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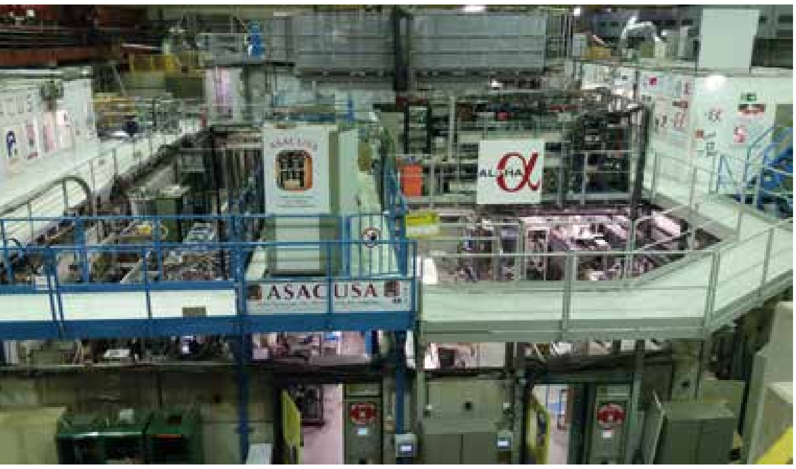
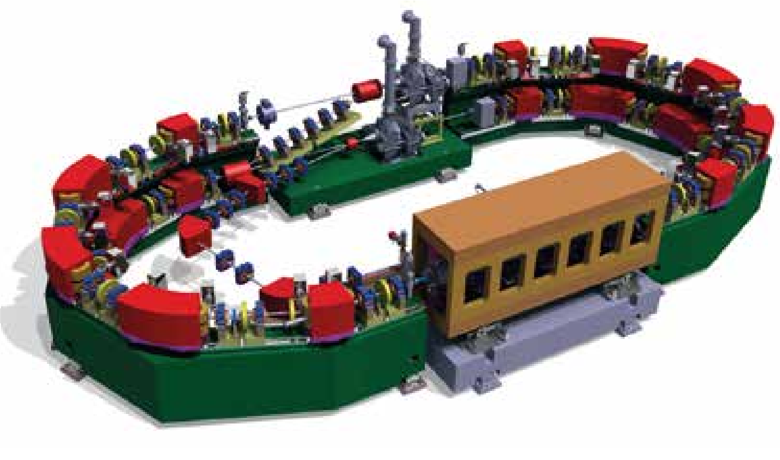
swiss physical society

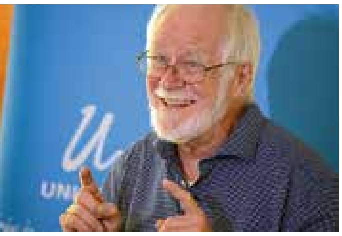
Nr. 53
November 2017

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP



The experimental zones of ALPHA and ASACUSA were part of the CERN "Antimatter Factory" visit during our recent annual meeting (p. 11)





Congratulations to this year's Nobel laureates in Chemistry and Physics:
Left: Jacques Dubochet, Right: Barry C. Barish, Kip S. Thorne and Rainer Weiss.
See p. 30 and 34 for more.

Picture sources: Top left: C. L. Cesar; top right: L. Rivkin (see caption on p. 33); middle left: Félix Imhof, © UNIL; middle right: Internet, various sources; bottom: SPS.

The award winners at this year's joint annual meeting (from left to right): Carlo Sirtori (Charpak-Ritz Award), Patrick Hofer, Evert van Nieuwenburg, Waiz Karim (SPS Awards), Mikhail Lemeshko, Tobias J. Huber, Christian Kohlfürst (ÖPG Awards), Viviane Lütz-Bueno (SGN Award), Johanna Gramling (CHIPP Award), Fabian Natterer, Nan Xu, Sinead M. Griffin (SPS Awards). Read more on p. 6.

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NN.

Wissenschaftlicher Redakteur - Rédacteur scientifique
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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*

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

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Member of
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SATW
Schweizerische Akademie der Technischen Wissenschaften
Académie suisse des sciences techniques
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Editorial

Lorsque l'on parle des conditions cadres pour la recherche en Suisse, on pense en premier lieu aux conditions financières. Cependant les questions qui ont été soulevées après le vote du 09/02/2014 montrent que la coopération internationale est aussi un des éléments qui font la force (et le succès) de notre recherche scientifique. ***M. le Secrétaire d'Etat à la formation, à la recherche et à l'innovation Mauro dell'Ambrogio*** nous fait connaître le point de vue du gouvernement sur le sujet. Nous tenons à le remercier pour avoir répondu à notre demande d'un éditorial. Notre pays étant plurilinguistique, le texte vous est offert dans trois langues nationales.

Minh Quang Tran, Vice-président de la SSP

Neue Erkenntnisse dank länderübergreifendem Austausch

Anfang September dieses Jahres fand in Hamburg die Eröffnungsfeier des European XFEL statt. Die Möglichkeiten dieser neuen Forschungsanlage, an deren Bau und Betrieb sich die Schweiz finanziell sowie intellektuell beteiligt, und die für Schweizer Forschende eine optimale Ergänzung zum ebenfalls kürzlich eingeweihten SwissFEL am Paul Scherrer Institut darstellt, beeindrucken mich tief. Spitzenwissenschaftlerinnen und Spitzenwissenschaftler aus der ganzen Welt und aus unterschiedlichen Disziplinen können sich künftig in Hamburg gegenseitig austauschen, zusammen Probleme lösen und neue Erkenntnisse zu Tage tragen. Auch verschiedene Forschungsgebiete der Physik werden davon profitieren: So können beispielsweise mit Hilfe der Röntgenblitze des European XFEL Plasmen erzeugt und untersucht werden, wie sie sonst nur im Weltall vorkommen.

Die offizielle Einweihung des European XFEL ist der jüngste Puzzlestein einer langjährigen Erfolgsgeschichte. Seit den 1950er-Jahren hat die länderübergreifende Forschungszusammenarbeit markant zugenommen. Physikerinnen und Physiker haben sich dabei oftmals als Wegbereiter hervorgetan. Beispielsweise in der Gründung des CERN oder der Europäischen Organisation für Astronomie (ESO), zwei international renommierte Institutionen. Aber auch internationale Organisationen wie die Europäische Weltraumorganisation ESA bieten Möglichkeiten für die Zusammenarbeit. Dies zeigt sich zum Beispiel beim optischen Teleskop CHEOPS (Characterising Exoplanet Satellite), welches an der Universität Bern zusammen mit Partnern aus anderen Ländern entwickelt, zusammengebaut und getestet wird.

Zusammenarbeit und Austausch von Ideen und Wissen ergeben sich nicht von alleine. Zum einen braucht es

Les échanges internationaux favorisent les nouvelles découvertes

Cette année, au début du mois de septembre s'est tenue à Hambourg la cérémonie d'inauguration du European XFEL. J'ai été très impressionné par les possibilités qu'offre cette nouvelle installation de recherche. La Suisse a participé à sa construction et contribue financièrement et intellectuellement à son exploitation. Cette installation constitue pour les chercheurs suisses un complément optimal au SwissFEL, inauguré récemment à l'Institut Paul Scherrer. Les chercheurs de pointe du monde entier, issus de différentes disciplines, pourront désormais se rencontrer à Hambourg pour échanger leurs idées, résoudre conjointement des problèmes et réaliser de nouvelles découvertes. Le European XFEL servira également à divers domaines de recherche en physique: ses rayons X permettent par exemple de produire et d'analyser des plasmas tels que présents dans l'espace.

L'inauguration officielle du European XFEL est l'évènement le plus récent d'une série de succès amorcée il y a longtemps déjà. Depuis les années 1950, la coopération transnationale en matière de recherche n'a cessé d'augmenter. Les physiciens y ont souvent fait figure de pionniers, notamment avec la fondation du CERN et de l'Organisation européenne pour l'astronomie (ESO), deux institutions de renommée internationale. Cela dit, les coopérations existent également grâce à des organisations internationales telles que l'Agence spatiale européenne (ESA). Preuve en est le télescope optique CHEOPS (Characterising Exoplanet Satellite), lequel est développé, construit et testé à l'Université de Berne, en collaboration avec des partenaires étrangers.

Divers facteurs sont essentiels au développement de la coopération et l'échange d'idées et de savoir. D'une part, il faut la volonté et les connais-

Nuove scoperte grazie agli scambi con altri Paesi

Quest'anno, all'inizio di settembre, si è svolta ad Amburgo l'inaugurazione dello European XFEL. Sono molto colpito dalle possibilità di questa nuova infrastruttura di ricerca, la cui costruzione e gestione vedono la partecipazione finanziaria e intellettuale della Svizzera. Per i ricercatori del nostro Paese rappresenta un complemento ottimale allo SwissFEL, anch'esso entrato in funzione di recente presso l'istituto Paul Scherrer. Ora scienziati di spicco di tutto il mondo e di varie discipline potranno incontrarsi nella città anseatica per risolvere insieme problemi e giungere a nuove scoperte. Anche diversi settori di ricerca della fisica ne trarranno vantaggio: ad esempio, grazie agli impulsi a raggi x dell'European XFEL è possibile produrre ed esaminare i plasmi, che altrimenti esisterebbero solo nello spazio.

L'inaugurazione ufficiale dello European XFEL è l'evento più recente di una lunga storia di successi. Dagli anni Cinquanta la collaborazione internazionale nella ricerca si è molto intensificata. In questo processo i fisici hanno spesso agito da «apripista», come nel caso della fondazione del CERN o dell'Osservatorio europeo au-

den Willen und die Erkenntnis dazu. Wir sehen uns vor grossen, globalen Herausforderungen, die kein Land im Alleingang lösen kann. Entscheidend ist deshalb, dass die Schweiz den seit jeher als selbstverständlich geltenden länderübergreifenden Austausch von Wissen, Ideen und Personen weiterhin aktiv und weltoffen mitgestaltet. Zum andern ist die länderübergreifende Zusammenarbeit ein Geben und Nehmen und setzt Leistungen in den jeweiligen Ländern voraus. In der Schweiz geniesst die Forschung eine hohe Priorität. Entsprechend betragen die Forschungsausgaben 3,4 Prozent vom Bruttoinlandprodukt; sie liegen deutlich über dem OECD-Durchschnitt (2,4 Prozent).

Ausschlaggebend ist jedoch nicht nur, wieviel Geld in Forschung und Entwicklung investiert wird, sondern insbesondere, wie diese Mittel verteilt werden. Seitens des Bundes sorgen wir zusammen mit den Kantonen für günstige Rahmenbedingungen, um die Schweiz national wie auch international als gefragten Denk- und Werkplatz zu positionieren und die Innovationsfreudigkeit auf einem hohen Niveau zu halten. Ziel aller Fördermassnahmen des Bundes ist es, den Akteuren und Institutionen zu ermöglichen, hierzu ebenfalls ihren Beitrag zu leisten.

Die Schweizer Bildungs-, Forschungs- und Innovationspolitik stützt sich vor allem auf folgende zentrale Rahmenbedingungen: Erstens ist das Forschungs- und Innovationsförderungssystem gut abgestimmt und auf Wettbewerb ausgerichtet. Die Förderung durch die öffentliche Hand ist grundsätzlich kompetitiv und delegiert an externe, unabhängige Gremien und deren Fachexperten wie der Schweizerische Nationalfonds. Das Bottom-up-Prinzip wird hochgehalten, auch was die Ausrichtung der Förderinstrumente betrifft. Es herrscht grosses Vertrauen der Politik in die Wissenschaft. Dies gilt auch für die Bestrebungen in der internationalen Zusammenarbeit. Ich komme auf mein anfängliches Beispiel, den European XFEL, zurück: Der Bund unterstützt die Teilnahme der Schweizer Forschung an internationalen Forschungsorganisationen durch den Abschluss von völkerrechtlichen Verträgen. Der Impuls zum Beitritt jedoch kommt von der nationalen Wissenschaftsgemeinde selbst; sie muss überzeugt sein davon,

sances nécessaires. Nous sommes face à d'importants défis planétaires qu'aucun pays ne peut affronter en solitaire. Il est capital que la Suisse continue à façonner activement et avec une ouverture au monde l'échange international de savoir, d'idées et de personnes, tradition considérée depuis toujours comme allant de soi. D'autre part, la coopération transnationale est basée sur le principe de réciprocité et requiert des prestations dans les différents pays impliqués. En Suisse, la recherche bénéficie d'une priorité toute particulière: les dépenses de recherche s'élèvent à 3,4 % du produit intérieur brut, ce qui est nettement au-dessus de la moyenne des pays de l'OCDE (2,4 %).

Le montant investi dans la recherche et développement n'est toutefois pas le seul critère important, la manière dont les fonds sont répartis est tout aussi fondamentale. A la Confédération, nous veillons avec les cantons à de bonnes conditions générales afin de positionner la Suisse en tant que pôle scientifique et industriel attrayant, tant à l'échelle nationale qu'internationale, et de maintenir à un niveau élevé le dynamisme d'innovation. Les mesures d'encouragement de la Confédération visent toutes à permettre aux acteurs et aux institutions d'apporter leur pierre à l'édifice.

La politique suisse de formation, de recherche et d'innovation s'appuie avant tout sur les conditions générales décrites ci-dessous. Premièrement, son système d'encouragement de la recherche et de l'innovation est bien coordonné et concurrentiel. Le financement par les pouvoirs publics est accordé essentiellement sur une base compétitive et sa gestion est déléguée à des organes externes et indépendants ainsi qu'à leurs spécialistes, dont le Fonds national suisse fait partie. Le principe ascendant (bottom-up) est privilégié, également en ce qui concerne l'orientation des instruments d'encouragement. La confiance des milieux politiques à l'égard de la communauté scientifique est solide. Cette confiance vaut aussi pour les efforts menés dans le cadre de la coopération internationale. J'en reviens à mon exemple du début: le European XFEL. La Confédération soutient la participation des chercheurs suisses à des organisations de recherche internationales en concluant des traités internationaux,

strale (ESO), due rinomate istituzioni a livello mondiale. Anche organizzazioni internazionali quali l'Agenzia spaziale europea (ESA) offrono possibilità di collaborazione, come è avvenuto ad esempio con il telescopio spaziale CHEOPS (Characterising Exoplanet Satellite), che è stato sviluppato, costruito e testato all'Università di Berna insieme a partner di altri Stati.

La collaborazione, lo scambio di idee e conoscenze non nascono dal nulla: da un lato occorre la forza di volontà e la capacità di sapersi muovere. Ci troviamo ad affrontare grandi sfide globali che nessun Paese può risolvere da solo. È pertanto fondamentale che la Svizzera continui a curare in modo attivo e aperto al mondo gli scambi di sapere, idee e persone – un aspetto spesso dato per scontato. Dall'altro, la collaborazione internazionale si basa sul principio della reciprocità e presuppone la prestazione di servizi nei vari Paesi partner. In Svizzera la ricerca riveste grande importanza: la spesa per questa voce rappresenta il 3,4 per cento del prodotto interno lordo, una cifra che supera nettamente la media OCSE (2,4 %).

Tuttavia, ciò che conta non è tanto il denaro investito in R&S, ma soprattutto come queste risorse vengono distribuite. Per conto della Confederazione la SEFRI provvede, insieme ai Cantoni, a creare condizioni quadro favorevoli per posizionare la Svizzera come polo intellettuale e industriale e per mantenere alta la capacità innovativa, sia a livello nazionale che internazionale. L'obiettivo delle misure di promozione della Confederazione è consentire agli attori e alle istituzioni coinvolti di fornire il loro contributo anche in questo ambito.

La politica svizzera in materia di educazione, ricerca e innovazione si fonda soprattutto sulle seguenti condizioni quadro. Primo: il sistema di ricerca e innovazione è ben armonizzato e basato sulla concorrenza. La promozione da parte degli enti pubblici è sostanzialmente competitiva e delegata a organismi esterni indipendenti e ai loro esperti, come nel caso del Fondo nazionale svizzero. Il principio bottom-up viene molto apprezzato, anche per quanto riguarda la configurazione degli strumenti di promozione. La politica ripone grande fiducia nella scienza e nei progetti di collaborazione internadass eine internationale Forschungsorganisation oder ein supra-nationales Forschungsvorhaben wichtige wissenschaftliche und technologische Impulse herbeizuführen vermag.

Zweitens geniessen unsere Hochschulen und Forschungsinstitutionen eine hohe Autonomie und entsprechend eine Offenheit der Themen. Keine staatliche Stelle schreibt vor, auf welchen Gebieten und in welchem Umfang geforscht werden soll. Die starke Stellung der Physik in der Schweiz haben die Forschenden über die Jahre hinweg selber erarbeitet. Ausdruck dafür sind unter anderem die sechs Nobelpreise, welche die Schweiz seit 1920 auf dem Gebiet der Physik erhalten hat. Diese Nobelpreise sind Aushängeschild für den Forschungsplatz Schweiz sowie Zeichen für dessen Attraktivität.

Drittens ist die Zusammenarbeit zwischen öffentlicher Hand und Privaten entscheidend. Zwei von drei Forschungsfranken stammen von privaten Investoren. Das setzt Risikobereitschaft voraus, ebenso wie Vertrauen in die Exzellenz des Forschungs- und Innovationsplatzes Schweiz. Die Arbeitsteilung zwischen öffentlicher Hand beziehungsweise öffentlichen Hochschulen (vorwiegend Grundlagenforschung) und Unternehmen (vorwiegend anwendungsorientierte Forschung und Entwicklung) hat sich bewährt. Daraus resultiert eine hohe Anwendbarkeit auch im Bereich der physikalischen Forschung, etwa in der Optik, der Nanotechnologie oder im Maschinenbau.

Schliesslich muss viertens die internationale Anbindung gewährleistet sein, indem ideale Rahmenbedingungen für die internationale Zusammenarbeit von Schweizer Bildungs- und Forschungsakteuren geschaffen werden. Ohne internationale Vernetzung sind bahnbrechende Erkenntnisse nicht denkbar. Spitzenforschung gelingt nur, wenn Spitzenkräfte über Landesgrenzen hinweg zusammenwirken. Bleiben wir also offen und nutzen wir das starke Fundament und das Vertrauen, dass wir dank der langjährigen Tradition der internationalen Zusammenarbeit aufgebaut haben.

Mauro Dell'Ambrogio, Staatssekretär für Bildung, Forschung und Innovation

cependant, c'est la communauté scientifique nationale elle-même qui doit montrer son intérêt à participer: elle doit être convaincue qu'une organisation de recherche internationale ou un projet de recherche supranational peut apporter d'importantes impulsions scientifiques et technologiques.

Deuxièmement, nos hautes écoles et nos institutions de recherche jouissent d'une grande autonomie et d'une liberté thématique en conséquence. Aucune autorité publique ne dicte quels domaines doivent faire l'objet de recherches et dans quelle mesure. La place particulière qu'occupe la physique en Suisse a été créée au fil du temps par les chercheurs eux-mêmes. Depuis 1920, la Suisse a d'ailleurs obtenu six prix Nobel de physique, qui servent de carte de visite pour la place scientifique suisse et démontrent son attrait.

Troisièmement, la coopération entre le public et le privé est décisive. Deux tiers des fonds de recherche proviennent d'investisseurs privés, ce qui présuppose une prise de risque tout comme une confiance en l'excellence de la recherche et de l'innovation suisses. La répartition des tâches entre les pouvoirs publics, à savoir les hautes écoles publiques (principalement axées sur la recherche fondamentale), et les entreprises (principalement axées sur la recherche orientée vers les applications et le développement) a fait ses preuves. Il en ressort une large applicabilité, également pour la recherche en physique, notamment en optique, en nanotechnologie et en construction de machines.

Pour finir, la connexion internationale doit être assurée, c'est-à-dire que les conditions cadres doivent être idéales pour permettre aux acteurs suisses de la formation et de la recherche de coopérer à l'international. Sans un tel réseau, les découvertes novatrices sont inimaginables. La recherche de pointe ne fonctionne que lorsque l'on réunit les meilleurs scientifiques par-delà les frontières. Restons donc ouverts et profitons de nos fondements solides et de la confiance que nous avons acquise grâce à cette longue tradition de coopération internationale.

Mauro Dell'Ambrogio, Secrétaire d'Etat à la formation, à la recherche et à l'innovation

zionale. Ritornando all'esempio iniziale dello European XFEL: la Confederazione stipula trattati internazionali per incentivare i ricercatori svizzeri a collaborare con organizzazioni internazionali. La spinta ad aderire proviene però dalla comunità scientifica nazionale, la prima che deve essere convinta del contributo che un progetto o un'organizzazione di ricerca internazionale può dare al progresso scientifico e tecnologico.

Secondo: le nostre università, i nostri istituti di ricerca godono di ampia autonomia e di conseguenza sono aperti ai vari temi. Nessun servizio statale prescrive in quali settori praticare la ricerca, né a quale livello. Il forte ruolo della fisica nel nostro Paese è frutto del lungo e costante impegno dei ricercatori – a riprova, i sei premi Nobel che la Svizzera vanta in questo campo dal 1920 a oggi. Questi riconoscimenti sono un importante biglietto da visita per il sistema della ricerca nazionale nonché un indice della sua attrattività.

Terzo: la collaborazione tra enti pubblici e privati è determinante. Due terzi delle risorse della ricerca provengono da investitori privati. Ciò presuppone una propensione al rischio, ma anche fiducia nell'eccellenza della Svizzera come polo di ricerca e di innovazione. La ripartizione dei compiti tra enti pubblici, ovvero tra le scuole universitarie pubbliche (soprattutto ricerca di base) e le imprese (per lo più ricerca applicata e sviluppo) si è rivelata valida ed efficace. Il risultato è un'elevata applicabilità anche nel settore della fisica, ad esempio in ambito ottico, in quello delle nanotecnologie o dell'ingegneria meccanica.

Quarto: bisogna garantire l'interazione con altri Paesi e creare condizioni quadro ideali per la collaborazione internazionale fra gli attori della formazione e della ricerca. Le scoperte rivoluzionarie non sarebbero pensabili senza scambi con altri Stati. La ricerca di punta ha successo solo quando i massimi esperti interagiscono tra di loro al di là dei confini nazionali. Restiamo dunque aperti e sfruttiamo il solido fondamento e la fiducia che abbiamo costruito negli anni con la collaborazione internazionale.

Mauro Dell'Ambrogio, Segreteria di Stato per la formazione, la ricerca e l'innovazione

The winners of the SPS Awards 2017

The SPS Award committee under the lead of Professor Louis Schlapbach selected the winners for 2017 out of numerous submissions.
The winners presented their work at the joint annual meeting in Geneva. Below you can read the laudationes written by L. Schlapbach (SPS Awards) and A. Fontaine & M. Q. Tran (Charpak-Ritz Award) and the summaries written by the authors.

SPS Award in General Physics, sponsored by ABB

The SPS 2017 Prize in General Physics is shared by ***Sinead M. Griffin*** *and* ***Patrick Hofer****.*

Sinead M. Griffin is awarded for her extraordinary PhD work in computational physics bridging cosmology with condensed matter physics. Griffin identified that the multiferroic hexagonal manganites, with their coupled ferroelectric and structural phase transitions, exhibit the same symmetry properties as those proposed for the Grand Unification Transition, shortly after the Big Bang. She then exploited the physics of the structural phase transition in this crystalline solid to model the process of cosmic string formation in the early universe.

Patrick Hofer is awarded for his excellent PhD thesis entitled "Dynamic Mesoscopic Conductors: Single Electron Sources, Full Counting Statistics, and Thermal Machines", an original and internationally visible contribution to modern quantum physics, which he had started with the late Markus Büttiker and finished with Eugene V. Sukhorukov & Christian Flindt at the University of Geneva.
With mathematical skills and physical intuition he investigated the controlled emission and entanglement of individual electrons in mesoscopic circuits, the statistics of current fluctuations and electron waiting times for phase-coherent quantum transport and thermal machines at the nano-scale.

The Early Universe in a Multiferroic

The hexagonal manganites play host to a range of properties from the technologically relevant – ferroelectricity, frustrated magnetism, magnetoelectric coupling, multiferroism, functional domains and domain walls – to being a model system for testing high- and low energy theories. Recent experiments using piezoresponse force microscopy (PFM), high angle annular dark field (HAADF) scanning transmission electron microscopy (STEM) and second harmonic generation (SHG) revealed an intriguing cloverleaf pattern caused by topological defects.
The formation of topological defects is central to understanding both the functional and exotic properties in these materials. The Kibble-Zurek mechanism, which remains an open question in cosmology, predicts a scaling law for the number of defects formed during a phase transition. Herein we pursue a complementary line of questioning by combining symmetry analysis, first-principles calculations, and phenomenological models. We show that hexagonal manganites form one-dimensional topologically-protected vortices. We then apply the Kibble-Zurek theory of topological defect formation to the hexagonal manganites to quantitatively corroborate our predictions arising from first-principles electronic structure theory with recent literature data. Finally we explore the crossover out of the Kibble-Zurek regime [1].
We next apply the developed topological description of hexagonal manganites to explain the formation of dual domains and domain walls in $InMnO_3$. Again using a combination of theory and calculations, we give a universal description of topological defects in both ferroelectric and non-polar domains and predict the resulting domain wall structures.
Finally, we propose a new class of materials with the hexagonal manganite structure to test the Hubbard Hamiltonian. We take a top-down approach to design a material ab initio with a half-filled non-degenerate band. We then characterize the electronic properties of the candidate materials, demonstrating Mott-insulating behavior and potential exotic superconductivity [2].

[1] S. M. Griffin et al., Phys. Rev. X **2** (4), 041022 (2012)
[2] S. M. Griffin et al., Phys. Rev. B **93**, 075115 (2016)

Dynamic Mesoscopic Conductors: Single Electron Sources, Full Counting Statistics, and Thermal Machines

We theoretically investigate different aspects of dynamic mesoscopic conductors with the ultimate goal of contributing to the development of quantum technologies. Our contributions can be grouped into three domains:

I) Controlled emission and entanglement of individual electrons:
We propose experiments to generate entanglement using single-electron sources. Investigating the noise properties of coherent single-electron excitations, we show that a single electron partitioned at a beam-splitter is entangled, making such systems potentially useful for quantum computation.

II) Statistics of current fluctuations and electron waiting times for phase-coherent conductors:
We develop a novel theory for joint electron waiting times and use this theory to describe single- electron sources. Furthermore, we connect the negative values that arise in full counting statistics (FCS) to an interference effect, showing that the FCS can be used to detect non-classical behavior.

III) Thermal machines at the nano-scale:
We propose two heat engines, one relying on the wave-nature of electrons, the other on the particle- nature of photons. The latter shows an intriguing separation of heat and work. We further propose a refrigerator that exhibits coherence-enhanced cooling, outperforming any classical analogue.

SPS Award in Condensed Matter Physics, sponsored by IBM

The SPS 2017 Prize in Condensed Matter Physics is awarded to to **Nan Xu** for his extraordinary postdoctoral work in experimental observation of Weyl semi-metals and topological Kondo insulators, two novel topological phases in condensed matter.
Using angle resolved photoemission spectroscopy at the Swiss Light Source he demonstrated the existence of Weyl nodes and Fermi arcs in TaP and could resolve the puzzle of different magneto-transport properties in transition-metal mono-phosphides which have similar fermi-arc states.
The results were published in best journals of physics with Nan Xu as 1st author and reached rapidly "highly cited" or "hot" paper standard (top 1%).

Topological quantum states visualized by ARPES: from topological Kondo insulator to Weyl semimetal

Topological quantum state represents a new class of materials with unique ground-state protected by topological invariant, which is not only fundamentally important in condensed-matter physics but also offers a promising opportunity for realizing the energy-saving electronics and quantum computer. Recently, topological classification of quantum phases has been extended from non-interacting insulators to strongly correlated insulators, and further to semimetals. Using state-of-the-art angle-resolved photoemission spectroscopy at Swiss Light Source, we have proved direct spectroscopy evidences of new topological quantum states, including:

- Direct observations of the metallic surface state and its helical spin texture in SmB_6 as evidences of the topological Kondo insulator [1].
- Direct observations of bulk Weyl cones, surface Fermi arcs and their correspondence in transition-metal monophosphides as experimental evidences of the Weyl semimetal [2].

[1] B. Q. Lv*, N. Xu*, H. M. Weng* et. al., *Observation of Weyl nodes in TaAs.* Nature Physics **11**, 724-727 (2015). (*contributed equally); N. Xu et. al., *Observation of Weyl nodes and Fermi arcs in TaP.* Nature Communications **7**, 11006 (2016); N. Xu et. al., *Distinct evolutions of Weyl fermion quasiparticles and Fermi arcs with bulk band topology in Weyl semimetals.* Physical Review Letters **118**, 106406 (2017).
[2] N. Xu et. al., *Surface and bulk electronic structure of the strongly correlated system* SmB_6 *and implications for a topological Kondo insulator.* Phys. Rev. B **88**, 121102(R) (2013); N. Xu et. al., *Direct observation of the spin texture in* SmB_6 *as evidence of the topological Kondo insulator.* Nature Communications **5**, 4566 (2014).

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

The SPS 2017 Prize in Applied Physics is awarded to **Waiz Karim** for his PhD thesis entitled "Metal nanostructures and their catalytic properties using top-down nanofabrication and single particle spectroscopy" which was honored with his 1st author publication "Catalyst support effects on hydrogen spillover" by W. Karim, C. Spreafico, A. Kleibert, J. Gobrecht, J. VandeVondele, Y. Ekinci, J. A. van Bokhoven, Nature, 2017, 541, 68–71. He pioneered work to combine nanofabrication & single-particle spectro-microscopy to visualize catalysis and achieved unprecedented precision in particle positioning and for the first time quantified spatial extent of 'Hydrogen spillover' to settle a 52 year old controversy. These achievements contribute to the fundamental understanding of the catalysis, essential to the development of sustainable processes.

Nanofabricated model systems combined with single-particle spectro-microscopy to visualize catalysis

Waiz Karim [1,2]*, Yasin Ekinci* [2]*, Jeroen A. van Bokhoven* [1,2]
[1] *ETH Zürich, Switzerland*
[2] *Paul Scherrer Institute, Switzerland*

Catalysts, which are often metal nanoparticles, are of vital importance in large-scale production of fuel and chemicals. Fabrication of catalytic model systems in a controlled manner with well-defined shape, size and position of catalytic particles as well as their study at the single particle level is necessary to gain deeper insight into chemical mechanisms in catalysis. We develop novel model surfaces using state-of-the-art top-down nanofabrication techniques such as extreme ultraviolet (EUV) lithography [1] and electron beam lithography (EBL) [2,3] to achieve nanometer precision over particle size and its positioning. Step-and-repeat exposures using EUV-achromatic Talbot lithography, which is robust to individual defects on the transmission mask, has enabled very high throughput fabrication of nanoparticles down to 15 nm feature size and 100 nm pitch, spread over an area of many cm2 in less than a few minutes [1].

We developed a new strategy to combine top-down nanofabrication together with X-ray photoemission electron microscope (XPEEM) at the Swiss Light Source to study catalytic nanoparticles [2,3]. EBL is used to achieve well-defined metal nanoparticles down to six nanometers and in-situ visualization of chemical action is done at the single nanoparticle level. This development is used to investigate the mechanism of hydrogen spillover, a critical phenomenon in heterogeneous catalysis [3]. Hydrogen spillover is the surface migration of hydrogen atoms from the catalyst onto and away from the catalyst support. Discovered in 1960s, it has since been widely controversial subject and evidence of its occurrence is disputed. Direct experimental proof of its existence does not exist due the lack of well-defined model systems and the inability to observe the effect directly. We employ EBL to place pairs of nanoparticles close to each other with an unprecedented accuracy of one nanometer and single-particle in-situ X-ray absorption spectromicroscopy was done to visualize hydrogen spillover. For the first time, distance dependence of hydrogen spillover has been experimentally visualized [3], and the hydrogen diffusion and migration mechanisms are elucidated by DFT calculations.

[1] W. Karim, S. A. Tschupp, M. Oezaslan, T. J. Schmidt, J. Gobrecht, J. A. van Bokhoven, and Y. Ekinci, Nanoscale, **7**, 7386 (2015).
[2] W. Karim, A. Kleibert, U. Hartfelder, A. Balan, J. Gobrecht, J. A. van Bokhoven, and Y. Ekinci, Scientific Reports, **6**, 18818 (2016).
[3] W. Karim, S. Clelia, A. Kleibert, J. Gobrecht, J. VandeVondele, Y. Ekinci, and J. A. van Bokhoven, Nature, **541**, 68-71 (2017).

SPS Award related to Metrology, sponsored by METAS

The SPS 2017 Prize related to Metrology is awarded to **Fabian Natterer** for his extraordinary postdoctoral work on the ultimate limits of the classical approach to high density magnetic storage media by a magnetically bistable Holmium atom; the work was recognized with his publication "Reading and Writing Single Atom Magnets" in Nature (March 2017, shared 1st authorship*) and highlighted in a Nature News & Views commentary. He demonstrated how to read and write the single Ho atom states using tunnel magnetoresistance and current pulses by a scanning tunnelling microscope. The Ho-atom magnetic moment was measured with unprecedented accuracy by dipole-dipole interaction with an electron spin resonance STM on nearby Fe-atom sensors.

*) „Reading and writing single-atom magnets", F. D. Natterer, K. Yang, W. Paul, P. Willke, T. Choi, T. Greber, A. J. Heinrich, and C. P. Lutz, Nature (2017). DOI: 10.1038/nature21371

Reading and Writing Single Atom Magnets

The giant leaps in miniaturization have enabled us to witness how mere thought experiments of single atom devices are suddenly close to becoming a physical reality. In magnetic storage media, by way of example, the smallest individually accessible magnetic bits contain few atom large clusters with magnetic lifetimes in the seconds range at cryogenic temperatures, but a recent report of magnetic remanence in ensembles of holmium atoms on magnesium oxide (MgO) promised a path toward data storage at the atomic limit [1]. It had been unclear, however, how the magnetic state of individual single atom magnets could be accessed. In the present work [2], we demonstrate the reading and writing of individual Ho atoms on MgO. We read the state of the Ho single atom magnet by tunnel magnetoresistance and write the state by a current pulse, using a scanning tunneling microscope. We are able to unambiguously prove the magnetic origin of the two bistable Ho states through STM enabled electron spin resonance on nearby sensor atoms. Via STM-ESR, we determine a large Ho out-of-plane magnetic moment of (10.1 ± 0.1) μB. We furthermore built a prototypical 2-Ho bit array to which we write all four states and which we read out directly via TMR and remotely on a sensor atom using ESR. We observe that the Ho single atom magnets independently retain their magnetic state over many hours. Our work marks the ultimate goal of miniaturization, and the realization of a programmable single atom magnet means that the thought experiment of single atom bits has now become a physical reality.

[1] F. Donati, S. Rusponi, S. Stepanow, C. Wäckerlin, A. Singha, L. Persichetti, R. Baltic, K. Diller, F. Patthey, E. Fernandes, J. Dreiser, Ž. Šljivančanin, K. Kummer, C. Nistor, P. Gambardella, and H. Brune, Science **352**, 318 (2016).
[2] F. D. Natterer, K. Yang, W. Paul, P. Willke, T. Choi, T. Greber, A. J. Heinrich, and C. P. Lutz, Nature **543**, 226 (2017).

SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS 2017 Prize in Computational Physics is awarded to **Evert van Nieuwenburg** for his PhD work entitled "Topology and Localization out of Equilibrium" in theoretical condensed matter physics. With his background in both computer science and theoretical physics, he introduced concepts from machine learning as very powerful methods in the toolbox of condensed matter physicists. He developed a new algorithm that allows to detect phase transitions solely based on "raw" numerical or experimental data, without any prior knowledge about the nature of the phases or transitions involved. Successful applications in topics like strongly-correlated non-equilibrium systems, disordered spin chains and quantum engineered systems such as photonic cavity arrays allowed publication in Nature Physics, February 2017 as 1st author with the title "Learning phase transitions by confusion", highlighted by accompanying "News & Views".

Learning phase transitions by confusion

Understanding the various phases of matter and the transitions between them is the central idea in condensed matter physics. Together with the concept of a phase of matter comes the concept of an order parameter that identifies it. Over the recent years, order parameters have become increasingly more complex (i.e. non-local), since the phases they identify have become more exotic. Identifying an order parameter can be a notoriously hard problem. Since it is nowadays less difficult to obtain large volumes of data -- either by experiment or by simulations -- it has become feasible to use machine learning techniques to identify order parameters. A well-known machine learning technique is that of supervised learning with a neural network. The neural network can be taught to classify inputs into distinct classes, by repeatedly showing it examples of pre-labeled pairs. As an example, one may train a machine to recognize low- and high-temperature snapshots of the 2-dimensional Ising model as being 'below' and 'above' the critical temperature. After it has been trained, one may ask it to judge where the transition point is by trying to classify snapshots close to the transition [1]. For more complicated models however, the phases may be unknown and hence pre-labelling the data is impossible. In such cases supervised learning must be replaced by unsupervised learning. We demonstrate a method for identifying the transition points using an unsupervised method [2]. We guess a labeling of the input data, and attempt to teach this to a network. If the classification is highly inconsistent (i.e. giving similar input data very different classification labels), the network is confused and has difficulties learning to classify inputs. If the guess of labels is consistent with the input, the network performs well in classifying inputs. The maximum of the performance curve as a function of guessed classification then identifies the most consistent labeling and hence the transition point. We demonstrate this approach by identifying the classical transition point in the Ising model, the topological transition in the Kitaev chain and the non-trivial eigenstate transition in a many-body localized system.

