:00		***Postersession with Apéro***
20:30		

Thursday, 29.08.2019, Room G 95

Time	ID	KOND III: Oxides *Chair: NN*
17:00	121	**Investigation of topological channels in twisted bilayer graphene** *Peter Rickhaus*
17:15	122	**Temperature dependent photoemission study of the charge-ordered phases in $IrTe_2$** *Maxime Rumo*
17:30	123	**Van der Waals magnetic materials: growth and characterization** *Dumitru Dumcenco*
17:45	124	**ARPES study of few layer black phosphorus crystals** *Florian Margot*
18:00	125	**Three Dimensional Lithography on Silicon Nanowire Arrays - An Electrochemical Approach** *Gilles Bourret*
18:15	126	**Optically active nanowires nucleated via a novel focused ion beam implantation method** *Suzanne Lancaster*
18:30	127	**Electrostatically-Defined Quantum Dots in Bilayer Graphene** *Annika Kurzmann*
18:45	128	**Imaging Disorder in a Bilayer-Graphene Channel** *Carolin Gold*
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 30.08.2019, Room G 95

Time	ID	KOND IV: Optical phenomena *Chair: NN*
11:15	131	**μ-fluidic sensing with a quantum cascade lab-on-a-chip** *Florian Pilat*
11:30	132	**Theoretical study of the intra-cavity dynamics behind phase locking of quantum cascade laser frequency combs** *Nikola Opačak*
11:45	133	**Dual-comb spectrometer by single Doppler shifted MIR QCL frequency comb** *Mehran Shahmohammadi*
12:00	134	**Picosecond pulses from mid-infrared quantum cascade lasers** *Johannes Hillbrand*
12:15	135	**Interband and quantum cascade laser frequency combs: From fundamentals towards monolithic spectrometers** *Benedikt Schwarz*
12:30	136	**Thermoelectrically cooled THz quantum cascade laser operating up to 210 K** *Lorenzo Bosco*
12:45	137	**Ring Interband Cascade Lasers Running in Continuous Mode Operation** *Hedwig Knötig*
13:00	138	**Optoelectronic devices based on non-polar ZnO/ZnMgO quantum wells** *Borislav Hinkov*
13:15	139	**n-type Ge/SiGe Quantum Cascade Devices for THz Electroluminescence** *David Stark*
13:30	140	**Superfluorescence from lead halide perovskite quantum dot superlattices** *Michael A. Becker*
13:45		***END***

ID	KOND Poster
151	**Time-resolved tunneling between Landau levels in a weakly coupled quantum dot in the integer and fractional quantum Hall regimes** *Marc P. Röösli*
152	**Characterization of Tannin-Furanic Foams by Raman Spectroscopy** *Maurizio Musso*
153	**Optimizing the mechanical performance of 3D-printed wood-fiber-reinforced biocomposites by adjusting the infill orientation** *Maurizio Musso*
154	**Finite-element mesh generation and simulation of magnetization dynamics in a three-dimensional artificial spin structure** *Sebastian Gliga*
155	**Ultra-low electronic temperature measurement in a cryogen-free dilution refrigerator with an ^4He immersion cell** *Giorgio Nicolí*
156	**Weyl Orbits Without an External Magnetic Field** *Tena Dubcek*
157	**Spin States in a Gate-Defined Quantum Point Contact in an InAs Two-Dimensional Electron Gas** *Christopher Mittag*
158	**Topological scars** *Seulgi Ok*
159	**The polar distortion and its relation to magnetic order in multiferroic $HoMnO_3$** *Nazaret Ortiz*
160	**Spin-strain effects in the frustrated magnet $Tb_2Ti_2O_7$** *Yulia Gritsenko*
161	**Ground state crossings on spin clusters from tunneling interference** *Ivo Aguiar Maceira*
162	**Bulk electronic and local magnetic properties of semiconducting 2H-molybdenum ditelluride** *Jonas Krieger*
163	**Magnetism in semiconducting molybdenum dichalcogenides** *Zurab Guguchia*
164	**Towards the fabrication of ZnO-based quantum cascade lasers with double-metal waveguides** *Hanh Hoang*
165	**Magnetic order on a Kagome-like lattice** *Virgile Favre*
166	**$RNiO_3$ (R = La_xPr_{1-x} ; x = 0.1 to 1.0) perovskites at the extreme: Where Metal-Insulator Transition reaches 0 K** *Yannick Maximilian Klein*
167	**Temperature-driven Topological Phase Transition and Intermediate Dirac Semimetal Phase in $ZrTe_5$** *Bing Xu*
168	**Sparse Sampling in Scanning Probe Microscopy** *Jens Oppliger*

169	**Orbit of an oscillating scanning probe microscope tip** *Lorena Niggli*
170	**Magnetic and superconducting properties of the iron arsenide pnictides $Ba_{1-x}Na_xFe_2As_2$ as seen by infrared spectroscopy** *Evgeniia Sheveleva*
171	**Growth of Crystal Phase Engineered Planar Films of III-V Semiconductors** *Philipp Staudinger*
172	**Heating and dynamics in Floquet conformal field theory** *Bastien Lapierre*
173	**Size Dependent Lattice Expansion in nanocrystalline BCC Tantalum: Unusual Superconductivity and Magnetism** *Subhrangsu Sarkar*
174	**Quantum Mechanical Simulations of sub-atomic resolution differential phase contrast imaging of magnetic materials** *Alexander Edström*
175	**Neuromorphic Computing with coupled VO_2 oscillators** *Elisabetta Corti*
176	**Rf modulation of surface-emitting mid-IR ring DFB Quantum Cascade Lasers** *Borislav Hinkov*
177	**Homogeneous, bound-to-continuum THz Quantum Cascade Laser: 1.65 THz spectral bandwidth and RF injection locking** *Andres Forrer*
178	**A polarization-rotating Vivaldi antenna for improved far-field patterns of broadband terahertz quantum cascade lasers** *Urban Senica*
179	**Microfabrication of devices for the measurement of non-local charge transport** *Jacopo Oswald*
180	**Elucidating the impact of B incorporation in GaAs through nanowire growth** *Hermann Detz*
181	**Dispersion measurements of Terahertz Quantum Cascade Fabry-Perot cavities and VECSELs** *Tudor Olariu*
182	**Magnetic field-effect on the charge order in underdoped $YBa_2Cu_3O_y$.** *Fryderyk Lyzwa*
183	**Stability of the Q-phase of $CeCoIn_5$ in the presents of localized magnetic impurities** *Junying Shen*
184	**The sound of the Q-phase in $CeCoIn_5$ - an ultrasound investigation** *Damaris Tartarotti Maimone*
185	**Polytypism in the $NbS_2 \pm \Delta$ system** *Catherine Witteveen*

Surfaces, Interfaces and Thin Films

Tuesday, 27.08.2019, Room G 95

Time	ID	SURFACES, INTERFACES AND THIN FILMS I: SURFACE CHEMISTRY *Chair: Wolfgang Werner, TU Wien*
17:00	201	**Probing solid-liquid interfaces with tender X-rays** *Zbynek Novotny*
17:30	202	**Electron Dynamics on $Cu_2O(111)$ Probed with Time-Resolved Photoemission** *Lisa Grad*
17:45	203	**Characterization of Sb_2Se_3 single crystal surfaces for photocatalysis** *Roberta Totani*
18:00	204	**Nanovoids in hexagonal boron nitride monolayer** *Huanyao Cun*
18:15	205	**Single-domain growth of h-BN on a "quasi-liquid" Pt(110) surface** *Dominik Steiner*
18:30	206	**On-surface synthesis and substrate transfer of aligned graphene nanoribbons** *Rimah Darawish*
18:45	207	**Origin of enantio- and regioselectivity for the PdGa (111)-supported Huisgen reaction: experiment and theory** *Martina Danese*
19:00		
19:30		***Public Lecture***

Wednesday, 28.08.2019, Room G 95

Time	ID	SURFACES, INTERFACES AND THIN FILMS II: MOLECULAR ADSORPTION AND ADVANCED METHODS *Chair: Zbynek Novotny, Uni Zürich*
14:00	211	**Investigating charge-state transitions of molecules on insulating films by atomic force microscopy** *Shadi Fatayer (i)*
14:30	212	**Energy-level Alignment for Tetraphenylporphyrins on Oxide surfaces** *Silviya Ninova*
14:45	213	**Charge Transfer at Metal-Organic Interfaces Promoted by Dielectric Interlayers: a Comparison of Different Organic Molecular Monolayers on the MgO/Ag(100)-Surface** *Christian S. Kern*
15:00	214	**Aurophilic interactions on surfaces** *Thorsten Wagner*
15:15	215	**Fusion of alkyl groups to form phenyl rings: a new on-surface reaction** *Amogh Kinikar*
15:30	216	**On-surface synthesis and characterization of N-doped undecacene: a combined experimental and theoretical study** *Kristjan Eimre*
15:45	217	**Bloch-wave damping by Plasmons in Highly Oriented Pyrolitic Graphite** *Wolfgang Werner*
16:00	218	**Direct measurements of contact resistance in MoS_2-based thin film transistors via Kelvin probe force microscopy** *Aleksandar Matkovic*
16:15	219	**InteractiveXRDFit: a new tool to simulate and fit X-ray diffractograms of oxide thin films and heterostructures** *Céline Lichtensteiger*
16:30		***END; Coffee Break***
19:00		***Postersession with Apéro***
20:30		

ID	SURFACES, INTERFACES AND THIN FILMS POSTER
231	**Material characterization with positrons - Unique and complementary insights** *Lars Gerchow*
232	**Modulated magnetic-field susceptibility measurements for in-situ studies of organic/ferromagnetic interfaces** *Aleksander Brozyniak*

233	**Role of the surface structure in determining ferroelectric polarization direction** *Chiara Gattinoni*
234	**Probing the origin of ferromagnetic stability in LSMO/SRO** *Anna Zakharova*
235	**Development of a Low-Temperature Scanning Field Emission Microscope with Spin Polarization Analysis** *Ann-Katrin Thamm*
236	**Electronic properties of hexagonal Boron Nitride on Pt(110)** *Marco Thaler*
237	**Exploring the electron transfer at cuprate/manganite interfaces** *Roxana Gaina*
238	**Detection and Analysis of Low-Energy Electrons by means of a Miniature Energy Analyser: Experimental Characterisation and Preliminary Results** *Alessandra Bellissimo*
239	**Multi-parameter Analysis of Genesis and Evolution of Secondary Electrons in the Low-Energy Regime** *Alessandra Bellissimo*
240	**Solvent induced crystallization and physical properties of silk sericin film** *In Chul Um*

Nuclear, Particle and Astrophysics (TASK)

Tuesday, 27.08.2019, Room G 55

Time	ID	TASK I: Precision Physics at Low Energy *Chair: Klaus Kirch, ETH Zürich*
14:00	301	**Analysis of the hyperfine splitting of the 5 → 4 transitions in muonic Re-185 and Re-187** *Stergiani Marina Vogiatzi*
14:15	302	**Multi-pass optical cavity for the measurement of the hyperfine splitting in muonic hydrogen** *Miroslaw Marszalek*
14:30	303	**Design of the detection system for the measurement of the hyperfine splitting in muonic hydrogen** *Laura Sinkunaite*
14:45	304	**Thin-Disk Laser for the Measurement of the Hyper-fine-Splitting in Muonic Hydrogen** *Manuel Zeyen*
15:00	305	**Ramsey spectrometer for matter-antimatter experiments** *Amit Nanda*
15:15	306	**Recent Measurements on Vacuum Muonium Production** *Narongrit Ritjoho*
15:30	307	**Data Analysis for the PSI Neutron Electric Dipole Moment Experiment** *Nicholas Ayres*
15:45	308	**Next generation active magnetic shielding for n2EDM** *Solange Emmenegger*
16:00	309	**Development of a caesium magnetometer array for the n2EDM experiment** *Duarte Pais*
16:15	310	**Johnson-Nyquist Noise Studies for the n2EDM Experiment at PSI** *Pin-Jung Chiu*
16:30		***Coffee Break***
17:00	311	**Momentum Spectroscopy of Neutron Beta Decay Products with NoMoS** *Waleed Khalid*
17:15	312	**Kaonic Deuterium X-Ray Measurements with the SIDDHARTA-2 Apparatus at DAFNE** *Marlene Tüchler*
		TASK II: Dark Matter and Neutrino I *Chair: Paolo Crivelli, ETH Zürich*
17:30	313	**Beyond colliders: exploring the dark sector with beam dumps** *Elena Graverini*
18:00	314	**Dark sectors searches at high-intensity colliders** *Federico Leo Redi*
18:15	315	**Search for long-lived heavy neutrinos with the CMS Experiment** *Vinzenz Stampf*
18:30	316	**NA64 - Search for dark matter at CERN SPS** *Emilio Depero*
18:45		
19:30		***Public Lecture***

Tuesday, 27.08.2019, Room G 91

Time	ID	TASK III: Detector *Chair: Ilse Krätschmer, HEPHY Wien*
17:00	321	**Performance of the Belle II Silicon Vertex Detector** *Christoph Schwanda*
17:15	322	**SiPM detectors for the LHCb SciFi tracker upgrade** *Sebastian Schulte*
17:30	323	**Integration of the FELIX readout in the ATLAS ITk Pixel data transmission chain** *Meghranjana Chatterjee*
17:45	324	**Characterisation of the opto electrical data conversion system for the ATLAS detector upgrade** *Roman Müller*
18:00	325	**Serial powering and high hit rate efficiency measurement for the Phase 2 Upgrade of the CMS Pixel Detector.** *Daniele Ruini*
18:15	326	**zfit: scalable pythonic fitting** *Jonas Eschle*
18:30	327	**ArgonCube: A Modular Approach for Liquid Argon Time Projection Chambers** *Roman Matthias Berner*
18:45	328	**First dual-phase xenon TPC with SiPM readout and its ultra-low energy calibration with ^{37}Ar** *Kevin Thieme*
19:00		
19:30		***Public Lecture***

Wednesday, 28.08.2019, Room G 55

Time	ID	TASK IV: High Energy Physics I *Chair: Günther Dissertori, ETH Zürich*
14:00	331	**First Observation of the Seeded Proton Bunch Self-Modulation in Plasma** *Marlene Turner (i)*
14:30	332	**Review of flavour anomalies** *Andrea Mauri*
15:00	333	**Search for new physics in heavy baryon decays** *Martina Ferrillo*
15:15	334	**Search for the lepton-flavour-violating decay $B^+ \to K^+ \tau^\pm \mu^\mp$** *Lino Ferreira Lopes*
15:30	335	**Angular analysis of $B^0 \to K^{*0} \ell^+ \ell^-$ decays at LHCb** *Zhenzi Wang*

15:45	336	**CP violation in beauty and charm at LHCb** *Julian Garcia Pardinas*
16:00	337	**Search for CP violation in angular distributions of $D^0 \to 4h$ decays at LHCb** *Tara Nanut*
16:15	338	**Towards a measurement of the charm mixing parameter y_{CP} in $D^0 \to h^+h^-$ decays** *Guillaume Max Pietrzyk*
16:30		***Coffee Break***
		TASK V: HIGH ENERGY PHYSICS II *Chair: Rainer Wallny, ETH Zürich*
17:00	341	**Model-independent measurement of charm-mixing parameters in $D^0 \to K^0_S \pi^+ \pi^-$** *Surapat Ek-In*
17:15	342	**Measurement of CP violation with the ATLAS experiment** *Emmerich Kneringer*
17:30	343	**Amplitude analysis of $B^0 \to (\pi^+\pi^-)(K^+\pi^-)$ decays** *Maria Vieites Diaz*
17:45	344	**Towards a measurement of the differential decay rate of the decay $B^+ \to \rho^0 \mu^+ \nu_\mu$ at LHCb** *Veronica Soelund Kirsebom*
18:00	345	**Observation of Hbb in CMS** *Krunal Bipin Gedia*
18:15	346	**Measurement of ttH(bb) in proton-proton collision data at 13 TeV** *Korbinian Schweiger*
18:30	347	**Search for top squark pair production in events with Z bosons** *Meinrad Schefer*
18:45	348	**Low-mass dielectron measurements in pp, p-Pb and Pb-Pb collisions with ALICE at LHC** *Elisa Meninno*
19:00		***Postersession with Apéro***
20:30		

Thursday, 29.08.2019, Room G 55

Time	ID	TASK VI: DARK MATTER AND NEUTRINO II *Chair: Tatsuya Nakada, EPFL*
14:00	351	**CHIPP Award talk** *NN*
14:30	352	**Neutrino point-source searches for multi-messenger astronomy with IceCube** *Anastasia Maria Barbano*
15:00	353	**The SST-1M telescope** *Cyril Martin Alispach*
15:15	354	**Xenon1T results** *Giovanni Volta*
15:30	355	**Light Dark Matter Search with Ionization Signals in XENON1T** *Shayne E. Reichard*
15:45	356	**Search for Dark Absorption in XENON1T** *Michelle Galloway*
16:00	357	**Analysis of high-energy events in XENON1T** *Chiara Capelli*
16:15	358	**Axion-Dark-Matter Search using Cold Neutrons** *Ivo Schulthess*
16:30		***Coffee Break***
Time	ID	**TASK VII: DARK MATTER AND NEUTRINO III** *Chair: Christoph Schwanda, SMI Wien*
17:00	361	**qBOUNCE: first results of the Ramsey-type GRS experiment** *Joachim Bosina*
17:15	362	**Studying the Extreme Behaviour of 1ES 2344+51.4** *Axel Arbet-Engels*
17:30	363	**Latest results on cross-section measurement at T2K near detector** *Stephanie Bron*
17:45	364	**Sensitivity study for proton decay via $p \to K^+ + \bar{\nu}$ in the Deep Underground Neutrino Experiment** *Christoph Alt*
18:00	365	**The search for neutrinoless double beta decay in ^{76}Ge** *Roman Hiller*
18:15	366	**DARWIN: a next-generation multi-ton xenon observatory** *Patricia Sanchez-Lucas*
18:30	367	**Prospects for neutrino-less double beta decay detection with the DARWIN experiment** *Yanina Biondi*
18:45	368	**Overview of MicroBooNE** *Thomas Josua Mettler*
19:00		***END; Transfer to Dinner***
19:30		***Conference Dinner***

ID	TASK POSTER
371	**Muonic Atom Spectroscopy: Preparations Regarding a Measurement of the Charge Radius of Radium** *Alexander Albert Skawran*
372	**Ultracold neutron production and extraction from the solid deuterium converter of the PSI UCN source** *Ingo Rienäcker*
373	**Measuring the Beryllium Isotopic Composition in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station** *Jiahui Wei*
374	**Cosmic-ray Magnesium flux measured with the Alpha Magnetic Spectrometer on the International Space Station** *Zhen Liu*
375	**Cosmic-ray Silicon Flux measured with the Alpha Magnetic Spectrometer on the International Space Station** *Yao Chen*
376	**Diffusion of muonic atoms in the muX gas cell** *Jonas Nuber*
377	**A 2.6m tall DARWIN Demonstrator** *Frédéric Girard*
378	**Identification of ^{137}Xe like a background for 0vbb searches with DARWIN** *Patricia Sanchez-Lucas*
379	**Beam EDM detector characterization** *Marc Solar*
380	**Experimental strategy to test Lepton Flavour Universality in $b \to s l^+ l^-$ decays at LHCb** *Sara Celani*
381	**Qualification of the Radiation-Hard Electron Monitor (RADEM) for ESA JUICE mission** *Patryk Socha*
382	**Real-time detection of Supernova Neutrinos in XENONnT** *Ricardo Peres*
383	**XENONnT: The next stage in the search for dark matter with liquid xenon** *Adam Brown*
384	**Lamb Shift of (Anti)hydrogen** *Gianluca Janka*
385	**The SHiP-Charm Experiment** *Dario De Simone*

386	**Detection System for NoMoS** *Raluca Jiglau*

Atomic Physics and Quantum Optics

Thursday, 29.08.2019, Room G 91

Time	ID	Atomic Physics and Quantum Optics I *Chair: NN*
14:45	401	**Terahertz quantum optics in the time-domain.** *Ileana-Cristina Benea-Chelmus (i)*
15:15	402	**Positronium and Muonium precision spectroscopy: Measurement of the 1S-2S and excited state hyperfine transitions** *Michael Heiss*
15:30	403	**Spatial hole burning in thin-disk lasers and twisted-mode operation** *Karsten Schuhmann*
15:45	404	**Direct field correlation measurement on the electromagnetic ground state** *Francesca Fabiana Settembrini*
16:00	405	**Phase transition in the dynamical response of driven-dissipative light-matter systems** *Matteo Soriente*
16:15	406	**Quantum dynamics of a harmonic oscillator in a bath of two-level atoms** *Katja Kustura*
16:30		***Coffee Break***
		Atomic Physics and Quantum Optics II *Chair: NN*
17:00	411	**Ultra-coherent micro-mechanical resonators for quantum information processing at room temperature** *Amir H. Ghadimi (i)*
17:30	412	**Rotational alignment decay and decoherence of molecular superrotors** *Benjamin Stickler*
17:45	413	**Spin drag in a one-dimensional quantum wire** *Anne-Maria Visuri*
18:00	414	**Non-Abelian Majorana fermions in topological s-wave Fermi superfluids** *Lauri Toikka*
18:15	415	**Diverging exchange force for ultracold fermionic atoms** *Christian Schilling*
18:30		***END***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Quantum Science and Technology

This session has been organised in collaboration with the NCCR QSIT.

Tuesday, 27.08.2019, Room G 60

Time	ID	Quantum Science and Technology I *Chair: Clemens Müller, IBM Rüschlikon*
14:00	501	**Introduction to QSIT Session** *Klaus Ensslin (i)*
14:15	502	**Scaling elements for ion trap quantum processors** *Jonathan Home (i)*
14:45	503	**Linking trapped-ion quantum nodes** *Tracy Northup (i)*
15:15	504	**Digital Quantum Simulation, Trotter Errors, and Quantum Chaos of the Kicked Top** *Lukas Sieberer*
15:30	505	**All-fibre postselection-loophole-free generation of a one-photon time-bin qubit characterised by energy-time tomography** *Maxime Jacquet*
15:45	506	**Experimental secure quantum computing with only classical clients** *Michal Vyvlecka*
16:00	507	**Quantum Communication: From Random Numbers To Teleportation** *Rob Thew (i)*
16:30		***Coffee Break***
Time	ID	Quantum Science and Technology II *Chair: Shabir Barzanjeh, IST Austria*
17:00	511	**A Broadband Rb Vapor Cell Quantum Memory for Single Photons** *Gianni Buser*
17:15	512	**Sub-second optical storage using dynamical decoupling in an atomic frequency comb memory** *Adrian Holzäpfel*
17:30	513	**Ultra coherent nanomechanical oscillators** *Tobias Kippenberg (i)*
18:00	514	**Quantum Simulation with Ultracold Dipolar Atoms** *Francesca Ferlaino (i)*
18:30	515	**Scattering from the dark and birefringent modes: new self-organisation phases** *Davide Dreon*
18:45	516	**Local spin manipulation of quantized atomic currents** *Laura Corman*
19:00		
19:30		***Public Lecture***

Wednesday, 28.08.2019, Room G 60

Time	ID	Quantum Science and Technology III *Chair: Matthias Mergenthaler, IBM Rüschlikon*
14:00	521	**Quantum Information Science with Superconducting Circuits** *Andreas Wallraff (i)*
14:30	522	**Gate-efficient simulation of molecular eigenstates on a quantum computer** *Marc Ganzhorn*
14:45	523	**Interacting TLS as sources of noise and fluctuations in superconducting circuits** *Clemens Müller*
15:00	524	**Transduction and entanglement generation with silicon nanobeam oscillators** *Johannes Fink (i)*
15:30	525	**Experimental Realization of Microwave Quantum Illumination** *Shabir Barzanjeh*
15:45	526	**Double Quantum Dots in an Undoped Germanium Heterostructure** *Andrea Hofmann*
16:00	527	**Coupling spins coherently to microwave photons** *Thomas Ihn (i)*
16:30		***Coffee Break***

Time	ID	QUANTUM SCIENCE AND TECHNOLOGY IV *Chair: Lukas Sieberer, Uni Innsbruck*
17:00	531	**Shot-noise of high-impedance quantum devices using impedance matching** *Christian Schönenberger*
17:15	532	**Electron-polariton interactions in the fractional quantum Hall regime** *Thibault Chervy*
17:30	533	**All fermionic non-Gaussian states are magic states for matchgate computations** *Barbara Kraus (i)*
18:00	534	**The information theory of reference clocks** *Ralph Silva*
18:15	535	**Quantum interference of topological states of light** *Oded Zilberberg*
18:30	536	**Quantum Computing and Detection of Cancer** *Beatrix Hiesmayr (i)*
19:00		***Postersession with Apéro***
20:30		

Friday, 30.08.2019, Room G 60

Time	ID	QUANTUM SCIENCE AND TECHNOLOGY V *Chair: Laura Corman, ETH Zürich*
11:15	541	**Progress in the quantum control of single molecules** *Ziv Meir (i)*
11:45	542	**Atom Interferometry: Gravity, Blackbody Radiation and Dark Energy** *Philipp Haslinger (i)*
12:15	543	**Long-Baseline Universal Matter-Wave Interferometry** *Sebastian Pedalino*
12:30	544	**Long-term stability analysis of a compact Ramsey-scheme vapor-cell atomic clock at 10^{-14} level** *Nil Almat*
12:45	545	**Towards spin-squeezing a solid** *Krzysztof T. Kaczmarek*
13:00	546	**Cavity-Based 3D Cooling of a Levitated Nanoparticle via Coherent Scattering** *Dominik Windey*
13:15		***END***

ID	QUANTUM SCIENCE AND TECHNOLOGY POSTER
551	**Fabry-Pérot interference in InAs/GaSb quantum wells** *Michele Masseroni*
552	**Investigating coherence limitations in transmon qubits** *Matthias Mergenthaler*
553	**Optimal Control of Superconducting Qubits** *Max Werninghaus*
554	**Entanglement in special relativistic settings** *Christoph Schöberl*
555	**Quantum informational analysis of neutrino oscillations via Leggett-Garg inequalities** *Christiane Schultze*
556	**Investigating noise sources with a triple quantum dot charge qubit** *Benedikt Kratochwil*
557	**Measurable Inequalities for higher dimensional Quantum Secret Sharing Protocols** *Michael Partener*
558	**Dissipative time-crystal phase in parametrically unstable optical cavities** *Kilian Robert Seibold*
559	**Entangled two-photon absorption and the quantum advantage in sensing** *Dmitry Tabakaev*
560	**Spin detection through parametric mode coupling in nanomembranes** *Jan Kosata*
561	**Quantum dynamics of an ultracold ion coupled to a nanomechanical oscillator** *Moritz Weegen*
562	**Quantum-Logic Assisted Molecular Precision Measurements Using a Network for The Distribution of The Swiss Frequency Standard** *Aleksandr Shlykov*
563	**Classical many-body time crystals** *Toni Heugel*
564	**Cavity Exciton-Polariton Condensates in Engineered Potential Landscapes at Room Temperature** *Fabio Scafirimuto*
565	**Bidirectional Microwave to Optical Gaussian Quantum State Transfer** *Alfredo Rueda*
566	**Entanglement transfer using local operations** *Antoine Neven*
567	**Integrating a fiber cavity along the axis of a linear ion trap** *Klemens Schüppert*
568	**High-rate photon pairs and sequential Time-Bin entanglement with Si_3N_4 ring microresonators** *Farid Samara*
569	**Optical spin-wave storage in a paramagnetic solid state crystal** *Moritz Businger*
570	**Coupled Quantum Dots in Bilayer Graphene with Tunable Barriers** *Chuyao Tong*
571	**Accuracy enhancing protocols for quantum clocks** *Yuxiang Yang*
572	**Can quantum algorithms in chemistry outperform their classical equivalent? Advanced Quantum Unitary Coupled Cluster methods for strongly correlated systems.** *Igor Sokolov*
573	**Strong magneto-mechanical coupling** *David Zöpfl*
574	**Dimerized states and dynamical instabilities in a blue-detuned cavity-BEC system** *Rui Lin*

MaNEP: Correlations and topology in quantum matter

THIS SESSION HAS BEEN ORGANISED IN COLLABORATION WITH THE ASSOCIATION MANEP.

