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Nobel Prize in Physics 2011
Sustainable energy
Space Exploration Technologies
Spontaneously polarized materials
Control in magnetic nuclear fusion

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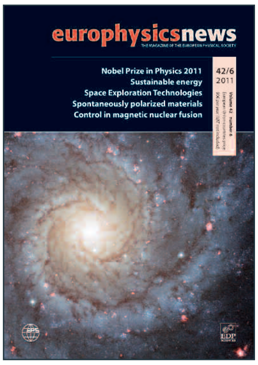

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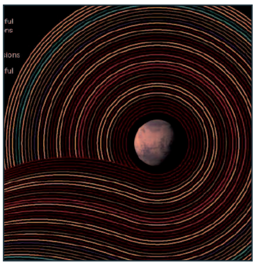
Cover picture: In this new Hubble image of the galaxy M74, we can also see a smattering of bright pink regions decorating the spiral arms.



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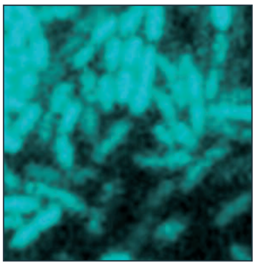
Space Exploration Technologies Pegases



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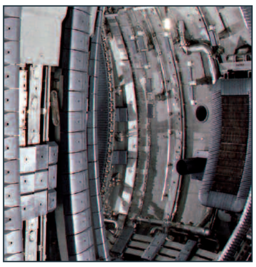
Fluctuations in biological systems



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Control in magnetic nuclear fusion

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Editor: Claude Sébenne (FR)
Email: claude.sebenne@impmc.upmc.fr

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

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

Graphic designer: Xavier de Araujo
Email: x.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: Sophie Hosotte

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
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The second
ASEPS meeting in Wrocław

The Second Asia Europe Physics Summit (ASEPS) took place 26-29 October 2011 in the dynamic Polish city of Wrocław. The participants included researchers, policy makers and representatives of science funding agencies from Asia, Europe and the USA. The main theme of ASEPS 2 was "Excellence in Physics through Cooperation", and Gui Lu Long from the Association of Asian Pacific Physical Societies (AAPPS) and I (as chairman), invited excellent speakers to address major topics related to: 'Grand Challenges in Physics', 'Large Research Infrastructures', 'Trends in Physics and Science Policy', and 'Promoting Individual Excellence in Physics'.

Working groups are structural features of ASEPS meetings and put the different research actors in the same room with the mission of discussing specific issues and of drafting recommendations to be presented to, and accepted by, all participants. The ASEPS 2 working groups looked at:

▲ **Prof. Luisa Cifarelli, President of the EPS, and Prof. Shoij Nagamiya, President of the AAPPS**

- Joint large scale programmes & networks: crisis creates opportunities;
- Physics at frontier of grand challenges: Energy and sustainable development, alternative energy resources;
- Education is a must: needs of more and better educated people for science and industry;
- Mobility of scientists, exchange programmes, obstacles, scholarships versus hiring people;
- Industry versus Academia: cooperate or die.

The recommendations and presentations are available on the website: www.aseps.net

The ASEPS meetings are organised by the EPS and the AAPPS to strengthen collaboration in physics research between Europe and Asia.

The EPS President, Luisa Cifarelli, and the AAPPS President, Shoji Nagamiya signed the "Wrocław Statement" (picture), pledging to continue the organisation of ASEPS meetings, and to work towards improving cooperation in physics between Asia and Europe.

While it is too early to see the impact of the recommendations from the Working Groups, we can already see an increased cooperation between physicists and learned societies in Europe and Asia. ASEPS meetings will continue, and will hopefully become the privileged forum for discussions related to Asia-Europe collaboration. The measure of our success will be frank, open, honest appraisals of the problems; successes and progress in achieving better and better collaborations in physics between Asia and Europe. ■

Maciej Kolwas,
Past President of the EPS

The Implementation of Bologna Reforms into Doctoral Education in Physics

Between August 2010 and May 2011 a study about the implementation of Bologna reforms into doctoral education in Physics was carried out by the International Centre for Higher Education Research at Kassel University.

The study was funded by the European Commission and carried out in close cooperation with the European Physical Society, representatives of from 26 national Physical Societies of Bologna signatory countries, and representatives from the STEPS II Network. Altogether 120 doctoral supervisors from 30 Bologna signatory countries filled out an online questionnaire. In addition, a secondary data analysis of Physics respondents to the 2008/09 EURODOC survey of doctoral candidates was carried out. The sample included 393 doctoral candidates in Physics from 26 countries.

The status of doctoral candidates is a highly disputed issue in the framework of the Bologna reforms which tend to cast them as students. Interestingly almost half of the doctoral supervisors (47%) and more than four fifth of the doctoral candidates (81%) stated that they are employed, most of them as teaching or research assistants at their university. Other means of funding are constituted by scholarships and repayable loans. Nine percent of the doctoral candidates are self-funded. The status perception is divided almost equally between early stage researchers (32%), students (34%) and being both (34%). Funding duration is typically between three and four years. Doctoral candidates from Belgium, France, the Netherlands, Slovenia, Sweden, and the UK/Ireland were very satisfied with their level of funding, while doctoral candidates from Lithuania and Spain were rather dissatisfied.

More than four fifth of the doctoral candidates (81%) stated that they are employed as teaching or research assistant

Except for the UK and Ireland where doctoral candidates are admitted frequently after their Bachelor degree, a Master degree is a required pre-requisite in most other Bologna signatory countries involved in the study. Often additional selection criteria have to be fulfilled in order to be admitted as doctoral student or candidate.

Doctoral education is increasingly integrated into doctoral programmes or graduate schools. Only 13 percent of the supervisors stated that they provide individual supervision only. Programmes or schools typically require coursework for which tuition fees have to be paid in a number of countries. This might explain the high percentage of respondents stating that their status is both being a student and an early stage researcher. The coursework mostly comprises research methodology, subject knowledge and transferable skills and is in 61 percent of the cases monitored, assessed and credited. Altogether 78 percent of doctoral candidates stated that they receive some kind of skills training. No requirements for coursework were the case particularly often in Portugal and Germany.

The growing number of programmes and graduate schools contributes to the trend that doctoral education is increasingly being formalised in structure as well as in process. Rights and duties of both supervisors and doctoral candidates tend to be regulated. In Italy, Spain, Portugal, and Sweden supervisors have to undergo special training before they are allowed to supervise.

Doctoral candidates rated the quality of supervision rather high. High and very high levels of satisfaction with the supervision were found in Denmark, Germany, Italy, Lithuania, Norway, Slovakia, Slovenia, and Sweden. Low levels of satisfaction were found among doctoral candidates in Austria, Belgium, Finland, the Netherlands, and UK/Ireland.

A high proportion of supervisors (91%) stated that doctoral candidates were involved on average 7.1 hours per week in departmental work not related to their research and thesis. In contrast, the doctoral candidates themselves estimated this kind of work to be on average 14 hours per week. The time budget for thesis related research was estimated to be slightly more than 34 hours per week.

Concerning the degree of internationalisation of doctoral education there was clearly some progress. At more than half of the universities from which our supervisor respondents came it was possible to submit the doctoral thesis in a foreign language (mostly English). In addition, it is also possible to include international supervisors and examiners. About 13 percent of doctoral candidates stated that they had spent some time abroad during their doctorate (only five percent of the supervisors stated this) and 20 percent of the EURODOC respondents were doing their doctorate in a country different from their home country. In addition, almost 40 percent (39%) of the same group of respondents said that they intend to stay abroad or move abroad after the award of the doctoral degree. Preferred countries for future work are the USA, Germany, France, Switzerland, UK, and Sweden.

The academic sector is clearly preferred for future employment (79% of doctoral respondents). However, more than half of the doctoral candidates (52%) would also accept employment in the public or private non-academic research sector. A surprisingly low proportion of doctoral candidates (2.4%) do their research in industry. Also coursework conveying transferable skills received a low level of satisfaction and was often an elective. Furthermore, 43 percent of the supervisors stated that there are no activities at their department to support transition into the labour market. Thus it is not surprising that most doctoral candidates had a preference to continue with academic research in a university after their doctorate.

The academic sector is clearly preferred for future employment (79% of doctoral respondents).

Concerning the implementation of Bologna reforms into doctoral education in Physics we find a mixed and heterogeneous picture. Structure and process of doctoral training are clearly more formalised and regulated than before. In most countries time-to-degree is three to four years. The idea of the "third cycle" is being distorted into a hybrid status of student and early career researcher at the same time with mixed forms of funding. Supervision and assessment are becoming more formalised and satisfaction with the quality of supervision seems to have increased. Transferable skills acquisition is no yet well taken care of although there are exceptions. Internationalisation has become a more important component and many doctoral candidates plan to seek employment abroad. However, more than half plan to stay in academic research aiming for post-doc positions. Employment in industry seem to be a less attractive option. ■

Barbara M. Kehm,
International Centre for
Higher Education Research
University of Kassel, Germany

Executive Committee Meeting, Wroclaw/PL, 25 October 2011 - Summary

- The EPS Executive Committee met at the Academic Hub, in the city centre of Wroclaw/PL.
- Six issues of the new **electronic newsletter e-EPS** have been published since May 2011, with a large success and actual 35000 subscribers. However, advertisement and distribution by the member societies could be amplified.
- The **new website** (integrating e-EPS) and proposing other new functionalities – *e.g.* the physicist's directory - will be online before the end of the year. The portal will also integrate the **Alliance of Physics Publishers** and offer a showcase to European physics journals.
- The ExCom has discussed **finances** 2011 and 2012. A budget line referring to activities connected with representation towards the European Community ("Brussel's activities") will more clearly identify these actions.
- The Passion for Light Workshop in Varenna on 16 Sept 2011 has brought together over 100 participants with the recruitment of many direct supporting partners to the International Year of Light. As a next step the IYoL has to be approved by the IUPAP General Assembly beginning of November.
- An EPS statement on **assessment** regarding unique features in physics will be drafted for January 2012. This could eventually be released jointly with APS.
- Various **educational projects** (PATHWAY, Odysseus) and the creation of a reflection group on EC educational policy have been discussed.
- The ExCom has discussed the composition of its new members, to be elected by council in March 2012. The Committee has been informed about the ongoing work of the search committee for a president-elect.
- The 15th **EPS General Meeting** will be held with ASEPS on 27 October 2011 in Wroclaw, president, treasurer and secretary will give presentations of the 2008-2010 reporting period.
- EPS is preparing a study on **"Physics and Economy"** in order to quantitatively evaluate the input of physics in industry. It has been proposed to use this study as a background document for a Forum Physics and Society edition "Physics in the marketplace", and eventual follow-up study at OECD level.
- The ExCom has met with representatives of the **Polish Physical Society** and the **Wroclaw University Physics Department**, being informed about its structure and activities. J. Langer (IF Pan Warsaw& Academia Europaea, London) has given insight in the future EU research strategy and expected developments for Poland, as well as the impressive scientific and economic situation of the Wroclaw region.
- The next ExCom meeting is scheduled for 26/27 January 2012 in Mulhouse. Forum Physics and Society 28/29 March followed by council 30/31 March 2012 will both be organized at CERN. ■

Martina Knoop,
Wroclaw, 25 October 2011

GIREP-EPEC Conference

Jyväskylä, Finland 1-5 August 2011

For the first week of August, Physicists, Physics teachers and Physics Education researchers from 33 countries gathered in the sunny Jyväskylä town in central Finland.

During the GIREP-EPEC Physics Education conference they came together to learn from each other and the nine invited speakers new practices to teach and learn physics. The theme of the conference, *"Physics alive"*, was carefully chosen to highlight the efforts toward increasing student motivation in Physics and teaching the developing field of Physics in lively manner. In addition, we wanted to encourage and support introducing Physics into broader settings of sciences and life.

The Departments of Teacher Education and Physics at the University of Jyväskylä were chosen to host the annual conference of international GIREP organisation (Groupe International de Recherche sur l'Enseignement de la Physique) The conference was a joint meeting with European Physical Society, European Physics Education Conference (EPEC). The previous GIREP-EPEC joint conference was held in Leicester, UK in 2009 and the next GIREP meeting will take place in Istanbul, Turkey in the summer of 2012.

After the opening words by Professor Matti Manninen, the Vice-Rector of University of Jyväskylä, the opening plenary lecture was given by Professor Paul Hewitt from San Francisco. Paul Hewitt is known for his book *"The Conceptual Physics"*, and his contributions and drawings in The Physics Teacher magazine. In his pictures, Hewitt offers physics in everyday occasions and the reader is encouraged to interpret the situation and predict what will happen next. In his opening lecture, Hewitt spoke on teaching concepts of physics by the formalism of their interdependencies known as equations. The next plenary speaker was Professor Walter Kutschera from the University of Vienna, who is known for his research work in basic nuclear physics, also from applications of long life radio isotopes, such that determining the age of the iceman Ötzi. In his presentation, professor Kutschera introduced applications of archeology, geophysics, molecule biology and astrophysics.

The plenary session of the Tuesday morning was opened by the chairman of the Physics Education Division of The European Physical Society, Professor Robert Lambourne. Lambourne announced the winner of the selection of the teacher of the year 2011, Becky Parker from Simon Langton boy school, Canterbury, UK. Parker has been involved in establishing the Langton Star Centre, where students can accomplish cosmology and astrophysics projects. As an honour to her altruistic work, Parker received a prize cheque of 1000€.

▼ Paul Hewitt introduced in the opening lecture what a first course of physics should be like.

