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20 Years of SOHO

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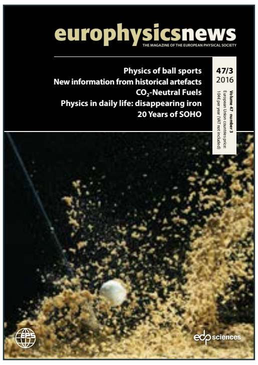
EPS

edp sciences



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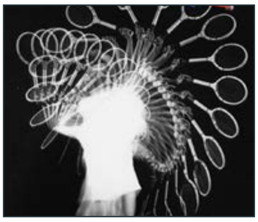
Cover picture: Golf ball being hit. See 'physics of ball sports' p.13 © iStockPhoto



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Physics of ball sports

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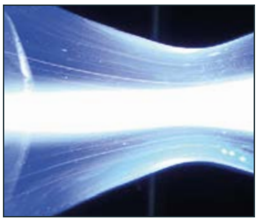
Discovering new information from historical artefacts



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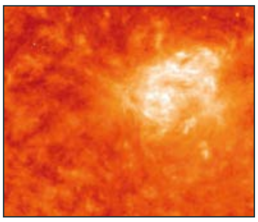
CO_2-Neutral Fuels



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20 Years of SOHO

[EDITORIAL]

EPS and Open Science Policy

Open science has become a significant way of promoting science and increasing its societal impact. Through open science, research results are rapidly available to other researchers, saving resources, improving the quality of research, providing new skills and access to knowledge in general. The systematic transition towards open science is being driven by new IT technologies and big data handling tools.

It is amazing to see how quickly this transformation takes place and is well received among citizens, companies and decision-makers as it increases also business opportunity. The European Commission and EU Council have expressed their wish to facilitate and accelerate the changes towards open science. In particular by bolstering and interconnecting existing research infrastructure, the Commission plans to create a new European Open Science Cloud. In February 2016 a call for expressions of interest was published in order to select members of the High-Level Advisory Group 'Open Science Policy Platform' (OSPP) [1] to be created. EPS expressed quickly its interest to become a member of this platform and I am very proud to announce that it has officially been nominated as such by Director General Robert Jan-Smits of DG Research of the European Commission. The launch of the OSPP is planned during the 27 May 2016 Competitiveness Council in Brussels.

At this point let me emphasize that Physics has long been at the forefront of open science. Indeed since the 17th century the societal demand for access to scientific knowledge started with the advent of academic journals when it became necessary for groups of scientists to share resources and do their work collectively. Today the development of internet and social networks has made the dissemination of scientific research and access to publications and data much easier. For example the arXiv has been used by researchers in most fields of physics to self-archive their research papers. The arXiv was created in 1991, before open access to scholarly articles reporting scientific research was discussed at the policy level. Other important areas in open science where physics has made pioneering contributions include outreach and public understanding, citizen science projects, and innovative science teaching. EPS has been intimately associated with the development of open science by fostering the free flow of scientific information among physicists from Eastern and Western Europe, through the organisation of conferences on both sides of the political and ideological divide that characterised Europe until the 1990s. Our Society was part of the working group that laid the ground work for the concepts behind the SCOAP3 consortium. EPS was also the lead organisation for the World Year of Physics in 2005 and the International year of Light in 2015. It is involved in various inquiry-based science education projects, and provided the initial network and selection process at national level for Physics on Stage (now Science on Stage). In addition, specialist input is provided by EPS Governance or members of our Divisions or Groups into policy debates. Recent examples include the EPS analysis of the "Importance of Physics to the Economies of Europe" [2] and the Position Paper by the Energy Group on "European Energy Policy" [3].

Physics has made pioneering contributions in outreach and public understanding, citizen science projects, and innovative science teaching

Finally, thanks to its large base of physicists from all fields of physics, active in academia, education, industry, research funding bodies, or scientific publishers, EPS will continue to be an active stakeholder in open science policies and practices. As such it also supports the Amsterdam Call for Action on Open Science [4], a living document that came out of the Conference 'Open Science – From Vision to Action' organised in April 2016 by the Netherlands' EU Presidency. Thus EPS is making another step forward in its Brussels activities, in agreement with the conclusions and recommendations of its Strategy Review Group presented at Council 2016. ■

Christophe Rossel
EPS President

References

[1] https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-policy-platform

[2] http://www.eps.org/resource/resmgr/policy/EPS_economyExSummary2013.pdf

[3] http://www.eps.org/resource/resmgr/policy/eps-pp-EuropeanEnergyPol2015.pdf

[4] http://www.openaccess.nl/en/events/amsterdam-call-for-action-on-open-science

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Editor: Victor R. Velasco (SP)
Email: vrvr@icmm.csic.es

Science Editor: Jo Hermans (NL)
Email: Hermans@Physics.LeidenUniv.nl

Executive Editor: David Lee
Email: david.lee@eps.org

Graphic designer: Xavier de Araujo
Email: xavier.dearaujo@eps.org

Director of Publication: Jean-Marc Quilbé

EPS Secretariat

Address: EPS • 6 rue des Frères Lumière
68200 Mulhouse • France
Tel: +33 389 32 94 40 • **fax:** +33 389 32 94 49
www.eps.org

Secretariat is open 09.00–12.00 / 13.30–17.30 CET except weekends and French public holidays.

EDP Sciences

Chief Executive Officer: Jean-Marc Quilbé

Publishing Director: Agnès Henri
Email: agnes.henri@edpsciences.org

Production: Thierry Coville

Advertising: Jessica Ekon
Email: jessica.ekon@edpsciences.org

Address: EDP Sciences
17 avenue du Hoggar • BP 112 • PA de Courtabœuf
F-91944 Les Ulis Cedex A • France
Tel: +33 169 18 75 75 • **fax:** +33 169 28 84 91

www.edpsciences.org

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17 avenue du Hoggar - Parc d'activités de Courtaboeuf
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EPS HISTORIC SITES

Cabinet of Physics
University of Coimbra, Portugal

The Cabinet of Physics of the University of Coimbra is the first Historic Site of the European Physical Society in Portugal. In a ceremony on March 11, 2016, a commemorative plaque was unveiled by Luisa Cifarelli, Chair of the EPS Historic Site Committee and João Gabriel Silva, Rector of the University of Coimbra.

The Age of Enlightenment, a period historically associated with changing mentalities in Europe, which had been shaken after the terrible Lisbon earthquake in 1755, was a brilliant period for the University of Coimbra: it was a time which brought about sweeping changes in the intellectual attitude towards natural phenomena. The Cabinet of Physics - situated in the building of the ancient Jesus College, at uptown Coimbra classified as a world heritage site by UNESCO in 2013 - was created in 1772, with the reform of the University of Coimbra.

To Marquis of Pombal, the Prime-Minister of Portugal and the Reformer of the University, it was imperative to promote the studies in Natural Philosophy. The Italians Giovanni Antonio Dalla Bella and Domenico Vandelli were hired as professors of the new Faculty of Philosophy. One of the most important accomplishments of this renewal project was the creation of the Cabinet of Physics, since the experimental teaching of this science was considered a major need.

▾ The Cabinet of Physics of the University of Coimbra

▲ From left to right: Helena Caldeira, Luiz Alte da Veiga, Décio Martins Ruivo, Teresa Peña, Luisa Cifarelli, Conceição Ruivo, Carlota Simões, Ermelinda Antunes, José António Paixão, João Gabriel Silva, Isabel Nobre.

Nowadays, at the Cabinet of Physics we find scientific instruments from the 18th and 19th centuries displayed in two old rooms: Room Dalla Bella (18th Century) and Room Figueiredo Freire (19th Century).

In Room Dalla Bella the instruments are presented in their original shelves according to the *Index Instrumentorum*, organized in 1788 by Dalla Bella, the first Director of the Cabinet of Physics. Many of the instruments were built in Lisbon by Joaquim José dos Reis (woods) and the brothers Schiappa Pietra (metals). Precision instruments have also been purchased in England, namely from George Adams, Edward Nairne, Francis Watkins, John and Peter Dollond, James Champneys, Edmund Culpeper, Benjamin Martin and Henry Pyefinch. From Italy arrived one Campani microscope and an instrument to illustrate the composition of movements, from Antonio Fabris. João Jacinto de Magalhães (1722-1790), a renowned Portuguese scientist, lived in Paris and London where he met Volta, Lavoisier, Franklin and Euler. He was responsible for sending to Portugal numerous scientific instruments, some with improvements of his own.

At Room Figueiredo Freire, instruments mainly from the first half of 19th century complete the exhibition. In the nineteenth century, electricity and electromagnetism were the most important fields of physics. José Figueiredo Freire (1786-1837) was the third director of the Cabinet of Physics, being responsible for its expansion into this room during the nineteenth century and for the development of a catalogue in 1824. At the beginning of the 19th century, the Physics Cabinet and the Astronomical Observatory of Coimbra commissioned many instruments to the English instrument makers William and Samuel Jones, Edward M. Clarke, William Harris and the French Hippolyte Pixii and Augustin Chevallier. There are also instruments made in Portugal: Jacob Bernard Haas, a German craftsman, who had a workshop of scientific instruments in London, moved to Lisbon around the year 1800.

The Cabinet of Physics is a European Historic Site since March 11, 2016. This recognition coincides with the commemoration of the University of Coimbra's 726th anniversary: 726 years have passed since the signing of the royal decree *Scientiae thesaurus mirabilis* on March 1, 1290. Thanks to King D. Dinis, the University of Coimbra's founding document already contained the word "SCIENCE". ■

Carlota Simões
Director of the Science Museum of the University of Coimbra
Décio Ruivo Martins
Scientific adviser for the collection of scientific instruments of the Science Museum of the University of Coimbra

NEW DPG PRESIDENT

On the 5th of April the Deutsche Physikalische Gesellschaft witnessed a change in command. In the Magnus-Haus in Berlin, Edward Krubasik handed over the presidency of the DPG to Rolf-Dieter Heuer, former Director General of CERN. He is the newest in a respectable list of people who headed the DPG in the past. The list contains names like Max Planck, Albert Einstein and Walther Gerlach, just to name a few. The presidency of the DPG is an honorary position, with a two year term. The DPG is the oldest physical society and – with over 62,000 members – the largest in the world. ■

▲ Rolf-Dieter Heuer (right) with his predecessor Edward Krubasik (left) and departing vice president Johanna Stachel (Photo: DPG / P. Chiussi)

EPS Council 2016

Over 80 participants attended the EPS Council meeting which was held on the campus of the Université de Haute Alsace, in Mulhouse (FR) on 31 March and 1 April 2016. EPS Council is the opportunity for the EPS Divisions and Groups, Member Societies and Action Committees to meet, and share information on the development of the EPS.

Highlights 2015

The meeting was graciously opened by the Professor C. Gangloff-Zielgler, the President of the UHA, who spoke of the opportunities for collaboration between the UHA and the EPS.

Christophe Rossel, the EPS President, provided an overview of the activities in 2015.

The EPS has 42 Member Societies that represent over 130,000 physicists in Europe. The EPS also has around 50 Associate Members representing large European research facilities, academia and industry. The 11 EPS Divisions and 6 EPS Groups cover all areas of physics and carry out many EPS activities.

The Executive Committee is charged with oversight and implementation of EPS activities. It has met 4 times since Council 2015. The meetings were efficient in discussing EPS priorities, as well as providing the opportunity to discuss with EPS Member Societies and Divisions and Groups. Summaries of Executive Committee meetings are prepared by the Honorary Secretary, and are available to all EPS members.

Action Committees, created by the EPS Executive Committee, administer policies and programmes of the EPS and provide the Executive Committee with advice on specific issues. The EPS currently has 5 Action Committees:

- **Conferences** (chair D. Vernhet), to administer conference qualifications and conference grants, and to advise on conference policy
- **Distinctions and Awards** (M. Ducloy until Council 2016, then J. Hermans), to review requests for endorsement, and propose the creation of new awards
- **Equal Opportunity** (L. di Ciaccio), to administer activities promoting equal opportunities in physics and propose policy and activities
- **European Integration** (G. Djordjevic) to administer activities for European integration and propose policy and activities
- **Forum Physics & Society** (A. Macdonald) to explore the bi-directional relationship between physics and society, run workshops and propose policies
- **Historic Sites** (L. Cifarelli), to administer the EPS Historic Sites programme
- **Young Minds** (A. Marino), to administer the EPS Young Minds programme, and advise on policies related to young scientists.

The EPS derives its scientific credibility from the expertise and quality of its Divisions and Groups. Divisions and Groups are active in creating and representing the various communities in physics. As physics is a very dynamic field, it is normal for Divisions and Groups to evolve. In 2015, the EPS Experimental Physics Control Systems Group was dissolved, and is now part of a larger international grouping of specialists in the field. The EPS is exploring new areas where physics is developing to attract and create communities to represent these fields. In 2015, EPS Divisions and Groups organised 13 of the world's premier conferences in all fields of physics. The EPS is actively involved in promoting scientific excellence, and awarded 31 prestigious prizes in 2015.

Physics for Development is an area where opportunities exist for increased EPS involvement. A Round table at Council on the topic was organised by E. van Groningen, the chair of the EPS Physics for Development Group. The round table brought together 5 experts, each presenting a different approach to tackling problems in physics for development. C. Rossel would like to develop more EPS activities in Physics for Development in the coming year. A Special Activity Fund has been created, which collects donations from many different sources. The Special Activity Fund will be overseen by a specific committee, and activities in field of physics for development could be financed from this fund.

The EPS is active in **publication**. Its flagship journal is EPL, publishing high quality letters in all fields of physics. EPL will celebrate its 30th anniversary in 2016. Novelties in 2015 included the introduction of Perspectives, and the introduction of the post of Deputy Editor to improve the communication with the co-editors. The quality of the content and the visibility of the journal have been enhanced, thanks to the hard work of the Editor in Chief Giorgio Benedek.

The EPS news magazine, E**urophysics News**, is distributed in 25,000 copies 5 times a year to 40 EPS Member Societies. Victor Velasco, the Editor, and Jo Hermans, the Science Editor rely on Council delegates to contribute to the continued development of the magazine.

The **European Journal of Physics** (EJP) is an international journal dedicated to maintaining and improving the standard of taught physics in universities and other higher education institutes. In 2015, Professor Michael Vollmer the editor in chief introduced many new initiatives, and witnessed the growth of submissions and the number of published articles in 2015.

The **EPS electronic newsletter**, e-EPS is published monthly. It is distributed to over 35,000 readers around the world. It contains news items about important developments in physics, as well as items of interest to the general community. The Editor, A. Bracco, leads the editorial team and is assisted by G. Gunaratnam, the Technical Editor.

EPS was involved in various policy initiatives in 2015. Among them are the publication of the **Statement on the Importance of Funding Basic Natural Science**, and the **EPS contribution to the European Energy Policy and Global**

Reduction of CO_2 emissions (the statements can be found here: http://www.eps.org/?page=policy). In addition, the EPS sponsored a workshop on **Integrating Access to Pan-European Research Infrastructures in Central and Eastern Europe** (INARIE) in Debrecen (HU). The workshop explored the barriers to access to research infrastructures encountered by researchers in small and medium-sized countries, and possible solutions. A declaration relating to the conditions for access to research infrastructures was signed by the presidents of Hungarian Academy of Sciences, of the EPS and by the chair of European Forum on Research Infrastructures (ESFRI) (http://www.eps.org/resource/collection/B77D91E8-2370-43C3-9814-250C65E13549/Debrecen_Declaration-signed.pdf).

The **Historic Sites programme** remains successful, with 8 new Historic Sites in 2015:

- Kamerlingh Onnes Laboratory, Leiden, NL
- Residencia de Estudiantes, Madrid (SP)
- The Fasor Lutheran Secondary School of Budapest, HU
- Ludwig-Maximilians-Universität [LMU], Munich, DE
- Mount Vesuvius Observatory, Hercolaneum, Naples, IT
- Inst. of Radium Research, Vienna, AT
- Einstein house, Bern, CH (EPS-APS)
- Hotel Metropole (Solvay), Brussels, BE

The Historic Site ceremonies are excellent outreach opportunities, bringing the EPS Member Societies into contact with local policy makers, and establish a lasting connection to the local community.

The EPS has been active in developing its presence in Brussels. Office space is shared with the European Association of Chemical and Molecular Societies (EuCheMS). Various activities have been developed and piloted using a specialist consultant in European policy. A meeting was organised in Brussels with the Presidents of EPS Member Societies to discuss priorities and concrete proposals for action. The EPS has provided input to the European Commission in areas such as potential members of the High level Group of the Science Advices Mechanism. The EPS was also one of the organisers of the workshop Science Advice in Europe, organised in Heidelberg in January 2016. To help the EPS in providing timely advice, an Advisory Board on Science Policy has been created. Made up of eminent, well respected scientists, the members of the ABSP will support EPS activities in Brussels.

Strategy Review

Council 2015 established a group to review the EPS Strategy 2010+. The review was constructive and analysed measures of success, actions, and/or new routes for the strategy and its operational implementation. Among the activities undertaken during the period that must be considered as highlights include the International Year of Light in 2015, the creation of the e-EPS newsletter, the introduction of the Historic Sites Programme, the Study on "The Importance of Physics to the Economies of Europe", the growth of the conference services department, and the introduction of new prizes such as the Edison Volta Prize and the Emmy Noether Distinction. It was noted that many of these activities span across the "federal" and "learned society" aspects of the EPS mission.

The Strategy Review Group nonetheless pointed out shortcomings still to be addressed in the coming years. Communications, both internally and externally need to be improved. Many activities of the EPS are not adequately communicated, inside and outside the EPS. There is potential for growth of both Individual Members and Associate members, and increasing the membership base has many advantages. A campaign to increase members needs to be devised and implemented. The Executive Committee needs to be comprised on motivated volunteers that can bring expertise in specific areas, *e.g.* education, publication, European relations *etc.* The Executive Committee should be structured by "portfolio", with systematic reporting on items of interest to the EPS.