Tuesday, 27.08.2019, Room G 85

Time	ID	CORRELATIONS AND TOPOLOGY IN QUANTUM MATTER I: DYNAMICS,MAGNETISM AND TOPOLOGY *Chair: Mark Fischer, Uni Zürich*
14:00	601	**Novel families of SU(N) AKLT states with arbitrary self-conjugate edge states** *Samuel Gozel*
14:15	602	**Generating multiple universality classes and nodal loops in Chern insulators by periodic driving** *Paolo Molignini*
14:30	603	**Localization properties of the interpolating Aubry-André-Fibonacci model** *Antonio Štrkalj*

14:45	604	**4D topology in a dynamical 2D system** *Ioannis Petrides*
15:00	605	**Novel structural and electronic phases of 2D transition metal dichalcogenides** *Oleg V. Yazyev (i)*
15:30	606	**Discovery and engineering of new topological quantum materials** *Niels B. M. Schröter*
15:45	607	**Tunable Berry Curvature Through Magnetic Phase Competition in a Topological Kagome Magnet** *Zurab Guguchia*
16:00	608	**Do topology and ferromagnetism cooperate at the EuS/Bi_2Se_3 interface?** *Jonas A. Krieger*
16:15	609	**Ultrafast dynamics of the magnetic fluctuations in the spin-chain $CuGeO_3$** *Eugenio Paris*
16:30		***Coffee Break***
		Correlations and topology in quantum matter II: Topological band structures *Chair: Johan Chang, Uni Zürich*
17:00	611	**Experimental results on the predicted Weyl semimetal PrAlGe** *Daniel Destraz*
17:15	612	**Low-energy band structure of Weyl-II candidate $MoTe_2$: a view from infrared spectroscopy** *Ana Akrap*
17:30	613	**Spin reorientation in ferromagnetic type-II Weyl Fe_3Sn_2** *Neeraj Kumar*
17:45	614	**A comparative photoemission spectroscopy and scanning tunneling microscopy study of the topological material $ZrTe_5$** *Björn Salzmann*
18:00	615	**Fractional corner charges in spin-orbit coupled crystals** *Marta Brzezińska*
18:15	616	**Hopf Insulators: Localized Representation and Observable Phenomena** *Aleksandra Nelson*
18:30	617	**High-Pressure Growth of the Newly Predicted Quantum Spin Hall Insulator Pt_2HgSe_3** *Enrico Giannini*
18:45	618	**Emergent topology in a 3D Kane-Mele system: Pt_2HgSe_3** *Irène Cucchi*
19:00		
19:30		***Public Lecture***

Wednesday, 28.08.2019, Room G 85

Time	ID	Correlations and topology in quantum matter III: Heterostructures and van der Waals materials *Chair: Oded Zilberberg, ETH Zürich*
14:00	621	**Strain-controlled dimensionality of interface metallicity in $LaVO_3$/$LaTiO_3$ multilayers** *Sophie Beck*
14:15	622	**$LaVO_3$ Thin Films under Epitaxial Strain** *Hugo Meley*
14:30	623	**A laser-ARPES study of $LaNiO_3$ thin films grown in-situ by sputter deposition** *Edoardo Cappelli*
14:45	624	**High sensitivity variable-temperature infrared nanoscopy of conducting oxide interfaces** *Weiwei Luo*
15:00	625	**Transport in sub-micrometric devices at the $LaAlO_3$/$SrTiO_3$ interface** *Margherita Boselli*
15:15	626	**Quantum Rings with Broken Symmetries** *Jochen Mannhart (i)*
15:45	627	**Semiconducting van der Waals Interfaces as Artificial Semiconductors** *Evgeniy Ponomarev*
16:00	628	**Anomalous Hall Effect in the Quantum Limit in Exfoliated Crystals of the Layered Antiferromagnet $Co_{1/3}NbS_2$** *Giulia Tenasini*
16:15	629	**Electrically-tunable flat bands and magnetism in twisted bilayer graphene** *Tobias Wolf*
16:30		***Coffee Break***
		Correlations and topology in quantum matter IV: Superconductors and parent electronic strucutres *Chair: Thomas Greber, Uni Zürich*
17:00	631	**Spin-orbit coupling and self energies in Sr_2RuO_4** *Anna Tamai (i)*
17:30	632	**Three-dimensional Fermi surface of overdoped La-based cuprates** *Masafumi Horio*
17:45	633	**Electronic and magnetic tuning of charge order and phonon anomaly in a cuprate spin ladder** *Yi Tseng*
18:00	634	**Ultra-High Resolution Neutron Spectroscopy of Low-Energy Spin Dynamics in UGe_2** *Marc Janoschek*
18:15	635	**Superconductivity without inversion and time-reversal symmetries** *Mark Fischer*
18:30	636	**Effect of electron count and chemical complexity in high-entropy alloy (HEA) superconductors** *Fabian O. von Rohr*
18:45	637	**Unconventional superconductivity with T_c = 30 K in stoichiometric ThFeAsN** *Toni Shiroka*
19:00		***END; Postersession with Apéro***
20:30		

ID	MaNEP: Correlations and topology in quantum matter Poster
641	**Magneto-optical spectroscopy on TaAs** *David Santos-Cottin*
642	**Magneto-transport and optical conductivity of type II Weyl semimetals: $TaIrTe_4$** *Florian Le Mardelé*
643	**Dynamical Structure Factor analysis of the Bilinear Biquadratic Spin-1 chain** *Mithilesh Nayak*
644	**Electronic Phase Transitions in Suspended Graphene Multilayers** *David Soler Delgado*
645	**Topological 0D Defect States in 3D Insulators** *Frank Schindler*
646	**Cavity-mediated fermionization of long-range interacting bosons** *Paolo Molignini*
647	**Study of the interface between infinite-layer $CaCuO_2$ and perovskite $SrTiO_3$** *Adrien Waelchli*

648	**Tuning of the depolarization field, built-in voltage and nanodomain structure in ferroelectric thin films and heterostructures** *Céline Lichtensteiger*
649	**Weak Localization and Antilocalization in Nodal-Line Semimetals: Dimensionality and Topological Effects** *Oded Zilberberg*
650	**Engineering electronic coupling of metal-insulator phases at $SmNiO_3/NdNiO_3$ interfaces** *Claribel Dominguez*

Skyrmions in magnetic materials

This session has been organised in collaboration with the Association MaNEP.

Thursday, 29.08.2019, Room G 95

Time	ID	Skyrmions in magnetic materials *Chair: NN*
14:00	661	**Topological Magnetization Solitons: From Fundamentals to Technology** *Stefan Blügel (i)*
14:30	662	**Topological Magnons and Edge States in Antiferromagnetic Skyrmion Crystals** *Sebastián Díaz*
14:45	663	**Imaging topological electron-spin textures by using atomic-resolution Lorentz TEM** *Xiuzhen Yu (i)*
15:15	664	**Field-induced skyrmion inversion in the room-temperature chiral magnet $Co_9Zn_9Mn_2$** *Victor Ukleev*
15:30	665	**Investigating Stability and Metastability in the Skyrmion system zinc-doped Cu_2OSeO_3** *Peter D. Hatton (i)*
16:00	666	**Bulk Magnon Modes in Cu_2OSeO_3 Detected by Brillouin Light Scattering Microscopy at Low Temperature** *Ping Che*
16:15	667	**Spiral spin-liquid and the emergence of a skyrmion-like state in $MnSc_2S_4$** *Oksana Zaharko*
16:30		***END; Coffee Break***
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

ID	Skyrmions in magnetic materials Poster
671	**Low frequency resonance mode in the insulating chiral magnet Cu_2OSeO_3 at low temperature** *Jilei Chen*
672	**Crystallite size dependency on magnetic phase diagram of Cu_2OSeO_3** *Priya Ranjan Baral*
673	**van Der Waals Epitaxy of Co-Zn-Mn on Graphene for Skyrmionic Applications** *Anna Kukolova*

Quantum Beam Science: bio, materials and fundamental physics with neutrons and X-rays

This session has been organised in collaboration with the Swiss Society for Neutron Science (SGN).

Thursday, 29.08.2019, Room G 85

Time	ID	Quantum Beam Science: bio, materials and fundamental physics with neutrons and X-rays I: Neutrons from Fundamental Physics to Novel Imaging Methods *Chair: NN*
14:00	701	**Weak measurements in neutron interferometry and experimental tests of general uncertainty relations** *Stephan Sponar (i)*
14:30	702	**Yet another approach to tackle the phase problem of diffraction experimentally** *Martin Fally (i)*
15:00	703	**Status of the Beam EDM experiment** *Estelle Chanel*
15:20	704	**High resolution neutron imaging at Paul Scherrer Institut** *Pavel Trtik*
15:40	705	**The PERC facility - prospects of high-precison neutron beta decay experiments** *Erwin Jericha*
16:00	706	**From omnidirectional sensitivity to polarized dark-field image with neutron grating interferometry** *Jacopo Valsecchi*
16:20		
16:30		***Coffee Break***
		Quantum Beam Science: bio, materials and fundamental physics with neutrons and X-rays II: New Spectroscopies of quantum matter *Chair: NN*
17:00	711	**Ultrafast quenching of phase coherence in cuprates revealed by TR-ARPES** *Elia Razzoli (i)*
17:30	712	**Nonequilibrium Dynamics of Collective Excitations in Quantum Materials** *Edoardo Baldini (i)*
18:00	713	**Time resolved Resonant Inelastic X-ray Scattering and Soft X-Ray Diffraction on Quantum Materials at Furka experimental station at Athos SwissFEL** *Cristian Svetina*
18:20	714	**Spin wave dynamics in ultrathin yttrium iron garnet measured with x-ray microscopy** *Joe Bailey*
18:40	715	**Ultrafast electron vortex beam and temporal holography in ultrafast electron microscope** *Ivan Madan*
19:00		***END; Transfer to Dinner***
19:30		***Conference Dinner***

ID	Quantum Beam Science: bio, materials and fundamental physics with neutrons and X-rays Poster
721	**Correlation between O-vacancies and electrochemical activity of $PrBaCo_2O_{5+x}$ ($0.17 \leq x \leq 0.79$)** *Elena Marelli*
722	**Design rules for high-temperature magnetic spirals in layered perovskites** *Tian Shang*

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

Friday, 30.08.2019, Room G 91

Time	ID	Combined Session *Chair: Laurie Porte, EPFL*
11:15	801	**Simulations of artificial populations with competing skills** *Johannes J. Schneider*
11:30	802	**Non-linear model-based optimization of stationary tokamak plasma profiles using RAPTOR** *Simon Van Mulders*
11:45	803	**Fast Electron Studies using the ECE suite of Diagnostics on TCV** *Arsène Stéphane Tema Biwole*
12:00	804	**Plasma Edge Turbulence Characterization Using Gas Puff Imaging on the TCV Tokamak** *Nicola Offeddu*
12:15	805	**Thermal characteristics of cellulose in relation to forest fire** *Alois Raemy*
12:30	806	**Kerr lens mode-locked femtosecond thin-disk lasers and their application for broadband THz and intracavity high harmonic generation** *Julian Fischer*
12:45	807	**Broadband high-power THz generation driven by ultrafast thin-disk laser oscillators** *Jakub Drs*
13:00	808	**Laser cooling of C_2^- in a digital RF trap for sympathetic cooling of antiprotons** *Emanuel David Oswald*
13:15		*END*

ID	Applied Physics & Earth, Atmosphere and Environmental Physics & Plasma Physics Poster
811	**First results on the effects of toroidal current on 3D equilibria in magnetic fusion devices** *Antoine Baillod*
812	**Impact of edge density fluctuations on Electron-Cyclotron beam propagation and absorption in tokamaks** *Jean Cazabonne*

Biophysics, Medical Physics and Soft Matter

Wednesday, 28.08.2019, Room G 91

Time	ID	Biophysics, Medical Physics and Soft Matter *Chair: Giovanni Dietler, EPFL*
17:00	901	**Amyloid fibril growth: A multiscale view** *Ioana Ilie*
17:15	902	**Effects of gravity on the alpha-synuclein aggregation** *Jiangtao Zhou*
17:30	903	**Picture of Wet Electron: A Localized Transient State in Liquid Water** *Michele Pizzochero*
17:45	904	**Gap plasmon resonance-enhanced high spatial resolution imaging by photothermal induced resonance in visible spectral range** *Serguei Sekatski*
18:00	905	**3D optical coherence microscopy with structured illumination and numerical focusing** *Anton Grebenyuk*
18:15	906	**Combined optical and acoustic trapping for optical tomography** *Mia Kvåle Løvmo*
18:30	907	**Phase behavior in polydisperse microgel suspensions controlled by spontaneous particle deswelling** *Urs Gasser*
18:45		*END*
19:00		*Transfer to Dinner*
19:30		*Conference Dinner*

ID	Biophysics, Medical Physics and Soft Matter Poster
911	**Microfabricated cantilever beams for rapid bacterial sensitivity tests** *Anton Malovichko*
912	**Simulation of a microfluidic system of droplets** *Johannes J. Schneider*

Pre-Conference Workshops

Monday, 26.08.2019, Room G 55

Time	ID	Pre-Conference Workshops
09:00	WS 1	**Machine Learning for Experimental Quantum Physics** ***Lecture***
11:00		*Coffee Break*
11:30	WS 2	**Programming a Quantum Computer with Examples in Quantum Machine Learning** ***Lecture***
12:30		*Lunch*
14:00	WS 1	**Machine Learning for Experimental Quantum Physics** ***Hands-On Workshop Part 1***
15:15		*Coffee Break*
15:45	WS 1	**Machine Learning for Experimental Quantum Physics** ***Hands-On Workshop Part 2***
17:15		*END*

Monday, 26.08.2019, Room G 85

Time	ID	Pre-Conference Workshops
14:00	WS 2	**Programming a Quantum Computer with Examples in Quantum Machine Learning** ***Hands-On Workshop Part 1***
15:15		*Coffee Break*
15:45	WS 2	**Programming a Quantum Computer with Examples in Quantum Machine Learning** ***Hands-On Workshop Part 2***
17:15		*END*

On the Origin of the Elements

Celebrating *150 Years of the Periodic Table* in a joint special session of SCNAT and SPS

Friday, 30 August 2019, 11:15 - 13:30, Room G 30

What Physics has to say about the Periodic Table

On 6 March 1869, Dmitry Mendeleev presented *The Dependence between the Properties of the Atomic Weights of the Elements* to the Russian Chemical Society, where for the first time all then known elements have been placed in a table. This table has grown in what is known today as the Periodic Table of Elements. Hundred fifty years later, the United Nations General Assembly and UNESCO proclaim 2019 as the *International Year of the Periodic Table of Chemical Elements* (IYPT2019, https://www.iypt2019.org) with activities, talks and events organized around the globe (for events in Switzerland see https://www.iypt2019.ch/en/switzerland). Mostly such events highlight the chemical properties of elements, their discovery or their relevance in the environment or in various applications as of today.

United Nations Educational, Scientific and Cultural Organization

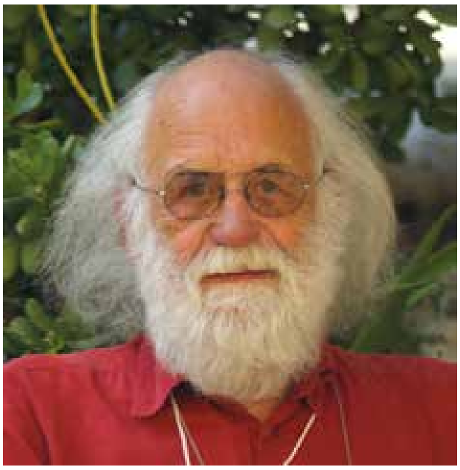
International Year of the Periodic Table of Chemical Elements

On the other hand, it is *Physics* that has lots to say about the origin of all the elements, about the understanding of the atomic shell structure, the structure of atomic nuclei, the inner structure of the protons and neutrons that make up the nuclei and that directly leads us to the physics of elementary particles. Particle beams come into play, when heavy ions are carefully shot on heavy nuclei to create previously unknown transuranium elements up to Oganesson with an atomic number of 118.

Time	ID	**On the Origin of the Elements - 150 Years of the Periodic Table** *Chair: Claus Beisbart, Uni Bern, SPS section "History & Philosophy of Physics"*
11:15	31	**Celebrating 150 years Periodic Table, historical remarks and current situation** *Heinz W. Gäggeler, Paul Scherrer Institut, 5232 Villigen and Dept. of Chemistry and Biochemistry, University of Bern, 3012 Bern* The first periodic table published by D. I. Mendelejeev in 1869 based on atomic masses and had empty positions that paved the way for the discovery of several new elements. With the discovery of Pu by Glenn Seaborg as a transuranium element a worldwide race for synthesis of new elements started, mostly at LBNL (Berkeley, USA) and JINR (Dubna, Russia), later also at GSI (Darmstadt, Germany) and at RIKEN (Japan). Currently, 118 elements are known and approved by IUPAC. The heaviest is Oganesson completing the 7th period of the periodic table. While all elements up to Md have been discovered by chemists, heavier ones were found in physics experiments. Chemical experiments have so far reached atomic number 114 (Fl). Efforts are actually made to extend the periodic table into the 8th period starting with element 119. The ultimate limit of the periodic table is predicted at atomic number 172 being the heaviest element with a stable electron shell structure.
12:00	32	**Big Bang and stars, two hot environments for making elements** *Georges Meynet, Geneva Observatory, 51 chemin des Maillettes, CH-1290 Versoix* The question of the origin of the elements of the Mendeleev table has triggered many lively discussions in the first part of the twentieth century. Some researchers thought that all the elements were produced during the early phase of the evolution of the Universe, while others had the opinion that the stars were the cauldrons in which all the nuclear cooking occurred. I shall explain why neither of these views was correct and how it was possible to make progresses in our understanding. I shall then continue by reviewing the physical principles that govern the evolution of stars and by describing the main nucleosynthetic events at the origin of the elements up to iron. I shall then illustrate the whole process of studying the origin of one element by focussing on the case of oxygen. I shall remind the first ideas about the nuclear processes involved, the astrophysical sites, how this knowledge can be used to make models for the chemical evolution of galaxies and how the predictions of these models can be compared with observational constraints. I shall conclude by describing a present-day highly debated question concerning this element: what is the abundance of oxygen in the Sun?
12:45	33	**Stellar Explosions and the Heavy Elements** *Friedrich-Karl Thielemann, Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel* The build-up of elements up to Fe in stars is governed by fusion reactions in stellar burning stages. The sequence of burning stages is led by the principle that ashes of the previous stage become the fuel of the following one. After the depletion of one fuel, not permitting anymore to make up for the continuing radiation losses which make stars shining, contraction sets in, leading to a temperature increase via the gain of gravitational binding energy. This continues until temperatures pass a threshold, permitting the fusion of reacting charged particles and nuclei via velocities (kinetic energies) which can overcome the repelling Coulomb forces. This stabilizes the star for the next burning stage until its fuel is also depleted. This sequence of events continues until nuclei with the highest binding energy per nucleon are reached, i.e. isotopes of Fe and Ni. What options remain to produce heavier nuclei ? Neutrons do not experience repelling Coulomb forces and neutron capture on nuclei can take place for any temperature. With sufficient amounts of neutrons available, heavy nuclei can be produced by a sequence of neutron captures and beta-decays up to the heaviest nuclei known in nature. The question is how such amounts of unstable neutrons can be provided in stellar environments. The answer is, either (a) via neutron-producing reaction in stellar evolution, or (b) in explosive events originating under conditions of highest densities, where capture of electrons (with high Fermi energies) on protons produced ample amounts of free neutrons. We will connect this to He-burning in stars, as well as neutron star mergers (only observed recently) and a rare class of supernovae.
13:30		***END***

In Memoriam Claus Fröhlich

With Claus Fröhlich, who died on 22 February 2019, we lost a physicist, whose enthusiasm, joy, and knowledge concerning the measurement of Total Solar Irradiance (TSI, earlier known as 'Solar Constant') made him the clear leader in this important field. He was a brilliant experimenter with a pronounced mathematical flair, who later also became an outstanding science manager. His collaborative spirit and open mind predestined him to bring the 'Physikalisch-Meteorologisches Observatorium Davos' (PMOD) and its World Radiation Center (WRC), which he directed from 1975 until 1999, to worldwide recognition.



Picture © T. Appourchaux

Claus was born in Zürich on 10 October 1936. His father Max grew up in the Canton of Glarus as the son of an English mother and a father, who directed a weaving mill with branches in Birmingham and Lagos in Western Africa. Max Fröhlich was a gold- and silversmith, whose influence on design extended well beyond Switzerland. Claus' mother was the daughter of a mechanical engineer who managed companies in France and Switzerland; although she wanted to become an engineer, she had to settle for training as a secretary. Being francophone she preferred the spelling of her son's first name as Claus.

Claus, whose outgoing personality led everybody to call him by his first name went to school in Zürich and studied physics at ETH. After graduating with a diploma thesis in experimental Solid State Physics in 1961, he remained in this field and chose Georg Busch and Fritz Kneubühl as advisers for his doctoral thesis on 'Phonon resonance scattering and thermic conduction in a silicon grain boundary'. For this work he received the Silver Medal of ETH.

After he had obtained a stipend from the Swiss National Science Foundation, he moved to Davos in 1969. There he was going to pursue the development of radiometers, specifically of pyrheliometers, i.e. instruments that measure the total solar irradiance; and when the World Meteorological Organisation (WMO) set up the World Radiation Center (WRC) in Davos, Claus became its Head. He later commented that he found the change from Solid State Physics to Atmospheric Physics – with the key aspects Radiation and Climate – inspiring. His thoughtful and innovative approach to the quinquennial International Pyrheliometer Comparisons in Davos assured that he was easily accepted in the solar-radiometry research community.

In 1979 Claus had the opportunity to put his instruments on a balloon in a joint project with the Observatoire de Genève. With the data acquired during the flight he demonstrated that the interior of the Sun may be studied by measuring the coherent oscillations of the solar atmosphere through observing them as radiance oscillations, and not only through Doppler measurements (as it was customary at the time). Claus thus also entered the community of helioseismology.

As a consequence, he was asked in 1981 to participate in the Phase-A Study of the European Space Agency (ESA) for DISCO (Dual Investigation of the Solar Constant and Oscillations) – a satellite that was going to measure the total irradiance of the Sun, as well as the coherent oscillations of its atmosphere from the first Lagrange Point L1. Albeit DISCO was not accepted for implementation as an ESA project, the instruments of particular interest to Claus were selected in 1988 as the VIRGO experiment (Variability of Solar Irradiance and Gravity Oscillations) for flight on the Solar and Heliospheric Observatory (SOHO). It was launched in December 1995 and – also located at L1 – is still operating today. Claus managed the VIRGO experiment as Principal Investigator, and guided its scientific use by a large international collaboration right to the end of his life. VIRGO has by now provided an accurate record of the Total Solar Irradiance (TSI) over more than two solar sunspot cycles and thus more than half of the full TSI record, which started in November 1978. The "TSI composite" (shown below) that Claus put together from various satellites is considered the "gold standard" in the field.

Starting in the 1979, Claus and his collaborators at PMOD/WRC have acquired experience in designing, building, calibrating and managing space experiments by participating in a number of projects, such as IPHIR (Inter-Planetary Helioseismology with IRadiance data). For this major project they collaborated with the French Laboratoire de Physique Stellaire et Planétaire (that later became the Institut d'Astrophysique Spatiale in Orsay) and the Crimean Astrophysical Observatory. For redundancy, they built two IPHIR instruments and placed one each on the two USSR PHOBOS probes. Eventually, only PHOBOS-II reached the Martian moon of the same name, but this still brought the hoped-for result: the first uninterrupted observation of the solar five-minute oscillation over 161 days! Later, the Davos group also designed and built instruments for EURECA (the 'EUropean REtrievable Carrier') and for the International Space Station (ISS). These were, moreover, useful for assessing the degradation of instruments owing to their use in space, and contributed further to the seminal literature on TSI and its variation written by Claus and his associates.

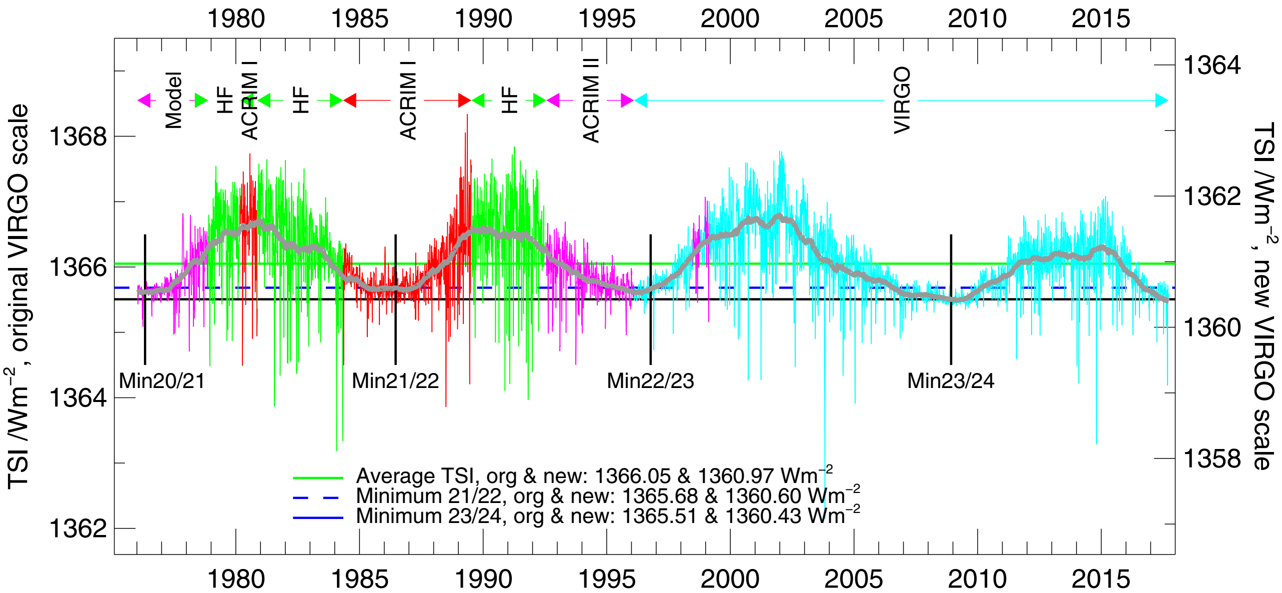
Claus was elected member of the Academia Europaea in 1990 and was honoured in 2017 with a prize by the Canton of Grisons in recognition of his scientific achievements, which "brought international fame to the research site Davos". Many of us knew Kornelia Grassmann, whom Claus married in 1963. She had come to Zürich in 1950, when her father took up a position at ETH. Later on Kornelia graduated as a goldsmith in Max Fröhlich's class at Kunstgewerbeschule.

In Davos the couple and their children lived in a solar house built in 1978, which Claus had designed based on thermal studies performed together with two of his PMOD collaborators. Later, when he was asked to assess energy aspects of a planned printing plant for a Zürich newspaper, he was able to suggest design changes that saved substantial sums, both in investment and use.

When the couple's children were old enough, Kornelia went back to school, passed the Matura, obtained a Licentiate in Theology, completed her studies at the C. G. Jung Institute in Küsnacht and practised as a psychotherapist until the 1990s, when her interests began to gravitate to painting.

It was congenial that two paintings by Kornelia, who had died four years before emblazoned Claus' death notice. The much-admired couple is survived by their three sons, Thomas, Markus and Roman, and by two grandchildren.

For his Davos colleagues, VIRGO team members, and contemporaries: Robert Brusa (Zürich), Wolfgang Finsterle (Davos), Hansjörg Roth (Basel); Bo Andersen (Svalbard), Thierry Appourchaux (Orsay), Bernhard Fleck (Greenbelt), Antonio Jimenez Mancebo (Tenerife); Heidi Blattmann (Zürich), Roger Bonnet (Bern and Paris), Vicente Domingo (Valencia), and Martin Huber (Zürich)



The Charpak-Ritz Prize 2019 is awarded to Benoît Deveaud

This year Professor Benoît Deveaud, best known to Switzerland from his former activities at EPFL and since 2017 acting as Vice Provost for Research at École Polytechnique (France), is honored for his "pioneering optical spectroscopy studies dedicated to the ultrafast and quantum optical properties of semiconductor nanostructures."

His PhD thesis has cast a profound understanding of the properties of chromium, as a deep impurity center, in Gallium Arsenide (GaAs). During his post-doctorate at Bell Labs (1986-1987), and the years following at CNET (1987-1993), he has implemented the first sub-picosecond luminescence set-up, with 300 femtosecond resolution, and studied phenomena of major interest in micro and nanostructures, such as the capture of electrons and holes in quantum wells, their intersubband scattering dynamics, the vertical transport of electrons in superlattices, the radiative behavior of excitons or plasmas in quantum wells and quantum wires.
Over the 25 years spent at EPFL in Lausanne, where he has been the director of the Institute of Quantum Electronics and Photonics for more than 10 years, he has expanded the knowledge of his team towards coherent optical spectroscopy by developing a whole ensemble of actively stabilized interferometers. The realization of coherent control experiments on polaritons in a configuration of parametric amplification, the demonstration of the coherent nature of Rayleigh scattering with respect to the phase of the exciting laser were the first steps of the route which leads to a profound understanding of the physics of semiconductor microcavities, in particular of their dynamics in the non-linear regime.