The first plenary lecture of Tuesday was given by Professor Carl Angell from the University of Oslo. Angell introduced the latest data from the international Trends in International Mathematics and Science (TIMSS) Study. Angell is also known as a long time leader of Norwegian International Physics Olympiad team. The second speaker on Tuesday was Professor Cecilia Jarlskog from Lund University. During her career, Jarlskog has represented the Nobel committee for years, and she has chaired it in 1999. Jarlskog's presentation was about the Standard Model and what lies beyond it.

The invited plenary speakers on Wednesday were professors Dimitris Psillos from the University of Thessaloniki and Matti Weckström from the University of Oulu. Psillos advocated the idea of evidence-based development of teaching materials, and Weckström introduced the principle of sophisticated vision systems in insects.

Thursday started by announcing the best poster prize. It was won by Tomas Franc from the Czech Republic, who had here participated to his first scientific conference. Well done! Franc received a 250€ prize for his poster, which introduced a method for high school students to explore the motion of astral bodies.

The first plenary speaker of Thursday was Professor Lynn Bryan from the University of Purdue. Bryan is an expert in designing curricula and teacher professional development. In her plenary talk, Bryan outlined the design of a useful and long term professional development programme for teachers. The second speaker of Thursday was Professor Arttu Luukanen from the Millimeter laboratory of VTT (Technical Research Centre of Finland). Luukanen introduced how the terahertz range of the electromagnetic spectrum can be harnessed to expose weapons hidden by e.g. terrorists or rioters.

The last but not least plenary speaker was Assistant Professor Wendy Adams from University of Northern Colorado. Adams demonstrated how lectures can be variegated by interesting simulations.

The social program of the conference started by the reception of Jyväskylä town in the beautiful theatre building designed - like so many other attractions in Jyväskylä - by Alvar Aalto. In addition, the guests cruised on lake Päijänne by the 100–year-old s/s Suomi. There was also a dose of Finnish tango music played by the duo Matti Ekman (accordion) and Matti Perälä (vocals) . Professor Matti Leino gave a welcome speech at the conference dinner in an old Finnish farmhouse. The dinner lecture, too, deserves an honorable mention. In it, Professor Jouni Viiri presented groundbreaking research by his friend and colleague, Professor S. Auna. The speech was titled "The correlation of the number of weekly sauna visits to PISA results". After the dinner, the more adventurous guests had an opportunity to improve their PISA ranking in the sauna and lake.

▲ Prize of the teacher of the year awarded to Becky Parker from Simon Langton boy school.

▼ Professor Robert Lambourne

The organisation committee of the GIREP-EPEC 2011 conference acknowledges every kind of support from the Finnish Cultural Foundation, the Federation of Finnish Learned Societies, the European Physical Society and the GIREP Organisation. ■

Anssi Lindell,
Chair of the Organising committee
Anna-Leena Latvala,
Secretary of the Organising committee
Anni Rossi,
photographs, GIREP-EPEC 2011,
Department of Teacher Education,
University of Jyväskylä

Euro'solar'physicsnews

On 26 September 2008, at the EPS Executive Committee meeting in CERN (Geneva), the decision was taken to cease activity of the Joint Astrophysics Division. The Executive Committee decided, upon the suggestion of the SPS Board, to set up a new European Solar Physics DIVISION (ESPD) in its own right to serve the European Solar Physics Community.

The various subject disciplines of the JAD within Particle Astrophysics, on the other hand, became the responsibility of the High Energy and Particle Physics Division of EPS. The EPS Council confirmed these decisions on 28 March 2009 during its meeting in Bad Honnef. We hereby report on the start-up of this new EPS division and, in particular, its recent first General Assembly.

The 13th European Solar Physics Meeting

The European Solar Physics community organized its 13th triennial stand-alone meeting (ESPM-13) in Ixia, on the Greek island Rhodes, from 12 to 16 September 2011. The location was well chosen for a conference on the physics of the Sun since Helios is the patron God of Rhodes and, moreover, the Sun was abundantly present during the meeting. There were 213 participants from 33 different countries, including the USA, Mexico, Colombia, Japan, Algeria, etc. Most importantly, however, about 70 (30%) of the participants were PhD students or young postdoctoral scientists. This ample participation of young scientists is characteristic for this series of meetings and is due to the low registration fee and the support offered by the ESPD (European Solar Physics Division) Board thanks to the sponsors of the meeting, incl. the EPS. This year we were able to waive the registration fee for a record-breaking 60 participants and, in addition, to partially or fully cover travel and/or lodging expenses for 55 participants, typically to PhD students and young postdoctoral researchers. The ESPM-13 was co-hosted by the Research Center for Astronomy and Applied Mathematics (RCAAM) of the Academy of Athens and the Institute for Space Applications and Remote Sensing (ISARS) of the National Observatory of Athens. Besides Manolis Georgoulis (RCAAM) and Georgia Tsiropoula (ISARS) the other members of the Local Organizing Committee were Drs. Costis Gontikakis (RCAAM), Spiros Patsourakos (U. of Ioannina), and Kostas Tziotziou (RCAAM & ISARS). The meeting received generous sponsorships by the Academy of Athens, the National Observatory of Athens, the European Space Agency (ESA) via the Solar and Heliospheric Observatory (SoHO) mission, the European Physical Society (EPS), the European Association of Solar Telescopes (EAST), the SOTERIA Project of the European Union, and the Piraeus Bank.

▼ESPD logo

The ESPD Board acted as the Scientific Organizing Committee of the meeting and selected a total of 250 scientific presentations, viz. 22 invited talks, 63 oral contributions, and 165 poster contributions. These presentations were organized in nine sessions, each with an oral part and a poster part. During the poster sessions, coffee was served and ample time was allocated to read and discuss the posters.

The ESPD president and Chair of the SOC, Prof. Stefaan Poedts, opened the scientific part of the meeting on the morning of Monday, 12 September, and chaired the first session on "Science with Cutting-Edge Heliospheric Missions". In this session, the five invited speakers updated the audience on the exciting scientific results and the potential of the major current solar missions and telescopes, viz. STEREO, Hinode, SUNRISE, PROBA-2 and the most important ground-based solar telescopes. Unfortunately, one more invited talk on the latest developments on the Solar Dynamics Observatory (SDO) mission was not given because of the speaker's last-minute inability to attend the meeting

Next, the scientific potential of the planned solar missions and ground-based telescopes was discussed in detail in the 2nd session on "The Science of Future Heliospheric Missions and Telescopes", incl. the EST, the ATST, LOFAR, the synergy between Solar Orbiter and Solar Probe Plus, Solar-C, LEMUR, SPARK, SolmeX, etc.

Session 3 then discussed "The Sun as a Whole: Large-Scale Flows, Helioseismology, Magnet-ism, and the Solar Cycle" with invited review talks on 'Helioseismology and Connections with Asteroseismology' and 'Implications of Solar Wind Magnetic Helicity for Dynamo Theory'.

The 4th session focused on the "Emergence and Evolution of Magnetic Flux in the Solar Atmosphere". It contained a more theoretical review talk on the role of magnetic flux emergence as a precursor of solar dynamic phenomena; and a more observationally oriented review talk on investigations of magnetic fields and their emergence in the solar atmosphere.

In session 5, the progress regarding the long-standing puzzles of chromospheric and coronal heating was discussed. The first review talk focused on the state-of-the-art of the coronal heating mechanisms, while the second review talk discussed the latest ideas on the role of chromospheric spicules in coronal heating.

The abundant observations of waves and oscillations in the corona and their use to determine coronal plasma parameters in coronal seismology were the subject of session 6 ("Transient Activity and Seismology of the Solar Atmosphere"); while the 7th session of the meeting dealt with "Solar Instabilities, Flares, and Coronal Mass Ejections" with invited talks on 'Particle Acceleration in Flares and CMEs' and 'Initiation and Early Evolution of CMEs: A Numerical Approach', the latter by Dr. Carla Jacobs (EPS Invited Speaker).

Session 8 focused on "the origin and properties of the solar wind" with an invited review talk with the same title. The subject of session 9 was "Solar Data Assimilation and Space Weather Research" with an invited review on 'Current Standing of Space-Weather Forecasting: Aims, Tools, and Challenges' and another invited review on 'Image Processing, Pattern Recognition, and Data Assimilation in the SDO ERA'.

▲ Urs Ganse (University of Wuerzburg) won the first 'EPS poster prize' and a copy of the CUP book "Advanced MHD".

New ESPD Board elected

During the "ESPD Business Meeting" that was organized on Tuesday (13 September) evening, the president (Prof. S. Poedts) first reported on the actions of the Board during the first two and a half years of the existence of the new Solar Physics Division of the EPS.

The old SPS Board served as the first ESPD Board and developed a vision and a 'master' plan. Small committees were set up to develop the statutes and bylaws of the new ESPD, to develop new web pages, and to establish contacts and official collaboration with the EAS. The ESPD statutes and bylaws have been prepared, modified after discussion in the ESPD Board and submitted to the EPS Council who approved them during its meeting of 19-20 March 2010 (Mulhouse, France). The new web pages are ready and are online (see: http://solar.epsdivisions.org/), but they need further development, of course. The collaboration with EAS has been described in an agreement for a "Joint Solar Physics Group (JSPG)" of the EAS and the EPS, as a successor of the former Joint Astrophysics Group. This agreement has been approved by the European Physical Society Council and the European Astronomical Society Council, see: http://solar.epsdivisions.org/news/.

▲ Manolis Georgoulis (co-Chair, RCAAM, Academy of Athens) and Georgia Tsiropoula (co-Chair, ISARS, National Observatory of Athens) thanked the sponsors for the much appreciated support, and the LOC and secretariat for the excellent organization.

The ESPD Board also submitted an EU FP7 CSA proposal (in SPACE call 2009) in an attempt to find financial support for its 'master plan'. The proposal made the threshold but was not funded, unfortunately. A new attempt is planned.

Clearly, the ESPD Board also spent a lot of time and energy in preparing ESPM-13, as it served as the SOC for this major solar physics conference.

After the report of the president and the questions about it, a new Board was elected by the EPS members. All six members of the previous Board who ran for a second term were re-elected. The new ESPD Board consists of the following members: Valery Nakariakov (UK, Pres.), Manolis Georgoulis (GR, vice-Pres.), Ineke De Moortel (UK, secretary), Gianna Cauzzi (IT, treasurer), Tom Van Doorsselaere (BE, Press Officer), Astrid Veronig (AT), Victor Melnikov (Russia), Hardi Peter (DE), Hana Mészárosová (CZ), Laurent Gizon (DE), Lucie Green (UK), and Hector Socas-Navarro (ES). The new ESPD Board thus consists of 7 men and 5 women. Moreover, during its first meeting, on Wednesday 14 September, the new ESPD Board decided to renew the co-optation of Manolo Collados (EAST Chair), Norma Crosby (SWWT Chair) and Silja Pohjolainen (CESRA Chair). In addition, Stefaan Poedts (past president) and Lyndsay Fletcher (past secretary) were co-opted for at least one year with the specific tasks to enable the transition to the new Board and to 'activate' the Joint Solar Physics Group (JSPG) that was created by the EPS and the EAS. The total ESPD Board (elected & co-opted members) thus consists of 17 people, viz. nine men and eight women!

▲ Prof. Stefaan Poedts thanked the first ESPD Board and the LOC for the fruitful collaboration and the appreciated crystal award.

▼ Close-up of Prof. Stefaan Poedts with the crystal award in front of the conference poster (left).

Social events on ESPM-13

Clearly, the excellent organization by the LOC had foreseen a few social events that enabled the participants of the meeting to enjoy the unique treasures and breath-taking views Rhodes offers. On Sunday evening, September 11, a welcome cocktail was offered at the dome indoor pool of the Rodos Palace hotel.

On Wednesday afternoon a tour was organized with guided visits at the *Palace of the Grand Masters* (within the *Medieval Fortifications of Old-Town Rhodes*) and the *Acropolis of Lindos*.

The Conference Dinner took place at the half-open Great Rotonda of Kallithea Springs on Thursday evening. During the excellent dinner, Manolis Georgoulis (head of the LOC) thanked the sponsors and the LOC. He also surprised the 'First President' of the European Solar Physics Division, Prof.Dr. Stefaan Poedts, with a warm thank notice and an engraved crystal award.

The dinner was interrupted a second time for the proclamation of the first 'EPS Poster Prize'. This 'best poster' contest was organized for the first time. The prize committee, Chaired by Gianna Cauzzi (ESPD treasurer), had a difficult time as there were many excellent posters and more than 50 works competing for the prize. The committee selected the poster of Urs Ganse (University of Wuerzburg) entitled: *"Kinetic Simulations of CME Foreshock Radio Emissions"* (U. Ganse, P. Kilian, F. Spanier, R. Vainio).

During and after the dinner, a band played traditional Greek music and a folklore dance group entertained the participants with a variety of Greek dances, ending by inviting the enthusiastic audience to participate in the Sirtaki and other popular dances. A lot of solar physicists took advantage of the situation to integrate in the Greek culture. Soon the dance floor was too small, and the evening too short... ■

Stefaan Poedts,
Past chairman of the
European Solar Physics division

STEPS TWO forum in Cyprus
Preparing good Physics Teachers

High-school physics education is *the* foundation for university physics and engineering study and highly recommended for university science studies at large (including medicine). It is also an important tool for giving a general science background to those who will follow different careers outside science. Reason enough for having a conference about the subject.

The acronym **STEPS** stands for 'Stakeholders Tune European Physics Studies'. It is an academic network using the partnership and expertise of EUPEN (European Physics Education Network) in the framework of the Erasmus academic networks programme.

The principle aim of the STEPS TWO project is to support the university Physics Departments in their strategic institutional development following the structural changes by the Bologna process.