[1] Juan Carrasquilla and Roger G. Melko, Nature Physics, **13**, 431-434 (2017)
[2] Evert P. L. van Nieuwenburg, Ye-Hua Liu and Sebastian D. Huber, Nature Physics, **13**, 435-439 (2017)

The SPS Award winners: Nan Xu, Fabian Natterer, Waiz Karim, Patrick Hofer, Evert van Nieuwenburg, Sinead M. Griffin.

Carlo Sirtori (right), the first winner of the Charpak-Ritz Award with Alain Fontaine (left), representative of the Société Française de Physique and Minh Quang Tran, SPS Vice-President.

Lauréat du prix Charpak-Ritz 2017

Premier lauréat du prix Charpak-Ritz (Prix conjoint de la *Société Française de Physique* et de la *Société Suisse de Physique*), **Carlo Sirtori** est un spécialiste des interactions entre la lumière et la matière condensée. Après plus de 7 ans à Bell Labs, dont 3 ans comme post-doc, chez Federico Capasso en 1990-93, il rejoint ensuite Thalès pendant 5 ans avant de devenir, en 2012, professeur de l'Université Paris 7, au laboratoire MPQ (P7-CNRS).

Carlo Sirtori a eu un parcours scientifique unique avec des résultats scientifiques et technologiques exceptionnels. Il a travaillé en particulier sur les tous premiers lasers semi-conducteurs à cascade quantique dans différents matériaux. Ces lasers sont devenus aujourd'hui des outils technologiques performants. Il a aussi démontré qu'on pouvait combiner très favorablement les lasers à cascade quantique THz avec d'autres technologies bien établies. Depuis une dizaine d'année il travaille aussi sur les polaritons de cavité, démontrant leurs injections électriques ce qui permet de concevoir des nouveaux composants à base de couplage fort où on peut obtenir par exemple des lasers sans seuil. Carlo Sirtori et son équipe ont le record mondial du couplage fort avec un anti-croisement de Rabi de plus de 70% de la transition. Dans ce régime, dit ultra-fort, les propriétés des systèmes couplés sont si modifiées que cela ouvre tout un nouveau champ de recherche fondamentale et appliquée où l'interaction avec le champ du vide permet de contrôler la matière.

Au cœur de résultats originaux reconnus par la communauté internationale, C. Sirtori et son groupe, innovent et portent un équilibre rarement atteint, associant l'exploration de propriétés quantiques fondamentales, et l'intégration des lasers THz avec d'autres technologies pour créer des développements pratiques de dispositifs industriels.

Light-matter interaction @ nanoscale

Carlo Sirtori, Paris Diderot, Sorbonne Paris Cité, Laboratoire Matériaux et Phénomènes Quantiques, UMR7162, 75013 Paris, France

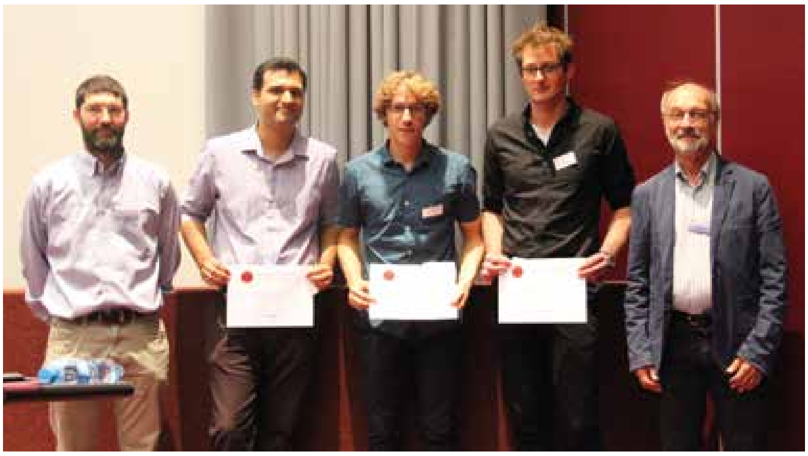
Light-matter interaction in condensed matter is a fascinating research field, at the intersection between physics and technology. Semiconductor quantum structures have played a very important role in this field and are a clear example of how fundamental physics and technology mutually enrich each other. The advent of epitaxial growth (bottom-up) has allowed the realization of 2-dimensional structures at the nanometer level, opening a wealth of new exploration in fundamental physics and producing highly performing technologies, such information and communication. The continuous progresses of these technologies have stretched the limit of fabrication processing (top-down) also to nanometer precision and today top-down and bottom-up techniques converge at the nanometer world. This allows the conception and realization of structures confining electrons and photons in the 3 dimensions of the space, which are ideal for engineering and exploring new quantum effects. Our interventions at the nanometer level can transform material global properties or produce individual quantum structures sensitive to single photons or single electrons.

This is the context of my research for the past 20 years, which I will briefly review during this presentation. Indeed, most of my carrier has been devoted to investigations of light-matter interaction in low-dimensional structures to conceive and realise high performance light emitters and detectors. I will begin by presenting our work on quantum cascade lasers, subsequently I will show how we got interested on ultra-strong light matter interaction in order to introduce new characteristic times in optoelectronic devices and I will conclude with our research on superradiance.

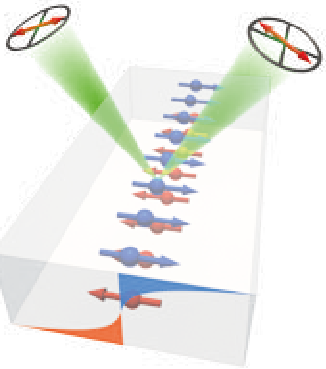
epl Journal Poster Award 2017

Antoine Pochelon

The ***epl Journal*** offered again this year three prizes for the best posters at the Joint Annual Meeting in Geneva, a way of promoting quality in poster presentation and content. Congratulation to the three winners, **Christoph Murer**, **Martin Bawart** and **Abhishek Sharma**! At the Poster Award Session, the winners had to present their work in 2 minutes, 2 slides, just to transmit – efficiently! – the flavour of their work. I would like to thank here the members of the selection committee for their dedicated work: Claude Ederer, Wolfgang Lucha, Antoine Pochelon (chair of the Jury), Helmut Ritsch, Dieter Süss and Michele Weber.



Abhishek Sharma, Martin Bawart and Christoph Murer, framed by the jury members Michele Weber (left) and Antoine Pochelon.



Magneto-optical detection of the spin Hall effect in Pt and W thin films

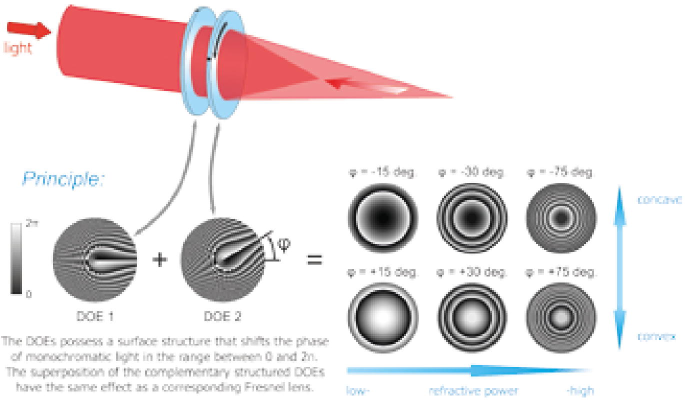
Christoph Murer et al., Department of Materials, ETH Zürich

A charge current flowing through a nonmagnetic conductor induces a perpendicular spin current due to the spin Hall effect. This on spin-orbit interaction based effect leads to an accumulation of opposite spins at opposite edges of the conductor, which has interesting applications in the field of spintronics. While most detection techniques of the spin accumulation due to the spin Hall effect rely on the utilization of a ferromagnetic detection layer, we here report the first direct measurement of a current-induced spin accumulation by utilization of the magneto-optical Kerr effect in Pt and W thin films (schematic representation in the figure left). For more information see: www.intermag.mat.ethz.ch

Multi-color operation of tunable diffractive lenses

Martin Bawart et al., Division of Biomedical Physics, Innsbruck Medical University

Tunable diffractive lenses consist of two stacked diffractive optical elements (DOEs) which are rotated with respect to each other around their central optical axis. These combined elements act as a highly efficient diffractive lens, which changes its optical power as a function of the mutual rotation angle. Here we show that the principle can be extended to produce polychromatic tunable lenses, i.e. lenses which have the same optical power and the same diffraction efficiency within the full tuning range at three or more selectable wavelengths. The basic principle is to use higher order DOEs, which will be polychromatic at harmonics of a fundamental wavelength. For more information please visit: www.i-med.ac.at/dpmp/bmp/research/patents/ or www.diffratec.com.



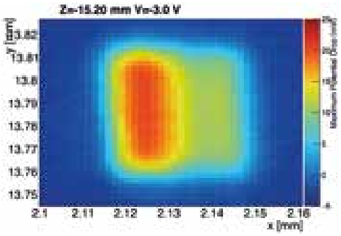
The DOEs possess a surface structure that shifts the phase of monochromatic light in the range between 0 and 2π. The superposition of the complementary structured DOEs have the same effect as a corresponding Fresnel lens.

E-TCT studies and Thermal Characterisations towards the ITK Phase II Upgrade

Abhishek Sharma et al., CERN Atlas Group & Oxford University

The ATLAS experiment at the LHC will upgrade its tracking detector in 2024 to better take advantage of the increased luminosity of the upcoming HL-LHC. The upgraded Inner Tracker (ITK) will consist of a barrel of concentric layers (5 pixels + 4 strips, with several endcap rings).

Substantial R&D is taking place in the area of silicon CMOS sensor technologies to find a candidate sensor which meets the stringent criteria of the HL-LHC operating environment as well as in the research of the Inner Detector mechanical support design and layout, specifically the design of scaffolding units known as staves. Edge-Transient Current Technique is being used to probe the charge collection and sharing properties of prototype silicon sensors, and towards the mechanical assessments, work is being undertaken to thermally characterise the support structures (staves) on which these very sensors are to be secured during operation of the HL-LHC. These characterisation studies will converge towards a final design and with data-taking expected to start by 2026. More: http://ade-pixel-group.web.cern.ch



Edge Transient Current Technique (E-TCT) measurement on a single 50 µm pixel of the TowerJazz 180 nm CMOS sensor prototype for ATLAS ITK.

Thermal Figure of Merit characterisation measurement on a 3-celled barrel stave sample using CO_2 cooling.

Report on the Joint Annual Meeting 2017 in Geneva

It was this year a great chance and a wonderful opportunity to be hosted by CERN, which for decades has accustomed us to regularly setting new fundamental milestones in particle physics, and whose spin-offs have sometimes radically changed our lives. One day of plenary talks at CERN, three days in the city at the *Centre International des Congrès de Genève* (CICG), a flexibility in location that allowed us to fully profit from interesting visits at CERN, and the excellent infrastructure of a professional conference centre.

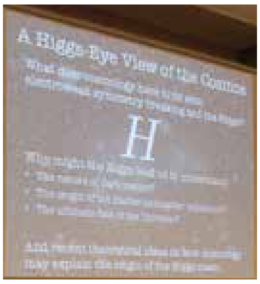
As mentioned in the opening of the conference by Minh Quang Tran, over 520 physicists and students of the Swiss and Austrian Physical Societies gathered in this 2017 Joint Annual Meeting, with about 360 coming from Switzerland, more than 100 from Austria and the rest from other countries, and a total of about 370 contributions (approx. 280 orals and 90 posters). The additional presence of CHIPP (Swiss Institute of Particle Physics) in this year's meeting also was evidently catalysed by the location of the meeting at CERN. We had as well the presence of SSAA (Swiss Society for Astrophysics and Astronomy) and of NCCR MARVEL, which all helped making this meeting a great success. There were 11 plenary talks, 2 evening public lectures with one at CERN and one at CICG.

In her welcoming words introducing the conference, CERN Director General Fabiola Gianotti exposed in a concise and smart way the long and impressive list of research activities at CERN, high-lighting recent discoveries and not missing out the spin-offs that emerged out of these activities in a natural and impressive way. With the three main-line research themes, accelerators, particle detectors and computers, CERN is also preparing the future of particle physics longing for new projects at increased luminosity and embarking to new energy domains. Rüdiger Voss, EPS president, drew our attention to the fact that science is sometimes attacked, which demands vigilance and a continued and open dialogue in which member societies play an important role. Reinhold Koch, ÖPG President, mentioned the synergies the joint meetings between ÖPG and SPG are offering, where the two sister societies can fully profit from each other, building up links that otherwise would not exist, and thereby enabling new opportunities, with one small but much appreciated opportunity to meet at CERN.

The CHIPP meeting started already Monday afternoon, before the official begin of the Annual Meeting on Tuesday late morning. On Monday afternoon and Tuesday early morning several guided visits to CERN infrastructure and experimental sites were scheduled. It was thus possible to see the ATLAS Visitor Centre at the Large Hadron Collider; the historical Synchrocyclotron, CERN's very first accelerator inaugurated in 1959; the CERN Data Centre with its massive computing and data handling infrastructure; the Antimatter Factory, where anti-hydrogen atoms are produced and measured; the AMS control room and data reception centre, directly linking to the international space station ISS and measuring primary cosmic rays; CERNs main Control Centre, where all accelerators are being orchestrated; the LHC Magnet test hall; and the Microcosm visitor centre.

A model of the Alpha Magnetic Spectrometer (AMS). The original is attached to the ISS and is delivering data already since 2011.

The General Assembly was well attended with 53 participants. The minutes of the GA will appear, as usual, in the SPG Mitteilungen No. 55. Let us just mention the election of Hans Peter Beck, Uni Bern, as new president of the SPS, and the outgoing president, Minh Quang Tran, EPFL, continuing his term as vice-president; further the election of two new board members representing the section "Physics in Industry", Andreas Fuhrer and Thilo Stöferle (p. 17).



The two evening public conferences were great moments. Tuesday evening at CERN, Matthew Philipp McCullough, CERN, in his brilliant "A Higgs-Eye View of the Cosmos" discussed how to find the way in the search of what the universe is made of, trying to mutually fertilize cosmology from particle physics and reciprocally: a two-way street! See the extended abstract on p. 21.
Thursday evening at the CICG, the astrophysicist and President of Swiss- and European academies Thierry Courvoisier spoke about "De la place de la Science dans la Société".

Starting from his field and the quite pragmatic role of past astronomy, for example as a supplier of time, astrophysics knowledge today situates precisely the place of man in an evolving universe. At the same time, fundamental research, even more than applied research, offers an enormous potential for return. Think for example at the general relativity, omnipresent in many applications like in portable phones, GPS … But knowledge implies also responsibility to the society and the need of communication, a long story where Thierry Courvoisier could bring us his valuable experience from his activity in the Academies.

The Conference dinner on Wednesday evening was a nice opportunity to profit of a wonderful sunny evening at the *Restaurant du Parc des Bastions*, between the *Mur des Réformateurs* and *Uni Bastions*. Jean-Marc Triscone, vice-rector of Uni Geneva welcomed the nearly 200 participants with an inspiring speech, high-lighting the role of physics in Geneva not only by the fact of CERN being in the nearby neighbourhood, but even before with important contributions made, e.g. by Charles Eugène Guye and Ernst Carl Gerlach Stückelberg leading to Uni Bastions being awarded as a EPS historic site (see *SPG Mitteilungen* Nr. 52, p. 32).

The summaries of the various topical sessions can be found below.

Antoine Pochelon, SPS Secretary

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

Both oral and poster presentations showed that applied physics lies at the basis of many ongoing research activities including, to name but just a few areas, lasers, condensed-matter, nano-sciences and technology, superconducting magnet applications, geomagnetic localisation, in parallel to computer simulations to help finding practical solutions in research and everyday life.
Two talks dealt with laser science and technology; the first used high-power femtosecond thin disk oscillators for THz generation with multi-megahertz repetition-rate. The second was about quantum cascade lasers working in the mid-infrared e.-m. spectrum for food-safety and medical diagnostics and thus both showed that the application of new physics developments are pushed at their limits.
Another talk presented the design of a compact synchrotron light source producing extreme ultraviolet e.-m. radiation for applications in the semiconductor industry.
One talk described the technology for the size selection of helium nanodroplets for tailoring synthesis of nanostructures; this technique is growing out as a novel medium for producing and spectroscopically characterizing a wide range of clusters and nanoscale materials.
Then, an overview of the current developments in superconducting magnets for application in proton and ion therapy gantries used for medical purposes, then experimental and numerical methods for the fluid dynamics and acoustic characterization of heat exchanger icing, followed by an interesting talk about a system based on geomagnetic field distortions devised for positioning in indoor environments.
Finally, the implementation of a numerical mass-balance glacier module in a regional climate model to better represent the evolution of weather systems in such environment in the long term has been described along with some interesting and promising results.

Stéphane Goyette, Uni Genève

After the apéro at the "Restaurant du Parc des Bastions",...

... Jean-Marc Triscone (left, with Minh Quang Tran) gave his speech, before...

... everyone could enjoy a good meal in the cozy atmosphere of the dining room.

Condensed Matter (KOND) and related focussed sessions

The KOND section organised a busy and well-attended program with 1 plenary talk,11 invited talks, 73 contributed talks and 42 poster presentations. The plenary talk by Richard Warburton from Uni Basel on "Quantum photonics with solid-state emitters" was one of several highlights. In addition to the general KOND program, four groups of co-organisers contributed focussed sessions, which were all well-attended by advanced researchers and young scientists (postdocs and PhD students) from various Swiss academic institutions:
1) Correlated-electron physics in transition-metal oxides, 2) Scientific opportunities with SwissFel, 3) Surfaces, Interfaces and Thin Films, 3) Emergent phenomena in novel low-dimensional materials, 4) Magnetism and spintronics at the nanoscale.

The session **Magnetism and Spintronics at the Nanoscale**, organized for the second time at the SPS meeting, was focused on the investigation of various magnetic properties of magnetic materials at different length and time scales. This session included two invited presentations (Dieter Süss, University of Vienna and Hans J. Hug, University of Basel & EMPA), fourteen contributed talks and fifteen posters, and was divided into two parts. The first session was mainly focused on "Nanomagnetism" and the second concentrated on "Dynamics and Magnetoelectric Effects". Several interesting fields of magnetism, such as Skyrmions, domain wall motion, artificial spin systems, the spin Hall effect, spin wave dynamics, and magnetoelectric effects were discussed. For characterization, various laboratory-based techniques (including magnetic force microscopy, transport measurements, magneto-optical Kerr effect measurements, Brillouin light scattering microscopy, ferromagnetic resonance microscopy, transmission electron microscopy) and large-scale facility methods (including scanning transmission X-ray microscopy, photoemission electron microscopy, low energy muons and neutrons) were covered. The discussion at the poster session was very lively and warm congratulations go to Christoph Murer, ETH Zürich for winning a prize for his poster on the magneto-optical detection of the spin Hall effect (see p. 10).

Laura Heydermann, PSI and ETHZ

Plasma Physics

This year's topical session on Plasma Physics attracted speakers from both the fields of magnetic confinement nuclear fusion as well as from accelerator physics.
In his invited talk, Prof. Christian Theiler from the Swiss Plasma Center (SPC), EPFL, presented a review of current research activities carried out with the Tokamak a Configuration Variables (TCV) at the SPC for studying the properties of plasma detachment in alternative diverted magnetic geometries. Heat and particles leaving the core region of a magnetic fusion device get deposited in a very narrow region of the reactor wall, leading to thermal loads at the limits of current available materials. Optimizing the detachment of the plasma from the wall, in particular by investigating novel magnetic geometries, provides a promising route. The TCV tokamak, with its unique geometrical flexibility, is the ideal machine for such studies. H. de Oliveira addressed the development of a fast-moving Langmuir probe array for diagnosing and better understanding the turbulent plasma dynamics in the edge plasma region, in particular near the so-called X-point region, which plays an essential role in diverted plasma configurations. The reciprocating probe, with accelerations up to 400 m/s^2, enables to rapidly scan a two-dimensional region of the plasma edge, so as to withstand the extreme thermal loads of more than 50 MW/m s^2.
A presentation by F. Pesamosca (SPC) addressed the development of a new feedback control system on the TCV tokamak to improve the control of plasma instabilities, in particular for stabilizing vertical plasma displacements and plasma shape. Shaping itself has an important effect on tokamak plasma stability and confinement properties. This new feedback control system holds the promise of ensuring real time control of advanced plasma configurations. As discussed in a talk by F. Carpanese (SPC), testing such a feedback control system requires a fast and realistic tokamak simulator. Such a simulator is currently being developed by coupling the equilibrium code LIUQUE with the transport code RAPTOR.
R. Agnello (SPC) discussed the development of a Neutral Beam system for heating plasmas in the ITER tokamak, currently being built in Cadarache, France. Achieving the required ion beams with an energy of 1 MeV and currents of 40 A can only be ensured efficiently with a negative ion source. The RAID experiment, currently being developed at the EPFL, provides a promising solution for such a source based on a Helicon plasma producing negative hydrogen ions.
Plasma sputtering is used at CERN for depositing thin niobium films on copper radio-frequency accelerating cavities, as was explained in a presentation by T. Richard. A dedicated experimental test bench has been developed in form of a cylindrical magnetron assembly in which sweeping Langmuir probes enable to diagnose both electron density and temperature profiles. These experimental measurements are used to validate numerical simulations, which are expected to help optimize the coating process. As presented in the talk by M. Turner (CERN), plasmas also play a central


Louis Schlapbach (right) presided the award committee this year for the last time. Between main course and dessert he got his well-deserved farewell presents from the newly elected SPS president Hans Peter Beck.

role in actual new generation particle accelerator concepts, as investigated with CERN's AWAKE experiment, based on the principle of plasma wakefield acceleration. AWAKE aims to create GV/m plasma wakefields over a length of 10m using a self-modulated 400 GeV proton drive beam.

Stephan Brunner, EPFL

TASK

CERN being the host of this year's annual meeting, the "**T**eilchen-, **As**troteilchen- und **K**ernphysik" session was particularly well represented and was organized jointly by the TASK section of the SPS, the Fachausschuss FAKT of the ÖPG and the Swiss Institute for Particle Physics (CHIPP).
The CHIPP plenary meeting, which was also open to our Austrian FAKT colleagues, took place on Monday the 22nd at CERN and activities of the various committees such as the European Committee for Future Accelerator and International Particle Physics Outreach Group, where the CHIPP nominates the Swiss representatives, have been reported.

On Tuesday, as an integral part of the SPS award ceremony where all winners of the various SPS prizes are honoured, the CHIPP prize for the best PhD thesis work in particle physics was awarded to Johanna Gramling from University of Geneva for her outstanding work on "dark matter searches with the ATLAS detector and her role in establishing the use of simplified models for their theoretical interpretation", as the laudatio states. On Wednesday, Johanna had the opportunity to present her work as first speaker of the TASK parallel sessions that took place at the CICG.

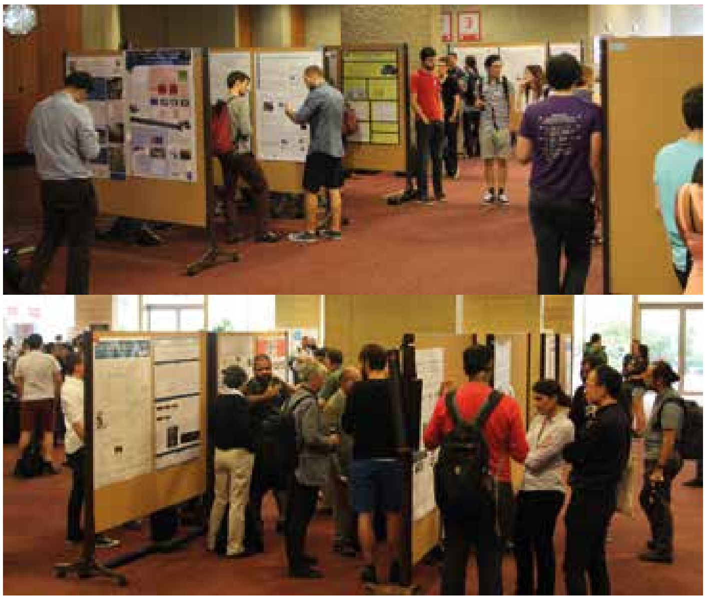
With the record number of more than 100 submitted contributions related to TASK, the talks of the parallel sessions were organised in one overview and nine topical sessions giving insight to the current theoretical and experimental status of particle and astroparticle physics at high-, medium-, and low energies. The TASK overview session served as an introduction to the subsequent topical sessions and started with a discussion of the effective mass signatures in multiphoton pair production followed by presentations of the status of the International Future Collider Study FCC and of the proton driven Plasma Wakefield Acceleration Experiment AWAKE at CERN. A very comprehensive overview of the physics at the future High Luminosity Large Hadron Collider was preceding an introduction to the Cherenkov Telescope Array experiment CTA as well as a presentation of the precision experiments with cold and ultracold neutrons. The following talks in the nine topical TASK sessions spanned over a wide range of topics from presenting new developments in detector and accelerator technologies for current and future projects to discussing the latest physics results and their impact on theoretical predictions, whether in agreement with the Standard Model or beyond the Standard Model Theory. Lively discussions on the experimental and theoretical aspects of physics continued to take place among the many participants during poster sessions and during lunch and coffee breaks.

This annual meeting once more stimulated communication not only among scientists from Switzerland and Austria working in the field of nuclear, particle and astroparticle physics, but even more so among physicists from all fields of physics, whether with high or low energies, whether in the micro- or macrocosm, whether experimental or theoretical, whether in applied or fundamental research.

Andreas Schopper, CERN

Theoretical Physics

The session took place on the afternoons of Wednesday and Thursday.
Before describing some of the highlights (in order of presentation) a remark may be fitting. There was a good number of interesting talks contributed by Austrian participants, even though the Austrian Physical Society did not use to have sessions in Theoretical Physics before they were introduced at recent joint meetings (Linz, Vienna). This is in stark contrast with the Swiss side, where the few contributed talks came, all but one, from Swiss researchers abroad.
Julien Guillod (Paris-Diderot) gave a talk on a certain class of solutions of the Navier-Stokes equation. In particular, he showed that one has non-uniqueness of the solution for given initial data that are not smooth. While this does not solve one of the Clay Millennium Problems, the hint the result carries is towards a disproof of the celebrated conjecture.
Christian Schilling (Oxford) presented a definitive result about the maximal occupation number of hard-core bosons. For N ordinary bosons this number is of course N, since all of them can be placed in the same single-particle state. To define hard-core bosons, pick any basis of the single-particle space and impose that no basis state is occupied more than once. States that are not part of the basis still can,



The poster session allowed for vivid discussions in all topical fields.

but by far less than N. The maximal number is now known explicitly.
Katharina Schwaiger (Innsbruck) considered fermionic Gaussian multi-particle states (a generalization of Hartree-Fock states) in connection with quantum information theory. She discussed items such entanglement, local communication and classical communication.
Jacob Shapiro (ETHZ) talked about a particular class (in the sense of Kitaev's table) of topological insulators and explained a result of bulk-edge correspondence in a regime of strong disorder.
Manfred Sigrist (ETHZ) gave a very nice overview about topology and unconventional superconductors. He then addressed edge currents in chiral superconductors and the puzzling question as of why they are not as strong as the theory originally predicted.

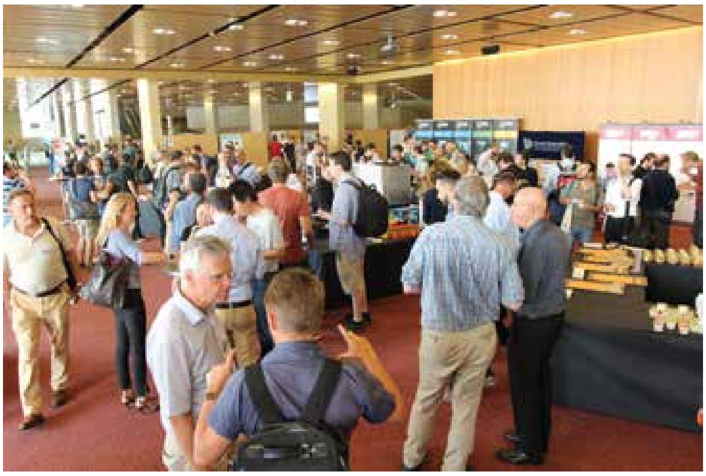
Gian Michele Graf, ETHZ

Atomic Physics and Quantum Optics

Two plenary speakers presented research highlights in the field of quantum optics and atomic physics. Interestingly, both speakers reported novel developments in the field of light-matter quantum interfaces, but using very different physical systems. Such interfaces will find important applications in future quantum technology, enabling quantum networks for distributed quantum computing and quantum communication.

Tracy Northup from the University of Innsbruck reported cutting-edge experiments with trapped ions. Read on p. 26 her extended abstract.
Richard Warburton from the University of Basel presented fascinating quantum optics experiments with semiconductor quantum dots. His extended abstract is on p. 22.
The two plenary talks exemplarily showed that the research fields of quantum optics, atomic physics and condensed-matter physics have developed very close connections in recent years.

The topic of light-matter interactions also featured in a first session of contributed talks on quantum optics and quantum information. The talks reported different realizations of quantum memories for photons, novel techniques for controlling the quantum state of photons, as well as studies of the use of light in super-resolution microscopy and different quantum information tasks. The second session was devoted to the topic of ultracold atoms and cavity quantum electrodynamics. It started with an overview talk of Helmut Ritsch from the University of Innsbruck, who gave an excellent pedagogical introduction to optomechanical and collective phenomena that can be observed with atoms in optical lattices. The following talks discussed matter-wave interferometry with atoms and large molecules, many-body physics with atomic quantum gases and related topics. The third session was dedicated to atomic precision spectroscopy. Gaetano Mileti from the University of Neuchatel gave a fascinating overview of the state-of-the-art in high-performance vapour-cell atomic clocks. The talk was followed by several presentations on antimatter spectroscopy and precision tests of fundamental symmetries of nature. The talks were complemented by a number of poster presentations, which documented once more that the field of atomic physics and quantum optics offers both the possibility for obtaining deep new insights into fundamental physics as well as opportunities for developing revolutionary technological applications.


Refreshing time during the coffee breaks...

Philipp Treutlein, Uni Basel

Physics in Start-ups

This year’s session organized by the Physics in Industry section was framed under the theme “Physics in Start-Ups”. Eight invited speakers from start-ups presented their technologies and shared their experience from their start-up endeavour. Paul Duvoisin from startups.ch moderated the session and provided an introduction into the Swiss start-up ecosystem. Currently, there are around 600 operating tech enterprises and start-ups in Switzerland, benefiting from the excellent infrastructure, human capital and innovation potential of the country. Since 2000, only 19 Swiss tech companies went public, in comparison to the acquisition of 99 Swiss tech companies in 2016 alone.
The first speaker was Markus Geiser from IRsweep. They were founded in 2014 as ETH spin-off with the mission to push high-performance mid-IR sensing to field applications. From experience, he recommended to talk to potential customers as early as possible. Initially, they aimed to sell their tool to breweries, but noticed that their techno-economic advantage was not sufficient to displace the status quo for such customers. So, they changed strategy and deliver now research tools which fill a technology gap to bio-technology departments at universities to have them explore and demonstrate the efficacy and maturity of the product in the lab.
FEMTOprint is a start-up initiated after a successful European project in 2014. The company uses ultrafast femtosecond lasers to machine glass into smart monolithic micro-systems. Andrea Lovera presented their successful approach to deliver a wide product portfolio early on, ranging from applications in medtech & life science to luxury watches and optical devices.
Crystalline Mirror Solutions was founded based on the requirement of the LIGO experiment for optical coatings with ultra-low thermal noise. Markus Aspelmeyer presented

David Murer (Dectris) elaborates on how to grow to a 100-person company within 11 years.

the spin-off's innovative GaAs/AlGaAs multilayer mirrors, not only useful in gravitational wave detectors, but also for atomic clocks and precision spectroscopy due to its low noise and high thermal conductivity.

Christian Teissl from Werkstätte Wattens presented the successful implementation of a FabLab as a useful bridge from physics-inspired ideas to real products. The lab acts as a light house for sustainable regional development, providing a maker environment for start-ups, as well as for educational purpose.

Dectris is another start-up enabled from large-scale physics experiments, namely from the development of hybrid-pixel X-ray detectors at the Swiss Light Source at the Paul Scherrer Institut. David Murer presented the X-ray pixel detector technology initially developed for scientific systems, such as synchrotrons, but recently targeted at applications in industrial and medical markets. He elaborated on their history from a start-up to a company with more than 100 employees within their 11 years of existence.

Dye-sensitized solar cells were invented by Prof. Michael Graetzel at EPFL. Asef Azam, the founder of Glass2Energy (now H.glass), explained his vision to advance renewable energy in urban environments by transforming glass surfaces into sustainable solar energy production facilities without losing transparency, aesthetics nor insulation functionalities. Currently, the first installations are in operation and under construction, with the technology offering conversion efficiencies between 3% for large-size industrial panels up to 13.8% for small panels in research labs.

Wind Energy 2.0 is the dream of TwingTec, with tethered drones, taking advantage of strong winds in altitudes of >100 m above ground, with a typical wind power density of 10 kW/m^2. Rolf Luchsinger compared the founding and raising of a start-up with the parenting of a child, going through euphoric joy at birth, the challenges while growing up and reaching maturity and self-sufficiency as a young adult. A current target market is the replacement of diesel generators at off-grid installations for mines, but the great vision is the creation of off-shore wind farms, as planned on the Giga islands in Dubai.

Gamification meets education in the world of the start-up Waltzing Atoms. Philipp Wissgott strongly believes that technology both requires and enables completely new learning methodologies, such as motivation through the unknown, the stimulation of the right questions instead of the right answers and by problem solving instead of memorizing.

Finally, the speakers gathered for a panel discussion to answer questions about intellectual property rights, a balanced co-founder share of the company and how to recruit and maintain a high-performing and effective team.

Thomas Brunschwiler and Patrick Ruch, IBM Rüschlikon

Biophysics, Soft Matter and Medical Physics

The topical session was held on Wednesday with first the well attended plenary lecture of Cornelia Denz (University of Münster) in the morning and then in the afternoon the invited and contributed talks. Denz presented a historical development of trapping techniques which was absolutely complete: from mechanical trapping through the first microscope with a device to hold small samples, then MEMS tweezers, microfluidic devices and at the end the optical trapping, which is her main research topic. Concerning optical trapping, the first evidences that light can exert forces were from Kepler's observation of the light pressure on the comet's tail. Later Lebedew [1] could study light pressure with a table top device.

She then went into the physical principles of trapping, namely a combination of a gradient force due to the electric field and scattering of the light, and continued with her research topic of producing multiple optical traps in dynamic mode, which allow to manipulate many particles and dynamically arrange them. Bacteria were trapped in 3D and manipulated and for example used to mix fluids on the microscale in microfluidic devices by the exploitation of the bacteria's flagella. Other applications concerned cell biophysics by employing new tools to investigate elasticity inside cells.

The Biophysics / Medical Physics session in the afternoon included 5 invited talks. Paolo De Los Rios (EPFL) spoke on the co-evolution method to investigate protein structure while Matthieu Wyart (EPFL) presented his work on the allosteric effect in proteins. Further Suliana Manley (EPFL) introduced to the audience single molecule high resolution optical microscopy and its application to investigate of biological division processes. Felix Naef (EPFL) presented his research on transcription regulation in a noisy environment of the cell. Aurélien Roux (UNIGE) spoke about the physics of membrane and how they can buckle under the effect of proteins to perform biological function.

8 oral presentations were also chosen among the submitted abstracts and covered various fields of biophysics and medical physics.

