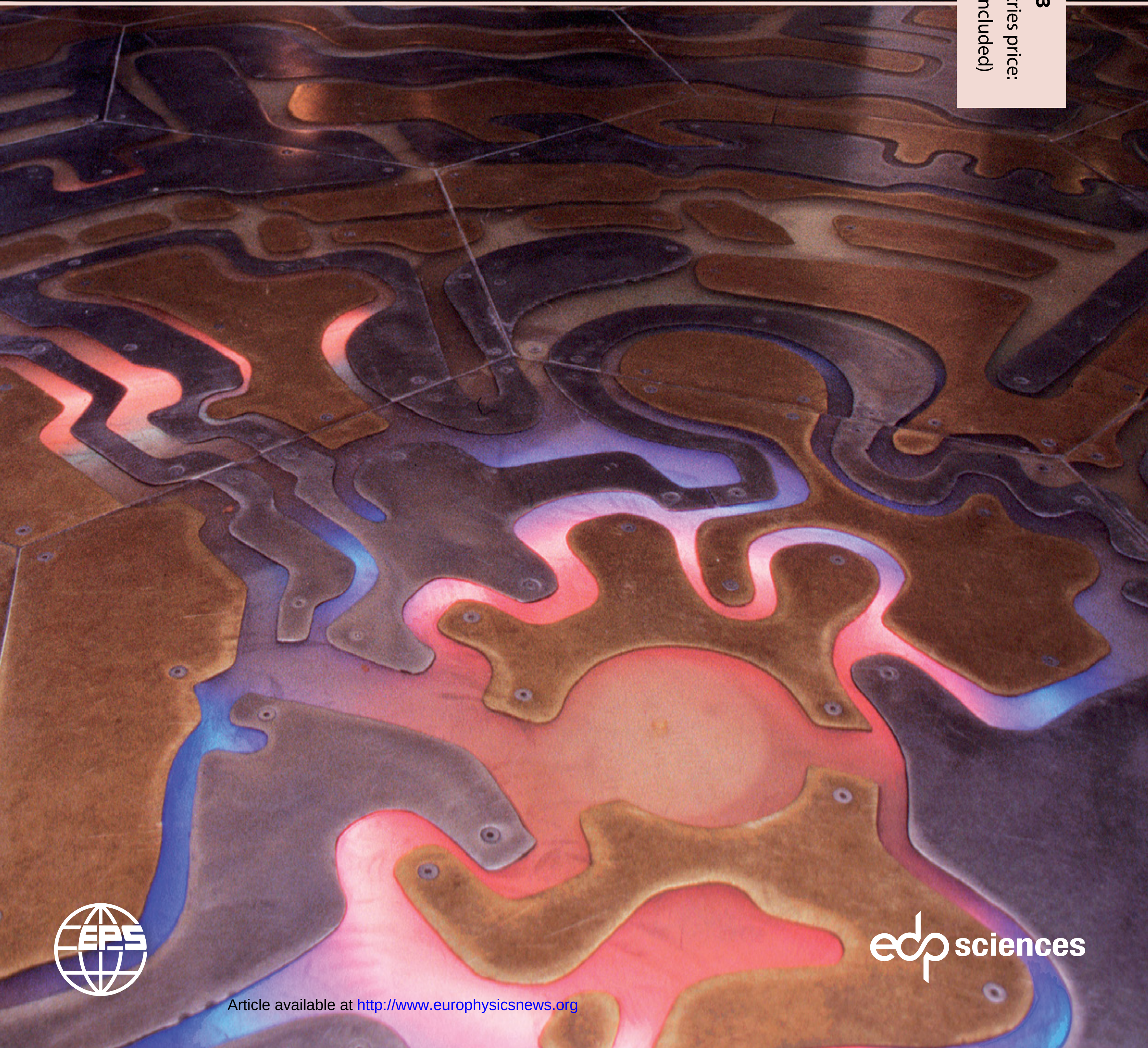
europhysicsnews

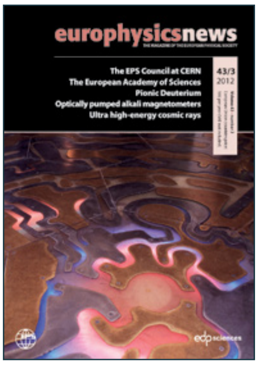
THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

The EPS Council at CERN
The European Academy of Sciences
Pionic Deuterium
Optically pumped alkali magnetometers
Ultra high-energy cosmic rays

43/3
2012

Volume 43 • number 3
European Union countries price:
90€ per year (VAT not included)





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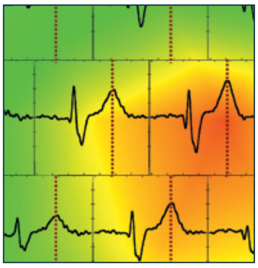
Cover picture: The "Cosmic Song", a work of art and a cosmic rays'detector by French sculptor Serge Moro, decorating the floor of the reception hall in building 33, at CERN. © Laurent Guiraud - CERN



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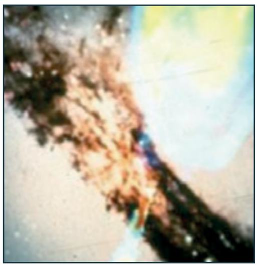
Optically pumped alkali magnetometers



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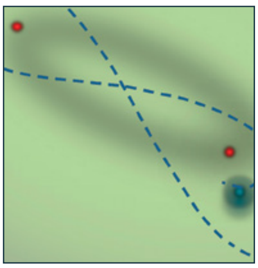
Ultra high-energy cosmic rays



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Europhysics news is the magazine of the European physics community. It is owned by the European Physical Society and produced in cooperation with EDP Sciences. The staff of EDP Sciences are involved in the production of the magazine and are not responsible for editorial content. Most contributors to Europhysics news are volunteers and their work is greatly appreciated by the Editor and the Editorial Advisory Board.

Europhysics news is also available online at: **www.europhysicsnews.org**.

General instructions to authors can be found at: **www.eps.org/publications**

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Subscriptions

Individual Members of the European Physical Society receive Europhysics news free of charge.

Members of EPS National Member Societies receive Europhysics news through their society, except members of the Institute of Physics in the United Kingdom and the German Physical Society who have access to an e-version at www.europhysicsnews.org. The following are 2011 print version subscription prices available through EDP Sciences (Prices include postal delivery cost).

European Union countries: 90 € (VAT not included, 19.6 %). **Rest of the world:** 108 €

Contact: EPN Europhysics News • BP 95 • 92244 Malakoff Cedex • **info@route66-agence.com** or visit **www.edpsciences.org**

ISSN 0531-7479 • ISSN 1432-1092 (electronic edition)

Printer: Fabrègue • Saint-Yrieix-la-Perche, France

Dépôt légal: June 2012

The EPS **Historic Sites**

Since 1972 we have seen the UNESCO declaring sites, buildings, monuments, gardens, animal habitats, *etc.* the world over as "cultural or natural heritage" for humankind. We are convinced that the same should also apply to our "scientific heritage" since science, and in particular physics, is an essential ingredient of our culture. Inspired by an analogous initiative of the American Physical Society in the US, the *EPS Historic Sites* initiative will take care of the survey of the European territory.

Launched by the EPS in 2011, this initiative is meant to signal, commemorate and protect important places in the history and development of physics across Europe. Sites with a national or broader (European/international) significance to physics may be considered for the award of the *EPS Historic Site* distinction. Commemorated locales will be recognised with a plaque, and an unveiling ceremony organised between the EPS and the site nominators.

Examples of what can be considered are: places (laboratories, buildings, institutions, universities, *etc.*) associated with an event, discovery, research or body of work, by one or more individuals, that made important, exceptional contributions to physics. Places where innovative instruments and/or apparatus were conceived, designed, developed and operated are also included. As a rule, the *EPS Historic Sites* initiative is not simply meant to designate residences or birthplaces of noteworthy physicists. A special *EPS Historic Sites* Selection Committee has been appointed by the Executive Committee, chaired by the EPS President.

The first Italian *EPS Historic Site* was declared and established in Rome in April 2012. Connected with the outstanding scientific research work by Enrico Fermi, the selected "scientific heritage" is the famous goldfish pond of the garden of the ancient Physics Institute of Panisperna Street. It was used by Fermi to establish for the first time on October 22, 1934, the importance of hydrogen-rich substances like water in slowing down neutrons for nuclear fission reactions. This "Fermi fountain" was solemnly sealed as *Historic Site of the European Physical Society*, with the unveiling of a commemorative marble plate, in the presence of the President of the Italian Republic. The involvement of the EPS, testifying the determination since 1968 of European scientists to strengthen the cultural unity of science in Europe, significantly enhanced the importance of the event.

In October this fall another *EPS Historic Site* will be inaugurated at the Hoza 69 Physics Institute in Warsaw, Poland, as already announced in 2011 during the special *Marie Sklodowska Curie Symposium on the Foundations of Physical Chemistry*, held in the frame of the *International Year of Chemistry* celebrations. Other proposals are already in the air, concerning Austria, Switzerland and Russia.

The European flavour of entitlement events, witnessing the spirit of cooperation of European scientists and highlighting the European scientific excellence, is doomed to be successful. You are strongly invited to make your own proposals concerning your own home countries. The impact and visibility of such a reconnaissance of our scientific legacy – for the EPS, and above all, for physicists and physics – are potentially unlimited. ■

Luisa Cifarelli
President of the EPS

For more information – and to nominate a Historic Site – please visit the EPS website (www.eps.org/?page=historic_sites) and use the appropriate nomination form.

The EPS Council, 30-31 March 2012

The EPS Council was held at CERN, Geneva, on 30-31 March 2012. Over 60 delegates attended representing the 41 EPS Member Societies, Divisions, Groups, Individual Members and Associate Members.

Welcome of Rolf Heuer, the CERN Director General

CERN is a unique place, with a wonderful atmosphere, where researchers of all ages from around the world come together for a common purpose. The LHC is operating well, and more important results are expected before the scheduled maintenance shut down in 2013. It is expected to be operating at full power after mid-2014. CERN prepares a strategy review, to be presented to CERN Council in 2013. EPS can play a role in its activities by underscoring the importance of basic research to the overall economy. The CERN appreciates EPS activities in the field of science and society, as well as in science policy, and its work in creating and maintaining networks of researchers in Europe.

▲ A. Proykova and L.Cifarelli

President's Report

In 2011, Council adopted EPS Strategy Plan 2010+ (see EPN 42/2, 4). It is now time to take stock of what we have achieved. This document recognised that the EPS has a role as a federation, as a learned society and as a publisher. As a federation of European national physical societies, the EPS organised the 'Second Asia Europe Physics Summit – ASEPS2' in Poland, the launch in Italy of the International Year of Light initiative and decided to start of a dedicated study on 'Physics and the European economy'.

The EPS responded to numerous EC consultations, for instance the ERA Framework Public Consultation on 'Areas of untapped potential for the development of the European Research Area', or the consultation on the Green Paper: 'Towards a Common Strategic Framework for EU research and innovation funding', or the one on 'Access to and preservation of digital information', all available on www.eps.org.

Links with learned societies outside Europe have been strengthened, in Africa, Asia and Latin America. The EPS and the American Physical Society also cooperate in the field of physics for development with the SESAME grant initiative, and are considering common statements.

As a 'learned society', the electronic bulletin 'e-EPS' was launched, and is now distributed to over 40,000 subscribers. The new EPS website has just gone online, with new structure, layout, contents, facilities, *etc.* The number of EPS Individual Members and of Associate Members increased in 2011 and this is also a goal in 2012.

Electronic bulletin 'e-EPS' was launched, and is now distributed to over 40,000 subscribers

The conferences of EPS Divisions/Groups continue to be outstanding, and they organised over 25 events in 2011, with more than 10,000 participants. Divisions and Groups are also active in awarding prizes in all fields of physics, and they awarded 21 prizes in 2011, recognising outstanding achievements in physics, contributions to the EPS, and promising young researchers. To strengthen the role of the EPS in the field of applied physics, the Technology and Innovation Group (TIG) has been reformed, and a TIG workshop is planned in 2012. Energy has also been central to EPS activities, with the preparation for 2012 of the second European Energy Conference (see report in p.08 of the present issue) in Maastricht (NL) and with the establishment of the Joint EPS-SIF International School on Energy in Varenna (IT).

Finally the EPS has undertaken a series of reorganizational steps, in particular concerning its committees. The staff and Secretariat have worked hard, under the guidance of the Executive Committee, to work towards the goals established in the Strategy plan 2010+. The EPS plans to continue efforts to make the EPS more visible and strengthen its impact.

Highlights 2011

In the area of physics education, the EPS published a series of documents looking at university studies in physics. The EC-funded study of the Bologna Reforms in Physics Studies was finalised, with the publication of the study of the implementation of the Bologna Reforms at the Doctoral level. The EPS also published 'Specification Descriptions' for physics studies at the bachelor, master and doctoral levels, available at www.eps.org.

The EPS was also a partner in two EC-financed projects in the field of education and outreach. The first is PATHWAY (www.pathway-project.eu/), which brings together partners in the field of science education. The project aims to study and propose a model derived from best practice for

inquiry-based science education. The second project , Odysseus is a contest for young students. Under the guidance of their teachers, students will prepare projects revolving around one of three major themes in space science: Solar System; Spaceship – global cooperation; and the Co-evolution of life. The contest and the project aim to engage and inspire the European youth in the "New Frontier". For more information and to participate:
www.eps.org/?page=odysseus
www.odysseus-contest.eu/?page_id=196
The EPS will undertake a study of Physics and the EU Economy, to explain to policy makers that physics makes an important contribution to the economy. The EPS study, which should be ready in 2012, will be based on the study conducted by the IoP on 'Physics and the UK Economy' (www.iop.org/publications/iop/2007/page_42716.html).
The 15th **EPS General Meeting** was held on 27 October 2011 in Wroclaw (PL). The President L. Cifarelli summarised the development of the EPS over the period 2008-2011. C. Latimer, EPS Treasurer, reported that the finances of the Society are satisfactory, especially in light of the financial difficulties in Europe. Not only were most activities maintained, many new activities were started, including for example the EPS electronic news bulletin 'e-EPS'. M. Knoop, EPS Honorary Secretary reported on the work of the Executive Committee. Much effort has been devoted to improving communications with Member Societies, and with Divisions and Groups. More information on the EPS General Meeting is available at: www.eps.org/?page=general_meeting
The **International Year of Light** is a global initiative, which was started by the EPS Quantum Electronics and Optics Division in 2010. Following the approval of the EPS Council, a resolution was presented to the General Assembly of the International Union of Pure and Applied Physics (IUPAP) in November 2011. Work is on going to gain support from UNESCO and the UN to have 2015 declared the International Year of Light. A prospectus describing the IYL is available at www.eps.org/resource/resmgr/activities/eps_iyol_2.pdf

EPS will undertake a study of Physics and the EU Economy, to explain to policy makers that physics makes an important contribution to the economy

Decisions

- Council approved the following individuals as **Honorary Members** of the EPS: **Viktor G. Baryakhtar**, **Jose Mariano Gago** and **Martin C.E. Huber** (see p.06-07 of the present EPN issue and: www.eps.org/directory/honorary-members)
- Council approved the following individuals as **Fellows** of the EPS: **Ugo Amaldi** (Italy), **Uwe Becker** (Germany), **Alain Bourdier** (France), **Adelbert Goede** (the Netherlands), **Ursula Keller** (Switzerland), **Stefan Poedts** (Belgium) and **Günther Rosner** (Germany).
- Council approved the award of the **Gero Thomas Memorial Medal** to **Peter Melville** (see p. 07 of the present EPN issue).
- Council approved the modification proposed by the Executive Committee to modify section 6 of Annexe 1 to the Constitution and By-laws concerning the **Individual Membership fees** as detailed in EPN 43/1, p.09.

Elections

The EPS Council warmly thanked **Maciek Kolwas**, immediate past President, as well as the other outgoing members of the Executive Committee for their hard work and dedication. The outgoing members are: **Marcis Auzins** (LV), **Hendrik Ferdinande** (BE), **Anders Kastberg** (SE), **Ana Proykova** (BG) and **Klaus Wandelt** (DE).
Council elected Professor **John Dudley** (Université de Besançon, France) as **President-elect** of the EPS. He will serve one year as Vice-President, and take up office as President in April 2013. See the presentation in p.06 of the present issue.
Council elected the members of the **Executive Committee** (The new members will be presented in the 43/4 issue of EPN):

- Representatives of Member Societies with more than 10,000 effective members: **James Hough**, IoP (UK) and **Thomas Müller**, DPG (DE)
- Representatives of Member Societies with less than 10,000 effective members: **Goran Djordjevic** (RS), **Martina Knoop** (FR), Secretary of the Executive Committee, **Els de Wolf** (NL).
- Representatives of Divisions and Groups: **Zsolt Fülöp** (HU), **Carlos Hidalgo** (SP), **Jo Lister** (CH), **Sofoklis Sotoriou** (GR).
- Representative of Associate Members: **Caterina Biscari** (IT).
- Representatives of Individual Members: **Colin Latimer** (UK).

Invited Speaker

F. Zwirner, Professor of Physics at Padova University, Italy gave and invited talk to Council Members, entitled "Particle Physics on the Move". He summarised the state of the research for Higgs Boson. ■

Ackowledgments

I would like to thank the CERN Director General, R. Heuer, the EPS President, L. Cifarelli and the EPS staff for their hard work and dedication for making this year's Council meeting a memorable experience.

David Lee,
Secretary General of the EPS

▾ The EPS council in CERN

Council, elections and nominations

This first part presents the elected president, new honorary members and the Gero Thomas medal recipient. A second part will be published in the next issue of EPN.