Such an extensive expertise has been essential to his team, within an international collaboration, to probe and assess, for the first time, the Bose Einstein condensation of polaritons in solid-state physics. Benoît Deveaud's team has further reported observations of polariton fluids including full and half vortices in condensates, Josephson oscillations, dark solitons with break-up of a polariton superfluid into pairs of vortices and finally the observation of the Feshbach resonance for polaritons.

The award ceremony will take place at the joint annual meeting of SPS and ÖPG at the University of Zürich on Wednesday morning, 28 August 2019 (see p. 4 and 11).

Progress in Physics (68)

Physics Education Research - An Applied Science (part 1)

Andreas Müller, Université de Genève, Faculté des Sciences / Section de Physique and Institut Universitaire de Formation des Enseignants, 1211 Genève

1 Introduction: Research and Development in Physics Education

Physics education research (PER) is a broad term covering a whole range of research and development: The former means research e.g. about how learners think, difficulties for learning, how well a given approach succeeds, and by what factors success (or failure) might be influenced [1]. The latter means development of new and innovative teaching and learning ideas and materials (such as simplified approaches to difficult topics, new experiments, use of information and communication technology (ICT), etc.

In the following, I will illustrate the branches "research" and "development" by some recent outcomes [1]. Obviously, a connection between them in the form of research-based development is desirable, which I will discuss. I will also cover some other aspects such as the importance of PER for teacher education, or its service functions for physics departments and institutions in the second part of this article.

2 Research – Why not try a scientific approach to physics education?

Learning is a dynamical process, driven by relevant forces and interactions, and leading from an initial to a final state; in that sense, a current metaphor is that of a "learning trajectory" [2, 3]. As much as physics itself, physics education research tries to understand such trajectories, and design them to attain a given target. The same holds, if one tries to increase the physics interest of students. In the last decades, physics (science) education is increasingly inspired by approaches of science itself, as promoted e.g. an article by C. Wieman "Why not try a scientific approach to science education?" ([4], providing the title of the section).

As much as in physics, physics education research then needs measurement methods for the characteristics of the initial and final (intended) state, and an understanding of the intervening "dynamics", i.e. teaching interventions and other, maybe uncontrolled and unwanted, influences. In the following, some illustrative examples of PER for these aspects will be given, sometimes also referring to important results from other areas of STEM (Science, Technology, Engineering, Mathematics) education [2].

2.1 Measurement

> *Figuring out what to measure, and how well to measure it, is critical in all fields. […] Although the specifics for how to do this are different between physics and education, the basic methods are much the same.*
> ***C. Wieman [5]***

1 The present paper is based on a related text about teacher education (arXiv preprint: 1807.00974 [physics.ed-ph]) and on numerous fruitful discussions with many collegues (see acknowledgements).

2 Throughout the paper, it is understood that PER is strongly linked to other parts of STEM education research, i.e. many of the statements hold also for other areas of science learning, or are based on findings in these.

There is an increasing awareness for the need of reliable measurement in physics education, and the development of methods for diagnosis, measurement and assessment has received sustained attention over the past two decades [5 - 9]. In particular, teachers have to know, whether a given approach really increases understanding or motivation, and they have to be able to test this in their own classrooms.

As an example of particular importance, we discuss conceptual learning, considered as fundamental for the scientific literacy of the future citizen [10], as well as for the more advanced competences of a scientist, such as calculation, experimentation, and problem solving ([11], part II): there are no reliable empirical or theoretical results, nor convincing ideas or innovations without understanding of what you are talking about. Moreover, it is a striking strength of physics that it can explain a large range of phenomena by a small set of basic concepts [12, 13]. However, science education research has provided ample evidence for many conceptual obstacles, or "misconceptions" [1], such as the idea that a moving object "looses force" or that the seasons are caused by different distances to the sun (see [14] for some further illustrative examples). Such ideas are found to be widespread and hard to change, even among university students (see e.g. [15, 16, 17]).

Figure 1 presents three classical examples: The first shows that a majority of learners think even at the beginning of university that space between particles of a gas is not empty (there is vapor or oxygen: ≈ 40%, pollutant: ≈ 20%, correct answer "nothing": 40%); this is reminiscent of the "horror vacui" of Aristotelian and medieval thinking ([23], ch. 4), and in

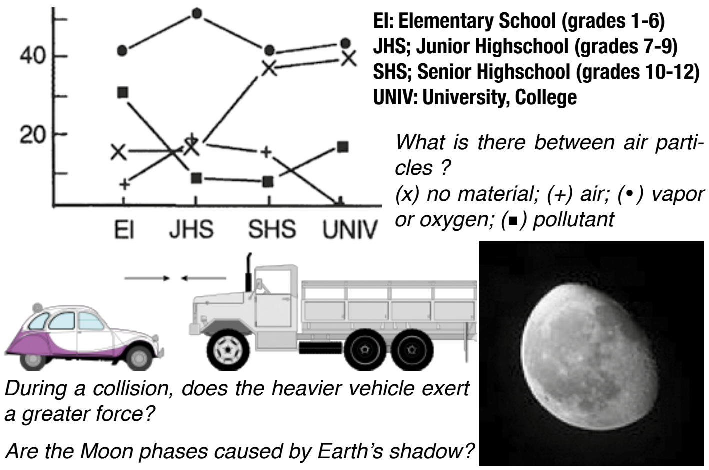


Figure 1: Some examples of misconceptions in physics and astronomy
a) microscopic structure of matter [18]
b) Newton's third law; % correct: end of Gymnasium 24% [19]; begin / end of introductory physics course 34% / 62% [20] / [21]
c) origin of moon's phases, % correct: begin / end of introductory college astronomy (without addressing the misconception explicitly) 12% / 32% [22]
https://upload.wikimedia.org/wikipedia/commons/7/7d/2013-01-02_00-00-55-Waning-gibbous-moon.jpg

fact this "parallelism" between individual and historical conceptual obstacles has been found also for other topics [24]. The second concerns a wide-spread difficulty with Newton's 3rd law, i.e. that in a collision the heavier vehicle (objects) also exerts more force. It is related to an unclear distinction of force and momentum (and maybe kinetic energy), again something that has also taken a long path in the history of physics [25]. Third, the misconception that the lunar phases are caused by Earth's shadow. The fact that it persists even when in contradiction with easy-to-make observations (a gibbous moon with its concave dark region, a crescent moon next to the sun) is an example of what is called the 'persistence' of misconceptions.

In order to measure the presence of a given set of misconceptions ("initial state"), any improvement of conceptual understanding ("final state"), and to compare the impact of various classroom interventions ("dynamics") the physics and science education research community has developed a series of concept tests, e.g. about the structure of matter, Newtonian mechanics, basic astronomy, and other fields [26]. These tests (also named "instruments" or "inventories") have been thoroughly discussed and improved (see e.g. [27] for mechanics), characterized according to standard psychometric characteristics [28], and analysed with more advanced methods [19]. Today comprehensive collections and reviews about concept tests are available for practitioners and researchers [26]. Another important element of physical reasoning known to be a major difficulty for learners are "multiple representations", i.e. the fact that understanding the link between scientific phenomena and their conceptual basis requires the learner to deal with multiple representations at different levels of abstraction. These levels comprise e.g. a verbal description of a geometrical optics experiment, a photograph of it, a schematic description through ray diagrams, and a formal description by the magnification equation. All these representations are necessary to achieve a proper understanding of an image formation process. As Kohl et al. put it "*good use of multiple representations is considered key to learning physics*", yet there is ample evidence that this "*good use*" is difficult even for learners up to university level [27, 29, 30 ch. 6, ch. 8]. Much as in the case of conceptual understanding, measurement of learning to use multiple representations is necessary, and various tests are available [31, 32]. Test for numerous other aspects of physics education exist, such as problem solving [33, 34 ch. 5] use of math [35] and other competencies [8, 36], and also for affective aspects (interest!) and attitudes [37].

2.2 Interventions

> *[R]eform in science education should be founded on "scientific teaching", in which teaching is approached with the same rigor as science at its best.*
> ***J. Handelsman et al. (2004), Science, 304, 521 [38]***

Of course, one does not only want to *measure* educational outcomes, but also to *improve* them. I present two examples of effective interventions in physics education. The first is about low physics interest at school, especially among girls and how to improve it, a problem teachers know very well and are facing in their daily teaching. One wide-spread approach to counter this is context based science education (CBSE), i.e. "using concepts and process skills in real-life contexts that are relevant to students from diverse backgrounds" [39]. Making science issues relevant to students and their everyday life can counter the wide-spread perception of physics as being dry, impersonal and irrelevant, and this is supposed to have positive effects on motivation and learning [40, ch. 19.4.3]. However, look at Figure 3: it shows a striking "scissor"-form, with perceived relevance of physics increasing over the years, yet interest showing a marked decrease. Thus, just taking account of physics contexts in the sense of "making it relevant" [41] is *not* sufficient to maintain (or generate) pupil's interest [3]. Moreover, this decrease shows a strong gender bias: At the end of 5th grade, physics lessons are perceived as interesting or very interesting by about 40% of the girls and 60% of the boys, at the end of grade 10, it is about 20% and still 60%, respectively. Girls thus most likely will avoid physics in favour of biology, for their educational and career choices. We observe the consequences in the matura tracks of the gymnasium, and our physics classes at university: a gender ratio ($N_{♀}$ / $N_{♂}$) of 0.2 – 0.3 [43], and the decisive step for this does already happen at the end of secondary level one [4].

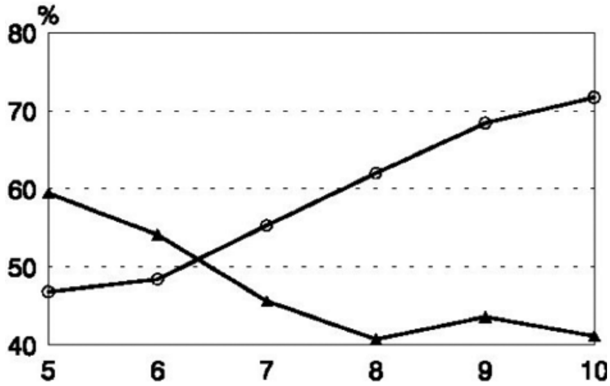


Figure 2: Development of interest (▲) for and of perceived relevance (○) of physics from begin to end of secondary level I in Germany (x-axis: grade; y-axis: % of maximum value, [42]).

What can be done? Figure 2 offers a revealing finding in that respect: When asking about the same physics topic related to different contexts, it turns out that girls interest for a biomedical context is much larger than that for a technical context; in fact it *increases* even against the general tendency during adolescence stated above (Figure 3; for boys the interest level for both contexts is similar and rather high (70%)). Note that context (kind of applications and activities) was shown to have a much stronger influence on physics interest than the specific content (subject matter): 80% of the variance of physics interest across the items of this study can be attributed to context, and only 20% by content. The Infobox "Context matters" presents concrete research-based examples of motivating contexts, leading to considerable effect sizes [5].

3 The interpretation is that in the period from the end of childhood (5th grade) to the young adults (10th grade), youths increasingly get aware of the large relevance of physics (science) for the world they live in, but that does not entail personal relevance and interest for themselves. This latter missing, one sees the a decline of interest, well-known from developmental psychology for this age group from almost all other school subjects as well.

4 Secondary level one is the school attendance period after primary till the end and of compulsory school, secondary level two the period after that (in the US system, this would be junior and senior high school, respectively).

5 The basic definition of an effect size (ES) is (MT – MC) / SD, where MT

Context matters

Context (of physics teaching) matters, and considerable beneficial effects have indeed been found e.g. in an extensive project about the research-based development and evaluation of teaching sequences using biomedical contexts for secondary level II: effect sizes for interest development before and after the sequence are *ES* = +0.45 with context vs. *ES* = –0.52 without context; [47, 48]. By way of example, the Fig. on the left shows an excerpt form the unit on forces on the backbone.

Other empirically validated forms of contexts interesting for young people have been provided by research [49]. Interestingly, among all areas of science, astronomy topics are among the most interesting ones for young people, much more interesting than many conventional school topics [50]. Another example for secondary level I physics is learning with problems based on newspaper articles and the real-life contexts provided by them (Newspaper Story Problems). When comparing the treatment group with a control group (learning with conventional tasks, but otherwise the same content, lesson plan, and the same teacher) there is a significant improvement of motivation (*ES* = 0.85, up to 1.3 for various topics), and a rather sustainable one (considerable improvement still after almost 4 months) [51]. An example for elementary kinematics is shown below, tasks are on average velocities and their comparison. For learning effects by the same approach see below.

Transatlantik-Weltrekord

(*si/apa*) Der Amerikaner Steve Fossett und seine neunköpfige Mannschaft haben am Mittwoch einen Transatlantik-Weltrekord (von West nach Ost) für Segelboote aufgestellt. Mit einem 38-Meter-Katamaran legten sie die 5417 Kilometer zwischen New York und der Südwestküste Englands in 4 Tagen, 17 Stunden und 28 Minuten zurück. Der Millionär Fossett unterbot den Rekord des Franzosen Serge Madec aus dem Jahr 1990 (6 Tage, 13 Stunden und 3 Minuten) um mehr als 43 Stunden.

Neue Züricher Zeitung, 11.10.2001

In sum, context is decisive for the development of physics interest, often more than content, but it has to be empirically tested *which* contexts are really interesting for young people; being "relevant" for adults (educators, researchers) is not sufficient (see also 2.4).

The second example is about physics learning in lecture type courses. Lecturers of introductory university courses often face the problem of having hundreds of students in their

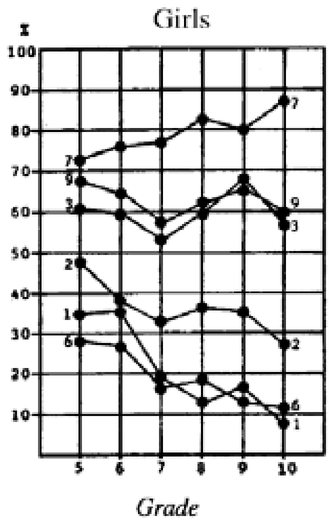


Figure 3: Percentage of girls with "great" and "very great" interest in selected contexts for the topic of mechanics (motion, force, pressure; [44]). Curve 7: artificial heart as blood pump; curve 2: pumping petrol from great depths (see [44] for the other contexts)

auditory, in particular in large enrolment universities or in physics minor classes. The classical solution for this is the frontal lecture, but there are doubts about the active intellectual engagement by students in this setting (look at the number of students using their smartphones in class, and this is only what you *see* of them not being involved). Are their more effective ways of conveying the basics of physics we consider as indispensable, and also e.g. to biology or medical students? Look at Figure 4, which shows the effects of a research-based teaching intervention in a introductory university course on electricity and magnetism. The teaching intervention introduces the following elements to enhance active intellectual participation of students [52]:

- preclass reading assignments + quizzes
- in-class clicker questions with student-student discussion
- targeted in-class instructor feedback (based on clicker data).

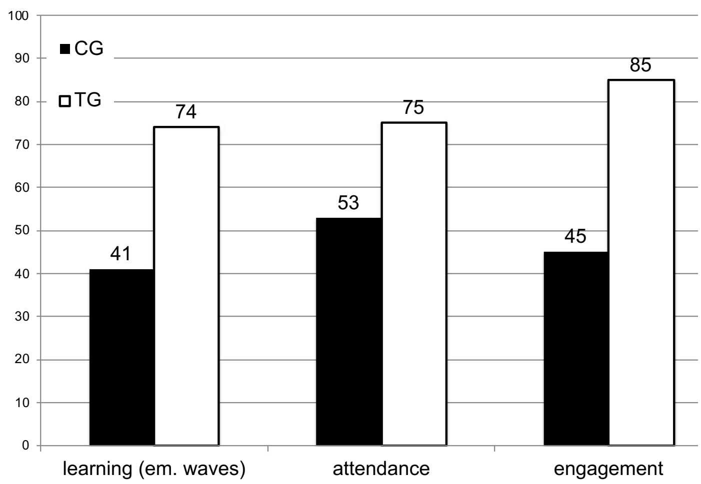


Figure 4: Comparison of effects of two teaching approaches on a learning test, attendance and active participation in a introductory university course on electricity and magnetism (y-axis: % of maximum value): CG (control group): traditional lecture style; TG (treatment group): "active learning" intervention, see text [52].

The results of a controlled comparison show a clear superiority of this approach over traditional lecturing for a learning test, attendance and active participation. The latter was assessed by an observation protocol for classroom behaviour; details of this and other elements of methodology and controls can be found in [52]. The effect on learning is 2.5 SDs, a very large value which the authors attribute to an instructional design which "maximized productive engagement". Moreover, this course method was well appreciated by students (e.g. "I would have learned more if the whole physics course would have been taught in that style": 77% agreement, 7% disagreement). The effectiveness of this

and MC are the means (of some variable of interest) for the treatment and control group, respectively, and SD is either the pooled standard deviation or that of the control group [45]. In simple terms, d thus measures the impact of an intervention in units of standard deviations of the sample under consideration. Usual effect-size levels (as established from comparison of a great many of studies in different areas) are small ($0.2 < d < 0.5$), medium ($0.5 \leq d < 0.8$) or large ($0.8 \leq d$) [45]. Many modifications and refinements of the concept of "effect size" have been developed and are used in the literature, see e.g. [46] for an overview.

kind of educational approach, called (inter-)active learning or interactive engagement according to various authors is backed by solid evidence over more than a decade, in particular by a large scale meta-analysis involving 225 studies and several ten thousands of students (see box "Active learning, interactive engagement").

There are many other examples of effective, evidence-based approaches for improving learning, such as selection of appropriate contexts for science learning. They may not only have positive effects on physics interest, as stated before, but also on learning. One example are the above-mentioned "Newspaper Story Problems" (effect sizes *ES* = 0.9 - 1.3 for the topics of elementary kinematics or of energy, [51]), or approaches integrating science, technology, and society [62]. Table 1 gives an overview of meta-analytic results for learning by various educational approaches.

Educational approach	***ES***	**ref.**
feedback [a)]	0.72	[58]
cooperative vs. individualistic science learning – school (primary and secondary) – university (undergraduates)	 0.95 0.51	 [59] [60]
enhanced questioning strategies [b)]	0.74	[59]
active learning approaches (for lectures) – across all sciences – physics	 0.47 0.72	[53]
homework – with feedback – without feedback	 0.83 0.28	[61]

Table 1: Meta-analytic results for learning (of science, if not stated otherwise) by some educational approches

[a)] *across all disciplines and a range of feedback methods*
[b)] *e.g., increasing wait time, adding pauses at key student-response points, including more high-cognitive-level questions, etc.*

2.3 Influences

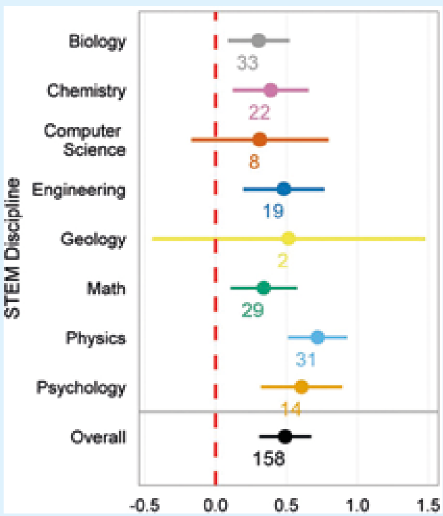
To understand (and design) educational processes one has to analyse them on a more fine-graded level than just comparing two approaches. Often a given educational measure will not work in the same way for different groups of learners (e.g. for boys and girls, see example regarding contexts above) or for different settings, and one has to study which influences are at play, from the side of the learner, teacher, setting, etc. A first informative example is about homework, a topic strongly debated among parents, teachers, and researchers: overall effects are between small and medium size (*ES* from 0.36 to 0.65), but a much clearer picture is obtained when taking account of feedback (by teachers comments or other methods) as influence, which leads to a large contrast (with: *ES* = 0.83, without: *ES* = 0.28; [61]). Of course, this does not close the discussion about homework, as feedback on homework is not always possible due to lack of time, or because several other influencing factors might be important in a given context. But this result is a useful element of this discussion: homework is *not* ineffective in general, as it is sometimes claimed, and feedback is decisive for its effectiveness.

Another example of an important influence, this time on the information processing level, is presented in the Infobox "Working Memory and Science Learning".

In general, as a recent review [71] puts it "*student success is influenced by such things as: demographics (age, gender, race, ethnicity, native language); intelligence and working memory; background knowledge and misconceptions; motivation, self-regulation, ability to pay attention, and persistence; self-concept and goal orientation, […]*" etc. It is e.g. a common situation at school that teachers face quite heterogeneous groups, and a recurrent problem is then that some innovation might work better for the those who score higher on some desirable attributes (interest, knowledge) already at the beginning than for those who score lower ("Matthew-effect", [72]). For physics learning, PER (together with general background form educational science) has provided many useful results about such influences, important for teaching practice, and in particular teacher education. The present article is limited to an example of an important influ-

Active learning, interactive engagement

The effectiveness of this kind of educational approach is backed by a large scale meta-analysis across several disciplines and many universities (see Figure and [53]) comparing active learning courses vs. traditional lectures. It yields an overall increase of learning by 0.47 SDs (for course exams, concept tests, and other assessment) and 0.88 SDs for concept tests in particular, as well as a decrease of failure rate from 34% to 22% (225 studies, ≈ 46000 and 29000 students for learning assessment and failure rate, respectively [53]).
For physics, a still larger effect was found for the overall effect on learning (0.72 SDs), a finding corroborated by another large study on introductory physics courses (600 classes, ≈ 45 000 students [54]). Similar approaches have been largely studied also at high school level, e.g. the predict-observe-explain sequence [55, 56, 57], which works even for demonstration experiments (which still are widespread and necessary for cost or security reasons), with the same main message: "Active learning increases student performance in science, engineering, and mathematics" [53], and it does so with considerable effect sizes, and is possible even in many teaching settings, including "frontal" ones [3].



Comparison of active learning courses vs. traditional lectures: Meta-analytic effect sizes (in SDs5) for learning (examination scores, concept inventories, or other measures) by discipline [53]. Error bars are 95% confidence intervals, below each data point the number of included studies is given.

Working Memory and STEM Learning

Several studies have yielded substantive correlations between working memory and STEM achievement, across age groups and across science disciplines (Table 2). All values found are larger (up to a factor 2) or at least comparable to the correlation between motivation and achievement [1], considered as very important e.g. by many science outreach initiatives by physics departments. Note that this is about working (or short term) memory, not long term memory. The interpretation, in terms of a metaphor, is that it is the CPU which limits interrelatedness and complexity which can be treated at a given time, not the hard disk drive capacity, and that these factors are decisive for the quality of knowledge and understanding, in particular for complex topics like physics. This might appear obvious, but it has very important implications for reducing "cognitive load" (working memory demand) for teaching and learning (limitations of space do not allow to present this in detail here, but see e.g. [63]).

STEM discipline (age/age group)	***r*** (correlation coefficient)	**comments**	**ref.**
physical sciences			
– chem. (uni. freshmen)	0.28 – 0.75	9 independent studies	[64]
– phys. (sec. I)	0.30		[65]
other STEM disciplines			
math (14 yrs)	0.54		[66]
science* (14 yrs)	0.50		
math (11 yrs)	0.58	large sample study, n ≈ 5000 – 10000 depending on test and age group	[67]
math (16 yrs)	0.63		
science* (11 yrs)	0.46		
science* (16 yrs)	0.60		
bio. (sec. I)	0.62		[68]
comparison value			
motivation-achievement	0.3 – 0.4	n > 500 000(!)	[69] [70]

Table 2: Correlation between working memory capacity and science achievement for different STEM disciplines and age groups (sec. I: secondary level one, uni.: university), to be compared to the correlation between motivation and science achievement, as comparison value. There is only one result for physics with a somewhat lower value, for which I do not have an explantion

**Note that "science" is taught in many countries not differentiated by disciplines.*

1 This holds also for the only study regarding physics, yielding a somewhat lower value than most other studies.

ence factor on the learner level [6] (working memory capacity), the method level (homework with or without feedback), and the teacher level (see 3.2). More complete discussions can be found e.g. in [1] and [73].

6 These influences are sometimes called “aptitude-treatment” or “attribute treatment” interactions in edcuational research.

2.4 Illusions (and ideology)

Let us come back to the necessity of measurement for taking educational decisions. Regarding science interest, we have already seen that it can be illusionary to believe that mere relevance is sufficient (Figure 3). A related result is about the PISA tasks, whose philosophy to ensure "relevance to students' interests and lives" is essential to PISA's understanding of scientific literacy ([10], p. 27). However, results show that for the available PISA items, students' perceived interest is at best medium, contrary to the basic assumption of PISA, and that it is also strongly overestimated by teachers [74]. Regarding learning, a first example is homework, already discussed in 2.3, where one sees that simplistic, ideological convictions ("homework is necessary"; "homework is punishment of families" [7]) do not lead anywhere.

Another example highly relevant for science education is inquiry-based learning (IBL), which finds strong support on the political level [75]. However, there is little empirical support for the effectiveness of IBL (*ES* = 0.31, [58]), and looking more closely, a meta-analysis on IBL in science by Furtak et al. [76] has shown that teacher guidance is a decisive influence factor: effect sizes are more than twice as large with guidance than without (*ES* = 0.65 and *ES* = 0.25, respectively). Unguided inquiry, as IBL is often understood, is thus not an effective approach for science learning. As in the case of homework, a differentiated, quantitatively based stance has to replace a simplistic, and sometimes ideological one.

Acknowledgements: This paper has benefited from numerous fruitful discussions with many collegues, in particular Hans Peter Beck (CERN), Bernhard Braunecker (Rebstein), Alice Gasparini (Geneva), Jean-Sébastien Graulich (Geneva), Hanns-Ludwig Harbey (Sierksdorf), Martin Pohl (Hamburg), Laura Weiss (Geneva).

Part 2 of this article will cover practical tasks of PER and services it can provide to the community (such as for teacher education). The contribution contains many empirical data and sources not necessarily well-known to physicists. In order to provide a proper documentation for these sources, the reference list is longer than usual in the "Progress in Physics" series.

References

[1] Docktor, J. L., & Mestre, J. P., Physical Review – Physics Education Research, **10**(2), 020119 (2014).
[2] Lehrer, R., and Schauble, L. (2006). Scientific thinking and science literacy. In K. A. Renninger, W. Damon, I.E. Sigel, and R.M. Lerner (Eds.), Handbook of child psychology (vol IV): Child psychology in practice. Hoboken, NJ: Wiley
[3] Meltzer, D. E., & Thornton, R. K., American journal of physics, **80**(6), 478-496 (2012).
[4] Wieman, C.,Change: The Magazine of Higher Learning, **39**(5), 9-15 (2007).
[5] Wieman, C. E., Educational Researcher, **43**(1), 12-14 (2014).
[6] Wieman, C., & Perkins, K., Physics today, **58**(11), 36 (2005).
[7] National Research Council (2001). Knowing what students know: The science and design of educational assessment (Committee on the Foundations of Assessment ; Pelligrino, J., Chudowsky, N., and Glaser, R., editors). Washington, DC: National Academy Press.
[8] Adams, W. K., & Wieman, C. E., International Journal of Science Education, **33**(9), 1289-1312 (2011)
[9] Liu, X. (2012). Developing Measurement Instruments for Science Education Research. Second International Handbook of Science Education.