Giovanni Dietler, EPFL

Astrophysics (session organised by the SSAA)

The Astronomy and Astrophysics session had as a general theme "star interactions" and covered topics going from star-star to star-planet interactions, passing through star-black hole and Sun-Earth interaction. The meeting gathered between 20 and 25 participants and consisted in 6 talks. The first by Tassos Fragos discussed the various channels through which binary black holes can be formed. This topic has received a new impulse since the first detections of gravitational waves produced by the merging of two black holes. Tassos Fragos showed in particular that low metallicity is a condition for the production of black holes with masses around 30 solar masses. Then followed a talk by Ying Qin who discussed the properties of the spin of the second black hole produced in a binary system then consisting of two black holes. He discussed the impact of mass

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[1] Peter Lebedew, Ann. der Physik, 6 (1901) 433-458

loss and tidal interaction. Matteo Balbo presented a talk about the interactions between the winds of two massive stars. He showed that in the interacting regions, the conditions are favourable for accelerating particles into cosmic rays. Thus, interacting stars might be interesting cosmic accelerators. Lionel Haemmerlé presented a work about the origin of supermassive black holes that are detected in the very early universe, so early that the process of formation should have been extremely rapid. He explored trough numerical models to which extent such supermassive black hole can be formed by accretion. With Aurélien Wyttenbach, we passed from massive star evolution to the study of exoplanets. Aurélien Wyttenbach explained how it has been possible using a high-resolution spectrograph (HARPS) and analysing the variation of the light during the passage of the planet in front of its host star to obtain information about the chemical composition of the planet atmosphere as well as about its thermal structure. Finally, Hongrui Wang discussed how the measurement of the total solar irradiance is done through space radiometers. He showed the importance of these measurements for understanding the climate evolution on earth and how some unavoidable degradation of the measurement facilities impacts the results. This session addressed many different topics and conveyed to the audience many very interesting pieces of information.

Georges Meynet, Uni Genève

© Pictures in this article: Karl Riedling: p. 11 (1-3); Antoine Pochelon: p. 11 (4); Thomas Brunschwiler: p. 16 (1); SPS: all others

New Committee Members

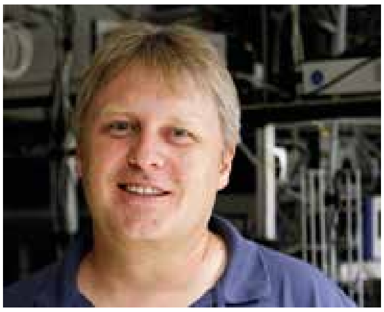
Dr. Andreas Fuhrer
(Chair of the section "Physics in Industry")

Andreas Fuhrer is a Research Staff Member in the Quantum Technology group at IBM Research - Zurich. He received a PhD in Physics from ETH Zürich in 2003 for his thesis entitled "Phase Coherence, Orbital and Spin States in Quantum Rings". For this research, he was awarded an ETH medal in 2003 and the SPS Award in Solid State Physics donated by IBM in 2004. He moved on to a post-doctoral position at Lund University, Sweden, in the group of Prof. Samuelson, working on his own project dedicated to further develop and understand quantum dot systems in InAs nanowires and InAs/InP nanowire heterostructures. From 2006 to 2008, Andreas Fuhrer was a "UNSW Vice Chancellor's/ NewSouth Global" fellow at the School of Physics at UNSW, Sydney, Australia, as a post-doc in the group of Prof. Simmons. His research was focused on phosphorus donor nanostructures in silicon fabricated by scanning tunneling microscopy and hydrogen resist lithography. Projects included the realization of gateable donor quantum dots and development of overgrowth techniques for atomically precise dopant placement in three dimensions. In 2008, he joined IBM where his current research interests lie in quantum computing with solid-state qubit systems such as superconducting qubits and silicon spin qubits. He previously worked on projects in semiconductor spintronics and further developed UHV based STM lithography techniques for fabrication of impurity-based semiconductor nanostructures.

He has already in the past helped to promote links between Swiss academic research, industrial S&T efforts and startups/SMIs and hopes to further develop this activity as part of his engagement in the “Physics in Industry” section of the SPS board.

More information: https://ibm.biz/AndreasFuhrer

Dr. Thilo Stöferle
(Chair of the section "Physics in Industry")



Thilo Stöferle studied physics at the University of Heidelberg and obtained his Master's degree (Diplom) on atomic beam experiments of adsorbate systems in 2001. In 2005, he received a PhD degree for his work on atomic quantum gases in optical lattices at the ETH Zürich in the quantum optics group of Prof. T. Esslinger. In his experimental work, he created new states of quantum matter in artificial crystals made of laser light, demonstrating effects of dimensionality and reaching into the strongly correlated regime, for which he was awarded the Medal of the ETH Zürich in 2005 and the Dimitris N. Chorafas prize in 2006.

In 2006, he joined the IBM Research – Zurich Laboratory as a post-doctoral research fellow in the Exploratory Photonics group, where he worked on organic lasing, quantum dot / polymer hybrid material and silicon photonic devices. Since 2007, he has been a permanent Research Staff Member at IBM. His current research interests in the Quantum Technology group are quantum fluids with exciton-polaritons, integrated nanophotonic cavities and quantum materials. He has published more than 45 articles in peer-reviewed journals and holds 12 patents.

From his engagement in the “Physics in Industry” section he expects to promote stronger connections of people and ideas between academics and high-tech industry in Switzerland, ranging from startups and SMEs to corporate research labs.

More information: https://ibm.biz/ThiloStoeferle

Plenary Talks

Meanwhile a well accepted service for our members: after the annual meeting we ask the speakers of the plenary talks to summarize their presentation as an extended abstract. The articles are later also collected as an own series on our webpage.

General Introduction to CERN, its mission and future projects

PT 1/2017

Martin Steinacher, CERN

To “accelerate science and innovation”, CERN executes its mission in the triangle of “research, innovation and education”. In order to push back the frontiers of knowledge, new technologies for accelerators and detectors are developed, scientists and engineers of tomorrow are trained and people from different countries and cultures are united at this unique place in Geneva.

Founded in 1954 by 12 European countries to propagate “science for peace”, CERN today has 22 Member States and 4 Associate Member States. Japan, Russia and the USA have an observer seat in Council. CERN operates with an annual budget of approx. 1.1 BCHF, employs 2’500 staff and 1’800 other paid personnel and welcomes 13’000 scientific users from more than 110 countries. With more than 3’000 PhD students in the LHC experiments, the age distribution of scientists at CERN peaks at 27 years.

The big scientific challenge is to understand the very first moments of our Universe after the Big Bang. Whilst astronomy looks back into the early Universe with ground and space based detectors and telescopes, CERN provides with its LHC a super-microscope able to reproduce conditions of highest energy where new particles are being created and their interactions being studied.

With the start of operation of the LHC (Large Hadron Collider, 27 km circumference, 14 TeV energy) in 2010, a new era in fundamental research began with the exploration of a new energy frontier in proton-proton or heavy ion collisions. In June 2016, CERN Council approved the High-Luminosity LHC project, an upgrade to increase the intensity of the beams by a factor of 10, providing a better chance to see rare processes and discover new particles.

At the four LHC beam intersection points, the experiments ALICE, ATLAS, CMS and LHCb are located in huge underground caverns. The detectors were designed, constructed and are operated and maintained by collaborations among up to 39 countries, 174 institutes and 3’170 members.

The Worldwide LHC Computing Grid (WLCG) is another international collaboration to distribute and analyse LHC data. It integrates computer centres around the Earth that provide computing and storage resource into a single infrastructure accessible by all LHC physicists. Actually, there are 170 sites spread among 40 countries.

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which in 2012 was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's LHC”.

Picture: © CERN

One of CERN’s main options for a flagship accelerator in the post-LHC era is an electron–positron collider at the high-energy frontier. The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear collider that has been under development since 1985 and currently involves 75 institutes around the world. An updated baseline-staging scenario focuses on an optimised initial-energy stage at 380 GeV that will be significantly cheaper than the original design up to 3 TeV.

Presently, CERN also executes a FCC (Future Circular Collider) conceptual design study and cost estimate scheduled for the next update of the European Strategy for Particle Physics (2018-2019). A 100 km circumference tunnel with infrastructures on either side of the French-Swiss border would allow an energy of 100 TeV should CERN be able to design and build 16 Tesla dipole magnets. Such dipoles would allow for doubling the proton energy in the LHC tunnel from 14 to 28 TeV.

At CERN, high-energy and particle physics drive innovation substantially and interface between fundamental research and key technological developments in the three domains of accelerators, detectors and large-scale computing. Knowledge and technology transfer fostered spin-offs in the domain of e.g. medical applications. Most prominently for hadron therapy but also in imaging as e.g. the PET scanner. Combining physics, computing, biology and medicine to fight cancer already gave very promising results.

The remaining part of CERN’s core mission are educational activities covered by a variety of programmes. They provide academic training sessions, young researchers with dedicated schools (physics, accelerators, computing) and offer a teacher school. There were more than 10’000 participants in the Teacher Programme since 1998. CERN welcomes annually 250 physics students at its summer student’s programme of two months.

The Experimental Physics Program of CERN

Manfred Krammer, CERN, Head of the Experimental Physics Department

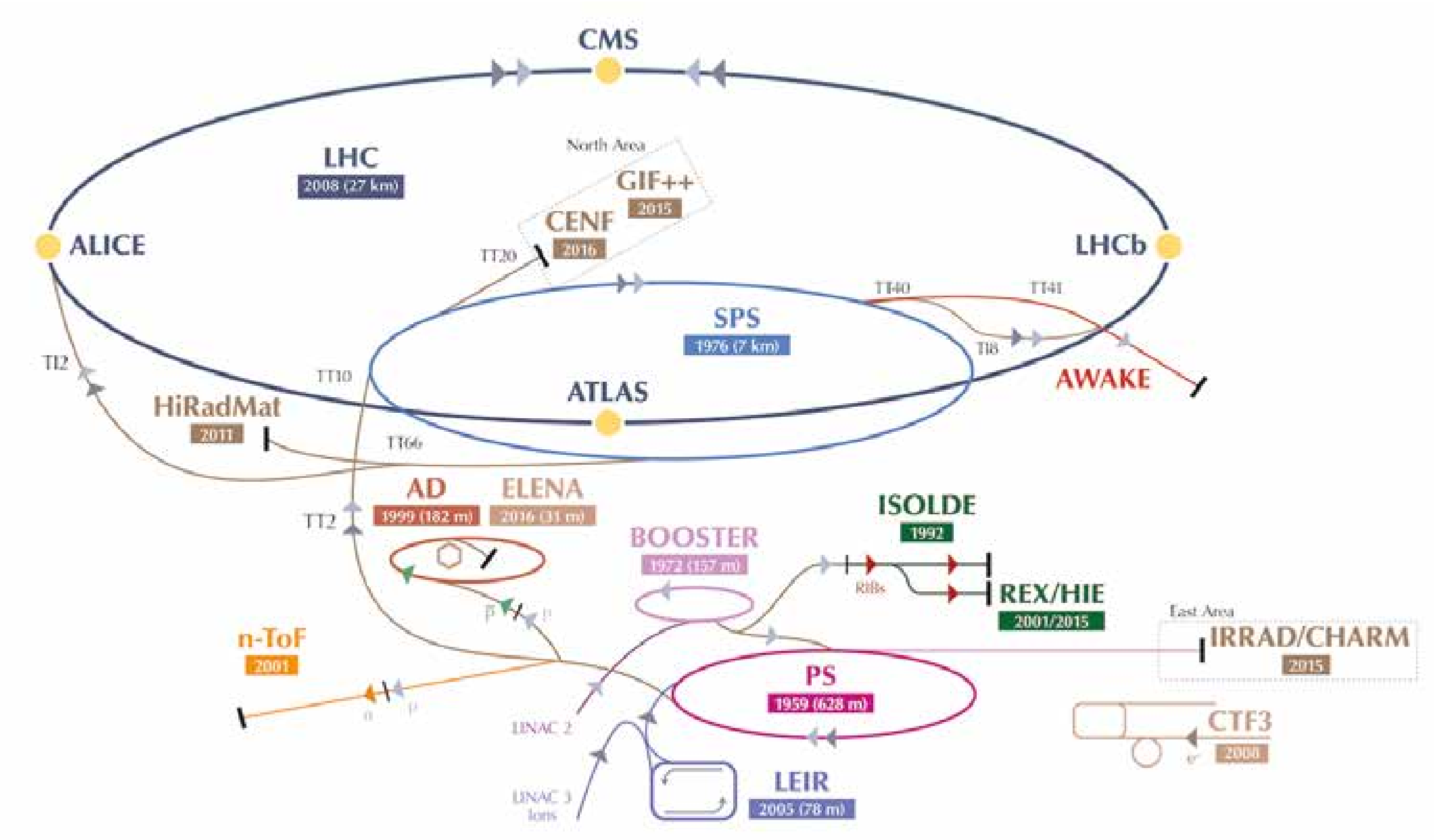
CERN the European Laboratory for Particle Physics provides the infrastructure and in particular operates accelerators for a large variety of physics experiments. About 13000 scientific users are registered at CERN. These scientists come not only from the 22 CERN member states but from a total of more than 100 countries to conduct experiments at CERN or meet their colleagues for discussion.
The scientific strategy of CERN has three pillars:

- Full exploitation of the Large Hadron Collider (LHC) including the upgrades and the High Luminosity LHC
- A scientific diversity program exploiting the accelerator complex at CERN and the knowledge available at CERN
- Studies for future accelerator facilities and experiments

The LHC is the flagship project of CERN. The accelerator with a circumference of 27 km accelerates protons and lead ions to unprecedented energies and allows the exploration of physics in a new energy regime. At present the machine is operating at a centre of mass energy for protons of 13 TeV. An increase to 14 TeV is foreseen in a few years. At the collision points several experiments collect data: 2 very large multipurpose experiments (ATLAS and CMS), an experiment dedicated to study the heavy quarks b and c (LHCb), an experiment focusing on the operation with heavy ions (ALICE), and a few smaller experiments (TOTEM, LHCf, MoEDAL). The physics studies performed within the experimental collaborations are very broad. They cover the study of particles and processes described by the Standard Model of Particle Physics (SM), the search for new particles, and precision measurements looking for deviations from the predictions of the SM that hence would point to a new theory of particle physics, the physics of the quark gluon plasma accessible through the collisions of lead ions, and of course the detailed study of the Higgs Boson discovered in 2012 by the LHC experiments ATLAS and CMS.

The scientific diversity program uses the infrastructure at CERN and the available accelerators covering a very large energy range (see fig. 1). Several of these accelerators are needed to fill the LHC with protons and lead ions, but all serve also for a specific scientific program. For example, the PS and SPS beams are used for fixed target experiments. These experiments use the primary proton beam or derived secondary beams of various particle types, which are then directed onto a target. The high energy reactions within the target are recorded by the experimental set-ups downstream of the target. Five particle physics fixed target experiments are presently operating at CERN: NA58, NA61, NA62, NA63, NA64 (NA stands for North Area, the location of these experiments). The range of energies probed by these experiments is between 1 GeV and a few 100 GeV. The physics program covers hadron spectroscopy, the study of the strong interaction, studies of quark gluon plasma, the search for very rare decays of the Kaon, electromagnetic processes in strong crystalline fields, the search for dark photons, and much more.

A large community of nuclear physicists from all around the world use the ISOLDE facility at CERN. In this facility radioactive isotopes are produced and made available to several



Picture: © CERN

experimental stations. Every year about 50 experiments in the fields of nuclear and atomic physics, nuclear astrophysics, material science and life science are selected and carried out. Using a large variety of target materials (e.g. U, Ta, Zr, Y, Ti, Si,…) and different ion sources (surface, plasma, laser) about 1000 isotopes of 75 chemical elements have been produced and made available for experiments. A new system for post-acceleration of these radioactive isotopes is being gradually commissioned and as of 2018 post-acceleration of up to 10 MeV per nucleon will be possible. New type of measurements will then become possible.

For the measurement of neutron cross-sections CERN operates a spallation source called nTOF. In two experimental areas, 20 m and 185 m from the target, neutrons with a very large energy range from 25 meV to 1 GeV are available for experiments. The wide energy range and the very high flux, in the closer experimental area up to 10^5/cm^2/pulse, enables the measurement of very small sample sizes and short lived isotopes.

CERN is the only place worldwide were scientists can perform experiments with anti-protons and anti-Hydrogen atoms. This facility is called Antiproton Decelerator (AD) after the decelerator which slows down anti-protons produced by a beam from the PS machine to 5.3 MeV. This energy is low enough to allow the study of anti-protons and the production of anti-Hydrogen by bringing the anti-protons together with positrons. However, to increase the capture rate for experiments and to allow experiments to work in parallel, CERN is presently commissioning an additional small decelerator called ELENA, which will reduce the energy of the anti-protons to as low as 100 keV. Six experiments are operating or being set up to perform measurements using the anti-protons. Physics goals are tests of the CPT invariance and the test of the weak equivalence principle by measuring the behaviour of anti-Hydrogen in the earth gravitational field. The experiments AEgIS, ALPHA, ASACUSA, ATRAP, BASE, and GBAR perform measurements of the magnetic moment of the anti-proton and spectroscopy of anti-Hydrogen and of exotic atoms, such a anti-protonic Helium - a Helium atom with one electron exchanged by an anti-proton. Several of the experiments will soon start to measure the influence of gravitation on anti-Hydrogen.

The CLOUD experiment at CERN is a very large climate chamber connected to the PS accelerator. The chamber allows to precisely simulate the conditions in the atmosphere and to study in the laboratory the influence of natural and human made aerosols on cloud formation. The cosmic radiation, another factor for cloud formation, is simulated by the beam from the PS. The measurements performed by our colleagues from climate research has helped to reduce the uncertainties and the tuning of global climate models.

The two non-accelerator experiments CAST and OSQAR use prototype magnets of the main LHC dipole magnets to search for axions and chameleons, hypothetical particles predicted as possible dark matter particles or solutions to the strong CP problem. In theory these particles would couple to photons in the strong magnetic field. The set-up of CAST allows to follow the trajectory of the sun and searches for particles emitted by the sun, while OSQAR uses a laser light and performs a “light shining through the wall” experiment. Here the axions, if existing, would be produced by the photons from the laser, travel through the wall, and couple back to photons in the second part of the experiment.

In recent years CERN has created the Neutrino Platform, a framework supporting the European neutrino physics community to prepare accelerator based neutrino experiments at CERN for experiments in Japan and the US. Several projects have already been conducted or are ongoing, e.g. the refurbishment of the ICARUS detector and the construction of BabyMIND, which is a component for a neutrino detector at JPARC (Japan). In the north area of CERN an extension to the existing hall was built, in which the construction of two very large liquid Argon TPC prototypes for the DUNE experiment in the US are progressing. The tests with charged beams will start in 2018. CERN scientists are participating in the ICARUS experiment, which is part of the short baseline multi detector program at Fermilab (USA) to probe unexplained anomalies in neutrino experiments, and in the long base line experiment DUNE. DUNE an experiment to be constructed in the Sanford Underground Facility (USA) will receive first neutrino beams from Fermilab in 2026. The main physics goals of DUNE are the determination of the mass hierarchy of neutrinos and the measurement of a possible CP violation in the neutrino sector.

Concerning future experiments and facilities at CERN, three studies are conducted:

- A study of an electron-positron collider (CLIC) starting at a centre of mass energy of 380 GeV for precision Higgs and Top physics and with the potential to go to a collision energy of up to 3 TeV.
- A study of a proton-proton collider achieving a centre of mass energy of 100 TeV (FCC). For such a machine the development of a new magnet technology and a new tunnel with a circumference of approximately 100 km is needed. The same tunnel could in a first stage host an electron-positron collider.

For both, CLIC and the FCC, the studies include also geological studies for the location in the Geneva area.

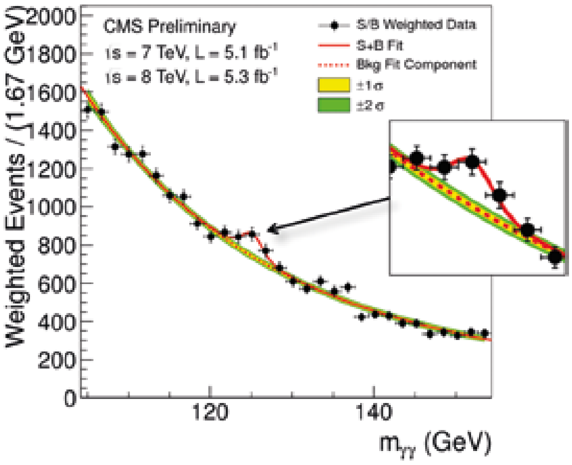
- A study of future experiments using the existing accelerator complex. The study is called “Beyond collider” and is conducted to identify experiments for the future scientific diversity program.

All three studies will conclude in time for the next update of the European strategy for particle physics, which is foreseen for 2020. With these studies as input and with the results from the LHC experiments and from other experiments worldwide the future directions of the physics program of CERN will be decided.

A Higgs-Eye View of the Cosmos

Matthew Philip McCullough, CERN

It is just over five years since we witnessed the now iconic images associated with the discovery of the Higgs boson.



This discovery has opened the door to a new era in particle physics. The Higgs field is a riddle, wrapped in a mystery, inside an enigma, but now we have the key. Unlike any previously discovered, it raises more questions than it answers.

For starters, the theory underpinning the Higgs sector of the Standard Model is analogous to the theory that describes superconductivity. To see this, compare the two equations governing their dynamics:

Ginzburg-Landau:

$$F = |(\nabla + 2ieA)\Phi|^2 + m^2(T)|\Phi|^2 + \lambda|\Phi|^4 + \ldots$$

Higgs Sector of the Standard Model:

$$\mathcal{L} = |(\partial_\mu + ig\sigma^a W^a_\mu)H|^2 - m^2(T)|H|^2 - \lambda(T)|H|^4 + \ldots$$

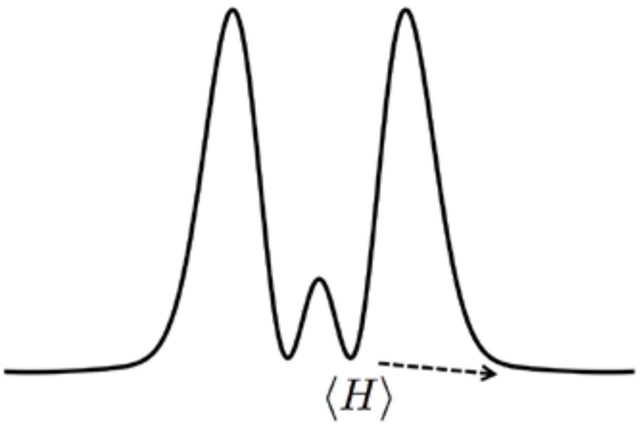
In both theories, below the critical temperature the field develops a non-zero vacuum expectation value everywhere, and the associated force-carriers become massive, screening the force they generate. (Photons for a superconductor, Electroweak forces for the Standard Model).

Thus we have learned we are effectively living inside a curious form of superconductor. But even more curious is that, unlike a standard superconductor, the parameters of the Higgs sector of the Standard Model are fine-tuned, much like a superconductor fine-tuned to sit right at the edge of the phase transition in a transition-edge sensor.

Traditional ideas that can explain such a puzzle, the most popular being Supersymmetry, have failed thus far to appear at the large hadron collider at CERN. This has recently prompted theorists to consider more exotic theoretical explanations. One of the most radical ideas is the “Relaxion”, put forth by Graham, Kaplan, and Rajendran two years ago. In this model the parameters of the Higgs potential evolved slowly in the early Universe during a period of cosmological expansion. Importantly in their model these parameters stop evolving just at the critical point due to a clever back-reaction mechanism, explaining an apparently finely tuned Higgs potential in the current epoch, long after this evolution took place.

The fine-tuning of the Higgs sector isn’t the only fundamental question we still haven’t answered. For example, we don’t know where all of the matter in the Universe actually came from! If we take the Standard Model of particle physics and evolve it from the hot big bang to the current epoch then one can calculate the prediction for the left over matter now. The answer is that it falls short. Intriguingly, however, it does actually contain all of the necessary ingredients to explain the matter abundance. Namely, during the phase transition when the Higgs moved out to a non-zero vacuum expectation value everywhere there were baryon-number violating processes active that can transform, for example, positrons into protons. There is also CP-violation in the interactions of the Higgs boson, allowing for a relative difference between particle and antiparticle to be realized. However, it is the detailed form of the Higgs sector that fails. If the phase transition had been strongly first order, with the Higgs field spontaneously jumping from one minimum to another, then the theory could work due to the fact that the process is out of thermal equilibrium. However, in the Standard Model the phase transition is not strongly first order, and thus the prediction for the matter abundance falls short. Note that all of this concerned the Higgs sector, and in models that do realize the observed matter abundance it is often the Higgs sector that needs to be modified. By studying the Higgs sector of the Standard Model in more detail at the LHC we may find evidence for the origins of the matter we are made up of.

Another curious fact about the Standard Model is that only the Higgs boson can have renormalisable interactions with new neutral scalar bosons. Renormalisable interactions are very special because if they are generated at a high energy scale they remain relevant at all energies. All of the interactions we know of in the Standard Model are renormalisable. We know there must be new neutral particles beyond the Standard Model, because we know that known matter only accounts for around 15% of all the matter in the Universe! The rest of it we call “dark matter”, because we don’t know what it is. All of this means that, although not guaranteed, the Higgs boson could provide glimpses of the dark matter, by interacting with it through this special interaction. In fact, this interaction is so special that we have a name for it: “The Higgs Portal”. Experimentalists at CERN are trying to peer through the Higgs portal by studying how the Higgs boson decays. Evidence for the dark sector would be revealed by



the Higgs boson decaying "invisibly" into new particles that we cannot see.

The ultimate fate of this talk was the ultimate fate of the Universe. Measurements of the properties of the Higgs boson and other particles at the LHC, combined with cutting-edge calculations of the shape of the Higgs field potential, have revealed it may have another minimum at very large field values with lower energy than the current vacuum.

This is not a merely academic observation, as it implies that the current Universe we live in has an expected lifetime of around 10^{139} years. After roughly that time we expect the Higgs field to decay to the new minimum where the laws of physics would be radically different. As with the other deep questions discussed above, if we find evidence for modifications of the Higgs sector at the LHC, then this would significantly change our predictions for the ultimate fate of the Universe.

In this talk I have attempted to explain how, by studying the detailed properties of the Higgs boson, we are searching for answers to the biggest questions we face: Where did the matter we are made of come from? What is the dark matter? What is the ultimate fate of the Universe? Why do the fundamental parameters of the Standard Model of particle physics take the special values they do? In all cases, we may find the answer through experimental measurements of the Higgs at the LHC.

Quantum Photonics with Solid-State Emitters

PT 4/2017

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Arguably, the only really useful single photon source in quantum technology is a source of close-to-perfect single photons. The demands are stringent in terms of purity (the level of anti-bunching), coherence (the level of indistinguishability) and brightness (the efficiency of the entire device). Such a source would find applications in device-independent quantum cryptography. The quantum repeater requires in addition a stationary bit at each node, for instance a coherent spin. Ideally therefore, a system is required with a coherent spin and an efficient spin-photon interface.

Implementing these ideas in the solid-state is appealing as nano-technology can potentially add a lot of device functionality. However, a solid-state environment is a source of noise. Example noise sources include phonons in the lattice, charge noise from fluctuating charges in the solid and spin noise from the fluctuating nuclear spins of the host atoms. Also, a solid-state emitter may emit not just a photon (the zero-phonon-line, ZPL) but also a photon together with a phonon.

Reported here is progress on two prominent solid-state emitters, a semiconductor quantum dot and the NV colour centre in diamond. The two emitters have complementary strengths and weaknesses. A semiconductor quantum dot is a source of high quality single photons but single spins dephase rather rapidly. Conversely, the NV centre hosts a highly coherent spin but the photons are of low quality. The goal of the research is to address the main weakness of the emitter while preserving the strengths. This means improving the spin coherence in the case of semiconductor quantum dots; and improving the quality of the photons in the case of the NV centre in diamond.

In the case of quantum dots, the noise in high quality material at low temperature is very low [1,2] and in the best case (resonant excitation at low temperature), transform-limited linewidths have been achieved [3], Figure 1. Even photons created at quite different times have a high degree of indistinguishability. The extraction efficiency out of the host material, GaAs, is low on account of the high refractive index. Most of the photons undergo total internal reflection and propagate laterally within the semiconductor. However,

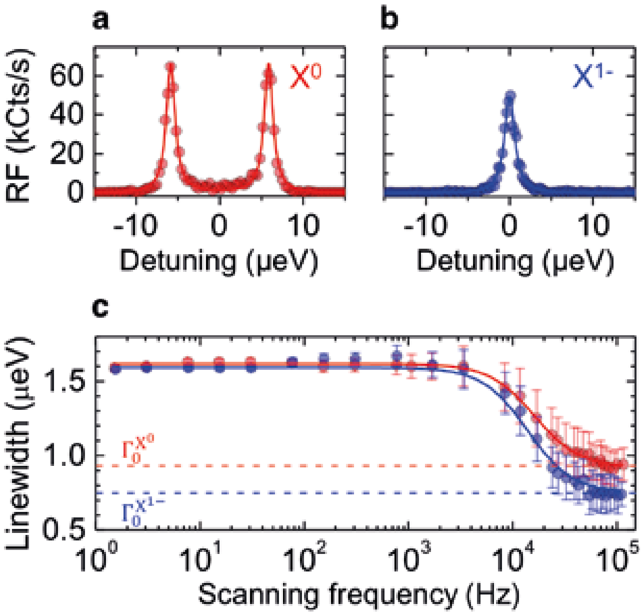

Figure 1: Resonance fluorescence (RF) on a single quantum dot. (a), (b) neutral exciton (X^0), charged exciton (X^{1-}) resonance fluorescence versus detuning at 4.2 K and zero magnetic field with 100 ms integration time per point. The solid lines are Lorentzian fits to the data. The linewidths are 1.3 μeV for X^0 and 1.5 μeV for X^{1-}, close to the transform limits 0.9 μeV and 0.8 μeV, respectively. (c) RF linewidth against scanning frequency. The linewidth approaches the transform limit for scanning frequencies above 50 kHz for both X^0 and X^{1-}.

the extraction efficiency can be boosted massively by engineering the photonic modes. One approach is to embed the quantum dot in a micro-cavity. At the resonance, emission into the micro-cavity mode is favoured over emission into the other modes; high efficiency results once the light is coupled out of the micro-cavity efficiently. A micro-cavity is under development [4]. The micro-cavity is a highly miniaturized Fabry-Pérot-type cavity. The top mirror has radius of curvature of just 10 μm and is located a few hundred nanometres above the semiconductor sample; the bottom mirror is integrated into the semiconductor heterostructure. The beam waist is approximately one wavelength in extent, 950 nm in this case. *In situ* tuning is facilitated by moving the sample with respect to the top mirror. On paper, a brightness of more than 80% can be achieved with the present design by working deep in the weak coupling regime of cavity-QED; and the strong coupling regime is accessible once the Q-factor of the micro-cavity is increased.

A quantum dot electron spin dephases rapidly on account of the interaction of the electron spin with the nuclear spins of the host material, GaAs. All the Ga and As isotopes have non-zero nuclear spins and couple to the electron spin via the hyperfine interaction. This interaction results in electron spin decoherence. To explore this, the inverse problem, the decoherence of the nuclear spins via an interaction with the electron spin, was addressed. A nuclear magnetic resonance experiment was carried out on the host nuclear spins of a single quantum dot [5,6]. In the absence of a quantum dot electron, the nuclear spins have a coherence time (strictly speaking, the Hahn echo decay time) of 5 ms. In the presence of a quantum dot electron spin, the nuclear spin coherence time drops by about a factor of hundred [6]. The proposed mechanism is a coupling of remote nuclear spins via the electron spin [6]. The implication is that the hyperfine interaction limits the electron spin coherence to tens of micro-seconds even at large magnetic fields. In principle, this decoherence mechanism can be suppressed by polarizing the nuclear spins; in practice, nuclear polarizations beyond about 50% have not been achieved. A hole spin is a viable alternative to the electron spin [1]. A pure heavy hole is predicted to decouple from the nuclear spins on application of an in-plane magnetic field. The extent to which this limit applies to a real hole spin has been investigated and found to hold even down to nano-electronvolt energies [7]. Lower bounds on the decoherence times have been established and are very promising for future applications [1,7].

In the case of the NV centre in diamond, one major problem is the low probability of phonon-free emission – the ZPL accounts for just 3% of the emission – yet it is only the ZPL photons which are useful in creating spin-photon entanglements. An additional problem is the radiative lifetime, 12 ns, long relative to that of a quantum dot, 0.8 ns. Finally, as in GaAs, there is also the challenge of extracting the photons efficiently out of the high-index host material. In principle, all these problems can be solved with a micro-cavity in spatial and spectral resonance with an NV centre. The micro-cavity results in faster recombination, preferential emission into the micro-cavity mode, and, crucially, an increase in the ZPL fraction. In practice, it has been challenging to secure these advantages largely because diamond nano-fabrication tends to worsen the spectral inhomogeneity of the NV centres. Our approach is to embed a diamond membrane into our miniaturized Fabry-Pérot cavity [8]. The membrane is created by etching a 50 μm thick diamond plate to thicknesses of a few hundred nanometres. Crucially, no lateral structuring is required. NV centres in these membranes have optical linewidths of approximately 1 GHz. While this is much larger than the transform limit, 10 MHz, it is smaller than the crystal field splitting of the NVs, 2.8 GHz, and smaller than the microcavity linewidth, 10 GHz. In the micro-cavity, the radiative decay time decreases to 6 ns corresponding to a Purcell factor of 2.0 [8], Figure 2. This modest Purcell effect masks a large change to the ZPL fraction. The point is that emission into the “leaky” lateral modes is not changed by the micro-cavity: the Purcell effect rests entirely on boosting emission into a single “vertical” mode. The ZPL fraction increases to close to 50% in this experiment.

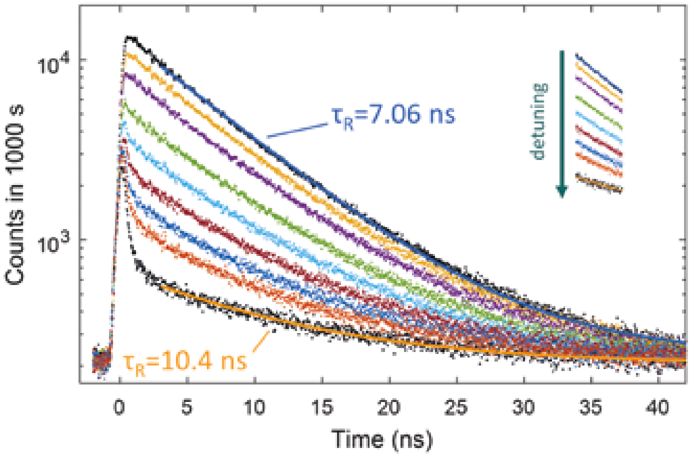

Figure 2: Decay curves measured on a single NV centre embedded in a highly miniaturized Fabry-Pérot cavity as the cavity is gradually tuned in frequency from the spectral resonance. Out of resonance, the decay time tends to 12 ns, the decay time of NVs in the bulk. On resonance, the decay time reduces to 6 ns, a clear Purcell effect. The overall Purcell factor of 2.0 corresponds to an increase in the ZPL fraction from 3% to close to 50%.

It is hoped that these advances will underpin future efforts to create remote spin-spin entanglements at useful rates for quantum technology.

This work was performed as a close collaboration with the groups of Daniel Loss, Patrick Maletinsky and Martino Poggio in Basel; and Andreas Wieck and Arne Ludwig at Ruhr-University, Bochum. The work was funded by SNF, NCCR QSIT and SNI.

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PT 5/2017

Technology dependance of reflective optical systems for EUV and astronomical applications

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Technology dependance of reflective optical systems comes in many forms and has different levels of system impact. The optical system is composed of parts such as a light source, an optical design and a light sensor. The optical design comprises optical components made with materials, surface shapes, coatings, etc., which are manufactured then assembled perhaps monolithically. In particular, from past to present, electroforming of reflective components has featured strongly in the manufacture of reflective optics for 13.4 nm soft X-ray extreme ultraviolet lithography (EUVL) and space based astronomical X-ray telescopes (see Figures 1 and 2).