THE NEW VICE-PRESIDENT OF THE EPS: JOHN DUDLEY

Originally from Otahuhu in New Zealand but holding also Irish and French nationality, John Dudley received B.Sc and Ph.D. degrees from the University of Auckland in 1987 and 1992 respectively. In 1992 and 1993, he carried out postdoctoral research at the University of St Andrews in Scotland before taking a lecturing position in 1994 at the University of Auckland. In 2000, he was appointed Professor at the University of Franche-Comté in Besançon, France, where he heads the Optoelectronics and Photonics research group consisting of 12 permanent staff and around 20 students and post-docs.

He has extensively taught physics from undergraduate to doctoral level and has particular interests in employing the history of science in teaching and promoting student career development. In New Zealand he was privileged to negotiations with Feynman's estate to ensure copyright-free public access of Feynman's first QED lectures given in New Zealand in 1979.

◂ John Dudley, the new Vice-President of the EPS (© Ludovic Godard – UFC)

His research focuses equally on experimental and theoretical studies in nonlinear optics, with emphasis on optical fibre propagation, ultrafast metrology, and extreme nonlinear dynamics. He has made major contributions in several different areas of study, specifically ultrafast self-similar dynamics and super continuum generation. He was named a member of the *Institut Universitaire de France* in 2005, elected a Fellow of the Optical Society of America in 2007 and elected a Fellow of the IEEE in 2011. He has served as an IEEE Distinguished Lecturer from 2008-2010, he has won the *Grand prix de l'électronique* "Général FERRIÉ" of the French *Société d'Electricité, d'Electronique et des Technologies de l'Information et de la Communication* and the Prize of the IXCORE Foundation in France. He has served as Chairman of the Quantum Electronics and Optics Division of the European Physical Society and, since 2010, has been Secretary of the EPS-led partnership to request UN declaration of an International Year of Light for 2015. ■

THE HONORARY MEMBERS OF THE EPS IN 2012

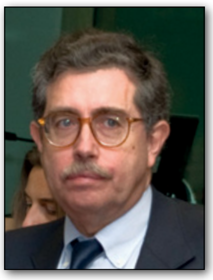
At its late March annual meeting in CERN (Geneva) the Council of the EPS has elected three new Honorary Members who are very briefly presented here.

Victor G. Baryakhtar

The esteemed Ukrainian physicist V. G. Baryakhtar is elected as Honorary Member of the EPS for:

- His scientific achievements, notably in theoretical and nuclear physics and his important contributions to the theory of relaxation processes in ferro-(anti)magnets and coupled spin - acoustical waves.
- His contribution to the civil society in the Ukraine, in particular for his leading role in the creation of the Ukrainian Physical Society.
- His outstanding results in the efforts of decreasing the consequences of the Chernobyl accident and his diffusion of truthful and scientifically sound information about this accident. (Italy, 2000)

José Mariano Gago



José Mariano Gago, former Portuguese Minister of Science, Technology and Higher Education and Professor of Physics is elected as Honorary Member of the EPS for:

- The reform of Higher Education and for the policies leading to the development of Science and Technology in Portugal, notably through improving

THE GERO THOMAS MEDAL: PETER MELVILLE

The European Physical Society is pleased to award the 2012 Gero Thomas Medal for outstanding contribution to the EPS to Peter Melville. Peter Melville is well known to most of us. He has visited all 41 EPS Member Countries, and has travelled extensively around the world. Among his many talents is a gift for languages. If you ever need to ask the maintenance personnel in Hungary for a key, he's the right person to have with you.

Peter as a physicist

Peter Melville obtained his PhD in 1971. In addition, Peter also has a Doctoral Degree in engineering (University of Birmingham, 1994) and a Masters degree in international law (University of East London, 1998). He began his career in in applied physics, doing research into superconducting power transmission cables. For the next 22 years, Peter continued to work in the energy sector, including renewable energy and electric vehicles (as early as 1989). His managerial skills were also recognised, he held a number of important positions, and had been appointed Head of Enterprise and International Relations for the Essex County Council when he was recruited by the IoP in 1995.

Until his retirement in 2007, Peter was a director at IoP in a variety of fields (qualifications, membership, engineering, industry) but his main role was Director of international affairs.

Peter and the EPS

Peter joined the EPS as an Individual Member in 1971 and attended the EPS General Conference in Wiesbaden (DE) in 1972. When the EPS expanded its activities to include applied physics, he was appointed as a member of the Action Committee on Applied Physics and Physics in Industry, and chaired the committee until 2000. He was instrumental in changing the committee into an EPS Group (now the Technology and Innovation Group). Peter was elected to the Executive Committee in 2003, and played a key role in the major redrafting of the EPS Constitution in 2004. Also in 2004, he was elected as Honorary Secretary of the EPS. Following the sad and sudden death of J. Beeby, Peter accepted to become the Honorary Treasurer of the EPS in 2009 and 2010. He is also one of the founding members of the Forum Physics and Society, and was involved in the FPS meeting in Zakopane (PL).

▸ Peter Melville during the Gero Thomas medal ceremony.

Peter as a person

Peter is a true European, and worked tirelessly throughout his career for the construction of the European physics community. He was the EPS ambassador, attending countless meetings of EPS Member Societies in Eastern and Central European Countries.

His broad knowledge and experience, combined with his ability to seek intelligent consensus were great assets for the Executive Committee.

Peter also has a wonderful singing voice, and appears in productions of the theatre troupe of his home town.

Please join me in a round of applause, and congratulations Peter. ■

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the research in the country's physics and astronomy departments by applying European standards,

- His important contributions in de development and adoption by the European Commission of the Lisbon Strategy for the European Research Area and for the Information Society in Europe,
- His continued support of the scientific excellence, notably coordinating widespread support from all sciences (including the EPS) for the creation of the European Research Council.

Martin C. E. Huber

Martin C. E. Huber, former head of the Space Science Department of the European Space Agency and current chairman of the Swiss Commission for the Jungfraujoch Research Station of the Swiss Academy of Sciences is elected as Honorary Member of the EPS for:

- His work in laboratory astrophysics and solar physics in space,
- His long-lasting commitment in supporting the European Physical Society, as Chairman of the Astrophysics Division and as President, and in particular for the organisation of the Einstein Centennial Celebrations in Bern (CH),
- His achievements in expanding the EPS role as the voice of physics in Europe and creating links with European policy makers,
- His work as Chairman of the Board of Directors, piloting the successful development of the EPL journal. ■

The 2nd European Energy Conference,

held in Maastricht, 17-20 April, 2012

In contrast to the First European Energy Conference in April 2010, which was severely hindered by volcano ashes making air travel virtually impossible, everything was near-perfect for the 2nd edition. The venue was the easy-to-reach Maastricht Exposition & Congress Centre, the organisation was excellent and the programme was exceptionally varied. There were plenary sessions in the morning and four parallel sessions in the afternoon.

The second European Energy Conference (E2C) was held under the patronage of the EU Commissioner for Energy, Günther Oettinger, with Harald Bolt (Forchungszentrum Jülich) as Conference Chair and Fritz Wagner (former EPS President) as Chair of the Steering Committee. Speakers included big names from Science, Industry and Politics like physicist Javier Solana (former NATO Secretary General and former EU 'Foreign Minister'), Jeroen van der Veer (former CEO of Shell), Osamu Motojima (Director General, ITER Organisation) and Wolfgang Burtscher (deputy Secretary General Research, European Commission), just to name a few. It illustrates one of the main conference goals: to be an interdisciplinary forum to promote cooperation and synergy in the field of Energy at a time where strategic decisions have to be made.

Interdisciplinarity

The E2C series is a joint venture between the European Science Foundation, the European Physical Society and the European Materials Research Society (E-MRS). At first glance, the prominent role of the E-MRS may seem a bit surprising. However, material science is playing an increasingly important role in the field of Energy. Just think of turbine blades where thermal-barrier coatings are vital to ensure flawless high-temperature operation. Or consider low-weight materials to replace steel for manufacturing high-efficiency cars. Or light, yet strong, composite materials for wind turbine rotors. And think of wall coatings for fusion reactors, which require heat-resistant metals like tungsten and low-Z ones like beryllium, and which have to withstand neutron bombardment.

On the economic and political front, energy security was mentioned as one of the most important challenges. The present dependence of energy consumers upon energy producers raises worries about the stability of some energy-producing countries. However, recent developments in the field of non-conventional (shale) gas will change the relation between producers and consumers. The total natural-gas reserves, including shale gas, are estimated to last for another 200 years, according to Jeroen van der Veer.

▲ One of the parallel sessions

▼ Javier Solana President of ESADE Center for Global Economy and Geopolitics in his plenary address Energy on an international basis

Research

But also many cutting-edge research projects were on the agenda. As an example, thin-film silicon solar cells can be produced by making use of the difference in band gap between amorphous and microcrystalline silicon. Whereas the former has a quantum efficiency which peaks around 500 nm, the latter peaks around 750 nm. This yields the opportunity to produce thin and flexible tandem cells, as shown by Aad Gordijn (Jülich). The efficiency so far is 15 % for small cells on glass in the lab, and over 11 % for 1.4 m^2 prototype modules. Another example is the innovative development in the field of Li-batteries, shown by Martin Winter (Electrochemical Energy Technology, University of Münster). He showed that, in principle, future Li-metal 'super batteries' could achieve an energy density of 3.8 kWh/kg, to be compared with a maximum value of 0.2 kWh/kg achieved today.

Cars

The efficiency of cars was another hot item. It was assumed that for internal-combustion-engine cars with a reasonable size, 35 km/L is achievable. This would be more or less in line with the expectations in the US, considering the difference in car size. As pointed out by Dan Arvizu, director of the National Renewable Energy Laboratory (Golden, CO, USA), the US target for 2020 is 54 miles per gallon, which translates into 23 km/L. Considering the long-term choice between electric cars and hydrogen-powered cars, the prevailing expectation at the conference was that electric would come out as the final choice. One important reason is that infrastructure requirements favour electric cars. Moreover, the transition from fossil-fuel driven to electric cars can be made gradually, and is in fact already taking place: from gasoline to hybrid to plug-in hybrid to completely electric. This obviously assumes that sufficient progress in battery development will be made. But even today, electric cars are compatible with most common car use. As pointed out by Rémi Bastien (Vice President, Renault, France), 87 % of daily trips are less than 60 km, while 32 % of B-segment cars never make more than 150 km/day.

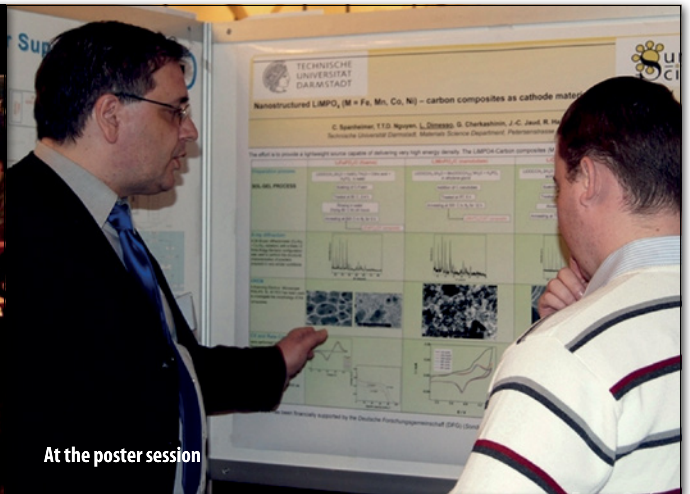
Cooperation with other disciplines, with industry and with politics is indispensible

Politics and money

Isn't there a critical note to be made about E2C? Yes, there is. It is the attendance. There were barely 400 participants from the total of Europe. Everybody who regularly visits an international conference in his or her field knows that 2000 participants are not uncommon. Such numbers should be easily reached for a broad conference like E2C. As pointed out by Wolfgang Burtscher, the EC proposes a total funding of 6.5 billion Euros for 'Secure, clean and efficient Energy' for the period 2014-2020. This shows that the EC recognises the fact that a smooth transition to a sustainable energy system is vital for the future of our globe. As one of the participants remarked: We may have a plan B, but we don't have a planet B. Indeed, European physicists must realise that their role in achieving a sustainable world is an essential one. But cooperation with other disciplines, with industry and with politics is indispensible. This is precisely what conferences like E2C can achieve. In his closing remarks, Fritz Wagner made a point: rather than focussing only on specialised conferences - which is what we tend to do traditionally - we should go (and send our students) to meetings like these which offer the necessary interaction between Academia, Industry and Politics. It will broaden our view and put our work into perspective. It will also help us to spend the above 6.5 billion wisely and responsibly. ■

Jo Hermans

Coffee break and poster session



At the poster session

The conference desk

The European Academy of Sciences (EURASC)

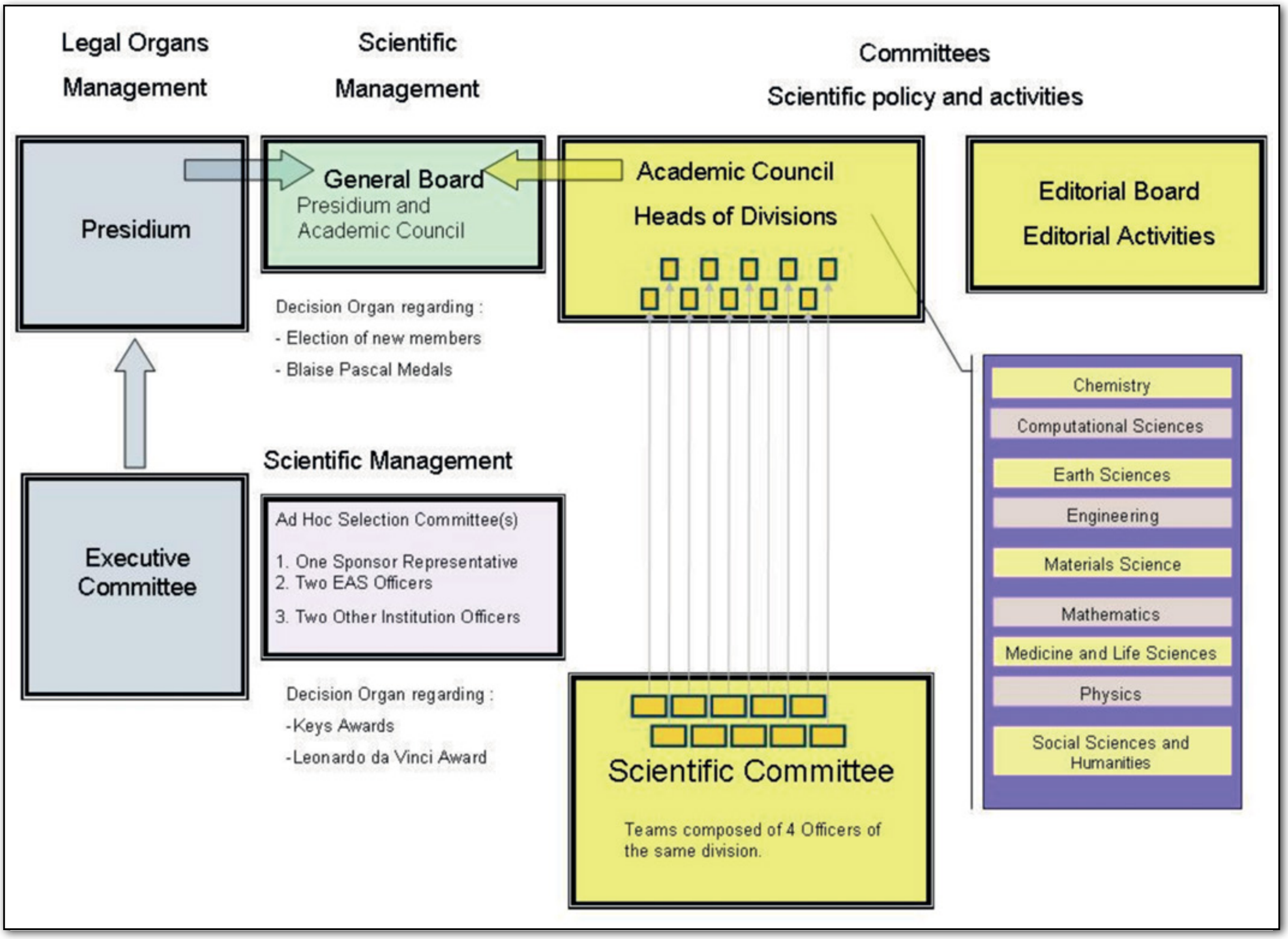
Most European countries have their own National Academies, with strong historical roots and high prestige of their members, both current and former. During the last decades, with the strengthening of the connections among European countries and in particular their academic and research institutions, a few supra-national Academies were created at the European scale: the Academia Europaea, the European Academy of Sciences and Arts, and the European Academy of Sciences (EURASC); respectively headquartered in London, Salzburg and Liège.

These academies potentially constitute the roots of a future - Continental - Academy of Europe, hopefully representing excellence throughout all of geographical Europe without national distinctions and using its expertise to assist in optimizing the future of our continent. This article is intended to enhance awareness of EURASC, the youngest of these initiatives, within the European community of Physicists.

United by a commitment to promoting fundamental research and excellence in science and technology, EURASC emerged from a project that started in 1999 with the goal to link universities, research organizations, industries, and governmental bodies. Its statutes were approved by Royal Decree of the King of Belgium of December 17, 2003. The name "European Academy of Sciences" is registered as a non-profit association of international interest.

EURASC is an institution that aims to recognise and elect to its membership the best European scientists with a vision for Europe as a whole, without any national prejudices and

▾ Organization chart of EURASC. The Academy is governed by the Presidium. The Academy elects its Scientific Committee that advises on scientific matters, identifies research priorities and helps in the organization of the international research networks. The Academy elects its regional representatives. The Presidium develops the policy of the Academy, endorses its annual activities programme and allocates the budget.



transcending national borders in both elections and actions, and with the aims of strengthening European science and scientific cooperation and of utilising the expertise of its members in advising other European bodies in the betterment of European research, technological application and social development.

Despite the fact that the European Academies Science Advisory Council can take care of cooperation between existing National Academies, we believe that the actions of the above mentioned three European academies do not overlap with the mission of national academies plus EASAC, but on the contrary complement it. As one example, these academies recognise European excellence through the award of prizes and medals. But also EURASC is completely independent of any national entity, in its membership, election processes, deliberations and actions; for example, multinational support is required at proposal and selection of members and awardees.