Council needs to be more involved in setting EPS priorities. More time at Council should be devoted to discussing EPS future activities. Council delegates should be asked prior to Council whether they have items that they would like to have discussed on the agenda. Input from Council delegates will be particularly important as the EPS becomes more involved in science policy in Europe.

EPS Distinctions

Council approved the following individuals as Fellows of the EPS:

- Luc Bergé, CEA, Paris, FR
- Eberhard Bodenschatz Max-Planck-Institut for Dynamics and Self-Organization Göttingen, DE
- Reinhard Brinkmann DESY Hamburg, DE
- Sydney Gales Institut de Physique Nucléaire, Orsay, FR
- Victor Malka Laboratoire d'Optique Appliquéz Palaiseau, FR
- Karlheinz Meier Kirchhoff Institut for Physics, Univerity of Heidelberg DE

Council approved the award of the **EPS Achievement Award** to Douglas I.J. MacGregor, University of Glasgow, Scotland, UK *for his outstanding leadership skills and his active promotion of the activities of the Nuclear Physics Division, increasing the visibility, significance and impact of the EPS.*

Council approved the award of the **EPS Achievement Award** to Jozef Ongena, Forschungszentrum Jülich DE *for his outstanding contributions to the EPS in his various functions over a long period of time and for his enthusiasm in promoting the image and the impact of the EPS with the scientific community, policy makers and other stakeholders.*

Council approved the award of the 2016 **Gero Thomas Medal** to Dénes Lajos Nagy, KFKI Research Institute *for Particle and Nuclear Physics, Budapest HU for his dedication and numerous contributions and commitment to the EPS in the fields of East West relations, and international scientific cooperation.*

▾ Jozef Ongena (left) and Christophe Rossel (right)

▲ (left to right) D. Lajos Nagy, C. Rossel, D. Lee

Council congratulated the 2016 laureate of the **EPS Edison Volta Prize** to Professor M.A.G. Orrit, University of Leiden, NL *for seminal contributions to optical science, to the field of single-molecule spectroscopy and imaging (first single-molecule detection by fluorescence and first optical detection of magnetic resonance in single molecule) and for pioneering investigations into the photo-blinking and photobleaching behaviours of individual molecules at the heart of many current optical super-resolution experiments.*

Modifications to the Constitution

Council adopted the proposal to modify the EPS Constitution, which increased the Membership fees:

- Individual Member Category 3a were increased to Euro 27.50
- Individual Member Category 3b were increased to Euro 55
- Individual Member Category 3c were increased to Euro 80
- Individual Member Category 3d were increased to Euro 20
- Individual Member Category 3e were increased to Euro 20

Past EPS Presidents

The EPS Council was pleased to welcome 8 former EPS President who presented their views on the achievement and challenges for the EPS. The former Presidents who attended were: R. Ricci (1989-1991), N. Kroo (1993-1995), H. Schopper (1995-1997), D. Weaire (1997-1999), M. Ducloy (2001-2003), O. Poulsen (2005-2007), F. Wagner (2007-2009) and John Dudley (2013-2015).

Election Results

Council elected the following individuals as members of the Executive Committee:

- Luc Bergé (FR)
- Siegfried Bethke (DE)
- Angela Bracco (IT)
- Ari T. Friberg (FI)
- Sylvie Jacquemot (FR)
- Gerd Leuchs (DE)
- Lucia Di Ciaccio (FR)
- Elisabeth Rachlew (SE)
- Christophe Rossel (CH)
- Frances Saunders (UK)
- Minh Quang Tran (CH)
- Victor Zamfir (RO)

Council warmly thanked the outgoing members of the Executive Committee for their hard work and dedication over the past years:

- John Dudley (FR)
- Carlos Hidalgo (SP)
- James Hough (UK)
- Zsolt Fülöp (HU)
- Thomas Müller (DE)
- Marian Reiffers (SK)
- Sofoklis Sotiriou (GR)

Presidential elections will be held during an exceptional Council meeting later in 2016.

David Lee
Secretary General of the EPS

2016 LISE MEITNER PRIZE

The Lise Meitner prize is awarded bi-annually by the European Physical Society for outstanding work in the fields of experimental, theoretical or applied nuclear science.

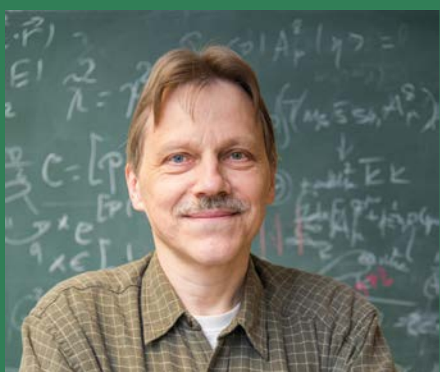
The 2016 Prize Laureate is Prof. Ulf-G. Meißner who works at the Universität Bonn and the Forschungszentrum in Jülich, Germany. The prize is awarded in recognition of Prof. Meißner's pioneering work on effective field theories in hadron and nuclear physics.

The full citation of the prize is: *"The 2016 Lise Meitner Prize is awarded to Prof. Meißner for his developments and applications of effective field theories in hadron and nuclear physics, that allowed for systematic and precise investigations of the structure and dynamics of nucleons and nuclei based on Quantum Chromodynamics."*

The prize consists of a Medal, a Diploma with the above citation, in addition to the prize money.

The Lise Meitner Prize is sponsored by:

- The Karin and Carlo Giersch Foundation;
- The KVI Centre for Advanced Radiation Technology, Groningen;
- The Nuclear Physics Institute Research Centre, Jülich;
- The Institute of Nuclear Physics, Orsay;
- The GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt;
- and the 3rd European Nuclear Physics Conference, Groningen, 2015.



▲ Prof. Ulf-G. Meißner

It is planned to present the prize medal and diploma to Prof. Meißner at a scientific meeting on Advances in Effective Field Theories to be held in Jülich later in the year. ■

Douglas MacGregor
Chair Lise Meitner Prize committee
Vice-Chair EPS Nuclear Physics Division

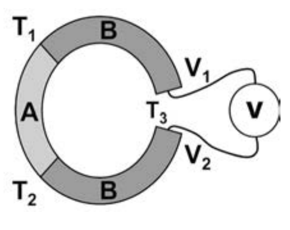
Highlights from European journals

CONDENSED MATTER

Back to basics with thermoelectric power

New study highlights the role of electron diffusivity when turning waste heat into electricity.

Many phenomena in physics, though well-known, are not necessarily widely understood. That's the case with thermoelectricity, which harnesses waste heat by coupling heat flux and electric current. However, understanding such phenomena is important in order to leave the door open for discovering novel manifestations of them. Thus, even today, physicists working in the area of thermoelectricity continue to ask fundamental questions about the underlying physical process. For example, in a recent study, the authors questioned the nature of the force that puts electrons to work when a temperature difference is applied across a thermoelectric material. Now, they have published a study showing that the force that puts electrons to work to harness the waste heat is linked to the ability of electrons to diffuse through the material. Potential applications in the field of electrical power production from waste heat include thermoelectric devices designed to boost power over a range spanning ten orders of magnitude: typically from microwatts to several kilowatts. ■



▲ Determination of the Seebeck coefficient for a circuit composed of two dissimilar materials.

■ **Y. Apertet**, **H. Ouerdane**, **C. Goupil** and **Ph. Lecoeur**, 'A note on the electrochemical nature of thermoelectric power', *Eur. Phys. J. Plus* **131**, 76 (2016)

NUCLEAR PHYSICS

First measurement of ^{60}Ge β decay

^{60}Ge, with its 28 neutrons and 32 protons, is an extremely exotic nucleus, discovered about 10 years ago when only three ions were produced. Its decay properties were measured for the first time in this work. In this experiment, performed at the National Superconducting Cyclotron Laboratory (MSU, USA), the ^{60}Ge ions were produced in ^{78}Kr beam fragmentation reactions and separated from the other reaction products in the A1900 separator. The ions were detected in the active volume of the gaseous time-projection chamber with optical readout (OTPC), where they later decayed. This detector allows exotic decay modes to be identified, even with very small statistics present. The decay of about 20 ^{60}Ge ions was observed by β-delayed proton emission yielding a branching ratio of ~100% and a half-life of 20^{+7}_{-5} ms. This value agrees well with theoretical predictions. ■

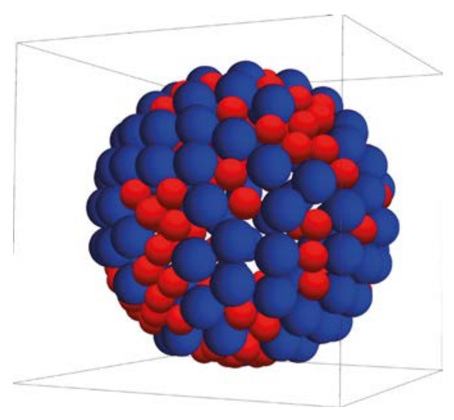
◄ A sample image recorded by the OTPC detector's CCD camera showing the particle trajectories. The vertical track corresponds to the ^{60}Ge ion entering the detector and the other track corresponds to the (β-delayed) proton.

■ **A. A. Ciemny +25 co-authors**, 'First measurement of ^{60}Ge β decay', *Eur. Phys. J. A* **52**, 89 (2016)

STATISTICAL PHYSICS

Jamming meets constraint satisfaction

Amorphous packing of spheres is also known as jamming. Jamming points are reached through a-thermal compression, when the space where particles can move shrinks to zero. This system is mechanically marginally stable and critical. Differently from usual phase transitions, the critical exponents – which are nontrivial – do not appear to depend on space dimension and have been computed in mean field theory. Our paper connects jamming to the Constraint Satisfaction Problems (CSP) of optimization theory, in the case of continuous variables. We study a neural network, the Perceptron, close to the capacity limit for storing random patterns: the jamming transition of the model. Parameters-dependent, one has a convex or a non-convex optimization problem: jamming is non-critical in the former but critical in the latter. Physically in the convex case jamming is approached from a liquid phase while in the non-convex case it occurs from a marginal glass phase. Surprisingly we find the same exponents as in spheres. We conjecture



◂ A jammed configuration of a binary mixture of spheres on the surface of a larger sphere.

a unique super-universality class for continuous non-convex CSP depending on the glassy nature of the configurations in the vicinity of jamming. ■

▪ **S. Franz** and **G. Parisi**,
'The simplest model of jamming', *J. Phys. A: Math. Theor.* **49**, 145001 (2016)

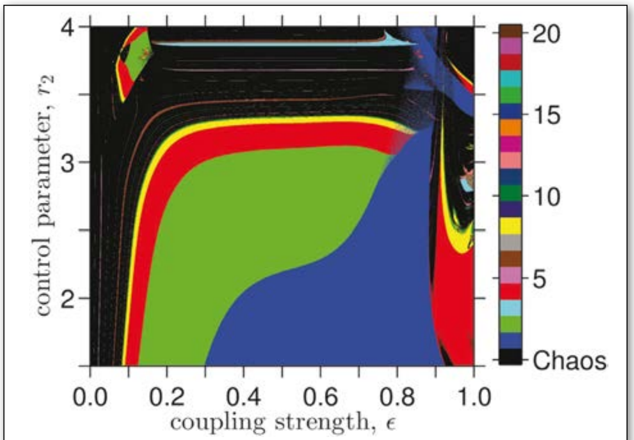
COMPLEX SYSTEMS

Electronic counterpart to ecological models revealed

Peering into the future of populations with the help of complex networks of predictive maps.

Predicting the future from the present—that's what logistic maps can do. For example, they can be used to predict the evolution of a population in the near future based on its present situation. They are relevant when studying systems such as entire populations, where the behaviour of the separate units—which have the ability to self-organise—cannot explain the behaviour of the system as a whole. The authors have now developed an electronic version of a logistic map that is capable of interacting with many other maps, making the model scalable.

▾ Two coupled logistic maps.



As a benchmark to explain new emerging behaviours of entire complex systems, they have studied networks of logistic maps coupled together at various levels. Their findings were recently published and make it possible to more easily compare previous computer simulations with experimental results obtained using this state-of-the art electronic model. ■

▪ **A. L'Her**, **P. Amil**, **N. Rubido**, **A. C. Marti** and **C. Cabeza**,
'Electronically implemented coupled logistic maps', *Eur. Phys. J. B* **89**, 81 (2016)

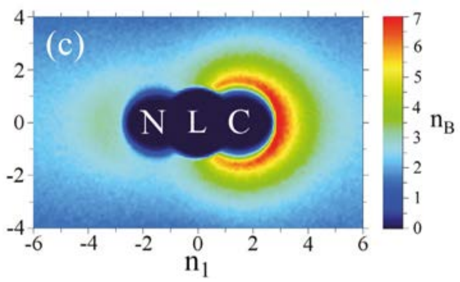
BIOPHYSICS

Tumble-proof cargo transporter in biological cells

New model shows how collective transport by synthetic nanomotors along biopolymer filaments can be effectively directed.

Ever wondered how a molecular nanomotor works when repairing DNA or transporting material such as organelles in the cell? Typically, nanomotors move along biopolymer filaments to go about their duties in the cell. To do so, they use the energy of chemical reactions derived from their surroundings to propel themselves.

▸ The average number density field of particles in the vicinity of the motor.



In a new study published recently, the authors show that small synthetic motors can attach to polymeric filaments and–unlike what previous studies showed–move along without changing either their shape or the direction in which they set out to move. The authors studied the motions of these nanomotors on a filament surrounded by solvent by creating a coarse-grained level biomimetic model featuring all chemical species as particles. They found that the local concentration of catalytic product helping fuel their movement leads to a reversal of the direction of the collective movement of nanomotors, provided that they are in high enough concentration. The work promises to stimulate further research on directed cargo transport to effectively deliver the likes of anti-cancer drugs or anti-pollutants. ■

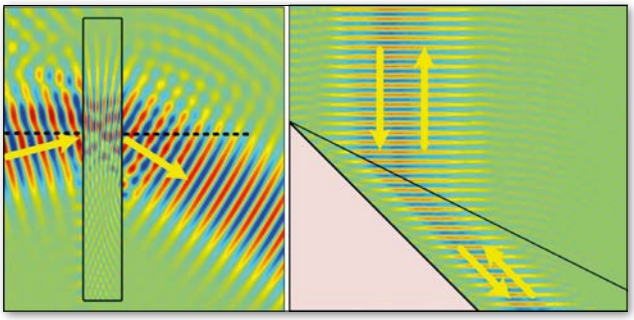
▪ **M-J. Huang** and **R. Kapral**,
'Collective dynamics of diffusiophoretic motors on a filament', *Eur. Phys. J. E* **39**, 36 (2016)

OPTICS

Negative refraction without **negative-index materials**

Transformation optics enables engineered metamaterials to manipulate spatial transformations, which can redirect the propagation paths of electromagnetic waves. Such a technology opens up a novel approach to control electromagnetic fields, and hence provides many possibilities to explore new physical phenomena and develop new devices. It can be employed to design unconventional and versatile devices based on metamaterials, such as free-space invisibility cloaks.

▾ Simulation of the electric field of a beam incident on a transformed lens (left) and object (right).



The authors have demonstrated a transformation-optics device to generate negative refraction and negative reflection without negative-index materials. In their contribution, they presented two kinds of transformation lenses with anisotropic material parameters: one inhomogeneous lens and one homogeneous lens. Their results verified the unusual properties of the transformation optical devices, and good wave-controlling performance was demonstrated. ■

■ **W. X. Jiang**, **D. Bao** and **T. J. Cui**,
'Designing novel anisotropic lenses with transformation optics', *J. Opt.* **18**, 044022 (2016)

QUANTUM PHYSICS

Repulsive Casimir forces **at quantum criticality**

Casimir forces act between macroscopic objects immersed in a fluctuating entity, which may be the quantum vacuum or material medium in a state hosting sizable fluctuations. These forces were first discussed in 1948 as an observable manifestation of the quantum nature of the vacuum, lying at the heart of quantum electrodynamics. At a somewhat later stage it was realized that a material medium brought to the vicinity of a critical state induces analogous interactions once some macroscopic bodies become immersed therein.

In most of the known cases the Casimir force is attractive in situations where the bodies in question are identical. This however turns out not to be a general rule.

In our theoretical work we addressed a system of bosonic particles in the vicinity of a quantum critical state, where both thermal and quantum fluctuations are strong. As our exact analysis indicates, the sign of the Casimir force between two bodies immersed in such a medium may be changed by varying the ratio between their separation D and the thermal de Broglie length λ. In the thermal regime $D>>\lambda$ the force in question is attractive, however, by varying the system setup so that $D<<\lambda$ one crosses over to a regime admitting repulsive Casimir interactions. ■

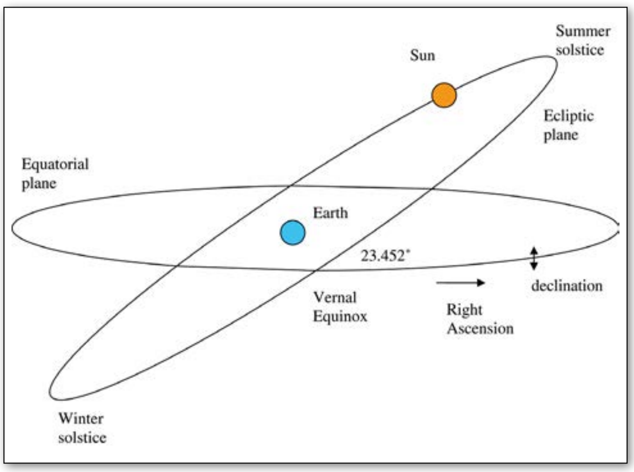
■ **P. Jakubczyk**, **M. Napiórkowski** and **T. Sęk**,
'Repulsive Casimir forces at quantum criticality', *EPL* **113**, 30006 (2016)

HISTORY

Timeless thoughts **on the definition of time**

On the evolution of how we have defined time, time interval and frequency since antiquity.