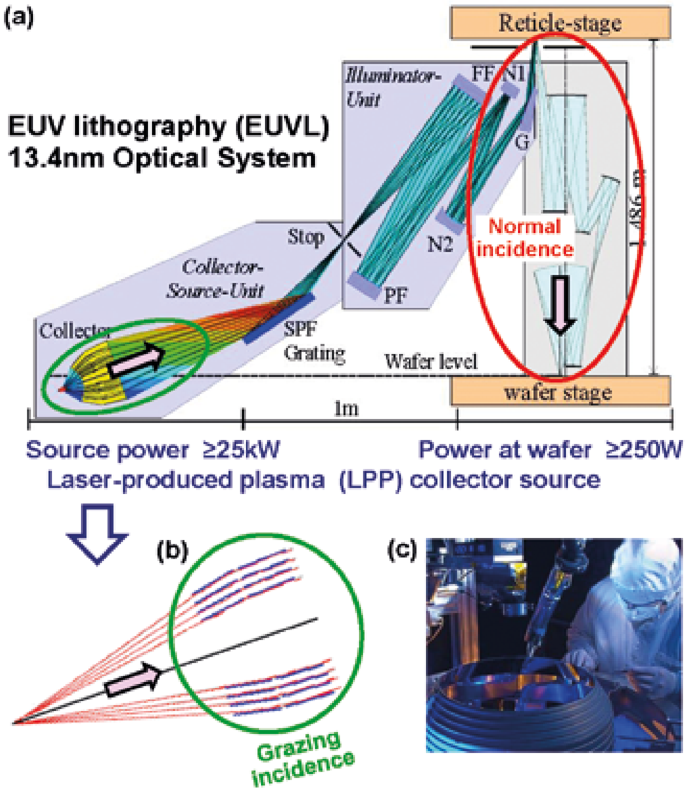

FIG. 1. (a) EUVL optical system with collector, illuminator and projector optics. (b) Type I Wolter wide field X-ray optics collector having two reflections from hyperbolic and parabolic mirrors. (c) Collector integration at optical bench. Respective images from Ref's [1], [2] and [3].

The EUVL optical system illustrated in Figure 1 employs grazing incidence mirrors and near normal incidence mirrors which in the case of the latter depends on computer controlled and ion beam precision polishing technology and short wavelength coating technology to maximize image quality and transmission. Although electroforming may be considered an old technology, when coupled with other technologies such as monolithic components and special coatings, electroforming is capable of producing unique optical solutions providing compactness and low mass. Indeed the electroforming process as shown in Figure 2. is also quite suitable for producing complex freeform reflective surface profiles.

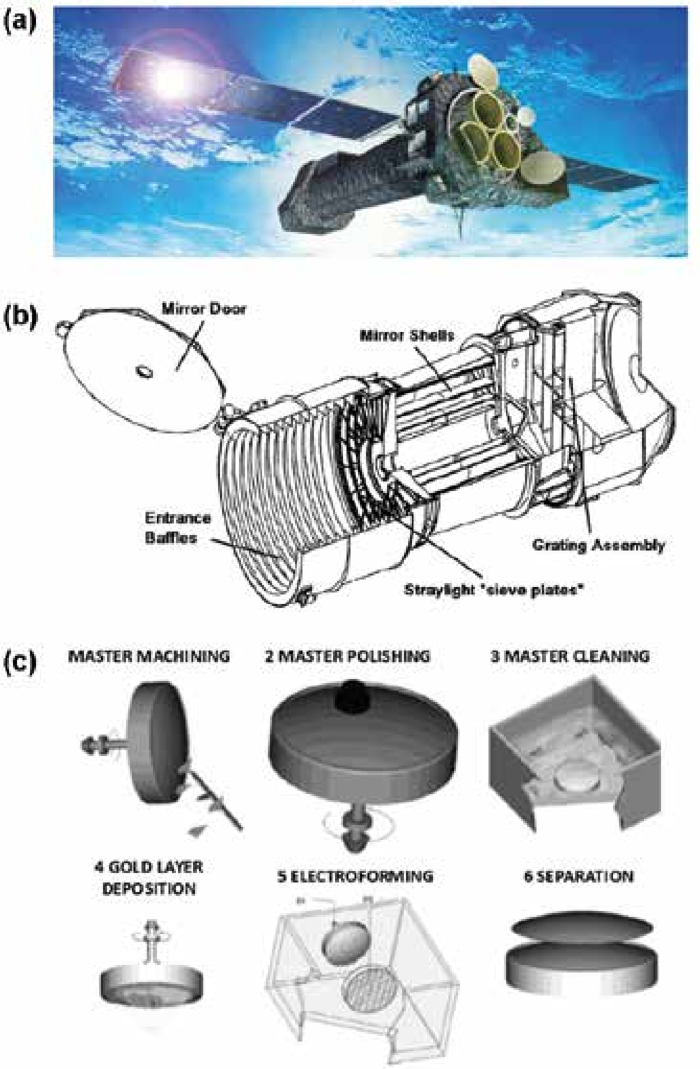

FIG. 2. (a) Artist impression of XMM Newton X-ray telescope. (b) Cut-out of XMM Newton telescope assembly. (c) Pictorial representation of the electroforming replication process. Respective images from Ref's [4], [5] and [6].

Reflective optical systems may have some disadvantages over refractive optical systems such as having a surface profile reflective index sensitivity about four times greater than a surface profile refractive index sensitivity, where a single mirror surface sensitivity for light in and light out is 1.0-(-1.0) giving I2.0I versus a single glass surface sensitivity for light in and light out is 1.0-1.5 giving I0.5I. However, this is mitigated by reflective optical systems normally needing far fewer optical surfaces than refractive optical systems and offering many potential advantages such as compactness, lightweight, multispectral and passive athermal capabilities. Therefore, mirror systems are actually becoming more popular and interestingly terrestrial and space based astronomical telescopes are utilizing ever larger apertures but have trended towards using smaller reflective panels and segmented mirrors (see Figure 3).

To maximize the performance of all-reflective imaging (and non-imaging) systems a combination of technologies may

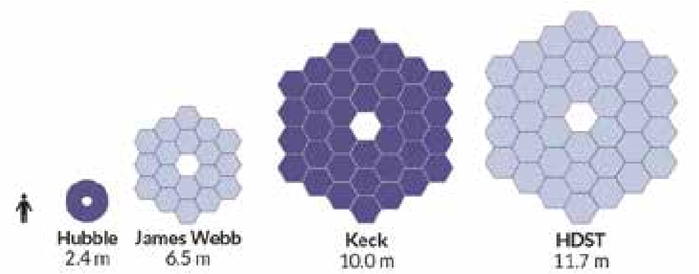

FIG. 3. Size comparison of large aperture astronomical telescope mirrors showing segmented mirror structure. Image from Ref. [7].

be required in future. These might involve optical design for the optimization of off-axis toroidal aspheric surface profile mirrors and additive manufacturing (AM) as a practical and cost effective means to produce mirror components with such profiles (see Figure 4).

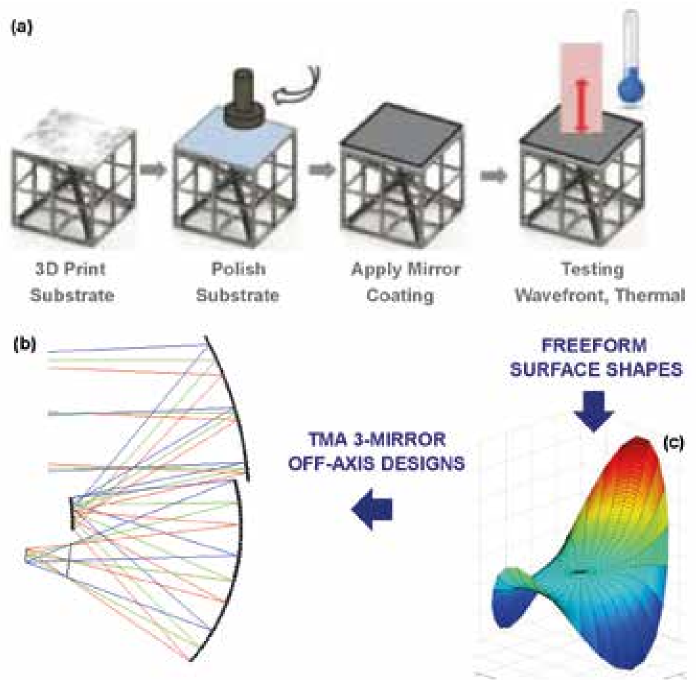

FIG. 4. (a) Additive manufacturing process. (b) Three mirror anastigmat (TMA) imaging system with at least one non-rotationally symmetric mirror. (c) Freeform surface profile. Respective images from Ref's [8], [9] and [10].

Additive manufacturing, also sometimes called 3D printing, appears to enable off-axis toroidal aspheric mirror based optical systems to be effectively realized. AM and versatile reflective optical system designs could signal the birth of much more advanced reflective optical systems for EUV and astronomical applications as well many other kinds of imaging (and non-imaging) systems for other applications.

Curved sensors are not new but they are another technology that may soon become commercially viable. Reflective imaging systems might benefit from such sensors because they release optical design degrees of freedom for optimization of maximum image performance (see Figure 5).

Looking back over the history of optical technology development it appears to have been quite slow until about the middle of the twentieth century. Perhaps development acceleration came with the invention of the laser and all the related developments that followed. However, most reflective optical systems including those for EUV and astronomical applications have depended on tried and trusted technologies. Reflective optical systems could become dependent on AM and optical design freeform surface technologies which may be strong drivers in the development of future EUV and astronomical applications.

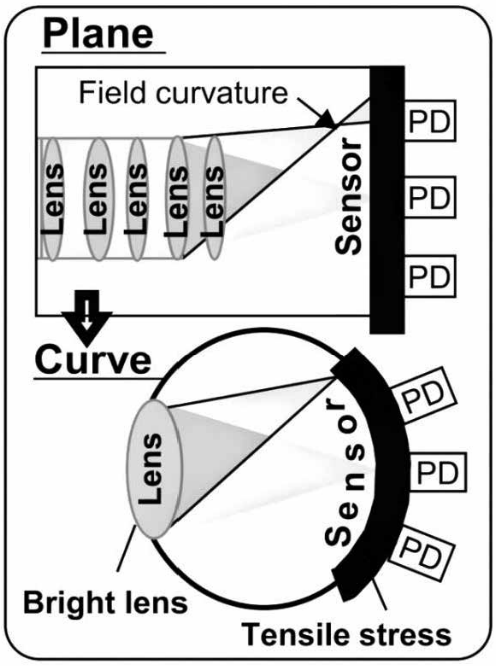

FIG. 5. Flat and curved sensors shown with lenses which can be replaced with mirrors. Image from Ref. [11].

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Angulon quasiparticle: novel approach to angular momentum in quantum many-particle systems

PT 6/2017

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In this work [1, 2] we have demonstrated that molecules immersed in superfluid helium form the quasiparticles of a new kind – the ‘angulons’ – which were recently predicted by us theoretically [3, 4]. Angulon represents a rotating quantum impurity – such as a molecule – dressed by a cloud of superfluid excitations.

Theoretical description of molecules interacting with solvents is extremely challenging and usually requires large-scale numerical simulations [5, 6]. However, even when the latter are computationally feasible, the amount of understanding one can extract from such ‘numerical experiments’ is quite limited. Treating molecules in superfluid helium as angulons allowed us to drastically simplify the problem and to provide simple interpretation for the experimental data collected over last 20 years, see Fig. 1.

Furthermore, the framework of angulons provides a simple and transparent way to understand the exchange of angular momentum between quantum particles and the surrounding environment. This allows to tackle previously intractable problems [7] as well as to uncover novel physical phenomena associated with angular momentum [8, 9]. Since orbital quantum impurities arise in numerous settings of atomic, chemical, and condensed matter physics, the applications of angulons reach far beyond molecules in superfluids.

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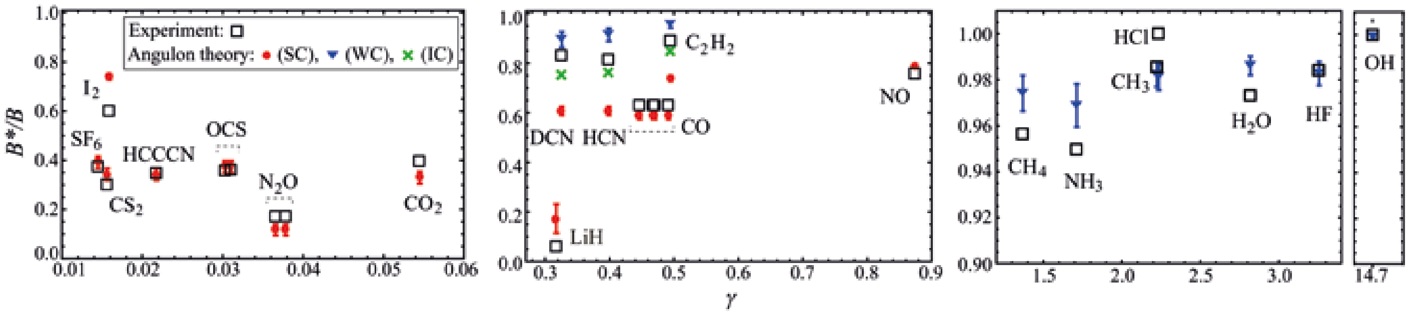

*FIG. 1. **Evidence of the angulon formation in experiment.** Renormalization of the rotational constant, B*/B, as a function of the two-body molecule-He interaction parameter γ [1, 2]. Left: heavy molecules, Middle: medium-mass molecules, Right: light molecules (note different y-axis scale). Experimental data (empty squares) are compared with the angulon theory in the strong-coupling regime (red circles), and the weak-coupling regime (blue triangles). Green crosses show the intermediate-coupling interpolation between the strong- and weak-coupling theories.*

Trapped-ion interfaces for quantum networks

PT 7/2017

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Networks play essential roles in both our everyday lives and in our work as physicists. The Worldwide LHC Computing Grid, based at the site of this year’s joint SPS/ÖPG meeting, is just one particularly striking example of how we rely on fiber-optic networks for communication and for computational tasks beyond the capability of individual devices. The importance of such networks for classical information encourages us to confront the question: How will we build an internet for quantum computers [1] ? That is, assuming that quantum computers will process and store information in quantum states, how will we distribute these quantum states between remote nodes of a network while still preserving fragile quantum superpositions and entangled states?

Such future quantum networks offer certain advantages that cannot be attained with even the most sophisticated classical networks. First, quantum networks provide a route to secure long-distance cryptography via quantum key distribution (QKD), which allows two remote parties to generate a shared secret key [2]. Second, distributed quantum

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computing will allow small-scale quantum computers to be linked together. Scaling up the number of quantum bits is an outstanding challenge for quantum computing, and one approach is to construct optical interconnects between computers [3]. Third, quantum networks may provide efficient solutions to intrinsically distributed problems.

A visionary approach to constructing quantum networks, outlined 20 years ago, is based on nodes consisting of three-level lambda-type atomic systems in optical cavities [4]. The role of the cavity at each node is to enhance the electric field associated with a single photon such that the system acts as an interface between single atoms and single photons. The cavity is tuned to match a frequency corresponding to one arm of the lambda system. When an atom in the cavity is driven by a laser field at a frequency resonant with the other arm, a single photon is generated from the vacuum field of the cavity through a cavity-mediated Raman process. That photon then leaves the cavity and travels to another node along an optical fiber or a free-space path, where is absorbed by an atom in a second cavity via the time-reversed version of the same process. Here, the cavity provides a coherent interface such that quantum information stored in the electronic states of the atom is mapped onto the photon, and vice versa.

Trapped ions provide an experimental platform that is well-suited to such an interface. In particular, the $^{40}\mathrm{Ca}^+$ ion, the building block for the experiments described here, has a lambda-type electronic structure available between the $4^2S_{1/2}$, $4^2P_{3/2}$ and $3^2D_{5/2}$ states. Single photons are created at the $4^2P_{3/2}$ to $3^2D_{5/2}$ transition frequency of 852 nm, which is compatible with fiber-optic communication. Meanwhile, the quadrupole $4^2S_{1/2}$ to $3^2D_{5/2}$ transition at 729 nm can be addressed directly with a narrow-linewidth Ti:sapph laser, enabling high-fidelity preparation of the ion's motional and electronic state as well as coherent gate operations [5]. We confine ions in a linear Paul trap under ultra-high vacuum. A high-finesse cavity 2 cm in length surrounds the Paul trap, and in-vacuum piezo stages allow the cavity to be positioned precisely with respect to the trap. The cavity is near-concentric in order to obtain a small mode volume and thus an increased ion-photon coupling strength [6].

Figure 1. An optical cavity integrated with a linear Paul trap under ultra-high vacuum is the basis for a quantum interface between ions and photons.

In order to map a quantum state from an ion to a photon, following the protocol of Cirac et al. [5], we implement a bichromatic Raman process, that is, two parallel cavity-mediated Raman processes [7]. In one process, the ion starts in the $4^2S_{1/2}$, $m_S = -1/2$ Zeeman state and a horizontally polarized photon is created in the cavity. In the second process, the ion starts in the $4^2S_{1/2}$, $m_S = +1/2$ Zeeman state and a vertically polarized photon is created. When the processes are driven simultaneously, a quantum state encoded in the ion's two Zeeman states is mapped onto the photon's polarization state. Afterwards, the technique of quantum process tomography is employed to verify that the information has been faithfully transferred. Tomography also allows us to understand how spontaneous emission can lead to errors in the mapping process.

We have focused thus far on a coherent, deterministic trapped-ion interface, but it is also possible to construct probabilistic, heralded interfaces for quantum networks [8]. In a heralded interface, quantum information transfer between remote locations is not achieved on every attempt, but when transfer does succeed, this event is heralded by a signal. For example, if each of two remote ions is entangled with a photon, then the detection of those two photons can be used to prepare the ions in an entangled state, which is subsequently available as a resource for teleportation of quantum information from one ion to another [9]. We have shown that a bichromatic Raman process in an optical cavity can be used not only for state mapping, as described above, but also to entangle ions with photons [10] and subsequently, ions with ions [11]. Optical cavities are not a requirement for such an interface, but they are a means to achieve efficient photon collection and thus to speed up communication within a network.

The building blocks that we have demonstrated to date for quantum networks have focused on an ion-photon interface at a single network node. To put these interfaces to work for quantum communication and quantum computing, it will be necessary in the future to link together multiple nodes, to suppress decoherence channels, and to optimize the efficiency of information transfer, challenging tasks that will require both new technological developments and close collaboration with our theoretical colleagues.

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The CHEOPS Mission: Goals and challenges

PT 8/2017

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In November 2012, the Science Programme Committee (SPC) of ESA selected CHEOPS out of 26 proposals as its first "small" scientific mission. This new mission class, the s-class, was associated with strict boundary conditions: 1) a cost-capped budget of 50 M€ for ESA and 2) a development time limited to 4 years. A CHEOPS Consortium consisting of Institutes from 11 ESA member States and led by Switzerland was constituted and took the responsibility of designing and building the payload (a single telescope) and to organise and run the entire ground segment while ESA was charged of procuring the platform, the launch services, and the CCD. Together ESA and the Consortium shared roughly in equal terms the 100 M€ cost of the entire CHEOPS mission.

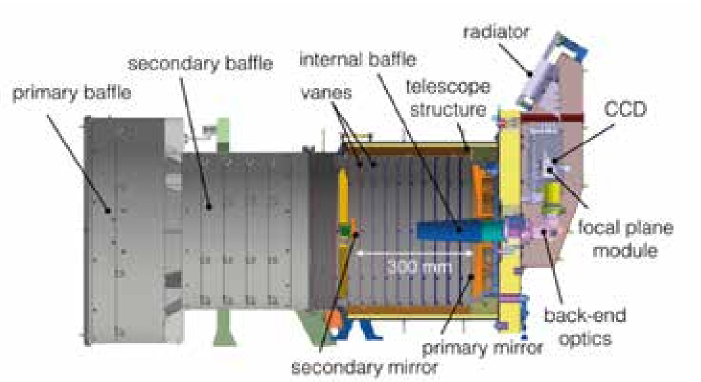

Fig. 1 CHEOPS telescope of 60 kg total mass. The main mirror has a 30 cm clear aperture and produces a defocused image on the CCD. The focal length is 1.6 m yielding a telescope focal ratio of f/5 and a field of view of 0.32 degree. Note the various baffles and vanes to reject stray light ensuring the required photometric precision.

Scientifically, CHEOPS will be the first mission dedicated to the search for transits of exoplanets by means of ultra-high precision photometry on bright stars already known to host planets. It will provide the unique capability of determining accurate radii for a subset of those planets for which the mass has already been estimated from ground-based spectroscopic surveys. It will also provide precise radii for new planets discovered by the next generation of ground- or space-based transits surveys (Neptune-size and smaller). By unveiling transiting exoplanets with high potential for in-depth characterisation, CHEOPS will also provide prime targets for future instruments suited to the spectroscopic characterisation of exoplanetary atmospheres. The combination of CHEOPS flying simultaneously with TESS and JWST while new, ground-braking, instruments are or will become operational on the ground (e.g. NGTS, ESPRESSO, NIRPS, etc.) opens unprecedented perspectives for exoplanet science.

To reach its science goals, CHEOPS will be able to measure photometric signals with a precision of 20 ppm over 6 hours for a magnitude 9 star in the V band. This precision will be achieved by using a single frame-transfer, back-side illuminated CCD detector located in the focal plane assembly of a 33-cm diameter on-axis telescope. The optical design is based on a Ritchey-Chrétien telescope that produces a defocused image of the target star while minimising the stray light contamination with a dedicated field stop and a baffling system. The spacecraft (280 kg) will be launched as a secondary passenger on a Soyouz rocket from Kourou into a 700 km altitude Sun synchronous orbit and will have a nominal operational lifetime of 3.5 years. Launch readiness is targeted for the end of 2018.

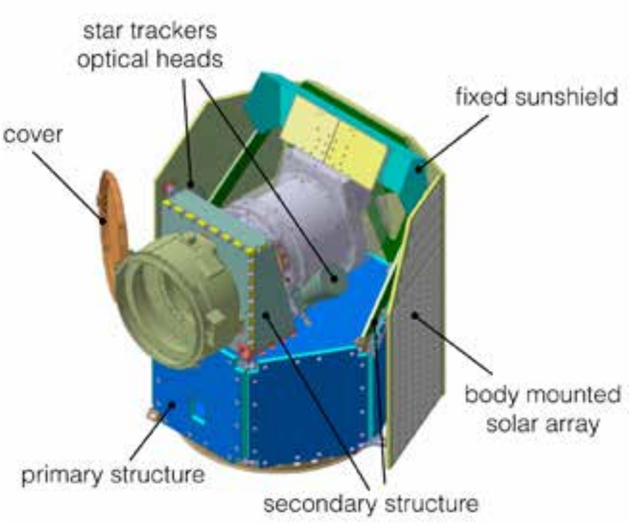

Fig. 2 CAD model of the CHEOPS Spacecraft showing the accommodation of the payload on the platform built by Airbus Defence and Space Spain and based on the AS-250 platform previously used for Earth observing satellites. The mass of the entire spacecraft including payload is 280 kg.

The ground segment is split in a Mission Operation Center (MOC) located at INTA in Torrejon near Madrid in Spain and a Science Operation Centre (SOC) located at the University of Geneva in Switzerland. The MOC will be performing the actual communications with the satellite both uplink and downlink. The SOC prepares the actual planning of the observations to be sent to the satellite, runs the reduction pipeline to transform the raw data received into actual science data, performs the required in-flight calibrations, monitors the health of the system, and archives the data.

Twenty per cent of the observing time of CHEOPS will be open to guest observers, and can be used to observe any targets not already included on the Consortium target list. Proposals will be requested annually through an open ESA Announcement of Opportunity (AO) to the general scientific community. To allow important new targets to be included in the open time programme at any time during the mission, up to 25 % of the open time will be allocated to a discretionary programme.

Spectroscopy of trapped antihydrogen atoms

PT 9/2017

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Precision studies of antihydrogen might shed light on one of the most tantalizing mysteries in physics: the asymmetry of matter-antimatter abundance in the Universe. The ALPHA collaboration performs measurements that will soon enter an uncharted regime of precision in the comparison of antimatter and matter comprising tests of the CPT (charge conjugation, parity inversion and time reversal) symmetry. These studies were but a dream two decades ago, motivated by impressive results in trapped and cold beam hydrogen laser spectroscopy [1,2] – reaching parts in 10^{12} resolution – and long lifetime trapping of antiprotons at CERN [3,4], as the object of study, cold antihydrogen, did not exist. High precision spectroscopy requires a long interaction time of the species with the radiation, thus the aim to produce cold and trapped anti-atoms.

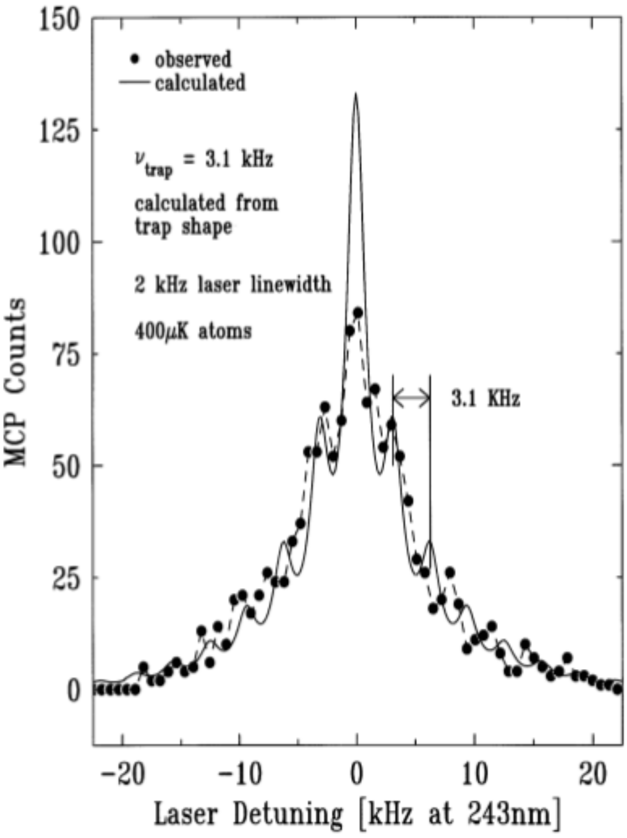

Fig. 1: Spectrum of the 1s-2s transition in cold trapped hydrogen at MIT (circa 1995) with a resolution of ~ 2 kHz [1]. The antihydrogen work is inspired by this spectrum to reach a frequency comparison between the atom and the anti-atom to 15 significant digits.

The ATHENA collaboration, housed at CERN's Antiproton Decelerator (AD), announced in 2002 the first production of low energy anti-atoms [5] synthesized from its constituents, trapped antiprotons and positrons. The TRAP collaboration soon followed up. Trapping of antiprotons, electrons used to cool the antiprotons, and positrons is achieved through Penning-Malmberg traps (for a review see Ref. [6]) consisting of a uniform solenoidal magnetic field – confining the particles radially – and cylindrical electrodes where potentials confine the particles axially. ATHENA employed an imaging annihilation detector, consisting of silicon strip detector – able to detect pions from the antiproton annihilation and reconstruct the vertex of the annihilation – and CsI crystals sensitive to the 511 keV gammas resulting from positron-electron annihilation. Other diagnostics tools employed include MCP, Faraday cup, and non-destructive image charge plasma detection. After that milestone, the effective temperature of the sample was inferred at > 100 K, too high to allow for trapping as the magnetic energy of a ground state (anti)hydrogen atom changes 0.67 K per Tesla.

In 2006 the ALPHA collaboration emerged from ATHENA and continued this work with a new apparatus superimposing a magnetic trap to the Penning trap. A magnetic trap requires an inhomogeneous field with a minimum magnitude in free space. Acting upon the magnetic dipole moment of the atom, with energy $W = -\boldsymbol{\mu} \cdot \boldsymbol{B}$, it can provide confinement of the atom if the magnetic moment is antiparallel to the field and the atom has a low kinetic energy, not to overcome the potential barriers. A common magnetic bottle configuration is the Ioffe-Pritchard trap, employing two Helmholtz mirror coils in the axis and a quadrupole field for radial confinement. For the synthesis and trapping of antihydrogen there is a need to trap the charged particles – requiring more homogeneous fields – and the neutral atoms simultaneously. ALPHA designed an Ioffe-Pritchard configuration with an octupole replacing the quadrupole. For trapping we needed further cooled species and a way to gently inject, with low speed, the antiprotons towards the positron cloud. Evaporative cooling [7] provided the necessary cooling. In the nested Penning trap configuration [8], cold antiprotons sit in a potential well neighboring the cold positron well, as different charges cannot be confined in the same well using static fields. ALPHA used first an autoresonance method, exploring the anharmonicity of the potential well by a strong drive radio-frequency sweeping, to inject the antiprotons into positrons. With that, ALPHA demonstrated the first trapping of antihydrogen [9] with 38 annihilation events as the magnetic trap was shut-off 0.17 s after mixing antiprotons and positrons. Later, a time delayed experiment was repeated where the trap was held for various times and then released. This showed trapping times longer than 1000 s, enough time to perform experiments. After this success a new apparatus was built incorporating optical windows for lasers access and separating the initial catching of antiprotons from the atom trap, towards a future accumulation and stacking of trapped antiprotons.

With stably trapped atoms, measurements can be performed. Being an exotic species, all physical quantities should be tested, including the charge neutrality of the anti-atom. Two experiments were performed, one where an electric field would deflect any residual charge to the left or to the right but would not deflect a neutral atom, and a second one where a stochastic field acceleration – kicks – would heat up and evaporate the anti-atoms if they had a residual charge. The results [10] are compatible with a null charge to 0.7 ppb of the electron charge which, combined with other measurements, yields a limit for the positron charge anomaly $|q_{e}^{+} - e|/e < 1\,\mathrm{ppb}$. An improvement in the trapping rate achieved in the 2016 run, by abandoning the AR mixing and going back to a primordial way of slowly merging the antiproton sample into the positron cloud by lifting its potential barrier, raised the rate of trapping by one order of magnitude and stacking was demonstrated [11]. Microwaves resonant with hyperfine transitions can induce a spin-flip leading to an immediate loss from the trap. This allowed a microwave spectrum and a measurement of the hyperfine constant [12] of antihydrogen consistent in 4 digits with that of hydrogen. And, finally, the era for high precision laser spectroscopy of antimatter has started. The first experiment demonstrated excitation of the 1S-2S transition in antihydrogen [13]. The frequency values involved show a consistency with that of hydrogen to parts in 10^{10}.

We now pursue a spectral lineshape on the 1S-2S transition. Given the experimental conditions a comparison of the antihydrogen and hydrogen frequencies to parts in 10^{12} may be achievable by 2018. This precision enters unexplored territory in CPT tests. Improvements will require further cooling – with ideas ranging from microwave [14] to Lyman-alpha cooling [15] – and enhancing the number of trapped atoms. Looking ahead, a possibility to trap hydrogen [16] in the same trap as antihydrogen and thus perform spectroscopy on both species in the same environment should enable a direct comparison with precisions of parts in 10^{15} and beyond [17]. Whether the CPT symmetry will hold true at these levels and whether gravity acts the same way – probed by “red shift” on the frequency and by ballistic experiments – on antimatter atoms, only nature knows. As experimenters with this exotic species at hand it is our duty to properly inquire nature’s responses.

Colleagues in the ATHENA and ALPHA collaborations and the CERN AD team are acknowledged for all this fantastic team work.

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Gravitational waves: a new window to explore the Universe

PT 10/2017

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The last two years saw the opening of a new window for exploring the Universe thanks to the first direct detection of gravitational waves. Gravitational waves have been predicted by Albert Einstein himself in the framework of his theory of general relativity. He first mentioned them in a paper appeared in 1916 and then in 1918 he wrote a paper with the title: “On gravitational waves” [1, 2]. Einstein, however concluded that it would be impossible to detect them. Einstein proved to be wrong: gravitational waves were detected in 2015 and on 3 October 2017 it was announced that the this year Nobel prize for physics will be awarded for their discovery to Rainer Weiss, Barry Barish and Kip Thorne.

In the sixties, Joseph Weber started designing and building the first gravitational wave detectors now known as Weber bars. However, their sensitivity was far too low to see any signal. The first indirect evidence for the existence of gravitational waves came with the discovery in 1974 of the first binary pulsar by Hulse and Taylor. In 1979, results were published detailing measurement of the gradual decay of the orbital period of the pulsar, which fitted precisely with the loss of energy and angular momentum in gravitational radiation (through gravitational waves) predicted by general relativity.

After many decades in developing bar detectors and then later on interferometers to detect gravitational waves, the first direct detection has been made in 2015 by the two Advanced LIGO (Laser Interferometer Gravitational Wave Observatory) detectors. LIGO was founded in 1992 by Kip Thorne (Professor at Caltech, born in 1940) and Ronald Drever (who passed away in March 2017), both at Caltech and Rainer Weiss (Professor emeritus at MIT, born in 1932) of MIT. LIGO consists of two observatories in the US which are some 3000 km apart: one near Hanford (in Washington state) and the other in Livingston (state of Louisiana). Barry Barish (Professor emeritus of Caltech, born 1936) has been the principal investigator of LIGO from 1994 till 2005 and director of the LIGO Laboratory from 1997 till 2005. He was instrumental in bringing the project to completion. Indeed, the construction of the observatories ended in 1999 and the first measurements started in August 2002 and lasted till 2010. Afterwards the detectors have been substantially upgraded and started again in February 2015. Meanwhile, hundreds of scientist in more than 40 Institutes worldwide are involved in the project, and are member of the LIGO Scientific Collaboration (LSC). On 14 September 2015 the two LIGO detectors simultaneously observed a transient gravitational wave signal, which has been interpreted as due to the merger of two black holes with masses of about 36 $M_\odot$ and 29 $M_\odot$, respectively, some 1.3 billion light-years away, which formed a new black hole of 62 $M_\odot$ with the energy equivalent of 3 solar masses emitted as gravitational waves. The announcement of the first detection followed then on 11 February 2016 [3].

On 15 June 2016, the LSC announced the detection of a second signal of gravitational waves, which was observed on 26 December 2015 [4]. Analysis of the signal indicated that this event represented the merger of two black holes about 1.4 billion light years distant, with masses of 14.2 and 7.5 solar masses, yielding a combined black hole of approximately 20.8 solar masses, with one solar mass radiated away.

On 1 June 2017, the LIGO scientific collaboration announced the discovery of a third event, which took place on 4 January 2017 and which was due to the coalescence of two black holes with 31.2 and 19.4 solar masses, respectively, and produced a black hole of 48.7 solar masses, with about 2 solar masses radiated away [5].

LIGO will operate for many more years, and in the meantime it has been joined by VIRGO, which is a detector located nearby Pisa, built mainly by Italy and France. From 1 August 2017 on all three second generation interferometers (LIGO Hanford, LIGO Livingston, and Virgo) were simultaneously taking science quality data for the first time. On 27 September 2017 VIRGO and LIGO announced the first three detector observation on 14 August 2017 of a gravitational wave due to the coalescence of two black holes of 30 and 25 solar masses, respectively, located at a distance of

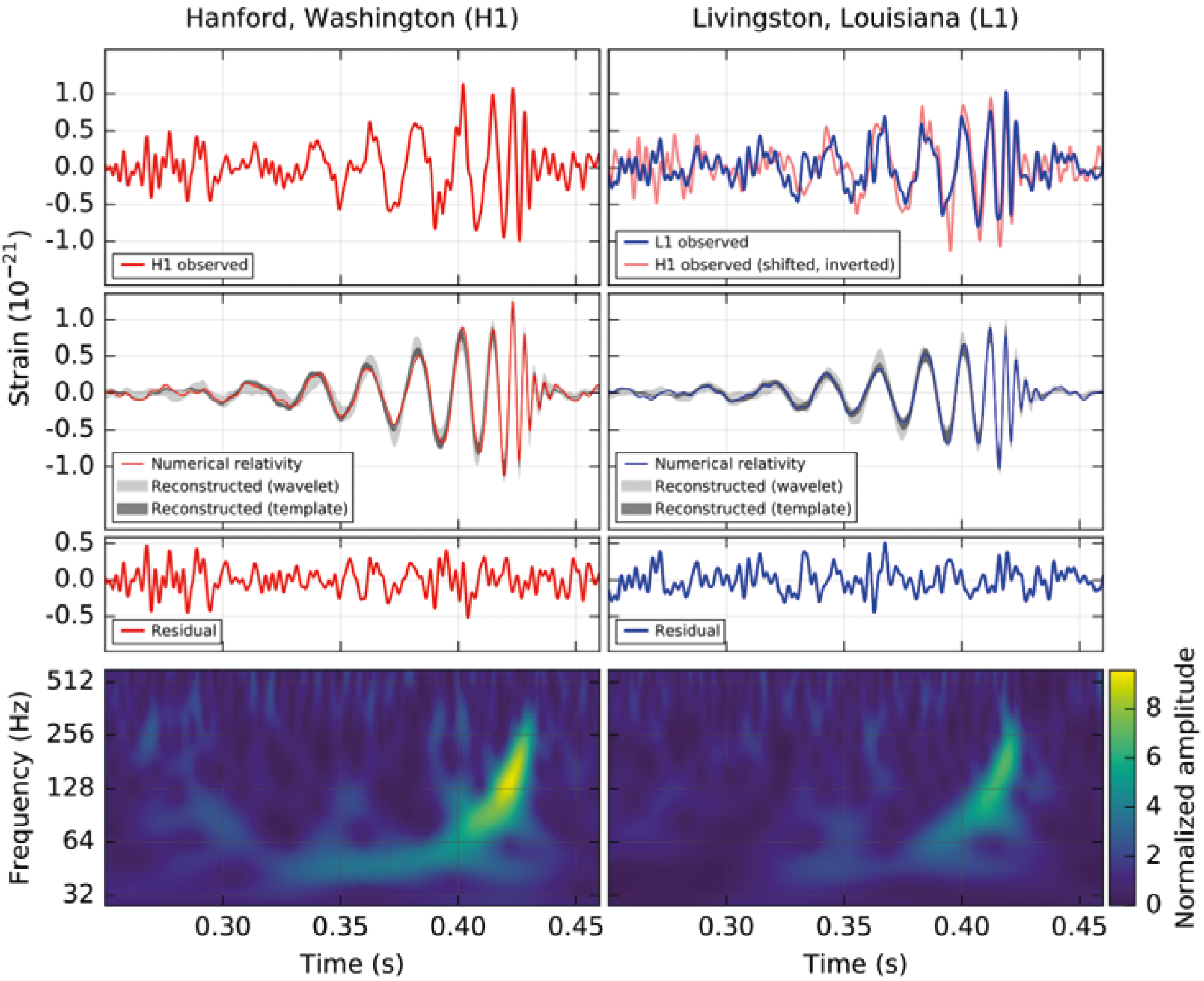

Figure 1: LIGO measurement of the gravitational waves at the Hanford (left) and Livingston (right) detectors, compared to the theoretical predicted values (From [3]).

about 540 Mpc, and leading to the formation of a black hole of about 53 solar masses. Thanks to the observation with VIRGO as well the position in the sky could be determined much better and allowed to probe, for the first time, the polarization content of the signal. The data strongly favor pure tensor polarization of gravitational waves, as expected from general relativity [6].