Shortage in Physics Teachers

There is a severe shortage in Physics Teachers in the EU. Depending on definition, the shortage is as large as 58%. Reasons underlying this shortage are, for example:

- Physics graduates can get much better-paid jobs and more rewarding careers elsewhere;
- Becoming a teacher is often considered an insufficient intellectual challenge;
- The life of a teacher is considered stressful, with poor working conditions;
- The social status of a school teacher is low.

One strategy to counter the shortage is to redefine physics as just a part of science and to have teachers teach more than one science subject, or teach 'integrated' or 'combined' Science courses. This was introduced, for example, in England and Wales. Unfortunately, the effect of this policy was completely counterproductive. The number of prospective physics teachers - not wanting to be forced to teach biology and chemistry - declined sharply, from about 600 in 1993 to about 200 in 1998. To counter this trend, the British government has recently created special financial incentives for training to become a physics teacher, viz., a GBP 9000 tax-free bursary.

Quality of Teaching

In addition to this decline in quantity, also the quality of teaching went down. Teachers with a chemistry or biology background did not always perform well in teaching physics concepts, let alone in doing inspiring physics demonstrations. The teacher was often just *telling* rather than *explaining*. An appalling real-life example is the explanation by a biology graduate Science teacher of how the eye produces an inverted image on the retina (see illustration, copied from classroom whiteboard; courtesy Gareth Jones).

It may be clear that such 'explanation' will not only confuse the pupils but will also be detrimental for any motivation to choose a university science study.

The 2011 Forum

The STEPS TWO Forum took place August 28-30 in Limassol, Cyprus. It was attended by 77 partners from 24 countries, plus an invited speaker from the US. Some of the conclusions drawn are:

1. Educate teachers in physics at the University level. While this is often regarded as an obstacle in recruiting prospective teachers, the reverse may be the case: the attractiveness and prestige of the profession will only go up.

2. It may be advantageous to educate physics teachers along a dedicated teacher track. The drawback of such teacher tracks may be that teachers often do not find out whether they are an inspiring and successful teacher until they actually teach. In case they fail, they have almost no alternatives. This is avoided if the teachers are educated as an all-round physicist with a pedagogical supplement.

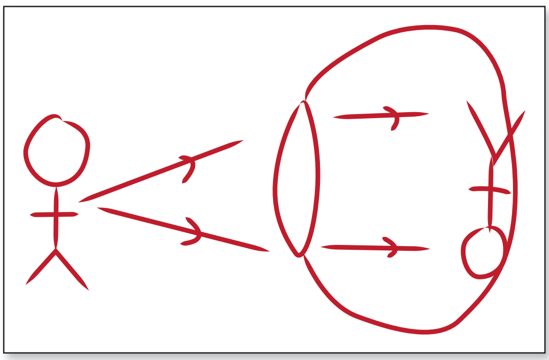
3. If physics teachers are required to teach more than one subject, the combination 'Physics plus Mathematics' is highly preferable to the combination 'Physics plus Chemistry and Biology'.

4. A STEPS TWO task force is bringing out an extensive proposal: *European Benchmarks for Physics Teaching Degrees*. It will first be sent to physics departments for comments, and finally to the EPS, to serve as an EU reference frame.

5. The social status of the teacher should be improved. The question is: how? Politicians may not want to hear this, but the answer may be very simple: better pay. ■

Jo Hermans,
Leiden University, The Netherlands

▼ Example of what can happen if a biologist teaches physics (see text).



The ESFRI Roadmap 2010

The European Strategy Forum on Research Infrastructures (ESFRI) acts towards a better coordination and utilisation of research capacities in Europe

ESFRI, the European Strategy Forum for Research Infrastructures, has stated in its Strategy Report 2011 that the implementation of the projects on the ESFRI roadmap is the most important duty for the next months and years. But also a more balanced distribution of the Research Infrastructures between all regions in Europe is essential for the scientific integration of Europe or more broadly, for the realization of the European Research Area (ERA). To reach the goal of a more balanced distribution of Research Infrastructures also innovative funding instruments have to be explored as the use of Structural Funds. Structural Funds can assist the regional development policy and the European research policy. Research Infrastructures are a guarantee for producing new ideas and developments, which turn into innovations and therefore support the creation of jobs. Research Infrastructures are a key instrument in attracting and bringing together researchers from different countries, regions or disciplines and they offer unique opportunities to train scientists and engineers.

The publication of the first European Roadmap for Research Infrastructures in 2006 was an important breakthrough. In its Strategy Report and Roadmap 2010, ESFRI now presents 48 projects, which have been selected over the last years from more than 260 originally submitted proposals. These projects correspond to the needs of EU research communities in the next 10 to 20 years, spanning the whole range of science and technology.

Current situation

The Europe 2010 Flagship Initiative-Innovation Union has set the strategic target that, by 2015, Member States together with the Commission should have completed or launched the construction of 60% of the priority European Research Infrastructures currently identified by ESFRI. Currently the main task of ESFRI is to launch this process.

In doing so, ESFRI is nevertheless monitoring scientific developments and emerging research challenges to promote the establishment of ERA.

Since 2002 ESFRI, which has been set up as a strategic instrument by the Member States and the European Commission, has devoted considerable efforts to the identification of new and upgraded Research Infrastructures of pan-European interest for the benefit of European research and innovation. Working Groups for different scientific areas, reaching from Humanities and Social Sciences to Physics and Engineering have evaluated the proposals that were received for incorporation in the roadmap. They have also a special task in developing the European landscape for Research Infrastructures, in assisting consortia in finding new partners and in shaping the research and innovation scope of the respective Research Infrastructures.

To help to develop a more evenly distribution of Research Infrastructures in Europe, ESFRI has launched the idea of "Regional Partner Facilities". These are mainly national or regional facilities of high scientific excellence linked with Research Infrastructures of pan-European relevance. A Regional Partner Facility must be itself a facility of national or regional importance in terms of conducted research, socio-economic returns, training and attracting researchers and technicians. The quality of the facility must meet the same standards required for pan-European Research Infrastructures. With that scheme, we hope to bring forward the European integration not only on the level of pan-European Research Infrastructures, but as well on a more regional level, giving the Regional Partner Facility the possibility to participate in a pan-European RI with narrower financial burden.

Realising a better utilisation of Research Infrastructures in Europe means also, that there is a need to implement the projects on the ESFRI

DEFINITION

Research Infrastructures are facilities, resources or services of a unique nature that have been identified by European research communities to conduct top-level activities in all fields.

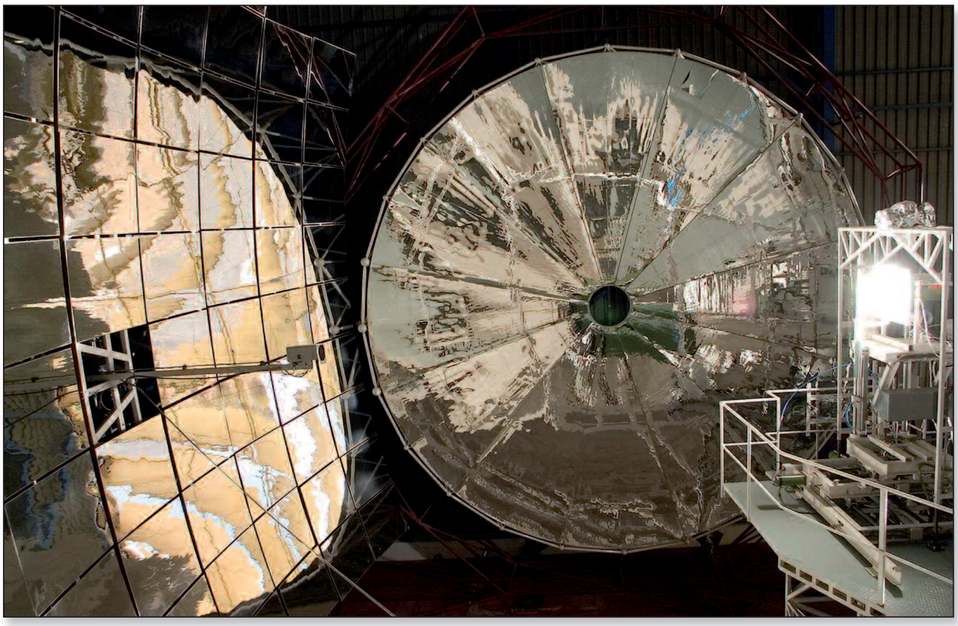
This definition of Research Infrastructures, including the associated human resources, covers major equipment or sets of instruments, in addition to knowledge-containing resources such as collections, archives and data banks. Research Infrastructures may be "single-sited", "distributed", or "virtual" (the service being provided electronically). They often require structured information systems related to data management, enabling information and communication. These include technology-based infrastructures such as Grid, computing, software and middleware.

In all cases considered for the roadmap, these infrastructures must apply an "Open Access" policy for basic research, *i.e.* be open to all interested researchers, based on open competition and selection of the proposals evaluated on the sole scientific excellence by international peer review.

roadmap as soon as possible. ESFRI has created a special Working Group with the aim to monitor and support the projects in their respective implementation phases. All projects are asked to work with the Working Group by identifying bottlenecks in the implementation process but also by forwarding best practice experience to the less advanced projects.

To improve cooperation between the different Research Infrastructures, it is also necessary to be informed about the different national strategies and plans for developing Research Infrastructures. Therefore ESFRI is also aiming to promote informal exchanges on national strategies and projects in order to develop common perspectives for the establishment or upgrade of Research Infrastructures of pan-European relevance. Since the ESFRI members are nominated by their respective Ministries/funding agencies they can help to bridge the sometimes existing gap between scientists, promoting a proposal, and the governmental level which has to decide upon the funding. ESFRI has already stimulated most of the Member States or Associated Countries to develop their own national roadmaps to prioritise their needs of Research Infrastructures in the future. These national roadmaps complement the ESFRI roadmap in focusing on national needs, capacities and competencies.

An excellent, balanced and efficiently working European Research Area needs Coordination and Cooperation.
One important step in creating the European Research Area (ERA) was the setting up of a new European legal framework (ERIC – European Research Infrastructure Consortium) in June 2009 with the assistance of ESFRI. This framework should considerably facilitate the construction and operation of pan-European Research Infrastructures. ESFRI is now advocating the ERIC framework regulation to reach acceptance in all Member States and Associated Countries.



▲ EU-Solaris is a networking approach from outstanding solar research centres in seven European countries. Further countries may join. Core activities will be carried out at the Plataforma Solar de Almería plus the CTAER land nearby. As an example, materials and processes can be tested in this Solar Furnace under high temperature and high radiation fluxes conditions.

The development of a common strategy for data acquisition and management is another crucial element for the success of Research Infrastructures. ESFRI therefore stimulates for all Research Infrastructures the full integration of data management in the development of the facility and supports the access to standardized, calibrated and inter-operable data.

The scientific integration of Europe needs a close cooperation of all involved stakeholders. Therefore ESFRI intends to strengthen its cooperation with European research

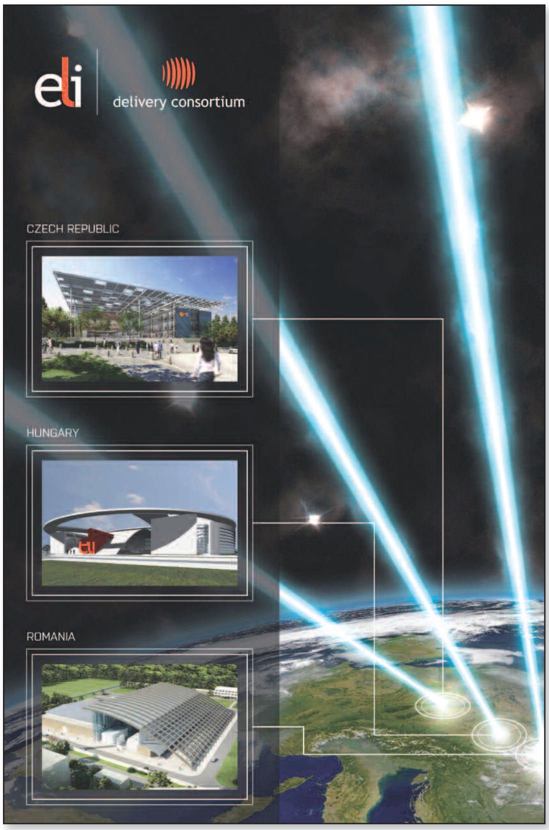
▼ Earth is a living planet with a complex biodiversity system. How this system maintains stability and adapts to external constraints (environments) cannot be deduced from the simple sum of its components and relations. However, better knowledge is increasingly important to develop novel approaches to understand and manage our living environment, allowing for the development of sustainable and science-based management strategies. The LifeWatch research infrastructure is the first global initiative to bring together data, software and computational facilities at an appropriate integrated large scale in order to support advanced analysis and modeling.

and innovation organisations such as EIROFORUM, EUROHORCS, EARTO, ESF, and others. ESFRI would also like to foster the cooperation with industry and industrial organisations, as research and innovation are the prerequisite for overcoming the current crisis and to continue with a sustainable growth.

In addition, ESFRI is also stimulating international (global) cooperation, to ensure that the full scientific and educational potential is used by the Member States and Associated Countries, recognising that already at present some of the ESFRI Research Infrastructures are global in their nature.

Evaluation

ESFRI is aware that the development of the European Research Area requires not only the setting up of new facilities but also to take into account the existing ones. At the ECRI conference 2008 ESFRI has received the mandate to develop an evaluation methodology for pan-European Research Infrastructures. The goal of ESFRI is to develop an evaluation scheme that could be used for ex-ante (new and upgraded Research Infrastructures) and ex-post (existing Research Infrastructures) evaluation in terms of their pan-European relevance. This evaluation scheme should be based on national and international evaluation systems for facilities of national and regional importance. In the future still a lot of work has to be done to reach harmonization of these evaluation systems following the same best practices.