The earliest definitions of time and time-interval quantities were based on observed astronomical phenomena, such as apparent solar or lunar time, and as such, time as measured by clocks, and frequency, as measured by devices were derived quantities. In contrast, time is now based on the properties of atoms, making time and time intervals themselves derived quantities. Today's definition of time uses a combination of atomic and astronomical time. However, their connection could be modified in the future to reconcile the divergence between the astronomic and atomic definitions. These are some of the observations made by the author of



▴ The solar year was often determined as the interval between consecutive spring equinoxes when the sun is directly over the equator.

this riveting work published recently, which provides unprecedented insights into the nature of time and its historical evolution. ■

J. Levine,
'The history of time and frequency from antiquity to the present day', *Eur. Phys. J. H* **41**, 1 (2016)

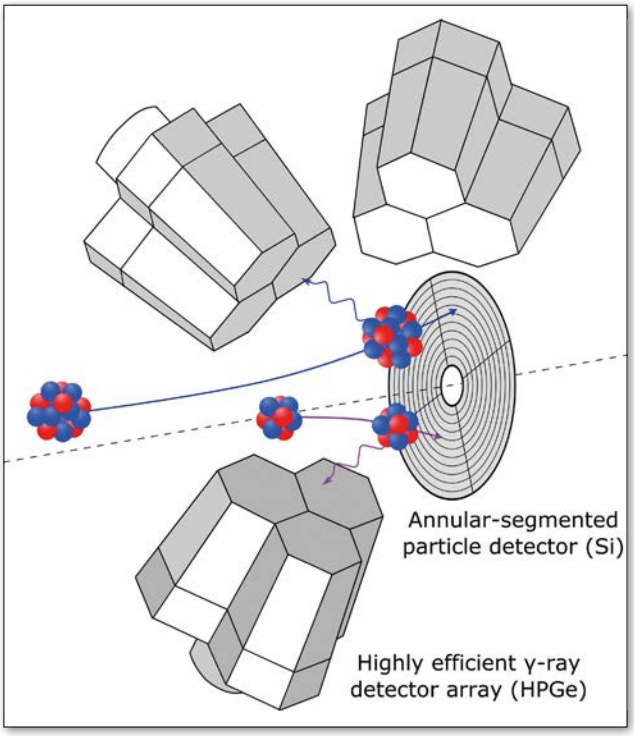
NUCLEAR PHYSICS

Analysing Coulomb-excitation experiments with exotic beams

This paper presents a number of novel and alternative analysis techniques to extract transition strengths and quadrupole moments from Coulomb excitation data with Radioactive Ion Beams (RIBs) using the GOSIA code. It is anticipated that related approaches and techniques will gain an even greater importance as a wider range of post-accelerated RIBs becomes available at the next generation of ISOL facilities.

Indeed, recent advances in RIB technology, in particular the increasing range of species and post-acceleration energies available from ISOL facilities, have led to a resurgence of the use of nuclear reactions to study the structure of nuclei. Specifically, Coulomb excitation at safe energies, where the surfaces of the colliding nuclei are kept apart (typically 2-5 MeV/A), is now giving unrivalled information on the electromagnetic properties of exotic nuclei, leading to knowledge of the nuclear shape or, more precisely, the charge distribution of individual states. The usefulness of the technique to extract key nuclear-structure information has been demonstrated since the 1960s with stable beam and target combinations.

▾ Dedicated detection arrays for particle-γ-ray coincidences are now routinely in use at radioactive-ion beam facilities around the world.

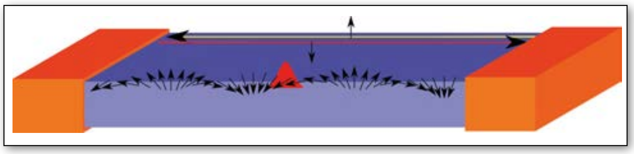


The paper addresses the situation where new challenges present themselves when studying exotic nuclei, including dealing with low statistics or number of data points, absolute and relative normalization of the measured cross sections and a lack of complementary experimental data, such as excited-state lifetimes, mixing and branching ratios. ■

M. Zielińska + 9 co-authors,
'Analysis methods of safe Coulomb-excitation experiments with radioactive ion beams using the GOSIA code', *Eur. Phys. J. A* **52**, 99 (2016)

CONDENSED MATTER

Charge and spin density in helical Luttinger liquids

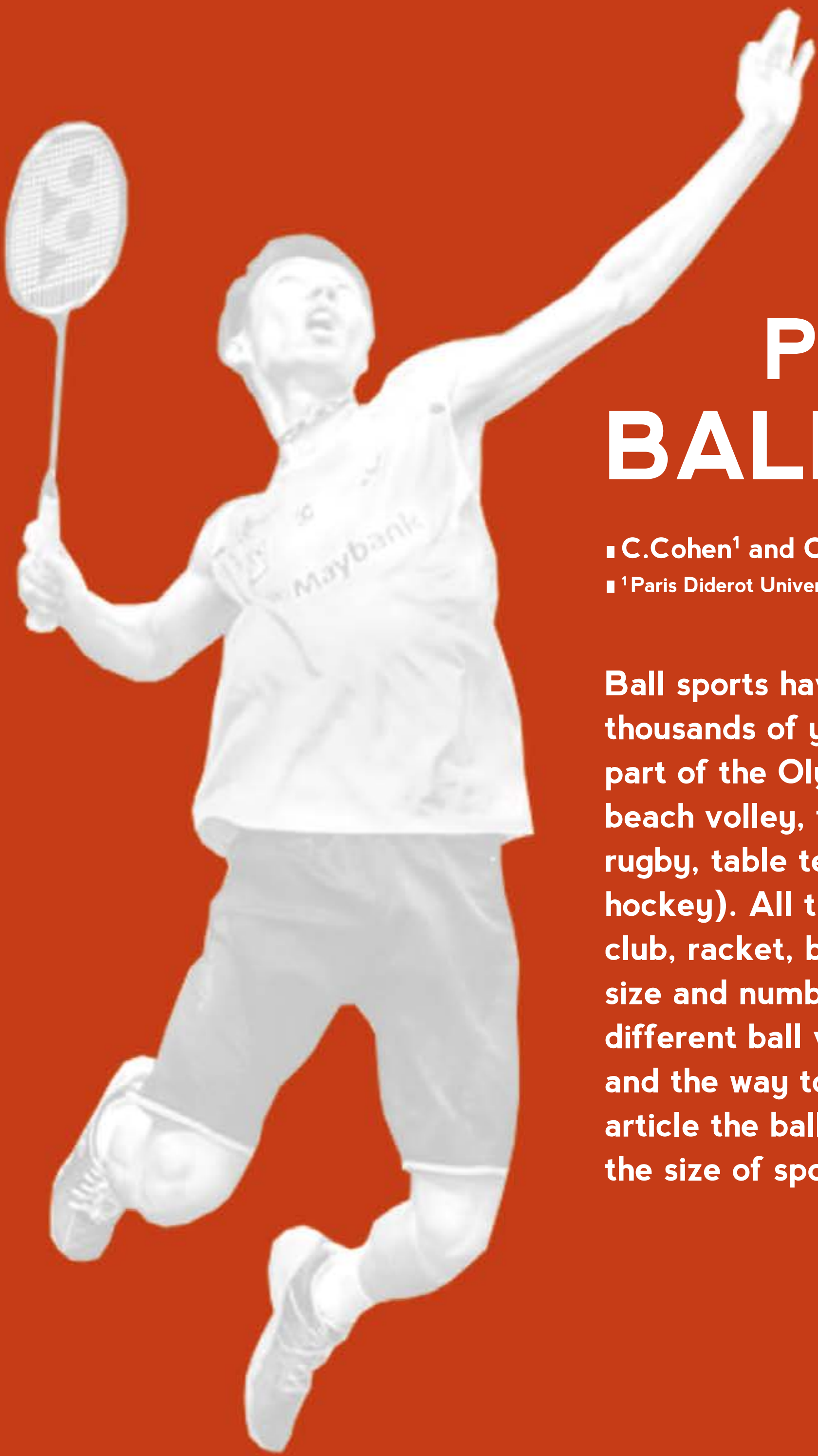


▴ Planar spin helix, pinned by an impurity.

Often an electron confined to one spatial dimension does not have many options. It can have spin up or down and it can go right or left. In helical systems the possibilities are further reduced: the spin projection is tied to the direction of motion. This phenomenon is called spin-momentum locking and takes place at the edges of two-dimensional topological insulators. Its consequences are exciting for spintronics: since spin up and down electrons counter-propagate, spin transport can be easily generated by charge currents. In our work, we identify peculiar properties of the weakly interacting helical Luttinger liquid. We address the interesting question: Are the charge density and spin correlations influenced by spin-momentum locking?

While for strong interactions the system becomes a Wigner crystal of fractional charges *e*/2 built on a strongly anisotropic spin wave (which we have shown in a previous publication), in this work, we demonstrate that, for weak interactions, density correlations are featureless, *i.e.* the density is not affected by impurities. However, spin correlations are well represented by a planar spin helix that can be pinned by magnetic impurities. ■

N. Traverso Ziani, **C. Fleckenstein**, **F. Crépin** and **B. Trauzettel**,
'Charge and spin density in the helical Luttinger liquid', *EPL* **113**, 37002 (2016)



PHYSICS OF BALL SPORTS

C.Cohen[1] and C.Clanet[2] – DOI: http://dx.doi.org/10.1051/epn/2016301
[1] Paris Diderot University, Paris, France and [2] École Polytechnique, Palaiseau, France

Ball sports have been part of human history for thousands of years [1]. Nowadays, 13 of them are part of the Olympic games (badminton, basketball, beach volley, football/soccer, golf, handball, hockey, rugby, table tennis, tennis, volleyball, water polo, ice hockey). All these games differ by launcher (hand, club, racket, bat), ball (size, shape and mass), pitch size and number of players. These differences induce different ball velocities. Apart from the velocities and the way to maximize them, we discuss in this article the ball trajectories and their impact on the size of sports fields.

Velocity in ball sports

One challenge shared by all ball games is to produce the fastest ball. This allows players to reach larger distances or to outpace their opponents. Figure 1 shows the record velocities in different ball sports. At the bottom of the ladder, one finds shot-put, handball and basketball, for which the ball is launched by hand at roughly 15 m/s. Increasing speeds are recorded for volleyball (37 m/s) and soccer (62 m/s), for which the ball is hit by hand or by foot. Another way to increase velocity is by using an instrument to propel the ball: a bat (54 m/s for baseball), a racket (73 m/s for tennis), a chistera (86 m/s for jai alai) or a club (91 m/s for golf). At the top of the ladder stands badminton: in 2013, Malaysia's Tan Boon Hoeng set a new record with a smash at 137 m/s. The first part of our discussion is dedicated to the physics associated to this velocity ladder.

Throwing vs. hitting

Figures 2(d) and 2(e) show chronophotographies of a baseball pitch and a handball throw. The time intervals between two snapshots are constant and take the values of 5 ms and 40 ms, respectively. The distances traveled by the hand (blue segment) and by the ball (red segment) between two consecutive snapshots, at the instant when they separate, are equal. From 2(e) one deduces that the velocity of the thrown ball (v_2') is equal to the velocity of the hand when it releases the ball (v_1):

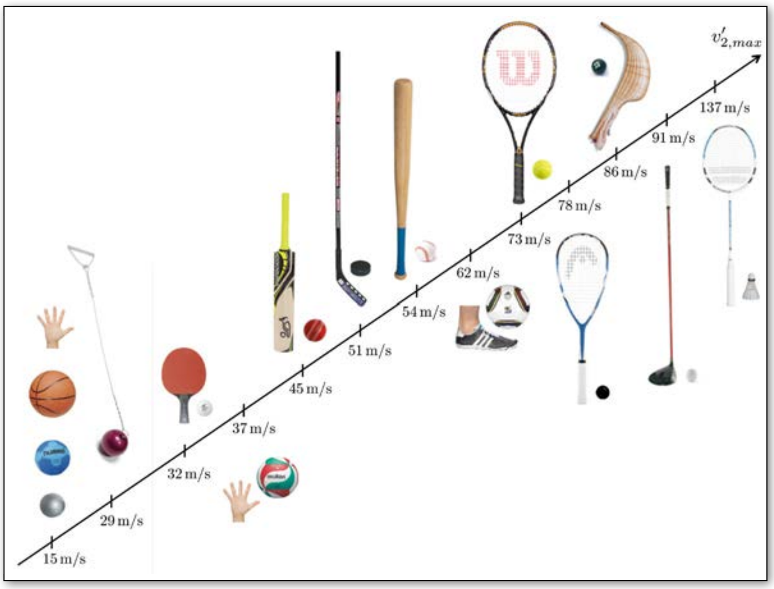
$$\frac{v_2'}{v_1}=1 \qquad (1)$$

For the examples presented in figures 2(d) and 2(e), we measure a velocity of 15 m/s for the handball throw and 45 m/s for the baseball pitch.

However, most games have chosen another way to launch the ball: via an impact. Figures 2(a), 2(b) and 2(c) show chronophographies, made by H.E. Edgerton, of a golf swing, a tennis serve and a baseball hit [2]. Again, the blue segments represent the distances traveled by the instrument (club, racket, bat) between two snapshots at the exact position of impact and just after it occurs, while the red ones represent the distance traveled by the ball. The red segments are systematically twice as long as the blue ones. The ball velocity is thus twice as large as the instrument's velocity. This factor two is a big advantage of hitting *vs.* throwing. However, to discuss the real difference between throwing and hitting, one must consider the velocity ratio between the ball and the instrument v_2'/v_1, derived from the momentum conservation [3]:

$$\frac{v_2'}{v_1}=\frac{(1+e)}{(1+m_2/m_1)} \qquad (2)$$

where m_1 and m_2 are the masses of the instrument and the ball, respectively. The coefficient of restitution e characterizes the dissipation at impact and is defined as: $e = -(v_2' - v_1')/(v_2 - v_1)$, where v_1 and v_1' are the velocities of the instrument before and after impact, respectively, and v_2 and v_2' similarly for the ball. In the elastic light ball limit ($m_2 << m_1, e \approx 1$), the velocity ratio is $v_2'/v_1 = 2$. This is the ideal hit limit. However, with energy dissipation or if the ball is not so light, the velocity ratio decreases. In order to compare the efficiency of hitting *vs.* throwing, we turn to figure 2(f) where the velocity ratio v_2'/v_1 is given as a function of the mass ratio m_1 / m_2 for all ball sports. This figure shows that for light balls ($m_2 / m_1 < e$), hitting is more efficient than throwing: all sports in which the ball is hit are in the blue area. By contrast, for heavy balls ($m_2 / m_1 > e$), one finds that it is more efficient to throw the ball. These sports are in the red area. As expected, smashing a handball towards the goal is not a good idea, first because it will be less efficient than throwing, and also because the impact will hurt the player. The velocity ratio (2) describes the efficiency of hitting *vs.* throwing, but in both cases in order to increase the ball velocity, one has to increase the velocity of the launcher.



▼ FIG. 1: Evolution of the maximum velocity in different ball sports.

How to increase the velocity?

There are three main ways, used in sport, to increase the velocity at impact: **1** - take advantage of the joints in order to enhance the velocity (figure 3(a)); **2** - use a racket, a club, a bat in order to artificially increase the length of the arm (figure 3(b)); **3** - use a deformable racket in order to get an extra elastic boost (figure 3(c)). We briefly discuss them below and show how they are connected to the speed ladder presented in figure 1.

For a given angular velocity ω, the velocity V of a straight arm of length L goes like $V = L\omega$. To change the velocity, one can thus either change L or ω. The articulated motion mainly plays on ω: indeed, for a given driving torque exerted by muscles, the angular velocity of the articulated limb is higher since the moment of inertia of an articulated limb (figure 3(a)) is smaller than for a limb with the same total mass and length but without articulation (rigid leg).