7 *http://www.lemonde.fr/vous/article/2012/01/07/devoirs-scolaires-le-chatiment-familial_1627076_3238.html*

Fraser, B. J., Tobin, K., McRobbie, C. J. (Eds.). Dortrecht: Springer
[10] OECD (2006). Assessing Scientific, Reading and Mathematical Literacy. A Framework for PISA 2006. Paris: Organisation for economic cooperation and development
[11] Fraser B. J., Tobin K. and McRobbie C. (Eds.) (2012). Second International Handbook of Science Education. Dordrecht: Springer
[12] Hund, F. (1969). Grundbegriffe der Physik, Mannheim: BI
[13] Kuhn, W. (2016). Ideengeschichte der Physik: Eine Analyse der Entwicklung der Physik im historischen Kontext. Heidelberg: Springer
[14] McDermott L. C. and Redish E. F. , Am. J. Phys. **67**, 755 (1999).
[15] Freeman S., et al., Proc Natl. Acad Sci USA **111**:8410–8415 (2014).
[16] Shtulman, A., & Valcarcel, J., Cognition, **124**(2), 209-215 (2012).
[17] Thacker, B., Dulli, H., Pattillo, D., & West, K., Physical Review - Physics Education Research, **10**(2), 020104 (2014).
[18] Novick, S., Nussbaum, J., Science Education **85**, 187 (1981)
[19] Planinic, M., L. Ivanjek, & Susac A., Physical Review - Physics Education Research, **6**, 010103 (2010)
[20] Wang, J., & Bao, L., American Journal of Physics, **78**(10), 1064-1070 (2010).
[21] Traxler, A., Henderson, R., Stewart, J., Stewart, G., Papak, A., & Lindell, R., Physical Review Physics Education Research, **14**(1), 010103 (2018).
[22] LoPresto, M. C., & Murrell, S. R., Journal of College Science Teaching, **40**(5), 14-22 (2011).
[23] Grant, E. (1981). Much ado about nothing: Theories of space and vacuum from the middle ages to the scientific revolution. Cambridge University Press.
[24] Krebs, R. E. (1999). Scientific development and misconceptions through the ages: A reference guide. Westport, Conn: Greenwood Press
[25] Jammer, M. (1957/1999). Concepts of force. New York: Dover
[26] Madsen, A., McKagan, S. B., & Sayre, E. C., American Journal of Physics, **85**(4), 245-264 (2017).
[27] Lichtenberger, A., Wagner, C., Hofer, S. I., Stern, E., & Vaterlaus, A., Physical Review Physics Education Research, **13**(1), 010115 (2017).
[28] Ding, L., & Beichner, R., Physical Review - Physics Education Research, **5**(2), 020103 (2009).
[29] P. B. Kohl, D. Rosengrant, and N. D. Finkelstein, Physical Review - Physics Education Research **3**, 1, 010108-1–010108-10 (2007).
[30] Treagust, D., Duit, R., Fischer, H. E. (2017). Multiple Representations in Physics Education. Dordrecht, Netherlands: Springer.
[31] P. Nieminen, A. Savinainen, and J. Viiri, Physical Review - Physics Education Research **6**, 2 (2010).
[32] Klein, P., Müller, A., & Kuhn, J., Physical Review - Physics Education Research, **13**(1), 010132 (2017).
[33] Docktor, J., & Heller, K. (2009, November). Assessment of student problem solving processes. In AIP Conference Proceedings (Vol. 1179) College Park: AIP, pp. 133-136.
[34] NRC (National Research Council, 2012). Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering, Washington, DC: National Academies Press.
[35] Caballero, M. D., Doughty, L., Turnbull, A. M., Pepper, R. E., & Pollock, S. J., Physical Review Physics Education Research, **13**(1), 010118 (2017).
[36] Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy, S., ... & Warren, A., Physical Review - Physics Education Research, **2**(2), 020103 (2006).
[37] Khine, M.S. (2015) Attitude Measurements in Science Education: Classic and Contemporary Approaches. Charlotte, NC: Information Age Publishing.
[38] Handelsman, J., Ebert-May, D., Beichner, R., & Bruns, P. Science, **304**(5670), 521 (2004).
[39] Glynn, S., Koballa, T. R., (2005). The contextual teaching and learning approach. In R. E. Yager (Ed.), Exemplary Science. Best practices in professional Development. Arlington (VA): National Science Teacher Association Press, pp. 75-84.
[40] Kircher, E.; Girwidz, R.; Häußler, P.: Physikdidaktik - Theorie und Praxis, Berlin, Heidelberg, New York: Springer.
[41] Nentwig, P., & Waddington, D. (2005). Making it relevant: Context based learning of science. Münster: Waxmann.
[42] Muckenfuß, H., Naturwissenschaften im Unterricht, Physik, **7**/31, 20-25 (1996).
[43] Office fédéral de la statistique/OFS (2019), Etudiants des hautes écoles universitaires. Berne: OFS
[44] Hoffmann, L., Learning and instruction, **12**(4), 447-465 (2002)
[45] Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Erlbaum.
[46] Fritz, C. O., Morris, P. E., & Richler, J. J., Journal of experimental psychology: General, **141**(1), 2 (2012).
[47] Colicchia, G. (2002): Physikunterricht im Kontext von Medizin und Biologie: Entwicklung und Erprobung von Unterrichtseinheiten zur Steigerung des Interesses und für den fachübergreifenden Physikunterricht. (Doctoral dissertation). München: LMU München, Fakultät für Physik
[48] Wiesner, H. & Colicchia, G. (2010). Improving students interest – medical and biological contexts in physisics education. In C. P. Constantinou (Hrsg.), Physics Curriculum Design, Development and Validation (GIREP Conference 2008) Nicosia: Learning in Science Group, University of Cyprus.
[49] Bennett, J., Lubben, F., Hogarth, S., Science Education, **91**(3), 347-370 (2007).
[50] ROSE – Relevance in Science Education (2007-2018), *http://rose-project.no/*; see in particular: Sjøberg, S., & Schreiner, C. (2010). The ROSE project: An overview and key findings. Oslo: University of Oslo and Sjøberg, S, Schreiner, C. (2007). Reaching the minds and hearts of young people: What do we know about their interests, attitudes, values and priorities? What about the interest for space science? Bern: International Space Science Institute, Bern, *http://roseproject.no./network/countries/norway/eng/nor-sjoberg-issi-2007.pdf*
[51] Kuhn, J., Müller, A., Perspectives in Science: Progress in Science Education **2**, 5-21 (2014).
[52] Deslauriers L., Schelew E., Wieman C., Science **332**:862-4 (2011)
[53] Freeman S., et al., PNAS **111**:8410–8415 (2014).
[54] Von Korff, J., Archibeque, B., Gomez, K. A., Heckendorf, T., McKagan, S. B., Sayre, E. C., ... & Sorell, L., American Journal of Physics, **84**(12), 969-974 (2016).
[55] Yin, Y., Science scope, **35**(8), 48-53 (2012).
[56] Yin, Y., Tomita, M. K., & Shavelson, R. J., International Journal of Science Education, **36**(4), 531-552 (2014).
[57] Liew, C. W., & Treagust, D. F., Australian Science Teachers' Journal, **41**(1), 68-71 (1995).
[58] Hattie, A. C. (2009). Visible Learning. A synthesis of over 800 meta-analyses relating to achievement. London, New York: Routledge
[59] Schroeder , C., Scott, T., Tolson, H., Huang , T., & Lee, Y., Journal of Research in Science Teaching **44**, 1436-1460 (2007).
[60] Springer, L., Stanne M., and Donovan S., Review of Educational Research, Vol. **69**, No. 1, 1999, pp. 21–52.
[61] Marzano, R., Gaddy, B., Dean, C. (2000). "What Works In Classroom Instruction". Alexandria/VA: Association for Supervision and Curriculum Development
[62] Yager, R. E., & Weld, J. D., International Journal of Science Education, **21**(2), 169 – 194 (1999).
[63] Sweller, J., Ayres, P., & Kalyuga, S. (2011). Cognitive load theory: Explorations in the learning sciences, instructional systems and performance technologies. New York, NY: Springer.
[64] Tsaparlis, G., Research in Science & Technological Education, **23**(2), 125-148 (2005).
[65] Chen, W. C., & Whitehead, R., Research in Science & Technological Education, **27**(2), 151-160 (2009).
[66] Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. Applied Cognitive Psychology **18**(1), 1-16 (2004).
[67] Donati, G., Meaburn, E. L., & Dumontheil, I., Learning and Individual Differences, **69**, 84-93 (2019).
[68] Chu, Y. C. (2008). Learning difficulties in genetics and the development of related attitudes in Taiwanese junior high schools. (Doctoral dissertation). Glasgow: University of Glasgow, Centre for Science Education
[69] Wild, E., Hofer, M. & Pekrun, R. (2001). Psychologie des Lerners. In A. Krapp & B. Weidenmann (Hrsg.), Pädagogische Psychologie – Ein Lehrbuch (4. Aufl., S. 207-270). Weinheim: Beltz Psychologie Verlag.
[70] Uguroglu, M. E., & Walberg, H. J., American Educational Research Journal 16(4), 375-389 (1979).
[71] Berry, A., Friedrichsen, P., and Loughran, J., (Eds.). (2015). Re-examining Pedagogical Content Knowledge in Science Education. New York: Routledge.
[72] Walberg, H. J., & Tsai, S., American Educational Research Journal **20**, 359-373 (1983).
[73] Koran, M. L. and Koran J., Journal of Research in Science Teaching **21**(8):793-808, (1984)
[74] Weiss, L., & Müller, A., Zeitschrift für Didaktik der Naturwissenschaften, **21**(1), 87-97 (2015).
[75] Rocard M. et al. (2007) Science Education Now. A Renewed Pedagogy for the Future. Brussels: European Commission
[76] Furtak, E. M, Seidel, T., Iverson, H., Briggs, D., Review of Educational Research, **82**(3), 300-329 (2012). doi: 10.3102/0034654312457206

For editorial reasons this article is split in two parts. Part 2 will be published in the *SPG Mitteilungen* Nr. 59.

Milestones in Physics (15)

New Materials:
Symmetries, Dimensions, Structural Order and Disorder in Solids (part 2)

Hans Rudolf Ott, ETH Zürich

For editorial reasons this article is split in two parts. Part 1 has been published in the *SPG Mitteilungen* Nr. 57.

B. Fractal Solids - Aerogels

I. Introduction

In 1977, the mathematician Benoit B. Mandelbrot, at the time an IBM staff member and a visiting professor at Harvard University, published the book *Fractals: Form, Chance and Dimension* [64] followed by, five years later, *The Fractal Geometry of Nature* [65]. Together they constituted a milestone in Mathematics but, as briefly described below, the concept of fractals soon also reached out into the physics of solids. Initially, the number of publications on the connection between the concept of fractals and real materials was rapidly growing in theoretical physics. Experiments caught on when it was realized that random structures often exhibit fractal geometry in terms of the mass scaling exponent D, the fractal dimension [66]. For our purposes we recall that for common bulk crystalline solids the mass inside a sphere is $M(r) \sim r^d$ and $d = 3$. For fractal structures, however, $M(r) \sim r^D$ with the fractal (or Hausdorff) dimension $D \leq d$, not depending on r but implying some kind of order in an apparently disordered structure. It also means that if $D < 3$, large fractal objects exhibit a low density, decreasing with increasing r. The use of generalized dimensions is an important ingredient of these disordered systems.

An example of materials with random structures are aerogels, porous networks of SiO_2 particles. The porosity and hence the density depends strongly on the chosen process of synthesis. Their respective macroscopic mass densities are much lower than that of common amorphous glass (a-SiO_2) and their structural characteristics as aggregated clusters result in very large internal surfaces. The first synthesis of an aerogel was published by Kistler in 1931 [67], without raising much interest for investigating their, in hindsight, particular physical properties, both theoretically and experimentally.

The connection to Mandelbrot's work was established by considering that aerogels grow by random aggregation of particles and therefore end up as disordered, i.e., non-crystalline solids in the sense outlined in chapter A (see part 1). A theoretical modelling of this type of growth processes was attempted by Witten and Sander, assuming a diffusion-limited aggregation (DLA) [68, 69]. Simulations on the basis of this model resulted in demonstrating that such aggregates assume fractal or, in other words, self-similar properties. Soon thereafter, Alexander and Orbach coined the term fractons [70], related with the notion of the density of states of modes of excitations of fractals. It didn't take long until experimentalists recognized the opportunities for experimental verifications of the predicted properties of this new type of model materials.

Because of the structural characteristics of these aerogels it is expected that for describing physical properties that depend on the structural configuration and related excitations, it is required to distinguish different length scales in the probed samples [66]. The smallest length scale, a, relates to the size of the individual a-SiO_2 particles which, by aggregation, form fractals, the backbone of the structure, extending over the medium length scale of the order of the fractals' correlation length ξ. On the largest length scale, fixed by the size of the sample, the material may be regarded as a homogenous entity. Its fractal character or self-similarity is thus spatially restricted to the range between a and ξ. The description of the lattice excitations hence varies and one distinguishes, with decreasing length scale, between phonons, fractons and particle modes, whereby fractons are highly localized vibrational modes of the fractal entities. The expected dynamical behaviour of fractal networks and the meaning of the various considered dimensions is discussed in detail in [66].

Early attempts to experimentally verify the fractal nature of the structural network of aerogels and its vibrational properties and to deduce corresponding characteristic dimensions were based on employing scattering techniques such as small-angle scattering of X-rays (SAXS) [71] and of neutrons (SANS) [72], complemented by Brillouin and Raman scattering of light [73, 74] and other techniques [75]. An early review [76] summarizes the results and concludes that different methods confirm that the identified mass-fractal structure of aerogels is reflected in their vibrational properties. In particular, the experimental evidence for the crossover from phonon to fracton behaviour is emphasized. The character of the vibrational modes is also expected to change when their wavelength gets shorter than the size a of the individual particles via a crossover from the fracton to the particle regime. Experimental evidence for this was obtained from inelastic neutron scattering data [77, 78].

II. Thermal properties of aerogels

As outlined in chapter A of part 1, our group at ETH Zürich was partly involved in experimental investigations of quasicrystals at about the time when aerogels and their expected specific structural and dynamic properties caught the attention of theorists and, subsequently, experimentalists. Therefore it seems natural that we also got interested in this topic and set out to identify possible links between the claimed fractal structure and selected physical properties of these solids. Complementary to the above mentioned efforts to uncover the length-scale dependent structural and vibrational properties of aerogels by performing experiments employing various types of scattering methods, we concentrated on measurements of thermal properties, such as the temperature dependences of the specific heat $C_p(T)$ and the

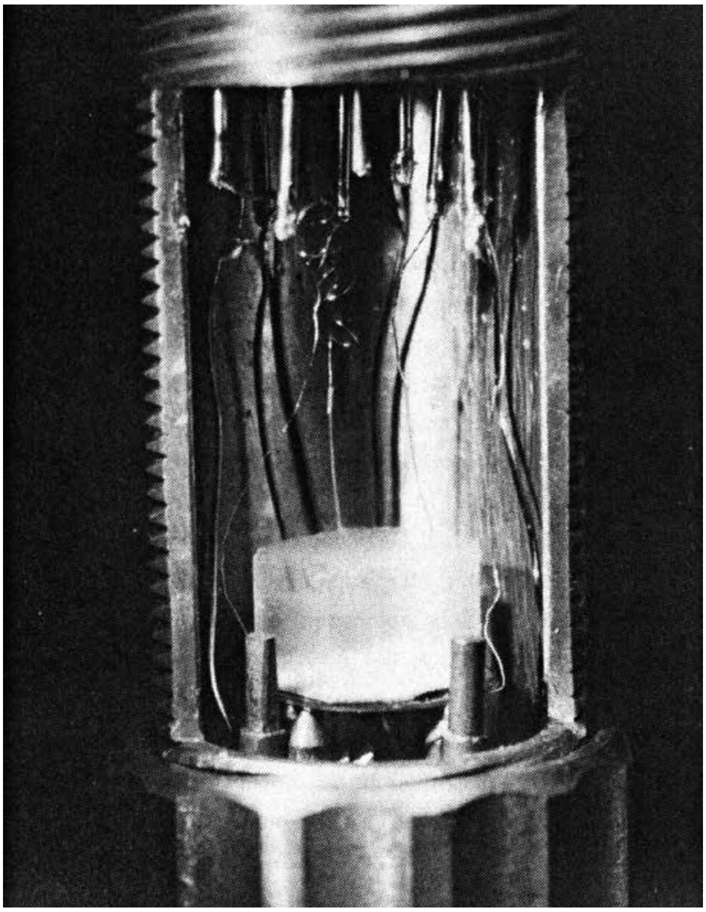


Fig. 12: Aerogel sample mounted in the calorimeter that allowed to extract data of both the speciific heat $C_p(T)$ and the thermal conductivity $\lambda(T)$ with a single measurement employing a dynamic technique.

thermal conductivity $\lambda(T)$. Since aerogels are electrical insulators, both these quantities are determined by structural excitations. As will be seen below, the really interesting temperature regime for our purposes is below 20 K and reaches down to below 0.1 K. The actors in this endeavour were Tycho Sleator, a post-doc from UC Berkeley, Angelo Bernasconi, a new doctoral student, and Dorte Posselt, a guest PhD-student from Risø National Laboratory in Denmark.

Although we were quite experienced in this type of measurements, some new problems had to be solved. First of all, this type of measurements in principle requires an efficient thermalization of the sample after externally imposed temperature variations. Since, due to the high porosity of the material, the internal thermal conductivity of aerogels is extremely low, this is not easy to achieve. The situation is aggravated because also thermal contacts to aerogels are, by nature of the material, rather weak and special measures in this regard were necessary. The general set-up of the samples that was used for all the measurements of the thermal properties described below is shown in figure 12. A particularly ugly fact that strongly influences the $C_p(T)$ data are remnants of unwanted impurities attached to the huge inner surface of aerogels, usually in the form of gases. This is exemplified in figure 13 where the influence of remnant hydrogen adsorbed on the inner surface of the sample on the low-temperature specific heat is demonstrated [79]. This also means that precooling the sample to low temperatures with the use of exchange gas is strictly prohibited. Therefore the precooling procedure took up to a week, a rather annoying situation. On the other hand, figure 14 demonstrates that

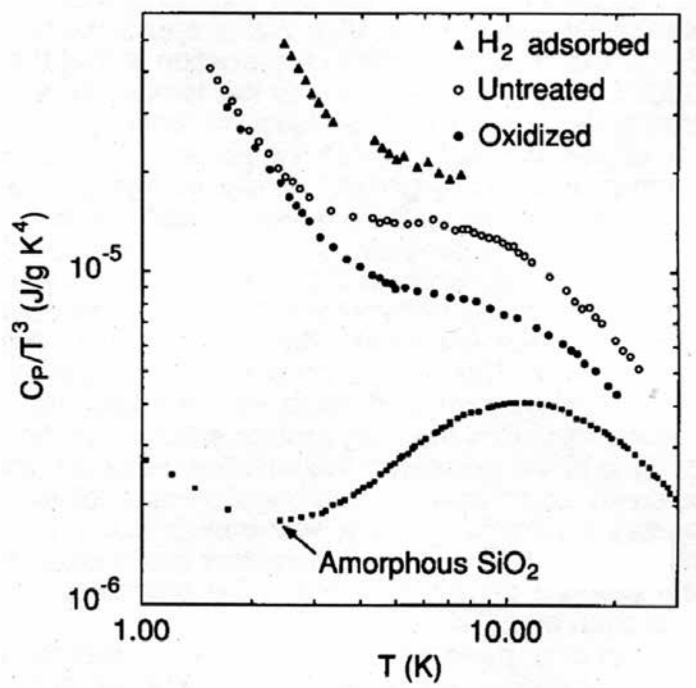


Fig. 13: Low-temperature specific heat $C_p(T)$ of a low-density (LD) aerogel sample under various conditions in comparison with bulk amorphous SiO_2.

the same types of adsorbants have no significant influence on the thermal conductivity.

Eventually all these problems were solved. The major contribution was the implementation of a dynamic method with which both the specific heat and the thermal conductivity could be extracted in one experiment at the chosen temperatures. The model on which the method is based and its physical realization are described in [80]. The comparison of data obtained from measurements probing samples of substantially different geometrical shapes and sizes confirmed that this dynamic method provides reliable data, also at very low temperatures. All samples measured were base-catalyzed Silica aerogels with different mass densities between 0.145 (low-density LD) and 0.275 (high-density HD) g/cm^3,

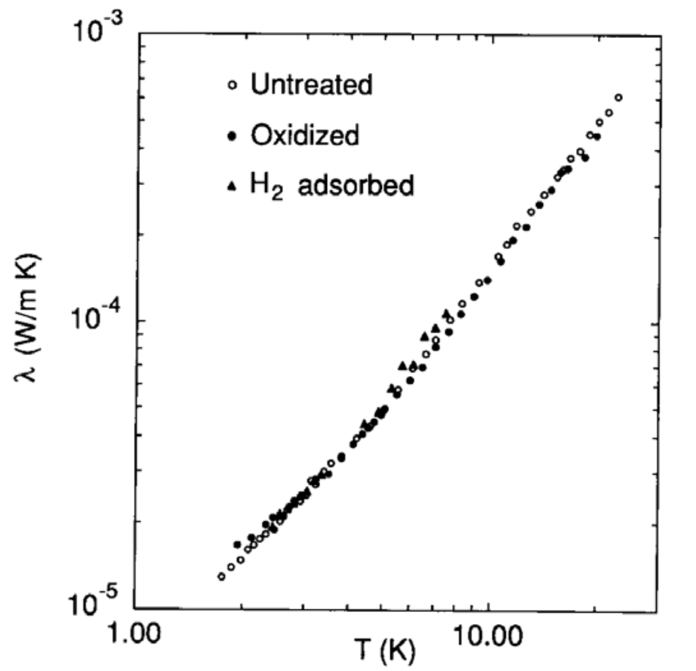


Fig. 14: Low-temperature thermal conductivity $\lambda(T)$ of an LD aerogel sample under various conditions.

and were provided by Airglass AB, Staffanstorp, Sweden. In order to remove unwanted synthesis-specific organic molecules from the inner surface which might add additional vibrational degrees of freedom, the samples were oxidized at elevated temperatures in an oxygen atmosphere. The samples were also characterized by additional experiments involving measurements of SANS, reported in detail in [81] and, with the help of R. Vacher, P. Xhonneux and E. Courtens at the IBM Laboratory in Rüschlikon, Brillouin scattering (BS) employing the same type of data analysis as is described in [82]. Yet, with the help of J. Gross and J. Fricke at the University of Würzburg, an additional set of data on the sound velocities was obtained employing a puls-echo method described in [83].

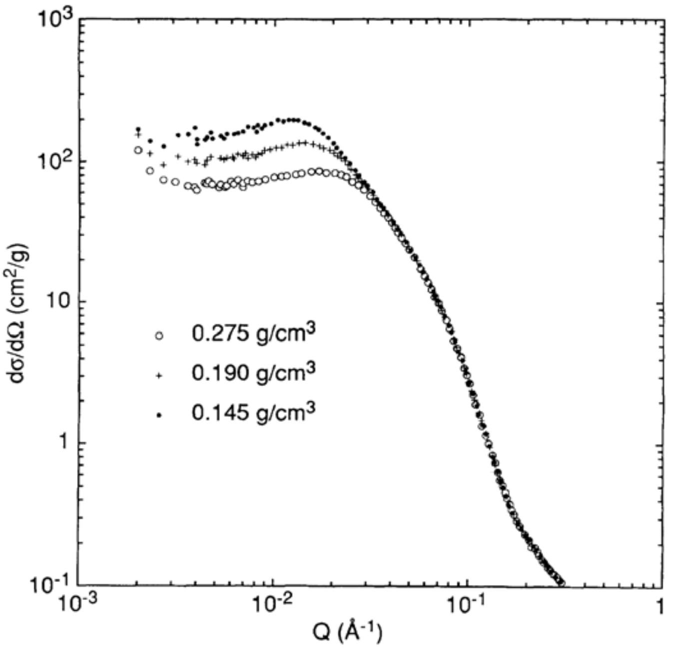


Fig. 15: SANS data on an absolute scale for base-catalyzed aerogels with 3 different densitities.

As an example, the SANS data for our samples are shown in figure 15. It may be seen that the SANS spectra of the samples with different mass densities exhibit structural similarities within a restricted length-scale regime and from the usual analysis of such data, a fractal dimension of $D = 2.2 \pm 0.2$ was deduced. With respect to the size of the individual a-SiO_2 particles, assuming them to adopt a spherical shape, their radius is estimated to adopt a value r ≈ 20 Å. These data imply that the coherence length ξ increases with decreasing density, from 210 Å in the high-density (HD) sample to 310 Å in the low-density (LD) material. The analysis of the BS measurements delivers the crossover frequencies ω_ξ and by setting $\omega_\xi = k_B T_\xi$, the crossover temperatures T_ξ. Both quantities increase with increasing density.

Usually the characteristic physical properties of aerogels are not compared with those of crystalline quartz (c-SiO_2) but rather with those of a-SiO_2. An early comparison of this sort was made with respect to thermal properties of base-catalyzed aerogels by De Goer and coworkers who concluded that speciific heat and thermal conductivity of aerogels are significantly different, both qualitatively and quantitatively, from those of bulk glassy materials, especially in the low-temperature regime at and below 1 K [84, 85]. Our results discussed below generally confirmed their findings but also provided additional important information, in particular with regard to verifications of theoretical-model predictions. Indeed, from our data we note that the usual concomitance of a linear-in-T variation of C_p and a T^2 dependence of λ in the same low-temperature régime is not observed in aerogels [86].

The main aim of our own contribution to this research was to cover the entire temperature range that would allow to map all three structural regimes mentioned above and to study the specifics of the transition regions around the length scales ξ and a. This implied that we had to extend the lower limit of the covered temperature regime to at least 0.05 K. As mentioned above it suffices to concentrate on data up to 20 K. A detailed discussion of theoretical aspects of identifying the vibrational properties of these three regimes is given in [87].

II.1. Specific heat

The specific heat at constant volume C_v of a solid depends only on the density $g(\omega)$ of active excitations which, in our case, is the density of vibrational states. In the temperature range of interest here, the directly accessible specific heat $C_p(T)$ is practically identical with $C_v(T)$. Hence, our data allow for a direct experimental check of different theoretical proposals of $g(\omega)$ in the different regimes of phonon-, fracton- and particle modes. Phonons may be regarded as collective modes of the network formed by the fractal clusters of spherical shape with wavelengths $\lambda > \xi$. The corresponding density of phonon states (DOS) is, as usual, $g(\omega) \sim \omega^2$. The vibration frequencies of fractons $\omega > \omega_\xi \sim v_s/\xi$ extend up to a cutoff frequency ω_F. The related DOS $g(\omega) \sim \omega^{\tilde{d}}$, with $\tilde{d}$ as the spectral dimension [70]. The particle modes are, obviously, internal modes of the small amorphous SiO_2 particles. It is this small size which complicates the relevant DOS for which both a bulk Debye-type ω^2 and a surface-type term ~ ω need to be considered [78, 88].

Figure 16 shows the temperature dependence of the specific heats in the form of C_p/T^3 of all three samples with low

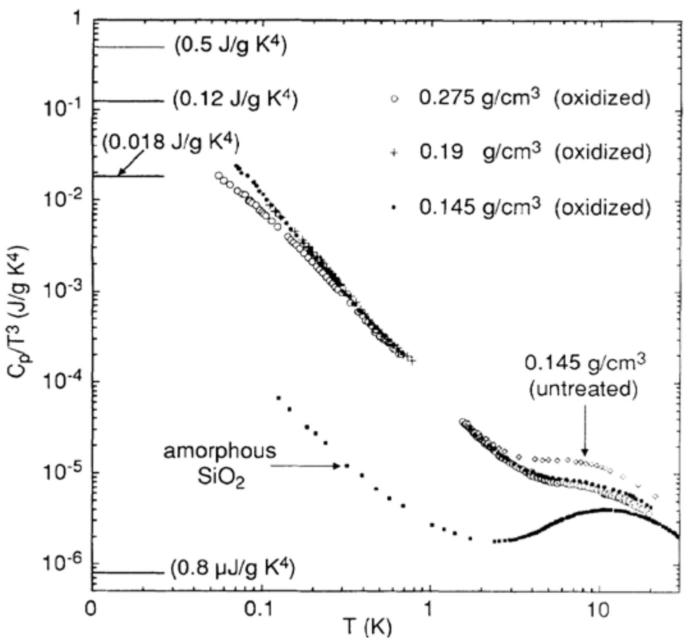


Fig. 16: C_p/T^3 of aerogels with 3 different densities at low temperatures on logarithmic scales in comparison with bulk a-SiO_2 [11,88]. For the understanding of the horizontal lines indicating the respective Debye limits see text.

(LD)- medium (MD)- and high (HD) mass density, respectively. For comparison also $C_p(T)$ data obtained for a-SiO_2 [11, 89] is shown. Most obvious is the order of magnitude difference between the two types of material, nota bene with the same chemical composition, below 1 K. This indicates that in this temperature range, the density of excitations must be much higher in aerogels than in the common glassy form of SiO_2. The above mentioned oxidation procedure is indeed effective in significantly removing extra specific heat as exemplified for the low-density material. We note that in the temperature range between 0.45 and 6 K, $C_p(T)$ obviously doesn't depend significantly on the mass densitiy ρ of the material.