In few years the interferometric detector KAGRA, using cryogenic technology, will become operational in Japan. This way there will be several *antennas* operating in different locations on Earth, which will allow a much better localization of gravitational wave sources enabling the observations in electromagnetic bands.

There are plans to build a gravitational wave detector in space: the LISA project (Laser Interferometric Space Antenna) which is an ESA mission in collaboration with NASA. In December 2015 the satellite LISA Pathfinder (LPF) by the European Space Agency (ESA) has been launched successfully. Following six apogee-raising manoeuvres, the spacecraft reached its final science orbit around the first Sun-Earth Lagrange point L1, 1.5 million km from Earth, on 22 January 2016.

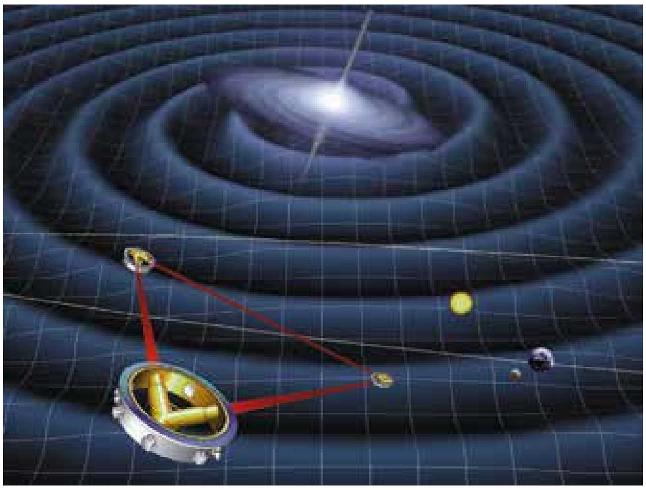

Figure 2: LISA (Laser Interferometre Space Antenna).

LPF goal was to place two test masses in a nearly perfect gravitational free-fall, and control and measure their relative motion with unprecedented accuracy, at the level required for a future space-based gravitational wave observatory, such as LISA. This requirement was achieved through innovative technologies comprising inertial sensors, an optical metrology system, a drag-free control system and micro-Newton thruster system. The LPF mission ended very successfully on 18 July 2017. Indeed, its performances were far better than expected [7, 8] and as a consequence ESA and NASA are pushing forward the LISA mission, which will be capable of detecting gravitational waves (GW) emanating from a wide range of objects in the Universe.

In November 2013 ESA has selected *The Gravitational Universe* [9] as the science theme to be explored by ESA's Large class mission L3. On 20 June 2017 ESA selected LISA [10] as the realization of the L3 mission, which at present is scheduled to be launched in 2034, but with the possibility left open for an earlier launch. The scope of LISA is to detect and study low-frequency GW from about 0.1 mHz to 1 Hz, and thus to complement ground-based gravitational observatories. LISA opens new possibilities for astrophysical studies by allowing, for instance, to detect supermassive black holes (typically of $10^6 - 10^7\ M_\odot$) merging at cosmological distances. Mergers of a supermassive black hole with another compact object (such as another black hole or a neutron star) produce a very clean GW signal which LISA will be able to measure with high precision. Alternative gravity theories influence the dynamics of such mergers and hence LISA is expected either to directly see the imprints of certain alternative theories or to put severe constraints on them. Another class of objects, which will be observed by LISA, are ultra-compact binaries, in particular of white dwarfs in our Galaxy. They are important sources of gravitational waves in the mHz frequency range. Moreover, it will be possible to detect or put strong constraints on the primordial gravitational wave background, which is just, as the cosmic microwave background, a leftover from the Big Bang. For LISA, the test masses will consist, similarly to LPF, of cubes of about 2 kg weight, housed in separate spacecrafts, according to present day plans, some 2.5 million km apart.

The discovery of gravitational waves has definitively opened a new window to explore the Universe. We are just at the beginning of using this new window and the prospects are bright to make important progress and new discoveries. Following all these rapid and successful developments the fact that the this year Nobel prize in physics has been awarded for the discovery of gravitational waves came no longer as a surprise.

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Accelerators: multifaceted instruments for science and industry

PT 11/2017

Lenny Rivkin, EPFL & PSI

Accelerators are developed and built to help advance the limits of our knowledge across a wide spectrum of fields. The high energy and precision frontiers in particle physics, synchrotron light sources with high intensity, coherence and extremely short pulses, intense neutron and muon beams as well as proton beams for medical applications, are some examples of recent advances that have taken place at the two world class accelerator laboratories CERN and PSI. The presentation will illustrate the on-going development of accelerator concepts beyond the existing technology including the high-field superconducting magnets, high gradient and compact accelerators. The current analytic capabilities of the present accelerator-based platform for experimental science are being transformed to a facility for industrial problem solving. The advanced manufacturing with analytics platforms will in turn play a crucial role in the development of advanced accelerator components that will form the basis for future accelerator-driven infrastructure.

In 1927 the first radio frequency (RF) accelerator was constructed and operated by a young Norwegian student Rolf Wideroe in Aachen, accelerating potassium ions to the energy of 50 keV. He successfully defended his 27 pages long PhD thesis that year, only to go on to invent and build several other types of accelerators that soon found various applications well beyond the original field of nuclear physics. Most of his long career Wiederoe dedicated to the design and production of accelerators for industrial and medical applications at the Brown Boveri Company in Baden, Switzerland, as well as to teaching accelerator physics at the ETHZ.

Close to 30'000 accelerators around the world are in use today to analyse and modify the physical, chemical and biological properties of matter. These modern industrial and medical tools represent close to 2 G$ market and are used in production of close to 500 G$ worth of goods. About 200 of them are used for fundamental and applied research, extending the tradition of building instruments to study Nature around us that started with optical telescopes and microscopes. Accelerators have become an essential tool for research and numerous applications enabling us to address society's essential needs.

Ninety years later we are planning an accelerator that would increase the particle energy by nine orders of magnitude, up to 50 TeV. The Future Circular Collider (FCC) study for the possible next large instrument at CERN is presently being conducted by a truly global collaboration involving 111 institutes from 25 countries and supported in part by the European Commission. An ambitious and challenging research and development program in high field superconducting magnets is under way (Fig. 1).

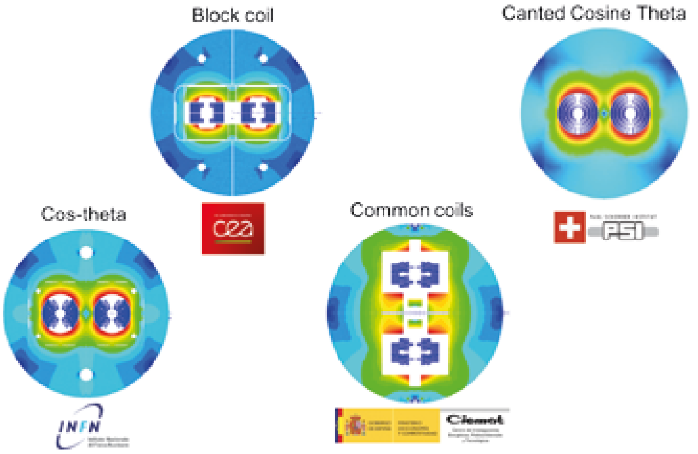

Fig. 1. The ambitious and challenging development program towards 16 Tesla superconducting magnets for the FCC is under way at CERN and around the world, including European national laboratories, as well as laboratories in USA and Japan. The Swiss State Secretariat for Education Research and Innovation (SERI) supports the future oriented accelerator project FCC at CERN and the development of accelerator concepts beyond the existing technology with an extraordinary grant as initial funding for these activities.

At the same time the novel imaging methods call for more performant and compact accelerators providing bright beams for biomedical applications as well as the semiconductor industry (Fig 2).

Fig. 2 (top right on the title page). A novel compact (5 by 10 m) very bright EUV light source COSAMI is being developed at the Paul Scherrer Institute. It is designed for actinic mask inspection of the next generation of integrated circuit chips.

Call for a new Scientific Editor for the *SPG Mitteilungen*

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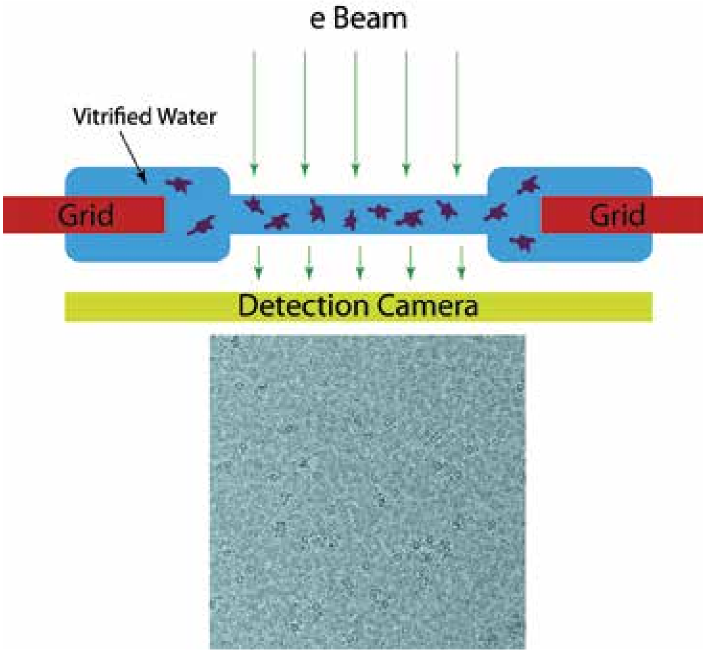
2017 Nobel Prize in Chemistry

Giovanni Dietler, EPFL

This year Nobel Prize in Chemistry is awarded to J. Dubochet (University of Lausanne), J. Frank (Columbia University) and R. Henderson (MRC Laboratory of Molecular Biology, Cambridge, UK), who have contributed to the development of electron microscopy up to the point that protein three-dimensional structure can be determined with a spatial resolution of few Ångström using electron microscopy.
This year Nobel Prize is actually awarded for a typical interdisciplinary work. The choice of the Chemistry label is actually just an expedient to award the Nobel Prize to an advancement in a field that does not belong to the classical divisions in science. The interdisciplinarity of this research comes from the fact that at least three elements were needed for the breakthrough: a) freeze the sample without damaging it and without creating water crystals that will interfere with the electron beam; b) have a mathematical procedure to reconstruct from the many 2 dimensional projections of a three dimensional object its 3 dimensional structure; and c) show that it can have a real impact on structural biology (branch of biology whose main task is to determine the 3 dimensional structure of biological samples).

It has to be said that biology has based its endeavor to understand living matter on the now famous dogma which states that “a strict relation between structure and function of a protein” exists. No wonder that biologists were avidly looking for 3 dimensional structures of proteins. The first high resolution structures of biological samples were myoglobin (Nobel Prize in Chemistry, 1962) and DNA (indirectly Nobel Prize in Physiology, 1962) obtained by X-ray diffraction method. X-rays remained the method of choice until NMR arrived (Nobel Prize in Chemistry, 2002). This trend lasted until few years ago when high computing capabilities arrived with modern Transmission Electron Microscopes equipped with direct electron detection cameras: with these improvements combined with cryo-microscopy, the game of structure determination radically changed. The main consequence is an almost exponential growth of the number of protein structures determined by this method and a strong competition between x-ray/NMR methods and cryo-electron microscopy method. It has to be said that x-ray and NMR methods will remain important tools when atomic precision is needed for a given structure.

The Nobel Prize to Jacques Dubochet [1] recognizes his contribution to the part related with the sample preparation. In fact, it is advisable that biomolecules should be observed and imaged in their natural environment, namely water. But water is not compatible with the vacuum condition required by electron microscopes and therefore the need of freezing the sample arose. This new requirement however came with additional experimental constraints: the frozen water should not be in crystalline state and the thickness should be small enough to permit to the electron beam to traverse it. The water crystals would partially damage the biological specimen while at the same time they would diffract the electron beam. The solution was found in the quick cooling of the sample in liquid ethane which permitted to freeze the water in an amorphous state (liquid like frozen state of water or vitrified state). The other major ingredient was the thickness of the sample on the electron microscope grid which should be thin enough to let the electron beam traverse it: the solution was found in spanning a thin water film on a specially treated electron microscopy grid. Detailed experimental conditions to operate the electron microscope play an important role and a slight defocusing of the electron beam improved the contrast for biological sample at the price of reducing the resolution.



Cryo-electron microscope image of a multidomain protein, courtesy of Dr. Davide Demurtas, CIME, EFPL.

More recently, the recording of the image received a strong impetuous with the Direct Detection Detector (direct electron imaging) and with electron counting techniques: this had the effect of strongly reducing noise and improving resolution. Improvements also in the alignment of the images of the single proteins in order to be averaged contributed to the emergence of cryo-electron microscopy combined with the increased computer power.

What should we expect for the future developments? Where is biophysics now heading? The physics community is already preparing the next revolutions along two paths: one is the single protein structure determination [2] and the other is the ultrafast X-ray diffraction method for investigating dynamics of biological molecule with atomic resolution using the x-ray free electron laser [3] and Switzerland is at the forefront of these revolutions.

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Progress in Physics (60)

Quantum Computing: From Basic Science to Applications

Andreas Fuhrer, Thilo Stöferle, IBM Research – Zurich

Quantum mechanics was developed a century ago, and has laid the foundations for many technological breakthroughs like the transistor or the laser. During the past four decades, it has become increasingly clear how the novel resources that are unique to the quantum world, superposition and entanglement, can be harnessed for radically new applications in communication, computing and sensing. In parallel, experimental methods and fabrication capabilities have progressed to a degree where individual quantum systems can be prepared, controlled and kept coherent with outstanding quality, such that ever more complex systems can be realized.

This convergence fuels the belief shared by many academic, governmental and industrial parties that we are currently at the dawn of a second quantum revolution. New quantum technology programs are being ramped up on a national level (Australia, Austria, Canada, China, Denmark, Germany, Japan, Netherlands, UK, USA). Moreover, the Quantum Technology Flagship initiative is gathering momentum as a European platform [1]. Large enterprises in the IT industry (Google, IBM, Intel, Microsoft) as well as a rapidly increasing number of startups are investing heavily in the development of novel quantum products that are expected to become available in the next few years.

Quantum communication, quantum sensing/metrology and quantum computing/simulation have been identified as the central pillars for this new wave of quantum technologies. In this article, we concentrate on quantum computing and digital quantum simulation which arguably requires the most complex quantum systems but also holds promise to solve computing problems that will remain intractable with any classical super-computer.

Computations with Qubits

Whereas classical computers work with binary bits that can be either 0 or 1 and gates that define logic operations on these bits, the resources for quantum computers are controllable two-level systems or qubits and corresponding quantum gates. Key to the power of the quantum computer is that qubits can be in a superposition of 0 and 1 "at the same time", i.e., the state of a qubit is defined in a quasi-analog way as vector on the Bloch sphere. Therefore, an N-qubit quantum computer in principle operates on a 2^N dimensional complex state space (Hilbert space) with state vectors that already for $N = 100$ could never be accurately stored on any classical computer. However, unavoidable coupling to the environment gives rise to uncontrolled, undesirable state changes. What makes things even more challenging, these cannot be corrected easily because also just measuring the state "collapses" it to either 0 or 1. Hence, decoherence and probabilistic readout of the result require clever quantum algorithms to fully exploit the promises of this so-called quantum parallelism.

The complexity of the algorithms that can be run on a quantum computer not only depends on the number of qubits but more importantly also on the effective error rate, which determines the number of operations that can be performed sequentially before errors mask the output of the calculation [2]. The current state-of-the-art is 10 - 20 qubits with effective gate error rates on the order of 10^{-2}. To further reduce the error rate of a quantum computer, both the coherence of the qubits and their fault-tolerant encoding will have to be improved in the future. Eventually this development is expected to lead to fault-tolerant universal quantum computing. It is expected that a 50+ qubit machine can be built in the next few years that could for the first time demonstrate a "quantum advantage" for a special purpose application that is incomputable using classical systems (see Figure 1). The next, much more important, step would be an "approximate quantum computer" that could solve "useful" problems, e.g., in quantum chemistry or binary constrained optimization but does not require full fault-tolerance. Such a system will require on the order of thousand high fidelity qubits. The ultimate goal is a universal quantum computer that features complete quantum error correction, e.g., by running the surface code [3] and shows exponential speedup over its classical counterparts for a range of important problems [4]. Reasonable current estimates of the rate of progress lead many people to believe that we are still more than a decade away from having such a system available to us.

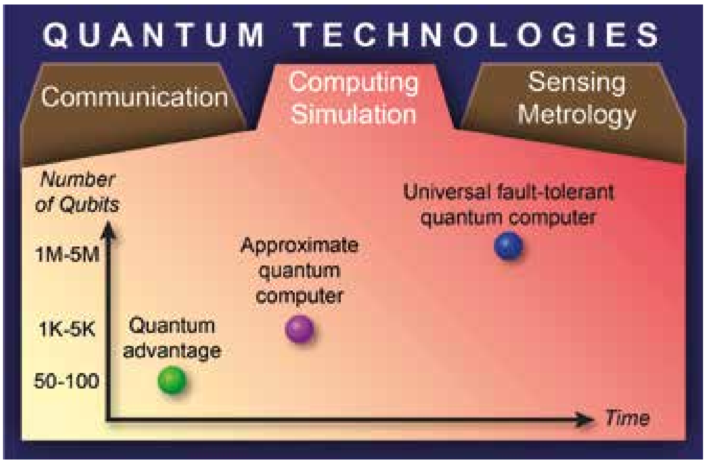

Figure 1: Quantum technology pillars and the expected scaling path towards a universal quantum computer.

As the race towards a useful quantum computer intensifies, only two physical systems have currently demonstrated 10+ qubits with long coherence time, high gate fidelity and reasonable connectivity. These are ion traps and superconducting qubits. At IBM, the focus is on the latter because they can be fabricated with standard chip fabrication methods. Furthermore, their manipulation with microwave pulses is relatively straightforward since much of the control hardware is similar to well-established wireless technology. Whereas other qubit architectures such as spin qubits in semiconductor nanostructures may become relevant in the future, we restrict ourselves here on the superconducting qubit technology and discuss its potential and future challenges in more detail.

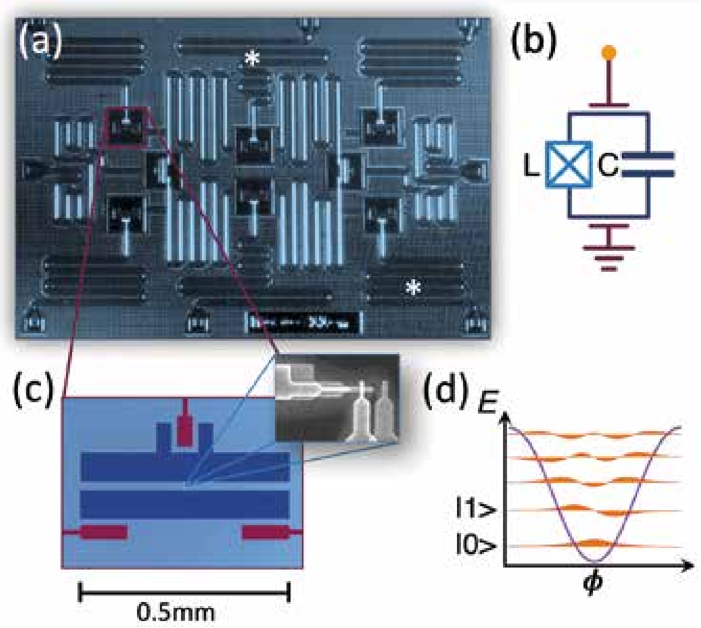

Figure 2: (a) Eight-qubit chip showing qubits (dark square shaped areas) and meandering CPW resonators for coupling and readout. (b) Equivalent-circuit model of a single qubit. (c) Transmon qubit with the large capacitors pads in blue and the ends of the CPW resonators in red. The inset shows a scanning electron microscopy image of the Josephson junction. (d) Energy spectrum of a transmon qubit.

Superconducting Qubit Architecture

Figure 2(a) shows an eight-qubit chip with the qubits coupled by meandering coplanar waveguide (CPW) resonators. Control of the qubits is achieved by sending microwave pulses to the ports surrounding the chip. Both qubits and CPW resonators can be viewed as LC-resonator circuits [see Fig. 2(b)] that are operated in the quantum regime where zero-point fluctuations are large compared to temperature. In this limit, a resonator circuit can be described by a harmonic oscillator model with photon number states at energies $\hbar\omega_0(n+\frac{1}{2})$. Dissipation (or damping) in these resonators is negligible due to the superconducting materials (niobium and aluminium) that are used, resulting in Q-factors on the order of millions. Figure 2(c) shows a zoom of a transmon qubit with two large blue superconducting capacitor pads. The small Josephson junction between the two pads acts as nonlinear inductance. This is responsible for making the oscillator potential anharmonic and allowing to address the two lowest levels as qubit states $|0\rangle$ and $|1\rangle$ [see Fig. 2(c)+(d)]. The Josephson junction consists of an aluminium oxide tunnel barrier between two superconducting aluminium electrodes and has the unique property of combining nonlinearity with negligible dissipation.

The transition frequency between the $|0\rangle$ and $|1\rangle$ states of such a fixed-frequency transmon qubit is designed to lie close to 5 GHz with a fabricated accuracy of about 1%. Its large capacitor pads facillitate strong coupling between CPW resonators and qubits and at the same time reduce the qubits susceptibility to charge noise. Read-out of the qubit state occurs by weakly probing the reflection phase of the CPW resonators that link the qubits to the outside world (two of them are marked with an asterix in Fig. 2(a)). Their resonance frequency depends on the qubit state which leads to a measureable change in the reflected microwave signal phase near resonance [5].

It is worth noting that over the past decade improvements in materials and circuit designs have led to a steady increase in qubit coherence, as illustrated in Figure 3.

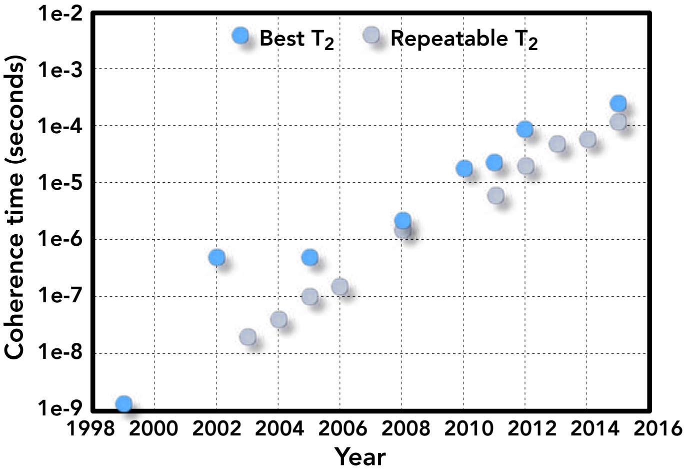

Figure 3: Improvement of superconducting qubit coherence times over the past two decades.

Quantum Circuits

The construction of arbitrary classical logic circuits can be achieved just using NAND gates, which are said to have functional completeness. Similarly, any digital quantum circuit can be built from single qubit rotations and a two-qubit entangling gate, the controlled-not (CNOT) operation, which inverts the state of the target qubit depending on the state of the source qubit. On the hardware level, single qubit rotations are implemented by modulating amplitude and phase of the microwave pulses that are applied to the qubits. The CNOT gate can be realized, e.g., by driving a source qubit at the transition frequency of a neighboring target qubit. This cross-resonance gate [6] in combination with single qubit rotations allows construction of arbitrary quantum circuits on a lattice of superconducting qubits.

The "IBM Q experience" provides a platform to explore basic quantum circuits on real quantum processors based on superconducting qubits. Figure 4 shows the web-interface, which allows simple implementation of basic quantum algorithms and is geared towards education. More functionality can be accessed through the Quantum Information Sofware Kit (*https://www.qiskit.org*) which provides an open-access programming interface for working with both the real quantum processors and a cloud-based simulator that currently handles up to 20 qubits. It uses OpenQASM [7] as an intermediate representation of quantum circuits and performs some important compilation and optimization tasks on the circuits.

Even though quantum processors such as the ones currently accessible through the “IBM Q experience” can still be simulated with relative ease on classical hardware, it is believed that future more powerful quantum processors could be used in the same way: They would be accessed through

Figure 4: The "IBM Q experience" web interface gives access to experimental quantum processors with 5 and 16 qubits for exploring basic quantum circuits. (see https://www.ibm-research.com/ibm-qx)

the cloud and in tandem with classical high performance computing systems for which they would act as accelerators in specific applications.

Near-Term Quantum Applications

On the long journey towards a large, fault-tolerant quantum computer, useful applications of approximate quantum computers will become available much earlier. On these intermediate systems, the limited number of sequential gates restricts the depth of meaningful quantum circuits that can be run, and algorithms will have to be tailored to cope with noise and errors [8]. Still, even a relatively small-scale quantum computer with hundred qubits can already process quantum states that could not even be stored in any classical memory.

One concrete example to make use of this quantum advantage is via a hybrid quantum-classical architecture: A quantum co-processor is used to prepare multi-qubit quantum states $|\Psi(\theta)\rangle$, parametrized by control parameters θ. The subsequent measurement of a cost function $E(\theta) = \langle\Psi(\theta)|\, H_q\, |\Psi(\theta)\rangle$, typically the energy expectation value of a problem Hamiltonian H_q, serves as an input for a classical computer to find new values θ in order to minimize $E(\theta)$ and converge towards the ground-state energy $E(\theta^*) = \min(\langle\Psi(\theta)|\, H_q\, |\Psi(\theta)\rangle)$.

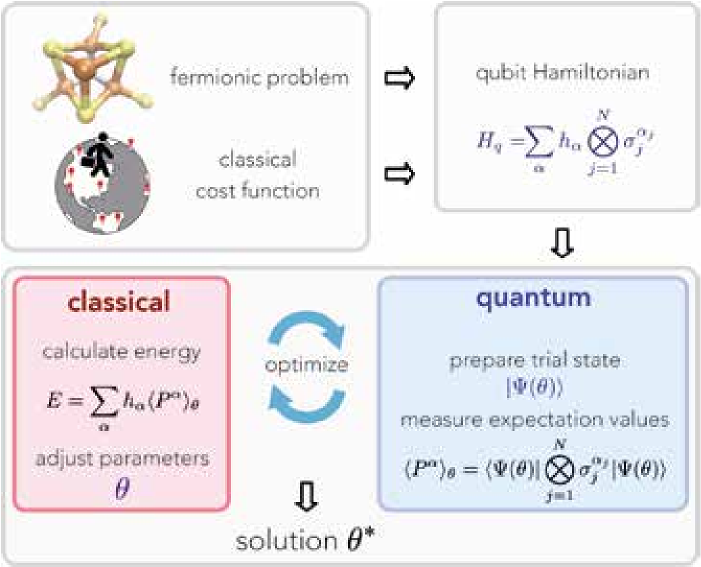

Figure 5: Process flow for the variational quantum eigensolver method. A trial state $|\Psi(\theta^*)\rangle$ is parametrically generated on the quantum processor. Expectation values of the Hamiltonian terms are measured and used on a classical optimizer to find the optimal parameters θ^* defining the solution $|\Psi(\theta^*)\rangle$.

This variational quantum eigensolver approach, which is outlined in Fig. 5, has recently been applied in various contexts in proof-of-concept experiments [9-11]. In fact, the Hamiltonian H_q can take many forms, the only requirement being that it can be mapped to a system of interacting qubits with a non-exponentially increasing number of terms. Here we distinguish two relevant cases: Hamiltonians that describe fermionic condensed-matter or molecular systems and Hamiltonians that describe the cost function of a classical optimization problem. For the latter, the mapping of the problem Hamiltonian to qubits is simple and yields an Ising spin Hamiltonian. For fermionic systems, the mapping from fermions to qubits is not straightforward and requires one of several schemes that exist to keep track of parity [8].

For both types of problems, one can either focus the effort on creating a sophisticated trial state that is known to be close to the expected solution with ideally few parameters θ [9], or use a hardware-centric heuristic approach with gates that can be implemented efficiently on a given platform. The latter technique was recently used to calculate the ground-state energy of H_2, LiH, BeH_2 as a function of the atomic separation of the corresponding nuclei [11].

Hence, even though errors from decoherence and imperfect gates in near-term quantum processors limit the depth of useful quantum circuits, the exponential capacity of such devices may still be used for preparing trial states that cannot be stored on any classical system. The challenge for this approach will be to find good parametrizations of trial states that are both hardware efficient and span the relevant solution space.

Building a Quantum Computing Ecosystem

The construction of a useful quantum computer comprises tremendous cross-disciplinary challenges within the next years, ranging from the design of hardware-efficient quantum algorithms, over building large qubit arrays and quantum gates that are sufficiently immune to decoherence, cross-talk and fabrication variations, to developing highly integrated specialized electronics and tools for control, driving and readout of the system. It is unlikely that a single enterprise or institution can succeed with all of this alone, and hence, a whole ecosystem needs to grow (Figure 6). Some of the effort here in Switzerland is already bundled in the National Center of Competence in Research (NCCR) “QSIT” [12]. There are many opportunities for academia, SMEs and startups to get involved and take part in this global race by developing and engineering the tools for the required hardware and software ecosystem. There is a clear sense in the community that we should not wait for a fully fault-tolerant quantum computer, but should leverage quantum advantages in near-term approximate quantum computers now, as we build up a quantum computing ecosystem. In other words, the exciting journey from basic science to applications is already fully on its way.

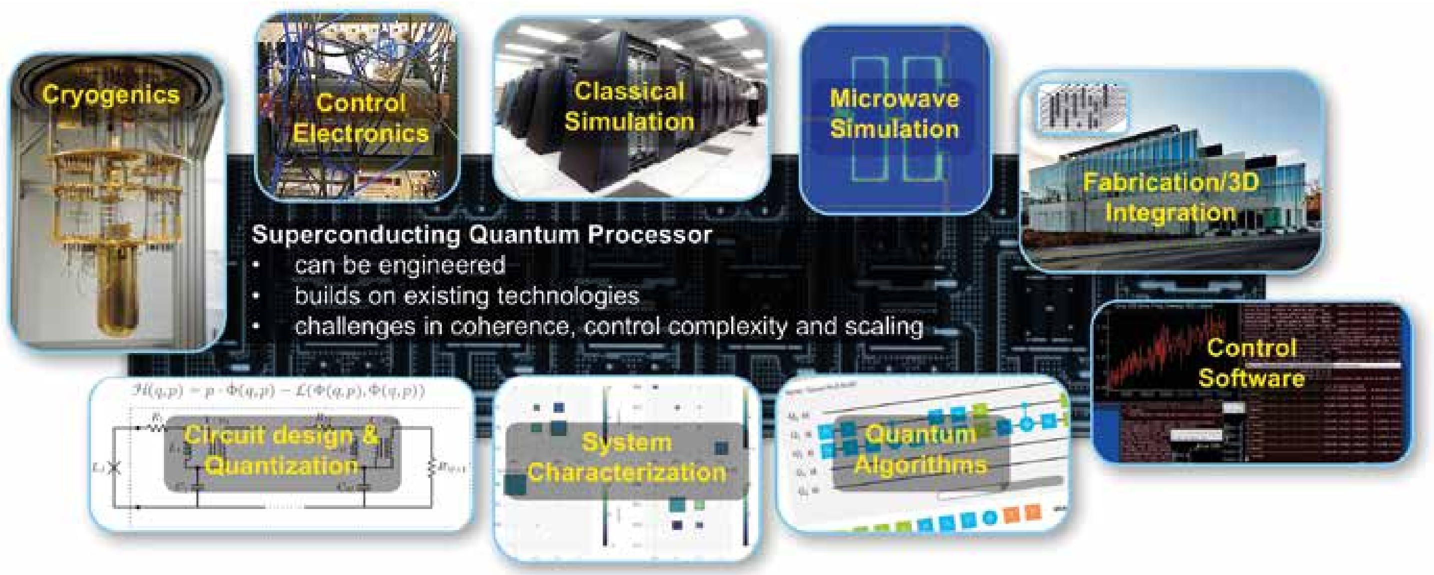

Figure 6: Ecosystem of hardware and software that is required to build a superconducting quantum processor.

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Milestones in Physics (11)

A Swiss physicist's contributions to European science policy

Martin C. E. Huber

Paul Scherrer's introductory physics lecture

Our physics course at ETH started in autumn of 1956. Paul Scherrer, professor of experimental physics, famous for vivid lectures, began with a lecture on physics relevant to space travel.

On the blackboard he derived the rocket equation and then illustrated it with a noisy 'rocket flight': upon ignition, a miniature-rocket, suspended on a wire, accelerated from the floor across the front of the lecture hall and disappeared through the ceiling. In a movie taken from an ascending sounding rocket with the camera looking down, we then watched how the Earth revealed its convex surface.

Scherrer had obviously chosen a spectacular theme for his introductory lecture. We don't know whether he also thought that the launch of an artificial satellite was imminent; but one year later, the launch of Sputnik would have proven him right. In any case, space research had started; in 1946, for example, US scientists had used captured German V2 rockets to photograph the ultraviolet spectrum of the Sun and were continuing such research.

Did this lecture spur my fascination with space? Certainly, but space research didn't exist yet in Switzerland [1], and a year later, Sputnik's launch caused primarily anxieties about its military implications. So, first of all, I had to study physics to later be able to do research. And while doing research, I began to appreciate the merits of international contacts and collaborations.

Before turning to my contributions to European science policy, it is appropriate to briefly touch upon my meandering early career, for this was the prerequisite for what then followed.

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[1] Except if one considered the investigation of meteorites as space research. The group around Houtermans in Bern were studying their composition, and the effect of prolonged exposure to space upon matter after it had fallen onto Earth.

Diploma at ETH in Zurich and thesis work in Basel and Stockholm

As 'Diplomarbeit' at ETH I built an apparatus for studying magnetic susceptibilities, a topic in solid-state physics. Following this work, I wanted to get to know another field, and decided to study molecular spectroscopy at the University of Basel with Ernst Miescher as thesis adviser.

To start with I developed a discharge tube that emitted the spectrum of interest, which I then could take to Stockholm. An 11-m grating-spectrograph there provided the high spectral resolution needed for a proper spectral analysis. During a two-month research stay, made possible through Miescher's excellent international relations, I recorded the spectra on photographic plates that I then took to Basel for the interpretation. Miescher suggested that I write my thesis concisely and in English [2] so that it could be published in its entirety: it appeared as a 21-page article on "Excited States and Rydberg Series in the Emission Spectrum of NO" [1].

An early foray into laser physics

When I couldn't find a suitable position in the field of spectroscopy upon completion of the doctorate, I stayed on at the University of Basel as teaching assistant. It was the early time of lasers then; and there was a general belief that almost any medium was going to lase, if placed in a laser cavity and suitably excited — 'gin and tonic' often being cited as an example. Miescher agreed that I try to see whether NO molecules would lase as well. With a laser built from scratch I was lucky enough to demonstrate such laser action. Although we could record the laser radiation with low resolution only, I knew from my thesis that, around the observed wavelength, there were several transitions of the NO molecule, whose lower levels were pre-dissociating. This would explain how the inverse population required for laser action was maintained [2] [3].