EURASC is a fully independent organization of distinguished scholars. With nine divisions, this Academy covers most domains of scientific knowledge; hard sciences, including engineering and medicine, as well as social sciences, humanities including philosophy of sciences etc… (see the organization chart on p.10). Membership recognises outstanding scientific excellence with a strong relevant European connection, including in its eligibility (i) citizens of a European country, (ii) persons residing - and working - at least 50 % time within Europe, (iii) non-European scientists of exceptional talent who, by virtue of their prestige and scientific accomplishment, bring valuable additional expertise to EURASC. The Academy elects its members, individuals or legal entities, only on their professional merits, without distinction of countries of origin, nationality, race, gender, language or religion (although in practice many members of EURASC also belong to national academies). Regarding financial income, in addition to modest individual annual contributions (currently 50 Euro/year), EURASC acknowledges financial support for its scientific activities and prizes from academic and private institutions (currently on average 20-25 kEuro/year).

As shown in the Figure, EURASC is managed by the Presidium, whereas the Executive Committee chooses the President and Vice President for two years. Nine scientific divisions exist to represent disciplines within the broader scope of the Academy, each headed by a subject committee charged with coordinating activities and interests of its members, selecting potential new members and prizewinners, and representing other divisional interests. The chairmen of the subject committees constitute the Academic Council, which advises the General Board. Further information on legal and scientific organs of management and the different committees (with concerned persons) can be found in the EURASC website (www.eurasc.org).

The Academy organizes seminars and symposia to promote both fundamental and applied sciences. An important action by EURASC is rewarding excellence through the award of prizes and medals. At the moment these are the Leonardo da Vinci Award, for "Outstanding Life-long Achievement", the Blaise Pascal Medals (normally five per year across the divisions) to recognise outstanding contribution to science and technology, and the Kepler award for European young scientists with the goal of steering the interdisciplinary cooperation of highly talented young scientists in Europe. A list of past awardees can be seen at www.eurasc.org where there are links to the different awards.

EURASC is still young and growing. It is planned to make its membership both greater in number and more completely representative than at present, always maintaining a very high standard of scientific excellence and international esteem together with a desire to support European science as a whole. Its actions should also grow. While decisions on admission to membership and actions will be subject to rigorous criteria and selection procedures, suggestions, backed by cases, are welcomed. ■

We believe that the actions of the above mentioned three European academies do not overlap with the mission of national academies plus EASAC, but on the contrary complement it

Bernard Barbara,
Emeritus Director of Research, CNRS, Institut Néel, Grenoble
Member of EURASC Presidium and Executive committee

David Sherrington
Wykeham Professor of Physics Emeritus, University of Oxford
Chairman of Physics Division of EURASC

NOMINATIONS FOR EDITOR IN CHIEF OF EPL

epl A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS

Nominations are now open for the Editor in Chief of EPL, a leading, global letters journal owned and published by a consortium of 17 physical societies in Europe. The Editor in Chief (EiC) needs to be a recognized authority and leading researcher in a field of physics, and have a broad knowledge and interest in physics and its frontiers. A proven ability to interact with senior scientists is required. The EiC will need to demonstrate strong commitment and leadership to further develop EPL as a top-ranking journal. Experience with the editorial process for a physics journal is also desirable. The EiC is central to enhancing EPL's position as a leading global physics letters journal. The term of office of EPL Editor in Chief is three and a half years. A job description is available at https://www.epletters.net.

Nominations may be made by the individual concerned, or by third parties not later than 15 July 2012. Nominations must include a CV, publication list and a brief covering letter by the individual concerned explaining their interest and qualifications for the post. Candidates should also discuss their ideas for the growth and development of EPL. Nominations should be sent to the chair of the selection committee care of the EPL Editorial Office (editorial.office@epletters.net).

Opinion:
A new deal – physics and society

Ove Poulsen, CEO, Lindø Offshore Renewables Center, Denmark

Science – particularly physics – is traditionally very engaged in the development of our societies. This has been true in good times as well as bad. Individually, physicists engage with outstanding issues of importance to society: such as energy or science education. As a profession, however, physics shows a different face, one centred on a very specific frame of reference. Physicists are preoccupied – even passionate – about their work, and it is this passion which defines their point of view.

As a concept, physics is traditionally seen as being academic; that is, taking place in universities and research organisations. This truncated view results in a self-inflicted isolation: the assumption that the school system must deliver good students and society must understand and appreciate the arguments of physicists. It would be interesting if physicists tried to understand society's need, and acted accordingly – for the betterment of society.

As a starting point for dialogue, the physics experts' frame of reference is not appropriate. Such physics-specific frame often results in signals that are unclear, as seen by society. The result is confusion and lack of influence on on-going important societal discussions that otherwise should benefit from the views of physicists.

The same lack of authority is visible in discussions around scientific education. Should physicists take a more active role in bridging the gap between the traditionalist views of elite training versus those of broadening scientific literacy?

It would be interesting if physicists tried to understand society's need, and acted accordingly – for the betterment of society

The answer may seem easy, but this is not the case. Often one hears the argument that physics is hard to study and thus only suitable for the select few. A tide that lifts all ships – on the contrary – defines a broader societal responsibility; one that often falls to the wayside when discussions inevitably focus on internal matters such as university rankings, research contracts and career management. Once again, the outcome is lacking in influence: with physicists ultimately "preaching to the choir".

Where do we go with this? It is fine to be preoccupied with internal matters; this however, it is not enough. The Forum Physics and Society (fps.epscommittees.org) is a European Physical Society outreach action that aims at strengthening the dialogue between physicists and society. We recently held our fifth meeting, on the topic of 'physicists in the marketplace': covering everything outside of university-based physics. Healthcare, energy, finance, industry, production, and policy are elements in this marketplace, where physics meets society while, at the same time, academic physicists seek shelter within their laboratories.

The forum revealed a need for physicists to develop a new sensitivity: firstly towards society as an entity, with its institutions and its challenges; and secondly, as a shared responsibility to better justifying the value of physics. Too often is the linear innovation chain cited by physicists to explain the importance of physics to modern technology, and to society in general. The linear innovation chain is convenient as it puts basic science in front of applied science and engineering science and technology and thus highlights basic science as the mother of all progress. For physicists to claim such linear innovation relationship is dangerous – even more so when put forward with great self-confidence, even by well-respected colleagues – and are in reality expressions of ignorance about the complexity of society and the mechanisms creating value to society. The real issues deal with the reindustrialization of Europe, the creation of new jobs and the ability to take knowledge into this marketplace.

Let us, therefore, work on improving our listening skills, on developing the ability to understand what is ***not*** being said and – first and foremost – on showing respect towards other competencies in our society. The challenge of European reindustrialisation has highlighted the need for greater production and value creation; knowledge is irrelevant if one does not possess the skills to act, to use this knowledge to create something outside of physics itself. ■

COMING EPS EVENTS

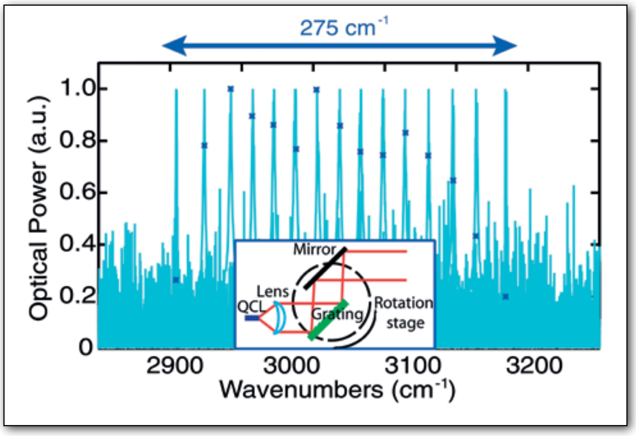
- **ICN+T 2012**, International Conference on Nanoscience + Technology *23-27 July 2012*, Paris, France www.icnt2012.org
- **MORE ON:** www.eps.org

Highlights from European journals

APPLIED PHYSICS

Sb-free quantum cascade lasers **(QCLs)**

The mid-IR spectral range is a region of great interest for numerous scientific and industrial applications such as environmental sensing, metrology and clinical diagnosis. In particular the first atmospheric window between 3-5µm is crucial where a large number of gases *e.g.* methane, nitric oxide, carbon mono-/dioxide or formaldehyde can be detected. The presence of very strong fundamental stretching modes of O-H, C-H and N-H bonds that can be orders of magnitude stronger than the overtones in the near-IR, brings the detection limits down to sub-ppb concentrations.



▲ Spectral tuning behaviour with corresponding peak optical output power of the external-cavity QCL and schematic sketch of the setup.

The unique feature of QCLs to tailor the emission wavelength makes them appealing sources for this kind of applications. Unfortunately the realization of QCLs in the first atmospheric window is especially challenging because a large conduction band discontinuity is needed to obtain high-energy photons. This is solved by using antimony in the lasing material. However, the growth of Sb-containing devices can be difficult and the fabrication techniques used for high performance QCLs lack compatibility.

Therefore the ETH team has focused on developing a Sb-free system by using strain-compensated InGaAs/InAlAs-AlAs on InP. In pulsed-operation watt-level emission at 3.3µm was obtained at room temperature, and lasing above 350 K could be observed. The laser performance is comparable to Sb-containing QCLs. Tunable single-mode emission between 3.15-3.4µm (Figure 1) was observed in a Littrow external-cavity configuration.

The team has begun to develop buried heterostructure QCLs to obtain continuous wave operation. By incorporating first-order distributed feedback gratings, for the first time in this spectral range single-mode emitting buried heterostructure QCLs could be realized. ■

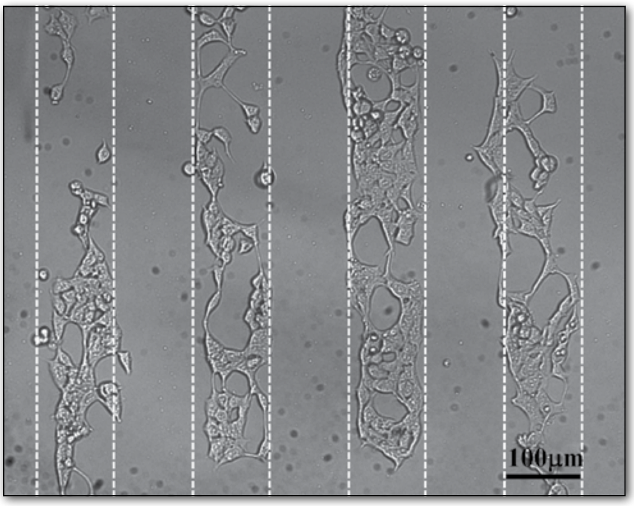
■ **A. Bismuto**, **S. Riedi**, **B. Hinkov**, **M. Beck and J. Faist**, 'Sb-free quantum cascade lasers (QCLs) in the 3-4 µm spectral range', *Semicond. Sci. Technol.* **27**, 045013 (2012)

BIOPHYSICS

Micro-pattern formation of extracellular-matrix (ECM) layers

Cell-based biochips/biosensors may advance various scientific and technological fields. For example, a neuronal network chip that simulates how our brains function, may be used to detect the cause of brain diseases such as Alzheimer's. Since living cells typically do not survive in direct contact with semiconductor surfaces, one of the major challenges for the development of cell-based biochips/biosensors is the formation of bio-interfaces that maintain living cells in an environment of microelectronics. Especially desirable is inexpensive technologies for attachment and arrangement of living cells on large areas of substrate surfaces according to one's design. In this study, we have developed a new and simple micro-patterning technique

▼ Micrograph of HEK 293 cell arrangement over patterned ECM strips on a Si substrate. The ECM shown here is Poly-L-Lysine and was patterned by application of low-temperature APPs through thin slits of a metal stencil mask placed firmly on the substrate. After plasma application and removal of the mask, HEK 293 cells were cultured on the substrate. The cells adhered to and proliferated on the remaining ECM strips. The white dashed lines here delineate the mask slit patterns.



for extracellular matrices (ECMs) deposited on Si substrates by low-temperature atmospheric-pressure plasmas (APPs) and a metal stencil mask. Low-temperature APPs are suitable for such patterning because of their ability to produce highly reactive species efficiently without causing thermal damages to ECMs. In this study, it is shown that, with a short-period application of APP, ECM layers of 1 cm^2 area deposited on Si substrates can be patterned for lines and intervals whose typical dimensions are in the range of 100 µm. ■

■ **A. Ando**, **T. Asano**, **T. Urisu and S. Hamaguchi**, 'Micro-pattern formation of extracellular-matrix (ECM) layers by atmospheric-pressure plasmas and cell culture on the patterned ECMs', *J. Phys. D: Appl. Phys.* **44**, 482002 (2011)

STATISTICAL PHYSICS

New model for epidemic contagion

Improved estimates on the geographical spread of infectious diseases are achieved by studying human mobility networks. Given that humans are considered as the hosts spreading the epidemics, the speed at which an epidemic spreads is now better understood thanks to a new model accounting for the provincial nature of human mobility.

▲ Star-shaped network representing human mobility © Vladimir Golovin/ photos.com

The authors modelled human mobility by accounting for the recurrent bi-directional travels of individuals around a central node representing their home location and forming a star-shaped network. Previous models are based on diffusion and would imply that people travel randomly in space, not necessarily returning to their home location again and again.
The researchers found that older diffusion-based models overestimated the speed at which epidemics spread. The speed of epidemics spreading through bi-directional travel, which is dependent on the travel rate, is significantly lower than the speed of epidemics spreading by diffusion.

In addition, the authors discovered that it is the time an individual spend outside their home location and not, as diffusion models suggests, the rate of travel between locations, which influences the speed of epidemics spreading and whether an outbreak goes global.
This model has yet to be tested against real data on human mobility before it can be used as a risk analysis and decision making tool for epidemics or in population dynamics and evolutionary biology. ■

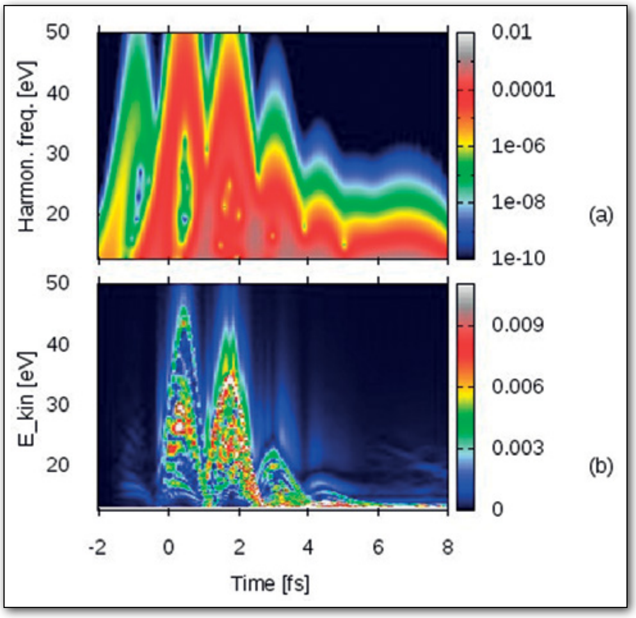
■ **V. Belik**, **T. Geisel and D. Brockmann**, 'Recurrent hostmobility in spatial epidemics: beyond reaction-diffusion', *Eur. Phys. J. B* **84**, 579 (2011)

QUANTUM PHYSICS

Electronic rescattering dynamics **in laser fields**

The interaction of intense laser fields with atoms gives rise to characteristic strong-field effects, most notably above-threshold ionization and high-harmonic generation. After the electron tunnels out of the atomic potential, it is accelerated by the laser field before being driven back to the parent ion by the same field. The returning electron energy ranges from a few to a few hundred eV depending on the field parameters. Upon rescattering, parts of the electron wave-packet may recombine with the atom under emission of energetic radiation of harmonics of the laser frequency. The harmonic radiation carries characteristics of the atomic potential, as well as of the rescattering electron.

▼ (a) Time-frequency analysis of the harmonic spectrum in a Coulomb potential; (b) Cut along the position of the nucleus of the Wigner quantum phase space distribution of the rescattering electron, visualizing the kinetic energy distribution of the electron as a function of time associated with the region near the parent ion.