▲ As the first research infrastructure project of the ESFRI Roadmap to be implemented in new Member States, the Extreme-Light-Infrastructure (ELI) will provide access to the most intense and shortest laser pulses ever for a large variety of science and research applications.

Conclusion

Research and Innovation are the key drivers of Europe's future, especially in periods of economic instability. The main challenge is how to make the best use of the available talent and resources. To achieve that, every effort should be made to implement the Research Infrastructures on the roadmap as soon as possible. ■

■■■ **Beatrix Vierkorn-Rudolph,**
ESFRI Chair

EPS 2010 Lise Meitner Prize (supported by CANBERRA)

Awarded to Prof. Juha Äystö (University of Jyväskylä, Finland) for "Accurate determination of nuclear fundamental properties by an invention of innovative methods of ion guidance and its applications".

Over the last few decades the development of Nuclear Physics has been characterised by the invention of methods aimed to increase the selectivity, sensitivity, and accuracy of measurements of basic nuclear properties. An important and innovative technological breakthrough has been the pioneering and ingenious method of guidance of ion beams, as first implemented by Prof. Juha Äystö at the University of Jyväskylä in the mid-1980s.

The ion-guide concept has subsequently become a universal tool for different nuclear reactions covering almost all elements of the Periodic Table. The idea realised was to thermalise the products in a noble gas buffer, which resets the charge state of all ions to unity. The singly-charged ions are then rapidly extracted and transported in an ultrasonic jet. Due to the speed of the process - a matter of milliseconds, and its selectivity when combined with an isotope separator, it is especially suited for the investigation of short-lived exotic nuclides. The ion-guide concept has now been adopted throughout the world and many experimental configurations are in operation, under construction or planned for the study of nuclei, atoms and elementary particles.

Prof. Äystö has recorded important scientific achievements at different operating facilities covering a very broad range of nuclear physics. Parallel to his very successful scientific research, built around the innovation of the ion guide, Prof. Äystö has been a leading figure in promoting nuclear physics throughout Finland and Europe. He has served the European Nuclear Physics Community by working on a wide variety of international scientific committees and panels. He is a prominent science policy person preparing the ground for the future development of the discipline. In these roles he has been one of the main figures bringing European Nuclear Physics to the forefront of the Nuclear Science in the world. ■

■■■ **Z. Fülöp,**
Chairman of the Nuclear Physics Division of EPS

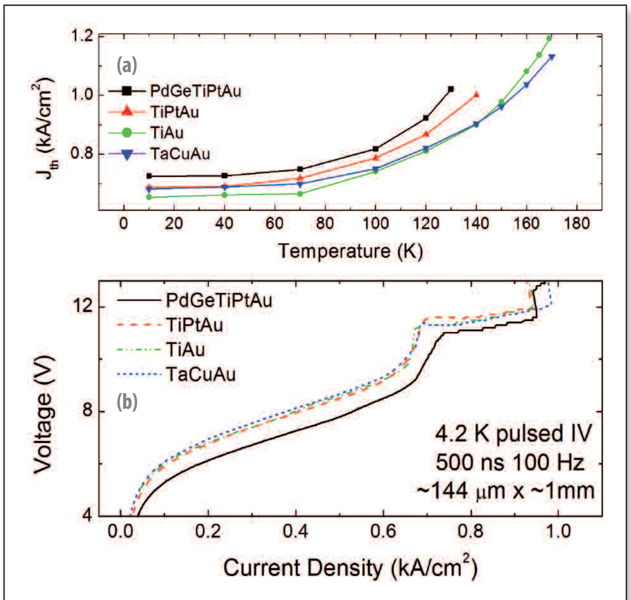
■■■ **K. Gridnev,**
Member of the Nuclear Physics Division of EPS

Highlights from European journals

APPLIED PHYSICS

Metal contacts in terahertz quantum cascade lasers

Schottky contacts should be avoided in electrically-pumped semiconductor laser devices because they cause an extra voltage drop at metal-semiconductor interfaces – wasting power, overheating device active region and degrading performance. Metal stacks of Ni/Ge/Au and Ti/Pt/Au are commonly employed to form ohmic contacts with n-type and p-type III-V semiconductors, respectively. The optical loss of these ohmic metal contacts is negligible in the visible-light/near-infrared range (~hundreds of THz) due to their much lower Plasmon frequencies (1-10 THz). The optical properties of these metals are therefore not a concern in conventional semiconductor diode lasers.



▲ (a) Threshold current densities of four THz quantum cascade lasers with different metal contacts. (b) Current-voltage curves of the devices at 10 K.

This drastically changes if the lasing frequency approaches the terahertz range (10^{12} Hz), *i.e.*, THz quantum cascade lasers (QCLs) that are based on GaAs/AlGaAs multiple quantum-well structures. The high tangent loss of the commonly-used metals in this frequency range could become a substantial part of the total waveguide loss of the lasers, however metal stacks (such as Ti/Au and Ta/Cu/Au) that exhibit low optical loss in the terahertz frequency range from non-ohmic contacts with III-V semiconductors. Researchers often face a dilemma when picking the metals – ohmic or non-ohmic contacts?

We experimentally investigated the electrical and optical behaviours of THz QCLs with four different Au- and Cu-based metal contacts. The QCL device with non-alloyed Ta/Cu/Au exhibits the lowest threshold current density and the highest lasing temperature in pulsed mode. The better performance is attributed to the lower optical loss of the device waveguide in spite of the formation of a Schottky contact. The findings clarify an important issue that will help researchers design and fabricate THz QCLs operating at higher temperatures and eventually at room temperature. ■

S. Fathololoumi, **E. Dupont**, **S.G. Razavipour**, **S.R. Laframboise**, **G. Parent**, **Z. Wasilewski**, **H.C. Liu** and **D. Ban**,
'On metal contacts of terahertz quantum cascade lasers with a metal–metal waveguide', *Semicond. Sci. Technol.* **26**, 105021 (2011)

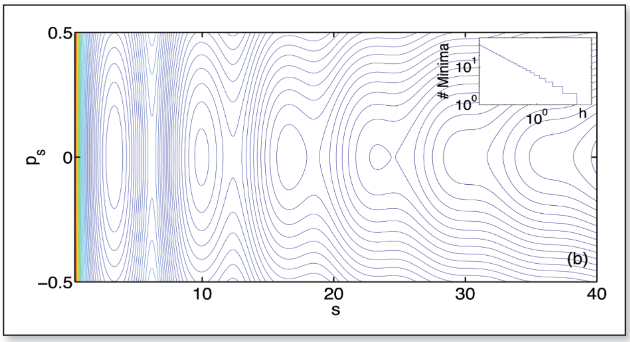
ATOMIC AND MOLECULAR PHYSICS

Effective long-range interactions in confined curved dimensions

Fundamental forces of nature such as the gravitational or Coulomb force mediated by the mass and charge of particles, respectively, decay according to universal laws with increasing distance between the particles. Still, these simple laws lead to the enormous beauty and amazing complexity of matter surrounding us.

In ultra-cold atomic physics the three-dimensional motion of neutral atoms or charged particles can be confined to a lower dimensional typically one- or two-dimensional trap by employing electromagnetic forces. If these traps are of curved character, which is possible e.g. in evanescent fields surrounding optical nano-fibres, they confine the motion to a curved low-dimensional manifold.

This opens the perspective of designing novel effective finite-range and possibly also long-range interactions since the dynamics is constrained to the curved geometry but the interaction takes places via the dynamically forbidden dimensions. The corresponding forces can now become oscillating with increasing distance between the particles and are widely tunable via the parameters of the confining curved manifold. Exploring as a prototype example the one-dimensional helix, it can be immediately shown that a plethora of local equilibrium configurations and consequently bound states emerge already for two particles even if the particles were repelling each other in free space. The number and depths of the local minima and wells can be tuned by modifying the pitch or curvature of the helix thereby establishing bound state configurations of different symmetries.



▲ Phase space picture of the effective long-range interactions indicating many local equilibriums. (Inset: Number of minima as a function of the pitch of the helix).

With an increasing number of interacting particles an ever-increasing wealth of symmetry-adapted and symmetry-distorted configurations create a very complex energy landscape exhibiting a dense spectrum of local equilibriums. It can be anticipated that the thermodynamical properties and quantum physics of the many-body interacting helical chain show novel structural properties such as enriched phase diagrams as well as an intriguing dynamical behaviour. ■

P. Schmelcher,
'Effective long-range interactions in confined curved dimensions', *EPL* **95**, 50005 (2011)

APPLIED PHYSICS

Stable p-type conductivity in Bi-doped ZnO

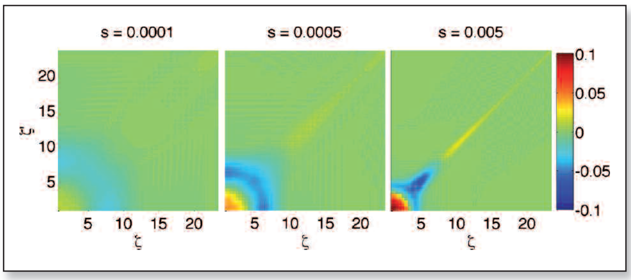
Zinc Oxide (ZnO) has potential applications in varistors, light emitting diodes and photo detectors. The primary obstacle against its use in optoelectronic devices is the lack of stable p-type material. ZnO is naturally an n-type material, its majority carriers being electrons and it must be doped to become p-type. Most p-type dopants introduce either deep or shallow acceptors and the resulting material is p-type with either very low carrier concentration or unstable conductivity. Many previous efforts to synthesize p-type ZnO used N, As and P as dopants. In the present study bismuth has been chosen.
Thin films of Bi-doped ZnO were grown with a pulsed laser deposition system using a homogeneous target. Sample thickness was about 150 nm. XRD results showed the wurtzite structure of the films and XPS confirmed the presence of Bi. No evidence of secondary phases was found. From Hall measurements made over repeated cycles, in-situ annealed 3 and 5% Bi-doped samples are p-type. However as-grown 3% doped films showed unstable p-type conductivity, which suggests that some form of activation of Bi in ZnO occurs during the post-growth annealing leading to the p-type conduction. In the as grown 5% doped samples, the Bi concentration seems high enough to impose p-type conduction. Bi substitution in ZnO lattice is known to produce acceptors; this is the case here as shown by photoluminescence experiments. Carrier concentrations were 5.4×10^{18} and 4.8×10^{19} cm^{-3} in annealed 3% and 5% Bi-doped samples, respectively. Temperature-dependent photoluminescence leads to an acceptor energy level at about 0.13 eV above the valence band. The p-type conductivity of these Bi-doped ZnO thin films is stable under oxygen-rich ambient or upon annealing. Thus, this study suggests a possible pathway for developing ZnO based optoelectronic devices. ■

J.W. Lee, **N.G. Subramaniam**, **J. C. Lee**, **S. Kumar** and **T. W. Kang**,
'Study of stable p-type conductivity in bismuth-doped ZnO films grown by pulsed-laser deposition', *EPL* **95**, 47002 (2011)

NUCLEAR PHYSICS

Renormalisation group for 3-body interactions in 1D

One important message emerging from developments of effective field theories and effective Hamiltonians for nuclear physics is that many-body forces are inevitable whenever degrees of freedom are eliminated. At the same time, first-principles calculations have shown that two-body forces alone are not able to give an accurate account of the energies of light nuclei and the saturation of nuclear matter. Three- (possibly more-) body forces are thus essential in low-energy nuclear physics. The construction of effective interactions through elimination of degrees of freedom can be done either by imposing a cut-off on the Hilbert space or by applying a transformation putting the Hamiltonian into a simpler form, such as a diagonal matrix.



▲ The three-body interaction induced by the renormalization group evolution starting from a Hamiltonian with only two-body forces. The three-body potential is plotted as a function of initial and final relative momentum variables, for three values of the flow parameter. It can be seen to approach a diagonal form as the flow progresses.

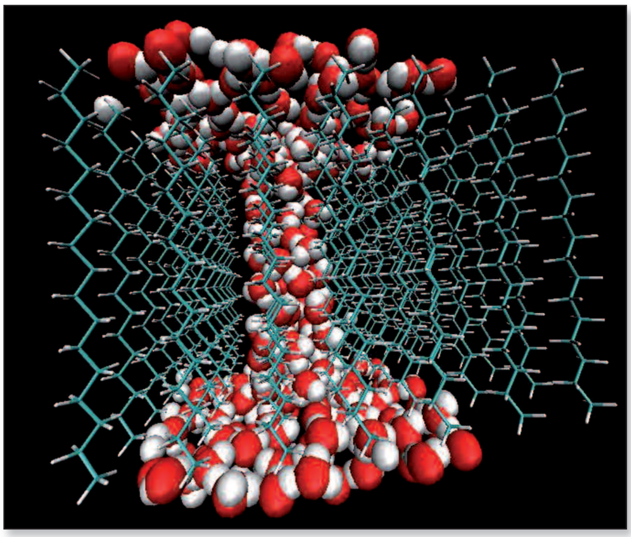
The Similarity Renormalization Group follows the latter route by means of a continuous set of transformations. It has proved to be a powerful tool in low-energy nuclear physics, when applied mainly in the context of expansions using harmonic-oscillator basis states. The present paper provides the first application of this method to three-body interactions in a momentum-space basis. Although the models studied are simple ones (bosons in 1D), the structure of the evolution equations has the full complexity of any set of three-body equations. The results show the expected decoupling of high- from low-momentum states for both two- and three-body interactions, which means that only low-momentum matrix elements of the evolved potentials are needed to describe low-energy states. This work paves the way for applications to few-nucleon scattering processes and nuclear matter, starting from realistic nuclear forces in three dimensions. ■

O. Åkerlund, **E.J. Lindgren**, **J. Bergsten**, **B. Grevholm**, **P. Lerner**, **R. Linscott**, **C. Forssén** and **L. Platter**, 'The Similarity Renormalization Group for Three-Body Interactions in One Dimension', *EPJ A* **47**, 1 (2011)

BIOPHYSICS

How do protein binding sites **stay dry in water?**

What is the the condition for model cavity and tunnel structures resembling the binding sites of proteins to stay dry without losing their ability to react, a prerequisite for proteins to establish stable interactions with other proteins in water?
To answer this, models of nanometric-scale hydrophobic cavities and tunnels are used to understand the influence of geometry on the ability of those structures to stay dry in solution. The authors study the filling tendency of cavities and tunnels carved in a system referred to as an alkane-like monolayer, chosen for its hydrophobic properties, to ensure that no factors other than geometrical constraints determine their ability to stay dry.