Becoming part of the 1960s brain drain, and getting involved in space research

A fellowship awarded in 1964 by the European Space Research Organisation (ESRO) enabled my wife and me to move to Cambridge, Massachusetts and work in the Harvard College Observatory (HCO). In its stimulating scientific environment, I could now expand my experimental skills into quantitative spectroscopy with shock tubes, and later into building space hardware for solar physics.

Initially, I was given the task to measure atomic transition probabilities by use of the 'hook method', a method based on determining the anomalous dispersion in the vicinity of absorbing transitions (Fig. 1). We used a shock tube to produce a slab of gas at a temperature comparable with that of the solar atmosphere. Surprisingly, our measurements showed that the transition probabilities, which had hitherto been used for determining the abundance of iron in the Sun, were off by about a factor of ten. Together with similar findings by other groups, this established an increase by nearly an order of magnitude of the traditionally assumed solar iron abundance.

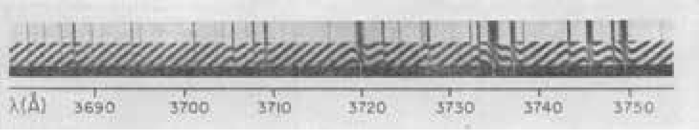

Figure 1 — Absorption and 'hook' spectra of iron, photographed simultaneously through a shock-heated gas. Anomalous dispersion generates well-developed 'hooks' around strong lines, whose absorption is saturated and would be difficult to determine. Combining absorption and hook methods extends the dynamic range of measurable line-strengths to 10^6; this improves the measuring accuracy. (Illustration taken from reference [4].)

About a year after I had started working at HCO, I was asked to assume the task of 'Cognisant Scientist' for a spectro-heliometer, i.e., an instrument to observe the vacuum-ultraviolet spectrum of the upper solar atmosphere that was to be launched as part of an *Orbiting Solar Observatory*, *OSO-6*. A Cognisant Scientist has to ensure that engineering changes, as they invariably arise in such projects, do not impair the scientific aims of the instrument; and to radiometrically calibrate the spectro-heliometer, i.e., to determine its absolute spectral responsivity [5] [6]. Work in laboratory spectroscopy went on, now in parallel with the new task.

Later during my sojourn at Harvard, we got involved in building a similar, but much larger instrument for the *Apollo Telescope Mount (ATM)* on *Skylab*, the first space station operated by astronauts. My responsibility there was again the radiometric calibration.

Return to Europe

Upon our return to Europe in 1973, I could take up a position in the newly created 'Atomic Physics and Astrophysics Group' at ETH Zurich. Kurt Dressler, Professor of Molecular Spectroscopy, and a physicist who had spent several years working at Princeton Observatory headed this group. At ETH I had teaching duties in the beginners' lab in physics; and after my 'Habilitation' I could lecture and take on graduate students and a postdoc. We further pursued the measurement of transition probabilities, performed spectroscopy on laser-excited Ba-vapour [7] and learned about Fourier-transform spectroscopy when measuring branching fractions with the 1-m Fourier-transform spectrometer [4] at Kitt Peak Observatory in Arizona.

Besides the research work at ETH, I participated in a study for a *Grazing Incidence Solar Telescope* (*GRIST*) at the European Space Agency, ESA; and it had been agreed that during my first two years at ETH, I would still spend considerable time in the US to support the calibration and science operations of *Skylab* (which was going to be launched in

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[2] Max Chrétien, professor at Brandeis University and a former student of Miescher was spending a sabbatical in Basel and kindly helped me to translate my original German text. This again showed me the benefit of contacts with colleagues from abroad.

[3] Ten years later, Miescher did observe the fine structure of the NO laser radiation, and confirmed the original assignment of the transitions involved in the laser action [3]. The mechanism is somewhat related to the excimer laser of rare gases. Molecules of rare gases do have bound molecular upper states, but their ground states are repulsive. The depopulation thus is guaranteed. In our case pre-dissociation, actually the consequence of a quantum mechanical mixing of bound and repulsive molecular states, led to the depopulation of the lower levels of the laser transitions.

[4] James W. Brault had designed this pioneering instrument, which worked in the infrared, visible and ultraviolet spectral regions, and written its software. He personally supported visitors in both solar observations and laboratory measurements.

May 1973 and then operated until February 1974). This also offered an opportunity to work on *Skylab* observations and publish their results [8].

Evolution in Swiss astronomy, and a start in European advisory committees

When Jan Stenflo became Professor of Astronomy in 1980, he founded the 'Institute of Astronomy' at ETHZ, which now also included the Atomic Physics and Astrophysics Group.

Then, in 1982, Switzerland joined the European Southern Observatory (ESO). Swiss members had now to be found for several ESO committees, among them the ESO Observing Programme Committee (OPC). After several astronomers had turned down an appointment, I was asked to take on this task. And this became my first involvement in European science policy.

As a neophyte in ground-based night-sky astronomy, I learned a lot while assessing fifty to a hundred concise 'Observing Applications' twice a year, and then to defend (or reject) them in the lively discussions during the OPC meetings. When ESO Council had elected me to chair the OPC three years later, Lodewijk Woltjer, ESO's Director General, rationalised this as follows: the OPC chair either does not submit observing applications (my case) or should have all of them accepted.

In parallel with this astronomy engagement at ESO I got entangled in space-science policy with the European Space Agency. Following the *GRIST* study, I joined ESA's Solar System Working Group (SSWG), and was later appointed to chair this group, too. This meant that *ex officio* I now also was a member of ESA's influential Space Science Advisory Committee (SSAC) [5]. There I had to advocate projects for solar system science in opposition to my counterpart, the chair of the Astronomy Working Group, who promoted projects for astronomy. The SSAC decided on the ranking of competing missions for both domains, and forwarded a recommendation to the Science Programme Committee (SPC). SPC then voted on which mission will go ahead as a project. Remarkably, SPC (with a single exception) always agreed to select and fund the missions recommended by SSAC. The key to this was that, for the ranking, SSAC members put their personal scientific interests aside and focused on the overall scientific merit of a mission, and then presented their recommendation as consensus.

Figure 2 — The Members of the H2000 Survey Committee and some of the Topical Team Chairmen as well as key ESA staff during a break in the Venice meeting in spring 1984, where the cornerstones and the overall structure of H2000 were decided. The tall person in front of the Campanile of San Marco was Léon van Hove, former Director General of CERN; his intervention during the discussions of the Survey Committee resulted in the acceptance of an additional cornerstone. (Photo by Mrs H. Schnopper)

ESA's long-term science programme «Space Science — Horizon 2000»

When Roger M. Bonnet became Director of ESA's Scientific Programmes in May 1983, he immediately started to develop *Space Science – Horizon 2000* (*H2000*), a long-term science programme [9]. Its overall structure was agreed in May 1984. And in January 1985 already, ESA Council meeting at Ministerial Level approved *H2000* together with the long-term prospect of an annual five-percent increase in the funding of ESA's Science Directorate [6]. What led to this remarkable result is described in Box 1.

To supervise the development of *H2000*, Bonnet appointed a Survey Committee, whose members comprised the SSAC, representatives of CERN and ESO, and of the European Earth science community, as well as experts from European Universities and Research Institutes — best characterised as senior statesmen [7] of European space research (Fig. 2 [8]).

Founding an International Space Science Institute (ISSI)

Helping to establish an International Space Science Institute — an idea of Johannes Geiss — was a controversial adventure. The new institute was going to be a place,

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[5] I thus became part of an uninterrupted sequence of Swiss SSAC members; chronologically, of Johannes Geiss (Bern), G. A. Tammann (Basel), myself, and Hans Balsiger (Bern). Later on, J. P. Blaser (ETH/PSI) and Willy Benz (Bern) also served as SSAC members.

[6] The 5% was the outcome of a difficult political process. SSAC recommended a 7 % increase, but it turned out that one of the national delegations in ESA Council would agree to 3 % only. This was of great concern to SSAC. We insisted on a 5 % increase with the following statement: "Above this threshold, a balanced programme with established priorities, supported by the European space science community, can be carried out. With a lower rate of increase, such a programme is out of reach. The absence of a long term plan would have serious consequences for the science programme since it will inevitably lead to a piecemeal approach with no consensus in the broad scientific community." As it turned out: "The ministers meeting in Rome finally agreed on the 5 % rate of increase …". [9] (p. 214) Under these conditions, a design-to-cost approach made *H2000* to the success it has become. (For comparison: "Until 2015, the German government increased support for all research organisations and the 'Deutsche Forschungs-Gemeinschaft' by 5 % per year; …, but {it} remains enviable at 3 %" [*scil.* until 2020]. [10])

[7] Kerstin Fredga from Sweden was the only woman from *academia* in the Survey Committee; consider though that the members of this committee were appointed 34 years ago.

[8] From left to right: Andrew C. Fabian*, Ian W. Roxburgh*, Edward P. J. van den Heuvel*, Franco Pacini** (Chair AWG), Henk Olthof (ESA, Secr AWG), Alan H. Gabriel***, Johannes Geiss***, George P. Haskell (ESA, Secr SSWG), D. Edgar Page (ESA, H/SSD), Bengt Hultqvist***, the author** (Chair SSWG), Gerhard Haerendel*, Michel P. Lefevbre*** (CNES, Earth Observation), Roger M. Bonnet (ESA, D/SCI), Dieter Stoeffler*, James Lequeux**, Kerstin Fredga***, Hugo Fechtig***, Johan A. M. Bleeker** (Chair Survey Comm), Giancarlo Setti** (ESO, also Fundamental Physics), Léon van Hove (CERN), Gillian Auclert (ESA, Secr to Roger Bonnet), Vittorio Manno (ESA Secr Survey Comm), Gordon P. Whitcomb (ESA, Future Missions Study Office), Herb Schnopper**. The single, double and triple asterisks (*, **, ***) indicate, respectively, Chairmen of Topical Teams, SSAC members, and Survey Committee Experts from European Universities and Research Institutes (s.e. ou o.).

I: The Venice meeting of the Survey Committee

At its final meeting in Venice in May 1984, the Survey Committee agreed on the general structure of *H2000*: it was to consist of

- a few large (L) ‘cornerstone’ missions, pre-approved for a well-defined mission theme
- a greater number of medium-size (M) missions to be selected later, in competition, plus
- several small (S) missions as well as instruments flown on Space Station.

Léon van Hove (*cf.* caption of Fig.2) intervened in the meeting, commenting on the number of cornerstones. Traditionally a long-term balance had been kept between solar system and astronomy missions. But at the Venice meeting it had been proposed to foresee only one cornerstone for solar system science but two for astronomy (Fig. 3).

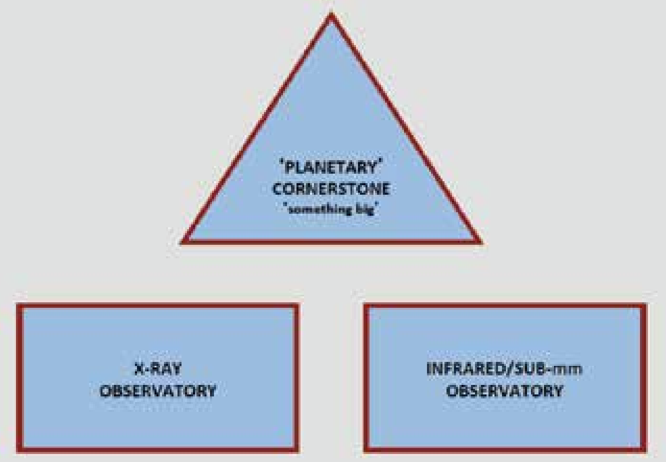

Figure 3 —Themes of cornerstones as originally presented to the Survey Committee.

Upon van Hove’s remark, it was up to me as chair of the Solar System Working Group to propose a solution; so I suggested inserting the *International Solar-Terrestrial Programme* (*ISTP*) as additional cornerstone. In this way the balance would be restored. *ISTP* consisted of two complementary missions [I], whose total cost was expected to correspond to that of a cornerstone.

On the second day of the Venice meeting, the Survey Committee agreed to insert *ISTP* as an additional cornerstone. With the themes selected for the *H2000* cornerstone missions, all major European space science communities could now look forward to a pre-approved mission theme in their field.

The final outcome of the Survey Committee meeting in Venice is seen in Fig. 4: it included ten medium-size missions (M), and a number of small missions (S) besides the four cornerstones. At the time, five of the ten M missions had already been under development and would be launched in the course of the 15 to 20 year programme; five M-size opportunities were still open for selection in competition in the course of *H2000*.

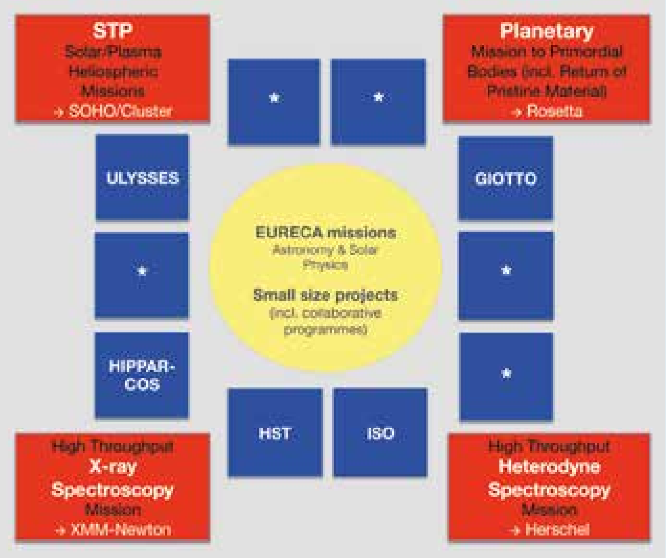

Figure 4 — The outcome of the Venice meeting: a long-term programme “Space Science — Horizon 2000” (H2000) with four cornerstones (red) [II], ten medium-size missions (blue, of which five had already been under development and five still to be selected in competition) plus some missions of small cost (yellow) [III]. The names and launch dates of all ESA science missions can be found with the help of the ESA mission navigator [12].

[I] The idea of realising *Cluster* and *SOHO* in the same time frame had been discussed in June 1983 at a meeting chaired by Stan Shawhan at NASA Headquarters in Washington, where representatives from ESA, ISAS (Japan) and NASA reduced the long list of mission-plans for solar, heliospheric and space-plasma physics of their space agencies. At this meeting Gerhard Haerendel (MPI for Extraterrestrial Physics) had championed combining the complementary *SOHO* and *Cluster* missions in an International Solar-Terrestrial Physics Programme (ISTP). ISTP was eventually recommended as a programme to be executed with priority. The cross-fertilisation of *SOHO* and *Cluster* was a subject of an ESA Workshop held in 1985 to discuss the STP cornerstone [11].

[II] The planetary cornerstone was originally foreseen as a mission in collaboration with NASA. When NASA had to pursue other plans in comet exploration, the return of material had to be abandoned; a lander was added instead.

[III] EURECA, the EUropean REtrievable Carrier, was an experiment platform. Eventually EURECA flew only once: with delivery in orbit by Space Shuttle Atlantis (STS-46) on 31 July 1992, and retrieval on 21 May 1993 by Space Shuttle Endeavour (STS-57). The EURECA platform is now exhibited in the Swiss Museum of Transport in Lucerne.

where scientists — meeting as international teams, working groups or in workshops — would add value to results from different space missions through multidisciplinary research [9]. I thought that such an institute, particularly through its interdisciplinary approach, would help to bring space science more into the scientific mainstream. There were later instances, where I was able to contribute to ISSI projects [13] [14] [15].

In spite of initial scepticism by many space scientists ISSI was set up in Bern as a foundation in 1995 [10] and became

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[9] For a concise description of ISSI’s mission, see http://www.issibern.ch/aboutissi/mission.html

[10] Following a proposal by Hanspeter Schneiter, Contraves donated the endowment.

a successful enterprise [11]. The financial support comes from ESA, the Swiss Confederation, the Swiss National Science Foundation, and the University of Bern as well as from the Russian Space Research Institute. ISSI now also deals with Earth observation science, and has a branch in Beijing. Thriving in its 23rd business year, ISSI in Bern hosts about a thousand visitors each year; and scientists who had earlier been sceptical are participating in its work — some of them have even taken on leading functions in ISSI's advisory committees and directorate.

Promoting fundamental physics within ESA's Science Programme

'Drag-free' spacecraft (with acceleration below 10^{-12} g, i.e., in the pico-gravity range) [12], became available in the 1980s. This made it possible to test the theory of General Relativity, by measuring minute potential deviations from its predictions, for example. I felt confident that ESA could, like NASA, make use of this technical innovation.

Fundamental physics had already been included in the long-term programme '*Space Science — Horizon 2000*' (*H2000*) [16]; and the periodic calls that invited space scientists to submit mission ideas always included fundamental physics as a potential field of research. But 'fundamental physics in space' came to fruition in ESA only after I had asked Rüdeger Reinhard, a senior staff member in ESA's Space Science Department (SSD) [13], to vitalise this field. As head of SSD's 'Fundamental Physics Office', Reinhard encouraged the European scientists working in this domain to submit pertinent mission proposals. Suddenly, now, mission ideas for fundamental physics missions reached a number that equalled those for solar-system science or astronomy.

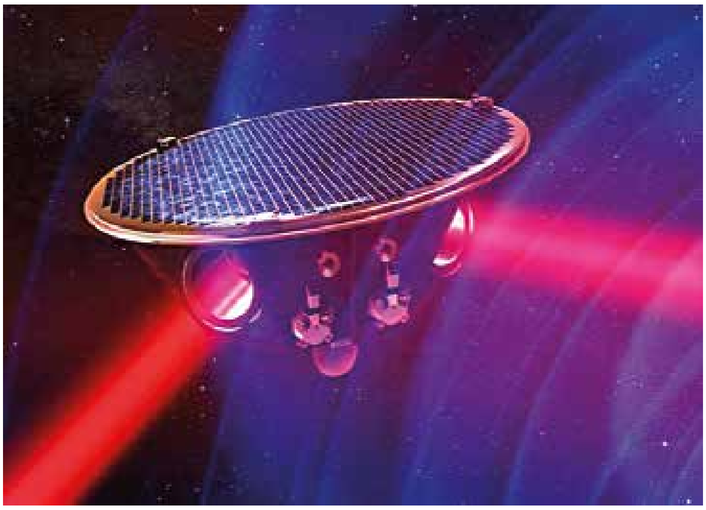

Fig. 5 — LISA will detect gravitational waves in space using a trio of satellites (like the one shown here) that will be separated by millions of kilometres. Lasers will be employed to measure the minute changes in their relative distance, induced by impinging gravitational waves. (© AEI/MM/exozet; GW simulation: NASA/C. Henze)

II: Intermezzo - Swiss contributions to fundamental physics in space

LISA's preparatory mission, *LISA Pathfinder* (LPF) has benefitted from decisive contributions by scientists and engineers of ETHZ and the University of Zurich (UZH). Six scientists and engineers from these institutions are now co-authors of the proposal for the actual *LISA* mission [17] (*cf.* Fig. 5).

That the biennial LISA Symposium was scheduled to take place in September 2016 in Zurich was a lucky coincidence, because 2016 turned out to be a grand year for gravitational wave research. In February the "LIGO Scientific Collaboration and Virgo Collaboration" announced that they had detected gravitational waves [18], and in June it was found that the performance of *LISA Pathfinder* was much better than expected, and already at the level of the *LISA* requirements. Riding on this success story, the *LISA* Symposium in Zurich attracted 250 participants. I considered it a great honour to give the after-dinner speech at this symposium [19].

A 'Fundamental Physics Advisory Committee' (FPAC) was then established with the best people in the field (whose names had been assembled by Rüdeger) [14]. FPAC now assessed the merit of mission ideas in parallel with the Solar System and Astronomy Working Groups (SSWG and AWG), and forwarded the best ones for final selection by the Space Science Advisory Committee (SSAC). One of these ideas, the 'Large Interferometer Space Antenna' (*LISA*), a mission to detect low-frequency gravitational waves (Fig. 5), has now been selected for launch in 2034 (see also Box 2) [15].

Returning from space to physics policy — EPS presidency, EPS13 in Bern and the ERC

After my retirement from ESA, Maurice Jacob of CERN, a former EPS President, encouraged me to stand for election as President of EPS. I was elected to this fascinating office for the time 2003-2005.

The European Physical Society was then planning to organise its 13th General Meeting (EPS13). This hopefully large conference was going to be held in Bern, during the centenary of Albert Einstein's *annus mirabilis* 1905. My predecessor as EPS President, Martial Ducloy, who had already smoothed the way to this event by ensuring that the United Nations declared the year 2005 to the 'International Year of Physics' (WYP2005) [16], chaired the international programme committee.

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[11] All ISSI publications are collected under http://www.issibern.ch/publications/sssi.html

[12] The symbol "g" stands here for the terrestrial gravity acceleration (9.81 m s^{-2})

[13] Rüdeger Reinhard had been Project Scientist for ESA's Giotto, a mission that flew by comet Halley's nucleus in March 1986. Fifty TV stations transmitted the fly-by from the ESA control centre in Darmstadt and it is fair to say that the Giotto mission (perhaps together with the numerous launches of Ariane rockets) 'put ESA on the map' with the broad public. Rüdeger died in January 2015, and could unfortunately not see that *LISA* was selected as a large ESA project (*cf.* next paragraph).

[14] Jean-Pierre Blaser, the former Director of the Paul Scherrer Institute, was the first chairman of FPAC.

[15] *LISA* was selected as large-class mission (L3) of *Cosmic Vision*, i.e. of ESA's current long-term science programme. A large-class mission (L) is today's equivalent of a cornerstone in *H2000*.

[16] UN uses the name 'International Year of Physics', while UNESCO, the organisation that had to pre-approve the event, called it 'World Year of Physics'; WYP2005 became the generally used abbreviation.

EPS13 had the forward-looking title «Beyond Einstein — Physics for the 21st Century» and was structured as three collocated meetings with themes that were based on the main subject matters that Einstein had pioneered in 1905:

- **Photons, Lasers and Quantum Statistics**, with the *photo effect* as starting point in 1905,
- **Relativity, Matter and Cosmology**, which had the *theory of special relativity* as its origin, and
- **Brownian motion, Complex Systems and Physics in Biology**, a set of topics that had arisen from Einstein's original publication on the *Brownian motion*.

This structure made it possible for all EPS Divisions to organise session within EPS13; in addition, CERN, ESA and ESO had agreed to contribute to the second theme — on Relativity, Matter and Cosmology. About 600 participants attended EPS13.

Perhaps the most important action we initiated in the EPS Executive Committee during my presidency was to champion the creation of a European Research Council (ERC) that included all sciences, including humanities and social sciences. It may seem curious today that in the early 21st century a 'Life Science Forum' tried to promote a European Research Council for Life Sciences only. That the 21st century was going to be the century of biology was an ephemeral illusion at the beginning of the 21st century that, however, had to be taken seriously.

The European learned societies formed the 'Initiative for Science in Europe' (ISE), which then helped steer toward an ERC for all sciences. José Maria Gago, a physicist and former Portuguese minister, led this effort and brought it to eventual success. Later, José recalled twice: "They could have done it."

Conclusion

These are some of the experiences of a physicist who had a Swiss education (Humanistisches Gymnasium Basel, ETHZ and University of Basel), but then spent many years working outside Switzerland. After a decade as postdoc and research associate in the US, there followed a dozen years at ETHZ (with, on the side, advisory functions in both ESA and ESO) and another dozen years as ESA staff member. This last employment, particularly, brought me together with people from all over the world. I met many great yet humble engineers, scientists and managers (or rather combinations thereof). In general, praise was placed where it belonged, and I admired the competence of the ESA personnel at all levels.

It struck me that Switzerland's influence in European organisations is often out of proportion with our country's size (an example is found in footnote 5). Reasons for this may be that as a small country we do not have 'big-power' ambitions, and that we respect democratic principles as a matter of course. Swiss scientists and engineers in Universities and Industry are benefitting from Switzerland's membership in intergovernmental organisations like CERN, ESA and ESO. They can get involved in major cutting-edge projects and observers have access to a variety of facilities, which would be beyond the capabilities of a single European country. I am grateful for having had the opportunity to work extensively with European inter-governmental scientific organisations and with European learned societies. I am also indebted to ESA's predecessor organisation ESRO, which provided an early ESRO-NASA International Fellowship that clearly was instrumental for launching this career.

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Physicists in Industry (5)

A Useful SW Tool for Thermal Estimations in Optics

Beat Aebischer and Bernhard Braunecker

Introduction

Physicists in industry very often have to take fast decisions, if e.g., specifications run out of tolerance in production, and one has to look rapidly for compensation means in the production chain. Since in most cases, there is not sufficient time to analyze the problem seriously, the decisions taken are more or less intuitive with the risk of leading to suboptimal solutions. Another stressful situation, especially in the optics industry, occurs when starting work on a new system layout. If the system specifications include operations under harsh environmental conditions, the designer has to identify the glass materials for the lenses as soon as possible due to their long delivery times. Since only a preliminary design exists at this early phase of the development, the selection of the expensive glasses bares some risk.

We have therefore developed a special SW tool for physically relevant estimations to manage better both unpleasant situations. Its purpose is to bridge the gap between pure intuition/experience and a full numerical Finite Element calculation. The results are approximations, but they at least point into the right physical direction. We wrote the SW in Matlab to allow easy case adaptions and plausibility checks. Further advantages are that the program runs on a portable laptop, and that the results are immediately available. In the following, we describe the physical models, which we used for thermal estimations in three optical projects. In the publication [1] we present the mathematical concept and the solutions for the first two applications (photogrammetric lenses, satellite terminals), while we treat the third application about laser processing in the following here in more detail.

Application 1: Photogrammetric Lenses

Fig. 1: Leica expert Thomas Pozivil and the **Ultra Aviogon Super UAGS-2.**

Leica Geosystems, former Wild Heerbrugg, produces big objective lenses for airborne photogrammetric cameras since many decades. Most prominent in the past was the *Reihenkamera* RC30 (see Box III), equipped with the *Ultra Aviogon Super 15/4 UAGS* (Fig. 1). The lens has a focal length of 153 mm, F-number 4, a field of view of 90°, and is exposing 9-inch square film in the visual and infrared spectral range. The cameras recorded nearly every square-meter of our earth on high-resolution photographic film. We see from Fig. 2 that the distortion error must be kept within ±2 μm in the film plane for all four semi-diagonals of 153 mm length, a requirement hard to achieve in production [2].

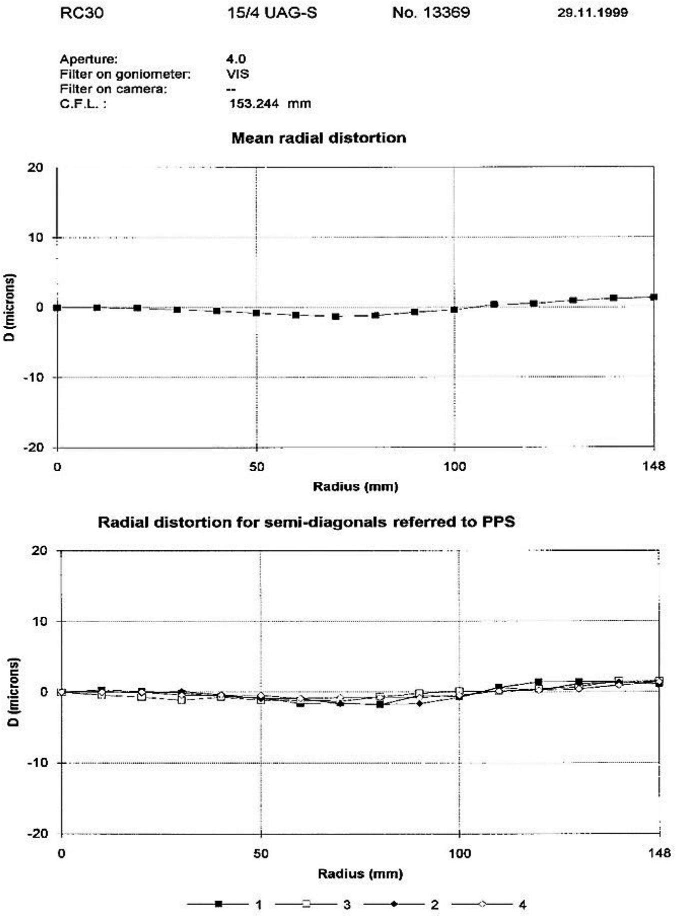

Fig. 2: Distortion error across the four semi-diagonals of a 9" square film.
a) Average b) the 4 individual semi-diagonals. No splitting allowed.

The technical construction drawing (Fig. 3) shows that the big lenses of up to 300 mm diameter are glued in the cylindrical housing with minimal mechanical contact to avoid any deformation of the strongly bended spherical surfaces. On the other hand, the mechanical mount must be stable enough to survive heavy shocks and vibrations from the airplane. To find the right balance needs a lot of experience in optical engineering.

Thermal Gradients in Large Scale Optics

The film lenses and their digital follow-up versions operate within the large temperature range from -30°C to +60°C. Therefore, one always had to consider athermalization

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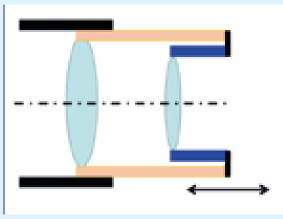
[1] Heat Conduction in Lenses, Beat Aebischer; Hindawi Publishing Corporation; Mathematical Problems in Engineering, Vol 2007, Article ID 57360; doi:10.1155/2007/57360

[2] We also note in Fig. 1 another technical challenge, the round pupil: The exit pupil must be non-obscured like a cat's eye, even under the large observation angle of 45°. The measurements confirm that the light fall-off at this field angle is 0.66, according to a $\cos^{1.2}$-law. This is a significant and non-trivial improvement, compared to the usual $\cos^4$-law, which would lead to only 0.25.

I: Passive Athermalization



To illustrate an example of a widely used passive method, we consider the simple case of two single lenses. The two radii of curvature, the glass thickness and the refractive indices of both lenses vary with temperature and cause an image defocus, which we can compensate by changing appropriately the air gap between the lenses. To this purpose, we fix the second lens on a special mount consisting of two materials with different thermal expansion coefficients, like Al and Invar, which is an old Swiss watchmaker's trick to keep the length of a pendulum independent of temperature.

Shifting two lens groups allows to correct besides defocus also the magnification, i.e. the focal length. The shifting values are typically 1.5 μm/°C. It is interesting to note that the famous glass ceramics Zerodur© of Schott AG, often used in astronomical mirrors due to its zero thermal expansion, is a mixture of two material phases, a crystalline one with negative thermal expansion coefficient and an amorphous one with positive coefficient. Swiss watchmaker technique in 3 dimensions!

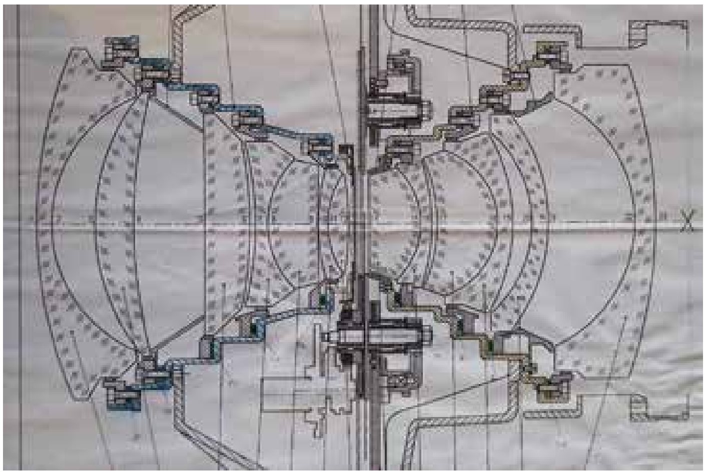


Fig. 3: Constructive details of an earlier ***UAGS*** *version. The film plane is directly behind the right lens (see Fig. 5).*

techniques to maintain the optical quality within the large temperature range. A standard method is described in Box I. However, the compensation only holds for *stationary* thermal conditions, i.e. when all parts are at the same new temperature. But what happens, when the user starts from an airport in the desert at a temperature of +60°C and reaches after few minutes a flying height of 5000 m, where the temperature drops down to about -30°C? This causes strong thermal gradients of the refraction index across the diameter of the big lenses, degrading the image sharpness and the carefully minimized distortion. Thus we were asked how strong and how long optical gradients in the glass material would deteriorate the image quality?

Modeling Heat Transfer

We model each optical element as a thin disk of radius R with rotational symmetry, ignoring its true 3D-shape. Then we obtain analytic solutions of the heat flow and the resulting temperature profile across the disk area with time. On the other hand, we exactly describe constraints like e.g. how, when and how long external heat is switched on, and we always use the correct material data of the glass disk and the glue, with which the disk is fixed in a metallic housing [3]. The diffusion time $t_c = R^2/\kappa$ is of central importance, where $\kappa = \lambda/(c_p\ \rho)$ is the thermal diffusivity in [m²/s], using the heat conductivity λ in [W/m/K], the specific heat (at constant pressure) c_p in [J/kg/K], and the density of the material ρ in [kg/m³]. For Schott glass N-BK7 with λ = 1.114 W/m/K, c_p = 858.0 J/kg/K and $\rho = 2.5{\cdot}10^3$ kg/m³ one obtains $\kappa = 5.2{\cdot}10^{-7}$ m²/s, while other common glasses like N-FK5 and N-LAF7 yield $4.7{\cdot}10^{-7}$ m²/s and $3.6{\cdot}10^{-7}$ m²/s, respectively.

Examples

We consider the temperature distribution as function of time across a cold glass disk, initially kept at -30°C and brought to an environment of +40°C. The material is Schott glass

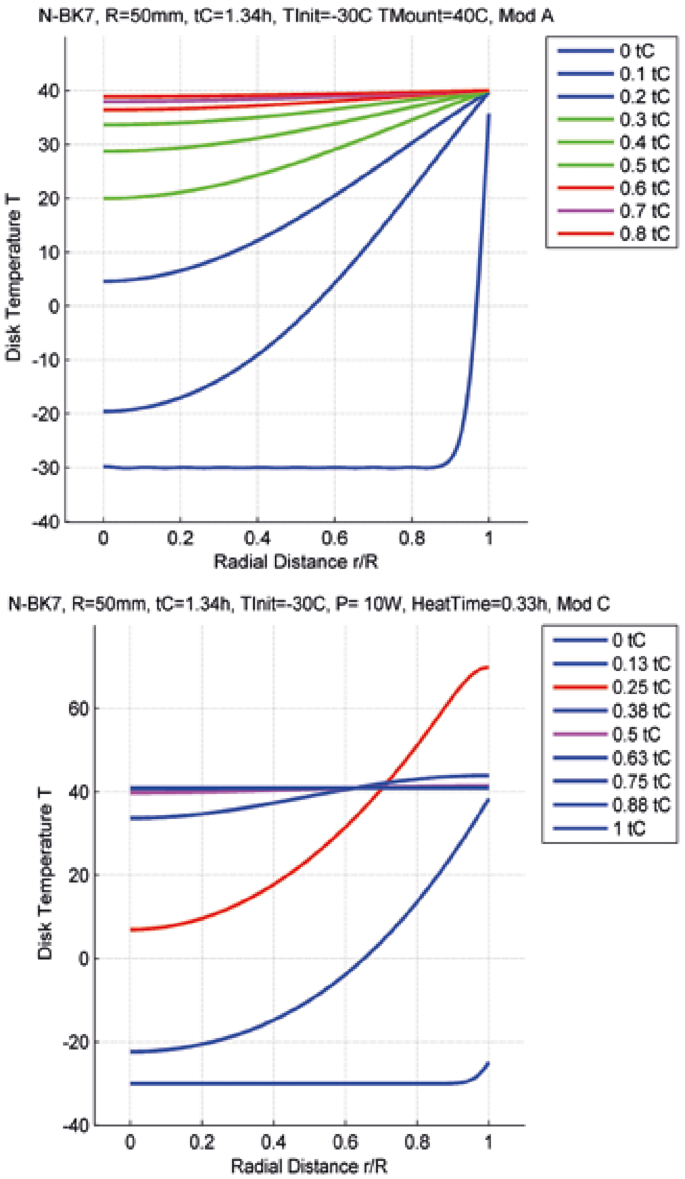


Fig. 4: Temperature distribution across a disk of radius R = 50 mm for different times t/t_c.
a) Pure diffusion, b) Heating 10 W for 20 minutes.

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[3] The differential equations, their analytical solutions, and several numerical examples are described in full detail in the publication cited in Footnote 1.

N-BK7, and when assuming a disk radius $R = 50$ mm, we obtain from above the surprisingly large value $t_c = R^2/\kappa = 1.34$ h[4]. The disk is glued into a metal ring, which carries a heating coil.