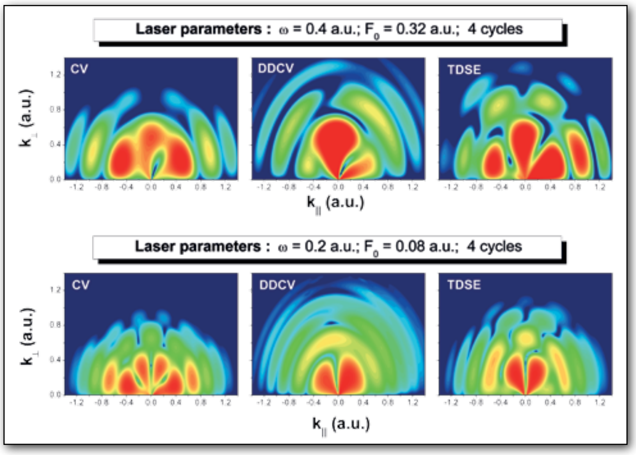
This sequence of processes can be directly visualized by a quantum phase space analysis. Using a Wigner phase-space distribution, one can relate the coordinate-momentum space distribution of the returning electron to the temporal emission pattern of the harmonic spectrum (see Figure).
Such relation between the time-frequency vs. the coordinate-momentum space distribution has been calculated for different atomic model potentials, the Coulomb potential supporting a Rydberg series and short-range potentials, with a finite number of bound states. The important role of dynamic bound-state polarization effects in the harmonic emission can be identified. The long-range part of the Coulomb spectrum modifies the local momentum distribution at the moment of rescattering. This might become important for an improved description of experiments aiming towards a tomographic reconstruction of the electronic structure of a system using the harmonic spectrum. ■

■ **S. Gräfe**, **J. Doose**, **J. Burgdörfer**,
'Quantum phase-space analysis of electronic rescattering dynamics in intense few-cycle laser fields', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 055002 (2012)

ATOMIC AND MOLECULAR PHYSICS

Laser-atom interacts: the electron at the mercy of the laser

The interaction between atoms and intense electromagnetic pulses with durations in the (sub) femtosecond time domain has proved to be a powerful tool to understand the dynamics of electrons inside matter. Among the theoretical methods developed to describe the electronic transitions produced by such ultrashort pulses we can mention the Coulomb–Volkov (CV) approximation, in which the combined action of both the atomic and laser potentials is taken into account only in the final channel. The CV approach has become a widespread method to investigate the physics behind photoinduced ionization processes. Nevertheless, it fails when the perturbative conditions are not fulfilled, for instance, when the ionization produced by an intense laser field takes place in an effective time much shorter than the pulse duration, or when the ionization requires multiphoton transitions.
Here we propose a doubly distorted CV (DDCV) model that goes beyond the standard CV theory by incorporating the effect of the laser field on both the initial and final electronic states on an equal footing. This improvement allows the method to account for dynamic Stark effects, which play an important role for long electron excursions originated by the laser electric field. We found that the DDCV approach provides reliable predictions of photoinduced electron emission distributions from H(1s) for different field intensities and wavelengths, including a range of laser parameters where the CV approach is



▲ Double-differential electron momentum distributions

inadequate. In addition, the extension of the DDCV approximation to complex atoms and molecules appears to be perfectly viable. ■

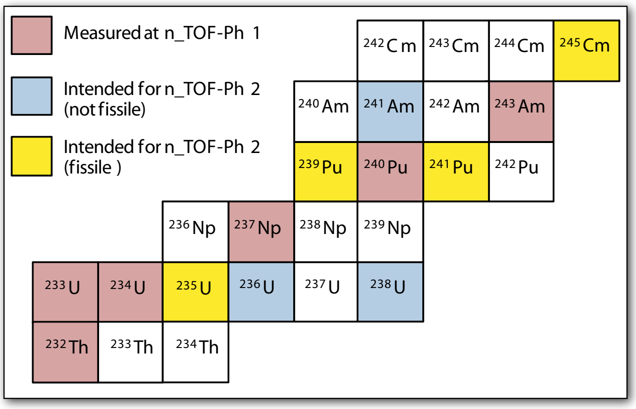
■ **M.S.Gravielle**, **D.G. Arbó**, **J. E. Miraglia and M.F. Ciappina**,
'Doubly-distorted-wave method for atomic ionization by ultrashort laser pulses', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 015601 (2012)

PARTICLE PHYSICS

Neutron-induced capture and fission reactions together

The accurate knowledge of (n,gamma) neutron-capture cross-sections for fissile isotopes is highly relevant for next-generation applications of nuclear technology. However, accurate measurements are difficult due to the gamma-ray background generated in competing (n,f) fission reactions.
Scientists at the CERN n_TOF facility have developed a new experimental setup that is capable of simultaneously measuring and identifying the capture and fission reactions.

▼ Minor actinide part of the table of isotopes indicating for which isotopes n_TOF has carried out measurements (n_TOF-Ph1) and for which measurements are intended (n_TOF-Ph2), differentiating between fissile and non-fissile isotopes.



The setup combines the existing 4pi BaF_2 Total Absorption Calorimeter (TAC) with a set of three MicroMegas detectors (MGAS). A successful test experiment was performed using moderated spallation neutrons in an energy region of 6-22 eV with a ^{235}U sample. Neutron captures were measured in the TAC while fission reactions were simultaneously detected in the TAC and MGAS. Coincident events recorded in the TAC and MGAS were selected and the specific TAC response to capture and fission events was exploited to select the two components by imposing conditions on sum energy and event multiplicity to disentangle them.

It was important to precisely determine the different detector efficiencies for both reaction types, which in turn allowed to derive capture and fission cross-sections, as well as their ratios. The comparison of the experimentally determined values with evaluated cross-sections showed good agreement between measurement and evaluation for both types of reaction.

Thus the experimental method was validated for an unambiguous extraction of cross-sections from a simultaneous measurement of the capture and fission reaction.

With the successful commissioning of the combined experimental setup, the n_TOF collaboration has now developed a tool that will enable them to target the accurate measurement of neutron-induced capture cross-sections of fissile isotopes. This new method brings interesting perspective for the necessary improvement of nuclear data for next-generation nuclear technology applications. The figure shows the neutron capture measurements of actinides performed at n_TOF ($^{233,234}U$, ^{237}Np, ^{240}Pu and ^{243}Am) and those intended for future experiments ($^{236,238}U$ and ^{241}Am). ■

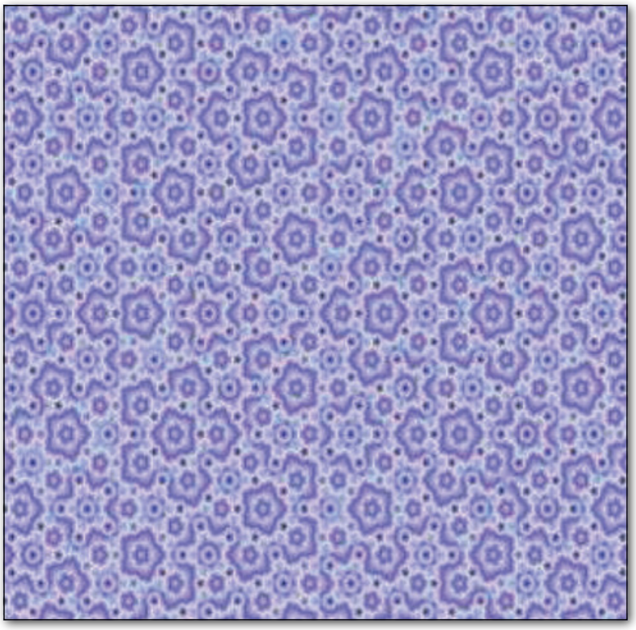
■ **C. Guerrero *et al.* (85 co-authors)**,
'Simultaneous measurement of neutron-induced capture and fission reactions at CERN', Eur. Phys. J. A, **48**, 29 (2012)

CONDENSED MATTER

Tiling pattern governs quasicrystals' magnetism

Few material classes have generated as much interest as quasicrystals. The present paper outlines the progress to date in the theory explaining the magnetic properties of these quasicrystals. In 2011, the fascination with quasicrystals was rekindled by the awarding of the Chemistry Nobel Prize to Daniel Schechtman for their discovery in 1984. Their structure differs from standard crystals in that they are packed in patterns that repeat in space, in an aperiodic fashion. The resulting structures exhibit a highly complex ordering with 5, 8, 10 or 12-fold symmetries, which are not manifested in periodic, classic crystals.

This review shows that by focusing on two-dimensional tiling, it is possible to study the magnetic properties of these quasi-periodic materials at the atomic scale. This article provides an overview of the specificities of 2D quasicrystal structures, including those known as Penrose (see illustration) and Ammann tilings. The author considers a model called the Heisenberg model to explain their magnetic properties compared with other types of perfectly ordered as well as disordered crystals and quasicrystals.



▲ The five-fold symmetry of the Penrose tiling

The author discusses the use of several simulation methods, both quantitative and numerical, to show that the magnetic state in quasicrystals is characterised by a relatively high degree of magnetic order, in which an internal characteristic of electrons, called spin, alternates between the up and down direction, described as the antiferromagnetic or Néel state. In addition, highly complex spatial distribution of local staggered magnetisation also occurs within such materials. ■

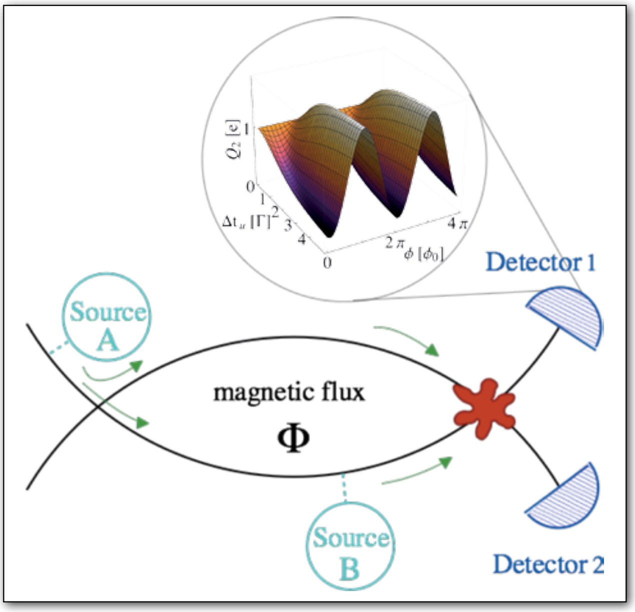
■ **A. Jagannathan**,
'The Heisenberg antiferromagnetic model in two dimensional quasicrystals', *Eur. Phys. J. B* **85**, 68 (2012)

QUANTUM PHYSICS

Single-particle interference versus two-particle collisions

The recent experimental realization of an on-demand coherent single-electron source [G. Fève *et al.*, Science (2007)] allows exploiting the individual particles' quantum nature in controlled single- and multi-particle effects in solid-state devices. In particular, it inspires to perform interference studies in electronic interferometers into which well-separated single particles - electrons or holes – are injected.

Stimulated by these possibilities, this article proposes a setup where the single-particle interference in an electronic interferometer is influenced by the presence of a second particle-emitting source placed in one of the interferometer arms. The two sources can be synchronized with respect to each other creating tunable and coherent modulation, and even suppression, of interference. Importantly, this study envisions and theoretically analyzes an experimental setup, in which both aspects of the quantum nature of electrons can be observed simultaneously: its wave-like and its particle-like behaviour.



▲ Electronic interferometer fed by two independent single-particle sources. The magnetic-field-dependent interference, as a function of the phase difference Φ, in the transmitted charge Q_2 is found to be suppressed with the occurrence of particle collisions at time difference $\Delta t_u=0$.

The time-dependent current shows an interference pattern, to which the second source adds a peculiar time-dependent phase determined by its working mode: this intriguing interference effect is convincingly explained by the particles' wave-like behaviour. Yet at the same time, a tunable coherent suppression of the interference is expected in the total transmitted charge, which is shown to be a feature of the particles' ability to collide. The coexistence of the two effects leading to interference suppression in the absence of dephasing is a fascinating challenge for our understanding of quantum mechanics. ■

■ **S. Juergens**, **J. Splettstoesser and M. Moskalets**, 'Single-particle interference versus two-particle collisions', *EPL* **96**, 37011 (2011)

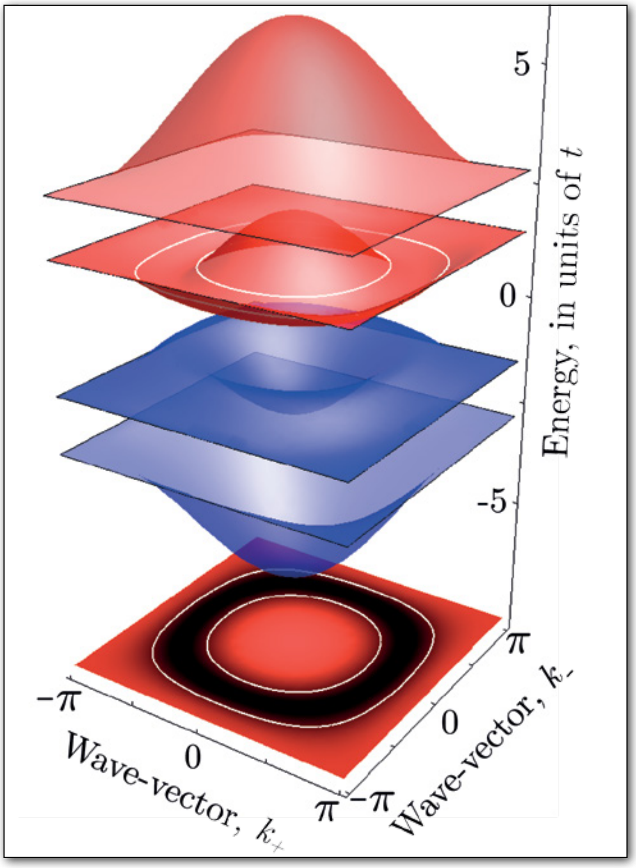
ATOMIC AND MOLECULAR PHYSICS

Spin-charge-density wave for ultra-cold atoms

Ultra-cold atoms in optical lattices can nearly ideally realize the simple Hamiltonians that model the behaviour of real condensed-matter systems, but with full control of parameters. Here, we show that Raman coupled ultra-cold fermions in a two-dimensional square optical lattice can have a different behaviour depending on their position in the lattice: at a certain site, the system gains energy if the fermion flips its spin, whereas in the sites around this one, the same process costs energy. This physical system is described by a tight-binding model with a Zeeman coupling that is different for neighbouring sites, thus dividing the lattice into AB sublattices. The single-particle spectrum has four bands; the third of which is shaped like a squarish Mexican hat (Figure). By filling up the energy levels up to the third band, the Fermi surface is squircle-shaped. This squarish-circle favours nesting and the system develops a coupled modulation in the density and spin, analogous to a spin-charge-density wave in solid- state systems. Using field-theoretical methods, we develop a generalized formalism, which allows us to account for coupled charge and spin degrees of freedom simultaneously. We then determine the critical value of the parameters for the occurrence of the phase transition to this inhomogeneous density and spin state, which occurs at an incommensurate wave vector. Our results could be observed with state-of-the-art spectroscopic techniques. The investigation of spin-dependent optical lattices is an important direction of research in the field of spintronics with ultra-cold atoms, which will further strengthen the bonds between condensed matter and atomic physics. ■

■ **D. Makogon**, **I. B. Spielman and C. Morais Smith**, 'Spin-charge-density wave in a rounded-square Fermi surface for ultra-cold atoms', *EPL* **97**, 33002 (2012)

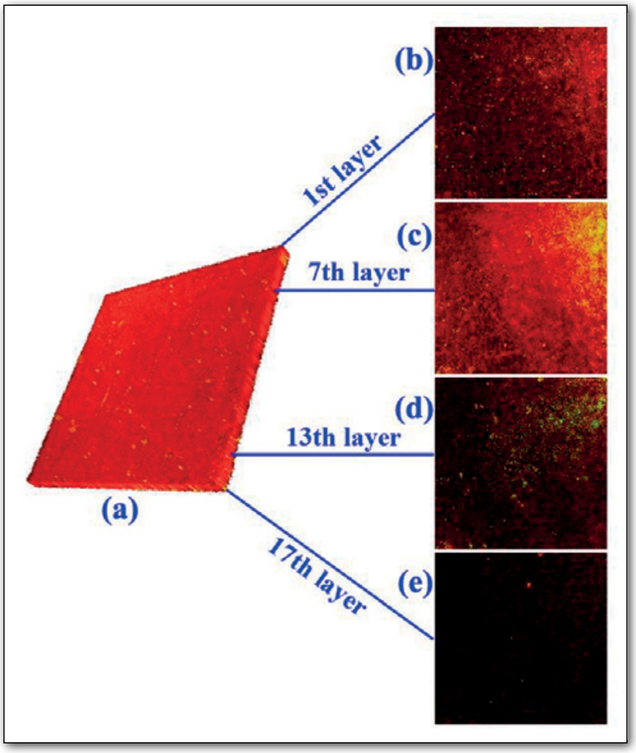
▼ Band structure: the Fermi energy (concentric squircles) is depicted by white contours (see also projection into the momentum plane).



APPLIED PHYSICS

Enterococcus faecalis biofilm **in an air plasma jet**

Enterococcus faecalis is a gram-positive bacterium, which often infects root canals during endodontic dental treatments and is among the most antibiotic- and heat-resistant pathogens, which strongly resist calcium hydroxide treatment. Inactivation of these pathogens is particularly challenging because they form thick self-organized biofilms. Effective inactivation of a record thick 25.2 μm-thick biofilm by using a handheld, 12 V DC battery-operated plasma jet device is reported.



▲. Effective inactivation of enterococcus faecalis biofilms. After only 5 min of the plasma treatment, all the bacteria are killed, not only on the surface but also in the 17th layer of the 25.2 μm-thick biofilm.

The plasma jet, called the Plasma Flashlight operates in open air at atmospheric pressure and does not require any external gas supply or wall power. This makes the Plasma Flashlight suitable for various point-of-care applications, such as in ambulance emergency outcalls, natural disaster rescue and military combat operations, treatments in remote locations, *etc.* It produces a plasma plume with the temperature of 20-28°C, which is very close to room temperature. The device is extremely energy efficient and only 60 mW DC power is required to sustain the discharge. The figure shows the results of inactivation of the *Enterococcus faecalis* bacteria in each of the 17 layers within a 25.2 μm-thick biofilm. These results advance our ability to effectively inactivate biofilms formed by notoriously drug- and treatment-resistant pathogens. The reported mobile, handheld plasma jet device may also be used for surface treatment and functionalization in nanotechnology, device fabrication, and several other applications where surface temperature sensitivity is an issue. ■

■ **X. Pei, X. Lu, J. Liu, D. Liu, Y. Yang, K. Ostrikov, Paul K. Chu and Y. Pan**,
'Inactivation of a 25.5 μm *Enterococcus faecalis* biofilm by a room–temperature, battery-operated, handheld air plasma jet', *J. Phys. D: Appl. Phys.* **45**, 165205 (2012)

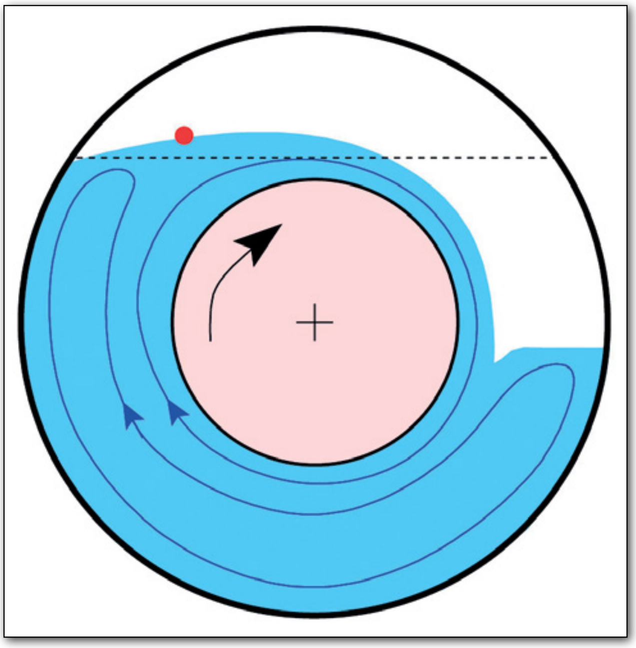
LIQUID PHYSICS

Swirls study to optimise contacts between fluids

A fluid dynamics model of the interface between two swirling fluids gives clues to how to optimise homogeneous feeding of cells in suspension from a liquid nutriments supply in a bioreactor. Studying mixing between two incompatible fluids shows that it is possible to control the undercurrents of one circulating fluid to optimise its exposure to the other. This is the work presented in this article.