Plotting C_p/T^3 is chosen in order to emphasize the deviation of the specific heat from the expected Debye-type behaviour with increasing temperature. For T << θ_D where θ_D is the Debye temperature, the prefactor A in $C_D(T) = A \times T^3$ depends on the mass density and the weight-averaged sound velocity v_s. The horizotal lines at the left margin of figure 16 indicate the respective calculated values from experimental values of ρ and v_s, starting from the top, for the LD, MD, HD and bulk a-SiO_2 material, respectively. For a-SiO_2 we note the onset of extra specific heat above the Debye limit below 2 K which varies linearly with T and is commonly attributed to excitations due to two-level systems as mentioned at the beginning of chapter A.II. in part 1. This situation is clearly different in the case of the studied aerogels where, with the exception of the high-density (HD) material, the C_p/T^3 ratio in the covered temperature range ($T > 55$ mK) is distinctly less than the calculated Debye limit. This in turn means that the Debye temperatures are very low. For the HD material we estimate $\theta_D = 18$ K. The same figure reveals an important difference between the HD and the LD material. At the lowest measured temperature the specific heat of the LD material is almost 2 orders of magnitude smaller than the respective Debye limit while at the same temperature this limit is almost reached for the HD material. Therefore the HD data for both $C_p(T)$ and $\lambda(T)$ is well suited to monitor the

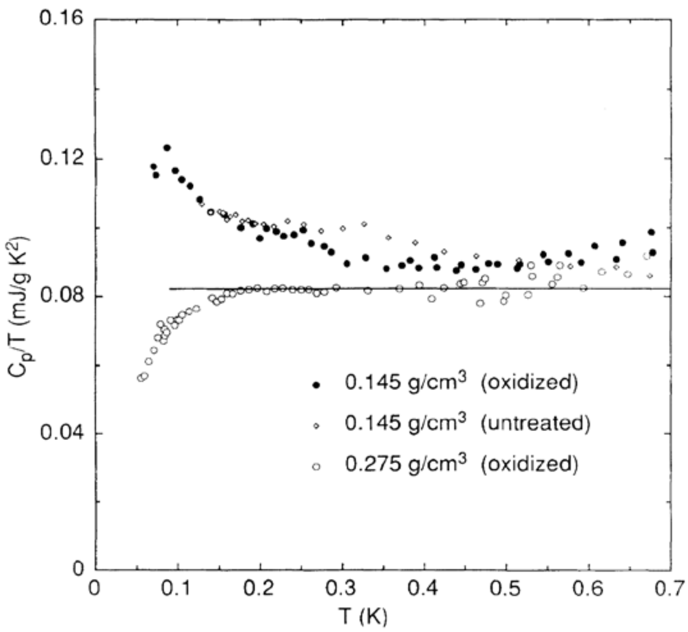


Fig. 17: C_p/T vs T between 0.05 and 0.7 K for LD and HD aerogel samples. The horizontal solid line emphasizes the near temperature independence of the C_p/T ratio for the HD material between 0.15 and 0.7 K.

cross-over regime from phonons to fractons. The LD data, however, serve to cover the entire fracton regime.

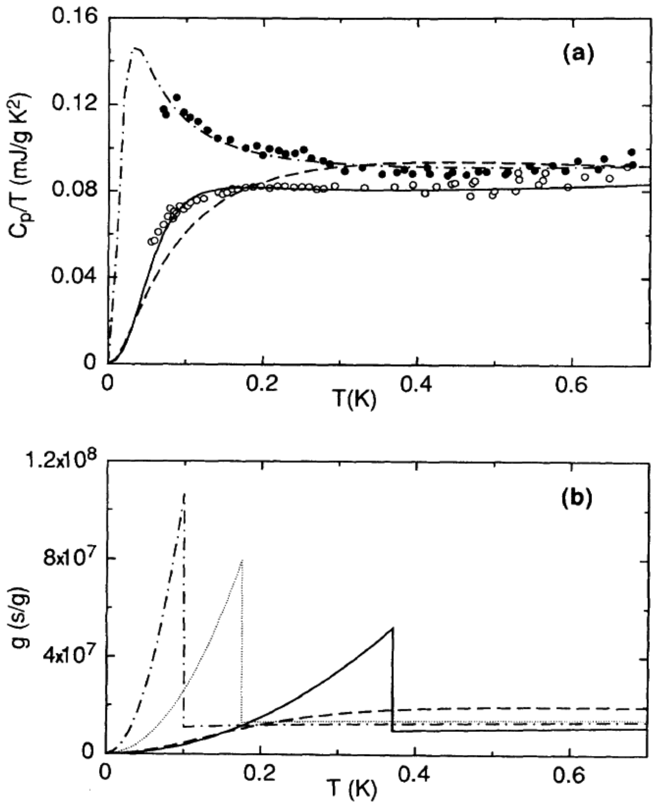


Fig. 18: (a) C_p/T vs T between 0.05 and 0.7 K for an HD (open circles) and a LD (filled circles) aerogel, respectively. The best fits, i.e., solid line for HD and dash-dotted line for LD in frame (a) are achieved with $g(\omega)$ represented by the same characteristic lines in frame (b). The broken lines demonstrate that a continuous $g(\omega)$ cannot fit the HD data shown in (a). The dotted line in (b) represents $g(\omega)$ that fits the data (not shown in (a)) obtained for the sample with $\rho = 0.19$ g/cm^3.

The C_p/T ratios of the LD and the HD aerogel for $T < 0.7$ K are plotted in figure 17. It may be seen that in this regime, the oxidation procedure does not influence C_p of the LD material. The horizontal solid line emphasises that between 0.15 and 0.7 K, the C_p/T ratio of the HD material is close to constant. It is obvious that, at the lowest temperatures, the T-dependence of specific heat and hence $g(\omega)$ in the crossover region, depends on the mass density. As demonstrated in figure 18, our data are consistent with a discontinuity of the DOS at the crossover, a feature that, on the basis of theoretical arguments and numerical calculations, is to be expected [90-92]. In some cases this claim found no support from other numerical calculations and experiment [83, 93-94] and therefore was seriously questioned. However, as shown in figure 18, fits with continuously varying $g(\omega)$ turned out to fail in reproducing the here presented experimental data. The respective successful fits provide numerical values for the parameters T_ξ and $\tilde{d}$. Both parameters vary with ρ. For the LD and HD material, respectively, the former adopts values of 0.10 K and 0.37 K while the latter is found to be 1.11 and 1.21. Thus it turns out that the fracton-phonon crossover may be identified for the HD material but not quite so for the LD material.

The high-temperature (T > 1 K) features of $C_p(T)$ are described in detail in [88].

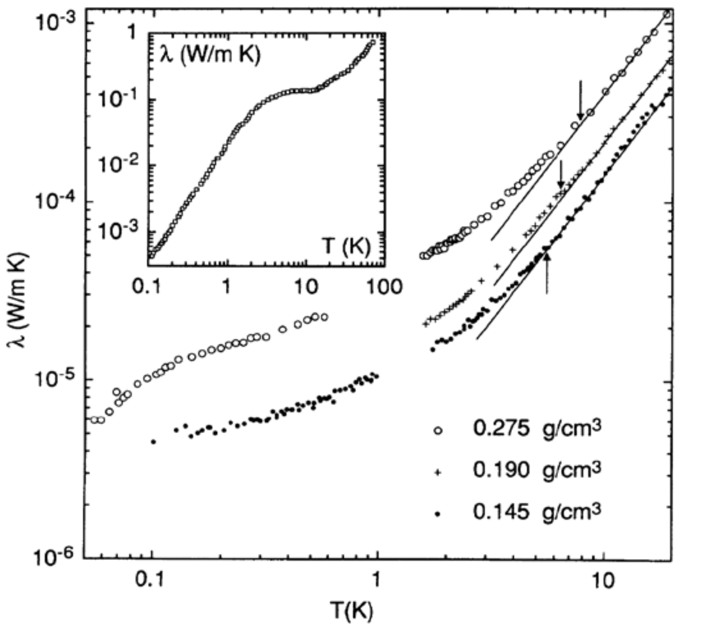


Fig. 19: The thermal conductivity $\lambda(T)$ of SiO_2 aerogels with different densities. The 3 parallel solid straight lines at elevated temperatures reveal that in this T-regime the variation of λ with temperature is the same for all samples. The inset shows $\lambda(T)$ for bulk a-SiO_2. The arrows mark the onset of the deviations from the universal power-law type of behaviour.

II.2. Thermal conductivity

Contrary to the specific heat data, the experimental values of $\lambda(T)$ are not affected by the oxidation procedure. In the main frame of figure 19, $\lambda(T)$ data for the aerogel samples with different densities are plotted on logarithmic scales. For comparison, the inset shows analogous data for bulk a-SiO_2. Both qualitative and quantitative differences between the two types of materials may be identified. Most obvious is the much lower, by between two and three orders of magnitude, thermal conductivity of the aerogels in comparison with glassy material in the covered temperature range. Moreover, the typical plateau in $\lambda(T)$ of a-SiO_2 between 2 and 10 K is clearly not observed in aerogels in the temperature regime of interest, confirming that simply assuming the scattering of phonons at two-level systems (or tunneling states) is not sufficient to explain the overall features of $\lambda(T)$ of the latter. The gradual flattening of $\lambda(T)$ with deceasing temperature is, for the HD material, followed by a distinct slope change below 0.13 K. This feature turns out to be related to the crossover from the fracton to the phonon regime as reflected in the HD $C_p(T)$ data. Likewise the LD $\lambda(T)$ data indicates that for the observation of the analogous feature of this material, the measurements would have to be extended to lower temperatures.

II.2.1. High temperatures

At high temperatures the power-law feature of $\lambda(T)$ is qualitatively the same for all three samples but the temperature where the deviation from the power-law behaviour sets in, as marked by arrows, increases with increasing density. As explained in detail in [88], this onset of slope change reflects, with increasing temperature, the crossover from the fracton to the particle regime. In general, the total thermal conductivity consists of three components

$$\lambda_{tot}(T) = \lambda_{ph}(T) + \lambda_{fr}(T) + \lambda_{par}^{aerogel}(T)$$

whereby each component is dominant in a restricted temperature range. At high temperatures the short wavelength particle modes dominate while at the lowest temperatures the excitations are simply phonons. In between, the new type of excitations termed fractons may be identified as explained below.

As mentioned above, the slope of $\lambda_{tot}(T)$ above 8 K is the same for all the measured samples with different densities and therefore must reflect the intrinsic properties of the material, i.e., a-SiO_2, via the particle modes. Since the basic particles are connected at singular points, this contribution is given by $\lambda_{par}^{aerogel}(T) = \lambda_{am} \cdot \phi$, where λ_{am} is the thermal conductivity of a-SiO_2 and $\phi \le 1$. The latter depends on the structure and the resulting connectivity between particles. Thus the parameter ϕ may be understood as the average density of connection points in a plane perpendicular to the heat flow. Considering the size of the single amporphous particles, it is realistic to assume that the mean free path is given by the diameter a of the assumed spherical SiO_2 particles of the order of 20 to 40 Å. In this case $\lambda_{par}^{aerogel}(T) = \frac{1}{3} \upsilon_a \cdot a \cdot \rho_a \cdot C_a(T) \cdot \phi$ [95]. The resulting simple relation between $\lambda_{par}^{aerogel}(T)$ and $C_a(T)$ is experimentally verified in [95].

It should be noted that in the range between 5 and 10 K, where $\lambda(T)$ of bulk a-SiO_2 exhibits the notorious plateau shown in the inset of figure 19, $\lambda_{par}^{aerogel}(T)$ and hence also λ_{am} varies significantly with temperature. This observation makes theoretical arguments [96, 97] to relate the plateau in bulk amorphous materials with fractal features at very low length scales (< 40 Å) of the latter questionable.

II.2.2. Low temperatures

In [95] it is demonstrated that $\lambda_{tot}(T)$ decreases strictly linearly with T below 3 K down to well below 1 K. Theoretically it has been shown [98, 99] that the sum of the pho-

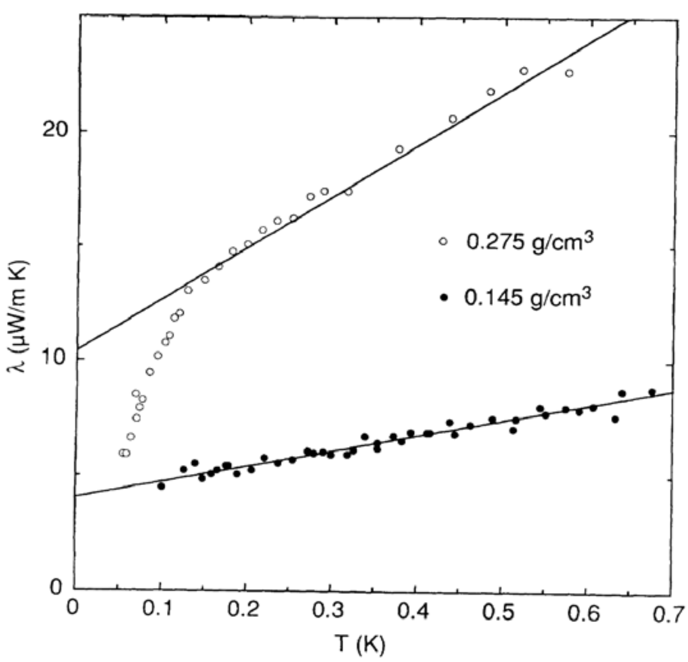


Fig. 20: $\lambda(T)$ between 0.05 and 0.7 K of the HD- and the LD aerogel sample, respectively. The solid-line fits are explained in detail in [88].

non and fracton contributions to $\lambda_{tot}(T)$ may be written as $\lambda_{ph,fr} = A + B \cdot T$. The phonon modes are saturated above the crossover and responsible for the temperature independent contribution *A*. Due to the anharmonic interaction between the phonons and the localized fractons, the fractons gain motion via hopping and thus contribute to the transport of energy. For our purposes, data for $\lambda_{tot}(T)$ of the HD and LD aerogels, respectively below 0.7 K are shown in figure 20. At the low end of the temperature regime, the features of the HD- and the LD material differ significantly. The clear drop of $\lambda_{tot}(T)$ of the HD sample reflects the fracton-phonon cross-over. No similar drop occurs for the LD sample, supporting the above-discussed interpretation of the specific-heat data and confirming that $T_\xi^{LD} < T_\xi^{HD}$ and therefore, the phonon-dominated regime is not accessed in this case. From the straight lines that fit the data, values for the characteristic length ξ of fractal clusters can be obtained. The resulting values for the HD and LD material are 370 ± 30 and 1030 ± 90 Å, respectively, larger than those evaluated from the SANS data, cited above. A similar observation was reported in [82], where ξ values evaluated from BS data were about 5 times larger than those obtained from SANS data of the same material. As demonstrated in [95], the here quoted larger values are consistent with evaluations of T_ξ invoking the experimental data for v_s.

III. Summary and Concluding Comment

The studies of thermal properties of aerogels described above resulted in the experimental verification of three different temperature regimes where different contributing structural excitations are dominating. These are, with decreasing temperature, the particle-, the fracton- and the phonon mode regimes. Especially the new, theory-based introduction of the fracton concept is well justified and supported by experimental observations.

It is at least amusing if not satisfying to see that a milestone in mathematics can be at the basis of vigorous theoretical and experimental activities in the physics of solids, involving a somewhat unusual type of material that might have remained largely unnoticed without the motivation from an unexpected direction.

References

[64] B. B. Mandelbrot, *Fractals: Form, Chance and Dimension*, (Freeman, San Francisco, 1977).
[65] B.B. Mandelbrot, *The Fractal Geometry of Nature*, (Freeman, San Fransisco, 1982).
[66] R. Orbach, Science **231**, 814 (1986).
[67] S. S. Kistler, Nature **127**, 741 (1931).
[68] T. A. Witten, Jr. and L. M. Sander, Phys. Rev. Lett. **47**, 1400 (1981).
[69] T. A. Witten and L. M. Sander, Phys. Rev. B **27**, 5686 (1983).
[70] S. Alexander and R. Orbach, J. Physique-Lettres **43**, L625 (1982).
[71] D. W. Schaefer and K. D. Keefer, Phys. Rev. Lett. **20**, 2199 (1986).
[72] R. Vacher, T. Woignier, J. Pelous, and E. Courtens, Phys. Rev. **37**, 6500 (1988).
[73] E. Courtens, J. Pelous, J. Phalippou, R. Vacher, and T. Woignier, Phys. Rev Lett. **58**, 128 (1987).
[74] Y. Tsujimi, E. Courtens, J. Pelous, and R. Vacher, Phys. Rev. Lett. **60**, 2757 (1988).
[75] D. Rojanski, D. Huppert, H. D. Bale, X. Dacai, P. W. Schmidt, D. Farin, A. Seti-Levy, and D. Avnir, Phys. Rev. Lett. **56**, 2505 (1986).
[76] R. Vacher and E. Courtens, Physica Scripta, T**29**, 239 (1989).
[77] R. Vacher, E. Courtens, G. Coddens, J. Pelous, and T. Woignier, Phys. Rev. B **39**, 7384 (1989).
[78] R. Vacher, T. Woignier, J. Pelous, G. Coddens, and E. Courtens, Europhys. Lett. **8**, 161 (1989).
[79] A. Bernasconi, T. Sleator, D. Posselt, and H. R. Ott, Physica B **165** & 166, 903 (1990).
[80] A. Bernasconi, T. Sleator, D. Posselt, and H. R. Ott, Rev. Sci Instrum. **61**, 2420 (1990).
[81] D. Posselt, PhD thesis, Risø National Laboratory, Denmark, 1990.
[82] E. Courtens, R. Vacher, J. Pelous, and T. Woignier, Europhys. Lett. **6**, 245 (1988).
[83] J. Gross, G. Reichenauer, and J. Fricke, J. Phys. D: Appl. Phys. **21**, 1447 (1988).
[84] A. M. De Goer, B. Salce, R. Maynard, and A. Zarembowitch, Europhys. Lett. **3**, 1205 (1987).
[85] A. M. De Goer, R. Calemczuk, B. Salce, J. Bon, E. Bonjour, and R. Maynard, Phys.Rev. B **40**, 8327 (1989).
[86] A. Bernasconi, T. Sleator, D. Posselt, J. K. Kjems, and H. R. Ott, Phys. Rev. Lett. **66**, 1070 (1991).
[87] A. Bernasconi, T. Sleator, D. Posselt, J. K. Kjems, and H. R. Ott, Phys. Rev. B **45**, 10363 (1992).
[88] H. P. Baltes, and E. R. Hilf, Solid State Commun. **12**, 369 (1973).
[89] P. Flubacher, A. J. Leadbetter, J. A. Morrison, and B. P. Stoicheff, J. Phys. Chem. Solids **12**, 53 (1959).
[90] P. F. Tua and S. J. Putterman, Phys. Rev. B **33**, 2855 (1986).
[91] B. Derrida, R. Orbach, and K-W. Yu, Phys. Rev. B **29**, (1984).
[92] A. Aharoni, S. Alexander, O. Entin-Wohlmann, and R. Orbach, Phys. Rev. B **31**, 2565 (1985).
[93] K. Yakubo, and T. Nakayama, Phys. Rev. B **36**, 8933 (1987).
[94] H. Conrad, U. Buchenau, R. Schätzler, G. Reichenauer, and J. Fricke, Phys. Rev. B **64**, 2316 (1990).
[95] D. Posselt, J. K. Kjems, A. Bernasconi, T. Sleator, and H. R. Ott, Europhys. Lett. **16**, 59 (1991).
[96] S. Alexander, C. Laermans, R. Orbach, and H. M. Rosenberg, Phys. Rev. B **28**, 4615 (1983).
[97] P. F. Tua, S.J. Puttermann, and R. Orbach, Phys. Lett. **98**A, 357 (1983).
[98] S. Alexander, O. Entin-Wohlman, and R. Orbach, Phys. Rev. B **34**, 2726 (1986).
[99] A. Jagannathan, R. Orbach, and O. Entin-Wohlman, Phys. Rev. B **39**, 13465 (1989).

Meilensteine der Physik (16)

Die CP-Verletzung im Standard Modell

Ralph Eichler, ETH Zürich und Tatsuya Nakada, EPF Lausanne

Die CP-Transformation kombiniert C für elektrische Ladungsänderung und P für Parität (zum Beispiel eine Linksschraube geht über in eine Rechtsschraube). Einzig die schwache Wechselwirkung verletzt C und P, alle anderen Wechselwirkung sind invariant unter C und P. Das W-Boson, der Vermittler der schwachen Wechselwirkung koppelt an linkshändige Elektronen e_L^- und an die CP-konjugierten rechtshändigen Positronen e_R^+. Wäre CP eine exakte Symmetrie, so wären die Naturgesetze für Materie und Antimaterie gleich.

CP-Verletzung wurde erstmals im Jahr 1964 im Zerfall der neutralen K-Mesonen beobachtet [1]. Unter der Annahme von CP-Paritätserhaltung haben die beiden Kaonen-Masseneigenzustände eine definierte CP-Parität CP = +1 resp. CP = -1:

$$K_S = \frac{1}{\sqrt{2}}(K^0 + \bar{K}^0) \text{ und } K_L = \frac{1}{\sqrt{2}}(K^0 - \bar{K}^0) \;,$$

und bei CP-Erhaltung sollten die Zerfallszustände auch Eigenzustände von CP sein. Es wurde jedoch das Gegenteil beobachtet:

$$\frac{K_L \to \pi^+\pi^-}{K_S \to \pi^+\pi^-} = \eta_{+-}^2 \approx 0.00224 \text{ und auch}$$

$$\frac{(\Gamma(K_L \to \pi^- e^+ \nu_e) - \Gamma(K_L \to \pi^+ e^- \bar{\nu}_e))}{(\Gamma(K_L \to \pi^- e^+ \nu_e) + \Gamma(K_L \to \pi^+ e^- \bar{\nu}_e))} \approx 0.00334 \;.$$

Im Standard Modell wird die CP-Verletzung durch eine einzige komplexe Phase in der Parametrisierung der Massenmatrix der Quarks vollständig beschrieben. Diese Phase erscheint in der 3×3 Matrix, welche die Flavour Eigenzustände der Quarks u, d, s, c, b, t in die Quark-Zustände der schwachen Wechselwirkung mit bestimmten Massen transformiert. Man nennt sie die *Cabbibo-Kobayashi-Maskawa Matrix* $V_{qq'}$ (CKM-Matrix) [2]. Die Matrix lässt sich parametrisieren mit drei Eulerwinkeln β, γ, θ und einer Phase δ. Es bedeuten im Folgenden $c_\gamma = \cos\gamma$ und $s_\gamma = \sin\gamma$ etc.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\gamma & s_\gamma \\ 0 & -s_\gamma & c_\gamma \end{pmatrix} \begin{pmatrix} c_\beta & 0 & s_\beta e^{-i\delta} \\ 0 & 1 & 0 \\ -s_\beta e^{i\delta} & 0 & c_\beta \end{pmatrix} \begin{pmatrix} c_\theta & s_\theta & 0 \\ -s_\theta & c_\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

In dem von Kobayashi und Maskawa vorgeschlagenen Modell mit drei Quark-Familien kann eine CP-Verletzung in der Zerfallsamplitude auftreten, wobei zwei unterschiedliche Zerfallsvorgänge interferieren. Dies erzeugt zum Beispiel einen kleinen Unterschied in den CP-Verletzungseffekten der beiden Zerfälle $K_L \to \pi^+\pi^-$ und $K_L \to \pi^0\pi^0$, parametrisiert durch η_{+-} respektive η_{00}, dessen kleine Differenz proportional dem phänomenologischen Parameter ε' ist. In anderen theoretischen Modellen, wie dem von Wolfenstein vorgeschlagenen Superweak-Modell [3] werden in den Zerfallsamplituden keine CP-Verletzungen erzeugt.

Da die Differenz ε' eine Differenz kleiner Zahlen bei geringen CP-Verletzungen ist, war die experimentelle Beobachtung sehr schwierig. Nach mehr als 30-jähriger Anstrengung wurde der Effekt $\eta_{+-} \neq \eta_{00}$ im Jahr 2001 durch Experimente bei CERN und FNAL endgültig etabliert. Die Größe des Effekts war mit den theoretischen Erwartungen des Modells von Kobayashi und Maskawa vereinbar.

Während die Zerfallsvorgänge durch schwache Wechselwirkungen von Quarks beschrieben werden, die mit Hilfe der Störungstheorie zuverlässig behandelt werden können, umfasst die Berechnung von tatsächlichen Zerfallsamplituden einen Beitrag der starken Wechselwirkung, da der Anfangszustand und der Endzustand aus Hadronen besteht. Dieser Beitrag kann nicht in Störungsrechnung hergeleitet werden. Daher sind die theoretischen Unsicherheiten in den Vorhersagen von ε' beträchtlich. Die Situation hat sich mit den jüngsten Fortschritten bei der Gitterberechnung deutlich verbessert. Die aktuellen Unsicherheiten sind jedoch immer noch dreimal größer als die experimentelle Unsicherheit.

Das CPLEAR Experiment am CERN

Im CPLEAR Experiment am CERN, an dem vier Schweizer Institutionen, die Universität Basel, die Universität Freiburg, das SIN (jetzt PSI) und die ETHZ eine wichtige Rolle spielten, wurden neutrale Kaonen in Proton-Antiproton Vernichtungen wie $p\bar{p} \to K^0 K^- \pi^+$ und $p\bar{p} \to \bar{K}^0 K^+ \pi^-$ untersucht. Dabei wird der ursprüngliche Flavour des neutralen Kaons durch das geladene Kaon und Pion markiert, die von dem $p\bar{p}$ Annihilationspunkt kommen. Da die Antiprotonen vor der Annihilation gestoppt wurden, sieht der CPLEAR Detektor wie bei einem Collider aus.

Im Experiment wurde die CP-Verletzung also nicht wie bisher mit K-Zerfällen untersucht, sondern durch Vergleich des Prozesses mit einem anfänglichen K^0 respektive mit dem CP-konjugierten Prozess mit einem anfänglichen $\bar{K}^0$. Die

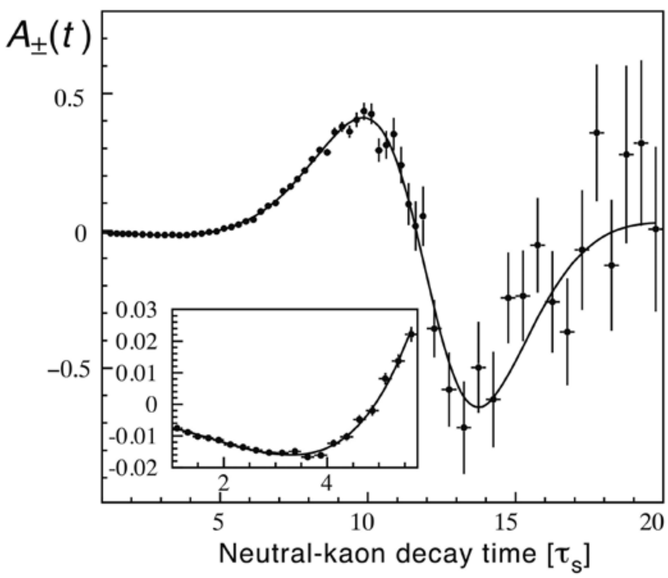


Bild 1: CP-Asymmetrie $A_\pm(t)$ gemessen durch das CPLEAR-Experiment. Durch einen Fit der theoretischen Verteilung wurde η_{+-} extrahiert. Die durchgezogene Linie zeigt das Ergebnis des Fits an.

von der Zerfallszeit abhängige CP-Asymmetrie für die anfänglichen K^0 resp. $\bar{K}^0$ in $\pi^+\pi^-$ Endzustände ist definiert als

$$A_{\pm}(t) = \frac{(\bar{R}_{\pm}(t) - R_{\pm}(t))}{(\bar{R}_{\pm}(t) + R_{\pm}(t))}$$

wobei $R_{\pm}(t)$ die zeitabhängige Zerfallsrate von $K^0 \rightarrow \pi^+\pi^-$ und $\bar{R}_{\pm}(t)$ die entsprechende Zerfallsrate von $\bar{K}^0 \rightarrow \pi^+\pi^-$ ist (siehe Bild 1). Eine von Null verschiedene Asymmetrie zeigt, dass die beiden Prozesse unterschiedlich sind, d. h. eine klare Demonstration einer CP-Verletzung. Durch den Fit der beobachteten Asymmetrie an die erwartete Form wurde im CPLEAR-Experiment der CP-verletzende Parameter $|\eta_{+-}| = (2.264 \pm 0.023) \cdot 10^{-3}$ extrahiert [4].

Ein weiteres interessantes Ergebnis des CPLEAR-Experiments bestand darin zu zeigen, dass die beobachtete CP-Verletzung im neutralen Kaon-System auf die CP- und T-Verletzung der $K^0 \longleftrightarrow \bar{K}^0$ Oszillationen zurückzuführen ist. Der Flavour des neutralen Kaons zum Zeitpunkt des Zerfalls kann mit semileptonischen Zerfällen identifiziert werden: $K^0 \rightarrow e^+\pi^-\nu$ und $\bar{K}^0 \rightarrow e^-\pi^+\bar{\nu}$. Daher kann das Experiment CP- und T-konjugierte Prozesse $K^0 \rightarrow \bar{K}^0$ und $\bar{K}^0 \rightarrow K^0$ sowie CPT- und CP-konjugierte Prozesse $K^0 \rightarrow K^0$ und $\bar{K}^0 \rightarrow \bar{K}^0$ vergleichen. Das Experiment beobachtete die Unterschiede im CP- und T-konjugierten Prozess und keinen Unterschied im CPT- und CP-konjugierten Prozess. Die erwartete Funktion der Asymmetrie zwischen $K^0 \rightarrow \bar{K}^0$ und $\bar{K}^0 \rightarrow K^0$ zeigt, dass die im neutralen Kaon-System beobachteten Phänomene der CP-Verletzung durch die CP- und T-Verletzung in den $K^0 \longleftrightarrow \bar{K}^0$ Oszillationen erklärt werden können [5].