It can be seen in Fig. 4a that we need the time t_c to reach the thermal equilibrium by heat diffusion. In Fig. 4b we want to speed up the warming and apply $P = 10$ W of heating power for 20 minutes by the coil. Then the final state is reached after about $0.5 \cdot t_c$ (magenta line), but with a temperature peak at the disk rim of about +70°C at the end of the heating interval (red line). What does this mean optically?

Temporary Optical Aberrations

Let us consider the ray refraction at the surface of a spherical lens with radius of curvature r_{Surf}, glass thickness d and index of refraction n. All three quantities depend on temperature: r_{Surf} and d by the thermal expansion coefficient of the glass material, and n by the empirical *Sellmeier* formula. Before tracing a ray through the lens surface at the lateral position r and at time t, we calculate the glass temperature T and correct r_{Surf}, d, and n accordingly.

We compare two image points in Fig. 5: the first one on-axis, i.e. in the center of the image plane, and the other one off-axis, i.e. lying at the edge of the image plane. The light rays of the off-axis pixel cross most of the big lenses at the periphery, where the temperature quickly reaches the environmental value, while the rays of a central pixel stay close to the axis.

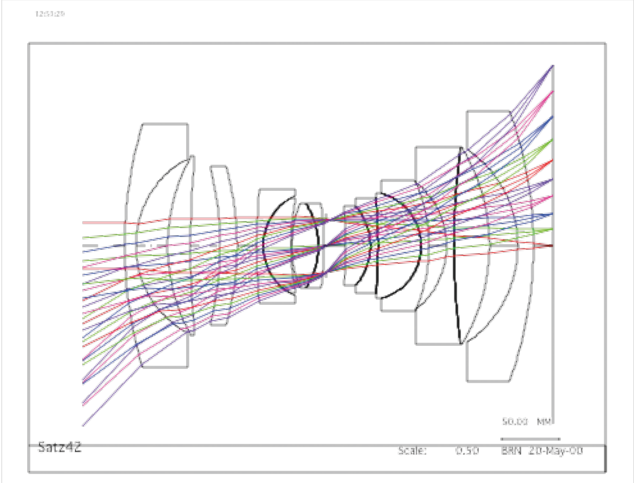

Fig. 5: UAGS-2, Design

When combined with the already mentioned mechanical movement along the optical axis of several lens groups, the off-axis image point thus will keep its best focus position. This is, however, different for the pixel in the central part, where the optical path crosses the inner lens segments, which reach the environmental temperature only later. This leads to a defocus varying with time. We therefore obtain some kind of *image curvature* for times shorter than typical values of t_c. Active heating and cooling would obviously shorten the time for the inner pixels to reach the thermal equilibrium, but at the cost of counterproductive over-heating at the rim zones (Fig. 4b). Thus our simple thermal modeling indicates that we had to flush the large lenses of the film camera by ambient air. This is different in the case of the digital cameras, where the lenses are of smaller diameter. They are mounted in a sealed housing, filled with protection gas, and the mechanical lens shifting (Box I) is part of the construction. We also introduced in the lens design a special aberration to efficiently manage thermal gradients at white light illumination[5].

All these considerations have to be made before the design work starts which can last several months. Nevertheless, the most reliable, but also expensive solution is to *overdesign* the lens performance (resolution, contrast, distortion) to master the quality degradation, at least for smaller temperature differences.

Application 2: Satellite Terminals

Here is another problem, now in connection with space telescopes, which send and receive laser radiation. The telescopes could be e.g. part of a laser altimeter for the exploration of a planet (Fig. 6), or of a laser communication system between two orbiting satellites[6]. The problem is to guide the laser beam with minimal loss through the optics, but to reject the incident solar radiation. Unwanted solar background radiation can result from reflections from earth's or the planet's surface, or from the sun suddenly appearing within the field of view of one of the communication terminals.

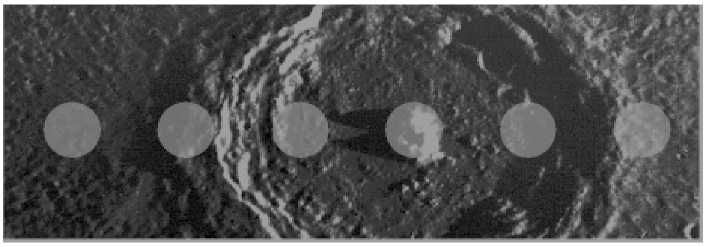

Fig. 6: Simulated Laserspots of 100 m diameter on Mercury, emitted from a 1000 km orbit with 10 Hz repetition frequency. The ground speed of the laser spot is 1.816 km/s.

Since the narrow band surface coating of all components within the optical path unavoidably has some residual absorption, one has to know the amount of the absorbed heat as function of time. The problem is similar to Application 1, since a time-variable thermal load can lead to gradients of the temperature across the component, causing defocusing of the laser radiation. Then the received and the emitted laser intensity can vary with time, which one has to know in case of an altimeter, or even to correct, when transmitting data, to keep the intensity dependent bit error rate constant.

In our SW tool we consider again a round filter glass of radius R and height h, which is glued in a cylinder mantle, kept at a constant temperature T_{Cyl}. We describe the sun illumination by a constant and homogeneous heat flux density q [W/m^2], exposing the whole disk area for the time duration t_{Exp}. As an example we show in Fig. 7 the case of a glass

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[4] A lens of 300 mm diameter would need $t_c = 12$ h.

[5] Most lenses for digital sensors are telecentric, i.e. the ray bundles hit the sensor at normal incidence. This allows designing the lenses with a small amount of longitudinal color aberration. Then thermally induced defocusing results only in a small spectral color shift for each pixel, but keeps the spot size and spot position.

[6] *http://www.sps.ch/artikel/physiker-in-der-industrie/optical-space-communication-information-transfer-from-point-to-point-reinhard-h-czichy-synopta-gmbh-st-gallen-2/*

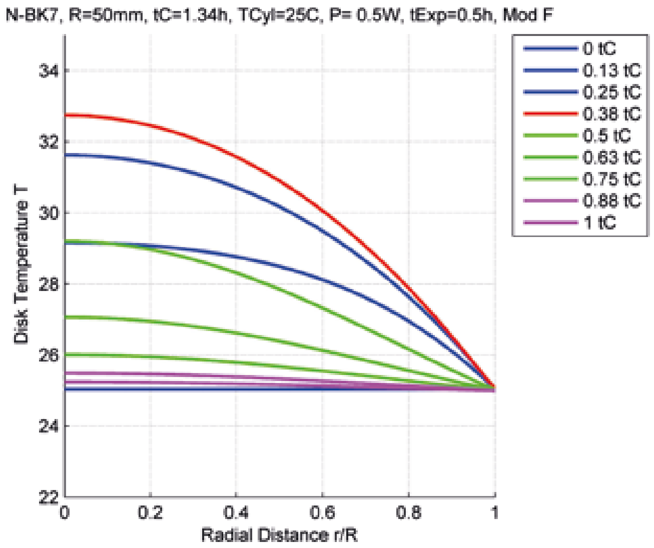


Fig. 7: Homogeneous exposure of a N-BK7 disk of radius R = 50 mm by 0.5 W for 30 minutes.

disk of N-BK7 of radius $R = 50$ mm, absorbing 0.5 W during 30 minutes. We see a general temperature increase until the heat switch-off time $t_{\text{Exp}} = 0.38 \cdot 1.34$ h $= 0.5$ h, where especially the disk center $r = 0$ raises up to 33°C. After ending the heat exposure, all parts reach the environmental temperature $T_{\text{Cyl}} = 25$°C of the cylinder mantle. Now it is easy to estimate as function of time the change of the refractive index, the optical power of each optical element, and finally the defocusing.

Application 3: A Heat Conduction Problem in Connection with Laser Ablation

We consider a high power laser capable of producing very short (sub-μs) pulses concentrated in a small spot. The workpiece being hit by such a laser pulse is heated up almost instantaneously and the material is evaporated. To determine how much material is evaporated one must know where the temperature grows above a threshold, namely the evaporation or the sublimation temperature. This will allow us to determine the radius of a hole which the laser beam burns in different materials.

a) Temperature profile

For a single laser pulse hitting well inside a slab of homogeneous material, the process is so fast that the material boundary has almost no effect on the temperature. Also, if one wants to burn a hole with a single pulse, the material must be thin enough. We therefore model the workpiece as an infinite plate and homogenize the temperature with respect to the z-coordinate (orthogonal to the plate). The problem is then described by the two-dimensional heat equation $\partial u/\partial t = \kappa \Delta u$ with initial condition given by the heating up due to the pulse and κ [m²/s] the thermal diffusivity. It is reasonable to model the pulse as a ***Gauss pulse*** with total energy E_{p} and ***full-width-half-maximum*** (FWHM) b. Using polar coordinates centered in the laser spot, the energy hitting the material is distributed as

$$e(r) = \frac{4\ln 2 E_p}{\pi b^2} e^{-4\ln 2 r^2/b^2} \quad , \tag{1}$$

so that

$$2\pi \int_0^\infty e(r)\, r dr = E_p$$

is the total pulse energy. Assuming all the energy is absorbed, the ***initial temperature*** is

$$u(r,0) = u_0 + \frac{e(r)}{c_p \rho h} \quad , \tag{2}$$

where c_p [J/kg/K] and ρ [kg/m³] are the specific heat and the density of the material, u_0 is the homogeneous temperature before the pulse hits, and h is the thickness of the plate. The temperature $u(r,t)$ is directly related to the two-dimensional euclidean ***heat kernel***

$$K(x,y;t) = \frac{1}{4\pi\kappa t} e^{-\|x-y\|^2/(4\kappa t)} \quad , \tag{3}$$

the fundamental solution of the heat equation for the initial condition (in the sense of distributions)

$$\lim_{t\to 0} K(x,y;t) = \delta(x-y) = \delta_y(x) \quad . \tag{4}$$

From (1), (2), and (3), one sees that

$$u(r,0) - u_0 = \frac{E_p}{c_p \rho h} K(x,0;t_b)\,, \quad t_b = \frac{b^2}{16 \ln 2\, \kappa} \tag{5}$$

and hence,

$$\begin{aligned} u(r,t) - u_0 &= \frac{E_p}{c_p \rho h} K(x,0;t+t_b) \\ &= \frac{E_p}{c_p \rho h} \frac{1}{4\pi\kappa(t+t_b)} e^{-r^2/(4\kappa(t+t_b))} \quad . \end{aligned} \tag{6}$$

To express the solution in dimensionless form, we introduce ***dimensionless variables*** $\tilde{r}, \tilde{t}, \tilde{u}$:

$$\begin{aligned} &\tilde{r} = \frac{r}{b}\,, \quad \tilde{t} = \frac{t}{T}\,, \quad \tilde{u}(\tilde{r},\tilde{t}) = \frac{u(r,t) - u_0}{U}\,, \\ &T := \frac{b^2}{\kappa}\,, \quad U := \frac{E_p}{c_p \rho b^2 h} \quad , \end{aligned} \tag{7}$$

and get

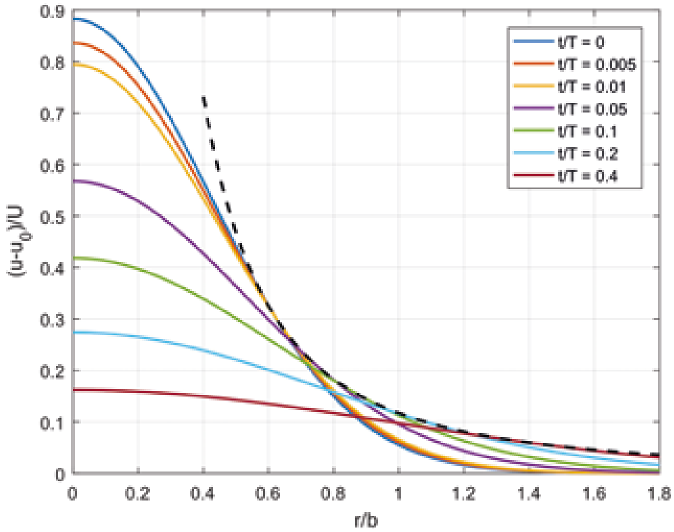


Fig. 8: Solution (8) for different $\tilde{t}$, together with the envelope $1/(e\pi\tilde{r}^2)$, shown as the black dashed line.

$$(8)\,\tilde{u}(\tilde{r},\tilde{t}) = \frac{1}{4\pi(\tilde{t}+\tilde{t}_b)}e^{-\tilde{r}^2/(4(\tilde{t}+\tilde{t}_b))}, \quad \tilde{t}_b = \frac{1}{16\ln 2} \approx 0.090168\,.$$

(Choosing $U' = \kappa^2 \rho h$ as the temperature scale would make the solution $\tilde{u}$ more complicated.)

Fig. 8 shows some numerical examples. For instance, $\tilde{u}(0,0) = 1/(4\pi\tilde{t}_b) = 4\ln 2/\pi \approx 0.88254$.

b) Maximal temperature after pulse arrival

At each radial coordinate the temperature reaches its maximum at a time $\tilde{t}$ determined by $\partial\tilde{u}/\partial\tilde{t} = 0$. This leads to the ***envelope*** shown in Fig. 8. Note, however, that for $\tilde{r} < 2\sqrt{\tilde{t}_b} = 1/\sqrt{4\ln 2} = 0{,}60056$ the envelope $1/(e\pi\tilde{r}^2)$ is due to curves $\tilde{u}(\tilde{r},\tilde{t})$for negative $\tilde{t}$, which are not physically present. The maximal temperature reached at a given radial coordinate $\tilde{r}$ is therefore given by

$$(9) \qquad \tilde{u}_{\max}(\tilde{r}) = \max_{\tilde{t}\geq 0}\tilde{u}(\tilde{r},\tilde{t}) = \begin{cases} \tilde{u}(\tilde{r},0)\,, & \tilde{r} \leq 1/\sqrt{4\ln 2} \\ 1/(e\pi\tilde{r}^2)\,, & \tilde{r} \geq 1/\sqrt{4\ln 2} \end{cases}$$

which is a monotonously decreasing function.

c) Radius of the burnt hole

We now consider a ***threshold temperature*** u_{thr}, e.g. the evaporation or sublimation temperature of the material and want to know for which radial coordinates r the maximal temperature u_{max} is above u_{thr}. As an estimate of the ***radius of the hole*** burnt by the laser pulse, one could use the value $\tilde{r}$ where $\tilde{u}_{\max}$ reaches $\tilde{u}_{thr}$. However, this would largely overestimate the radius, because the heat of evaporation, which we did not take into account yet, greatly decreases the available energy!

We denote by $Q = Q_{melt} + Q_{ev}$ [J/K] the specific heat needed to melt and evaporate the material. The evaporation of a hole of radius $\tilde{r}$ then needs (in addition to heating up to u_{ev}) the energy

$$(10) \qquad E_Q = \pi r^2 h\rho Q\,.$$

In reality, this energy is dissipated gradually as the hole forms and grows. A complete description of this process and its interaction with heat diffusion would involve a ***free boundary problem***, which we cannot solve analytically. As a simple ***approximation***, we let all of E_Q dissipate at the pulse arrival time $t = 0$ and allow only the ***excess energy*** $E = E_p - E_Q$ to diffuse as described by (8). This may underestimate the heat loss due to diffusion to the neighbouring material and therefore slightly overestimate the hole radius. Another effect in the same direction is that some pulse energy may not be absorbed. We still hope to get a reasonable approximation in most cases.

To ***summarize*** our approximation: Given E, compute $\tilde{r}$ from the condition $\tilde{u}_{\max}(\tilde{r}) = \tilde{u}_{thr}$ with E_p replaced by E in (7) and with $u_{thr} = u_{ev}$. Then $r = \tilde{r}\,b$ is the hole radius corresponding to the pulse energy $E_p = E + E_Q$ (where E_Q depends on the radius r just determined).

The condition $\tilde{u}_{\max}(\tilde{r}) = \tilde{u}_{thr}$ can only be satisfied if $\tilde{u}(0,0) \equiv 4\ln 2/\pi \geq \tilde{u}_{thr}$. Solving for $\tilde{r}$ (and using (8)) we thus get

$$(11)\,\tilde{r} = \begin{cases} 0, & \tilde{u}_{thr} \geq c/\pi \\ \sqrt{\ln(c/(\pi\tilde{u}_{thr}))/c}\,, & c/(e\pi < \tilde{u}_{thr} < c/\pi \\ 1/\sqrt{e\pi\tilde{u}_{thr}}\,, & \tilde{u}_{thr} \leq c/(e\pi) \end{cases} \qquad \begin{array}{l} c := 4\ln 2 \\ e \equiv \exp(1) \end{array}$$

The condition for a hole to form, $4\ln 2/\pi > \tilde{u}_{thr} \equiv (u_{thr} - u_0)/U$, is equivalent to

$$(12) \qquad E_p > \frac{\pi}{4\ln 2}(u_{thr} - u_0)\,c_p\rho b^2 h =: E_{p,\min}\,.$$

For ***iron*** we use the approximate values
ρ = 7870 kg/m^3, c_p = 450 J/kg/K, κ = 2.3·10^{-5} m^2/s,
u_{ev} = 2862°C, Q_{melt} = 2.6·10^5 J/kg, Q_{ev} = 6.1·10^6 J/kg.

With b = 10 μm, h = 1 mm, and u_0 = 25°C, we get $E_{p,\min}$ = 1.14 mJ.

Fig. 9 shows example plots of the approximate hole radius r as a function of the pulse energy E_p. As expected, the curves start to get positive at a threshold $E_{p,\min}$, which for the

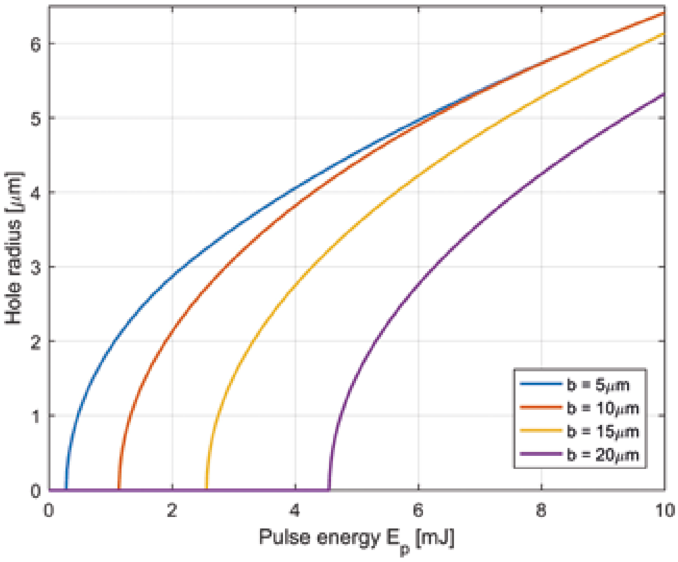


*Fig. 9: Hole radius r as a function of the pulse energy E_p for an **iron** sheet of thickness h = 1 mm. The pulse width (FWHM) b is given in the legend.*

II: Note on Nondimensionalization

The problem of the hole radius just discussed involves **11** physical parameters: E_p, b, h, ρ, Q_{melt}, Q_{ev}, u_{thr}, u_0, c_p, λ, κ. However, there are only **two** relevant nondimensional internal parameters that describe the whole process, e.g.

$$(13) \qquad \tilde{u}_{thr} = \frac{u_{thr} - u_0}{E}c_p\rho b^2 h \text{ and } \tilde{Q} = \frac{Q_{melt} + Q_{ev}}{c_p(u_{thr} - u_0)}\,,$$

since with the function $f_{11}\colon[0,\infty)\to[0,\infty)$ defined by equation (11) one can write

$$(14) \qquad \tilde{r}\,(E_p = E\cdot(1 + \pi\tilde{r}^2\tilde{u}_{thr}\tilde{Q})) = f_{11}(\tilde{u}_{thr})\,.$$

The parameter $\tilde{Q}$ is the quotient of the *latent* heat required to melt and evaporate the material in the hole and the *sensible* heat needed to bring the same material to the boiling point. For the metals appearing in Fig. 10 it ranges from 5 to 12. (Also $\tilde{u}_{thr}$ is a quotient of energies: the sensible heat needed to bring a volume b^2h to the boiling point and the excess energy $E = E_p - E_Q$.)

red curve is the value 1.14 mJ given above. The plot clearly shows the advantage of focusing the pulse. Let us finally admit that assuming ρ, c_p, and κ to be constant from room to evaporation temperature is another simplification we have made. Please see the comment on the Nondimensionalization of the involved physical parameters in Box II.

d) Different materials

Based on the simulation we finally compare the exposure of different metal sheets of 1 mm thickness by a laser beam with Gaussian radius (FWHM) **b = 15 μm** and an applied pulse energy **E_p < 10 mJ**. The material data are taken from the web [7].

We see in Fig. 10 that the size of the burnt hole grows from the pair Fe/Cu to Ti and to the pair Al/Si. This ranking and the nearly identical behavior of Fe/Cu, respectively Si/Al, are surprising, since their physical data vary considerably. It indicates the complexity of the thermal process. The much larger hole radius when exposing Mg, however, is easier to explain, since its volume specific evaporation heat of 9.16 GJ/m^3 is 5.3 times smaller than that of iron with 48.9 GJ/m^3.

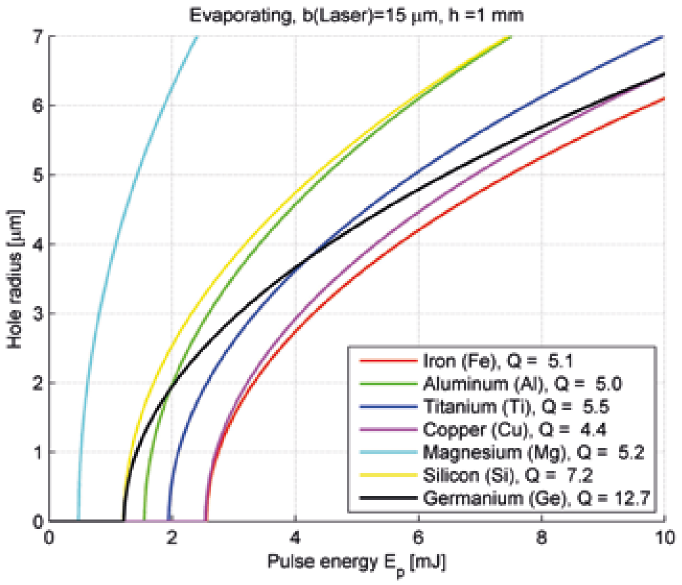


Fig. 10: The same as in Fig. 9, but for different materials, characterized by the nondimensional $\tilde{Q}$ of Box II.

Final Remark

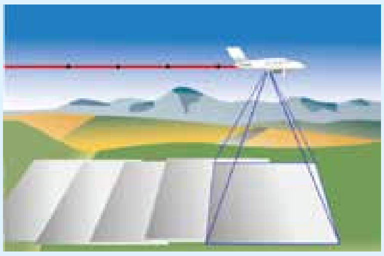
Describing real technical situations by simplified geometrical models allows analytical solutions of the involved physical mechanisms. We have shown concepts for three thermal diffusion processes. The advantage of closed solutions is a better understanding of the underlying physics, which is necessary to make the right decisions in the prephase of R&D work, or when problems occur in production. We are planning to extend our models to moving sheets of metal, ceramics and glass, exposed by time modulated ultra-short laser pulses. Results will/may be published in a later issue of this series.

Beat Aebischer got a diploma in Theoretical Physics from the University of Bern and later a PhD in Mathematics from the same university. For 6½ years he has worked in pure mathematics, partly on a Swiss National grant at Yale University. In 1995 he joined the department *Product and Process Technology* of Leica Geosystems, Heerbrugg, which later became the *Hexagon Technology Center* (HTC).
His specialties are physical and mathematical modeling, signal processing, and calibration and compensation.

Hexagon AB offers a full palette of products in industrial metrology, terrestrial and aerial surveying, mining, and remote sensing. It was founded in 1992 in Stockholm and has incorporated Leica Geosystems in 2005. The Hexagon Technology Center (HTC) is its main laboratory for developing new technologies.

III: Analog Aerial Camera RC30

The film box of the *Reihenkamera* RC30 contained about 600 m high-resolution rollfilm. Pictures were recorded with (60 - 80)% overlap. The recording of the same ground pixel in adjacent film frames allowed to extract the height information by triangulation. The film transport was motorized and the film was pressed against the mechanical exposure frame, before the high-speed shutter opened. To compensate the forward motion blur the film frame was moved against the flight direction with the speed $v = v_{Ground} \cdot f / h$, where f is the focal length, h the flying height and v_{Ground} the speed over ground. The price of a RC30 was about 1 Mio CHF and about 400 units were sold worldwide.



Spatial resolution and Optical Transfer Function OTF of the lenses:
The resolution limit was set by the graininess of the used film material to 150 linepairs/mm in the visible and near IR spectrum, an important quantity for lower flying heights of about 500m. For larger flying heights of up to 3 km, where the atmosphere acts like a lowpass-filter for frequencies > 75 lp/mm, the OTF product of lens and atmosphere had to be maximized. This led to the demanding OTF value of 0.75 for the lenses.

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[7] http://periodictable.com/Properties/A/VaporizationHeat.st.log.html

Europas neuer Röntgenlaser
Der European XFEL erzeugt das brillanteste Röntgenlaserlicht der Welt

Helmut Dosch, Vorsitzender des DESY Direktoriums, Hamburg, DE

Am 1. September 2017 ging der European XFEL in der Metropolregion Hamburg offiziell in Betrieb. Was vor über 20 Jahren als Vision beim Forschungszentrum DESY begann und auf den Weg gebracht wurde, ist damit Wirklichkeit geworden: der weltweit leistungsfähigste Laser für Röntgenlicht und eines der größten und ambitioniertesten europäischen Forschungsprojekte. Der neue Röntgenlaser erzeugt ultrakurze, extrem intensive Röntgenblitze – 27 000 Mal pro Sekunde und mit einer Brillanz, die eine Milliarde mal höher ist als die der besten herkömmlichen Röntgenstrahlungsquellen. Wissenschaftlerinnen und Wissenschaftler aus aller Welt werden an dieser modernsten Hochgeschwindigkeitskamera für den Nanokosmos viele grundlegende und revolutionäre Erkenntnisse gewinnen – und damit die Basis für die Innovationen von morgen legen. Der Schweizer Staatssekretär für Bildung, Forschung und Innovation, Dr. Mauro Dell'Ambrogio, bezeichnete den European XFEL auf der Eröffnungsfeier als „neues Wahrzeichen der weltweiten Wissenschaftslandschaft, das ein brandneues Spektrum möglicher Experimente eröffnet."

Herzstück des neuen Röntgenlasers ist der längste supraleitende Linearbeschleuniger der Welt. Dieser produziert und beschleunigt Elektronenstrahlen außergewöhnlich hoher Qualität, die anschließend in periodischen Magnetstrukturen, Undulatoren, das brillante Röntgenlicht erzeugen. Insgesamt 17 europäische Institute haben im Rahmen eines internationalen Konsortiums unter der Leitung von DESY den Beschleunigerkomplex des European XFEL realisiert. Mit ihrer Gründung im Jahr 2009 übernahm die European XFEL GmbH mit Gesellschaftern aus elf Ländern, zu denen auch die Schweiz gehört, die Koordination des Gesamtprojekts und bereitete den Nutzerbetrieb durch Aufbau der Photonenstrahlführungen und Experimentierplätze vor. Als Hauptgesellschafter der European XFEL GmbH trägt DESY die Verantwortung für den Bau und Betrieb des Teilchenbeschleunigers.

Der Einsatz modernster Beschleunigertechnologie bietet entscheidende Vorteile, dank denen sich der europäische Röntgenlaser von ähnlichen, mit konventionellen Beschleunigern arbeitenden Anlagen abhebt: Die Supraleitung ermöglicht einen Elektronenstrahl, der aus langen Zügen von hintereinander gereihten, stark gebündelten Elektronenpaketen besteht. Dadurch ist die Wiederholrate der Röntgenblitze und somit auch die mittlere Brillanz (Leuchtstärke) am European XFEL um Größenordnungen höher als an den anderen Anlagen. Bestimmte Experimente sind daher nur am European XFEL möglich, andere können weit schneller durchgeführt werden. Auch lassen sich mit der höheren Anzahl von Elektronenpaketen mehr Messplätze gleichzeitig bedienen.

Fig. 1: Blick in den 2,1 Kilometer langen Beschleunigertunnel des European XFEL mit den gelben supraleitenden Beschleunigermodulen. ©: DESY 2017

Werdegang des Projekts

Die ersten Planungen für das ehrgeizige Projekt begannen vor zwei Jahrzehnten bei DESY. Die Idee: Supraleitende Strukturen mit ausreichend hohen Beschleunigungsfeldern könnten einsetzbar sein, um in langen, hintereinander geschalteten Linearbeschleunigerabschnitten hochenergetische Elektronenstrahlen zu erzeugen. Dazu gründeten die wichtigsten Akteure der supraleitenden Hochfrequenz-Beschleunigertechnologie die TESLA Collaboration mit dem Ziel, die Technologie weiterzuentwickeln und vor allem erschwinglicher zu machen. Das Forschungszentrum DESY bot seinen Campus in Hamburg als Standort für die notwendige Infrastruktur und eine Testanlage an, in der die neu entwickelten, supraleitenden Beschleunigermodule erprobt werden konnten. Das erste Modul wurde in Zusammenarbeit mit zahlreichen Institutionen in der Welt gebaut, von denen später viele auch am European XFEL mitwirken sollten. Im Jahr 2000 produzierte die Testanlage bei DESY erstmals Laserlicht nach dem sogenannten SASE-Prinzip der selbstverstärkten spontanen Emission (Self-Amplified Spontaneous Emission). Damit bewies die Anlage die Machbarkeit eines supraleitenden Röntgenlasers. Heute ist dieser Prototyp aller Freie-Elektronen-Röntgenlaser weltweit unter dem Namen FLASH als Nutzeranlage für Forschung mit weichem Röntgenlicht (90 bis 4 nm) regelmäßig ausgebucht. Nach Jahren internationaler Verhandlungen begann im Jahr 2007 die Projektvorbereitungsphase für den European XFEL, der offizielle Projektstart erfolgte 2009 mit der Gründung der gemeinnützigen Betreibergesellschaft European XFEL GmbH.

Bau und Betrieb des Linearbeschleunigers

Der Beschleuniger des European XFEL besteht aus knapp 100 supraleitenden Beschleunigermodulen, an deren Realisierung DESY in Deutschland, CEA Saclay und LAL Orsay in Frankreich, INFN Milano in Italien, IFJ-PAN Kraków, IPJ Świerk und Soltan Institute Warsaw in Polen, CIEMAT Madrid in Spanien und BINP Novosibirsk in Russland beteiligt waren.

Während der Vorbereitungsphase wurde noch etwa ein Beschleunigermodul pro Jahr zusammengebaut. Um auf die für den European XFEL erforderliche Produktionsrate von durchschnittlich acht Resonatoren und Kopplern sowie einem Modul pro Woche zu kommen, musste die Produktionsrate um mindestens einen Faktor 30 beschleunigt werden. Zwei europäische Unternehmen, die von DESY und INFN Milano gemeinsam betreut wurden, teilten sich die Herstellung von 800 Resonatoren aus dem von DESY bereitgestellten Metall Niob. Für die Qualitätskontrolle der verwendeten Materialien baute DESY eine eigens dafür ausgelegte Infrastruktur auf. Die Qualifizierung der Resonatoren erfolgte ebenfalls bei DESY, wo die Resonatoren bei 2 K getestet wurden.

Die Inbetriebnahme des supraleitenden Linearbeschleunigers begann im Dezember 2016 mit dem Abkühlen des kompletten Kältesystems. Die erste Injektion eines Elektronenstrahls in den Hauptbeschleuniger erfolgte im Januar 2017. Im März konnten erstmals Elektronenpakete mit einer für den Laserbetrieb ausreichenden Strahlqualität auf eine Energie von 12 GeV beschleunigt und in einem Strahlfänger am Ende des Beschleunigers gestoppt werden.

Am 2. Mai gelang schließlich der entscheidende Meilenstein: Mit dem Passieren des Strahls durch den Undulator SASE1 erzeugte der European XFEL sein erstes Laserlicht, zunächst bei einer Wellenlänge von 0,9 nm. Am 23. Juni wurde der Strahl zum ersten Mal in die Experimentierhalle geleitet. Die Wissenschaftlerinnen und Wissenschaftler begannen daraufhin, den Strahl zu charakterisieren und führten erste Testexperimente für die Inbetriebnahme der Experimentierstationen durch. Mit Wellenlängen von 0,2 nm und ausreichender Leuchtstärke ermöglichten die Röntgenblitze bereits Aufnahmen mit atomarer Auflösung. Im September begann der Forschungsbetrieb mit externen Nutzern.

Wissenschaftliche Vision

In der Erforschung der Struktur und Funktion von Materie – von Molekülen, Nanoclustern, bis hin zu neuen Materialien und Biosystemen – stehen wir vor einer Reihe von gewaltigen Herausforderungen und ungelösten Fragen, unter anderem:

- Wie können wir die Strukturen von ungeordneter Materie mit ähnlicher Präzision verstehen, wie wir es für kristalline Materialien entwickelt haben?
- Können wir die Bewegung von Molekülen, Atomen, Ionen und Elektronen bei (bio-) chemischen und katalytischen Reaktionen in Echtzeit verfolgen?
- Was sind die Eigenschaften von Materie weitab vom Gleichgewicht?
- Können wir Materialien auf der Ebene einzelner Elektronen und Spins kontrollieren?

1 Allgemein	
Baukosten	1.22 Milliarden Euro
Bauzeit	2005 - 2016
Jahresbudget	117 Mio Euro
Belegschaft	300 Mitarbeiter
Beteiligte Länder	11
2 Beschleuniger	
Gesamtlänge	2.1 km
Beschleunigungsstrecke	1.7 km
Energie	17.5 GeV
Anzahl Beschleunigungsmodule	101 (supraleitend)
3 Röntgenpulse	
Wiederholrate	27‘000
Wellenlänge	(0.05 – 4.7) nm
Pulsdauer	(2 - 100) fs (FWHM)
Mittlere Leuchtstärke	$1.6*10^{25}$ (Photonen/s/mm^2/mrad^2/ 0.1 % Bandbreite

Tabelle 1: Einige Kennzahlen des European XFEL. Zum Vergleich mit dem SwissFEL X-Ray Laser siehe: SPG Mitteilungen, Nr. 51 (März 2017), Seite 7-9

Der europäische Röntgenlaser hat das Potential für bahnbrechende Entdeckungen in der Physik, der Chemie und in der Biologie. Weil er extrem intensive Röntgenblitze generiert, ist er besonders für die Untersuchung von ultraschnellen Prozessen in verdünnten Systemen prädestiniert. Der European XFEL wird in den nächsten Jahren zu völlig neuen Einsichten in den Nanokosmos führen, welche wichtige Beiträge zu neuen Konzepten im Design von neuen Materialien und Medikamenten liefern.

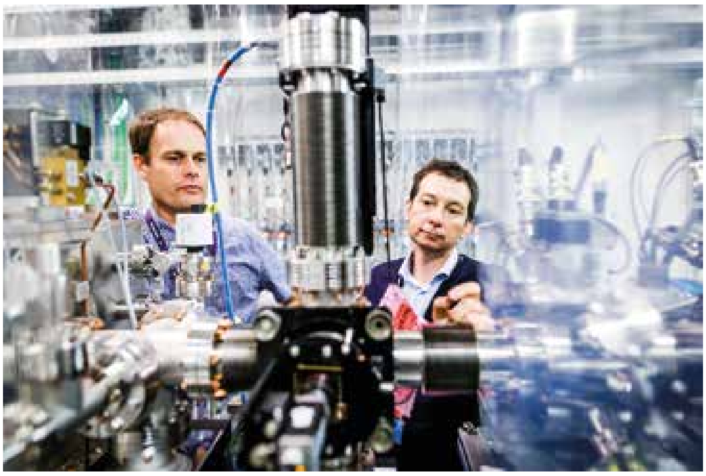

Fig. 2: Erste Experimente am European XFEL: Anton Barty (links) und Henry Chapman (rechts) an der European-XFEL-Experimentierstation SPB/SFX. ©: DESY/Lars Berg

Erste Experimente

Die ersten wissenschaftlichen Experimente am neuen Röntgenlaser starteten im September 2017. Zu den ersten Nutzern zählte ein Forscherteam um Anton Barty und Henry Chapman vom Center for Free-Electron Laser Science (CFEL) bei DESY. Sie nutzen die Messstation SPB/SFX (Single Particles, Clusters, and Biomolecules / Serial Femtosecond Crystallography), um die atomare Struktur verschiedener Biomoleküle zu analysieren. Dieses Instrument ermöglicht die Untersuchung von Molekülen, die mit anderen Methoden nur schwer oder in manchen Fällen überhaupt nicht analysiert werden können.