The authors compare quantitative experimental observations of a viscous fluid, similar to honey, with numerical simulations. They focus on a fluid, partially filling the space between two concentric cylinders with the inner one rotating, a system previously used to study roll coating and papermaking processes. They observe the presence of several flow eddies, stemming from fluid flowing past the inner cylinder, causing it to swirl, and the appearance of reverse currents including one orbiting around the rotating cylinder and a second underneath. They make the second eddy disappear by increasing the fluid filling or its velocity. Instead of using a highly viscous oil combined with air as a top fluid, this model could be applied to a suspension of bioreactor cells typically used to produce biotech medicines, combined with a light oil-containing nutriments as a top fluid. Ultimately,

▼ A representation of the two currents occurring between the concentric cylinders.



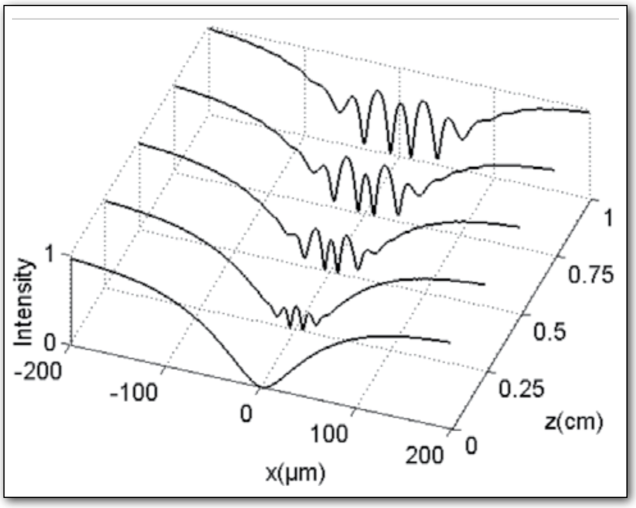
it could help identify the right parameters and adequate mixing time scales to ensure that nutriments feed all the cells homogeneously with no segregation. ■

▮ **J. Peixinho**, **M. Mirbod and J.F. Morris**,
'Free surface flow between two horizontal concentric cylinders', *Eur. Phys. J. E* **35**, 19 (2012)

OPTICS

Solitary waves induce waveguide that can split light beams

Simulations are performed to help understand the occurrence of multiple solitary optical waves that are used to reconfigure optical beams. Researchers have designed the first theoretical model that describes the occurrence of multiple solitary optical waves, referred to as dark photovoltaic spatial solitons. Because the shape of dark solitons remains unaffected by the crystal in which they travel, they induce waveguides, which can be used, for example, to reconfigure optical beams by splitting them.



▲ **Formation of the multiple dark photovoltaic solitons from even initial conditions in steady state regime.**

Dark solitons are generated in so-called photorefractive crystals – crystals that respond to an incoming light beam by decreasing their refractive index as optical intensity increases, causing the incoming beam to defocus. This effect is called nonlinear self-defocusing. Dark solitons occur when the diffraction of an incoming beam by the notch, located at the crystal's entrance, is compensated by the crystal's self-defocusing effect. As a result, dark solitons can induce waveguides for light beams, allowing them to travel unchanged through photorefractive crystals. The authors develop the first numerical simulation to model the formation and evolution of one-dimensional multiple dark solitons inside a photorefractive crystal, relying on an approximation technique called the beam propagation method. By expanding the width of the dark notch located at the entrance of the crystal, which, unlike in previous studies, was not given any special function, they showed it was possible to create multiple dark solitons. These solitons appeared in either odd or even numbers, depending on the initial beam phase or amplitude. The authors also confirmed previous findings that showed that when multiple solitons are generated, the separation between them becomes smaller. Further, the solitons become progressively wider and less visible, the farther away they are from the main dark notch entry location. ■

▮ **Y. Zhang**, **K. Lu**, **J. Guo**, **K. Li and B. Liu**,
'Steady-state multiple dark photovoltaic spatial solitons', *Eur. Phys. J. D* **66**, 65 (2012)

APPLIED PHYSICS

High carrier injection **for all-silicon laser**

Presently, laser diodes are mainly used to convert electronic signals into optical signals in fast communication systems. They are manufactured with a wide variety of semiconductors different from silicon and the incorporation of these lasers in silicon layers leads to distortion of the signals, degradation of sensitivity, and limits the reliability. Silicon, with more than 95% of the international market share, dominates other semiconductors. A silicon laser source would provide the ideal improvement for future high-speed electronics. The structure of silicon limits its light-emitting efficiency and, despite the very fast development of silicon based electronics, optical applications of silicon devices have not been conducted thoroughly.
The question "which silicon device will be useful for transforming electronic signals into optical signals?" is still relevant today. This paper presents an advance in optoelectronic silicon devices since it introduces and formulates a process for the creation of an optical active layer inside silicon devices. A degradation of the structure is induced by hot carriers injection. The process has been controlled by the analysis of the junction characteristic. The authors suggest that the created defects disturb the lattice periodicity by creating energy states in the band gap of the silicon. The model is based on a population inversion associated with a defect layer for carrier confinement and an electrical stimulation of light is demonstrated. The emitted light is localized is an area close the emitter-base junction. The authors measure the amplification of emitted light, and they showed that defect layer appears as an optical cavity.
This groundwork introduces practical ways for improving the optical properties of silicon devices for optoelectronic applications. ■

▮ **H. Toufik**, **W. Tazibt**, **N. Toufik**, **M. El Tahchi**, **F. Pélanchon and P.Mialhe**,
'High carrier injection for all-silicon laser', *Eur. Phys. J. AP* **58**, 10103 (2012)

Optically pumped alkali magnetometers for biomedical applications

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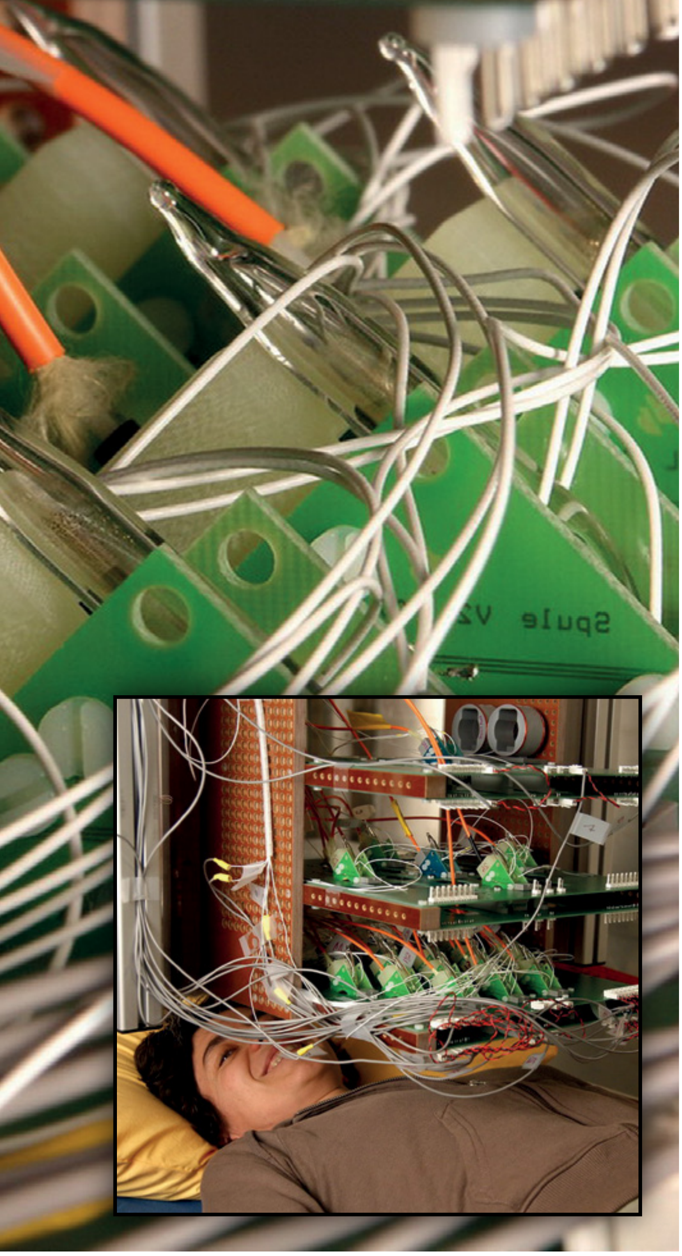
Atomic magnetometers are novel sensitive devices for medical diagnosis. They use laser radiation to prepare spin-coherent atomic samples and to monitor their perturbation by the magnetic field of interest [1]. In recent years, they have reached sensitivities comparable to [2], or better than [3] SQUID magnetometers. We discuss the principles of atomic magnetometers based on optically detected magnetic resonance (ODMR) and review their biomedical applications.

▲ Partial view of sensor array in the 19-channel Fribourg magnetocardiography (MCG) device and (inset) subject positioned for MCG measurements (Details in the text).

Optically pumped atomic magnetometers measure the Larmor frequency ν_L at which the bulk magnetization of a spin-polarized alkali metal vapour in a glass cell precesses around the field of interest $\vec{B}_0$. The precession frequency is related to the modulus of the magnetic field by $\nu_L=(\gamma/2\pi)|\vec{B}_0|$, where $\gamma/2\pi\approx 3.5$Hz/nT for ^{133}Cs, so that the magnetic field measurement consists in a frequency measurement. In so-called ODMR magnetometers, ν_L is determined by Optically Detected Magnetic Resonance using laser radiation.

The general principle of an ODMR magnetometer can be understood as follows: A bulk spin polarization is created in the atomic medium through optical pumping, a process introduced in the 1950s, by which angular momentum of polarized light, resonant with an atomic



absorption line, is transferred to the atomic medium by multiple absorption-emission cycles. With circularly polarized light, the medium acquires in this way a vector magnetization – called orientation –, while linearly polarized light produces a tensor magnetization – called alignment. Here we consider only vector polarization $\vec{S}$ and the associated bulk vector magnetization $\vec{M} \propto \vec{S}$. The (suitably oriented) magnetic field $\vec{B}_0$ exerts a torque on $\vec{M}$, which induces its precession around $\hat{B}_0$. This precession – together with spin relaxation – produces a steady-state magnetization, whose direction and magnitude differ from the magnetization initially created by optical pumping. Detection relies on the fact that the optical absorption coefficient of a spin-polarized atomic medium depends on the magnitude and orientation of its magnetization. The alterations of the magnetization by the magnetic field can therefore be probed by recording the transmitted light power. In the simplest realization of an ODMR magnetometer, a single light beam serves both to prepare and to probe the magnetization.

Modern Optically Pumped Magnetometers (OPMs) use narrowband laser light, whose frequency is stabilized to a specific absorption line of the atomic medium. They use a coherent drive (modulation) mechanism for synchronizing the spin precession initiated by optical pumping. The drive at frequency ν_{mod} leads to a modulation of the transmitted light intensity, whose amplitude and phase are extracted by phase-sensitive (lock-in) detection. The various modulation techniques deployed for the phase-synchronous drive of the spins distinguish between the growing number of magnetometer types known today.

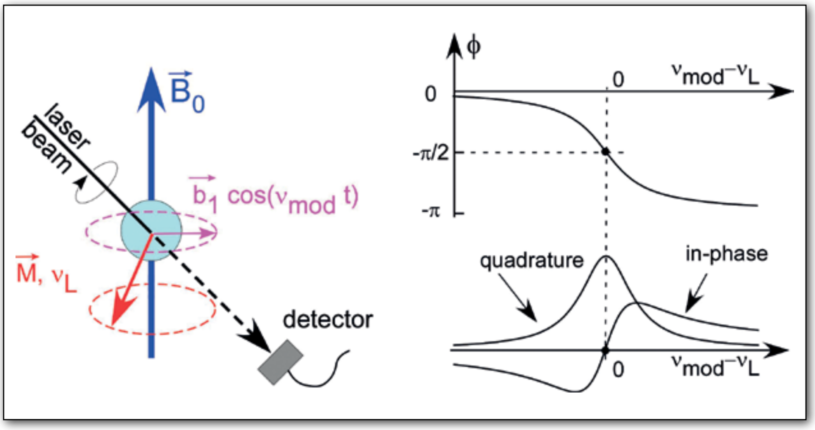
In the ODMR magnetometer (Figure 1, left) the synchronizing coherent drive is provided by an additional weak magnetic field oscillating (or rotating) at the frequency ν_{mod}. The amplitude and phase relations between the drive and the magnetometer response in terms of the transmitted intensity modulation, are those of a classical harmonic oscillator: the amplitudes of the in-phase and quadrature components have a resonant dispersive and absorptive Lorentzian dependence, respectively, on the detuning $\delta\nu = \nu_{mod} - \nu_L$, while the phase ϕ between drive and response has an arctan-dependence on $\delta\nu$ (Figure 1, right). The near-resonance linear dependence of the dispersive signal or the phase signal on $\delta\nu$ is used in an electronic feedback loop that ensures that the drive frequency ν_{mod} tracks the Larmor frequency ν_L in a phase-coherent manner: ν_{mod} then carries the magnetometric information. The magnetometric sensitivity is determined by the ratio of the resonance linewidth and the signal-to-noise ratio (SNR) of the optical detection. Narrow resonances must ensure long spin coherence relaxation times, made possible by preventing spin depolarization due to collisions with the cell walls. This is achieved in our magnetometers by a polarization-preserving wall coating [4] (other magnetometers use inert buffer gases to slow down wall collisions). The ODMR magnetometers are operated near the shot noise limit of the detection light with a SNR (in a 1 Hz bandwidth) in excess of 10^5, yielding intrinsic sensitivities of a few 10 $fT/Hz^{1/2}$, or below [2].

Biomedical applications

ODMR magnetometer detection of cardiomagnetic fields

The magnetic field of the beating human heart is the strongest field of medical interest, albeit more than a

▾ FIG. 1: Left: In the ODMR-magnetometer, the transmitted light intensity is modulated when the rotating (oscillating) weak drive field b_1 is synchronized to the processing magnetization $\vec{M}$. Right: Signals extracted by phase-sensitive detection. The dots mark the working point that is established by electronic feedback.

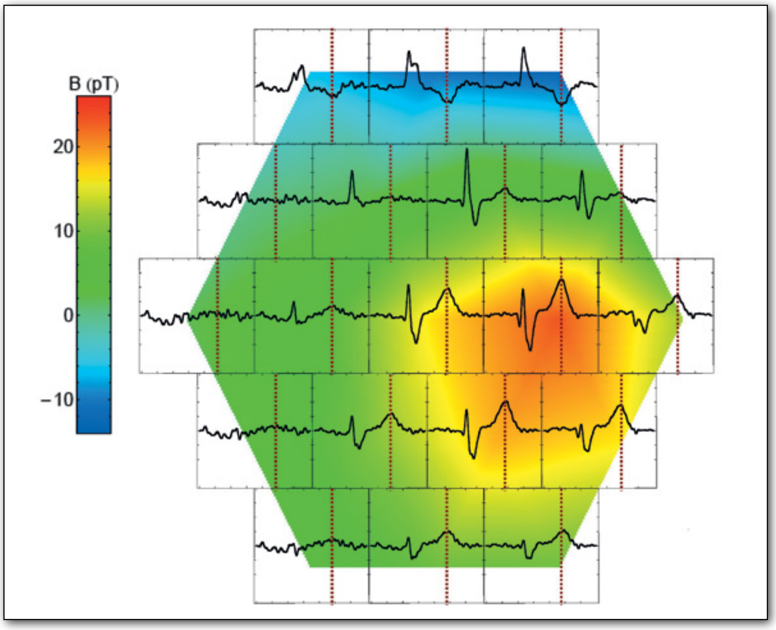


million times weaker than the (weak) geomagnetic field. A magnetocardiogram (MCG) is a representation of the time dependence of the out-of-chest component of the cardiac magnetic field during one period of the cardiac cycle. For measuring MCG signals, fluctuating environmental magnetic fields and their gradients have to be suppressed by appropriate shielding in combination with first- or second-order differential measurements involving two or three sensors, respectively. In practice, the ambient field is cancelled and an offset field of a few percent of the earth field is applied perpendicular to the subject's chest, so that the magnetometer(s) oscillate at the corresponding Larmor frequency. The projection of the magnetic field from the heart onto the direction of the offset field modifies the Larmor frequency and this modification represents the actual MCG signal.

In 2003, we could show for the first time that MCG signals can be detected by two laser-driven OPMs forming a first-order gradiometer [5]. By moving the subject with respect to the magnetometers we were able to record two-dimensional maps of the magnetic field distribution from the heart [6]. Cardiomagnetic map dynamics during the QRS-complex and the T-wave can be seen as animations in [6]. These early measurements were done in a μ-metal shielding room, where the subject had to lie still during the 2 hours required to record all data for the animations. In a subsequent multi-year effort we have developed a 25-sensor array [7] which allows us to infer dynamic maps from the simultaneous recording of MCG signals at 19 positions over the chest (see Fig. 2). This brought the measurement time down to less than 2 minutes.