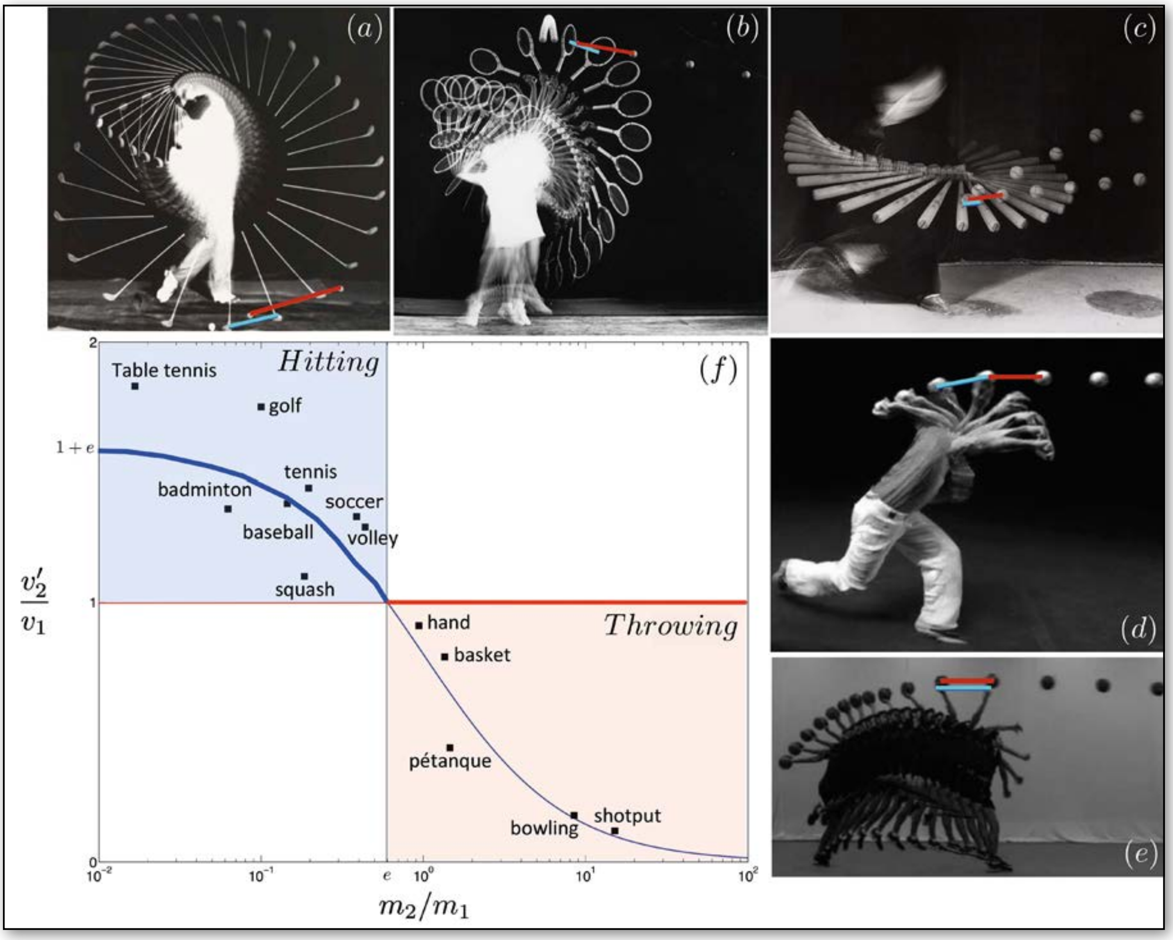


FIG. 2: Chronophotographies of golf (a), tennis (b), baseball bat (c), baseball pitch (d) and handball throw (e). The graph (f) shows the evolution of the velocity ratio between the ball and the launcher v_2'/v_1 as a function of their mass ratio m_2/m_1.

The relation $V = L\omega$ also states that the larger L, the larger the velocity. Using a racket, a club or a bat is one way to achieve this "arm stretching". Looking back to figure 1, one notices that the slowest sports do not use this "trick", contrary to the fastest ones.

However, tennis and badminton are two sports for which the ball is hit with rackets of same lengths, and with similar hit efficiency. But the maximum velocity of a badminton shuttle (137 m/s) is twice the tennis record (73 m/s). To understand badminton breaking velocity records, one must consider the elasticity of the shaft which is also a way to change the angular velocity. The badminton racket is slender and easy to bend, contrary to the tennis racket, which is very rigid. When the handle is set in motion, the badminton racket head doesn't follow instantly, and the shaft bends, all the more as the acceleration is high. Figure 3(c) shows a chronophotography of a badminton smash: When the shaft bends, elastic energy is first stored into deformation and then released into kinetic energy. If the impact occurs when the restoring velocity is at its maximum, the velocity of the racket head is up to twice as fast as its rigid counterpart.

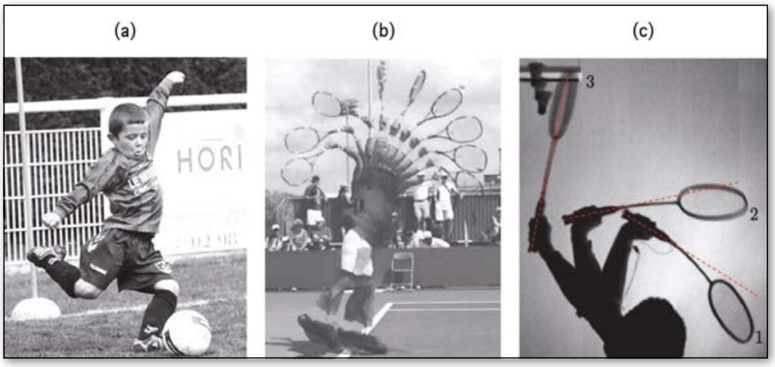
If we summarize our discussion, we observe in figure 1 that the maximum velocity achieved with the hand alone is 15 m/s (handball). If the length of the arm is doubled (using a racket), the velocity will also be doubled (30m/s). However, with a racket, there will be an impact and not a throw, which means that the velocity of the ball will get an extra factor 2 (equation (2)). We thus expect velocities around 60 m/s which is not far from what is observed in baseball (54m/s) and tennis (73 m/s). Finally, if elasticity is used, this velocity can again be doubled. Velocities around 120 m/s are thus expected in sports where flexible rackets are used such as badminton (137 m/s).

Parabola vs. Tartaglia

Once thrown, the ball follows its path, submitted to its weight ($M\boldsymbol{g}$) and to the aerodynamic forces which we write in simplified form as $-\frac{1}{2}\rho S C_D U \boldsymbol{U}$, with ρ the air density, S the section of the ball, C_D the drag coefficient and $\boldsymbol{U}$ the ball velocity (U is its modulus). The motion of the ball is thus dictated by Newton's law:

$$\underbrace{M\frac{d\boldsymbol{U}}{dt}}_{①} = \underbrace{M\boldsymbol{g}}_{②} - \underbrace{\tfrac{1}{2}\rho S U \boldsymbol{U} C_D}_{③} \qquad (3)$$

This equation states that the momentum change per time unit ① is related to the sum of two forces, the weight ② and the drag ③. When these two forces balance ②=③, the particle has reached its terminal velocity $U_\infty = \sqrt{2Mg/\rho S C_D}$. If the ball is launched with an initial velocity U_0 smaller than U_∞, the drag is smaller than the weight and the equality ①=② imposes the classical parabola (figure 4(a)). In the opposite case where $U_0 >> U_\infty$,



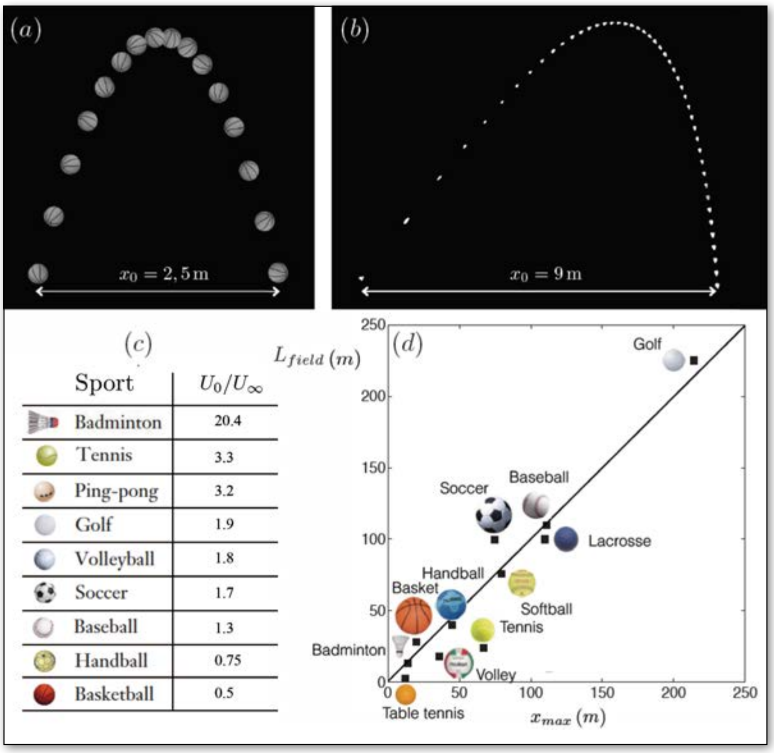
▲ FIG. 3: (a) Soccer kick. (b) Chronophotography of a smash in tennis by Stanislas Wawrinka. (c) Chronophotography of a smash in badminton by Michael Phomsoupha.

gravity can be initially neglected and the ball follows a triangular curve, called a Tartaglia (figure 4(b)) [4].

To know which trajectory is observed in each ball sport, one can compare the record velocity to the terminal speed. Figure 4c shows that, for most of sports, drag dominates weight and we observe Tartaglia, except for handball and basketball. Badminton is the paradigm of aerodynamical sports. Figure 4(b) displays the chronophotography of a badminton shot: the shuttlecock, hit at 58 m/s, first goes straight and its velocity decreases strongly over a characteristic length $L = 2M/\rho SC_D = 4.5$ m which results from the equality ①=③ in equation (3).

As velocity decreases, weight becomes important and makes the shuttle turn downward ①=②+③. Finally, it falls vertically at a constant velocity U_∞: ②=③. But we never have a parabola [defined by the equality ①=②].

▼ FIG. 4: The two main trajectories observed in ball sports: (a) parabola, (b) Tartaglia. (c) Ratio of record velocity and terminal velocity. (d) Size of sports fields vs. maximum ball range.



Impact on the size of the sports fields

Parabola and Tartaglia are both characterized by a maximal range, x_{max}, which can be calculated [5] and which imposes a physical constraint to the size of sports fields. Indeed, it's no use playing on a 100 m-long field, if the maximal range of the ball is 10 m. Figure 4(d) shows a strong correlation between the size of sports fields and the maximal range, x_{max}, of the associated balls, from table tennis to golf. We conclude that the size of sports fields is mainly imposed by the physics of the ball flight [6].

Some points in fig. 4(d) are below the line having slope 1, which means that the field is small compared to the range. In tennis, volleyball and table tennis, the field is thus reduced in order to make it difficult to keep the ball inside. This difficulty is underlined by counting points when the ball goes out. For sports above the line, like soccer and golf, staying on the field is easy and no points are associated to a ball going out. Instead, a small target is introduced that the players must reach in order to score. The physical line thus separates target sports from sports for which the pitch itself is the target.

Conclusion

The study of ball games has led us to explore internal ballistics (the projectile propulsion), as well as external ballistics (the trajectory of the projectile). We have tried to show that, despite the diversity of sports, they are all linked by strong physical constraints that impact their practice without removing the joy of playing.

About the authors

Caroline Cohen is a Post Doc Researcher at Matière et Systèmes Complexes (MSC) of Paris Diderot University. She earned her PhD on the Physics of Sports.

Christophe Clanet is CNRS researcher and director of the hydrodynamics laboratory at Ecole Polytechnique (LadHyX). He develops a group of research on Sports Physics.

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[5] C. Cohen, B. Darbois-Texier, G. Dupeux, E. Brunel, D. Quéré, and C. Clanet, *Proceedings of the Royal Society of London. Series A* **470**, 20130497 (2014).

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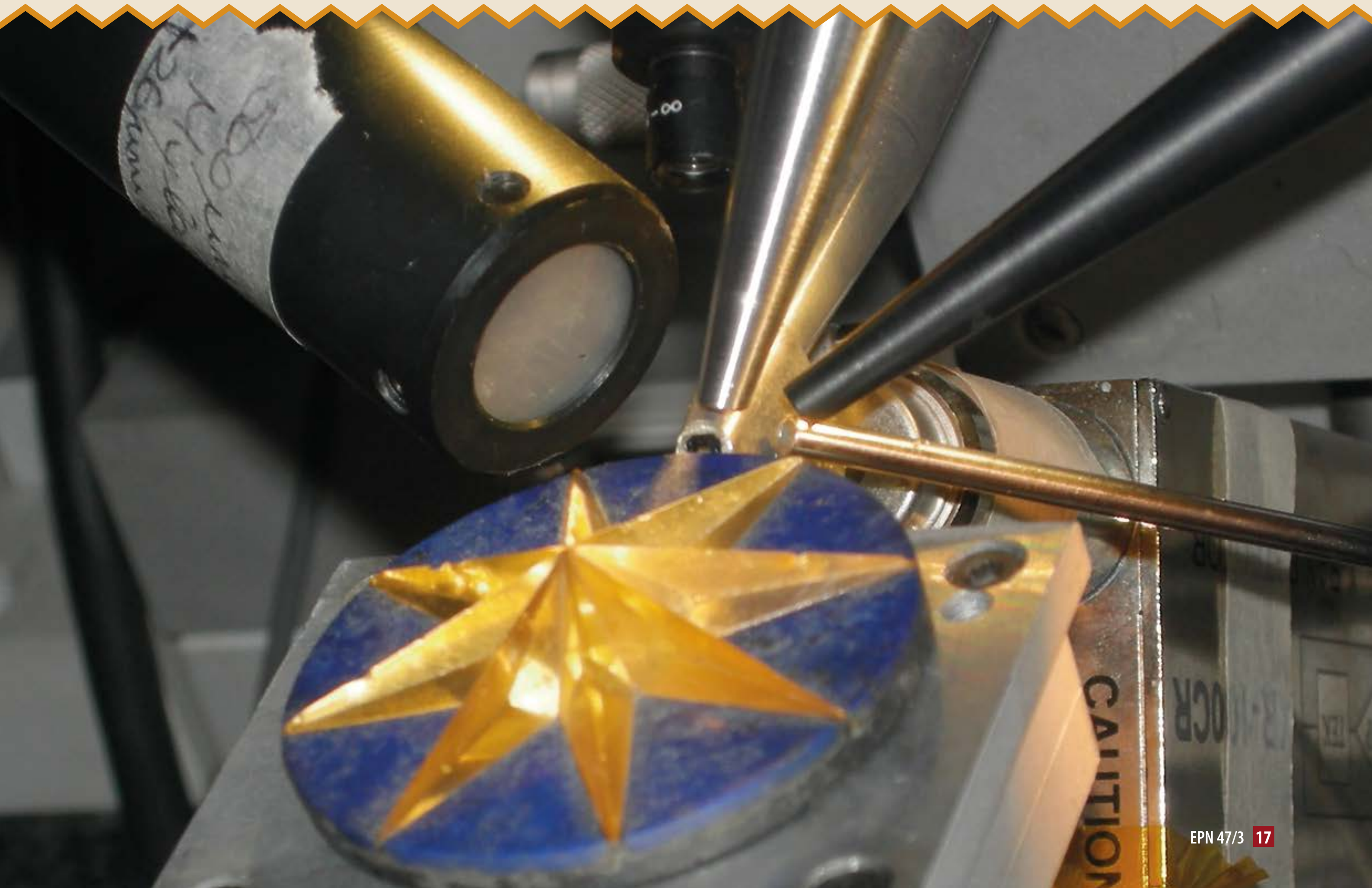
DISCOVERING NEW INFORMATION FROM HISTORICAL ARTEFACTS USING ELECTROMAGNETIC RADIATION AND CHARGED PARTICLES AS A PROBE

A. Macková [1,2], Ž. Šmit[3,4] and L. Giuntini[5,6] – DOI: http://dx.doi.org/10.1051/epn/2016302

[1] Nuclear Physics Institute of the Czech Academy of Sciences, v. v. i., 250 68 Rez, Czech Republic
[2] Department of Physics, Faculty of Science, J.E. Purkinje University, Ceske Mladeze 8, 400 96 Usti nad Labem, Czech Republic
[3] Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia
[4] Jožef Stefan Institute, Jamova 39, POB 3000, SI-1000 Ljubljana, Slovenia
[5] Dipartimento di Fisica e Astronomia, Università di Firenze, Via Sansone 1, I-50019, Sesto Fiorentino, Italy
[6] INFN, Sezione di Firenze, Via Sansone 1, I-50019, Sesto Fiorentino, Italy

Archaeological artefacts included in cultural heritage contribute to the knowledge of our roots, which may help us to learn about our future. Although the connection between ancient times and nuclear technology seems farfetched, this paper will try to show how nuclear radiation of various kinds can be irreplaceable in the elemental composition analysis of an archaeological find.



The first steps and the present days

Scientific methods in archaeology and art began to be systematically applied in the late eighteenth century by the German scientist Martin Heinrich Klaproth (1743–1817), who published the first-ever quantitative analysis of an alloy of some Greek and Roman metal coins. Much later, in the early 1960s, various types of ion beam analyses (IBA) were developed and put into routine use. Further developments of IBA-based analytical methods were related to progresses in low-energy accelerators, in detectors for particle, X-ray and γ-ray and in systems for processing experimental data [1].

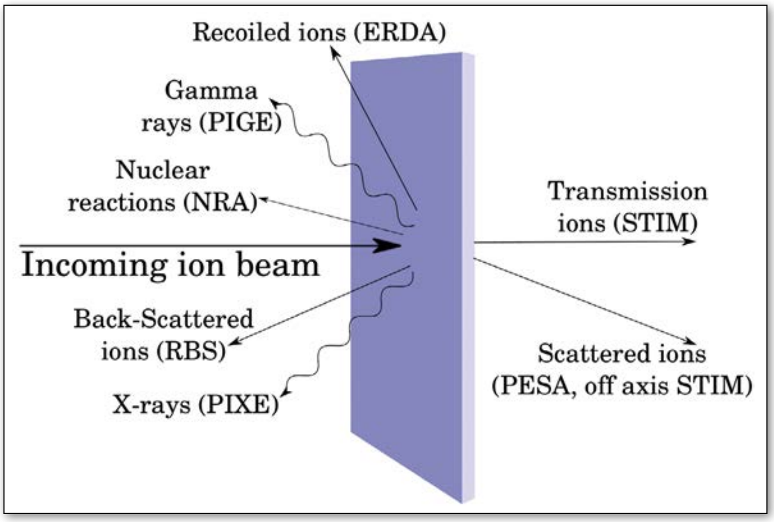
Ion beams of several MeV, produced by small accelerators, penetrate into matter, interact with the atoms of the sample and produce, among other phenomena, X-rays and γ-rays, which carry information about the investigated artefact. The small accelerators can provide a wide range of ion beams (protons, alphas and heavy ions), with flexible energy range (and thus adjustable probed depth) and diameter of the beam (from millimetre to micron size). They can thus provide tailored tools for the study of the diverse objects of Cultural Heritage.