In der ersten Phase ging es zunächst um Pionierarbeit: Um die neue Maschine zu nutzen, müssen die Instrumente eingestellt und kalibriert werden. Die Feinabstimmung beginnt damit, die Proben schnell genug in den Röntgenstrahl zu befördern. Der European XFEL produziert Röntgenblitze mit einer Taktrate von nur 220 Nanosekunden. Das heißt, dass in weniger als einer millionstel Sekunde vier Blitze in der Experimentierstation ankommen. Die Proben bestehen aus winzigen Proteinkristallen, die im Röntgenlicht detaillierte Informationen über ihre atomare Struktur preisgeben. Allerdings hat man bei jedem Kristall nur einen einzigen Schuss,

Fig 3: Die 3,4 km lange Röntgenlaseranlage European XFEL verläuft zu einem großen Teil unterirdisch. Die drei Betriebsgelände (rot umgrenzt) liegen in Hamburg (DESY-Bahrenfeld und Osdorfer Born) und im Süden der Stadt Schenefeld (Kreis Pinneberg, Schleswig-Holstein). Luftaufnahmen: FHH, Landesbetrieb Geoinf. und Vermessung. ©: European XFEL

weil der intensive Röntgenblitz den Kristall nahezu sofort verdampft. Daher muss alle 220 Nanosekunden ein neuer Kristall in den Röntgenstrahl befördert werden.

Auch der Detektor muss schnell genug sein, um alle 220 Nanosekunden ein neues Röntgen-Beugungsmuster der Proteinkristalle aufzunehmen. Das heißt, er muss in weniger als einer millionstel Sekunde vier Bilder machen. Um das zu erreichen, ist der European XFEL mit den schnellsten Röntgenkameras der Welt ausgestattet, die für die jeweilige Messstation maßgeschneidert wurden. Der Detektor der SPB/SFX-Station ist von einem internationalen Konsortium unter Leitung der Detektorgruppe aus dem DESY-Forschungsbereich Photon Science entwickelt und gebaut worden.

Zeitgleich mit der Messstation SPB/SFX hat auch an der Messstation FXE (Femtosecond X-Ray Experiments) der wissenschaftliche Experimentierbetrieb begonnen. FXE wurde entwickelt, um eine Art Molekülkino zu produzieren, das den genauen zeitlichen Ablauf chemischer Reaktionen zeigen kann.

Kurzmitteilungen - Short Communications

PiA – Physik im Advent

Physik im Advent ist ein spezieller Adventskalender bei dem Jungforscherinnen, Jungforscher, sowie alle die Lust haben, 24 physikalische Rätsel und Experimente zum Selberexperimentieren anzupacken.

Vom 1. bis zum 24. Dezember 2017 wird jeden Tag per Video-Clip ein Experiment zum Nachmachen vorgestellt. Auf http://physik-im-advent.de können die Fragen im Laufe des selben Tages beantworten werden, und am darauffolgenden Tag wird die Auflösung ebenfalls per Video gezeigt.

Die Teilnahme bei Physik im Advent ist gratis und steht allen offen. Für Schülerinnen und Schüler ab dem 5. bis und inklusive 10. Schuljahr, einzeln, als komplette Klassenverbände oder auch für ganze Schulen aus der ganzen Welt gibt es sogar Preise zu gewinnen. Jüngere oder ältere Schülerinnen und Schüler, Eltern, Studierende oder Lehrkräfte sind auch herzlich eingeladen, können aber bei der Preisverteilung nicht berücksichtigt werden.

Die Schweizerische Physikalische Gesellschaft offeriert die Preise für alle die, die in der Schweiz zur Schule gehen in einer eigenen nationalen Verlosung, es lohnt sich daher besonders mitzumachen.

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http://www.sps.ch

PiA Physik im Advent

– der etwas andere Adventskalender im Dezember 2017
Mitmachen und rechtzeitig anmelden unter physik-im-advent.de

Physik im Advent zu Hause oder im Klassenzimmer? Jeden Tag neue physikalische Experimente und spannende Aufgaben als Videoclip entdecken. Für Schülerinnen und Schüler der Klassen 5 – 10. Experimentieren, Staunen und Ausprobieren – allein oder in der Gruppe. Viele tolle Preise für einzelne Schülerinnen und Schüler, aber auch für die ganze Klasse.

Code scannen und mitmachen!

International Day of Light www.lightday.org

The International Day of Light is a UNESCO-led initiative to follow the highly successful International Year of Light and Light-based Technologies 2015.

The following information is an extract from the first IDL Newsletter (http://mailchi.mp/3c3ac163b30f/international-day-of-light-newsletter-september):

International
Day of Light
16 May

“An annual International Day of Light will provide an enduring focal point for the continued appreciation of the central role that light plays in the world. All sectors of society can participate in activities to raise awareness of science and technology, art and culture, and their importance in achieving the goals of UNESCO - education, equality and peace.

The International Day of Light will be proclaimed at the General Conference of UNESCO in November 2017 and the inaugural celebration is planned for ***16 May 2018*** *at UNESCO headquarters in Paris. The International Day of Light Secretariat is reaching out to the wider community to stimulate the organisation of local events worldwide, and collecting resources for a dedicated new webpage that will be fully online in November.*

We can also announce that we already have confirmed over 50 National Nodes organizing national initiatives. Remember that whilst we are aiming for most local events to coincide with the kick-off event on 16 May 2018, we appreciate that this date will not work for everyone, and so even if your event takes place at some other time, provided it aligns with the goals of UNESCO, it can be officially recognized as an International Day of Light event. If you are planning to organize an event and wish to ask for inclusion on our official calendar, please contact us at dayoflight@eps.org and let us know the details. In fact, since there is some flexibility with the date, you can plan to organise your own event and attend the inauguration in Paris - attendance at the Paris kick-off is free of course, but will require registration. More details will be coming in November. “

The national nodes for Switzerland will be the same as for IYL2015, the SPS (www.sps.ch) to stimulate more events from academic institutions, and Swissphotonics (https://www.swissphotonics.net/home) to cover more industrial activities.

B. Braunecker

IYL2015 was initiated by UNESCO as part of its International Basic Sciences Program, and was managed by a special secretariat, hosted at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste/ Italy. About 10’ 000 activities were performed by 148 countries reaching over 100 million people.

IBM’s Zurich Lab Honored with Historic Site Distinction

Chris Sciacca, Comm. Manager (EMEA), IBM Research

“Teamwork, not only within the borders of a country, but also among countries, has become an imperative necessity of our jet-age era. Advances in the fields of human endeavours are due to a large extent to the cooperation of the best brains and talent available everywhere.”

These words were spoken in 1956 by then IBM CEO Thomas Watson Jr. during the opening ceremony of IBM’s Zurich research lab, its first outside of the United States.

More than 60 years later, the lab has achieved countless scientific innovations, most notably the scanning tunnelling microscope and high temperature superconductivity, and on 26 September 2017 these accomplishments were honored by the European Physical Society (EPS) as a Historic Site, joining the Einstein House Bern, the CERN Synchrocyclotron, and the University of Geneva as the only other such sites in Switzerland.

The news was unveiled in a ceremony at the IBM lab with more than 60 employees and guests. After a short presentation on the history and future of the lab by the current director IBM Fellow Dr. Alessando Curioni, and department manager, Dr. Walter Riess, and a panel discussion with three former lab directors spanning from the 1960s to today, a plaque was unveiled in front of attendees including several distinguished guests: Rüdiger Voss, EPS President and K. Alex Müller, Nobel Laureate and retired IBM scientist.

Voss also spoke and shared some additional surprising news to the attendees, “This IBM location has achieved many firsts, including the first industrial lab on the EPS Historic Sites List. This will hopefully add some encouragement to industry to keep up their investments in basic research as the ultimate foundation for the progress of science and technology."

It's not well known that Switzerland wasn't IBM's first choice for its first international lab. In 1955, IBM scientist Arthur Lee Samuel, a pioneer in early computer gaming and artificial intelligence, had narrowed down the list to England, Switzerland and the Netherlands, in this order.

He ultimately recommended Zurich, Switzerland, to Watson Jr. based on its proximity to talent at ETH Zurich and due to its openness to allow other European scientists to work at the lab. Today, IBM Research - Zurich has employees from more than 45 nationalities working on scientific research scaling from Big data to atoms.

2016 Kavli Laureates for Nanoscience Honored at Symposium

Chris Sciacca, Comm. Manager (EMEA), IBM Research

30 years and 9,000 citations later the inventors of the atomic force microscope (AFM) were recognized last year with the Kavli Prize in Nanoscience "for the invention and realization of atomic force microscopy (AFM), a breakthrough in measurement technology and nanosculpting that continues to have a transformative impact on nanoscience and technology."

The Kavli Foundation in collaboration with the Norwegian Academy of Science and Letters has started to follow up the formal ceremony in Oslo with a series of symposia near or at the home locations where the laureates conducted their research or are now based.

In support of this effort on 25 September, IBM and the Kavli Foundation, with support by the Norwegian Academy of Sciences and Letters, hosted *Atomic Force Microscopy: Yesterday, Today and Tomorrow* at the SwissRe Centre for Global Dialogue in Rüschlikon, Switzerland, to honor two of the three pioneers responsible for AFM: Gerd Binnig and Christoph Gerber.

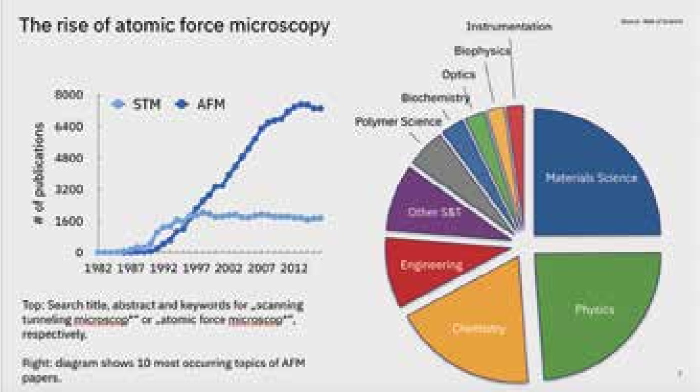
Nearly 200 guests were in attendance including Ambassador Mr. Thomas Hauff, Norwegian State Secretary Mr. Bjørn Haugstad, Swiss State Secretary Mr. Mauro Dell'Ambrogio, Government Councillor Ms. Carmen Walker Späh and Nobel Laureate K. Alex Müller. The audience also contained nearly 50 students representing several Norwegian and Swiss universities.

In addition to celebrating the AFM, one of other important themes highlighted by all of the speakers was the need for talent, particularly in the areas of science, technology, engineering in math. A point made clear by Dr. Alessandro Curioni, an IBM Fellow and the director of the IBM Zurich Lab.

"This symposium is also about recognizing the value of growing talent in science, technology, engineering and mathematics or STEM and encouraging more students to choose this career path. The fact is, we simply need more STEM talent here in Europe."

Curioni pointed to several IBM examples of contributing, in particular at its $90M collaborative nanotechnology center, which is shared between IBM scientists and four ETH Zurich professors and dozens of students.

IBM post-doc scientist Dr. Niko Pavliček, whose research was recently on the cover of Nature Nanotech.(12, 308), was the keynote speaker on the agenda explaining the past and the future of the AFM, which is incredibly diverse in its application - see Figure 1.



Following a 30 minute break attendees were treated to a panel discussion with the honorees moderated by journalist Olivier Dessibourg.

After several questions on stage, a question from the audience was posed about knowing when you are on the right path to a eureka moment.

Binnig offered the following advice, "My strategy is, I prove to myself that this is the wrong path, and if I can't prove this is the wrong path I continue."

Watch the replay of the event:
http://swissre.adobeconnect.com/p1ufa4fkh6gf/
http://swissre.adobeconnect.com/pl33eoq5gagn/

Kritische Metalle: Wie die Schweizer Industrie vorsorgen kann

Der Begriff "Kritische Metalle" umfasst diverse Spezialmetalle wie Indium oder Lithium, die für moderne Technologien unverzichtbar sind. Bei einigen davon besteht die Gefahr einer Versorgungsknappheit. Ein Bericht der SATW gibt einen Überblick über die Situation in der Schweizer Industrie.

Moderne Technologien in Bereichen wie Elektromobilität, Energieproduktion oder Information und Kommunikation verbrauchen immer mehr Spezialmetalle, die noch zu Beginn des 20. Jahrhunderts kaum eingesetzt wurden. Heute spielen diese Metalle wegen ihrer spezifischen Eigenschaften bei verschiedenen Anwendungen eine zentrale Rolle: Indium ist beispielsweise ein wichtiger Bestandteil für den Bau von Flachbildschirmen, Platin wird für die Herstellung von Autokatalysatoren benötigt, Tantal für die Produktion von Flugzeugturbinen oder Kondensatoren und Lithium in zunehmendem Masse für die Herstellung von Akkus.

Risiko einer Versorgungsknappheit

Diese und andere wirtschaftlich wichtige Metalle stammen üblicherweise aus dem nicht-europäischen Ausland, oft konzentriert auf wenige oder gar einzelne Herkunftsländer. Diese ausgeprägte Konzentration birgt das Risiko einer Versorgungsknappheit und bringt importierende Länder in eine wirtschaftliche Abhängigkeit. Viele dieser Metalle wurden von verschiedenen Seiten, zum Beispiel von der EU, als "kritische Rohstoffe" klassifiziert und werden häufig unter dem Begriff "kritische Metalle" zusammengefasst.

Wissen im eigenen Unternehmen oft gering

Alle Akteure sind gefragt, sich rechtzeitig mit dem Thema zu befassen und Strategien zu entwickeln, wie drohende Engpässe verhindert oder umgangen werden können. Eine Umfrage des Entwicklungsfonds Seltene Metalle ESM in der Schweizer Industrie ergab 2015 jedoch, dass das Wissen über verwendete Metalle im eigenen Unternehmen oft gering ist: Die Mehrheit der Befragten gab an, die kritischen Metalle in ihren Halbfabrikaten nur teilweise oder gar nicht zu kennen. Aber auch Unternehmen, die über dieses Basiswissen verfügen, wissen oft wenig über die genaue Struktur ihrer Lieferketten. Die meisten Firmen gaben in der Umfrage zudem an, dass kritische Rohstoffe kein Teil ihres Risikomanagements seien.

Publikation zur Situation in der Schweiz

Im April 2016 organisierten der Entwicklungsfonds Seltene Metalle ESM, MatSearch Consulting Hofmann, die Empa sowie Life Cycle Consulting Althaus mit Unterstützung der SATW einen Workshop zum Thema "Daten-Netzwerk für kritische Rohstoffe". Moderierte Diskussionsgruppen befassten sich mit dem Einfluss kritischer Rohstoffe auf den Schweizer und den europäischen Markt. Sie identifizierten Hindernisse für eine adäquate Priorisierung des Themas in Unternehmen sowie bei relevanten Akteuren und besprachen Möglichkeiten, mehr Transparenz im Bereich kritischer Rohstoffe zu schaffen.

Daraus ist die Broschüre "Kritische Metalle: Wie die Schweizer Industrie vorsorgen kann" entstanden, die einen Überblick über das Thema mit speziellem Fokus auf die Schweiz bietet.
Als grösste Herausforderung wurde nicht ein Mangel an Daten identifiziert, sondern ein unübersichtlicher Informationsfluss und fehlende Möglichkeiten für Firmen, sich individuell zu informieren sowie mangelndes Wissen über Strategien, wie mit Rohstoffknappheit umgegangen werden kann. Die grösste Herausforderung für die Schweiz und Europa besteht darin, das Bewusstsein für die Problematik der sicheren Verfügbarkeit kritischer Rohstoffe zu erhöhen.
www.satw.ch/rohstoffe

Auskunft
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Geschäftsstelle
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Métaux critiques: quelles solutions de prévoyance pour l’industrie suisse?

Le terme de «Métaux critiques» comprend divers métaux spéciaux comme indium ou lithium qui sont essentiels pour les technologies modernes. Pour certains il existe un risque de pénurie. Une brochure de la SATW offre un aperçu de cette thématique, en portant une attention particulière à la Suisse.

Au début du 20e siècle, les technologies utilisant comme matière première des métaux jugés aujourd’hui critiques étaient rares. Au cours des dernières décennies, la situation a toutefois fortement évolué: en raison de leurs propriétés particulières, ces métaux jouent aujourd’hui un rôle central dans différentes applications. Par exemple, l’indium est utilisé pour la fabrication d’écrans plats, le platine pour les catalyseurs automobiles, le tantale pour les turbines d’avions et les condensateurs, le lithium pour la production d’accumulateurs.

Risque de pénurie

Ces métaux, ainsi que les autres métaux économiquement importants, sont généralement exportés par quelques rares pays non-européens. Cette forte concentration implique un risque de pénurie et engendre une dépendance économique pour les pays importateurs. Un grand nombre de ces métaux ont été classés comme «Matières premières critiques» par différentes sources, par exemple au niveau de l’Union européenne; ils sont désormais regroupés sous le terme de «Métaux critiques».

Connaissances dans les entreprises souvent limitées

Tous les acteurs sont donc appelés à se pencher sur ce thème en temps opportun et à élaborer des stratégies permettant d'éviter ou de contourner les situations de pénurie. En 2015, un sondage réalisé par le Fonds de développement pour les métaux rares (ESM) dans l'industrie suisse a toutefois révélé que les connaissances sur les métaux utilisés dans les entreprises sont souvent limitées: la majorité des personnes interrogées ont déclaré connaître peu voire pas du tout les métaux critiques dans leurs produits semi-finis. De même, il est fréquent que les entreprises disposant des connaissances de base ignorent la structure exacte de leurs chaînes logistiques. La plupart d'entre elles ont également déclaré que les matières premières critiques ne faisaient pas partie de leur gestion des risques.

Brochure sur la situation en Suisse

En avril 2016, le Fonds de développement pour les métaux rares (ESM), MatSearch Consulting Hofmann, l'Empa ainsi que Life Cycle Consulting Althaus ont organisé, avec le soutien de la SATW, un atelier sur le thème «Réseau de données pour les matières premières critiques». Des groupes de discussion se sont intéressés à l'influence de ces matières sur les marchés suisse et européen. Ils ont ainsi identifié les obstacles à une priorisation adéquate du thème dans les entreprises et ont discuté des moyens d'accroître la transparence dans ce domaine.

Le résultat est la brochure «Métaux critiques: quelles solutions de prévoyance pour l'industrie suisse» qui offre un aperçu de cette thématique, en portant une attention particulière à la Suisse.

Le plus grand défi ne porte pas sur le manque de données, mais sur la complexité du flux d'informations, le manque de possibilités pour les sociétés de s'informer à titre individuel, ainsi que la méconnaissance des stratégies permettant de gérer la pénurie des ressources. Le principal défi pour la Suisse et l'Europe consiste à sensibiliser davantage à la problématique d'une disponibilité fiable des matières premières critiques.

www.satw.ch/fr/ressources

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Symposium "Mit Bürgi zu den Sternen"

Viele Schweizer kennen Jost Bürgis (1552-1632) Konterfei noch von den früher im Schulunterricht benutzten Logarithmentafeln, aber nur wenige kennen auch Details seines Wirkens und seiner Person. Die Gründe dafür sind vielfältig, aber es lag leider auch an der knorrigen Person Bürgis, eines Autodidakten, dessen Leistung von etablierten Kreisen oft nur widerwillig anerkannt wurde, und der sich entsprechend zurückhaltend verhielt. Es ist nun das Verdienst einer Reihe von Experten, dass Bürgi in den letzten Jahren die ihm gebührende Beachtung widerfuhr, indem sie neue und höchst erstaunliche Facetten seines technisch-wissenschaftlichen Werkes aufzeigten.

Man wird Bürgi noch mehr gerecht, wenn man ihn als wichtige Person einer Zeitepoche würdigt, die als Vorphase der Aufklärung gilt. Die Aufklärung setzte ab 1650 ein, also nach Ende des 30-jährigen Krieges, und sie war getragen von Persönlichkeiten wie Blaise Pascal (1623-1662), Baruch de Spinoza (1632-1677), Isaac Newton (1643-1727) und Gottfried Wilhelm Leibniz (1646-1716). Sie prägte nachhaltig unsere europäische Kultur bis heute. Die zuvor bestehende Bevormundung durch doktrinäre Strukturen wurde von rationalem Denken abgelöst, das auf den Erkenntnissen der Naturforschung, des Experimentierens beruhte. Dazu bedurfte es der technischen Fähigkeiten von Genies wie Bürgi.

Für uns Physiker ist Bürgis jüngerer Kollege Johannes Kepler (1571-1630) einer der wichtigsten Protagonisten an der Schwelle zur Neuzeit, dessen Wirken wir täglich in der Forschung sowohl im Ångström- wie im Parsec-Bereich spüren. Nun zeigt sich, dass Kepler Bürgi viel mehr zu verdanken hat als man bislang annahm, und diese Erkenntnis sollte vermehrt ins öffentliche Bewusstsein rücken.

Es ist das Anliegen einer Jost-Bürgi-Initiative, an Bürgis Geburtsort Lichtensteig im Toggenburg alljährlich ein internationales Symposium am jeweils zweiten Wochenende nach Ostern durchzuführen. Im anstehenden Symposium 2018 "Mit Bürgi zu den Sternen" soll im ersten Teil über neue Erkenntnisse zur Person und zum Werk Bürgis aus Historikersicht berichtet werden, während im zweiten Teil der Versuch unternommen wird, mögliche Auswirkungen seiner Tätigkeiten auf die Neuzeit, und hier speziell in der modernen Astronomie und der Raumfahrt, anzusprechen.

Mehr Informationen: www.jostbuergi.com

Bernhard Braunecker

2. Internationales Jost-Bürgi-Symposium

Lichtensteig im Toggenburg (CH)

Samstag, 14. April 2018, 9:15 -13:00 Uhr

Jost-Bürgi-Halle, Bürgistrasse 14 - Eintritt frei

Mit Bürgi zu den Sternen

Astronomie	Raumfahrt
Aurora Sicilia Aguilar	Claude Nicollier

Jost Bürgi schon am Symposiumsfreitag:
13. April 2018, 14:00 h: Medienkonferenz
15:00 h: Workshop der Bürgi-Experten

SYMPOSIUMSERÖFFNUNG DURCH MATHIAS MÜLLER, STADTPRÄSIDENT LICHTENSTEIG *09:15 h*	
WER WAR DIESER JOST BÜRGI WIRKLICH? **DER MATHEMATISCH-TECHNISCHE GENIUS**	**FRITZ STAUDACHER** BÜRGI-BIOGRAPH, WIDNAU
NICHT NUR DIE STERNE – **DIE ENTDECKUNG VÖLLIG NEUER FACETTEN**	**DR. JÜRGEN HAMEL** ASTRONOMIE-HISTORIKER, BERLIN (DE)
URSUS’ HYBRIDES MODELL – **EINE HIMMLISCHE DEMONSTRATION**	**PROF. DR. GÜNTHER OESTMANN** UHRMACHER U. HISTORIKER, BERLIN (DE)
JOST BÜRGIS ZÜRCHER HIMMELSGLOBUS – **VIER KERNKOMPETENZEN BÜRGIS VEREINT**	**BERNARD A. SCHÜLE** KURATOR SCHWEIZER NATIONALMUSEUM
PAUSE (25 min.) *10:55 – 11:20 h*	
MODERNE MESSKONZEPTE – **ANGEREGT DURCH BÜRGISCHE ANSÄTZE**	**DR. BERNHARD BRAUNECKER** SWISS PHYSICAL SOCIETY (SPS)
DIE BILDUNG VON STERNEN UND PLANETEN – **WAS ZEITMESSUNGEN ÜBER DEN RAUM SAGEN**	**DR. AURORA SICILIA AGUILAR** UNIVERSITY OF DUNDEE (UK)
FASZINATION DER RAUMFAHRT – **ERKENNTNISSE EINES ASTRONAUTEN**	**PROF. DR. CLAUDE NICOLLIER** SWISS SPACE CENTER, EPF LAUSANNE
SCHLUSSWORT *SCHLUSS DES SYMPOSIUMS 13:00 h*	**PROF. DR. PETER ULLRICH** UNIVERSITÄT KOBLENZ-LANDAU (DE)

Symposiumspartner

SPS swiss physical society

SAG SAS

VSMP
SSPMP
SSIMF

www.jostbuergi.com

LICHTENSTEIG
MINI STADT IM TOGGENBURG

MIT BÜRGI ZU DEN STERNEN

WER WAR DIESER JOST BÜRGI WIRKLICH?
DER MATHEMATISCH-TECHNISCHE GENIUS

Jost Bürgi vereine in sich die aussergewöhnlichen Fähigkeiten eines Archimedes und Euklid, sagten Bürgis Zeitgenossen wie der Kaiserliche Mathematicus Ursus und Wilhelm IV. von Hessen-Kassel. Gemäss Johannes Kepler sei Bürgi mit einem Baum vergleichbar, der ständig wachse und dessen wahren Dimensionen erst eine spätere Generation erkenne. Am 1. Symposium erlebten wir seine neuen mathematischen Methoden, diesmal erkennen wir weitere bis anhin unbekannte neue Facetten.

NICHT NUR DIE STERNE –
DIE ENTDECKUNG VÖLLIG NEUER FACETTEN

Neue Erkenntnisse über Jost Bürgi lassen aufhorchen: so zeigt die Analyse eines bis anhin unbeachteten Manuskriptes Bürgis aus dem Jahre 1598, dass er in allem, was er tat, den Dingen auf dem Grund ging. So nicht nur in der Astronomie und in der Mathematik, sondern ebenfalls im Uhren- und Instrumentenbau und sogar in der Analyse seiner dafür verwendeten Metalle. Hier am Symposium werden diese bis jetzt unbekannten Untersuchungen und Erkenntnisse Bürgis erstmals vorgestellt.

URSUS’ HYBRIDES MODELL –
EINE HIMMLISCHE DEMONSTRATION

Drei Kosmosvorstellungen prägten die wissenschaftliche Diskussion der Frühen Neuzeit: das bisherige geozentrische Modell des Ptolemäus, das heliozentrische des Copernicus, und das hybride von Tycho Brahe bzw. von Ursus und anderen. Der mit Ursus befreundete Bürgi baute für diesen 1587 ein Modell, das der Referent auf Empfehlung von Ursus-Biograph Dr. Dieter Launert 2014 rekonstruiert hat. Beide Experten stellen es auf dem Symposium erstmals vor.

JOST BÜRGIS ZÜRCHER HIMMELSGLOBUS –
VIER KERNKOMPETENZEN BÜRGIS VEREINT

Das Schweizerische Nationalmuseum ist seit 1981 im Besitz von Jost Bürgis Wunderwerk des Himmelsglobus (1594), der auf einer nur 14,2 cm grossen vergoldeten Kugelschale 1026 Markierungen von Fixsternen trägt. Der Globus ist uhrwerkgetrieben und beschreibt seinem Besitzer tagaus tagein eine grosse Anzahl astronomischer Funktionen mit hoher Genauigkeit. Diese erzielte Bürgi durch seine vielseitigen und aufeinander abgestimmten mathematischen und technischen Kompetenzen.

MODERNE MESSKONZEPTE –
ANGEREGT DURCH BÜRGISCHE ANSÄTZE

Als epochale Leistung Bürgis gilt die Zuverlässigkeit seiner Messgeräte, so wie es die Sekundengenauigkeiten seiner Uhren und astronomischen Instrumente eindrucksvoll belegen. Wir können heutzutage darauf aufbauend Einzelmessungen in Bruchteilen von Zeit- und Bogensekunden, aber auch kombiniert ausführen. Dazu zeigen wir als erstes den Datenaustausch zwischen Satelliten mit Laserlicht, und erinnern danach, auch als Überleitung zum nächsten Vortrag gedacht, an den für die Astrowissenschaft wichtigen und mit komplexester ETH Technik versehenen Satelliten "Herschel".

DIE BILDUNG VON STERNEN UND PLANETEN –
WAS ZEITMESSUNGEN ÜBER DEN RAUM SAGEN

Viele Abläufe der Planeten- und Sternentstehung finden auf Längenskalen statt, die selbst mit leistungsstärksten Teleskopen nicht direkt messbar sind. Mit neuartigen Ansätzen und verhältnismässig kleinen Teleskopen, die aber über längere Zeitabschnitte operieren, kann man die zeitlichen Änderungen von Messungen in räumliche Eigenschaften übersetzen, um die Oberfläche von Sternen sowie Regionen erdähnlicher Planeten zu erkunden.

FASZINATION DER RAUMFAHRT –
ERKENNTNISSE EINES ASTRONAUTEN

Hirn, Hand und Herz sind für den Astrophysiker und Astronauten Claude Nicollier ein Dreiklang, der auch im Weltraum Bedeutung hat. Wer mit 26-facher Schallgeschwindigkeit um die Erde kreist und alle 90 Minuten einen Sonnenaufgang erlebt, hat wahrlich ausserirdische Erlebnisse. Sie werden nur möglich, wenn alles exakt berechnet und präzise in die Realität umgesetzt wird. Kein anderer Astronaut hat im Weltraum anspruchsvollere instrumentelle Probleme zu lösen gehabt als er. Doch das sind nicht die einzigen Parallelitäten Nicolliers mit Bürgi.

DIE REFERENTEN

FRITZ STAUDACHER

Co-Produzent des Bürgi-TV-Dokudramas "Himmel hab’ ich gemessen", Verfasser der Biographie "Jost Bürgi, Kepler und der Kaiser", Initiator und Leiter des Internationalen Jost-Bürgi-Symposiums Lichtensteig. Früher Leiter Corporate Communications des Leica-Konzerns und der Leica Geosystems AG.
www.alprhein.ch

DR. JÜRGEN HAMEL

Astronomiehistoriker, langjähriger Mitarbeiter der Archenhold-Sternwarte Berlin, Buchautor, Mitherausgeber der Werke von Copernicus und Kepler sowie der wissenschaftlichen Schriftenreihe "Acta Historica Astronomiae" und Chefredakteur der Zeitschrift "Astronomie + Raumfahrt im Unterricht".
jhamel@astw.de

PROF. DR. GÜNTHER OESTMANN

Technische Universität Berlin, Wissenschaftshistoriker und Uhrmacher, 2013 mit dem "Prix Gaïa" ausgezeichnet. www.guenther-oestmann.de/
Sein Dialogpartner ist **Dr. Dieter Launert**, Heide (D), Mathematikhistoriker, Ursus-Biograph und Bürgi-Editor sowie vor seiner Pensionierung Rektor der Meldorfer Gelehrtenschule.

BERNARD A. SCHÜLE

Seit 1984 Kurator für Technologie und Brauchtum am Schweizerischen Nationalmuseum in Zürich und somit auch verantwortlich für die wissenschaftlichen Instrumente.
Heute ist Bernard A. Schüle Leiter des Objektzentrums im Sammlungszentrum des Schweizerischen Nationalmuseums in Affoltern am Albis.

DR. BERNHARD BRAUNECKER

Ehemaliger Optik-Entwicklungsleiter bei Leica Geosystems AG in Heerbrugg. Zur Zeit zuständig für die "SPG Mitteilungen" im Vorstand der Schweizerischen Physikalischen Gesellschaft SPG (www.sps.ch), sowie Mitglied des Wissenschaftlichen Beirats der Schweizerischen Akademie der Technischen Wissenschaften SATW (www.satw.ch).

DR. AURORA SICILIA AGUILAR

Astrophysikerin, Lecturer an der Universität Dundee (UK), Schwerpunkt Stern- und Planetenbildung. Forschungstätigkeiten am Harvard-Smithsonian Center for Astrophysics, Max-Planck-Institut Heidelberg, UAM Madrid, Universität St. Andrews (UK). Mitglied internationaler Forschungsgruppen und des Physics-Outreach-Teams in Dundee.
https://sites.dundee.ac.uk/asiciliaaguilar/

PROF. DR. CLAUDE NICOLLIER

Der Militär-, Linien- sowie NASA-Testpilot und Astronaut Claude Nicollier ist der einzige Schweizer mit Weltraumpraxis und auch der einzige Europäer mit vier Weltraummissionen, und diese dazu noch mit jeweils unterschiedlichen Raumfahrzeugen. Zum geflügelten Wort wurde Bundespräsident Ogis Gruss "Freude herrscht, Monsieur Nicollier" bei seinem ersten Weltraumaufenthalt 1992.

Wissenschaftliche Symposiumsleitung: Dr. Bernhard Braunecker und Prof. Dr. Peter Ullrich

Ausschreibung der SPG Preise für 2018
Annonce des prix de la SSP pour 2018

Auch im Jahr 2018 sollen wieder SPG Preise, die mit je CHF 5000.- dotiert sind, vergeben werden.

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

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

Der Antrag muss folgende Unterlagen enthalten:

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

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

En 2018, la SSP attribuera à nouveau des prix de CHF 5000.- chacun, à savoir:

- Le prix SSP offert par le centre de recherche ABB Schweiz AG pour un travail de recherche d'une qualité exceptionnelle dans tout domaine de la physique
- Le prix SSP offert par l'entreprise IBM pour un travail de recherche d'une qualité exceptionnelle en physique de la matière condensée
- Le prix SSP offert par l'entreprise Oerlikon Surface Solutions pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique appliquée
- Le prix SSP offert par le METAS pour un travail de recherche d'une qualité exceptionnelle faisant référence au domaine de la métrologie
- Le prix SSP offert par l'entreprise COMSOL pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique numérique

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

Une nomination complète contient:

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

Ces documents seront envoyés électroniquement en format "pdf" directement au comité de prix (svp. comprimez des fichiers très grands (zip):

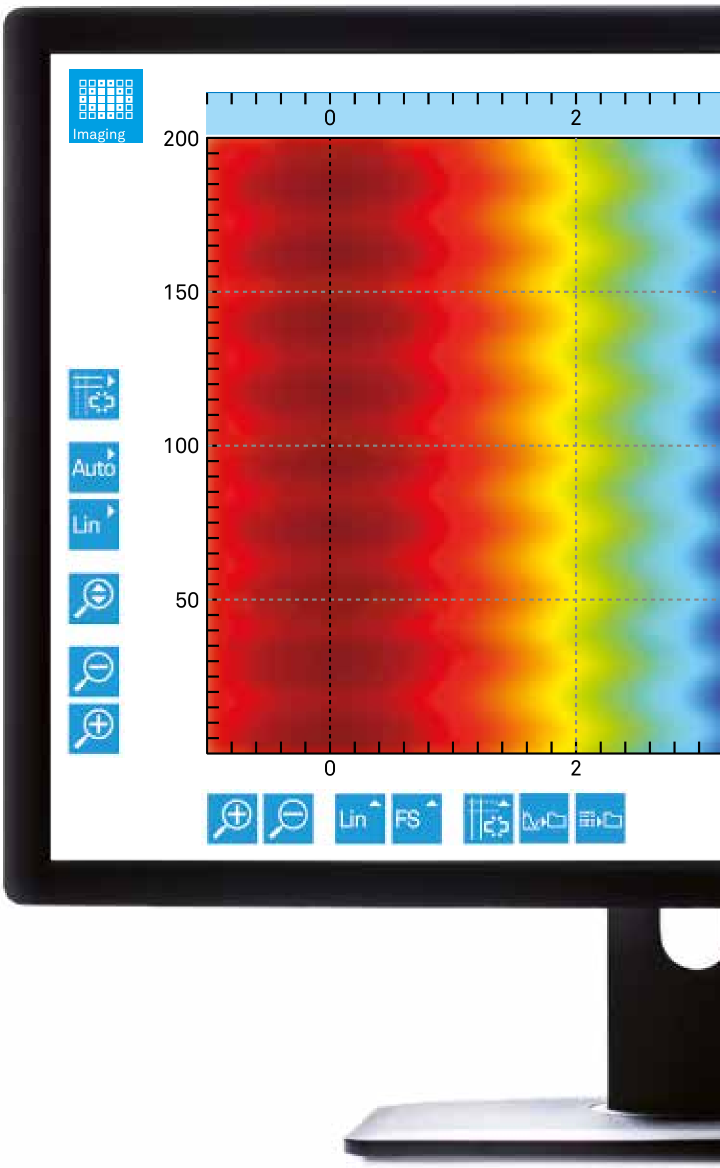
awards@sps.ch

Einsendeschluss: 28. Februar 2018

Die Preise werden an der Jahrestagung der SPG 2018 in Lausanne überreicht. Das Preisreglement befindet sich auf den Webseiten der SPG: *www.sps.ch*

Délai: 28 février 2018

Les prix seront attribués à la réunion annuelle de la SSP qui se tiendra en 2018 à Lausanne. Le règlement des prix se trouve sur les pages Web de la SSP: *www.sps.ch*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