A close-up view of the apparatus used to record the signals of Fig. 2 is shown in the introductory illustration, where one sees a sub-ensemble of the 25 identical compact magnetometer modules, in which the geometry of Fig. 1 is implemented. An optical fibre (orange) brings the light to the module, in which the circularly polarized beam traverses the vapour cell, after which it is detected by a photodiode. The field $\vec{b}_1(t)$ is produced by two coils laid out on the (green) printed circuit boards. The (white) coaxial cables bring the current to these coils and carry the photocurrent to the electronics. The system is operated by a complex system [7] of phase-sensitive detectors and electronic feedback loops controlled by a digital field-programmable gate array system. In view of potential hospital installations we performed these measurements in a double-walled aluminium shielding room which provides sufficient suppression of magnetic fields oscillating at the line frequency.

▾ **FIG. 2:** Magnetocardiogram (MCG) map of the human heart. The individual graphs represent 19 denoised MCG traces recorded by a hexagonal array of 19 atomic magnetometers (see title figure) spaced by 50 mm, and located 25 mm above the chest. The magnetic field values at the times marked by the vertical dotted red lines (T-wave) were used to construct the underlying map by interpolation [9].



Alternative schemes for MCG detection

Since our first demonstration of MCG detection by laser-pumped atomic magnetometers in 2003, a growing number of research teams have joined the field. In 2007, MCG traces were recorded in an unshielded environment using a magnetometer based on frequency modulation [8]. More recently, MCG detection by chip-scale ODMR magnetometers was compared to SQUID-based detection in the high performance magnetic shielding room at PTB-Berlin [9]. Spin-exchange relaxation free magnetometers [3] have been applied for recording magneto-encephalographic signals [10], and have recently produced human [11] and fetal [12] MCG signals of outstanding quality.

Discussion

The noninvasive and contact-free detection of cardiomagnetic fields has a high potential for the early detection of cardiovascular diseases, which themselves represent the most common cause of death in industrialized countries. MCG maps allow, *e.g.*, the localization of abnormal current sources in the myocardium related to arrhythmias and other heart conditions. Source localization from measured magnetic field distributions (the so-called inverse problem) profits from the fact that the magnetic fields – in contrast to the electric fields detected in standard ECG signals – are not perturbed by the tissue between the heart and the detector.

However, more than 40 years after the first recording of MCG signals by liquid He-cooled SQUID magnetometers, the method of MCG diagnostics has not yet found a way into every-day clinical practice. There is hope that atomic magnetometers operated at room temperature will help to change this situation.

Outlook

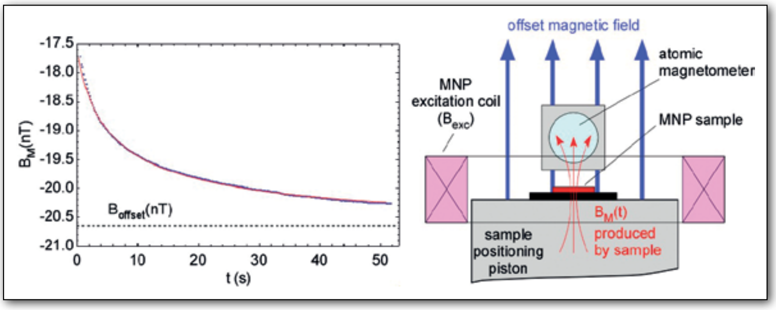
Atomic magnetometers are about to find another promising application in the field of biomedical imaging. The method relies on the detection of the magnetic field produced by magnetic nanoparticles (MNP) [9]. Since a few years, such particles are being used in medical applications, such as drug delivery, hyperthermic therapy, MRI contrast enhancement, and medical imaging. The latter application uses MNPs embedded in functionalized shells that preferentially attach to (or are taken up by) specific biological entities such as organs, tumors, or cells. The relaxation time of the magnetization of bound MNPs surpasses that of unbound particles by orders of magnitude. The spatial mapping of these relaxation times, monitored by recording the corresponding magnetic field decays with OPMs thus opens new ways for the imaging of organs and tumors. The technique is known as magneto-relaxometry (MRX). We are currently investigating MRX signals from super-paramagnetic iron oxide nanoparticles (Fig. 3) using the apparatus described in [7].

Conclusion

Although OPMs have been around for more than half a century, the advent of affordable tunable laser sources has opened new perspectives for atomic magnetometry, as witnessed by the growing number of novel magnetometric techniques developed in the past decade. For many applications, OPMs have the potential to replace cryogenic SQUID detectors which have been for a long time the undisputed kings in low-field magnetometry, and in biomedical applications. ■

About the author

Antoine Weis received a Ph. D. degree in physics (1984) from ETH Zurich. He worked at MPI for Quantum Optics (Garching) and was Associate Professor at the University of Bonn. Since 1999 he holds the Chair for Atomic Physics at the University of Fribourg. His work on biomagnetometry has been honoured by an Innovation Award from the Wall Street Journal Europe in 2003 and has been nominated for the Leibinger Innovationspreis in 2004.



▲ **FIG. 3.** Magneto-relaxation signal from super-paramagnetic nanoparticles containing 5 mg of iron following a several seconds long magnetization in a field B_{exc} of 5 mT (unpublished).

Acknowledgements

The MCG project would not have been possible without a generous grant from the Velux Foundation. The nanoparticle project is supported by a Sinergia grant (CRSII2 130414) from the Swiss National Science Foundation.

References

[1] A recent comprehensive review of the field was given by D. Budker, *M. Romalis in Nature Physics* **3**, 227 (2007).

[2] S. Groeger, J.-L. Schenker, R. Wynands, A. Weis, *Eur. Phys. J. D* **38**, 239 (2006).

[3] I. K. Kominis, T. W. Kornack, J. C. Allred, M. V. Romalis, *Nature* **422**, 596 (2003).

[4] N. Castagna, G. Bison, G. Di Domenico, A. Hofer, P. Knowles, C. Macchione, H. Saudan, A. Weis, *Appl. Phys. B* **96**, 763 (2009).

[5] G. Bison, R. Wynands, A. Weis, *Appl. Phys. B* **76**, 325 (2003).

[6] G. Bison, R. Wynands, A. Weis, *Opt. Expr.* **11**, 904 (2003).

[7] G. Bison, N. Castagna, A. Hofer, P. Knowles, J.-L. Schenker, M. Kasprzak, H. Saudan, A. Weis, *Appl. Phys. Lett.* **95**, 173701 (2009).

[8] J. Belfi, G. Bevilacqua, V. Biancalana, S. Cartaleva, Y. Dancheva, L. Moi, *JOSA B* **24**, 2357 (2007) .

[9] S. Knappe, T. H. Sander, O. Kosch, F. Wiekhorst, J. Kitching, L. Trahms, *Appl. Phys. Lett.* **97**, 133703 (2010).

[10] H. Xia, A. Ben-Amar Baranga, D. Hoffman, M.V. Romalis, *Appl. Phys. Lett.* **89**, 211104 (2006).

[11] R. Wyllie, M. Kauer, G.S. Smetana, R.T. Wakai, T.G. Walker, *Phys. Med. Biol.* **57**, 2619 (2012)

[12]. R. Wyllie, M. Kauer, R. T. Wakai, T. G. Walker, arXiv:1202.5019v1 (2012).

LETTER TO THE EDITORS

Comments on the article on wind energy of C. le Pair *et al.* in Europhysics News 43/2, 22

The authors state "quantifying the efficiency (of wind energy) ... is by no means a simple matter." As true as this is, however, they present many simplifications to show the unsuitability of wind power as a large-scale energy provider. Besides several wrong statements, our major concern is the complete neglect of the fact that the current energy system is in a strongly transitional phase. Any analysis based on yesterday's configuration of power plant mix, transmission and distribution, and load management cannot contribute much significant insight into possibilities of future energy systems. It is state of the art to consider different types of energy producers, trans-national transport of energy, forecasting and diversification methods, demand side management, and so on. The challenge is to transform an old inflexible power system into a new complex and adaptive one. The insights obtained from the physics of complex systems have shown that, based on a deep understanding of the interaction of dynamic subsystems, intelligent coupling and control are required to achieve an efficient overall performance. This implies that a simple rigid coupling will lead to efficiency losses like those complained by the authors.

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The nature and origin of ultra high-energy cosmic rays

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■ DOI: 10.1051/epn/2012302
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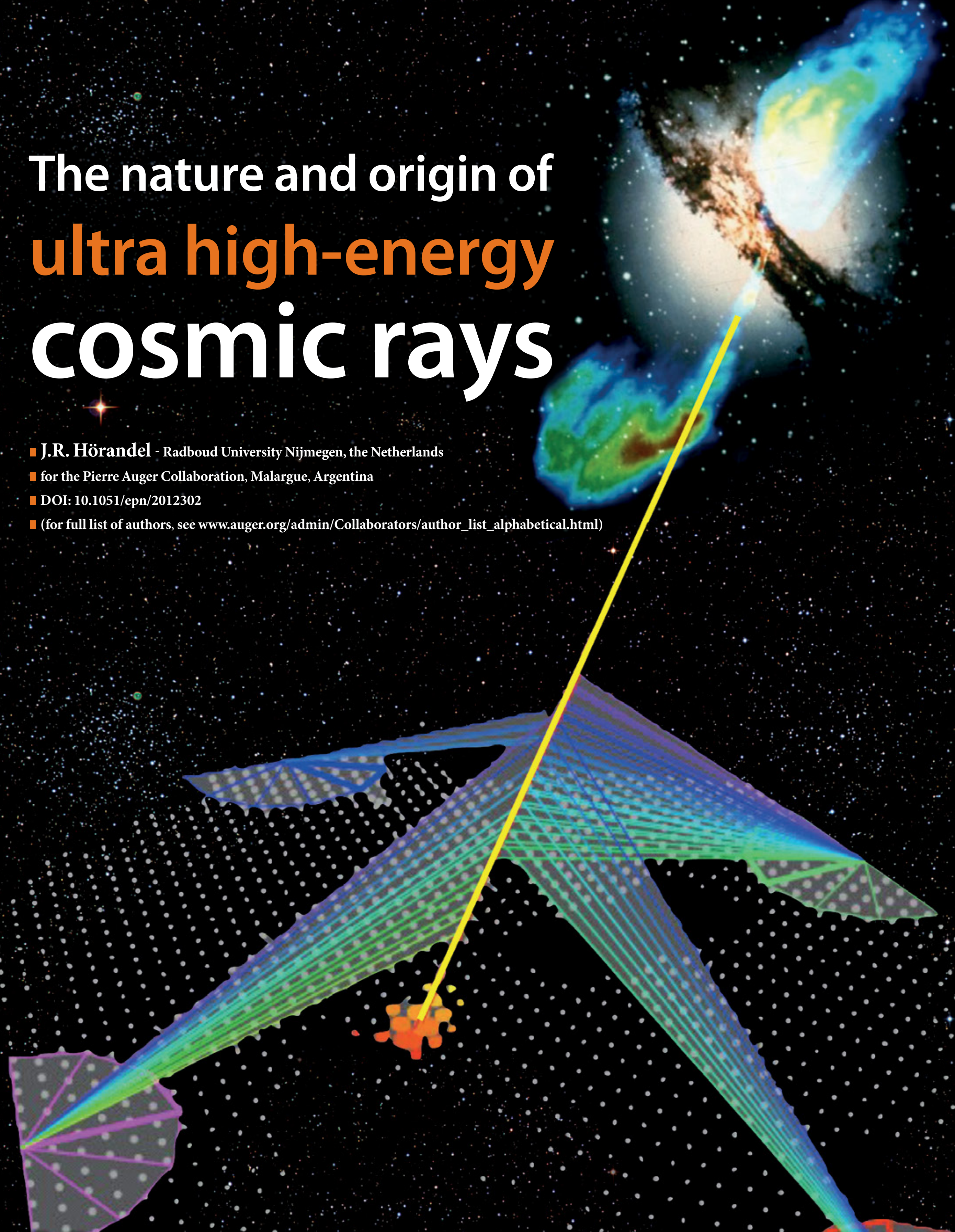


The Earth is exposed to a permanent rain of cosmic particles from outer space [1]. Most of the particles are fully ionised atomic nuclei, moving with relativistic energies. The bulk of them with energies up to 10^{17} eV originate within our Milky Way. They are most likely accelerated in supernova remnants. Some particles have a thousand times higher energies, *i.e.*, around 10^{20} eV. This corresponds to the kinetic energy of a tennis ball with a mass of 50 g and a velocity of 90 km/h.

However, in the tennis ball the energy is distributed between about 10^{24} atomic nuclei, while in cosmic rays the energy is concentrated on a single nucleus. This illustrates the immense energies of the highest-energy particles in the Universe. They exceed the energies reached in terrestrial, man made accelerators (like the Large Hadron Collider LHC in Geneva) by a factor of a hundred million.

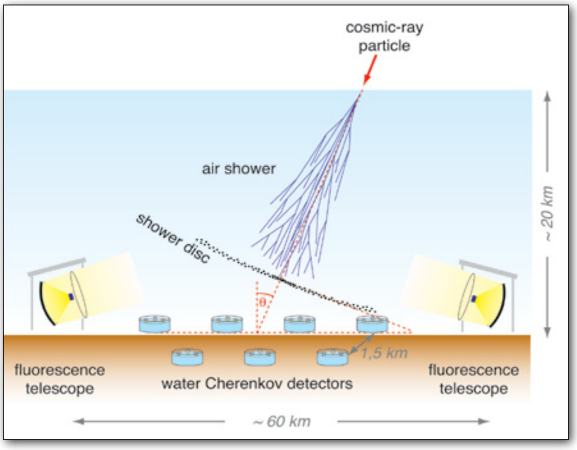
Possible origin

The energy density contained in the flux of extragalactic cosmic rays can be inferred from the measured all-particle energy spectrum, see below. To sustain the observed all-particle flux at energies exceeding 10^{17} eV, an energy density of 3.7×10^{-7} eV/cm^3 is required from cosmic rays originating beyond our galaxy [2]. The power required for a population of sources to generate this energy density over the Hubble time of 10^{10} years (the age of the Universe) is 5.5×10^{30} W/Mpc^3 (cf. glossary). Assuming a typical number density for classes of astrophysical sources in the Universe, this number can be converted into an average energy output per source. This leads to about 2×10^{37} W per active galaxy or approximately 2×10^{45} W per cosmological gamma ray burster. The coincidence between these numbers and the observed output in electromagnetic energy of these sources explains why they are considered promising candidates to accelerate highest-energy cosmic rays.

The cores of active galaxies are particularly interesting candidates. It is assumed that these galaxies host a black hole in their centre. The black hole attracts matter in an accretion disc. A fraction of this matter is ejected perpendicular to the disc, in the direction of the poles of the system, in a collimated particle stream at relativistic velocities – a jet. Astrophysical calculations show that particles can be accelerated to extremely high energies in such jets. In this scenario, these highest-energy particles propagate through the intergalactic space into our Milky Way and finally the Solar System, where we measure them at Earth.

The Universe is filled with leftover photons from the Big Bang. Each cubic centimetre contains about 400 photons with a radiation temperature of about three Kelvin (the 3 K background radiation or cosmic microwave background). The cosmic-ray particles lose energy through photo-hadronic interactions with these photons in the "GZK effect" [3]. It occurs at energies exceeding 6×10^{19} eV. As a consequence, particles can travel only a limited distance in an otherwise mostly empty/transparent Universe. In other words, the sources of the particles must be located inside a sphere around the Earth. The range of protons with energies around 10^{20} eV amounts to about 100 Mpc.

To clarify the origin of the highest-energy particles, their properties have to be measured. Our investigations focus on three main features: energy and arrival direction of the particles plus the particle type (photons, protons, atomic nuclei). The highest-energy cosmic rays are extremely rare. At Earth about one particle is registered in an area of 100 square kilometres in a hundred years. To measure such particles requires a huge measurement device which is operated for a long time. Such detectors are constructed on the surface of the Earth, rather than in space. The primary cosmic rays themselves are not measured, but secondary particles induced by them in the atmosphere, forming 'extensive air showers'.



▲ **FIG. 1:** Schematic view of the Pierre Auger Observatory

The Pierre Auger Observatory

The Pierre Auger Observatory combines two complementary techniques to measure air showers. On their way through the atmosphere the secondary particles stimulate nitrogen molecules in the air to emit fluorescence light. This light is measured with large telescopes. In addition, secondary particles reaching ground level are registered in an array of particle detectors. The latter are water Cherenkov detectors, measuring the light emitted by relativistic particles passing through a water tank. The set-up is sketched in Fig. 1. The world's largest cosmic-ray detector is located in Argentina, close to the city of Malargue at 1400 metres above sea level. It covers an area of 3000 square kilometres of Pampa. The Observatory has a hexagonal footprint with a diameter of about 60 kilometres.

EXTENSIVE AIR SHOWERS

In an extensive air shower the kinetic energy of elementary particles is used to produce new particles. According to the famous Einstein formula, $E = mc^2$, energy (E) can be converted into mass (m) - c is the speed of light. When a high-energy particle impinges onto the Earth's atmosphere it hits an atomic nucleus of an air molecule. New particles are produced with again extremely high energies. They also interact and a cascade of secondary particles is produced, an extensive air shower. Billions of secondary particles can be produced from the energy of a single cosmic-ray. The secondary particles move in a flat disc, with a thickness of only a few metres, at almost the speed of light through the atmosphere, see Fig. 1. The number of particles in a cascade first increases exponentially as the initial energy is distributed over more and more particles. When the (average) energy per particle in the shower falls below a critical energy, no further particle multiplication is possible and the number of particles in the cascade decreases due to absorption in the atmosphere. The point at which the shower contains a maximum number of particles is known as the shower maximum.