CP-Verletzung bei schweren Quarks

Da die Kaonen nur aus leichten Quarks bestehen und die CP-Verletzung damals nur hier beobachtet wurde, war es in den 1980er Jahren nicht klar, ob die komplexe Phase eine universelle Beschreibung der CP-Verletzung auch bei schweren Quarks wie Charm oder Bottom zulässt. Die erste ausgearbeitete Idee, nach der CP-Verletzung bei B-Mesonen zu suchen, entstand in der Schweiz.

Das Potenzial für das Studium der CP-Verletzung im B-Meson-System im Rahmen des Standardmodells wurde 1981 zuerst von Carter und Sanda [6] und anschließend von Bigi und Sanda [7] in mehreren Arbeiten untersucht. In diesen Papieren wurde darauf hingewiesen, dass die CP-Verletzung im B-Mesonen-System sehr gross sein kann. Es wurde auch darauf hingewiesen, dass bei einigen Zerfallsmodi, wie dem Zerfall des neutralen B-Mesons in einen $J/\psi K_s$ Endzustand, der Effekt einer CP-Verletzung ohne Unsicherheiten aufgrund starker Wechselwirkungen berechnet werden kann. Dieser Aspekt weckte grosses Interesse an der Messung der CP-Verletzung bei B-Mesonen Zerfällen und führte zu verschiedenen Ideen für den Bau einer B-Mesonen-Fabrik.

Obwohl das b-Quark im Jahr 1977 durch ein Experiment mit einer Hadron-Maschine am Fermi National Accelerator Laboratory (FNAL) entdeckt wurde, sind experimentelle Studien über B-Mesonen lange Zeit von e^+e^- Speicherringen wie bei DESY in Hamburg oder in Cornell dominiert worden. Am CERN und FNAL wurden mehrere Experimente mit einem festen Target konstruiert, um B-Mesonen Zerfälle zu untersuchen. Ihr Erfolg war eher begrenzt, nicht viel mehr als das Messen der Quark-Produktionsquerschnitte.

Die Zukunft des SIN-Projekts einer B-Mesonen Fabrik

Anfangs der 1980er Jahre, vor der Fusion des Schweizerischen Instituts für Nuklearforschung (SIN) und des Eidgenössischen Instituts für Reaktorforschung (EIR) zum Paul Scherrer Institut (PSI), hatten beide Institute Ausbaupläne. Am EIR dachte man über einen nuklearen Heizreaktor nach. Am SIN entstand 1983 die Projektidee ASTOR (Accelerator and Storage Ring), ein Zyklotron, bei dem die 600 MeV Protonen des SIN Zyklotrons auf 3 GeV beschleunigt, beim Maximalradius gespeichert und anschliessend gepulst extrahiert werden. Es sollte die Vorstufe einer European Hadron Facility (EHF) sein, einer sogenannten Kaon Factory (Schryber, Joho *et al*). Die Endenergie von 20-30 GeV wird durch ein fast cycling Synchrotron erreicht. Weil eine internationale Beteiligung nicht in Sicht war, wurde das Projekt 1986 fallen gelassen. J. P. Blaser, der damalige Direktor des SIN entschied, statt dessen auf einen Elektron-Positron Collider zu setzen, der auf der Υ(4S) Resonanz eine grosse Anzahl B-Mesonen erzeugen konnte. (Eichler, Nakada, Schubert, Weseler, Wille [8]).

Das Projekt wurde ausgearbeitet [9] und hatte auch eine parasitäre Nutzung von Synchrotronstrahlung im Auge (Schlapbach, Abela [9]). Als dann 1989 auch hier keine internationale Beteiligung am Bau des Beschleunigers gewonnen werden konnte, wurde das Projekt vom Schweizerischen Schulrat (heute ETH-Rat) gestoppt. Auch ein kurzes Intermezzo, eine B-Mesonen Fabrik im ISR-Tunnel des CERN mit zusätzlichem Schweizer Geld zu bauen, versandete schnell.

Der Schulrat war jedoch beeindruckt von der Gemeinschaft der Teilchenphysiker, die sich über Instituts- und Landesgrenzen hinweg zusammengetan hatten, um ein gemeinsames Projekt auf die Beine zu stellen. Er ermunterte daher die Schweizerische Wissenschaftsgemeinschaft, statt dessen einige Schwerpunktprogramme zu definieren wie zum Beispiel Umweltnaturwissenschaften, Biotechnologie, Optik und Leistungselektronik, welche für die Wirtschaft in der Schweiz einen grösseren Beitrag leisten würden als die reine Grundlagenforschung.

B-Mesonen Fabrik am SLAC in USA und KEK in Japan

Die Idee einer B-Mesonenfabrik wurde dann weltweit an verschiedenen Orten aufgegriffen. Es gab Pläne am DESY in Hamburg, in den USA am Cornell und am SLAC in Kalifornien sowie am KEK in Japan. Schliesslich wurden zwei solche Elektron-Positron Speicherringe am SLAC und am KEK mit deutlich grösserer Luminosität von $L = 3 \times 10^{33}$ cm^{-2} s^{-1} ~ 10^{34} cm^{-2} s^{-1} auf der Υ(4S) Resonanz gebaut, als es bei Vorläufern möglich war.

Betrachte die Produktion der Υ(4S) Resonanz und den Zerfallsmodus $e^+e^- \rightarrow \Upsilon(4S) \rightarrow \bar{B}^0 B^0$. Die Wellenfunktion des Endzustands mit gleicher negativer Parität und C-Parität wie die Resonanz ist dann

$$\Psi(t, \vec{p}, -\vec{p}) = \frac{1}{\sqrt{2}}[\, B^0(\vec{p})\,\bar{B}^0(-\vec{p}) - B^0(-\vec{p})\,\bar{B}^0(\vec{p})\,](t)$$

wobei $\vec{p}$ den Impuls des B-Mesons bedeutet. Die beiden

B-Mesonen sind instabil und zerfallen zu verschiedenen Zeiten t_1 und t_2 in mehrere mögliche Endzustände.

Zur Zeit $t = t_1$ zerfalle ein $B^0(\vec{p}) \rightarrow l^+ \nu_l X$. Die Ladung des Leptons l^+ gibt an, dass ein B^0 und nicht ein $\bar{B}^0$ zerfallen ist. Das andere B-Meson ist dann zur selben Zeit $t = t_1$ ein $\bar{B}^0(-\vec{p})$ und oszilliert später in ein $B^0(-\vec{p})$. Beide B-Mesonen haben einen gemeinsamen Zerfall, entweder direkt oder über die Oszillation in das Antiteilchen. Die beiden Moden interferieren und wegen $\bar{B}^0 \rightarrow J/\psi K_S \neq B^0 \rightarrow J/\psi K_S$ lässt sich durch Oszillation und Interferenz eine Asymmetrie $A(t_1,t_2)$ bilden

$$A(t_1,t_2) = \frac{(N(l^+\nu X \; bei \; t_1, J/\psi K_S \; bei \; t_2) - N(l^-\nu X \; bei \; t_1, J/\psi K_S \; bei \; t_2))}{(N(l^+\nu X \; bei \; t_1, J/\psi K_S \; bei \; t_2) + N(l^-\nu X \; bei \; t_1, J/\psi K_S \; bei \; t_2))}$$

$$A(t_1,t_2) = \sin(2\arg(V_{td}))\sin((\Delta m)(t_1 - t_2)$$

Dabei bedeutet Δm die Massendifferenz der beiden Zustände $B_{1/2} = {}^1\!/_{\sqrt{2}}(B^0 \pm \bar{B}^0)$. Die komplexe Phase in der CKM-Matrix $arg(V_{td})$ ist relevant. Experimentell wird die Zeitdifferenz $t_1 - t_2$ durch die Differenz der Zerfallslängen bestimmt. Oddone [10] hatte die Idee, den Elektronen und Positronen im Speicherring unterschiedliche Energien zu geben, sodass die B-Mesonen vor dem Zerfall einen gemeinsamen Impuls in Strahlrichtung bekommen.

Die Geometrie der Kollisionszone von Elektronen und Positronen ist sowohl vom Speicherring als auch vom Detektor mit gegensätzlichen Anforderungen eine von mehreren Herausforderungen gewesen. Es brauchte ein enges Strahlrohr, um nahe an den Wechselwirkungspunkt zu kommen, um die Genauigkeit der Zerfallslänge zu erhöhen.
Den Detektor vor Synchrotronstrahlung mit Kollimatoren zu schützen bei gleichzeitiger Kühlung des Strahlrohrs, waren weitere Herausforderungen.

Im Jahre 2001 wurde dann an beiden Orten in USA und Japan auf diese Weise die CP-Verletzung, wie im Standard Modell vorhergesagt, mit einer Asymmetrie von 70% auch bestätigt [11][12].

Das LHCb-Experiment am CERN

Ermutigt durch den Erfolg der Tevatron-Experimente in der B-Physik in den 90er Jahren, wurden verschiedene Vorschläge zur Durchführung von Experimenten mit B-Mesonen an Hochenergie-Hadron-Kollidern gemacht. Ein prominentes Beispiel ist das LHCb-Experiment am Large Hadron Collider (LHC), das vom Beginn der LHC-Operation Daten erfolgreich aufgenommen hat. Die LHCb-Kollaboration wurde gebildet, indem drei Vorschläge für LHC Detektoren zusammengeführt wurden: COBEX, ein Collider-Experiment mit einem Vorwärtsspektrometer, GAJET, ein fixed-target Experiment mit einem Gasstrahl-internen Target, wo die Universität Lausanne und das PSI zu den Initiatoren gehörten, und LHB, ein fixed-target Experiment mit einem aus dem LHC extrahierten Protonenstrahl. Die Verschmelzung der drei Kollaborationen ergab sich aus der Empfehlung des LHC-Ausschusses, eine neue Kollaboration zu schaffen, indem sie sich zusammen schlossen, und ein auf dem Collider-Modus basierendes Experiment vorzuschlagen. Dabei wurden die positiven Aspekte der drei

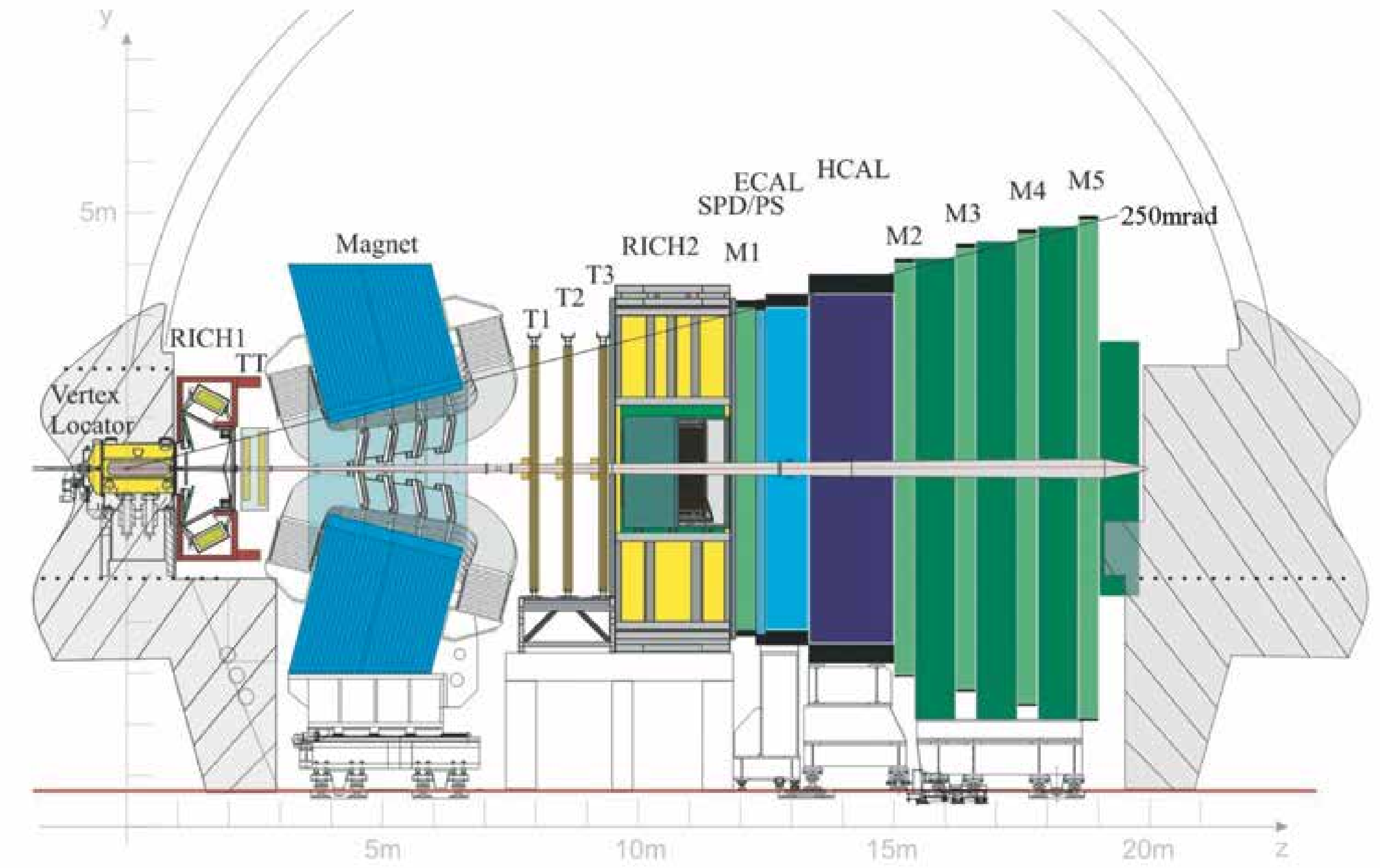


Bild 2: Schematische Darstellung des LHCb Detektor mit Vertex Detektor (VELO), Ring Imaging Cherenkov Detektors (RICH-1 und RICH-2), Tracking Detektoren (TT, T1, T2 und T3), Szintillator-Pad-Detektor(SPD), Preshower Detektor (PS), Elektromagnetisches Kalorimeter (ECAL), Hadroniches Kalorimeter (HCAL), Muon System (M1, M2, M3, M4 und M5)

Experimente kombiniert. Aus der Schweiz waren Teams der EPFL (zuvor an der Universität Lausanne) und der Universität Zürich Gründungsmitglieder des Experiments. T. Nakada, damals noch am PSI angestellt, war der erste Sprecher und Leiter der Kollaboration.

Der resultierende LHCb-Detektor sieht dem für ein Experiment mit einem Fixed-Target sehr ähnlich, da er b-Hadron-Paare nutzt, die vorwiegend in Vorwärtsrichtung (Strahlrichtung) der pp-Wechselwirkungen erzeugt werden (Bild 2). Die durchschnittlichen Impulse dieser b-Hadronen sind gross, so dass ihre Zerfallszeit mit einer hervorragenden Auflösung gemessen werden kann. Die Vorwärtsgeometrie ermöglicht auch einen sehr effizienten Trigger der ersten Stufe, der auf dem Transversalimpuls eines einzelnen Teilchens basiert. Noch während des Baus durchlief das Experiment eine umfassende Neuoptimierung des Detektors, wodurch das Materialbudget des Trackingsystems für eine effiziente Ereignisrekonstruktion reduziert und ein Software-Trigger mit hoher Rate eingeführt wurde, um die Fähigkeit des Experiments mit dem sich entwickelnden Status der Physik aufrechtzuerhalten. Letzteres erwies sich als besonders wichtig, da *Babar* und *Belle*, die Experimente der beiden B-Fabriken weit über das ursprünglich erwartete physikalische Ergebnis hinausgingen.

Bis Ende 2018 hat das LHCb-Experiment ~9 fb^{-1} an Daten gesammelt. Es hat bei vielen vorgeschlagenen physikalischen Prozessen Ergebnisse erzielt, wie z. B. die beste Messung des Winkels γ der CKM Matrix durch CP-Verletzungen von B-Meson-Zerfällen in die Endzustände mit D- und K-Mesonen [13]. Ferner die weltweit beste Grenze für CP-Verletzungen in den $B_s \rightarrow J/\psi KK$ -Zerfällen [14] und die erste Beobachtung von CP-Verletzung im D-Meson-System [15]. Die letzten beiden Prozesse sind daher besonders empfindlich für neue Physik jenseits des Standardmodells. Überraschend auch die zunächst nicht für möglich gehaltene Bestimmung von V_{ub}, dem kleinsten Element der CKM-Matrix [16], und das Studium der semileptonischen B-Mesonen Zerfälle mit Tau-Leptonen, um eine mögliche Verletzung der Lepton-Universalität zu studieren [17]. Dies ist zwar keine CP-Verletzung, ist aber ein überraschendes Ergebnis in der Spektroskopie und mit mehr Statistik in den kommenden Jahren könnte es neue Physik signalisieren. Das Experiment durchläuft derzeit ein umfangreiches Upgrade Program, welches das Sammeln von Daten mit höherer Luminosität mit einem effizienteren Full-Software-Trigger ermöglichen soll. Im Jahr 2021 soll mit der Datenaufnahme wieder begonnen werden.

Ausblick

CP-Verletzung ist eine notwendige Bedingung für die Baryongenesis und muss die beobachtete Asymmetrie zwischen Materie und Antimaterie im Universum erklären. (Sakharow [18]). Obwohl die komplexe Phase in der CKM-Matrix phänomenologisch viele Beobachtungen beschreibt, greift sie bei der Materie-Antimaterie Asymmetrie im Universum um Grössenordnungen zu kurz.

Gemäss dem TCP-Theorem, der Erhaltung der TCP-Symmetrie, bedeutet eine CP-Verletzung auch eine Zeitumkehrverletzung (T-Verletzung). Ein elektrisches Dipolmoment (edm) eines Elementarteilchens würde eine T-Verletzung signalisieren und es wird danach an mehreren Orten gesucht. Ein Beispiel ist die Suche nach einem endlichen edm des Neutrons am PSI. Im Standardmodell ist der beobachtbare Effekt zu klein. Eine endliche experimentelle Zahl würde somit einen neuen Ursprung der CP-Verletzung signalisieren.

Es gibt auch Hinweise, dass im Lepton Sektor das Äquivalent der CKM-Matrix, die sogenannte *Pontecorvo-Maki-Nakagawa-Sakata (PMNS) Matrix*, welche für die Neutrino Flavour Oszillationen verantwortlich ist, ebenfalls eine von Null verschiedene komplexe Phase besitzt. Das Neutrino Experiment Tokai-2-Kamioka (T2K) mit Beteiligung der Universität Genf hat die Phase $\delta_{CP} = -1.79^{+0.91}_{-0.66}$ bestimmt [19].

Referenzen

[1] J. H. Christenson et al., Phys.Rev.Lett. **13** (1964) 138
[2] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49** (1973) 652
[3] L. Wolfenstein, Nucl. Phys. B **246** (1984) 45
[4] A. Apostolakis, et al., CPLEAR Collaboration, Phys. Lett. B **458** (1999) 545
[5] A. Angelopoulos, et al., CPLEAR Collaboration, Phys. Lett. B **444** (1998) 43.
[6] A. Carter and A. Sanda, Phys.Rev. D **23** (1981) 1567
[7] I. Bigi and A. Sanda, Nucl. Phys. B **193** (1981) 85
[8] R. Eichler, T. Nakada, K. Schubert, S. Weseler, K. Wille, SIN-PR-86-13 (1986)
[9] PSI-Proposal PR-88-09, (1988)
[10] P. Oddone, in Proceedings of the UCLA Workshop "Linear Collider BB Factory, Conceptual Design", D. Stork ed. World Scientific p. 243 (1987)
[11] B. Aubert et al. (BABAR Collab.), Phys.Rev.Lett. 87 (2001) 091801
[12] K. Abe et al. (Belle Collab.), Phys.Rev.Lett. **87** (2001) 091802
[13] The LHCb collaboration, R. Aaij et al. J. High Energ. Phys. **08** (2018) 176.
[14] The LHCb collaboration, R. Aaij et al. J. High Energ. Phys. **08** (2017) 037.
[15] The LHCb collaboration, R. Aaij et al. arXiv:1903.08726, Submitted to PRL
[16] The LHCb collaboration, R. Aaij et al. Nature Phys. **11** (2015) 743-747
[17] The LHCb collaboration, R. Aaij et al. Phys. Rev. D **97**, 072013; The LHCb collaboration, R. Aaij et al. Phys. Rev. Lett. **115**, 111803
[18] A. D. Sakharov, Pisma Zh.Eksp.Teor.Fiz. **5** (1967) 32, Sov.Phys.JETP Lett. **5** (1967) 24
[19] T2K Collaboration, L. Haegel, PhD-thesis Universität Genf, 2018

Ralph Eichler (*1947) promovierte in Physik an der ETH. Forschungstätigkeiten in Stanford, Los Alamos, Hamburg, Zürich und am Paul Scherrer Institut (PSI). 1989 Professor für Physik an der ETH. Von 1995-1997 Forschungsleiter (Sprecher) der H1-Kollaboration am DESY in Hamburg und 2002-2007 Direktor des PSI und wissenschaftlicher Vertreter der Schweiz im CERN Council. Von 2007 bis Ende 2014 Präsident der ETH Zürich. Ab 2015 Stiftungsratspräsident von Schweizer Jugend Forscht.

Tatsuya Nakada (*1955) promovierte in Physik an der Universität Heidelberg. Forschungstätigkeiten in CERN und Paul Scherrer Institut (PSI). Von 1995-2008 erster Forschungsleiter (Sprecher) der LHCb-Kollaboration am CERN, 2011-2013 Wissenschaftlicher Sekretär für die europäische Strategiesitzung des CERN-Rates und Vorsitzender der Strategiegruppe für die europäische Strategie für Teilchenphysik. Seit 2003 Professor für Elementarteilchenphysik an der EPFL. 2015 Ehrendoktor der Universität Zürich.

30 Years of PSI: Evolving into a User Lab

Martin Jermann, Hans Rudolf Ott, Leonid Rivkin, Paul Scherrer Institute

A report on 30 years of a multitude of activities in physics, chemistry, biology, medicine and engineering with a fair coverage of all the achievements in these scientific and technical disciplines, requires more space than was allotted to us. We therefore decided to concentrate on PSI's development to a multidisciplinary, internationally competitive user laboratory. Although some external experts were very sceptical that this strategy would succeed, we intend to show below that they were wrong.

The beginning is tedious

The Paul Scherrer Institute (PSI) officially went into operation on January 1, 1988. It was a merger of the two previously individual Institutes of the ETH domain, then termed Annexanstalten des Bundes, namely the *Schweizerische Institut für Nuklearforschung* (SIN) [1] and the *Eidgenössisches Institut für Reaktorforschung* (EIR), both situated on opposite banks of the river Aare near Villigen and Würenlingen, respectively. Its first director was Jean-Pierre Blaser, professor of physics at ETH Zürich and director of SIN, who had lead the project of the merger, strongly assisted by his deputy Dr. Wilfred Hirt.

The research areas were represented by specific departments. The two dominating units were dedicated to particle physics (ex SIN) and nuclear energy and –safety (ex EIR), respectively. Distinctly smaller units hosted biology and medical applications, solid-state and materials physics, and activities in non-nuclear energy and environment (see Fig. 1). From its beginning it was intended that PSI should have close ties to Swiss universities by directly involving scientists based at these institutions but also acting as research leaders of the respective research departments. It was clear from its beginning that PSI needed to define its mission as a multidisciplinary institute with high academic and technical standards and the different visions were discussed, starting on January 15, 1988, in so called Direktionskonferenzen (DIRK), assembling all the department heads and important representatives of the administration with respect to finances and human resources. Under the leadership of Blaser and Hirt, various options for future developments were considered and debated.

It was agreed that PSI should, to a large extent, develop into an internationally competitive user laboratory, serving scientists from Switzerland but also, for obvious reasons, in significant numbers, attract users from abroad. This was already the case for particle physics with the environment around SIN's proton facility and muon factory. In this respect, the already existing and singled-out project, the realization of the spallation neutron source (SINQ) based on SIN's proton accelerator, played the role of an incubator for extending this trend. After the approval of the construction of SINQ by the Swiss parliament in 1986, the project was launched under the auspices of PSI as an interdepartmental enterprise and was, as all the other units, heavily relying on the department of technical support. The design of the source itself comprised a number of innovations that required a lot of work in developing the necessary technical components including their design. At the same time it was clear that, in order to obtain an internationally competitive neutron source dedicated to using neutron scattering for investigating static and dynamic properties of condensed matter, the proton current extracted from the proton accelerator had to be enhanced significantly. It was thus decided that, in parallel with the construction of the source itself, the project termed *current enhancement* proceed with high priority.

Another early and important task to be tackled was to develop a clear vision on the content of activities concerning energy research and its balance between nuclear and non-nuclear energy. At the same time, ideas on new developments

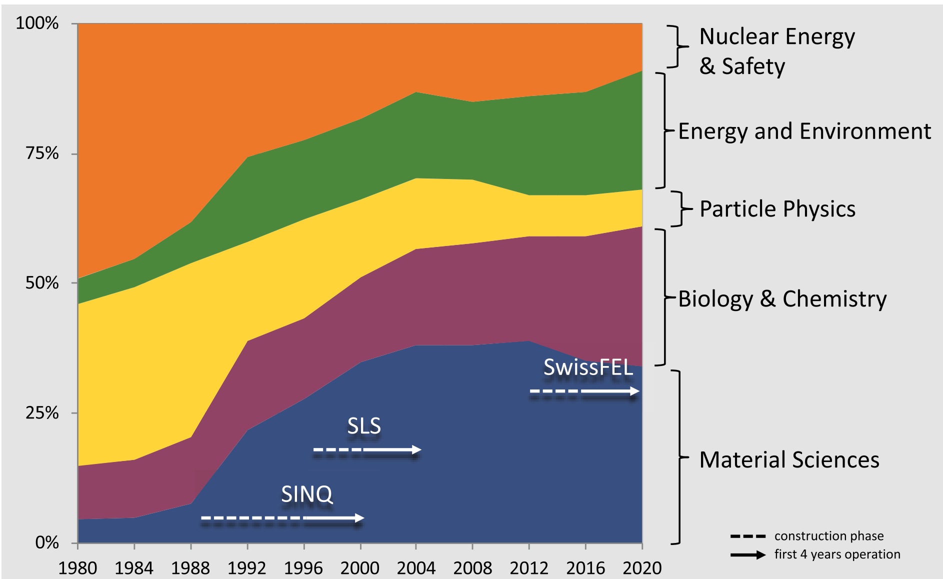


Fig. 1: History of research activities at PSI

for securing PSI's long-term future were considered. An intention that was favoured by some was to extend PSI's program in particle physics by installing a so called B-factory (see this issue of *SPG Mitteilungen* on p. 40). Although a promising project scientifically, it did not get much support from the ETH Schulrat and finally, in mid September of 1989, was abandoned. Already at the end of that month, the condensed-matter fraction of the DIRK came up with an alternative option, the construction of an electron synchrotron acting as a light source; even more courageous actors envisioned the installation of a free-electron laser (FEL). This idea, of course, came not out of the blue. After recognizing the potential of electron synchrotrons as intense light sources, such installations were established in many countries, in particular in the USA, Germany, France and England, later

1 The history of SIN and its legacy are well documented in Andreas Pritzker, Geschichte des SIN, munda Verlag, Küttigen, Schweiz, 2013

also in Italy, Japan and Sweden. Various opinion leaders in the field were then convinced that for the benefit of future cutting-edge Swiss-based research in physics, chemistry and specifically also biology, the availability of a national and internationally competitive installation of this kind was highly desirable. Subsequently through 1991 the option of an electron-synchrotron light source was further developed under the lead of interims director Hirt as a *Direktionsprojekt* as the discussions in the DIRK regarding new developments of activities of the institute got stuck because no convincing conclusion was reached.

Fig. 2: The SINQ experimental hall

In this difficult situation, Meinrad Eberle, professor for combustion technology at ETH Zürich, stepped in as the new director of PSI in spring 1992. He faced a number of problems including a slower than anticipated progress in the implementation of SINQ. As usual for projects with pioneering character, some technical difficulties in the realization process arose and their solutions were not easy to achieve. The subsequent 3 years were characterized by significant financial strains and detailed screenings of the then current department programs. Even activities regarding the extension of PSI's experimental infrastructure were questioned. A newly established research committee consisting of internal stakeholders and internationally renowned experts in their field helped to evaluate existing and planned activities and to advise the management accordingly. Although dimmed down for a while, the light of prosperity and innovation never quite went out. In October 1994, a national hearing on the appropriateness of a light source at PSI marked the turning point and within one month, the project was back on the agenda of the Schulrat, now renamed to ETH Rat. Meanwhile also the construction of SINQ had taken up speed and PSI's future as an attractive user lab looked again much brighter.