Nuclear analytical methods successfully applied in archaeometry

Archaeometry involves non-invasive surveys of the terrain, science-based dating methods and analytical techniques for object characterization. Nuclear physics contributes significantly to the dating methods (radiocarbon dating) and to analytical methods with techniques sensitive to practically all the elements of the periodic table and capable of reconstructing the spatial distribution of the elements present in the sample [2, 3].

It should be emphasized that applications of nuclear analytical methods on the cultural heritage have recently been collected for a new, topical paper published by the Nuclear Physics Board of the European Physical Society publication, of a few highlights of which we would like to present here.

▾ **FIG 1:** A schematic description of ion elastic and inelastic ion collisions with solid matter inducing different phenomena. Their products are elastically scattered ions and/or elastically recoiled light nuclei, X-rays produced in ion inelastic collision with the target atoms, and products of nuclear reactions.



How ion beam methods work

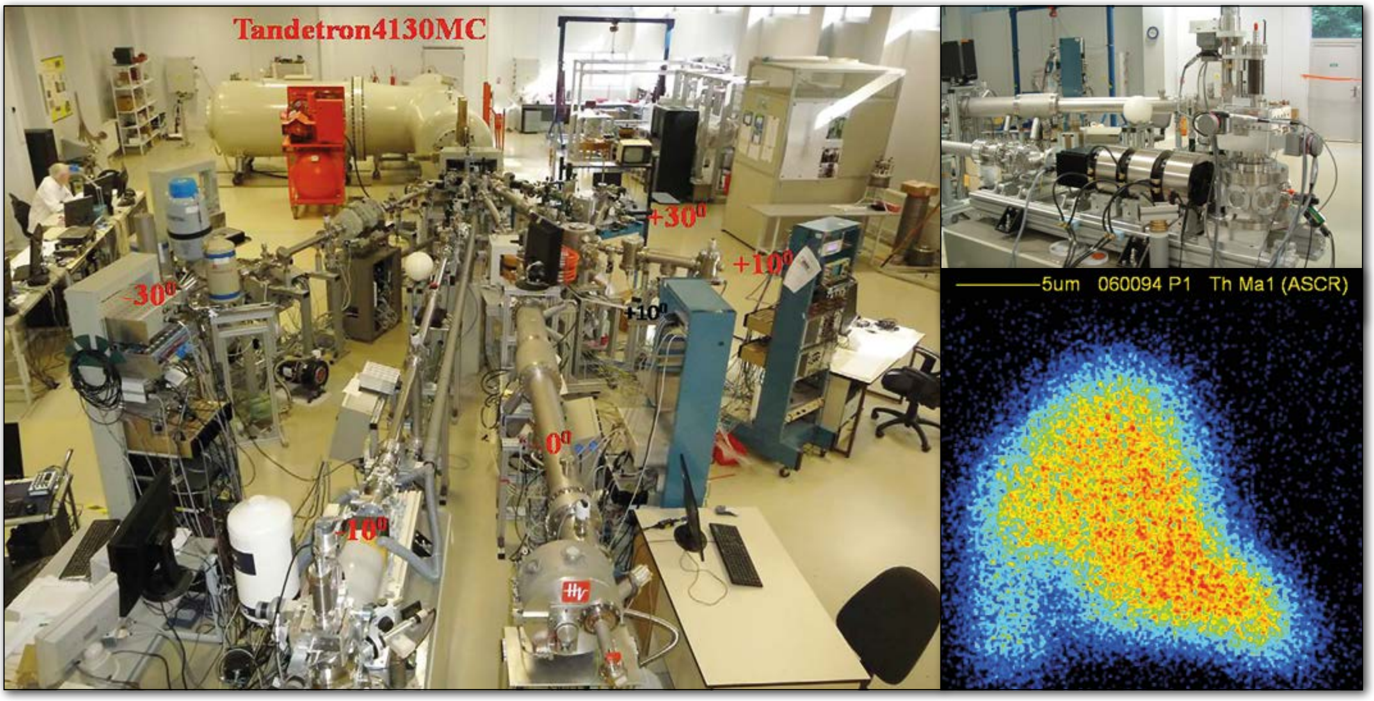
Rutherford backscattering spectrometry (RBS) is an analytical non-destructive method which is based on the measurement of the energy spectra of MeV ions (protons, He^+, Li^+, or heavier ions) elastically scattered from solid samples [2, 3]. From the analysis of the backscattered particles' energy distribution it is possible to determine the elemental amounts in the sample and their depth distributions.

When ions and matter interact via nuclear reactions, charged particles and/or γ-rays are produced (see Figure 1). The **Nuclear Reaction Analysis** (NRA) technique is based on the study of the energy spectrum of these charged particles and γ-rays. The yield of nuclear reaction products is proportional to the reaction cross sections (which define the probability of each type of interaction) and the density of target atoms in the sample. Most frequently used reactions are (p,α), (d,p), and (d,α), which allow indicating the presence and the concentration of several isotopes typically from ^{1}H to ^{32}S, such as ^{2}D, ^{12}C, and ^{16}O [2-4], just to name a few. Energy loss by the incident ion can be used to determine depth profiles by resonance scanning using a (p, γ) reaction, where γ-rays are detected. **Particle-Induced Gamma Emission** (PIGE) is based on nuclear reactions, most typically (p, γ), induced in specific isotopes. The energy of the γ-ray lines indicates the elements, while the intensity is related to their concentrations.

Particle-Induced X-ray emission (PIXE) exploits X-ray emission for elemental analysis [2, 3]. The energy of a peak in the X-ray spectrum is specific for a particular element, and its intensity is proportional to the elemental concentration. PIXE has a very low detection limit, down to several ppm in standard practice.

A big technological progress was made after the **ion microbeam** development. In a microbeam, the ion beam from the accelerator passes through a lens (a combination of magnetic quadrupoles with alternated polarities) focusing the high energy ions. The samples are irradiated with an ion beam focused onto a spot that can be as small as a few hundreds of nm in diameter. Standard IBA techniques are used to characterize the irradiated object. By raster-scanning the beam over the sample surface, a 2D or 3D distribution of elements can be determined with nm depth resolution and lateral resolution limited by the size of the beam spot, see Figure 2 [4, 5, 6].

Some archaeological artefacts cannot be placed in a vacuum chamber because of their large size or the presence of volatile components. Such samples can be analysed using an **external ion beam**. The beam is extracted from the evacuated beam line into air through a thin window, made of thin metal foils, strong plastic materials like kapton, or Si_3N_4. Practically all setups now allow the scanning measurement mode that produces elemental

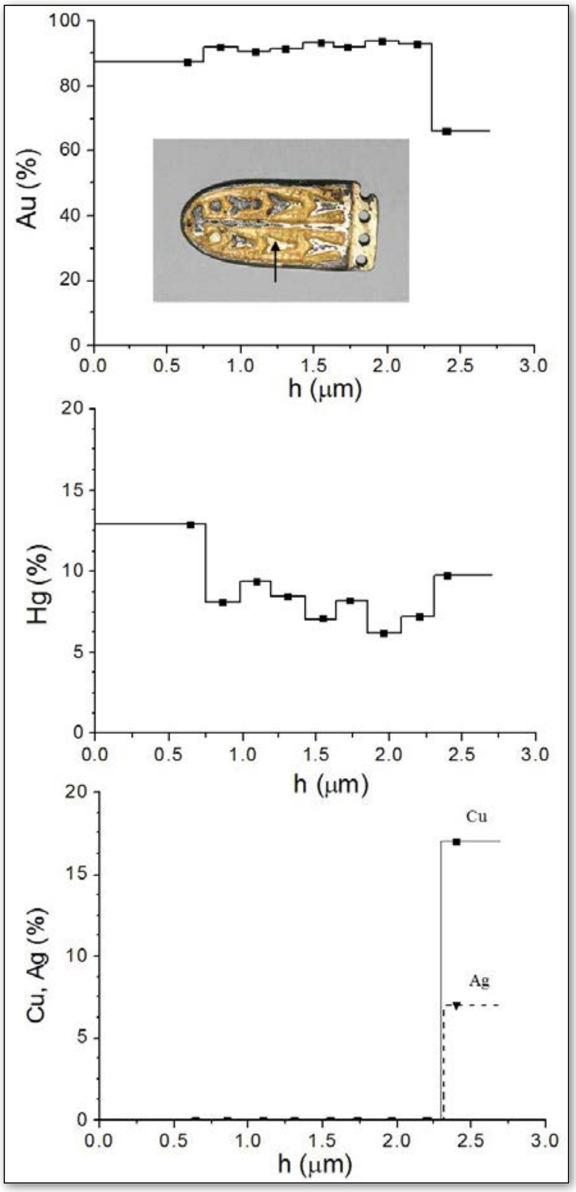


concentration maps. The target is surrounded by an array of detectors. Normally there are at least two X-ray detectors, one with a thin window detector for soft X-rays and a detector with a large solid angle (but equipped with an additional absorber) for hard X-rays. The external microbeam set-up can be improved to be versatile and allows all IBA techniques to be used individually or in combination [6], namely PIXE–PIGE–RBS with protons, PIXE–PIGE–NRA with deuterons, PIXE–RBS with He^+ ions [1-6].

▲ **FIG 2:** Typical ion beam lines arrangement at the Tandetron accelerator (Center of Accelerators and Nuclear Analytical Methods NPI CAS, Rez, Czech Republic) with the microbeam facility at -10°. Shown are the ion beam line (left panel), the microbeam vacuum chamber for placing specimen in the upper right corner, and elemental map (Th visualized) of the inclusion in the granitic rocks in the lower right corner.

Examples of the archaeological artefacts analyses

The example of metal analysis demonstrates the identification of the gilding technique, see Figure 3. The object studied comes from the Early Medieval Age, which favoured gilded silver or bronze jewellery. The methods applied were differential PIXE and RBS with in-air proton beam [6]. Differential PIXE is based on the sequential measurement in the same spot such that protons reach different target depths. This is achieved by the variation of the proton incident angle or by the variation of proton energy. The results of the de-convolution procedure are concentration profiles, which can reach up to a few tens of microns below the target surface. Figure 3 shows the elemental concentration profiles of a gilded strap end [7, 8].



▸ **FIG 3:** The elemental concentration profiles of the gilded layer on a gilded strap end from the from the Early Medieval Age obtained obtained by differential PIXE; *h* denotes the distance from the surface.

> **Ion beams of several MeV interact with the atoms of the sample and produce X-rays and γ-rays, which carry information about the investigated artefact**

▲FIG 4: An artwork from the 'Collezione Medicea' during IBA analysis carried out at the external microbeam at INFN-LABEC in Florence.

The amount of additional elements (Cu, Hg) in the gold layer undoubtedly reveal the amalgamation gilding technique used.

Examples of elemental composition study of precious stones

PIGE was very efficiently used for light elements and PIXE for medium and heavy elements in qualitative and quantitative analysis of emeralds and garnets, popular among Romans and their barbaric successors. Emeralds contain a known fraction of beryllium, which can be measured either directly or taken into account numerically for the calculation of matrix effects. The provenance sites of the precious stones are certainly of interest as they indicate the extent of trade routes established by the Romans [9, 10] and can be determined via various trace element concentrations in the precious stone. The fluid channels in a set of emeralds excavated in a Roman grave from Slovenia point to a source in Egypt, while emeralds from another grave may be traced to Afghanistan.

Another interesting application is the study of the origin of Lapis lazuli. Lapis lazuli is a semi-precious blue stone widely used for different purposes since the antiquity. However, at present there are still some lacking pieces of information about its trade in ancient times [11, 12, 13]. An external proton microprobe was used, as the external beam allows for non-invasive, multitechnique (PIXE, PIGE and ionoluminescence IL) study of objects of almost any shape and dimension, see Figure 4. For the provenance discrimination the study focused on markers, such as for example the presence or absence of the trace elements in the stone of a specific mineral phase. After this study, some of the markers found on rocks have been successfully used to identify the origin of six precious artworks.

Conclusions

The application of atomic and nuclear techniques in the study of archaeological objects provides a historian or archaeologist with 'material' information that can help in the understanding of the way of life in ancient times. This knowledge is necessary for the testing of the authenticity and provenance of artefacts and for the preparation and implementation of the necessary restoration work. All of these objectives are common to the very large community of people working in the field of archaeometry, *i.e.* the 'application of science to art and archaeology'.

About the Authors

Anna Macková is currently the Head of the Tandetron Laboratory, an instrument responsible for the CANAM (Centre of Accelerators and Nuclear Analytical Methods) infrastructure, a part of the Nuclear Physics Institute of the Czech Academy of Sciences, v. v. i., Czech Republic. She is a nuclear physicist dealing with ion beams of a wide range of masses and energies for the development of new progressive materials, nanostructure deposition and characterization, microbeam applications *etc.* She is an Associate Professor at J. E. Purkynje University.

Žiga Šmit is full Professor at the Faculty of Mathematics and Physics, University of Ljubljana, and scientific adviser at the Jožef Stefan Institute, Ljubljana, Slovenia. His interests are in fundamental principles and application of PIXE and PIGE spectroscopies using in-air proton beams. His main experience includes analysis of archaeological artefacts, geological and environmental samples.

Lorenzo Giuntini is an applied nuclear physicist, one of the founders of the LABEC, the Florence laboratory of the National Institute of Nuclear Physics for the study of cultural heritage and environment by nuclear techniques. He has been the initiator of the Florence microbeam and his main expertises are external microprobe, IBA and XRF. He presently serves as one of the two responsible of the Tandem laboratory in Florence and is associate professor of experimental physics at the University of Florence, Italy.

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[Letter to the Editors]

by Wolfgang Kundt,

DOI: http://dx.doi.org/10.1051/epn/2016303

Dear Editor,

Today I approach you because of the science-fiction contribution on GW140915 by Angela Di Virgilio, in your issue 47/2 (2016) on pages 9-10, claiming that this GW event was launched by two stellar-mass black holes. It ignores a number of serious results during the past 7 years, by Pankaj Joshi, Bahram Mashhoon, Hernando Quevedo, Daniele Malafarina, and even Stephen Hawking (on 24 Jan. 2014), having proved that BHs are no longer expected, as results of gravitational collapse. It was derived by applying the chirp mass formula from John Wheeler's published lecture notes to the emission event, an analytical formula which has been derived for 2 point masses circulating around each other at large separations, and successfully applied to several binary neutron stars, but whose validity expires as soon as two stars approach each other close enough for tidal deformations, and for the emission of strong gravitational waves. The emitting masses then turn ill-defined. Instead, above gravitational signal has most likely been emitted by two coalescing neutron stars, at a(smaller) distance of <~ 30 Mpc, a fate which will some day likewise be shared by the Nobel (*cf.* https://wolfgangkundt.wordpress.com). ■

The author responds

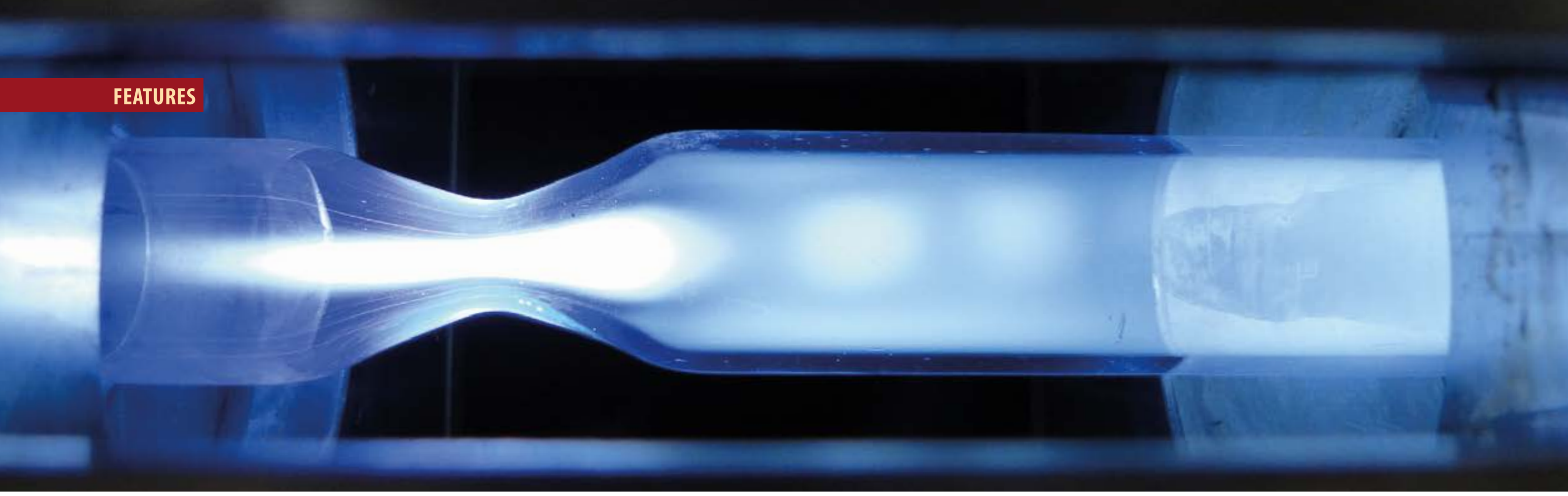
Dear Prof. Kundt,

Some more exotic interpretations of the GW140915 event are possible, but the interpretation given by the LIGO/Virgo collaboration is probably the most economic and simple at the current stage of our knowledge. I'm more in the experimental side and my personal reaction in front of this event is that the antennas must be improved in the low-frequency part of the spectrum. I'm not the right person to fully address and reply your question; the GW community is rather large and this question need to be addressed to the right people. In any case, in order to give you a quick answer, I have discussed a bit with my colleagues and in the following I report some comments.