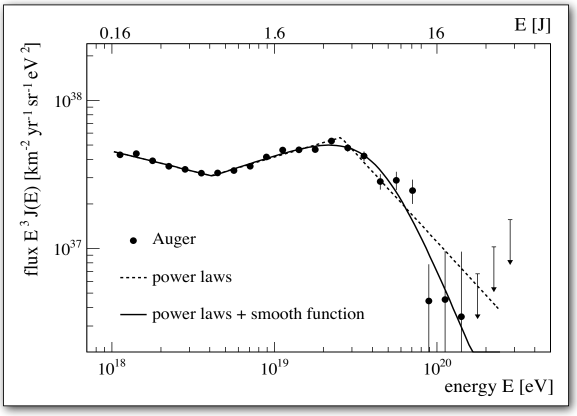


FIG. 2: All-particle cosmic-ray energy spectrum, as measured by the Pierre Auger Observatory [5]. The flux of cosmic rays is depicted as a function of particle energy. The flux on the ordinate has been multiplied by the energy cubed.

The highly sensitive telescopes can register air showers at distances of several tens of kilometres. This implies that air showers can be observed simultaneously by more than one telescope. The extension of the path of the original particle yields the axis around which the air shower develops. This can be measured to infer the arrival direction of the cosmic-ray particle.

Recent results

Energy spectrum

For the measurement of the energy spectrum, *i.e.*, the flux of the incoming cosmic particles as function of their energy, it is crucial to establish an absolute energy scale. The fluorescence light emitted from electrons during their passage through air has been measured in the laboratory at accelerators [4]. This is our "yardstick" to calibrate the energy scale of the observed fluorescence light in an air shower. Since the fluorescence telescopes can be operated only in moonless nights, a second cross-calibration step is necessary. Air showers which are observed simultaneously by the fluorescence telescopes and the surface detectors are used to establish an absolute energy scale for air showers registered only by the surface detectors. Finally, the flux of registered particles can be plotted as function of energy as shown in Figure 2 [5].

One recognises two structures in the spectrum:

- A dip around 4×10^{18} eV. This is believed to be caused by interactions between the cosmic particles and the photons of the 3 K microwave background. The cosmic rays lose energy due to the production of electron-positron pairs.
- A fall-off at energies exceeding several 10^{19} eV. There are presently two possible explanations for this feature:

1. The cosmic accelerators accelerate particles up to a maximum energy, which is proportional to the magnetic field in the astrophysical source times the charge of the corresponding particle. Thus, one expects that heavy nuclei (with larger atomic number) are accelerated to higher energies and the mass composition of cosmic rays is expected to become heavier with increasing energy.
2. As mentioned before, at energies exceeding several 10^{19} eV cosmic rays interact with the photons of the 3 K microwave background (GZK effect). Thus, cosmic rays lose a significant fraction of their energy due to photon-pion production. Nuclei break up through the GZK effect and it is expected that the composition of cosmic rays is modified during the propagation process.

Mass composition

The identification of the type of the impinging cosmic-ray particle is experimentally the biggest challenge. Incoming particles such as atomic nuclei (of different masses), photons, and neutrinos induce cascades in the atmosphere. The longitudinal development of the showers depends on the particle type. This is the key to measuring the particle species with an air shower experiment. Heavy nuclei interact early in the atmosphere, while light particles penetrate much deeper. This implies that for heavy nuclei the whole shower development takes place higher up in the atmosphere as compared to light particles. Thus, a measurement of the height of the shower above ground is a good estimate for the mass of the primary particle. Technically, we measure the distance between the detector and the position at which the shower contains its maximum number of particles. The investigations indicate that cosmic rays are composed of light particles (such as protons and helium nuclei) at energies around 10^{18} eV. The data exhibit a trend towards heavier nuclei with increasing energy. At energies around 4×10^{19} eV, shower properties consistent with a heavy elemental composition (*e.g.* silicon or iron nuclei) are observed [6]. At higher energies, at present, no mass measurement is available due to the small flux of particles at such energies. These mass measurements do assume that we can correctly extrapolate hadronic physics from accelerator experiments.
In addition to nuclei, the Auger Observatory is also sensitive to photons and neutrinos [7]. No such particles have been detected yet and thus, upper limits have been established: at energies exceeding 10^{18} eV less than a few percent of the measured particles are photons or neutrinos.

Arrival directions

In practice, the measurement of the arrival direction is the smallest experimental issue. However, a correct astrophysical interpretation of the data is a big challenge since charged particles are deflected in magnetic fields in the Milky Way and in intergalactic space.

GLOSSARY

eV, electronvolt, energy unit, 1 eV = 1.6×10^{-19} Joule
hadron, a hadron is composed of quarks (examples for hadrons are protons and neutrons)
light year, distance unit, 1 light year = 9.4605284×10^{15} m
muon, elementary particle with properties similar to an electron and a mass of 200 electron masses
Mpc, mega parsec, distance unit, 1 Mpc = 3.08×10^{22} m
pion, elementary particle composed of two quarks

The Auger Observatory provides two complementary approaches to determine the direction of an incoming cosmic ray. Stereo observations of the showers with multiple fluorescence telescopes provide a three dimensional picture of the shower in the atmosphere and, thus, the orientation of the shower axis, pointing back into the direction of the incoming particle. Secondly, the measurement of the arrival times of the individual particles at the surface detectors allows to measure the shower disc, with the arrival direction being perpendicular to it, see also Fig. 1.

A sky map of the arrival directions of the highest energy particles, with energies exceeding 6×10^{19} eV is shown in Fig. 3 [8]. Statistical investigations show that the particles do not arrive isotropically at Earth. The arrival direction of cosmic rays seems to be correlated with the general distribution of matter in the Universe. Several particles seem to originate close to the direction of Centaurus A, a nearby active galactic nucleus, only about 12 million light years from the Earth.

The deflection of the particles in magnetic fields in the Universe is proportional to the charge of the particles. At the highest energies the average deflection amounts to about 2.7 degrees times the particle's charge. Hence, a possible correlation of the arrival directions of cosmic rays with astrophysical objects can be most easily explained by low-charge (*i.e.* light nuclei) cosmic rays.

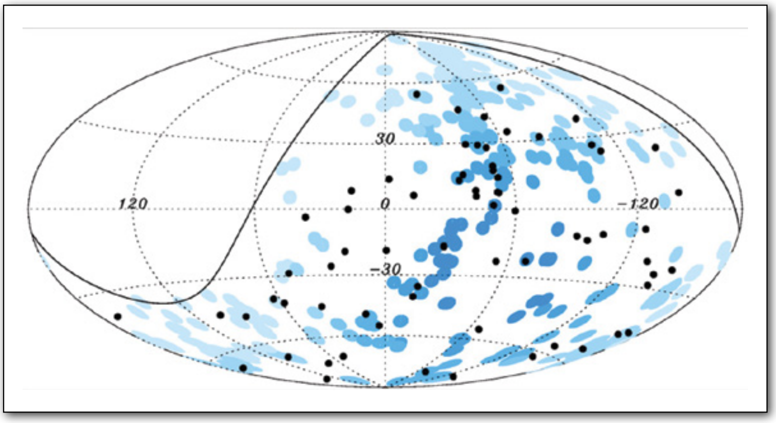
Conclusions

The Pierre Auger Observatory provides the most accurate measurements of highest-energy cosmic rays to date. However, the origin of the highest energy particles in the Universe cannot yet be established beyond doubt.

If the observed fall-off in the energy spectrum is due to the GZK effect, the composition observed at Earth depends on the mix of nuclei being emitted from the sources and modifications to it during the propagation through the Universe. In case of a light composition (small charge), the particles would be only marginally deflected in magnetic fields and the particle trajectories would point back to their sources.

If the fall-off in the energy spectrum is caused by the maximum energy attained in astrophysical accelerators, this would yield a heavy composition at Earth (large charge) at the highest energies, as seen by a trend in the observed mass composition. In this case an interpretation of the arrival directions of cosmic rays is more difficult.

A possible key to resolve this issues are detailed studies of hadronic interactions in the atmosphere such as, *e.g.*, the measurements of the proton-proton interaction cross sections at energies exceeding the energies of the LHC [9] and direct measurements of the interaction parameters at the LHC. Such data will further improve our understanding of the development of air showers in the atmosphere. With this increased knowledge we hope to clarify the origin of the highest energy particles in the Universe in the near future. ■



▲ **FIG. 3:** Arrival direction of the highest energy cosmic rays ($E > 6\times10^{19}$ eV) on the sky, as measured by the Pierre Auger Observatory [8]. The black dots indicate the measured cosmic rays. The blue circles represent the positions of active galactic nuclei (AGN), the intensity is proportional to the fraction of time during which the particular source can be seen by the Auger Observatory. The map is in Galactic coordinates.

About the Author

Jörg Hörandel studied Physics at the University of Karlsruhe, Germany, where he also obtained his PhD in 1997 and later his Habilitation/Venia Legendi in 2004. Since 2007 he is assistant professor of astroparticle physics and astronomy at Radboud University Nijmegen, the Netherlands.

Acknowledgement

The Pierre Auger Observatory has been built and is operated by scientists from many countries around the world, see www.auger.org and www.auger.org/admin/Collaborators/acknowledgments.pdf.

The author would like to thank Roger Clay for his valuable comments on the manuscript.

References

[1] M. Nagano, A.A. Watson, *Rev. Mod. Phys.* **72**, 689 (2000); J. Blümer, R. Engel, J.R. Hörandel, *Progress in Particle and Nuclear Physics* **63**, 293 (2009).

[2] J.R. Hörandel, *Reviews in Modern Astronomy* **20**, 203 (2008) and references therein

[3] K. Greisen, *Phys. Rev. Lett.* **16**, 748 (1966); G.T. Zatsepin, V.A. Kuz'min, *JETP Lett.* **4**, 78 (1966).

[4] F. Arqueros, J.R. Hörandel, B. Keilhauer, *Nuclear Instruments and Methods A* **597**, 1 (2008).

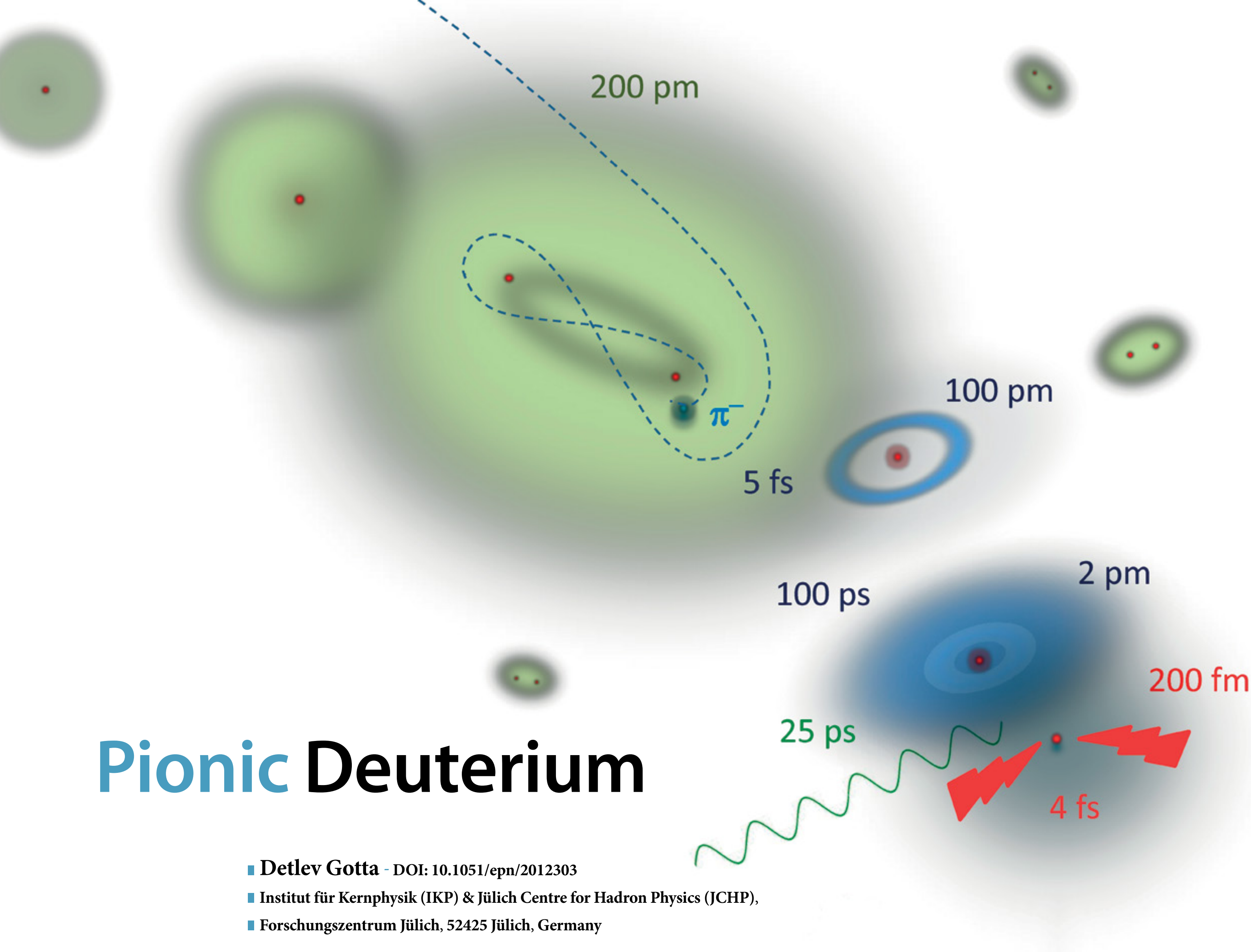
[5] J. Abraham *et al.* (Pierre Auger Collaboration), *Physics Letters B* **685**, 239 (2010); J. Abraham *et al.* (Pierre Auger Collaboration), *Physical Review Letters* **101**, 061101 (2008).

[6] J. Abraham *et al.* (Pierre Auger Collaboration), *Physical Review Letters* **104**, 091101 (2010).

[7] J. Abraham *et al.* (Pierre Auger Collaboration), *Astroparticle Physics* **31**, 399 (2009) ; J. Abraham *et al.* (Pierre Auger Collaboration), *Physical Review D* **79**, 102001 (2009).

[8] J. Abraham *et al.* (Pierre Auger Collaboration), *Science* **318**, 938 (2007); J. Abraham *et al.* (Pierre Auger Collaboration), *Astroparticle Physics* **29**, 188 (2008); P. Abreu *et al.* (Pierre Auger Collaboration), *Astroparticle Physics* **34**, 314 (2010).

[9] R. Ulrich *et al.* (Pierre Auger Collaboration), *Proceedings of the 32nd International Cosmic Ray Conference*, Beijing, 946 (2011).



Pionic Deuterium

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Atoms formed after Coulomb capture of negatively charged pions rapidly develop to nuclear dimensions and eventually decay by strong interaction. The strong force affects energy and line width of X-rays emitted during a de-excitation cascade which allows precise measurements of hadronic quantities by means of crystal spectrometers. Pionic deuterium - involving the lightest composite nucleus - constitutes a bridge between particle and nuclear physics.

▲ Length and time scales of pion capture at a deuterium molecule, subsequent de-excitation cascade, and nuclear decay

The close relation between particle and nuclear physics is evident from prediction and discovery of mesons (medium heavy particles) mediating the short-range nuclear force. The lightest one – the pion – though 270 times heavier than an electron is still light on the typical nuclear scale of 1 GeV/c^2, and its interaction with the nucleon is a corner-stone in understanding the nuclear force.

The description is based on quantum chromodynamics (**QCD**), where elementary particles and forces are quarks and gluons which, however, are not realised as individual particles in nature (confinement). Nevertheless, symmetries of QCD determine properties of the directly accessible, but composite, strongly interacting particles (hadrons) – the mesons, nucleons as well as nuclei. Effective field theories like chiral perturbation theory (χPT) - the modern low-energy approach of **QCD** - exploit chiral symmetry founded on the small masses of the light quarks u, d and s. In a perturbative approach, where order parameters are momenta, pion mass, and fine structure constant α, strong and electromagnetic interactions are treated on the same footing [1-4].

Exotic atoms

The existence of negatively charged muons (a "heavy" electron), mesons, and antiprotons suggested immediately the formation of atomic systems with a nucleus $A(Z,N)$ by eliminating electrons (Box 1). Such **exotic atoms** were predicted in the late 1940s and verified experimentally soon after at accelerator facilities. Later on, systematic and high-statistics precision studies became possible at meson factories and dedicated low-energy antiproton storage rings.

Exotic atoms are created as highly excited systems. During an atomic cascade, de-excitation occurs among others by Auger electron and X-ray emission, which allows a variety of studies [5]:

- mass and spin of the captured particle,
- nuclear moments (from muonic atoms),
- test of bound-state quantum electrodynamics,
- behaviour of excited many-electron systems,
- muon catalyzed fusion, and
- the strong force at low energies by measuring shift and broadening of low-lying atomic levels.

Exotic hydrogen plays an outstanding role as it directly probes the elementary hadron-proton system and - using isotopes - additionally the interaction with the neutron.

Pion-nucleon scattering

Neglecting the electric charge, (almost) identical strong interaction properties of proton and neutron led to the concept of isospin symmetry. Nowadays, it is identified with the (approximate) symmetry of u and d quarks building up the nucleons.

In terms of isospin, three pions $\pi \equiv (\pi^{\pm,0})$ and two nucleons $N \equiv (p,n)$ combine (analogue to spins) to 1/2 and 3/2 states. Therefore, in the limit of isospin invariance two different scattering lengths $a_{\pi N}$ are sufficient to determine all $\pi N \rightarrow \pi N$ reactions. For experimentally important channels, isospin conservation and charge symmetry yield

$a_{\pi^- p\rightarrow\pi^- p} - a_{\pi^+ p\rightarrow\pi^+ p} = -\sqrt{2}\cdot a_{\pi^- p\rightarrow\pi^0 n}$ and

$a_{\pi^+ p\rightarrow\pi^+ p} = a_{\pi^- n\rightarrow\pi^- n}$.