▲ Simulations are used to study the ability of model tunnel structure to stay dry

They show that the minimum size of hydrophobic cavities and tunnels that can be filled with water is in the nanometer range. Below that, the structure stays dry because it provides a geometric shield; if a water molecule was to penetrate the cavity it would pay an excessive energy cost to release its hydrogen bonds. By comparison, water fills carbon nanotubes that are twice smaller (but slightly less hydrophobic) than the alkane monolayer, making them less prone to stay dry.
It is also shown that the filling of nanometric cavities and tunnels with water is a dynamic process that goes from dry to wet over time. Water molecules inside the cavities or tunnels may arrange in a network of strong cooperative hydrogen bonds. Their disruption through thermal fluctuations induces the temporary drying of the holes until new bonds are re-established.
Among many potential applications, one in biophysics would be to study water-exclusion sites of proteins, and understand the physical phenomenon linked to the geometry of those sites, underpinning the widespread biological process of protein-protein associations. ■

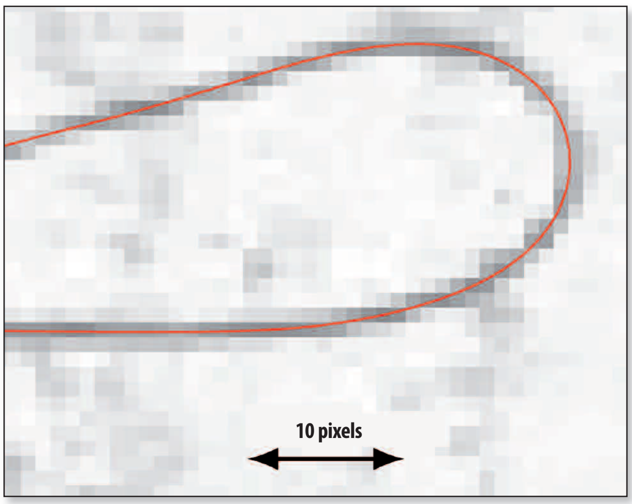
E.P. Schulz, **L.M. Alarcón** and **G.A. Appignanesi**, 'Behavior of water in contact with model hydrophobic cavities and tunnels and carbon nanotubes', *Eur. Phys. J. E* **34**, 114 (2011)

APPLIED PHYSICS

Curvilinear shapes by Virtual Image Correlation

The problem of the accurate identification of a contour arises in many fields of physics. This contour can be an image of an elongated object, for example a fibre, a filament or a structure of larger dimension such as the cable of a bridge. It can also be a front of a physical event, such as a thermal or chemical front revealed by a convenient marker.
Current methods are optimized in the sense of the capacity of detection of a contour hidden in a noisy image, mainly for medicinal applications. The given information consists in a ▶

▲ Image of a fibre dragged in a fracture by a flow motion and its shape identification (in red)



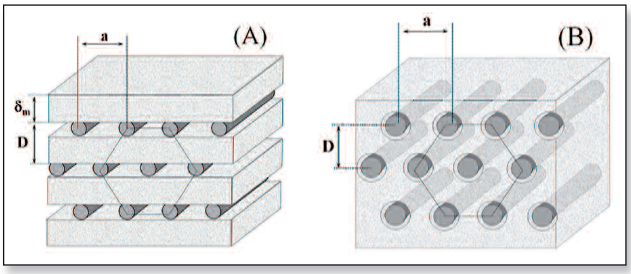
discrete set of locations (generally a set of pixels). Due to this discontinuous nature, the derivatives (slopes and curvatures) require a filtering and the result depends on its choice. However this knowledge is crucial for many applications. For example fluxes computations depend upon slopes; momentums on beams (in mechanics) depend upon curvatures.
The proposed method, issued from the Digital Image Correlation methods used in solid mechanics, is more focused on the precision of the identification, in the sense of metrology. It consists in the research of the best fit between the image of the physical contour and a virtual image, a curve roughly of the same thickness as the contour. This curve (the virtual beam) is defined analytically thus the obtained shape and its derivatives are smooth, given with confidence and defined at any scale of refinement.
The method can be easily extended to edge detection. It will also be possible to use an analytical expression of the considered problem thus the method will give its best coefficients, leading to a straightforward identification of the phenomenon from an unfiltered image. ■

B. Semin, **H. Auradou** and **M.L.M. François**, 'Accurate measurement of curvilinear shapes by Virtual Image Correlation', *Eur. Phys. J. Appl. Phys.* **56**, 10701 (2011)

BIOPHYSICS

New complex may offer safer alternative for gene therapy

The authors have created a complex system designed to hold DNA fragments in solution between the hydrophilic layers of a matrix of fatty substances (also known as lipids) combined with a surfactant (used to soften the layers' rigidity). One possible application that has yet to be tested is gene therapy.
Although gene therapy was initially delivered using viral vectors, recent attempts at devising alternative vectors have exploited positively charged lipids to form complex structures holding DNA fragments with electrostatic forces. However the positively charged ions (cations) used in this type of vector have proven toxic for human cells.
Until now, only positively charged fatty substance were thought capable of holding DNA in a complex vector. The authors of this study have proved otherwise by creating an electrically neutral matrix, structured like a multi-layered cake, which holds the DNA fragments at a high concentration in solution between the layers.
It appears that DNA fragments within the complex self-organise over time. These fragments spontaneously align parallel to one another and form rectangular and hexagonal structures across the layers. This ordering in a special matrix holds the key to creating non-toxic gene therapy delivery vectors.
The change of atomic-level interactions within the layers and the appearance of interactions at the interface between the



▲ Self-organized DNA fragments in a non-cationic L_α lipid phase

layers and the DNA molecules may explain the emergence of ordered structures at high DNA concentrations.
The next step of this research involves elucidating the precise physical forces that hold the complex together. Applications of such technology go beyond gene therapy vector design, as the same principle can be applied for the delivery of other particles such as chemical drugs. ■

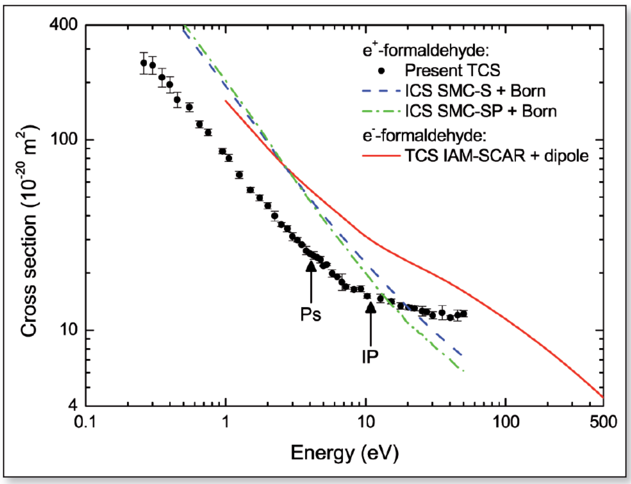
E.R. Teixeira da Silva, **E. Andreoli de Oliveira**, **A. Février**, **F. Nallet** and **L. Navailles**, 'Supramolecular polymorphism of DNA in non-cationic L_α lipid phases', *Eur. Phys. J. E* **34**, 83 (2011)

ATOMIC AND MOLECULAR PHYSICS

Positron and electron collisions with formaldehyde

New interest in electron and positron scattering from atoms and molecules has grown in the last few years. Understanding the fundamental forces, like the Coulomb and the dipole interaction, driving the collisional processes between the incident particle and the target, both experimentally and in the development of scattering theory, is a crucial topics in physics.

▼ Experimental and theoretical total cross sections (TCS) for positron (e^+) and electron (e^-) scattering from formaldehyde and calculations of the elastic integral cross section (ICS) for positrons. The black arrows labelled "Ps" and "IP" indicate the energy thresholds of the opening of the positronium formation and direct ionisation scattering channels, respectively.



Formaldehyde (CH_2O) is a relatively small and simple fundamental organic species, from which many chemical compounds are derived. In addition, this molecule is characterised by a strong dipolar nature, a property which is expected to play a significant role in affecting the probability of very low-energy scattering. Despite these interesting properties, it had attracted only very little attention so far. The very first absolute cross sections for low energy positron and electron scattering from formaldehyde are reported here, hereby filling in a gap in the available knowledge on this key species.

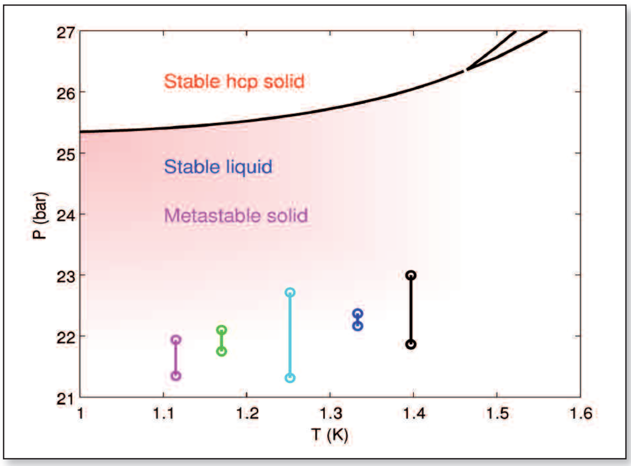
Experimental total cross sections and calculated elastic integral cross sections for positrons in the energy range ~0.25-50 eV, together with theoretical results of electron total cross sections are presented. As can be seen from the results shown in the figure, the very large slope and magnitude of the low-energy cross sections reflect well the largely polar nature of formaldehyde. As a result of this work, formaldehyde can be used as an excellent candidate species against which further advances in scattering theory might be benchmarked. ■

A. Zecca, **E. Trainotti**, **L. Chiari**, **G. García**, **F. Blanco**, **M. H.F. Bettega**, **M.T. do N. Varella**, **M.A.P. Lima** and **M.J. Brunger**,
'An experimental and theoretical investigation into positron and electron scattering from formaldehyde', *J. Phys. B: At. Mol. Opt. Phys.* **44**, 195202 (2011)

SOLID STATE PHYSICS

Observation of metastable hcp solid helium

Crystalline solids can be brought into metastable state with respect to fusion only if surface melting is avoided. Overheated metals have indeed been observed by embedding small samples in carefully chosen matrices. Because of its constant melting pressure at low temperatures, hcp solid helium offers a unique possibility to achieve a metastable solid via pressure variations. Intense positive and negative pressure swings far from any interface can be achieved using focused sound waves. In hcp solid helium, the sound velocity is anisotropic and a dedicated non-spherical sound emitter has to be used. The wave amplitude is small enough not to melt the crystal at its interface with the emitter. As it propagates, its amplitude increases and pressures below the static melting line are obtained in the solid bulk. The pressure is measured via the refraction index changes of the medium using an interferometric imaging technique. The main result of this work is shown on the figure: hcp solid helium between -2 and -4 bars below the melting line has been produced and observed. A side result is that the crystal seems to become unstable beyond this value. We feel that the stretched quantum solid is an interesting new system to be understood in details. ■



▲ **Partial phase diagram of helium and minimum pressures achieved at different temperatures between 1.1K and 1.4K. The metastable domain is below the melting line.**

F. Souris, **J. Grucker**, **J. Dupont-Roc** and **Ph. Jacquier**,
'Observation of metastable hcp solid helium', *EPL* **95**, 66001 (2011)

PLASMA PHYSICS

Electron impact dissociation of ND^+: formation of D^+

Nitrogen is a common contaminant species in fusion reactors such as the ITER (International Thermonuclear Experimental Reactor). Thus, the collisional properties of nitrogen-containing plasma compounds are widely studied experimentally and theoretically. Here we show the results of absolute cross section measurements for the electron impact dissociative excitation of ND^+ yielding D^+, especially at low electron energies near the onset of the dissociation. The identification of indirect and resonant processes is a particular challenge in that energy regime. Excitation is likely to be influenced by vibrationally excited levels populated within the $X^2\Pi$ ground state of $ND^+(v)$. Two mechanisms can produce these levels: (i) the endothermic reaction $D_2^+(v') + N$ and (ii) the ion–molecule reaction $D_2(v'') + N^+$. The latter is the first step in a sequence of molecular activated processes, which confirms that such a reaction chain is important for an understanding of the overall plasma chemistry. The low experimental energy threshold observed in the present studies indicates that the importance of contribution of Rydberg states via the capture of the incoming electron into doubly excited electronic states of (ND)**. ■

J. Lecointre, **D.S. Belic**, **S. Cherkani-Hassani** and **P. Defrance**,
'Electron impact dissociation of ND^+: formation of D^+', *Eur. Phys. J. D* **63**, 475 (2011)

Nobel Prize in Physics 2011

Dark Lords of the Universe: How exploding stars unlocked the past and the fate of the Universe

■ Rien van de Weygaert - DOI: 10.1051/epn/2011601

The Nobel prize of Physics 2011 has been awarded to the three researchers responsible for one of the most startling scientific discoveries of the past decades. Saul Perlmutter, Adam Riess and Brian Schmidt (figure 1) receive the prize for the discovery of the accelerated expansion of the Universe and for revealing the presence of a mysterious dark energy dominating the dynamics and the fate of the Universe.