The claim that BHs have been proved not to exist is a bit misleading in this context. For example, the Hawking opinion you cited is mainly concerned with the real, absolute "blackness" of BHs, which is quite unrelated with the behaviour of these maybe "not completely black" objects when they collide. All these alternatives, naked singularities and so on, are surely interesting and worth to be experimentally tested.

Coming back to GW140915, trying to avoid too speculative physics, or as you said science fiction, for sure there is a clash between the observed signal (its frequency and its duration) and your suggested interpretation as a pair of neutron stars. For a NS-NS coalescence the signal is expected to remain in the LIGO sensitivity band much longer, mainly because a NS is much more compact that a 30 solar mass BH. This prediction is not based on the quadrupole approximation you are referring to, but on the analytical post Newtonian expansion and, in the final stage, on numerical simulation of full General Relativity. Quite remarkably, there is an overlap region where the two approaches agrees very well.

In any case, my personal hope is to have soon GW antennas on and with improved sensitivity, especially at low frequency, in order to help clarifying all this complicated matter. ■



CO_2-NEUTRAL FEATURES

By Adelbert Goede and Richard van de Sanden
Dutch Institute for Fundamental Energy Research DIFFER, PO Box 6336, 5600 HH Eindhoven, the Netherlands
Corresponding authors: a.p.h.goede@differ.nl and m.c.m.vandesanden@differ.nl – DOI: http://dx.doi.org/10.1051/epn/2016304

Mimicking the biogeochemical cycle of System Earth, synthetic hydrocarbon fuels are produced from recycled CO_2 and H_2O powered by renewable energy. Recapturing CO_2 after use closes the carbon cycle, rendering the fuel cycle CO_2 neutral. Non-equilibrium molecular CO_2 vibrations are key to high energy efficiency.

Renewable Energy, the need for storage

The need for energy storage arises from the fact that Renewable Energy (RE) generated is ill-matched to demand. Increasingly supply exceeds demand to the extent that it cannot be accommodated by the electricity grid, however smart. This calls for conversion into added value products, lest it be wasted by curtailment. The German RE scenario expects 34.5 TWh electricity surplus by 2030, increasing to 110-148 TWh in 2050 [1]. For the Netherlands, RE surplus is expected to amount to 1.5 TWh in 2025 (~1% total energy production), increasing to 30-55 TWh in 2050 [2]. For France, these numbers are 15 TWh for 2030 and between 44 and 91 TWh for 2050 respectively [3].

At high RE penetration scenarios foreseen by the EU 2050 Energy Roadmap, a more fundamental driver of energy storage appears; load duration curves prove incongruous to RE supply curves [4]. Only large-scale seasonal energy storage can overcome this limitation.

Energy storage comes in many shapes and sizes directed at specific power and energy requirement, each coming with their own characteristic pros and cons. One way to meet the large-scale seasonal energy storage requirement is through storage in chemical bonds. As compared with flywheels, batteries, compressed air and pumped hydro, chemicals offer higher energy density storage and are easily transported and distributed. Converting RE electricity into methane offers long-term and large-scale energy storage capacity, 552 TWh for the Dutch gas network alone. By comparison, Norway stores approx. 15 TWh hydro power, whilst average daily European electricity production is of order 10 TWh.

Rather than strengthening the electricity grid, integration of the electricity grid with the existing EU gas grid would provide the required balancing of load and relieve the electricity grid from peak load. This is the power to gas (P2G) scheme, illustrated by Figure 1. Capital investment in electric grid expansion is avoided whilst economic advantage is gained by the fact that transportation of gas is more than a factor 10 cheaper than transport of electric energy, see Table 1. Additional routes for handling surplus RE are also shown. A profitable one is power to chemicals (P2C), through electrification of the chemical industry. Transport offers another important route for conversion of surplus renewable electricity into fuel (P2F), which may well prove essential in meeting 2050 EU transport emission targets. Case in point is long haul flight, for which there is no sustainable alternative, but for bio-kerosene, of which there is too little, being bogged down in the fuel vs food and fuel vs flora trilemma.

Economic feasibility of energy storage has been subject to various studies [1-3]. Current projections expect a business case to emerge in the 2030 timeframe. Economic advantage is gained initially by exploiting periods of low electricity price supported by government regulation, but ultimately depends on the price of carbon [5]. Currently, the Emission Trading Scheme sets too low a price on CO_2, whilst the UN principle "polluter pays" has yet to be enforced by levying a carbon tax.

CO_2-Neutral Fuels – Avenues explored

Low Carbon Energy, decarbonisation of the energy system, the common mantra of energy policymakers today, suggests no place for hydrocarbons in a future energy system, promoting hydrogen, ammonia or batteries instead. A CO_2-neutral fuel would, however, also act to stabilise carbon emissions, akin to the natural biogeochemical cycle, yet benefitting from existing infrastructure. Prerequisite is the recycling of CO_2 after use, extracting CO_2 either from flue gases or directly from ambient air to account for dispersed sources.

Nature's ability to form hydrocarbons by photosynthesis has inspired many in their quest to replicate the process and to produce synthetic fuels with high energy density that are sustainable. To date, several avenues are being explored; the direct route of solar photons into fuel including the natural and artificial approach and the indirect route through the intermediate of electricity [6]. Challenges include high energy efficiency, high energy density and throughput, use of abundantly available materials and a rapid response to intermittent supply of electricity.

Although conceptually attractive, the direct conversion route has a long way to go to reach useful efficiencies. Indirect conversion technology already produces fuel at an order of magnitude higher energy efficiency. For example, photo-voltaically driven electrolysers produce hydrogen at about 20% overall efficiency. Employing the reverse water gas shift reaction to create syngas, followed by Fischer-Tropsch reaction to produce liquid hydrocarbon fuel, reaches an overall energy efficiency of 10% [7].

Electro-chemical conversion traditionally is based on alkaline electrolysers. Recently, Polymer Electrolyte Membrane (PEM) electrolysers have shown higher energy efficiency and density, but scarce platinum is employed as a catalyst at the cathode. Still higher energy efficiency, power density and output pressure go with Solid Oxygen Electrolyser Cells (SOEC), operating at high temperature (700-800°C) and pressure (50 bar) to produce hydrogen at over 80% energy efficiency. Recently, SOEC produced syngas in one step by co-electrolysis of CO_2 and H_2O [8]. Issues include life time and degradation of the electrodes at high current density. The fuel cathode is made of porous nano structured Ni/YSZ (Y_2O_3 stabilised ZrO_2), the electrolyte layer consists of YSZ (Yttria stabilised Zirconia) and the oxygen anode is a porous SrO doped $LaMnO_3$ (LSM/YSZ). The electrode-electrolyte interface layer is key to performance. Recently, perovskites, including LSCF (Lanthanum Strontium Cobalt Ferrite) and SSC (Samarium Strontium Cobalt) have shown promising stable high current density performance [9].

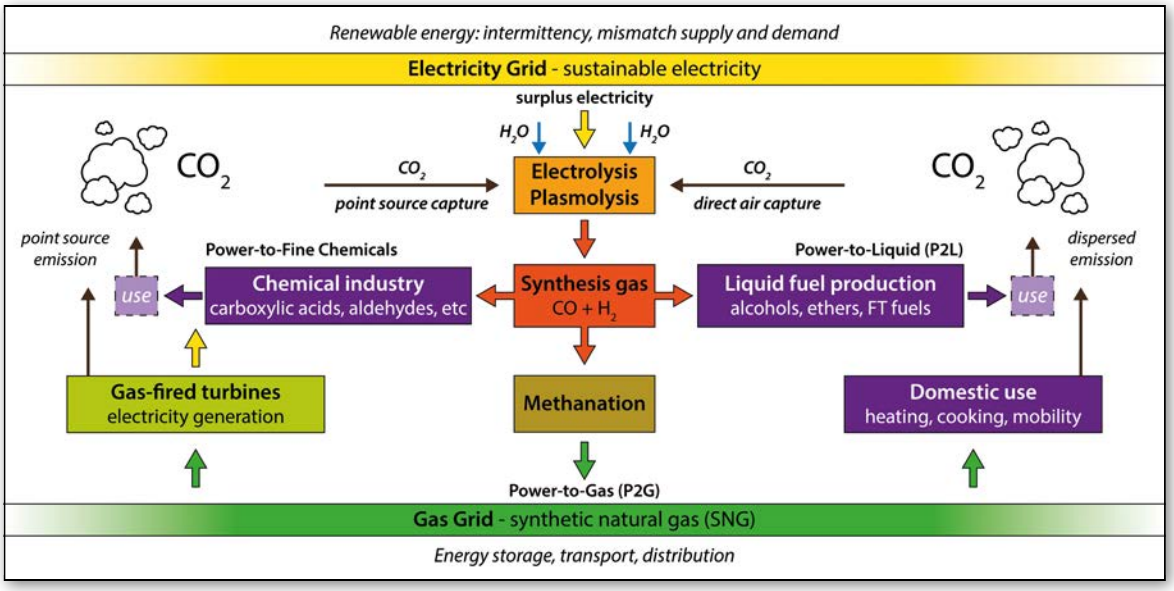
	Power: BritNed	Gas: BBL
Length	260 km	230 km
Investment	600 M€	500 M€
Capacity	1 GW	20 GW
Specific investment costs	€ 230 /kW/100km	€ 11 /kW/100km

Source: GasUnie, the Netherlands.
Ref.: Nord Stream gas pipeline from Russia to Europe via Baltic: € 9 /kW/100km

◂ **Table 1:** Comparison of capital investment cost per kW power transported for electricity and gas transport lines from the Netherlands to the UK in comparable situation. Gas is a factor 20 cheaper. Source: Dutch Gas Unie.

Plasma-chemical conversion or plasmolysis increases the power density by more than an order of magnitude compared with SOEC [10-12]. High gas flow rates allow upscaling to high CO production rates at MW level. No scarce materials are employed and a plasma rapidly responds to intermittency. The plasma eases conditions for splitting CO_2 through vibrational excitation of the molecules. Such plasma is weakly ionised - only one in 10^5 molecules is ionised - and relatively cold, similar to a fluorescent lamp. The energy to produce the plasma is a relatively low factor in the energy balance.

To close the fuel cycle and render it CO_2 neutral, CO_2 emitted must be recaptured after use of the hydrocarbon produced, from point source initially (fossil fired power, cement, steel plants), from the atmosphere eventually to account for dispersed CO_2 emissions (cars, ships, planes).



◂ **FIG. 1:** Power to Gas (P2G) scheme converting Renewable Electricity (RE) into synthetic gas or liquid fuel (P2F) or chemicals (P2C). Syngas (H_2, CO_2) is the central element from where methane, Fischer-Tropsch fuel or other chemicals are formed. After use, the CO_2 emitted is captured and recycled in order to render the fuel cycle CO_2 neutral. The critical element, both technically and economically, is the splitting of water and CO_2 into syngas.

Alternatively, CO_2 may be captured from the ocean taking advantage of the higher concentration. Both, direct air and ocean CO_2 capture plants are not linked to emission sites; plants may be sited anywhere around the globe. Research challenges include the development of energy efficient materials to capture and desorb CO_2, including ionic liquids [13, 14].

Carbon capture and utilisation (CCU) will close the carbon fuel cycle, however, raises the question of scale and cost of the carbon capture plants. For example, a direct air capture plant is similar in size to a concurrent wind farm producing the electricity required to convert the CO_2 captured into fuel. This implies non-trivial infrastructure. Cost on the other hand, often seen as an impediment to carbon capture, is an order of magnitude lower than the cost of splitting CO_2 or H_2O, hence not a cost driver at system level.

Plasmolysis - the physical picture

A plasma offers advantages in CO_2 splitting including high energy density and high gas throughput with scope for upscaling. A microwave discharge creates the plasma and accelerates the electrons which vibrational excite the CO_2 molecules by a slight touch (max. cross section at 0.4 eV) like a clapper ringing a bell. The CO_2 molecules, whilst chiming away, occasionally bang into each other, exciting overtones thereby ratcheting up vibrational energy of one molecule at the expense of others. Eventually, this leads to breaking the CO_2 molecular bond at 5.5 eV energy, releasing a CO molecule and oxygen atom. This oxygen radical is put to good use by reacting with another CO_2 molecule producing a second CO molecule at 0.3 eV energy. The net energy expended per CO produced is thus lowered to 2.9 eV, much smaller than the dissociation energy of 5.5 eV and the 7 eV or more electron energy required for vibronic excitation of CO_2 by Franck-Condon transition.

This process directs energy along a path where it is most effective in dissociation, rather than heating the gas: it exploits a non-equilibrium process where vibrational energy exceeds the translational and rotational energy. Vibrational up pumping under non-equilibrium conditions is a robust process based on the asymmetric stretch bond of the CO-O potential well. Pioneered by the Russians during the cold war, this scheme is reported to reach energy efficiencies of over 80% [10-12]. The only snag: results have never been reproduced in the West. Worse, details of the non-equilibrium vibrational kinetics have never been verified experimentally.

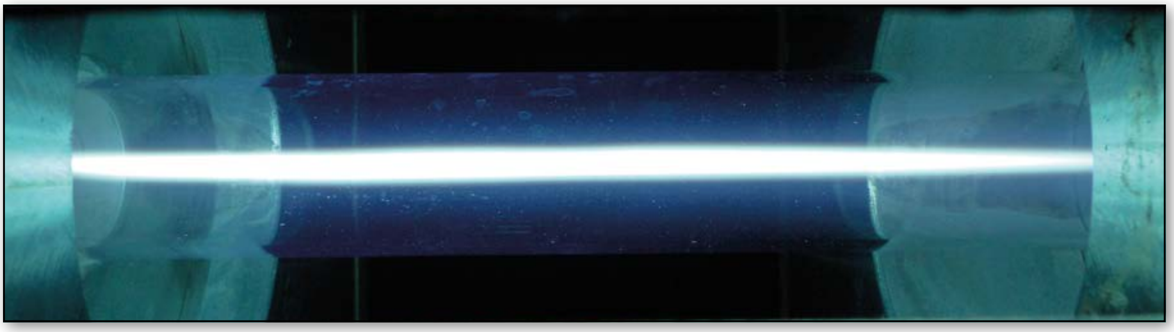
Recently, researchers at the Dutch Institute for Fundamental energy Research (DIFFER) together with colleagues at the University of Stuttgart Institute for Interfacial Research and Plasma processes (IGVP) have explored the route to CO_2 neutral fuels [15]. The IGVP microwave plasma facility (915 MHz, 30kW) coupled to a cylindrical cavity creates an axial electric field sufficiently high (~10 kV/m) for ignition and maintenance of the CO_2 plasma, see Figure 2. The electric field may be regarded as stationary because electron neutral collisions and plasma processes occur on much shorter time scale (<< 1ns) in comparison with the oscillation period. The CO_2 gas is injected tangentially at the entrance of the cylindrical reaction chamber creating a vortex gas flow. Flow rates are up to 75 standard ltr/min, gas pressures in the range 200-800 mbar. A nozzle expands the gas to supersonic speed causing the gas to cool. A cold gas is needed to prevent vibrational relaxation into translational energy [12].

Experimental results

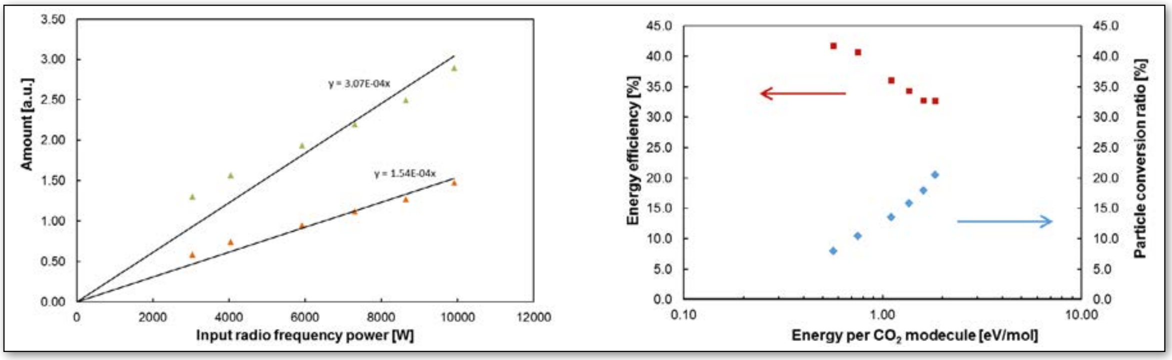
Gas composition measurements are carried out by quadrupole mass spectrometry (QMS) and optical emission spectroscopy (OES) which reveal the particle conversion ratio to increase linearly with RF power, whilst highest energy efficiency is reached at low RF power, see Figure 3.

Optical emission spectroscopy (OES) provides complementary information on the plasma dissociation process. UV-visible light emitted by the plasma is observed through a slit in the microwave cavity shown in Figure 2, collected and guided by fibre optics to a commercial spectrometer with spectral range 175-725 nm at ~ 2 nm resolution, sufficient to resolve the electronic bands, but not the vibration-rotation fine structure. Reaction products CO and O_2 exhibit emission spectra in the UV-visible. This is not the case for CO_2 where only some weak absorption bands in the far UV 140-160 nm exist.