In pionic hydrogen (πH), energy shift ε and level broadening Γ of the atomic ground state 1s can be attributed to the elementary processes elastic and charge exchange scattering, respectively [6]:

$\varepsilon_{1s}(\pi H) \propto a_{\pi^- p\rightarrow\pi^- p} + \ldots$

$\Gamma_{1s}(\pi H) \propto (a_{\pi^- p\rightarrow\pi^0 n})^2 + \ldots$

For pionic deuterium, the shift is due to the coherent sum of proton and neutron scattering

$\varepsilon_{1s}(\pi D) \propto a_{\pi^- p\rightarrow\pi^- p} + a_{\pi^- n\rightarrow\pi^- n} + \ldots$

Ellipses stand for the strong (owing to the different mass of u and d quark) and the electromagnetic isospin symmetry violation.

> Exotic atoms allow 'scattering experiments' at relative energy 'zero'

Isospin and charge-symmetry breaking corrections are quantifiable consistently by the methods of χPT [6]. Multiple scattering and nuclear structure effects, as occurring in the case of πD, are well under control [9]. Hence, $\varepsilon_{1s}(\pi D)$ constitutes a decisive constraint on the scattering lengths as obtained from πH, particularly, as chiral symmetry requires one of the isospin amplitudes - the isoscalar scattering length $a^+ \equiv a_{\pi^- p\rightarrow\pi^- p} + a_{\pi^+ p\rightarrow\pi^+ p}$ - to vanish in leading order [1,2]. In other words, the $\pi^- p$ and $\pi^+ p$

BOX 1: CHARACTERISTICS OF EXOTIC ATOMS

Slowed down to kinetic energies of a few eV, negatively charged muons, pions, kaons, or antiprotons (x-) are captured in the Coulomb field of a nucleus A(Z,N) at approximately the outmost electron (e) shells. Due to the large mass ratio m_x / m_e, the subsequent quantum cascade starts from highly excited atomic states. For example, in pionic hydrogen and antiprotonic xenon, initial principle quantum numbers n are distributed around 16 and 200, respectively, occupying there most of the possible angular momentum states ℓ.

The mass dependence of binding energies E_n and radii $r_{n\ell}$ reveals the dimensions of such atoms:

$E_n = \mu c^2 \alpha^2 Z^2 / n^2$

$r_{n\ell} = R_B \cdot [3n^2 - \ell(\ell+1)]/2$.

Exotic-atom Bohr radii $R_B = \hbar c / \mu c^2 \alpha Z$ range from about 50 to 3 fm for Z=1 to 82 (μ denotes the reduced mass of particle and nucleus). Binding energies increase - compared to electronic atoms - to a few keV for exotic hydrogen (Z=1) up to MeV for heavy nuclei like lead (Z=82).

De-excitation cascade

In medium and high Z atoms, de-excitation is very fast mainly due to internal processes. It proceeds at the fs scale preferentially by Auger electron emission in the upper and X-radiation in the lower part of the cascade. Collisional effects, *e.g.*, electron refilling may occur in dense media.

By contrast, the exotic hydrogen cascade, assumed to develop within a few 100 ps, is dominated by collisional de-excitation already at low densities. The electrically neutral x^-H system penetrates deeply into the electron cloud of neighbouring atoms, where the nuclear Coulomb field induces an s-state admixture in higher ℓ states. Consequently, for strongly interacting particles the atomic cascade depletes because of inelastic nuclear reactions from the beginning and X-ray yields depend strongly on density. In pionic hydrogen and deuterium, typical yields are a few per cent for Lyman series (Fig. 1).

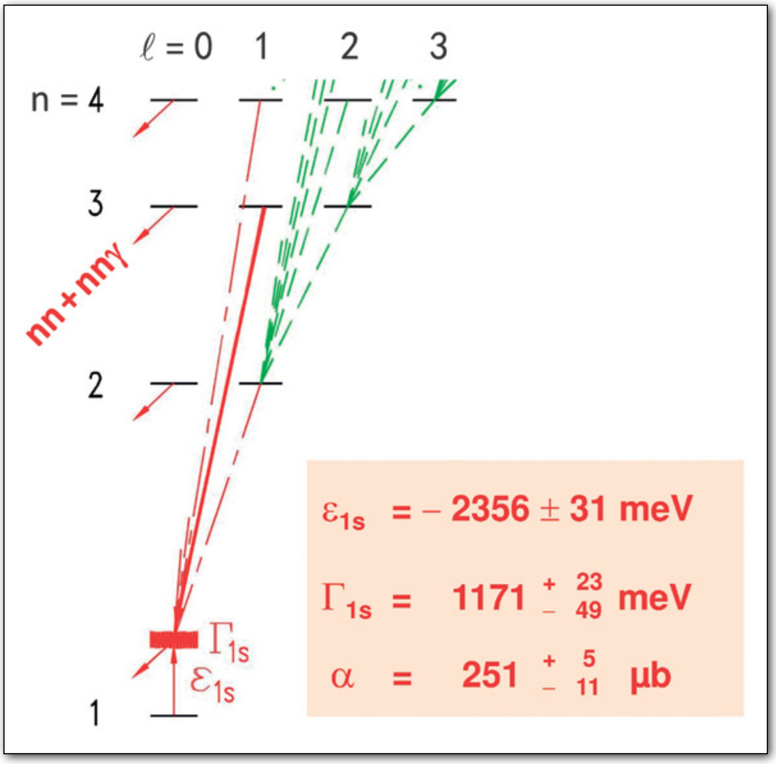
Strong-interaction effects

The small distances enhance significantly the overlap of the wave function of orbiting particle and nucleus. In hadronic atoms - systems formed with pions, kaons, or antiprotons - the nuclear force contributes to the binding energy observable as an X-ray line shift ε. Nuclear reactions reduce the life time Δt of low-lying atomic states which manifests itself in an additional line broadening Γ according to the uncertainty relation $\Gamma \cdot \Delta t \approx \hbar$.

The shift is attributed in leading order to elastic hadron-nucleus scattering and the broadening accounts for inelastic nuclear reactions. In this way, for atomic s-states, ε_{ns} and Γ_{ns} measure real and imaginary part of the effective complex hadron-nucleus scattering length $a_{\pi A}$ [10]

$$\varepsilon_{ns} - \frac{i\Gamma_{ns}}{2} = -\frac{4}{n} \cdot \frac{E_n}{R_b} \cdot a_{\pi A}$$

Atomic binding energies are well below the typical hadronic scale of 1 GeV. Hence, exotic atoms constitute a laboratory for "scattering experiments" at relative energy "zero" without the need to extrapolate cross section data.



▲ **FIG. 1:** Low-lying atomic levels in pionic deuterium and recent experimental results [7]. The shift ε_{1s} is obtained by comparing the measured X-ray energy with the (calculated) pure electromagnetic value. The broadening Γ_{1s} is extracted from the line shape. The small (negative) value for $\varepsilon_{1s}(\pi D)$ is a consequence of chiral symmetry resulting in a minor repulsive interaction. For comparison, latest results given for pionic hydrogen are $\varepsilon_{1s}(\pi H) = +7120 \pm 11$ meV (indicating the strongly attractive π^-p interaction) and $\Gamma_{1s}(\pi H) = 823 \pm 19$ meV [8].

interaction is of identical magnitude but opposite in sign.

Deviation from zero of a^+ measures the extent of chiral symmetry breaking, which is linked to the nucleon's mass and strangeness content [4]. Obviously, in the limit of charge symmetry, the leading order of $\varepsilon_{1s}(\pi D)$ is given by a^+.

In πN reactions involving charged pions, isospin breaking effects are calculated to be a few per cent only. In the case of $\varepsilon_{1s}(\pi D)$, however, they were predicted to contribute outstanding 40% because of the smallness of a^+ [11]. Verification via πD and πH precision experiments [7,8] constitutes an important success within the framework of χPT [9].

Pion production and absorption

For pion absorption, $\pi NN \rightarrow NN$, energy-momentum conservation requires at least $A=2$ nuclei. In πD, as charge exchange is suppressed by isospin conservation, the level broadening $\Gamma_{1s}(\pi D)$ is **not** generated by πN scattering, in contrast to the πH case. $\Gamma_{1s}(\pi D)$ is dominated by true absorption $\pi^- d \rightarrow nn$. About 25% of the decays are due to radiative capture $\pi^- d \rightarrow nn\gamma$.

Exploiting time reversal invariance and charge symmetry, *i.e.*, assuming for matrix elements $|A_{\pi^- d \rightarrow nn}| = |A_{\pi^+ d \rightarrow pp}|$, the broadening measures the s-wave pion production strength α [7]:

$\Gamma_{1s}(\pi D) \propto |A_{pp \rightarrow \pi + d}|^2 \propto \alpha$.

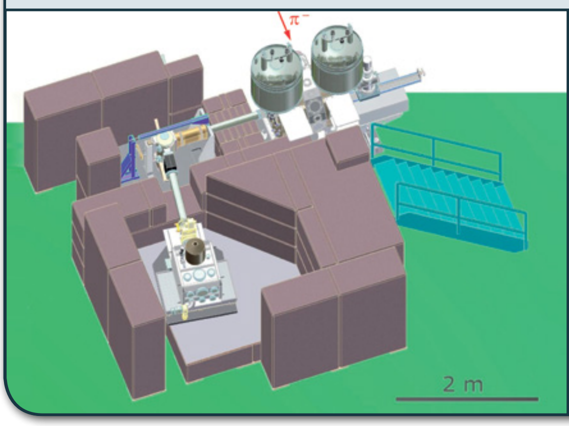
Given that exchange of virtual pions essentially contributes to nuclear binding, α constitutes an important quantity in the description of nuclei in terms of elementary processes [12].

Experimental approach

High-intensity and low-energy pion beams of up to several 10^8 pions per second are available at the meson factory of the Paul Scherrer Institut [13]. Exotic atom formation was optimized by means of the cyclotron trap [14], a superconducting split coil magnet, which winds up the range curve of the particle beam in order to achieve an X-ray source of suitable extensions for the crystal spectrometer. In this way, the stop density at pion beams is enhanced by about a factor of 200 compared to a linear arrangement. A gas cell, cooled to 25K to increase the D_2 density, defines the stop volume.

The crystal spectrometer was set up with a spherically bent Bragg crystal and charge-coupled devices (**CCDs**) for X-ray detection. Count rates are a few tens per hour

BOX 2: A JOHANN-TYPE SET-UP FOR EXOTIC-ATOM X-RAY SPECTROSCOPY



Crystal spectrometer set up at the low-energy beam line of the Paul Scherrer Institut. Pions are stopped in the cyclotron trap (upper right with its liquid helium reservoirs). The Bragg crystal is mounted inside a vacuum chamber (upper left). The diffracted X-rays are detected with the CCD array (bottom left). The massive concrete shielding (roof not displayed) suppresses substantially beam-induced background.

Johann-type set-ups allow a simultaneous measurement of an angle (*i.e.*, an energy) interval according to the extensions of X-ray source and detector in the direction of dispersion – indispensable in low-rate applications like ultimate resolution spectroscopy of exotic atoms [5].

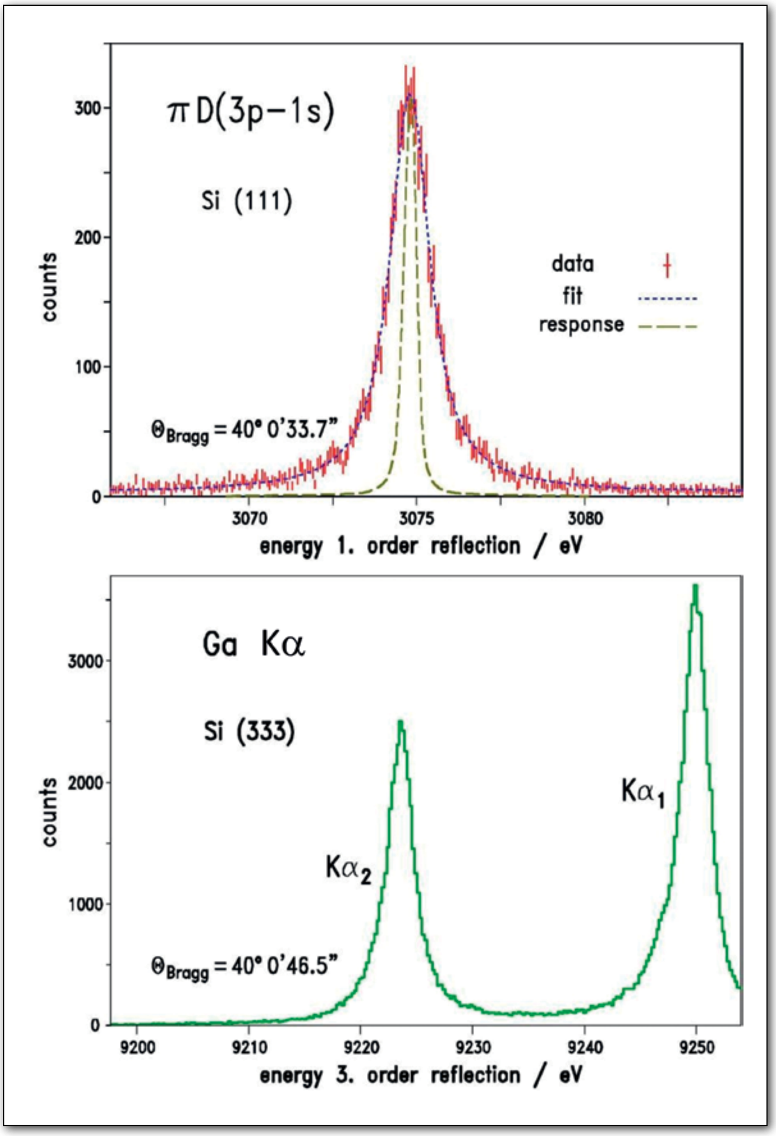
for the Lyman β transition $\pi D(3p\text{-}1s)$, which is very low compared to dedicated X-ray facilities like synchrotron light sources. X-ray source, Bragg crystal, and detector are part of a vacuum system to keep absorption losses small (Box 2).

X-rays from the $\pi D(3p\text{-}1s)$ transition are diffracted in 1. order under the same Bragg angle as gallium $K\alpha_2$ X-radiation in 3. order providing the energy calibration (Fig. 2). The fluorescence radiation was excited by means of an X-ray tube from a GaAs sheet installed inside the gas cell, which allowed alternating measurements of πD and *Ga* X-rays without any mechanical change.

Fluorescence X-rays are inapplicable to calibrate resolution functions because of their complex line shape, and nuclear γ-rays are not available in the few keV range. Therefore, as a novel approach the spectrometer response was determined by using X-rays from highly charged ions [15].

The ions were produced at high rate in an electron-cyclotron resonance source, usually taken to provide ion beams. Such ions are proven to be slow by means of optical spectroscopy, ensuring Doppler broadening to be small.

In particular suited are the very narrow M1 transitions. For helium-like argon, the energy coincides within 25 eV with the one of the $\pi D(3p\text{-}1s)$ transition.



▲ **FIG. 2:** $\pi D(3p\text{-}1s)$ transition (top) and *Ga* $K\alpha_2$ calibration line (bottom) measured in 1. and 3. order, respectively, using a spherically bent silicon crystal cut along the 111 plane (from [7]). The spectrometer resolution (narrow peak - top) was determined with X-rays from helium-like argon to be 436 ± 3 meV (FWHM). This value is close to the theoretical limit of 403 meV as calculated from intrinsic crystal properties and aberrations owing to the setup geometry.

Summary

X-ray spectroscopy of exotic atoms by crystal spectrometers as a precision tool to determine low-energy **QCD** parameters has been developed continuously to exploit the increase in performance of modern accelerator facilities. The experimental accuracy has reached the per cent level or better, which coincides with recent theoretical achievements within the frame work of effective field theories. ■

About the Author

Study of physics and PhD (1981) at University of Karlsruhe (TH). Research on pion-nuclear physics and exotic atoms. Since 1986 at IKP of the Research Centre Juelich. Spokesperson collaborations "Antiprotonic Hydrogen" (LEAR/CERN), "Pion Mass" and "Pionic Hydrogen" (PSI/former SIN). Professor for experimental physics at University of Cologne.

References

[1] S. Weinberg, *Phys. Rev. Lett.* **17**, 616 (1966).

[2] Y. Tomozawa, *Nuovo Cim. A* **46**, 707 (1966).

[3] J. Gasser and H. Leutwyler, *Phys. Rep.* **87**, 77 (1982).

[4] A.W. Thomas and W. Weise, *The Structure of the Nucleon*, Wiley-VCH, Berlin, (2001).

[5] D. Gotta, *Prog. Part. Nucl. Phys.* **52**, 133 (2004), and references therein.

[6] J. Gasser, V.E. Lyubovitskij, and A. Rusetski, *Phys. Rep.* **456**, 167 (2008).

[7] Th. Strauch *et al.*, *Phys. Rev. Lett.* **104**, *142503 (2010) ; Eur. Phys. J. A* **47**, 88 (2011).

[8] D. Gotta *et al.*, *Lect. Notes Phys.* **745**, 165 (2008).

[7] V. Baru *et al.*, *Nucl. Phys. A* **872**, 69 (2011).

[8] U.-G. Meißner, U. Raha, and A. Rusetski, *Phys. Lett. B* **639**, 478 (2006).

[11] S. Deser *et al.*, *Phys. Rev.* **96**, 774 (1954).

[12] V. Lensky et al, *Eur. Phys. J. A* **27**, 37 (2006).

[13] www.psi.ch/science/large-scale-facilities.

[14] L.M. Simons, *Physica Scripta T22 (1988) 90; Hyperfine Int.* **81**, 253 (1993).

[15] D.F. Anagnostopoulos *et al.*, *Nucl. Instr. Meth. A* **545**, 217 (2005).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