▲ **FIG. 1:** The three Nobel prize laureates, at the occasion at which they received the Shaw Prize for astronomy in 2006. From left to right: Saul Perlmutter, Adam Riess and Brian Schmidt.

In 1998, the Supernova Cosmology Project (SCP), led by Saul Perlmutter (Lawrence Berkeley National Laboratory, UC Berkeley), and the High-z Supernova Search Team (HZSNS), led by Brian Schmidt (ANU, Mount Stromlo Observatory, Australia) and Adam Riess (JHU & STScI, Baltimore), almost simultaneously published the findings of their supernova monitoring campaigns. They themselves were startled to discover that the cosmic expansion is accelerating, instead of the deceleration that was anticipated by the prevailing standard cosmology. Their observations revealed that since the last 6-7 billion years, the dynamics and fate of the Universe have been dominated by a mysterious medium causing gravitational repulsion. Observations since have established that dark energy - the general name now in use, coined by Michael Turner in 1999 - represents no less than 73% of the energy budget of nature.

The repercussions of this discovery are far reaching and represent a historic paradigm shift in our view of the world and the cosmos. It has dramatic ramifications for the ultimate - bleak - fate of the Universe. Moreover, it may have profound consequences for our understanding of gravity at energies occurring at the very first moments of the Big Bang. Ever since, the nature of the dark energy has remained the greatest enigma of 21st century physics. It did not come as a surprise that in 1998 Science magazine branded it the year's scientific breakthrough.

Over the year running up to their discovery the two teams, independently, had been monitoring around 50 supernovae, specifically the type called Supernova Ia (Figure 2). These rare and catastrophic explosions are violent thermonuclear deflagrations or detonations of white dwarf stars, and may reach a brightness comparable to that of an entire galaxy like our own Milky Way. Their enormous brightness allows type Ia supernovae to be detected over vast cosmological distances, currently reaching out to supernovae which exploded a mere 3 Gigayears after the Big Bang, or more than 10 billion years ago. The seminal importance of supernovae Ia is that they are one of the few astronomical objects whose intrinsic luminosity is quite accurately known. Both factors make them an ideal standard candle for measuring the distances over cosmologically significant depths.

Supernovae

Amongst supernovae two major types are distinguished, Supernovae I and Supernovae II. Of interest for the Nobel prize winning discovery is the subclass of Supernovae Ia. These represent rare events that occur only a few times per millennium in a galaxy like the Milky Way. Tycho's supernova in 1572 was one, and probably also SN1006. The latter first appeared on the sky between April 30 and May 1 of the year 1006 and is the brightest stellar event in recorded history. Type Ia supernovae are the result of the violent thermonuclear explosion of a white dwarf star. A white dwarf is the remnant of a star that completed its normal life cycle when the energy supply from nuclear fusion ceased. It is limited in mass to 1.38 solar masses, the Chandrasekhar mass, beyond which electron degeneracy pressure can no longer support the star. When the star is part of a binary system and is gradually accreting mass from its binary companion, it will start to collapse once it surpasses this limit. When it concerns a carbon-oxygen white dwarf, a rather common type, the carbon and oxygen ignite nuclear fusion as the core is heating up to temperatures in excess of billions of degrees. A few seconds later, the nuclear fusion reactions proliferate throughout a major fraction of the star in a runaway deflagration. Recent research suggests that some of the Supernovae Ia may have a different origin and are the result of the merging of two white dwarfs. In both situations, the vast amounts of energy that are released completely unravel the star in the subsequent violent supernova explosion. The light curve of a supernova Ia, i.e., the evolution of its brightness as a function of time, is marked by a characteristic peak shortly after the explosion and a gradually fading tail in the following months, powered by the radioactive decay of Nickel and Cobalt.

Three important developments paved the road for the groundbreaking discovery by the Nobel laureates. The first was the introduction of large mosaic charge-coupled device (CCD) cameras on 4-meter class telescopes, enabling the systematic search of thousands of galaxies over large areas of the sky for the rare supernova events. It was crucial to find the supernova at least before or around it would reach peak brightness. A second major development was the dramatic increase in computing power in the 1980s, enabling the vast amount of data processing necessary for an automated search of supernovae amongst the millions of galaxies that were monitored. The most important breakthrough was the finding that Supernovae Ia can actually be used as accurate cosmic standard candles. The discovery was made possible by the high quality supernova light curves and spectra obtained by the Calan/Tololo Supernova Search, led by Mario Hamuy. This enabled Mark Phillips in 1993 to find a tight correlation between the rate at which the luminosity of a type Ia supernova declines after the explosion and its absolute brightness. The luminosity distance of the supernovae is determined by relating the observed brightness to the inferred intrinsic brightness.

Redshift and Expansion

Driven and inspired by these important advances, the competing SCP team of Perlmutter and HZSNS team of Schmidt & Riess set out to measure the expansion history of the Universe. To infer the expansion history of the Universe, the distances to supernovae are measured as a function of their cosmic redshift. In cosmology, redshift is a direct manifestation of the expansion of the Universe: a source that has a redshift z emitted its light when the Universe was (1+z) smaller. In a strongly decelerating Universe, the physical distance of a supernova with a given redshift would be less than that in a weakly decelerating (or accelerating) Universe. At that redshift, it would translate into an object whose observed brightness would be higher in the strongly decelerating Universe. One may only imagine the surprise when it turned out they were even fainter, by ~0.25 mag, than they would be in an empty freely expanding Universe, indicating that the expansion has been speeding up for the past 6-7 billion years.

To reach and solidify this surprising finding, the SCP and HZSNS teams had to deal with a range of major practical and scientific challenges. On the practical side, there was the overwhelming logistic and political challenge of assuring vast amounts of (strongly contested) observing time on a range of telescopes, including 4 meter-class ones for probing the high redshift universe. Various astronomical effects might render the measurement of any subtle cosmological effect insignificant, and had to be corrected for. One major influence is that of dust, affecting the observed brightness of supernovae. Another major uncertainty was the poorly understood influence of heavy chemical elements on the supernova light curves. Such effects are sufficiently worrisome to have cast considerable doubt on the perplexing findings of the supernova teams. Their results remained intact, even after putting their results under heavy scrutiny through a large range of tests dealing with each imaginable pitfall or artefact. Of crucial importance was that independently the other competing team reached the same conclusion. Almost overnight, our view of the Universe underwent a major paradigm shift.

Paradigm Shift

To fully appreciate the significance of their discovery, we need to step back in time and assess the situation in cosmology in the late 1980s and 1990s. With hindsight, we can best characterize it as a brewing crisis. On the one hand, there was a successful "standard" cosmology. The Friedmann-Robertson-Walker (FRW) Big Bang universe had been augmented by an inflationary phase that should have taken place in the very early Universe. It offered a natural explanation of several of the remarkable fine-tunings of the FRW universe models. One ►

of the firm predictions of inflation is that the universe should have a flat geometry. This means that the energy density of the Universe should be equal to the critical density (~2×10^{-29} g cm^{-3}), the density at which the Universe would have a flat geometry. It would imply that it is filled with vast amounts of undetected dark matter. However, by 1995 a range of astronomical observations had indicated that the total amount of dark and baryonic matter could not exceed 30% of the critical density. Perhaps the clearest mark of the impending crisis was the finding by the APM galaxy survey that the clustering of galaxies on Megaparsec scales differed significantly from the prevailing 'standard cold dark matter' cosmology. It led George Efstathiou, Steve Maddox and collaborators to remark that only the presence of a cosmological constant could make sense of these results. Equally pressing were the questions concerning the age of the oldest stars. Stars with ages of 13-15 billion years had been found in globular clusters. Even after this estimate got tuned down, they remained billions of years older than the implied age of the cold dark matter dominated Universe: an unacceptable situation.

In the previous decades there had been occasional speculations about the return of the cosmological constant as a major factor in the cosmological power game between the various cosmic constituents. Dismissed by Einstein himself after Hubble's discovery of the expansion of the Universe, as his "biggest blunder", the cosmological constant Λ would be the first suggestive source of a cosmic acceleration. In an attempt to estimate its natural magnitude on the basis of a quantum-mechanical interpretation as the energy of the vacuum, Yakov Zel'dovich in the late 1960s and Steven Weinberg in the mid 1980s argued that it should be no less than 120 orders of magnitude larger than suggested by observations. At an estimated 73% of the critical density, the dark energy content of the Universe falls "somewhat" short of Zel'dovich's estimate and underlines our total lack of understanding with respect to the nature of the dark energy.

In this situation of crisis, the discovery by the Nobel Laureates instantly settled the doubts and discussions. This may explain why their astonishing conclusion got almost instantly accepted and overnight changed the standard view of the Universe. In a sense it was a classic example of Kuhnian scientific revolution.

▼ FIG. 2: Type Ia supernova SN2011fe is clearly visible as the bright, bluish star in the upper, right portion of spiral galaxy M101. The image was obtained on 18 September 2011 with the Mayall 4-meter telescope at Kitt Peak National Observatory. Image courtesy: T.A. Rector (University of Alaska Anchorage), H. Schweiker & S. Pakzad

Consequences

What is the harvest of this seminal discovery? Vast, and even superseding that of Brian Schmidt's Australian vineyard, despite the fine wines he produces. Dark energy appeared to the fore as dominant dynamical influence in the Universe. The acceleration implies that the age of the Universe is substantially higher than previously assumed and the present age estimate of 13.7 Gyr solves the stellar age problem completely. With the exception of a few remaining issues, the current concordant ΛCDM Universe model appears to agree with an amazingly large and ever growing range of astronomical observations. Nonetheless, the fate of the Universe looks bleak, our fate lonely. Long before it will reach a near empty Dark Era, some 10^{100} years in the future, we will have lost contact with all surrounding galaxies as the accelerated cosmic expansion will have moved them out of view: the end of Cosmology.

Inspired by the far-reaching ramifications of an accelerating Universe, a fast growing train of ever more extensive and costly research projects in astronomy, cosmology and physics is setting out to unravel the mystery of the dark energy. At the moment, not one of the hundreds of proposed theories has been able to unravel its nature. A large number of new profound questions have emerged, and a sense of thrill has taken hold of the astronomy and physics communities. The key to the dark lord of the world may very well be the key to our existence. It was in 1998 that the lock was detected, by the 2011 Nobel laureates. ■

About the Author

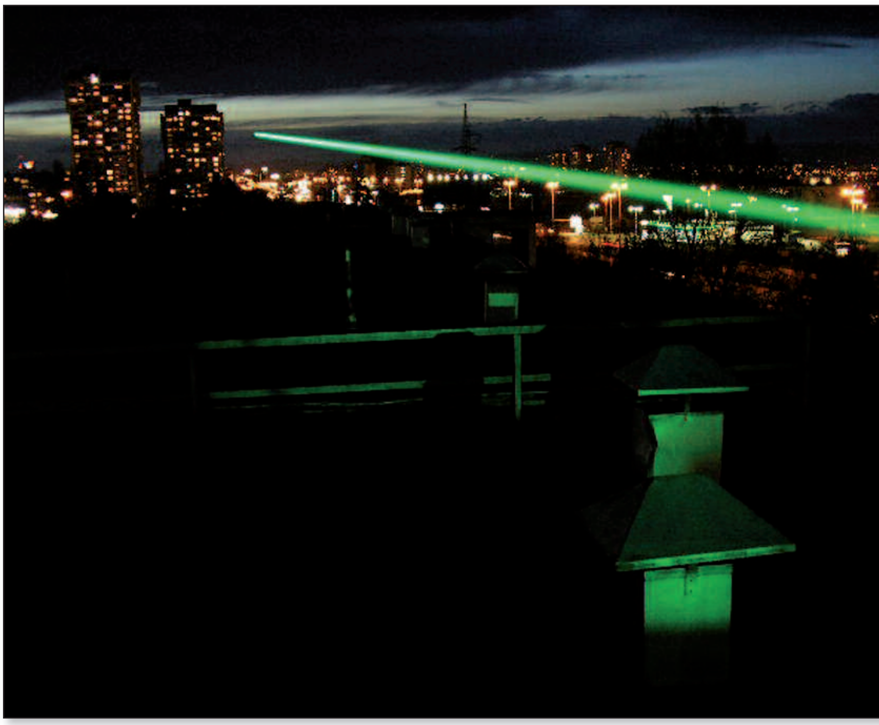
Rien van de Weygaert is professor of cosmological structure formation at the Kapteyn Astronomical Institute, University of Groningen. His research interests include cosmology, cosmological structure formation, the large scale galaxy distribution, computational geometry and topology and the history of astronomy.

Physics in the middle of the Balkans

■ Alexander G. Petrov, Nicholay S. Tonchev and Oleg I. Yordanov - DOI: 10.1051/epn/2011602

Half a century ago, the Bulgarian Physics community created the Union of the Physicists in Bulgaria (UPB), as in many other countries in that post war period. In this article we outline the history of Physics in Bulgaria, its current state and discuss its future place and perspectives within the Balkan region and in Europe.