New large facilities: Full steam ahead

Indeed the project plans and the concept of the Swiss synchrotron light source SLS were ready by September 1995. The Swiss Federal Council agreed to support the construction of SLS in November 1996. The Swiss parliament finally approved its execution in 1997 and the foundation stone was laid in June 1998. Concerning SINQ, the first neutrons left the source in 1996 and regular user operation at the then worldwide strongest spallation neutron source started in 1997. Initially four experimental stations in the form of spectro- and diffractometers were available but the planning for new instruments had started 2 years earlier and their implentation was on track. The efficiency of SINQ was significantly enhanced by an in-house development of so-called neutron mirrors which, after an intense in-house R&D activity, proved to be so effective that their production ended up in an industrial spin-off enterprise.

The success in enhancing the strength of the proton beam to the range of 2 mA also had consequences regarding the current density and brightness of muon beams serving as sensors for probing internal magnetic fields in solids in μSR experiments. This experimental method was already in use at the former SIN, but the new conditions offered innovations in its application. A particularly attractive new possibility in form of an intense low-energy muon beam was realized and used in the first operational instrument of its kind worldwide. It opened the way for this experimental technique to study thin films and layered materials, both rapidly gaining importance in technical applications.

As may be seen from Fig. 1, these efforts to create new experimental opportunities had a strong impact on PSI's investment of resources in the field of materials sciences and enhanced the benefit of a large number of users from Switzerland and abroad. After 1997, Swiss researchers had the privilege to profit from the access to different experimental methods for investigating microscopic properties of condensed matter at internationally competitive or, in parts even leading, large facilities at the same location in their own country. With the SLS under construction this situation promised to improve further. The implementation of the facility and the building hosting it proceeded according to plan and the first experimental stations went into test phase at the end of 2001.

Fig. 3: The SLS experimental hall

As expected, its performance parameters emittance and brightness proved to be excellent. The first user meeting was attended by more than 100 participants involved in research in physics, chemistry, materials-, surface- and environmental sciences. Initially, experienced users tested the beamlines and their endstations with experiments employing spectroscopy or microscopy of surfaces, tomographic microscopy with x-rays, microscopy with photoemitted electrons and protein crystallography. The regular operation for users began in 2002 and all first results turned out to be very promising. In particular the outstanding spatial and time stability of the resulting x-ray beams was responsible for the fact that in a very short time, SLS became the installation of choice for innovative studies in protein crystallography. In parallel to the operation of the facility, specialists responsible for the installations engaged in design and construction of innovative detectors and new sources for extremely short x-ray pulses extending the range from picoseconds down to femtoseconds. Particularly satisfying was the rapidly growing interest of industrial firms to finance and use part of the instruments for their proprietory research.

The rapid successes during the first years of SLS' operation, induced new ideas with respect to a further extension of PSI's role as a user lab responding to new scientific developments. The aim to create opportunities for investigations of condensed matter, i.e., solids, soft matter and liquids, employing coherent radiation soon turned the focus on the implementation of continuously tunable, laser-like radiation in the UV and x-ray spectral range. The progress in accelerator technology, involving very bright electron sources and advanced undulator magnets resulted in the likely possibility to obtain coherent radiation around 1 Ångstrom wavelength by controlling the motion of free electrons in free-electron lasers (FEL). At around 2000, the first installations in Asia, the USA and Europe were at early stages of planning. For Swiss-based stakeholders it was soon clear that in order to again play a significant role in that field, the construction of a corresponding source in Switzerland was mandatory.

Fig. 4: The SwissFEL undulator magnets

Ralph Eichler, who succeeded Meinrad Eberle as PSI Director in 2002, encouraged the development of innovative technical ideas that finally resulted in the design of a compact and cost-effective, i.e., affordable installation under the name of SwissFEL. It was after Joël Mesot became PSI Director in 2008, that the usual application procedure involving the federal administration and political establishment started in 2010 and the realization of the SwissFEL was approved by the parliament in 2012.

By the time SwissFEL was inaugurated in 2017 four short wavelength FELs were lasing: LCLS at Stanford, SACLA in Japan, PAL-XFEL in South Korea and European XFEL in Hamburg. Compared to the storage ring based light sources these facilities produce 10 orders of magnitude more coherent photons in a pulse of femtosecond duration. Continuously tunable wavelength hard x-rays extend the powerful experimental techniques developed with the short pulse conventional lasers to atomic resolution. By the end of May 2019 SwissFEL was producing attosecond x-ray pulses.

PSI's role as a base laboratory for particle physics

In parallel to the efforts of *extending* the attempted user-lab function of PSI, the nucleus of this type of mission, the program covering particle physics at medium energies, continued to attract researchers from Swiss universities and from abroad to this date. The enterprise stays based on the already mentioned existing proton beam and to a large extent involves high-precision experiments searching, for instance, for the limits of so-called rare events that would violate the existing and seemingly sturdy standard model of particle physics. The very nature of these studies requires highest experimental and technical skills as well as a long-term commitment to the cause. One example for such projects is the search for the forbidden μ-eγ decay which is active since the early days of PSI. Another long-term enterprise is dedicated to investigating the properties of muonic hydrogen which, only recently, resulted in a value of the proton radius that is in conflict with results from spectroscopy-type experiments and awaits further clarifications. Likewise, a search for the electric dipole moment of the free neutron turns out to require an ongoing and non-trivial refinement of the experimental set-up and a lot of patience.

From its start, PSI also contributed, and still does, to supporting the build-up of experimental infrastructure related to particle physics by the respective Swiss research community at other user labs such as CERN. A particularly important and successful contribution is the design, construction and implementation of the innermost silicon pixel detector of the CMS detector at the large hadron collider (LHC) and its recent upgrade. This development resulted in a very successful industrial spin-off that uses this technology to produce fast x-ray pixel cameras that are used at synchrotron light sources all over the world.

Benefits of PSI's accelerator based advanced technologies

These advances in detectors and light sources allowed PSI researchers to develop pioneering imaging techniques. Phase-contrast 3-D tomography methods with nanometer resolution play a revolutionary role in such diverse fields as medical applications and computer micro-chip inspection. The Swiss industry stands to profit from similarly impressive neutron based imaging methods developed at PSI. Key areas in this context are advanced manufacturing and digitalisation.

Interestingly, the advanced accelerator technology expertise being developed at PSI for the light sources is proving highly relevant to the ambitious future collider CERN projects.

Physics and accelerator technology in the service of human health

Just after the merger, human health became an applied research priority at PSI based on the knowledge and experience in accelerator technology and particle physics at SIN and the nuclear chemistry and radiochemistry research used for nuclear technology developments at EIR. Innovative projects on cancer therapy using elementary particles have been running already at SIN with the development of the PIOTRON facility, using negative pi-mesons for the treatment of deep seated tumors, and with the construction of the OPTIS facility for treatment of eye melanoma with high energy protons. The EIR had projects running for accelerator based isotope production for cancer diagnostics in collaboration

Fig. 5: The first compact proton therapy PSI gantry (Gantry 1)

with the SIN since middle of the 80's. The cancer treatment activities had been strengthened and extended at PSI over the last 30 years. OPTIS was the first facility for eye tumor treatment with protons in Europe. To today, close to 8000 patients with ocular melanoma have been treated at PSI in collaboration with the Ophthalmic Institute "Jules Gonin" in Lausanne. This is the highest number of eye tumors treated with protons in a single facility worldwide. A tumor control rate of > 98 percent was achieved.

Based on the successful first clinical results using protons at the OPTIS program PSI started a proton therapy project for the treatment of deep-seated tumors with a new innovative technology. A low intensity beam of 5-10 μA was separated with an electrostatic splitter from the > 1 mA proton beam of the 590 MeV isochronous cyclotron. The beam was degraded to energies below 250 MeV and injected into a 360° rotational compact gantry, using a dynamic parallel pencil beam delivery technique. The irradiation method - called "discrete spot scanning" – has several advantages: most conformal dose delivery with an optimal spearing of health tissue, improved treatment efficiency and potential for intensity-modulated treatment. The innovative treatment method is used for patient treatment at PSI since end of 1996 and established itself over the past 10 years as the beam delivery and irradiation standard for most of the proton therapy facilities worldwide. More than 60 proton therapy facilities are using the PSI technology today.

In 2001 PSI decided to expand the activities by launching the PROSCAN project. A dedicated compact superconducting 250 MeV proton cyclotron was developed in close collaboration with industry and a second gantry (Gantry 2) with advanced beam scanning features was realized. In parallel OPTIS was replaced by an upgraded version (OPTIS2). In 2012 PSI decided together with the University Hospital Zurich to expand the PSI proton therapy facility by an additional gantry (Gantry 3) for intensifying the clinical research. Gantry 3 came into clinical operation middle of 2018.

Summing up

In this review on *30 Years of PSI* we hope to have demonstrated that with talent and determination even a small country like Switzerland may succeed in building up an internationally competitve multidisciplinary user lab that not only serves a substantial part of the Swiss natural-science community including medicine but also attracts top researchers from abroad. In this sense, PSI has turned into a real asset of Swiss science. Finally, it should not be forgotten that this achievement would not have been possible without the trust, courage and will of political decision makers and funders to support the development outlined above.

Fig. 6: The PSI campus consisting of the former SIN (west bank) and EIR (east bank). 1: SINQ, 2: SLS, 3: SwissFEL

Physicists in Industry (9)

Switzerland Innovation: One Innovation Park at Five Sites

The Switzerland Innovation Park is a network of technology centers equally distributed throughout the country, at which research institutes and industry closely cooperate. The purpose is to transform novel technologies with a certain degree of maturity into marketable products. The centers which are focussed on the regional strengths and competences should help mainly SMEs to adapt new technological concepts, but also to attract new companies to the region. The Swiss Government supports the network by providing land and loans of CHF 350 million. The program started in 2012, four sites were approved in 2014 and Biel was added as number five in 2015.

Another attempt is currently in preparation by the government of the canton St. Gallen adressing the field of 'Health Technology', whereby Empa, the university of applied science, the cantonal hospital and the HSG want to merge their expertise with local companies.

The current centers are
- Park Network West / EPFL in Lausanne with connections to Geneve, Sion, Fribourg and Neuenburg
- Park Zürich in Dübendorf
- Park Basel Area in Allschwil
- Innovaare Park in Villingen
- Park Biel/Bienne in Biel

https://www.switzerland-innovation.com/de/home

In the following we describe how the Innovation Park "PARK INNOVAARE" in Villigen (AG) supports start-up companies in the field of accelerator technology.

BB

CERN know-how goes to the market

Benedikt Vogel

CERN in Geneva is the leading particle physics laboratory worldwide. Large particle accelerators based on the most innovative technologies are used there for fundamental research. One year ago, the innovation park "PARK INNOVAARE" in Villigen (AG) launched, together with CERN, the BIC of CERN program: it supports start-ups and high-tech micro-companies using CERN technologies for commercial applications. These days the second call for proposals has started.

In 2016, the foundation "Switzerland Innovation" launched innovation parks at five locations. Here, companies from Switzerland and abroad are asked to develop innovative products and services together with researchers. One of the locations is Villigen in the canton of Aargau. This is where the Paul Scherrer Institute (PSI) is based, and it was beneficial to put one of the innovation parks near this important research institution of the ETH domain. In the middle of last year, PARK INNOVAARE launched a development program designed to encourage start-up companies to use CERN's accelerator technologies in commercial applications. " With this new initiative, the combined expertise of the Paul Scherrer Institute and CERN is accessible for companies at PARK INNOVAARE", says Dr. Francesco Colonna, member of the steering committee.

Founded in July 2018, the Business Incubation Centre (BIC) of CERN Technologies - the official name of the funding and incubation program - listed a number of technology fields that are considered accelerator technologies: for example big data / ICT, detectors, high performance electronics, cooling systems, magnets, sensors, control and monitoring systems or vacuum technology. These technologies are not only needed in the construction and operation of particle accelerators, they can also be used in medicine and biomedicine, in aerospace, in the environmental field and even in the preservation of monuments, as the promoters of the BIC of CERN Technologies emphasized at the time.

In November 2018, a jury included the Geneva-based company Securaxis in the funding program of the "Business Incubation Centre of CERN Technologies" in PARK INNOVAARE in Villigen (AG). From left to right: Glenn Meleder (CEO Securaxis), Benno Rechsteiner (CEO PARK INNOVAARE), and Aurélie Pezous (Knowledge Transfer Officer at CERN). Photo: Darya Bachevskaya

Geneva start-up develops a security-application

Meanwhile, a year has passed and the incubation program is proud to present a promising first incubatee: In November 2018, a jury has chosen a first company to benefit from the developing program, the start-up *Securaxis*. Securaxis was founded at the end of 2015 by Glenn Meleder, who had previously worked as an IT specialist at the International Committee of the Red Cross (ICRC) in Geneva. The company is developing security solutions around acoustic sensors, whose data are processed by means of artificial intelligence.

When Real-Time Event Detectors (RTExD) are deployed in a city, they are able to detect explosions or fires in real-time and alert rescue services. According to the company, the detectors also help in traffic management. In addition, they are able to monitor bridges, dams or tunnels to preventively detect any imminent damage caused by material failure via acoustic signals.

The acoustic detectors require a powerful system for data collection and processing. For that purpose, Securaxis intends to use technologies that were specially developed at CERN to read out the very extensive data from the various particle physics experiments (C2MON). "Our technology has the decisive advantage over camera surveillance that no privacy problems arise," says company founder Glenn Meleder. “Further, we can help municipalities lower their costs with our early acoustic warning system.“

New chance for high-tech start-ups

Securaxis's two-year program includes management coaching by the Institute of Management of the University of Applied Sciences in Northwestern Switzerland (FHNW), a start-up capital of CHF 50,000, technical support from CERN and PSI expert technicians, and the possibility of facilitated access to complementary technologies of PSI and CERN at favorable conditions. The company keeps its seat in Geneva, where six persons are working. In its first incubation year, Securaxis is setting up a two-people office at PARK INNOVAARE.

The winner start-up Securaxis had been selected by a jury out of 31 proposals. On April 10, 2019, the second round of the funding program was launched. In this round, up to two start-ups can be included in the support program. Project ideas must be submitted by the end of May. A central requirement of any application: The company must use intellectual property or know-how of CERN in the field of accelerator technologies. In October 2019, the jury will decide.

Further information about the BIC of CERN program at:
https://www.parkinnovaare.ch/cern-bic

The SATW Technology Outlook TO2019

Bernhard Braunecker

Introduction

One of the key tasks of the Swiss Academy of Engineering Sciences SATW is the pre-recognition of technologies with relevance to Switzerland’s economy. To this end SATW publishes a Technology Outlook report called TO every two years. The third report was presented on May 7, 2019. It describes how forty-eight experts assess the potential of thirty-seven promising technologies within a time horizon of three to five years, but now taking into account quantitative evaluation parameters for the first time. The whole report can be downloaded from the SATW website
https://www.satw.ch/de/frueherkennung/technologies/ .

Technology Fields

The TO series is a comprehension of recommendations to facilitate e.g. politicians to make the right decisions, but also to stimulate common R&D-programs between industry and institutes. The report focusses on four main clusters, which are

- The *Digital World* with subchapters for Cybersecurity, Industry 4.0 and Artificial Intelligence, but also Blockchains and Robotics. Cybersecurity is defined as Cryptography and Quantum computing, while part of Industry 4.0 is the concept of Digital twins.
- *Energy and Environment* including Decentralized Energy Concepts and Storage.
- *Manufacturing Processes* including Photonics.
- *Life Science* including Bio- and Medical engineering.

Evaluation Process

A *technology readiness index TIR* of more than five is common to all thirty-seven candidates, indicating that at least prototypes or a zero-series were successfully tested so far.
Each technology is described by two parameters, the *economic importance* x and the *available competence in Switzerland* y. The first one is given by $x = U \times (M + R_R + R_G)$, i.e. by the product of turnover U and the market potential M, which, however, is slightly modified by R_R taking into account if there are any regularity restrictions and by the public acceptance factor R_G. The available competence y is the sum of two terms $y = F_A \times K_A + F_I \times K_I$, which both are the product of the number of institutes F_I or SMEs F_A in Switzerland and their competence K_A or K_I , respectively. The numerical values of all mentioned parameters are estimates of the SATW experts, based on their contacts to research and industry. The data are semi-quantitative, but nevertheless reflect the long term experience of professionals and their realistic expectations.
Each technology is visualized as point in the two-dimensional coordinate system (x,y) after being properly normalized, which is divided into four quadrants defined as "Stars", "Self-runners", "Hope-bearers" and "Niches".

Top Ranking

The TO-findings are that top technologies from an economic point of view are *Big Data*, *sustainable food production*, *connected machines*, *photonics* and *smart cities*. The leading competencies available in Switzerland are *learning ma-*

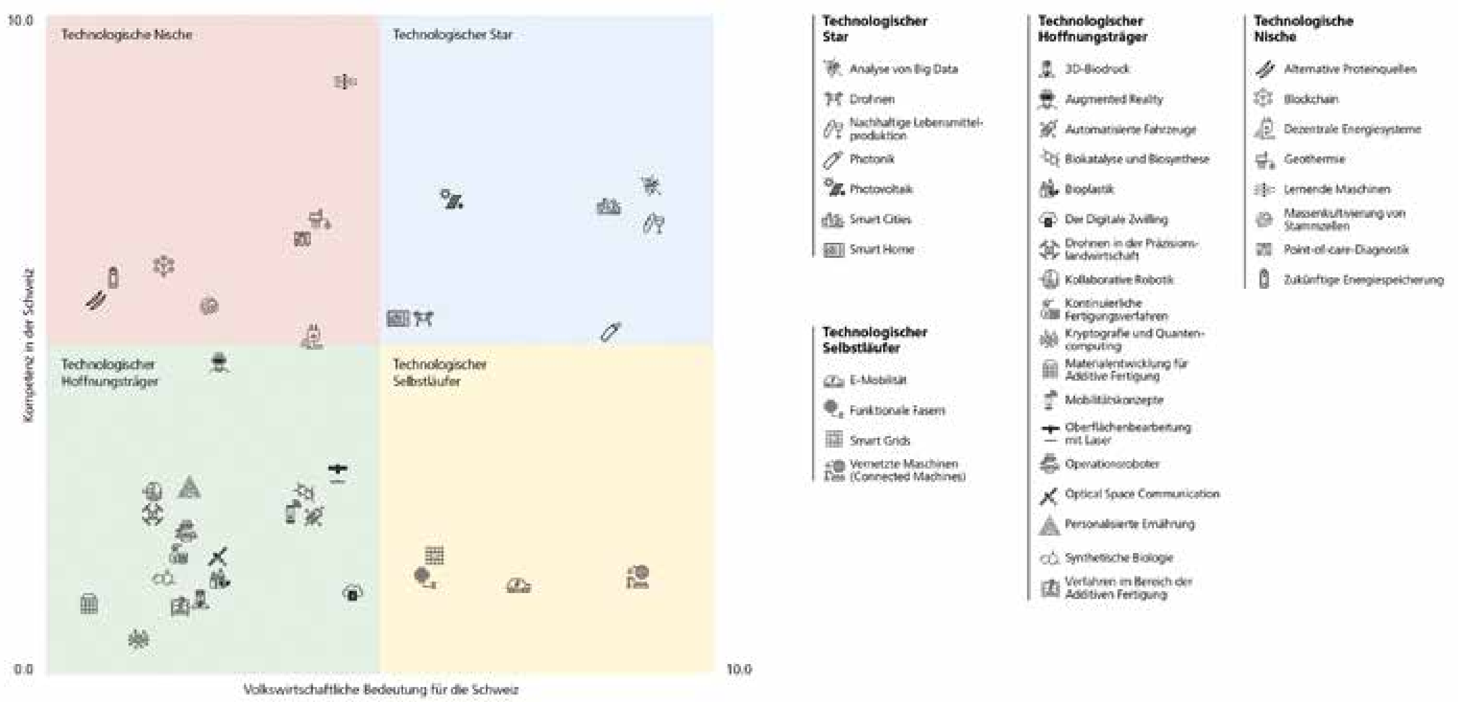


Figure 1: Relative Importance of Technologies for Switzerland

chines & neuronal networks, *photovoltaics*, the *analysis of Big Data* and again *sustainable food production* and *smart cities*.

Driven by Physics

Next we consider those technologies where physical know-how can obviously further push their efficiency.

- ***Stars***
  Photonics per se but also as enabler technology is chosen as a technology star by the experts. Switzerland has high competence in research and industry, and photonic applications can be found meanwhile as major driver in all Swiss industries. But we still need a lot of R&D work in Physics to create new concepts, materials, sensors and components for optical communication, material processing by lasers, medical diagnostic and operating instruments, space systems, defense applications and consumer products.
- ***Niches***
  Here are explicitly mentioned *Energy storage* and *decentralized systems*. But new ideas, concepts and technologies are urgently required to find the best solution for a reliable energy production and storage and for the demands set by climatology.
- ***Hope-bearers***
  It is rather difficult to judge about the future of the technologies in this segment. Most experts, however, recommend to carefully monitor their further development. We note that the use of *ultrashort pulse laser technology* for material processing is mentioned, but also as a consequence the development of best suited materials for additive production. Material and processing tool must be considered as unit. We also see the high expectation to further extend the successful Industry 4.0 concept by the idea of *Digital twins or shadows*. And finally we find *Cryptography and Quantum computing*, which, however, is more the placeholder for arising technologies like *Q-simulation*, *Q-communication*, *Q-optomechanics*, etc.
- ***Self-runners***
  Technologies in this segment are considered as already mature, well established and profitable but with small R&D activities in Switzerland. The message is to increase the research effort to move them to the Star segment. We mention explicitly *connected machines* where new photonic components could improve significantly the data flow between machines with respect to speed, size and energy consumption.

How can Physics help to further improve the series?

It would be extremely helpful to add a *trend vector* to each (x, y) position indicating the direction in which the technology will probably develop. The uncertainty of the vector direction could be reduced by considering the actual research activities. The broader and the more intensive research is driven internationally, the greater will be the momentum to push the candidate to a higher TIR Index, i.e. faster to full technical maturity. This would also allow to consider the readjustment of the (x, y) position which occurs every two years, with more fidelity. Then a permanent screening of promising candidates is mandatory. Again science like Physics can carefully watch the research sceneries.
Finally, Physics can also help to improve the performance of already established technologies within the (x, y)-matrix. The concept of *Digital twins* should be understood as part of '*Cyber Physical Systems*', where physical modelling can significantly stabilize production processes, but also increase the efficiency of instruments. [1]

1 See Editorial in the SPG Mitteilungen Nr. 57 https://www.sps.ch/artikel/communications/

An Overview of Physics Olympiads and Tournaments at gymnasial and university level, national and international

Antoine Pochelon, EPF Lausanne, Lukas Gallmann, ETH Zürich, Cyrille Boinay, WO, Bern, Samuel Byland, MNG Rämibühl, Zürich, Evgenii Glushkov, EPF Lausanne

At a pivotal age where important choices have to be made, physics olympiads and tournaments offer to young women and men - from the gymnasial level to university, individually or in teams - the possibility to measure themselves with physics. It gives them also the opportunity to meet other young people in a stimulating atmosphere. The aim of this overview is to show the various possibilities for young people with an interest in physics.

Age class	National	International	Registration to next national selection
Gymnasial, High-school , Berufsschule, Ecole des métiers < 20 years	**SwissPhO** Physics Olympiad	**IPhO** International Physics Olympiad **EuPhO** European Physics Olympiad	Registration and participation directly under *www.physics.olympiad.ch* 19 Aug. 2019 - 30 Sept. 2019
Secondary school (last participation in the year of their graduation)	**SYPT** Swiss Young Physicists' Tournament	**IYPT** International Young Physicists' Tournament	March 2020 (dates to be announced on *www.sypt.ch*), probably SYPT Physics Week (supervised preparation) in February 2020
Younger students 12 to 16 years of age	**SYNT** Swiss Young Naturalists' Tournament	**IYNT** International Young Naturalists' Tournament	March 2020 (dates to be announced on *www.synt.ch*), probably SYNT Workshop (supervised preparation) in February 2020
University students, Bachelor & Master level	Swiss Selection for the Int. Physicists' Tournament	**IPT** International Physicists' Tournament	December 2019. Information and registration (updates in September): *switzerland.iptnet.info* website for next IPT available in August (see *iptnet.info*)

Physics Olympiad in Switzerland

The science olympiads have their roots in Central European school competitions. Once UNESCO and several other pioneers became involved, the number of participants and professions represented increased. The first International Physics Olympiad was held in 1967. Switzerland has participated since 1995, with considerable success.

National elimination rounds involving a multi-stage selection and training process are held to determine the five most promising new talents, who then go on to participate in the European and International Olympiad. In Switzerland and Liechtenstein this process is run by nine specialist associations (biology, chemistry, computer science, economics, geography, mathematics, physics, philosophy and robotics), which together form the umbrella association of the **Science Olympiad**. The associations are funded through donations. Young people do not have to pay to participate in the Science Olympiad, and the association members work on a voluntary basis. All motivated students at secondary education II level are eligible to participate.

The Physics Olympiad embodies a unique spirit of engagement, passion for science and open-mindedness, as clearly demonstrated by the number of volunteers involved. Over 800 participants per year are able to network and communicate with people beyond language and cultural borders. For the young people involved, the Physics Olympiad is a one-off, unforgettable and exciting experience. Furthermore, the Olympiad takes place during a crucial decision-making phase of the students' lives and helps to generate perspectives within science. See also p. 55.

The **International Physics Olympiad** (IPhO) is an annual physics competition for high school students under the age of twenty. It is one of the seven International Science Olympiads. The first IPhO took place in Warsaw, Poland, in 1967. Today, 75 countries from five continents participate. In 2016, the IPhO was hosted by the University of Zürich [1].

The **European Physics Olympiad** (EuPhO) is a contest for Secondary II students. The third edition in 2019 was hosted by the University of Latvia in Riga. EuPhO is the little sister of the International Physics Olympiads [2].

Swiss Physics Olympiad (SwissPhO)

www.physics.olympiad.ch
President: Sebastian Käser

Science Olympiad - Wissenschafts-Olympiade, (supporting all domain olympiads)

www.science.olympiad.ch
President: Michele Dolfi

Contact address:
Science Olympiad — *info@olympiad.ch*
Hochschulstrasse 6 — +41 31 631 39 86
CH-3012 Bern

International Physics Olympiad (IPhO)
European Physics Olympiad (EuPhO)

IPhO	Olympiad's Location	Result of Swiss Team
2019	Tel Aviv, Israel	(7-15 July)
2018	Lisbon, Portugal	-
2017	Yogyakarta, Indonesia	**B**: 2, **H**: 3
2016	Zürich, CH [1]	**B**: 1, **H**: 4
2015	Mumbai, India	**B**: 2, **H**: 3
2014	Astana, Kazakhstan	**S**: 2, **B**: 4
2013	Copenhague, Danmark	**B**: 2, **H**: 3
2012	Tallinn, Estonia	**S**: 1, **B**: 2, **H**: 2

EuPhO	Olympiad's Location	Result of Swiss Team
2019	Riga, Latvia	**H**: 3
2018	Dolgoprudny, Moscow, Russia [2]	**H**: 1

B: bronze medal, **S**: silver medal, **H**: honorable mention

Websites:
IPhO: *http://ipho.org/*
en.wikipedia.org/wiki/International_Physics_Olympiad
EuPho: *https://www.facebook.com/eurpho/*
https://eupho2019.lv/

Physics connects young students from all over the world: International Physics Olympiad 2016 in Switzerland (Credits: Roman Ernst)

Participants of the 2019 finals of the Swiss Physics Olympiads. (Photo: Markus Meier)

Swiss and International Young Physicists' Tournament (SYPT, IYPT)

The International Young Physicists' Tournament (IYPT), sometimes also referred to as the „Physics World Cup", is a scientific competition among secondary school students interested in physics. A so-called *Physics Fight* lines up three teams of five students each. They in turn take the roles of *reporter* (presents the solution to one of the given IYPT problems), *opponent* (criticises the solution and leads the discussion with the reporter), and *reviewer* (reviews the contributions of the reporter and opponent). All three teams get scores from a jury of experts.

The 17 *IYPT problems* are published about a year before the tournament. They are open-ended questions chosen such that no single or clear correct solution exists. Each presentation will show different aspects of the problem. Careful preparation and creativity in solutions are as important in order to receive high grades from jurors as are correct school physics and mathematics.