The CO emission line strength (3^{rd} positive, 5B triplet) is shown to increase linearly with RF power, confirming the QMS data. Similarly, the line strength is seen to increase linearly with gas pressure. These results are consistent with a power balance model, showing electronic excitation to be linearly proportional to microwave power



▸ **FIG. 2:** CO_2 plasma discharge at 3 kW absorbed power at 500 mbar pressure and 75 standard ltr/min gas flow rate



◄ **FIG. 3: left panel:** Production of CO and O_2 by plasmolysis of CO_2 as a function of absorbed microwave power. The drawn lines are constrained by the stoichiometry of CO and O_2 products. **Right panel:** Energy efficiency and particle conversion in terms of energy Ev per incoming CO_2 molecule. Particle conversion increases with power whilst energy efficiency reaches highest value at low power.

and neutral gas density, consistent with electron excitation of CO in the sigma singlet ground state.

The reduced electric field E/n (n is neutral gas density) has been identified as the key parameter controlling energy efficiency [15]. An ancient concept in plasma physics, it expresses the potential drop an electron experiences in between collisions and is typically ~10^{-16} Vcm^2. Lowering the reduced electric field enhances the energy efficiency, albeit at the expense of conversion ratio. Through randomisation E/n is proportional to the electron temperature. Thus, a low electron temperature plasma (T_e~1eV) is favoured from the viewpoint of energy efficiency, however, leads to conflicting requirements between ionisation degree which requires higher electron temperature. This suggests that optimum conditions may be reached by decoupling plasma formation from dissociation by a two stage plasma reactor or by shaping the electron energy distribution function (EEDF) with a bump in the high energy tail. Similarly, the reduced electric field can be shown to scale inversely with electron containment time, offering another route to high efficiency, in addition to control of the EEDF under non-equilibrium conditions.

Challenges ahead

Having demonstrated the splitting of CO_2 into CO and O_2 by plasmolysis, the next step is to separate the effluent gas stream into its constituent parts. Following that, methane and higher order hydrocarbons must be formed selectively at high efficiency. Oxygen pumping membranes, such as electrically driven SOEC or pressure driven MIEC (Mixed Ionic Electron Conducting) are a first try. Exothermic water gas shift or parallel electrolytic hydrogen production creates syngas, the central element from which traditional chemical pathways lead to P2G, P2C and P2L, or in short P2X.

Outlook

CO_2–neutral fuels based on synthetic hydro-carbons and recycled CO_2 offer advantage over hydrogen, ammonia and batteries in that infra structure is readily available, whilst the high energy density fuel allows long haul transport to remain feasible. Here plasmolysis is featured as an energy efficient means to split the CO_2 molecule into CO and O_2. Cold weakly ionised CO_2 plasma electrons serve to vibrational excite CO_2 molecules into a thermal non-equilibrium state conducive to dissociation. The scheme offers advantages over electrolysis in power density, upscaling to megawatt level, instant response to intermittent renewable electricity and no use of scarce materials.

The EU Energy System is undergoing profound change. Rather than concentrating on the energy source, a system approach is needed which includes energy storage and the recycling of waste. A number of challenges remain in the conversion of CO_2 back into hydrocarbons. Direct conversion of solar photons into fuel and the indirect route via renewable electricity require understanding at the basic research level. Technical challenges include upscaling and system response to intermittent power. To date, P2X energy storage is not economically feasible - that is not unless the cost of waste recycling, be it CO_2 or radioactive, is factored into the price of fossil fuel and nuclear power... ■

Acknowledgement

We are greatly indebted to DIFFER staff Waldo Bongers, Martijn Graswinckel, Erik Langereis and Univ. Stuttgart IGVP staff Martine Leins, Jochen Kopecki, Andreas Schulz and Mathias Walker, who contributed substantially to this paper. This work is funded by the Dutch FOM-NWO research organisation and by the Dutch Top sector Energy TKI Gas.

About the Authors

Adelbert Goede worked on the European fusion machine JET from 1975 to 1988. From 1988 to 2008 he worked on the European Space Agency Envisat as Co-Principal Investigator of the SCIAMACHY instrument measuring global greenhouse gas distributions from space. In 2006 he returned to energy research picking up on a proposition of his 1975 PhD thesis on off-shore wind energy.

Richard van de Sanden is director of the Dutch Institute for Fundamental Energy Research DIFFER and a professor in applied physics at the Technical University Eindhoven. He is a member of the Dutch Royal Academy for Arts and Sciences. Recently, he was awarded the American Vacuum Society Plasma prize.

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[Physics in daily life]

by L.J.F. (Jo) Hermans

Leiden University, The Netherlands - Hermans@Physics.LeidenUniv.nl - http://dx.doi.org/10.1051/epn/2016305

Disappearing iron

Something funny happened to the iron wood rests in my fireplace. The rods sticking into the fire were originally 15 mm by 15 mm, but steadily thinned down to about 7 mm. Granted, this happened over quite a number of years. But the question remains: Where did the iron go?

It is unlikely that it has evaporated: the boiling point of iron is over 3100 K, and the vapour pressure is far below 10^{-10} bar even at 1000 K. The iron has not even melted, which would require about 1800 K, a temperature that the iron never reaches in my fireplace: judging from its dark red color at the highest temperature reached, it never exceeds about 900 K. This is not hot enough for melting, and barely sufficient to make the iron a bit soft, which made one of the pieces bend at the thinnest spot under its own weight.

What must have happened is that the iron has oxidized somewhat according to the exothermic reaction $4Fe + 3O_2 \rightarrow 2Fe_2O_3$. In other words: the iron has burned down a bit.

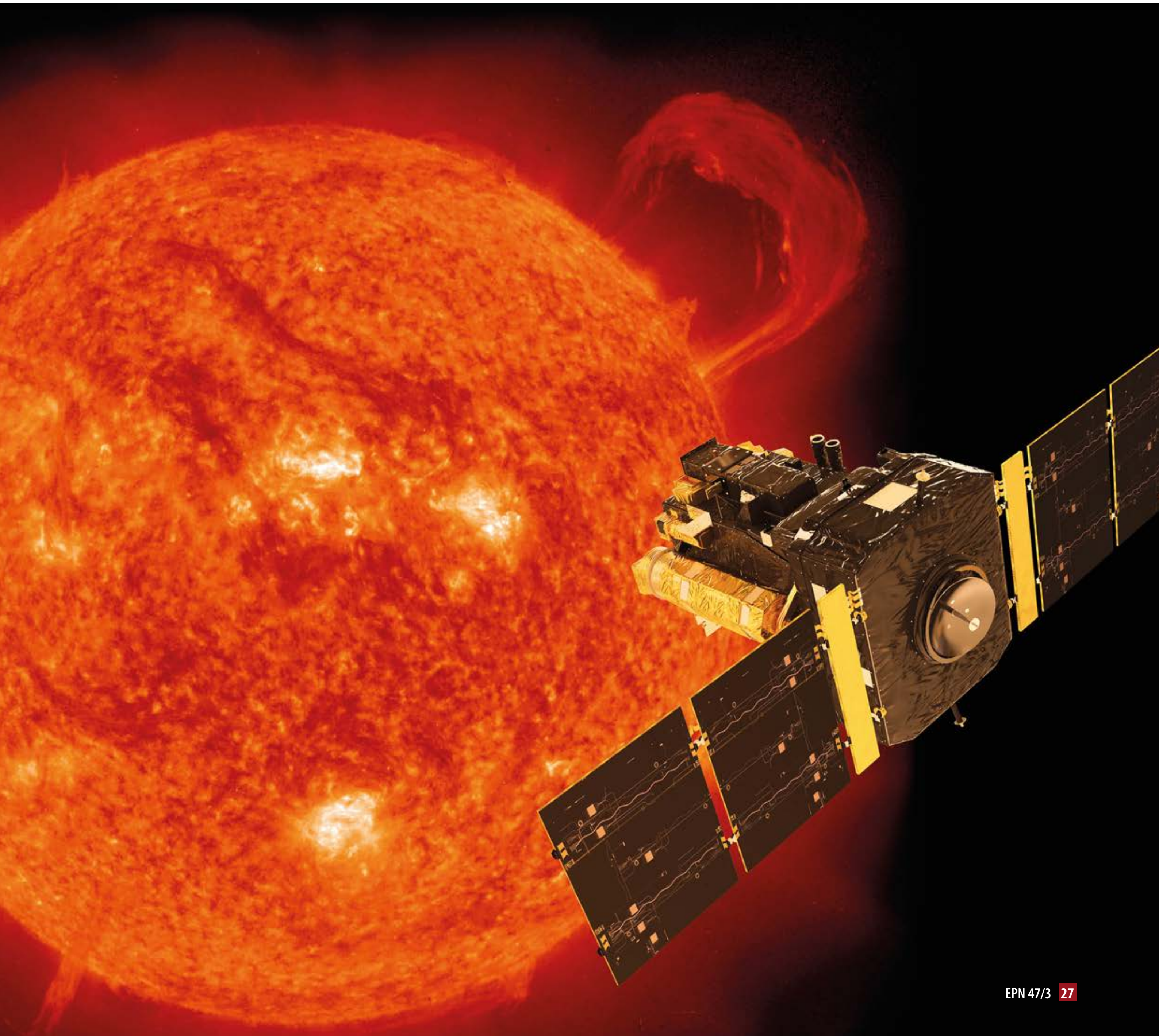
Of course! Just think of the cutting torch, or flame cutter. This instrument neatly cuts through iron using precisely this reaction. It does not make the iron melt, it makes it burn. In this case extra oxygen is supplied to keep the reaction going. The oxide formed has a much lower melting point than the pure iron, so it is deposited at some cooler place. Which provides an extra reason to clean my chimney once in a while.

Incidentally: the fact that the reaction is exothermic has its bright side: some chemical hand warmers make use of this oxidation of iron, as skiers and mountain climbers may remember. So at least nature provides me with some extra heat while eating my wood rests. ■

20 YEARS OF SOHO

Bernhard Fleck[1] and Daniel Müller[2] – DOI: http://dx.doi.org/10.1051/epn/2016306
[1] ESA, SOHO Project Scientist and [2] ESA, Solar Orbiter Project Scientist

The Solar and Heliospheric Observatory (SOHO), a joint mission of ESA and NASA, has provided unparalleled insight into the Sun over the past 20 years - from its interior, through the hot and dynamic atmosphere, out to the solar wind and its interaction with the interstellar medium. SOHO also plays a vital role in forecasting potentially dangerous space weather situations by continuously monitoring solar storms, and unexpectedly also became the most prolific discoverer of comets in the history of astronomy.



◂ P27: Extreme-ultraviolet image of the Sun taken by SOHO on 14 September 1999.

A cooperative effort between ESA and NASA

The SOHO spacecraft was built for ESA by Europe's aerospace industry and was launched by NASA on 2 December 1995. Mission control is based at NASA's Goddard Space Flight Center near Washington DC. Of the satellite's 12 science instruments, nine come from multinational teams led by European scientists, and three from US-led teams.

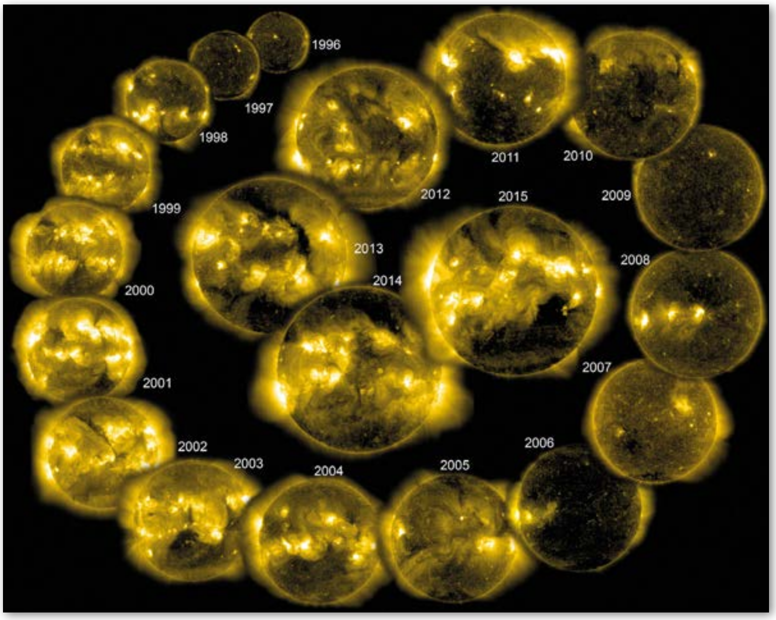
SOHO is stationed 1.5 million km from the Earth. It follows a halo orbit around the 1st Lagrangian point, where it enjoys an uninterrupted view of the Sun. There, the combined gravity of Earth and Sun keeps SOHO in an orbit locked to the Earth-Sun line. Originally planned for a two-year mission, its numerous extensions have allowed it to cover nearly two 11-year solar cycles. SOHO is thus the longest-lived Sun-watching mission, which by now allows us to compare the Sun's behaviour not only at different times in one cycle, but also during different cycles (FIG. 1).

Seeing the inside of the Sun

Just as seismology reveals the Earth's interior by studying earthquake waves, solar physicists probe the interior of the Sun using a technique called helioseismology. The oscillations detectable at the visible surface are due to sound waves reverberating through the Sun's inner layers. These oscillations are usually described in terms of normal modes. By precisely measuring the mode frequencies, one can infer the Sun's temperature, density, atomic abundances, interior structure, as well as the age of the solar system, and even pursue tests of the constancy of the gravitational constant.

In addition to exploiting the techniques of "global helioseismology", SOHO opened and pioneered the new field of "local area helioseismology", providing the first 3-D images and flow maps of the interior of a star, and even images of activity on the far side of the Sun.

▾ FIG. 1: The changing face of the Sun and its outer atmosphere – the corona – from 1996 to 2015 over almost two complete solar cycles. The images were taken by SOHO/EIT in the Fe XV 284 Å filter showing the Sun's hot corona at about 2 million °C and illustrate the waxing and waning of activity during the 11-year solar cycle.



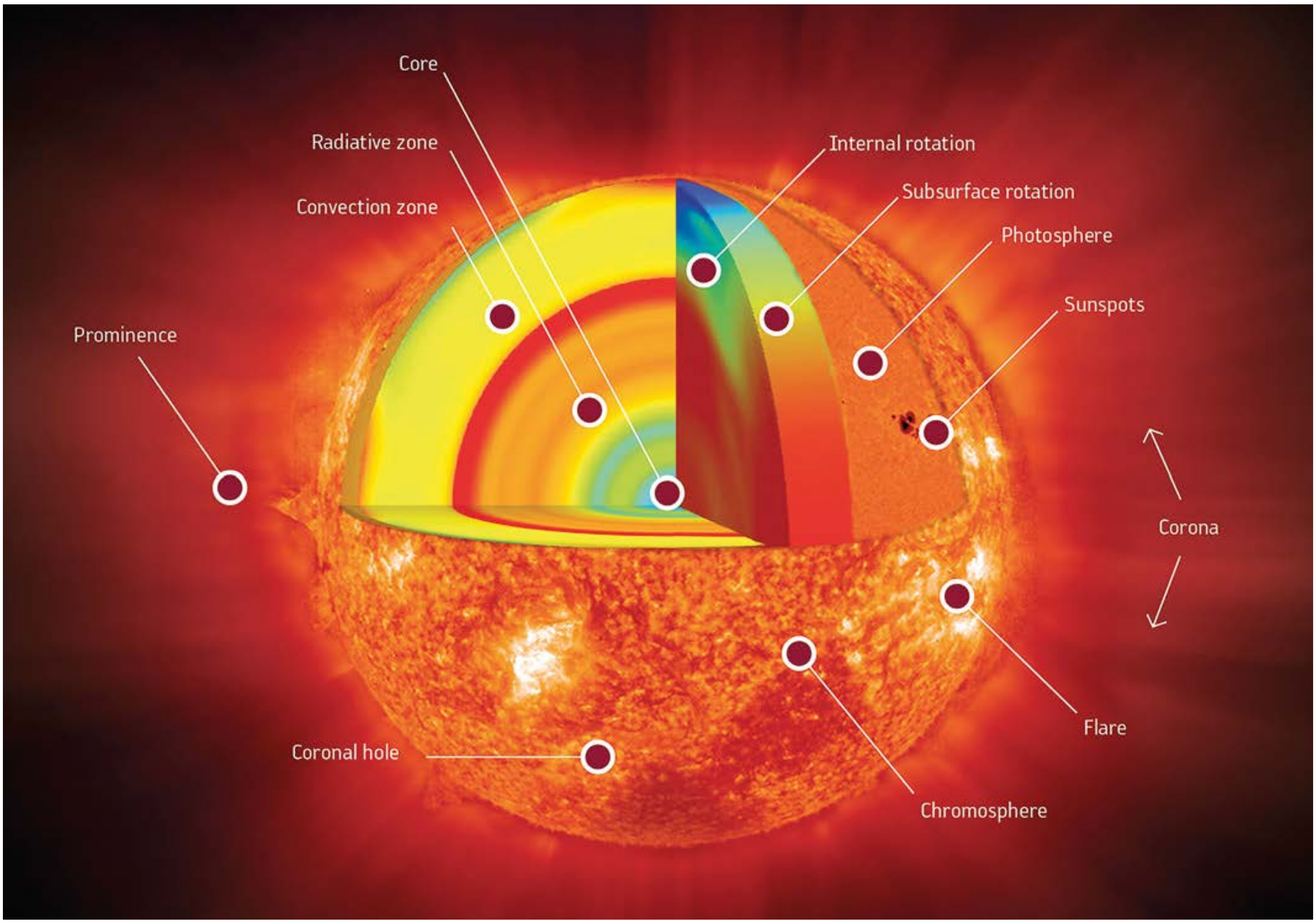
SOHO discovered 'sunquakes' and a slow subsurface current of gas flowing from the equator towards the poles. Deeper inside the Sun, about a third of the way towards the center at the transition between its turbulent outer shell – the convection zone – and the more orderly radiative zone, SOHO found that the Sun's rotation profile changes abruptly (FIG. 2). Near the equator the outer layers rotate faster than the inner layers. At mid-latitudes and near the poles, the situation is reversed. The boundary region between these two layers is of particular interest because it is where the solar dynamo that creates the Sun's ever-changing magnetic field is believed to operate.