If founded formally in 1971, UPB has a much longer and illustrious history. Twenty years after the liberation from the Ottoman rule, the physicists and mathematicians founded the Bulgarian Physical and Mathematical Society (BPMS, Sofia, March 29, 1898). Note that the secular education with limited mathematics came into the Bulgarian schools as late as in the 1830s-40s, the first Bulgarian high school starting in the early 1860s. The first higher education institution arrived as a pedagogical school in 1888 to become in 1904 the Sofia University (SU).
Facing more and more students and professionals beyond 1950, BPMS split (1971) into Bulgarian Physical Society and Bulgarian Mathematical Society. On November 25, 1989, two months after the fall of the Berlin wall, the Bulgarian Physical Society reorganized and became the Union of the Physicists in Bulgaria.
Independent of political vagaries, the presidents of UPB or previous organizations have always been outstanding physicists. In the difficult 1945-1950 period the president was Georgi Nadjakov, Fellow of the Bulgarian Academy of Sciences (FBAS), who had worked with both Marie Curie and Paul Langevin in the 20-ies. His discovery of the photo-electret state of matter led to the photocopier invention by Chester Carlson. One of the Institutes of the BAS bears Nadjakov's name. We can also cite Christo Christov, FBAS, president of BPS from 1971 to 1986, and Milko Borissov, FBAS (1986-1989). The first UPB president was Ivan Zlatev, until 1992, succeeded by Ivan Lalov who, during his term (1992-2001), served for a short period as Minister of the Bulgarian Ministry of Education, Science and Technologies. Matey Mateev, FBAS, succeeded him in 2001 until his sudden death in 2010. During Mateev's term as Minister of Education and Science in the early nineties, the first law organizing the democratic education was prepared and successfully passed by the Bulgarian Parliament. In the latest 7th Regular UPB Congress, held in April 2011, one of the authors of this article, A.G.Petrov, FBAS, was elected UPB President for the next three years term.



▲ **FIG. 1:** The high power CuBr-vapor laser beam over the skyline of Sofia during the 2005 laser show staged by the Union of Physicists in Bulgaria to celebrate the World Year of Physics. The laser is operating from the roof of the Institute of Electronics, Bulgarian Academy of Sciences.

Current state of Physics, Physics education in Bulgaria and UPB activities

Today, UPB has a membership of over 400, among 100 of whom active. The mission of UPB is to support and coordinate the activities of its members in fundamental and applied research, industry, medical physics, environmental protection, secondary and university education in physics and to popularize the achievements in physical sciences. With an annual budget of only 7500 €, the Union supports 16 regional branches in virtually all major Bulgarian cities. The funding comes from the Kozloduy nuclear power plant, Nuclear Regulation Agency of Bulgaria, Ministry of Education and Science and private companies. Majors in Physics are offered in 4 of the Bulgarian higher schools: Sofia (258 students), Plovdiv (157), Blagoevgrad (68) and Shumen (46) universities. The number of graduates in 2010, however, was only 185.

There were 40 PhDs the same year. In addition, chairs of Physics are established in all technical and medical schools, which brings the number of students exposed to some form of Physics education to 1539. Considering also the reduced share of Physics in the curriculum of the elementary and secondary schools, its current impact on society is unacceptable for the community. Our efforts are towards changing that.

The other troublesome issue is the extremely low funding for research and instruction. The 7 physics institutes of BAS together receive 3.89 M€ of state subsidy to which 2.2 M€ are added through various projects. The state subsidy for university physics is estimated to be 1.26 M€ plus 0.5 M€ from projects. This sums up to a miserable 7.85 M€ all together in 2010. The part of the GDP devoted to science in Bulgaria is not only the lowest in EU but also lower than in many third world countries. Bulgaria is the only European country that did not secure support for science from the EU structural funds. This unfortunate situation, discussed recently in Nature[1] was since further aggravated by the widespread mismanagement of the science funding by the government bureaucrats[2]. The low government funding for science results in a limited number of science-involved firms and to a negligible private funding for science. This vicious circle could be cut out either by a conceptually different government policy or by external pressure. The Bulgarian scientists fought back by mobilizing the international community: many colleagues, among them nine Nobel prize winners and six Fields medallists signed the petition in defence of the Bulgarian science, www.science.nauka2010.com Especially active in voicing their support was the European Physics Community to whom we extend our hearty gratitude.

UPB organizes or endorses a number of conferences in Bulgaria each year. One of the major events run by UPB is the Annual Spring National Conference on Physics Education. In its 3 days programme, it covers: up-to-date educational issues, methodology of teaching, classroom physics experiments and student presentations. Each conference has its own focus, for example, for the 39th this year, it was the 100th Anniversary of the Rutherford Model.

Reaching out to the Balkan region and to Europe.

UPB is one of the founders and active member of the Balkan Physical Union (BPU), created in 1985 as a non-profit organization without any governmental sponsorship. The aim is to promote collaborations and joint research projects between the countries in the Balkan region in all fields of Physical sciences. Many conferences, workshops and schools have been organized by the national physical societies of the Balkan countries under the banner of the BPU. The leading event is the General conference of the BPU, which, according to the BPU Constitution, is to convene every three years consecutively in different countries. The first was in Greece (1991). The 4th held in Bulgaria (2000) brought up 800 attendees presenting 750 oral or poster communication. The last took place in Greece in 2009: over 450 papers were published in a 1500 pages volume (No. 1203 of AIP Conference Proceedings). The next, 8th conference, will be in Romania (2012).

The collaboration between UPB and EPS sizably intensified during the last two decades and a lot more could and should be done. Two major EPS events took place in Bulgaria: the 23rd meeting of the European Group on Atomic Spectroscopy (2002) and the 36th EPS Conf. on Plasma Physics (2009) to which 558 colleagues (103 students) attended. The young Bulgarian physicists welcomed the 46 EPS grants provided between 2001 and 2007 to attend various European events. UPB participated to several EPS initiatives: the laser show of the 2005 Year of Physics and the European scientists' night in 2008, 2009 and 2010.

UPB publishes two Physics journals, the professional, peer reviewed, *Bulgarian Journal of Physics* (BJP, papers in English) and the more popular *World of Physics*. We take the present opportunity to invite members of EPS to submit contributions to BJP in all branches of Physics. ■

About the Authors

Professor Alexander G. Petrov, PhD(1974), DSc(1987), FBAS, is Director of the Institute of Solid State Physics (ISSP) at the Bulgarian Academy of Sciences (BAS) and President of UPB. He has authored over 175 papers and a monograph, *The Lyotropic State of Matter*, Gordon and Breach, NJ-L (1999). He is a recipient of the Freedericksz Medal of the Russian Liquid Crystal Society (2005) and of the Prize for Outstanding Contribution to Science in Bulgaria (2007).

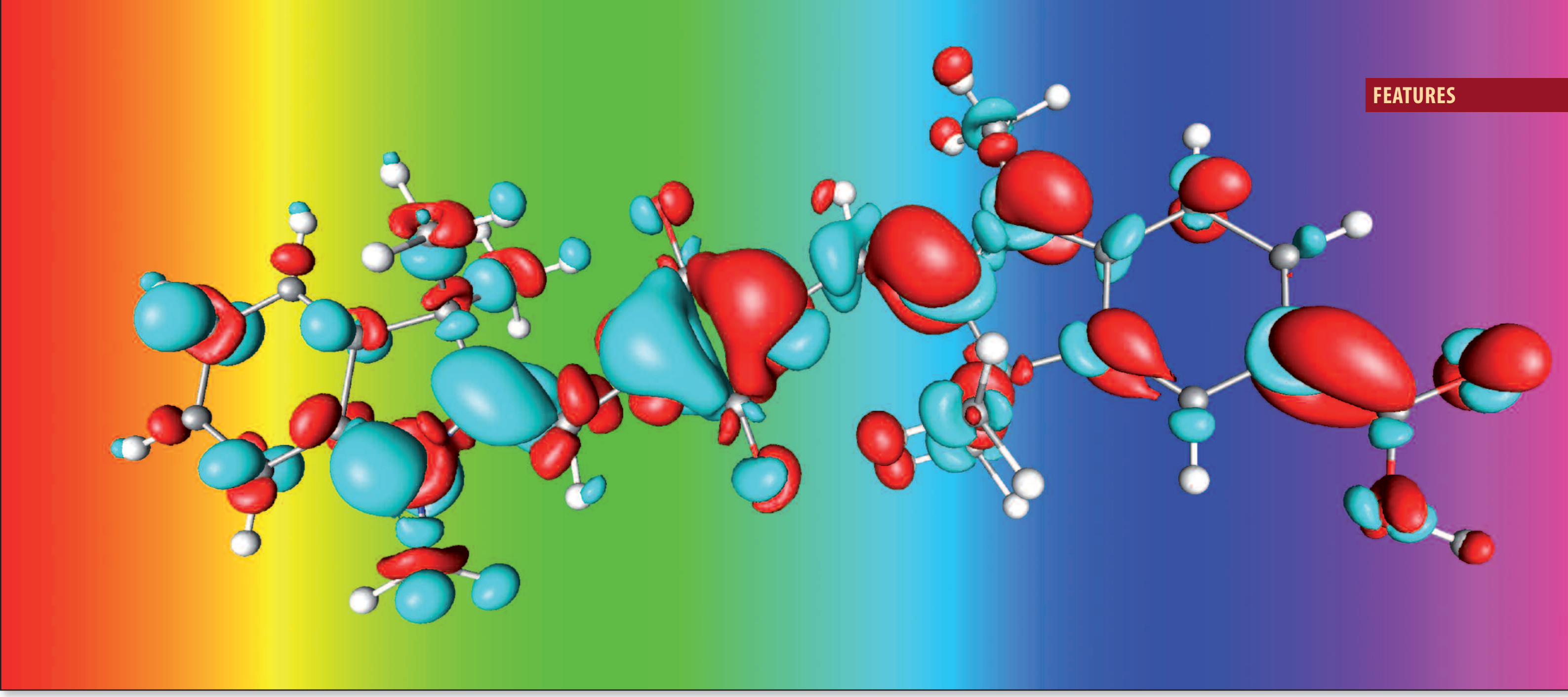
Professor Nicholai S. Tonchev, PhD (1976), DSc (1986) is Chairman of the Scientific Council of ISSP at BAS. He has authored over 100 papers and is a co-author of two monographs: "The Approximating Hamiltonian Method in Statistical Physics" (in Russian), Publ. House of BAS, Sofia (1981) and "Theory of Critical Phenomena in Finite-Size Systems; Scaling and Quantum Effects", World Scientific (2000). He is Editor-in-Chief of the Bulgarian Journal of Physics and Scientific Secretary of the BPU.

Dr. Oleg I. Yordanov is Head of the Laboratory of Microwave Physics and Technologies, Institute of Electronics, BAS. His MSs (1977, SU) was in field of Mathematical Physics; his PhD thesis (1991, BAS) was on scattering of EM waves from rough surfaces. He is an Editor of the *World of Physics*.

NOTES

[1] A. Abbott, Science fortunes of Balkan neighbors diverge, *Nature* **469**, 142 (2011)

[2] A. Abbott, Bulgarian funding agency accused of poor practice, *Nature* **472**, 19, (2011)



▲ Excited state of a dye molecule

Sustainable energy:
How quantum chemistry can help

■ Ralph Gebauer – The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy – DOI: 10.1051/epn/2011603

Computer simulations of electronic and structural properties can give detailed insight into atomic-scale processes in functional materials. Such studies play an important role in the quest for better strategies to harvest and store renewable energy.

One of the biggest challenges for science and engineering today is the global energy crisis. According to BP's 2011 Statistical Review of World Energy [1], the worldwide primary energy consumption in 2010 was 503 × 10^{18} J, which corresponds to an average energy consumption rate of 16 terawatt (TW). Most of this energy is obtained from fossil fuels, with roughly equal parts of oil, coal, and natural gas. Rapid growth of the global population and per capita energy consumption will lead to a considerable projected increase in energy consumption during the next decades. Under moderate assumptions the world energy consumption rate can be forecast to roughly 28 TW in 2050 [2]. Such an increase of the projected energy consumption is in stark contrast with the diminishing availability of affordable fossil fuels. The drastic increase of oil and coal prices in recent years show that the current consumption rate of fossil fuels is pushing the possible extraction rates to its limits. Moreover, the menace of climate change due to the ever-increasing levels of CO_2 in the atmosphere calls for a drastic reduction in our use of fossil fuels.

Renewable Energy

One possible way to address this looming energy crisis is by greatly increasing the use of renewable energy sources like wind, hydro or solar energy. Amongst all those sustainable energy sources, by far the largest resource is the sun. In one hour, about 430 × 10^{18} J of solar energy strike the earth, a quantity which is comparable to all the energy which the world is currently consuming in one year. In spite of such a great potential, only a very small fraction of today's energy is provided by the sun, mostly in the form of fuels from biomass. Two main reasons for the low utilization of the sun's potential are the prohibitively large cost of current photovoltaic technologies and the intermittent nature of sunshine.

The issue of the high cost of photovoltaic electricity is generally recognized as a major hurdle for the widespread use of this technology. Traditional photovoltaic panels are usually based on silicon p-n junctions or on thin films of CdTe, a semiconductor. Such panels have seen a strong reduction in price in recent years, mainly due to mass production and the availability of large quantities of pure silicon as raw material. In spite of such progress, the adaptation of this ▶

technology is still dependent on public subsidies like guaranteed feed-in tariffs for renewable electricity.

The issue of intermittency is less publicly discussed, but is equally important. If renewable energy sources are to provide a considerable fraction of the world's energy, then they must be available whenever demand is high. This necessity leads to the requirement of affordable energy storage. For many applications like transport, such storage should also provide a high volumetric and gravitational energy density.

Computational modeling

All these challenges related to the conversion and storage of energy are currently the focus of many research efforts around the world. The interdisciplinary nature of the issues calls for strong collaboration among experts from diverse fields of science: basic physics to biology, chemistry, materials science and engineering.

Amongst these fields, chemistry holds the center stage, since progress in the development of a new device must be accompanied by the design and synthesis of corresponding functional materials. But within the field of chemistry itself, collaborations between theorists and experimentalists are crucial for the successful development of such materials. For example, computer simulations of the atomistic and electronic structure of a new compound can lead to a clearer understanding of the key processes which underlie the functioning of a device. Insight on the atomic scale is therefore the first step to a targeted improvement of materials.