Swiss Young Physicists' Tournament (SYPT)
International Young Physicists' Tournament (IYPT)

Aimed age class: secondary school

International Tournaments:

IYPT	Tournament's Location	Result of Swiss Team
2018	Beijing, China	Bronze Medal (10th of 32)
2017	Singapore	Bronze Medal (13th of 30)
2016	Ekaterinburg, Russia	Gold Medal (3rd of 29)
2015	Nakhon Ratchasima, Thailand	Bronze Medal (11th of 27)
2014	Shrewsbury, UK	Bronze Medal (14th of 28)
2013	Taipei, Taiwan	Gold Medal (3rd of 26)
2012	Bad Saulgau, Germany	Silver Medal (7th of 28)

The first participation of a Swiss team at the IYPT dates back to 2003 (Uppsala, Sweden: Switzerland 16th of 23). The association "Pro International Young Physicists Tournament in der Schweiz" (Pro IYPT-CH) was founded in 2004. It hosted the IYPT 2005 in Winterthur, Switzerland and has organised the national tournament (SYPT) since 2008.

Websites:
SYPT: *www.sypt.ch* IYPT: *www.iypt.org*
IYPT 2018 (Beijing, China): *www.iyptc.cn*
IYPT 2019 (Warsaw, Poland): *www.iypt.pl*

Number of countries at international tournament: 30 (still increasing)

President of Pro IYPT-CH:
Samuel Byland, MNG Rämibühl, Rämistrasse 58, 8001 Zürich, *samuel.byland@sypt.ch*

Team leaders for IYPT 2018:
Emilie Hertig (*emilie.hertig@sypt.ch*) and Eric Schertenleib (*eric.schertenleib@sypt.ch*)

President of IYPT: Dr. Martin Plesch
Samuel Byland has been a member of the IYPT Executive Committee since 2014.

Team participating at the SYPT 2019. Discussing the solution presented by another team is an essential part of a "Physics Fight". © Cyrill von Krähenbühl

In preparing for the IYPT students do not just learn how to tackle difficult physics problems, but also how to work in a team, use computers to collect and analyse data, present scientific results and debate. The Physics Fights are in English, helping the students prepare for their future at university, where an increasing number of lectures and seminars are held in English.

The Swiss Young Physicists' Tournament (SYPT) is a national tournament in the spirit of the IYPT. Important differences are the smaller teams (three instead of five students) and the fact that participants can choose the problem they want to present. At the SYPT more than twenty teams from all parts of Switzerland meet for two days, typically at a university. Although it is a physics competition, the tournament is much more than that. Participants greatly enjoy meeting other likeminded students and there is enough time to get to know each other.

While preparing for the SYPT, the participants work on their problem at their own school and/or at an SYPT Physics Week, where they are supported by experienced coaches. At the SYPT each participant has once the role of the reporter, opponent and reviewer. In the final fight the most successful three teams aim for the title of the *SYPT Champion*.

The best participants are invited for the *SYPT Team Qualification* where they try to get one of the five spots in the Swiss team for the IYPT.

Swiss and International Young Naturalists' Tournament (SYNT, IYNT)

The International Young Naturalists' Tournament (IYNT), is a science competition, modelled after the IYPT and aimed at younger students, 12 to 16 years of age. A so-called *Science Fight* lines up three teams of six students each. They in turn present and discuss their solutions to one of the 23 given IYNT problems, criticise the other team's solution and review the performances of the other teams. All three teams get scores from a jury of experts.

17 of the IYNT problems are published about a year before the tournament. They are divided into three groups for the first three rounds. In the first two groups one usually finds problems from all natural sciences, but also from mathematics and computer science. They invite for both theoretical and experimental investigations and offer the students a first glimpse at scientific work. To receive good grades from the jurors they should apply their scientific knowledge and demonstrate an understanding of scientific procedures.

The third group of problems is titled "Invent Yourself", where students are presented with a topic and should phrase their own research question, which they then work on. The remaining six problems are published at the beginning of round four. They need to be solved and presented within 45 minutes with no aid from the tutors being allowed.

In preparing for the IYNT students do not just learn how to conduct scientific experiments, but also how to work in a team, use computers to collect and analyse data, present scientific results and debate. The Science Fights are in English, helping the students prepare for their future at university, where an increasing number of lectures and seminars are held in English.

The Swiss Young Naturalists' Tournament (SYNT) is a national tournament in the spirit of the IYNT. Important differences are the smaller teams (two instead of six students), the fact that participants can choose the problem they want to present and the omitted review. At the SYNT more than twenty teams from all parts of Switzerland meet to present and discuss their findings, typically at a university. Although it is a science competition, the tournament is much more

Swiss Young Naturalists' Tournament (SYNT)
International Young Naturalists' Tournament (IYNT)

Aimed age class: students aged 12 to 16 (by year of birth)

International Tournaments:

IYNT	Tournament's Location	Result of Swiss Team
2018	Tbilisi, Georgia	Gold Medal (1st of 15)
2017	Nanjing, China	Gold Medal (2nd of 18)

The Swiss team participated twice at the IYNT and could qualify for the final on both occasions. The association "Pro International Young Physicists' Tournament in der Schweiz" (pro IYPT-CH) was founded in 2004 and has organised the national tournament (SYNT) since 2017. It has also organised the SYNT's older sibling, the SYPT since 2008.

Websites:
SYNT: www.synt.ch IYNT: www.iynt.org

Number of countries at international tournament: so far 17 different nations (still increasing)

President of Pro IYPT-CH:
Samuel Byland, MNG Rämibühl, Rämistrasse 58, 8001 Zürich, samuel.byland@synt.ch

Team leaders for IYNT 2018:
Richard Fitzpatrick, Florian Koch (florian.koch@synt.ch)

President of IYNT: Dr. h.c. Evgeny Yunosov than that. Participants greatly enjoy meeting other likeminded students and there is enough time to get to know each other.

While preparing for the SYNT, the participants work on their problem at their own school and/or at an SYNT Workshop, where they are supported by experienced coaches. At the SYNT each participant has once the role of the reporter and opponent. In the final fight the most successful teams aim for the title of the SYNT champion. What is more, the best participants get the chance to represent Switzerland at the IYNT.

International Physicists' Tournament

The International Physicists' Tournament (IPT) is the biggest international competition in physics for teams of university students, which encourages the ability to innovate and communicate to solve complex physics problems that we see in everyday life. IPT unites hundreds of young scientists from around the world, who are passionate about physics, more than 150 of which participate each year in the International Final. Around 20 nations are represented annually, each one sending their best team to the tournament.

Preparation begins 8 months before the tournament (typically, at the end of August), when teams, consisting of 4-6 students each, receive a list of 17 problems which have no known solutions in scientific literature. The problems are usually connected to everyday phenomena that many of us have observed in our daily lives. However, they have to be treated on a high scientific level, which adds to their complexity. For each problem, the teams try to create a theoretical model that they further verify with experiments and simulations, analyse the obtained data and present their study in the best way possible. This very much resembles the shape of an independent research project [3].

The tournament is composed of four preliminary rounds, a semi-final and a final. During each round, each team not only presents its solution to one of the problems but must also debate on its validity with an opposing team. This helps students build the skills of defending their models and experimental procedures. A third team is responsible for the analysis of strengths and flaws of the other two teams. The roles vary throughout a round, allowing each team to present a solution, oppose another team and, summarize the debate happening between the two other teams.

The IPT lets you get hands-on research experience early in your scientific career. In contrast to the standard lab exercises, it provides you with the unique freedom to choose your own way of tackling an open physics problem – from literature study to data analysis – exactly like research is carried out in the scientific world! You will be working in a team with like-minded peers on various physics experiments (which are, usually, pretty fun to do!), learning to present your research and getting experience in scientific debates. You will also get an opportunity to publish the results of your research after the IPT in scientific journals. Last, but not least, you will largely expand your network of contacts in the scientific community and enjoy an amazing atmosphere of a week-long event together with your team and students from all over the world!

International Physicists' Tournament (IPT)

Aimed age class: 18-24 years old (Bachelor & Master students)

IPT	Tournaments' Location	Result of Swiss Team
2019	Lausanne, Switzerland	5th of 19
2018	Moscow, Russia	1st of 16
2017	Göteborg, Sweden	13th of 18

IPT has been created in 2009 following a long tradition of Physics competitions in Eastern Europe.

Websites:
General: *iptnet.info*
http://en.wikipedia.org/wiki/International_Physicists%27_Tournament
Last edition : *2019.iptnet.info*
Next edition: available in August

All information about participating in the next national selection (2020): *switzerland.iptnet.info* or by e-mail *switzerland@iptnet.info*

Swiss representative in the international organizing committee:
Evgenii Glushkov, *evgenii.glushkov@epfl.ch*
Captain of the last Swiss team:
Nicholas Greensmith, *nicholas.greensmith@epfl.ch*

President of the International Organizing Committee:
Vivien Bonvin, EPFL (2015-2017)
David Collomb, University of Bath (2017-2019)

Final reviewer led discussion in a fight, with, from left to right: Kiev opponent, Sweden defender, Brazil reviewer. © A. Pochelon

[1] International Physics Olympiads, Zürich, 10-17 July 2016, A. Pochelon, *SPG Mitteilungen* 50, p. 68, 2016
47th International Physics Olympiad 2016 in Zurich, S. Birrer, I. Steinegger, *SPG Mitteilungen* 44, p. 19, 2014
[2] Die Europäische Physikolympiade EuPhO 2018 in Moskau, A. Mastrocola, SwissPhO, *SPG Mitteilungen* 55, p. 61, 2018
[3] Great success at the International Physicists' Tournament, Evgenii Glushkov, *SPG Mitteilungen* 55, p. 58, 2018

25th Swiss Physics Olympiad finals in Aarau: Swiss teams for European and International Physics Olympiads selected

Lukas Gallmann, SPS Secretary, ETH Zürich

For its 25th anniversary, the annually recurring Swiss Physics Olympiad (SwissPhO) attracted a record-high number of 815 participants from high-school level schools all across Switzerland and Liechtenstein. The finals of the 2019 edition of the Swiss Physics Olympiad took place on March 16th and 17th at the Neue Kantonsschule in Aarau. The 26 finalists were selected in two prior rounds of the competition. Between the first and the second round, as well as before the finals, a preparation camp was offered to the students that qualified for the respective next round. At the finals, the participants had to solve a set of theoretical problems as well as to perform an experiment. From the best students, the teams representing Switzerland at the European (EuPhO) and International (IPhO) Physics Olympiads were selected.

The theoretical exams at the finals of the SwissPhO took 6 hours in total. As one of the problems, the students had to investigate the optical phenomenon of a halo, which is caused by ice crystals in the upper atmosphere and most prominently manifests itself as a circular ring around the sun or the moon. In the experimental part, the students were asked to determine the mass density of an oil. For this, the participants were provided with a beaker, a test tube, a pipette, a ruler, metal nuts and water. The students had to figure out themselves how to use these items and which physical theorems to apply in order to yield the desired quantity. As an additional challenge, they were not allowed to measure the test tube dimensions as part of their experimental procedure.

The results were announced in an award ceremony on Sunday, March 17th. During this festive conclusion, the solution to the tricky experimental problem was demonstrated. To provide the enthusiastic audience with impressions on a current topic of applied experimental physics, Prof. Jérôme Faist from ETH Zürich gave an inspiring presentation about his research on quantum cascade lasers and their application in chemical and medical diagnostics.

The 15 finalists that gathered the most points in the final round of the competition were awarded with a medal; bronze, silver and gold medals for five students each. The five gold medal winners thereby qualified to join the Swiss team for the International Physics Olympiad that is scheduled to take place from July 7th to July 15th in Tel Aviv, Israel. A second group of medalists was selected to represent Switzerland at the European Physics Olympiad in Riga, Latvia at the beginning of June. The teams will receive experimental and theoretical training in preparation of these international events. We wish both Swiss teams a lot of success at these highly competitive international tournaments!

The two participants that achieved the highest scores at the finals were awarded with the “Nachwuchsförderpreis / Prix de la Relève” of the SPS. The first prize went to Cédric Solenthaler from Kantonsschule am Burggraben in St. Gallen and the second prize was won by Hiro Farré from the Institut Le Rosey in Rolle. SCNAT is kindly helping us to fund this award and financially support the activities of SwissPhO.

Winners of the SPS “Nachwuchsförderpreis / Prix de la Relève”: Hiro Farré (left) and Cédric Solenthaler (middle); Lukas Gallmann representing the SPS (right).
All photos by Markus Meier, SwissPhO

It needs to be stressed that besides financial support, SwissPhO heavily relies on countless hours of work contributed by an enthusiastic group of volunteers – several of whom have participated as students in SwissPhO competitions themselves. These volunteers provide an invaluable contribution to the promotion of the next generation of physicists.

How we organized the IPT and (almost) survived

Evgenii Glushkov, Laboratory of Nanoscale Biology (LBEN), EPFL

To win a tournament is one thing, to organize it – something completely different. This is what a team of students from EPFL had to learn last April, when EPFL held the 2019 edition of the International Physicists' Tournament (IPT) – the biggest international competition in physics for teams of university students. For me, as the team leader of the EPFL team in 2017-2018, it was also a drastic change to become the main organizer of such an important event, hosting more than 200 participants from 20 countries.

Any organization starts with people, and the IPT 2019 was no exception. We started as a group of 4 students (all former IPT participants), trying to pitch this idea to the Physics Section of EPFL in May 2018 and somehow, after the EPFL team won the IPT 2018 in Moscow, everyone around was really motivated to host the next edition of the tournament in Lausanne. Another nice surprise came from the former head of the Physics Section, prof. Jean-Philippe Ansermet, who agreed to be the president of the Local Organizing Committee (LOC) and let us have regular LOC meetings in his amazing office.

The next step after forming the core of the organizing team was to secure the funding for the event. Immense help here came from various institutions within EPFL (Physics Section, School of Basic Sciences, Institute of Physics), as well as the vice-presidency for education. Their timely support allowed us to quickly secure the accommodation for the participants of the IPT 2019 already during autumn and slowly, but steadily, start a broader search for funding to be able to feed the participants with proper amounts of nice Swiss food, entertain them both scientifically and culturally and smoothly run the tournament. This turned out to be a long and exhausting experience and there were days, when we were leaving the LOC meetings without being sure if we can actually pull the whole thing through. Nevertheless, after half a year of work, we were finally (almost) confident, that we have sufficient funds not to let the international delegations starve to death on the Swiss ground. For that we can't but thank the SPS, who supported the IPT 2019 through the MAP platform of SCNAT! It was also very pleasant to see the strong support from other Swiss institutions (ETHZ, SNI, PSI, EMPA) and companies (Sensirion, Roche, GMP, Logitech), as well as to be officially supported by the City of Lausanne.

Financial matters aside, all of a sudden it was already February and the registration for the IPT 2019 was officially open. We spent the next month or so collecting the information on food preferences, T-shirt sizes and other sensitive participants' data. And when the first boxes with the brochures from sponsors started flooding our storage room, we realized how close we were to actually running (or ruining?) the tournament. A couple more weeks of settling the last details with the caterers, suppliers and administrative bodies and the Easter weekend fell upon our small team of organizers giving us a little break before the event.

Captain of the French team from ENS Lyon, presenting the problem "Water Dancing Ball". © C. Beaubis

The next week is best described by "controlled chaos", which from time to time went out of control. I probably shouldn't concentrate too much on all the unplanned situations which were arising during the tournament, but more on how brilliantly the organizing committee managed to solve them on the fly. For us and for the fellow volunteers it was probably the most valuable experience one could only get during the Easter week. It was also amazingly nice to work in close collaboration with the broader IPT community, especially the members of the International and Executive Organizing Committees of the IPT, without whom it would be close to impossible to run the tournament. Another great opportunity came from the Swiss National Science Foundation, whose grant allowed us to invite many experienced jury members from abroad to reduce the pressure on the local jury and set higher judging standards.

Participants of the IPT 2019 at the new iconic square on EPFL campus - Place Cosandey. © F. Daburon

Part of the Local Organizing Committee at the Farewell Dinner: J.-Ph. Ansermet, E. Glushkov, Q. Dubey (in front), D. Mari, A. Vernier and J. Fisher (at the back, barely visible). © V. Navikas

During the Easter week itself the rooms of EPFL have witnessed two days of preliminary physics fights, a semi-final with six best teams, lab tours, aperitifs and live music, a self-made fondue for 200 people, group photos on the newly built Cosandey square, lots of positive emotions, science and fun! A separate praise should go for the excursion to CERN, where the participants could enjoy going underground to the famous tunnels and seeing all the experiments of the LHC. Logically enough, the tournament ended with an impressive final physics fight between teams from France and Ukraine, showing some beautiful experiments demonstrations (e.g. a meter-high tesla coil). It was followed by a (hopefully) not-so-boring award ceremony decorated with talks from two passionate science communicators from UK- Jessica Wade and Wendy Sadler. The cherry on the IPT cake was the farewell dinner, where all participants could just relax, communicate with each other in an informal setting and enjoy the well-deserved freedom (and some delicious food and drinks).

It is really hard to transmit what it was like to be a part of IPT 2019 at EPFL. To get a glimpse of it, you should probably watch some of our videos on Youtube, but to truly feel it… I would definitely recommend taking part in one of the forthcoming editions, either as a participant, juror, volunteer or just a spectator! EPFL has been the outpost of IPT in Switzerland for many years now, but more and more people in other Swiss universities become interested in taking this challenge and representing Switzerland at the international final. Basel, Bern, Fribourg, Geneva, Neuchâtel, Zurich… are we going to see your teams next year?!

Rückblick Bürgi Symposium

Das 3. Internationale Jost Bürgi Symposium in Lichtensteig (Kanton St. Gallen), dem Geburtsort Bürgis, wurde auch diesmal an zwei Tagen durchgeführt. So trafen sich am Freitagnachmittag, 3. Mai 2019 Historiker verschiedener Fachrichtungen, um Bürgi, seine Zeit und sein Umfeld aus verschiedenen Blickwinkeln zu beleuchten. Am nächsten Tag vormittags wurden zuerst von zwei renommierten Kunsthistorikern einige Bürgi Uhren aus Wien und Dresden vorgestellt, Meisterwerke, die Eleganz und Präzision vereinen. Anschliessend im zweiten Teil kam das Erbe Bürgis zur Sprache: die heutige Zeitmessung im Sportbereich, eine schweizerische Dominanz, und dann der Weg von der Quarz- zur Atomuhr. Unser Kollege Beat Jeckelmann von METAS konnte die anspruchsvolle Physik didaktisch so geschickt den etwa 100 Zuhörern vermitteln, dass wir nur begeisterte Kommentare hörten.

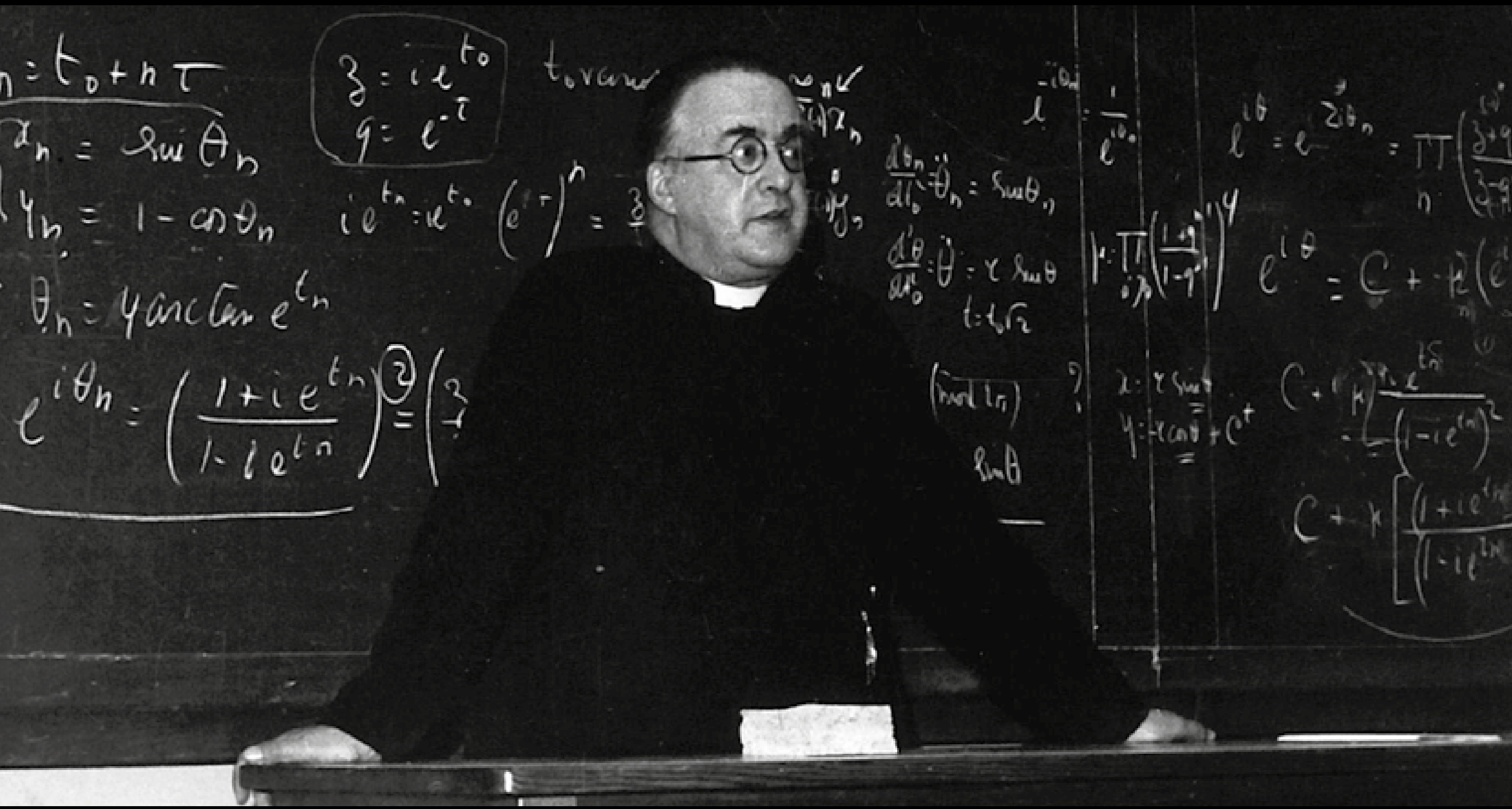
Die Vorträge finden sie in online unter
https://www.jostbuergi.com/symposium/ und
https://www.jostbuergi.com/experten-workshop/ .

Links: Bürgis Uhren in Kassel; rechts: Detail der Mondanomalienuhr (Vortrag Michael Beck)

Symposium

125th Anniversary of Georges Lemaître

21 November 2019, Kuppelsaal, Hauptgebäude, Universität Bern, Hochschulstrasse 4, 3012 Bern



Georges Edouard Lemaître (1894 - 1966) was a Belgian physicist, astronomer, and Roman Catholic priest. He proposed an expanding universe and is the central founding father of the Big Bang model of the Universe.

Afternoon Program (14:15 - 18:00)

Harry Nussbaumer (ETH Zürich)
Lemaître and the Astronomical Environment of the 1920s

Jean-Pierre Luminet (CNRS Marseille)
Philosophical aspects and implications of Lemaître's contributions to modern cosmology

Norbert Straumann (Universität Zürich)
On Lemaître's inhomogenous cosmological model of 1933 and its recent revival

Evening Program (19:00 - 20:00)

Friedrich-Karl Thielemann (Universität Basel)
Making the Elements in the Universe: From the Big Bang to Stars and Stellar Explosions

Further information

www.sps.ch
www.scnat.ch

Free entrance, no registration required

⟨S|P|S⟩ swiss physical society

Organisation:
SPS: Claus Beisbart (Claus.Beisbart@philo.unibe.ch)
SCNAT: Marc Türler (marc.tuerler@scnat.ch)

scnat swiss academy of sciences

In the last issue of the *SPG Mitteilungen* we pre-announced a special symposium on Thursday, 21 November 2019 to celebrate Georges Lemaître's 125th birthday. In the meantime the program has been completed. Please find the abstracts of the four presentations below.

Lemaître and the Astronomical Environment of the 1920s

Harry Nussbaumer, ETH Zürich

Georges Lemaître entered astronomy during the first half of the 1920s. It was a time, when our knowledge of astronomy and cosmology went through a fundamental transformation. The observational basis of the new cosmology were the nebulae, which today we call galaxies. I will present an abbreviated history of the discovery of their true nature, beginning in the early 17th century, and reaching its climax in 1925.
The 1920ies also saw the beginning of a proper understanding of the internal constitution of the stars, the source of their radiative energy, the chemical composition of the universe, and there was much discussion and speculation on the origin of the elements.
As a prelude to modern cosmology I shall recall a speculation of Karl Schwarzschild from the year 1900. There will be a jump to 1917 with Einstein and de Sitter. This will be followed by Lemaître's insight of 1925 into a fundamental misconstruction of de Sitter, which had been confusing observers and theoreticians since 1917. After this I will proceed to Lemaître's discovery of the expanding universe. (The latter two points will be dealt with more thoroughly by Luminet.)
Hubble's observational publication in 1929, of a linear relationship between nebular redshifts and distances, will be situated in its historical context. I shall do the same with Einstein's conversion from his static to a dynamic model of the universe.

Philosophical aspects and implications of Lemaître's contributions to modern cosmology

Jean-Pierre Luminet, CNRS Marseille

I will provide an epistemological analysis of the developments of relativistic cosmology from 1917 to 1934, based on the seminal articles by Einstein, de Sitter, Friedmann, with a special focus on Georges Lemaître, the true father of Big Bang theory. In particular I shall discuss the contents of his famous article of 1927 on the expanding universe, recalling the controversy about the so-called Hubble's law that was first presented in the original paper published in French, but disappeared in its English translation of 1931. Next I shall discuss the two articles of 1931 in which Lemaître introduced the concepts of the primeval atom and of the quantum origin of the universe, pointing out how negative reactions from Einstein, Eddington and others were based on a wrong philosophical interpretation of Lemaître's models. Eventually, Lemaître produced major contributions to relativistic cosmology until 1934, so that most of the ingredients of the present-day standard cosmological model, such as the accelation of the expansion due to a repulsive dark energy, the interpretation of the cosmological constant as vacuum energy or the possible non-trivial topology of space, had been anticipated by Lemaître in this golden period.

On Lemaître's inhomogeneous cosmological model of 1933 and its recent revival

Norbert Straumann, Physik-Institut, University of Zürich

After Lemaître's most famous paper in 1927 on the expanding universe he published during his fruitful years from 1931-1934 a whole series of important contributions to cosmology. In my talk I discuss only his long paper of 1933 on an inhomogeneous cosmological model, now usually called for some reasons the Lemaître-Tolman-Bondi model. This interesting generalization of the Friedmann-Lemaître models has in recent years, after the discovery of the accelerated expansion of the universe in 1998, been revived in a number of studies. One motivation was to see whether *inhomogeneous* matter distributions could induce an accelerated expansion, without invoking dark energy. I will summarize the outcome of detailed confrontations of Lemaître's model with cosmological observations (Hubble diagram of supernovae, background radiation).

Making the Elements in the Universe: From the Big Bang to Stars and Stellar Explosions

Friedrich-Karl Thielemann, Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel

The early universe within the Friedmann-Lemaître-Robertson-Walker prescription provides the framework for Big Bang nucleosynthesis, determined by the ratio of baryons to photons η (of the order 10^{-10}) being inversely proportional to the entropy of a radiation-dominated plasma. The high entropy, indicating very small densities for the temperatures encountered, are the reason that no elements heavier than He and Li are produced.
The build-up of elements in stars is governed by fusion reactions. Burning stages produce as ashes the fuel of the following stage and reflect that the fusion of heavier nuclei requires higher temperatures for overcoming higher Coulomb barriers. This sequence of events, from H- over He-, C-, Ne-, O-, and Si-burning, continues until nuclei with the highest binding energy per nucleon are reached, i.e. isotopes of Fe and Ni.
How can heavier nuclei be made? Neutrons do not experience repelling Coulomb forces, thus heavy nuclei can be produced by a sequence of neutron captures and beta-decays. But what is the source of unstable neutrons? Two options exist: (a) neutron-producing reactions in stellar evolution, or (b) explosive events starting with high densities, which permit the capture of electrons (with high Fermi energies) on protons in order to produce neutrons.

DC bis 500 kHz / 5 MHz

MFLI Lock-in Verstärker
MFIA Impedanzanalysator

Preise ab
CHF 6 210.–

Preise ab
CHF 11 270.–

Alle Geräte enthalten

- Spektrum Analysator
- Parameter Sweeper
- Oszilloskop mit FFT
- Imaging Modul
- Threshold Unit Tip Protection
- MATLAB®, LabVIEW®, .NET, C und Python API

Erweiterungsoptionen

4 PID/PLL Regler

- PID Advisor hilft beim Einstellen der Parameter
- Auto-tune minimiert den mittleren PID Fehler
- PLL Mode mit ±1024 π Phasenbereich für robusten Betrieb

AM/FM Modulation

- Generation und Analyse AM/FM modulierter Signale
- Analyse Seitenbänder höherer Ordnungen
- Individuelle Filtereinstellungen für jede Frequenz

Zurich Instruments

Your Application. Measured.

Intl. +41 44 515 0410
info@zhinst.com
www.zhinst.com

Weitere Fragen?
Kontaktieren Sie uns!