SOHO also shed light on the 'solar neutrino problem': When SOHO was launched, there was a discrepancy between the rate at which neutrinos were predicted to be created by nuclear fusion in the deep solar interior and the rate measured at Earth. SOHO determined that the "standard model" of the solar interior was correct, and that the discrepancy had to be explained by the physics of the neutrino. This was subsequently confirmed by measurements of the Sudbury Neutrino Observatory, which provided compelling evidence for so-called flavour transitions of solar electron neutrinos, a discovery that was awarded the Nobel Prize in Physics in 2015.

The dynamic solar atmosphere and the solar wind

The question of why the Sun's outer atmosphere, the corona, has a temperature of 1–2 million degrees when the visible surface is 'only' about 5500 °C has long been a mystery of solar physics. SOHO has revealed an extremely dynamic atmosphere where magnetic flux is constantly emerging from the Sun's interior and the energy supply through "braiding" of the large-scale coronal magnetic field by small-scale flux replacement is sufficient to heat the tenuous corona. Moreover, SOHO observations led to the discovery of new dynamic phenomena such as solar tornadoes and global coronal waves – disturbances associated with coronal mass ejections that can travel around the entire solar globe.

One of the prime goals of SOHO has been to observe where the solar wind – electrically charged atomic particles streaming from the Sun – is produced and how it is accelerated to beyond 3 million km/h. Scientists have made great strides in answering this fundamental question by analyzing data from SOHO. They measured the acceleration profiles of both the 'slow' and 'fast' solar wind and found, *e.g.*, that the fast solar wind streams into interplanetary space by 'surfing' on waves produced by vibrating magnetic field lines. SOHO also revealed that heavy solar wind ions in coronal holes – darker, cooler and less dense areas of the Sun's corona where the Sun's open magnetic field reaching into space allows hot ionized gas to escape – flow faster and are heated hundreds of times more strongly than protons and electrons, and



▲ **FIG. 2:** The anatomy of our Sun. Left cutaway: The Sun's interior explored with sound waves. Red depicts layers where sound travels faster than predicted by theory, implying that the temperature is higher than expected, while turquoise and green indicates slower speeds and lower temperatures. The prominent red layer marks the transition between the turbulent outer convection zone and the more stable inner radiative zone. Right cutaway: The Sun's internal rotation, where red depicts fast rotation and blue slower rotation. Outer layers: Visible light images show sunspots, cool dark features in the photosphere, which lies below the chromosphere. Flares, resulting from the release of a buildup of magnetic energy, and coronal mass ejections (CMEs, giant clouds of electrically charged atomic particles launched into space) often occur in magnetically active regions around sunspot groups.

that they have highly anisotropic temperatures reaching hundreds of millions degrees Kelvin in the direction perpendicular to the magnetic field.

SOHO, the space weather watchdog

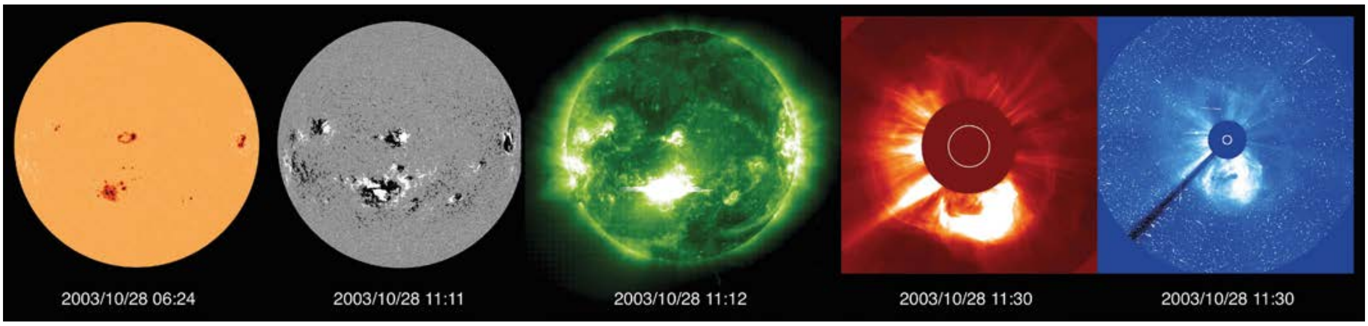
With its near-continuous monitoring of the Sun, SOHO has revolutionized our understanding of the Sun–Earth connection and dramatically boosted space weather forecasting capabilities.

The major driver of space weather are coronal mass ejections (CMEs), the most powerful eruptions in the Solar System, which propel billions of tonnes of ionised gas into space at millions of kilometers per hour (FIG. 3). If CMEs hit Earth, in addition to causing intense auroral displays in polar regions by electrically charging atoms in our upper atmosphere, they can cause major geomagnetic storms, damage satellites, disrupt telecommunications, endanger astronauts, lead to corroded oil pipelines and cause current surges in power lines. As our society becomes increasingly dependent on space-based technologies, our vulnerability to "space weather" becomes more obvious, and the need to understand it and mitigate its effects becomes more urgent.

SOHO is a pioneer in detecting when such a solar storm is incoming. It has studied more than 20 000 CMEs to date, pinpointing their sources on the Earth-facing hemisphere of the Sun, and determining their speed and direction to provide up to three days' warning – sufficient to take mitigating action on Earth. From its vantage point matching Earth's orbit, the observatory also makes in situ measurements when a CME and its energetic particles arrive.

The day star's brightness variations

Monitoring variations of the total solar irradiance (TSI) as well as variations in the extreme ultraviolet (EUV) flux from the Sun are an important part of SOHO's long-term studies. Both these quantities are important for understanding possible effects of solar variability on climate and for disentangling natural variations from anthropogenic effects. While the total solar irradiance varies by less than 0.1% over an 11-year solar cycle, the irradiance in the EUV part of the spectrum changes by as much as 30% on the time scale of weeks and by a (wavelength-dependent) factor of 2 to 100 over the solar cycle.

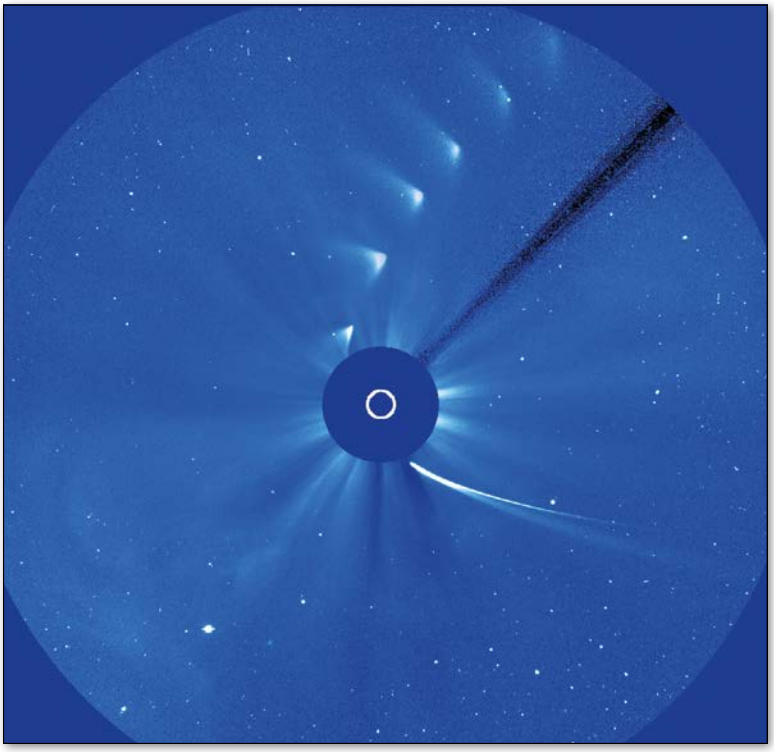


▲ **FIG. 3:** Halloween Storms of 2003: For two weeks in October-November 2003, the Sun featured three unusually large sunspot groups, which gave rise to 11 X-class flares – the most energetic class of flares – including the strongest ever recorded. First left: giant sunspot groups seen by SOHO's MDI instrument on 28 October 2003 in visible light. Second: MDI magnetogram on the same day, illustrating the magnetic complexity of these active regions. Third: SOHO/EIT image at the time of an X-ray flare, seen as the bright emission just below the centre of the disc. The linear horizontal feature is an artefact due to saturation of the CCD detector. Fourth: SOHO/LASCO C2 image at minutes after the flare, with a 'halo CME' (Coronal Mass Ejection) completely surrounding the occulting disc. Fifth: LASCO C3 image of the expanding halo CME, where energetic particles hitting the CCD detector appear like 'snow'. The flare location and the halo were a clear indication that the CME was heading towards Earth.

A prolific comet-hunter

Besides watching the Sun, SOHO is also the most prolific comet discoverer of all time: more than 3000 comets have been found, over 95% of those by amateurs accessing SOHO's publicly available real-time data via the Internet. Prior to the launch of SOHO in 1995, only a dozen or so comets had ever been discovered from space, while some 900 had been discovered from the ground. Most of the comets discovered by SOHO are 'sungrazing' comets that perish in the Sun's heat. Some survive, albeit in various states of degradation: SOHO has watched many comets lose their heads and tails during their solar encounter (FIG. 4).

▼ **FIG. 4:** The demise of Comet ISON as it came within 1.2 million km of the Sun on 28 November 2013, fading from view in the following days. The small white circle in the center indicates the position and size of the Sun behind the telescope's occulting 'coronagraph mask', seen as the wider disc. The mask blocks out the dazzling light that otherwise drowns out this region, allowing details of the corona to be seen.



Near-loss and dramatic recovery

The SOHO mission almost ended on 25 June 1998 when control was lost during a routine spacecraft manoeuvre. It took three months to restore operations in one of the most dramatic recovery operations in space history, including just over two weeks to thaw frozen hydrazine propellant in the tank and pipes. Unexpectedly, all 12 instruments survived despite the extreme temperatures they suffered during the time that contact was lost.

But the drama was not over yet: Subsequently, all three gyroscopes of the spacecraft failed, the last one in December 1998. In a race against time, new software that no longer relied on gyroscopes for attitude control was developed and installed in February 1999, allowing the spacecraft to return to full scientific operations. This made SOHO the first spacecraft to be stabilised in three axes without gyroscopes. Despite these problems, engineers have kept SOHO functioning ever since, with all its instruments performing well.

Conclusions and future

In complex areas of research such as solar physics, progress is not made by just a few people. The scientific achievements of the SOHO mission are the results of a concerted, multi-disciplinary effort by a large international community of solar scientists, involving sound investment in space hardware coupled with a vigorous and well-coordinated scientific operation and interpretation effort.

Since 1995, SOHO has been joined by several other solar space missions, which have been providing observations at higher spatial and temporal resolution, from additional vantage points. However, even after 20 years and although only 8 of the original 12 science instruments are in active use, SOHO continues to provide unique and important measurements of our star.

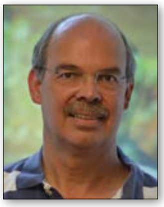
Looking ahead, the next solar space missions are the joint ESA-NASA Solar Orbiter and the NASA Solar

Probe Plus missions, both to be launched in 2018. Solar Orbiter will be leaving the plane of the ecliptic to explore the uncharted polar regions of the Sun, as well as investigate the connections between the Sun and its surrounding heliosphere from inside planet Mercury's orbit. Solar Probe Plus, on the other hand, will be approaching the Sun even further — to within 10 solar radii — to sample the plasma of the hot and tenuous solar corona in situ.

Acknowledgements

The great success of the SOHO mission is a tribute to the many people – too many to name here – who designed and built this exquisite spacecraft and these excellent instruments, to the engineers who brought it back from the dead (twice), and to the many people who diligently work behind the scenes to keep it up and running.

About the Authors



Bernhard Fleck is the ESA Project Scientist of the SOHO mission and has been based at NASA GSFC near Washington, DC, USA, since 1995. His research interests include the dynamics of the solar atmosphere, in particular wave-propagation characteristics in the chromosphere.

Daniel Müller worked from 2005-2010 as ESA's Deputy Project Scientist for SOHO at NASA GSFC. He is currently Project Scientist of the ESA-NASA Solar Orbiter mission, based at ESA's Space Research and Technology Centre (ESTEC) in the Netherlands. His research interests include the dynamics of the solar atmosphere, high-performance computing, and visualization techniques for complex data sets. ■

Further reading

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[Letter to the Editors]

by Miguel Ferrero
Full Professor of Theoretical Physics.
Physics Department. Oviedo University. Spain.
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The world is better than it has ever been

Reading the brief opinion article of C. Hidalgo in the 47/1 number of Europhysicsnews one may get the impression that the world is falling apart. The pessimism permeates the two columns of the paper, in which strong words and expressions (inequality, social instability, unemployment, *etc.*; by the way, the word inequality is repeated eleven times) are used. This pessimism is very old. Against Enlightenment, the Romantic and all kind of pessimist counter-Enlightenment were opposed, Schopenhauer being one of the most notorious. But, fortunately, the state of the world is not as bad as the "declinists" seem to think. From my point of view the questions to answer in this respect are:

First.- Have we (humans) made progress in the last 70 years, let us say?, and

Second.- Is it possible to quantify the progress or regression?

To answer these questions a physicist should look to the data, not to personal intuitions, subjective impressions or following the opinions of any other scholar. And the reality is that, in this lapse of time:

1. 1.- Extreme poverty has more than halved worldwide (more than a billion people have escaped it).
2. Material wellbeing has increased at its greater pace ever, measured by increase of life expectancy; worldwide access to education, including women; income; decline of mortality; and so on.
3. The number of people killed in armed conflicts has decreased by at least 60%.
4. The number of democracies has tripled.
5. *etc.*

This is not the place to make a detailed account of these data. For a critical and personal assessment, the interested reader may consult: https://ourworldindata.org (Max Roser) and http://humanprogress.org (Marian Tupy). I also recommend reading: The Better Angels of our Nature (Steven Pinker, 2011). So, progress can and has been quantified and the result is that the world is better than it has ever been. Does this mean that we have to fall into complacency? A clear no should be given: we must keep the pace to further improve. But to push in the good direction we need to know the reality that the data is giving to us. ■

Opinion: Excellent Universities: How do we foster them?

Dieter M. Imboden, Professor emeritus, ETH Zürich

What makes an outstanding university? – Those who launched the German Excellence Initiative (EI) about ten years ago must have been convinced that there is a way to recognize university excellence and a recipe to get there. From 2006 to 2017, the German federal government and its states allocate a total sum of 4.6 billion Euro to a special programme with the aim at promoting world-class research at German universities. Should this programme be continued?

Before taking a decision about the future of the programme, the Joint Scientific Programme (Gemeinsame Wissenschaftskonferenz) wanted to find out whether the programme has had a significant and measureable impact on Germany's universities. In 2014, an international evaluation panel, consisting of ten scientists from six different countries, was given the task to assess the effect of the programme on German universities, primarily on their excellence in research. I had the honour to chair this group of eminent scientists.

Early in their work, the panel members concluded that, given the typical time scales necessary to fundamentally change universities, it would not be an adequate strategy to assess the change of the international standing of Germany's universities since the start of the Excellence Initiative. Instead, based on information from universities that according to international rankings belong to the world top, the panel identified elements that seem to be linked to excellence: High university autonomy, good governance shaped by a wise balance between competence at the top and creative freedom at the bottom, moderate student numbers per faculty, the right to select for talented students, a reasonable teaching load of the staff that enables a fruitful combination of teaching and research, and finally – the key element – an adequate and steady financing.

It became clear that some of these points are not ideal at German universities. To illustrate the most obvious one, the finances: If the total sum set aside for the EI per year (about 500 million Euro in 2015) would be given to one single university, for instance, to the Technical University Aachen, with the additional money Aachen would reach roughly the budget of the University of Michigan (with similar student number) or of the Swiss Federal Institute of Technology (ETH) Zürich (with less than half the students). Instead, the 500 million Euro are presently distributed to 44 German universities.

Although the financial situation is not going to change overnight, there is plenty of room for improvement in the German university system provided it is given enough time and politics remains on a steady track with a long-term perspective. That is the principal reason why the panel in its report, published in January 2016, unanimously recommended to continue the EI, to focus it on the one original goal, that is, to enable world-class research at German universities, and to resist the temptation to use the EI for easing other deficits of the academic system, urgent though they may be. Independently from the question of finances, the panel identified two areas that are central for becoming a world-class university, namely advancing "university differentiation" and strengthening "governance".

> **A successful process of differentiation requires suitable governance structures that rest on autonomy and strong leadership.**

Differentiation means that universities concentrate on areas of competitive advantage and, in turn, are willing to cut back – or even abandon – areas where the needed quality cannot be reached. A successful process of differentiation requires suitable governance structures that rest on autonomy and strong leadership. I am personally convinced that these elements are vital for all German, all European universities, whether or not they profit from a special scheme like the EI. Differentiation would not mean, as colleagues especially from the humanities often fear, that smaller areas would completely disappear, although they may disappear from some universities, but become stronger at others. If we want to keep the universal academic knowledge on the highest possible level, then in a world that is increasingly interlinked and globalized we should abandon the idea that every university has to be a universe for itself, but rather build national or supranational networks of excellent universities that together continue to give the word universitas its true meaning.

Let me finish with a personal plea: Strong governance of universities can only succeed if our best researchers, in a later phase of their career, are willing to support the concept of academic self-governance by being ready to become university leaders and use their talents for the benefit of those institutions that at an earlier stage of their career have given them the basis for their own academic success. Think about it if next time you will be confronted with such a challenge. ■

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