Photovoltaics

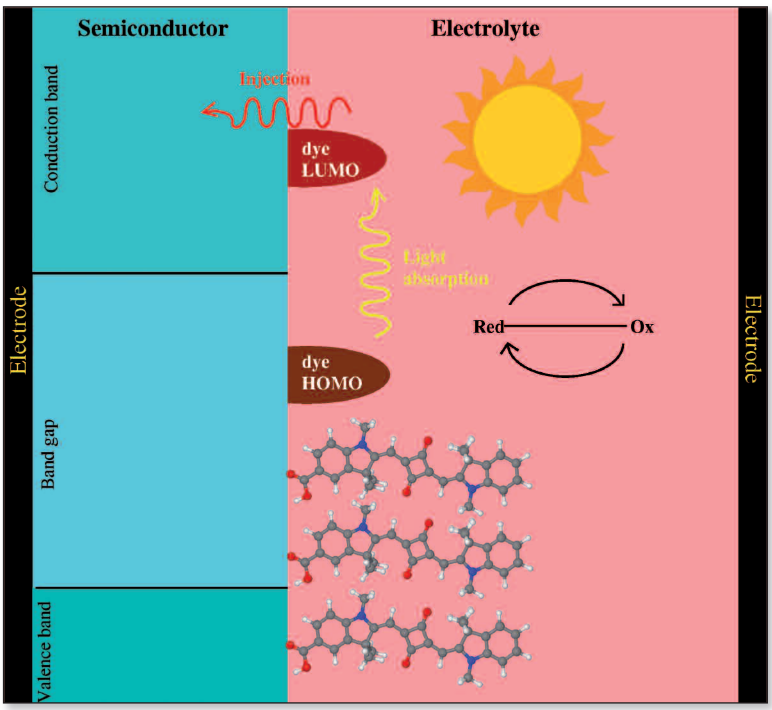
An area where research has led to strong progress recently is the field of so-called dye-sensitized solar cells (DSSCs). A DSSC captures light using dye molecules that strongly absorb in the visible frequency range. These dye molecules are attached to the surface of a wide-bandgap semiconductor (often TiO_2). In contrast to traditional solar cells, where the light absorption happens inside the semiconductor, the wide-bandgap material in a DSSC cannot directly harvest solar photons. Instead, the dye molecules act like antennas that capture the sunlight. Following photo-absorption, the excited electron is quickly transferred to the conduction band of the semiconductor from where it is led to an electrode. The hole that the electron leaves behind on the dye molecule is filled from an electrolyte surrounding the semiconductor. The electrolyte is in contact with a second electrode used to close the electrical circuit. This design of a DSSC is depicted schematically in Fig. 1.

Such "third generation" photovoltaic devices do not require ultra-pure, defect-free materials that are expensive to obtain. Dye molecules and the DSSCs can be produced using traditional "wet chemistry" methods. The prospect of low-cost production methods and abundant raw materials are the attractive features of third generation devices. Moreover, efficiencies of up to 11% have been reported for DSSCs. Nevertheless, much research is still needed to improve this technology and make it a viable alternative to standard solar cells.

Theoretical modeling can intervene at various levels in DSSCs. Firstly, the optical absorption properties of the dye molecules themselves can be computed. Theoretical spectroscopy has always been a core discipline of quantum chemistry. When new dye molecules are considered, preliminary quantum chemical studies can help identify promising candidate molecules. While the synthesis of a new dye can take several months and require well-equipped laboratories, a theoretical spectrum can be obtained within hours, long before the molecule in question has even been produced. In other cases, researchers might consider various ligands to enhance the optical properties of a given molecule. Also in those cases, the availability of computed absorption spectra can guide the choice of ligands.

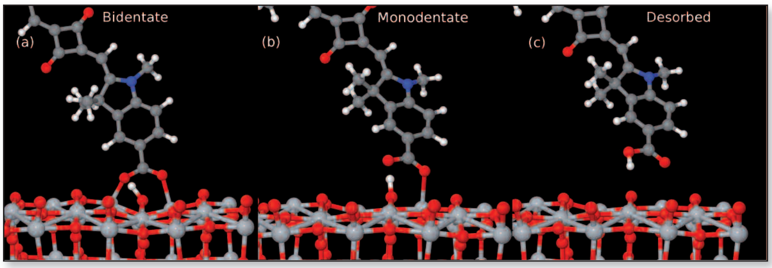
A second area of theoretical interest is the interaction of the dye molecules with the surface atomic structure. Molecular dynamics simulations can reveal the preferred adsorption sites of molecules and give information about the stability of alternative adsorption geometries. The presence of a liquid electrolyte further complicates the situation. Computer simulations can shed light on the role of the electrolyte in the stability of surface structures and dye adsorption. In Fig. 2 an example is shown where the interaction with liquid water leads to the desorption of a dye from a TiO_2 surface [3].

Particular theoretical focus has been drawn to the injection of the excited electron from the dye into the conduction band manifold of the semiconductor. The time scale of this process is a very important factor determining the



▼ FIG. 1: Schematic representation of a dye-sensitized solar cell. Solar illumination creates an electronic excitation in dye molecules which are attached to the surface of a wide-bandgap semiconductor. A typical excitation might be from the dye's highest occupied molecular orbital (HOMO) to its lowest unoccupied molecular orbital (LUMO). The excited electron is subsequently injected into the conduction band manifold of the semiconductor. A hole-conducting electrolyte is used to restore charge neutrality on the dye and make contact with the second electrode.

efficiency of the device: if the injection process is slow, the excited electron can de-excite radiatively or thermally towards its ground state and the corresponding energy is lost. Quantum mechanical computations have shown that in some systems the interaction between the excited state on the dye and the semiconductor is strong enough so that the electron injection can occur in a few femtoseconds. This is much faster than typical atomic vibrations, which might lead to alternative de-excitation mechanisms. Moreover, in this case, theoretical insight into the factors determining the injection time can lead to a more targeted choice of surface - dye couples [4].



▲ **FIG. 2:** Snapshots from a molecular dynamics simulation of the desorption of a dye molecule from a TiO_2 semiconductor surface. Panel **(a)**: Initially the dye molecule is attached to the surface. The dye is deprotonated, and the proton (white ball) is attached to a surface oxygen atom (red ball). Panel **(b)**: One of the dye's bonds to the surface is weakened, which leads to the transfer of the surface proton to the molecule and finally to the detachment of the molecule from the surface, see panel **(c)**. The surrounding electrolyte molecules are not shown for clarity.

Energy storage

One possibility to store the energy of intermittent renewable sources is to convert the energy into chemical bonds. Using CO_2 and water as raw materials, an artificial photosynthetic system might produce hydrocarbons that can be easily stored and transported. Various routes to such a system are currently examined. The approaches range from genetically modified forms of algae or bacteria up to electro-catalytic systems where (renewable) electricity is used to produce chemical fuels. One important step in such catalytic processes is the oxidation of water to produce the electrons and protons needed to reduce CO_2 to a fuel, as shown schematically in Fig. 3.

The oxidation of water leading to the formation of one oxygen molecule involves four electrons. An efficient catalyst to drive this electrochemical reaction should be such that each one of the four distinct electron transfer steps occurs at nearly the same cost of energy. This is a rather demanding requirement since each step involves chemical species with very distinct oxidation states. Interestingly, nature has managed to satisfy this requirement nearly perfectly in the oxygen-evolving complex of photosystem II [5]. Man-made catalysts, however, suffer from the necessity to apply so-called over-potentials that reduce the efficiency of the water splitting [6].

Quantum chemical simulations can shed light on the involved energy levels and how they depend on the molecular geometry of the catalyst. Theoretical electrocatalytic studies allow exchanging ligands or varying the chemical environment in a controlled manner. Computer simulations can therefore not only lead to a clearer picture of the functioning of a catalyst at the atomic scale, but they can also lead to suggestions on how to improve efficiencies.

Conclusion

Developing an affordable and reliable energy infrastructure for the future is a formidable task. In spite of the abundant availability of sustainable energy in the form of sunlight, a large-scale switch to solar energy is still hindered by high costs of current technologies and the difficulty to store intermittent electrical energy. Progress in these areas can be made possible by bringing together expertise from various fields. In particular, theoretical modelling at the atomic scale is a useful tool for a better understanding of the elementary processes and can lead to a guided development of new materials. ■

About the author:

Ralph Gebauer studied physics in Karlsruhe and Lyon. He obtained his PhD from the Ecole Normale Supérieure de Lyon in 1999. After two years as a postdoc at Princeton University, he joined the Abdus Salam International Centre for Theoretical Physics in Trieste in 2002 where he is working as a research scientist in the Statistical Physics and Condensed Matter Section. His research interests lie in atomistic simulations using density-functional theory as well as in computational spectroscopy.

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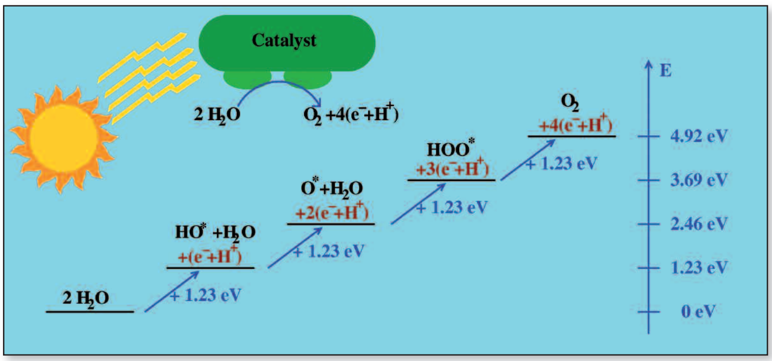
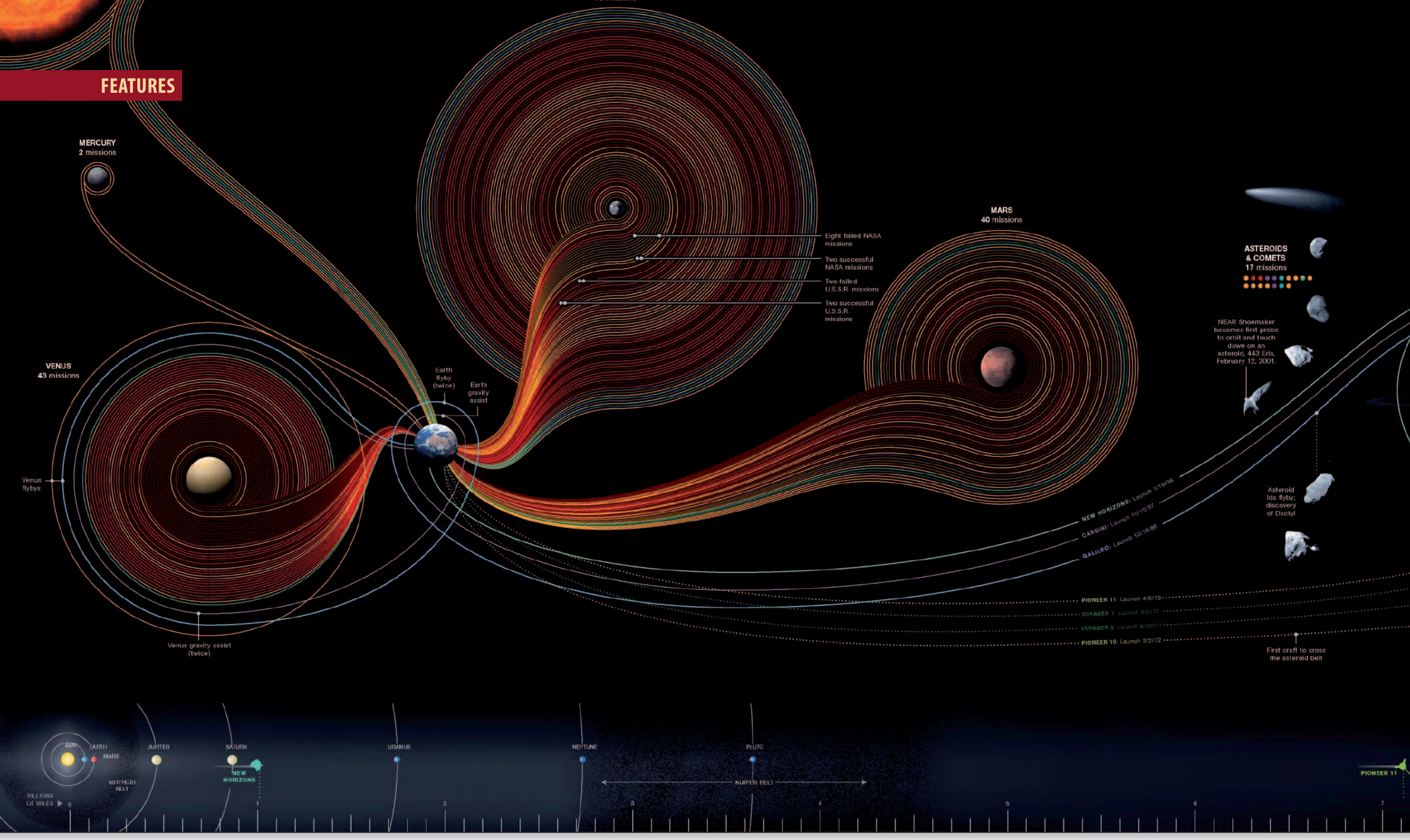
▼ **FIG. 3:** The oxidation of water is an essential step for the storage of energy in form of chemical fuels. This process involves four distinct electron transfer processes. An ideal catalyst should be able to perform each of these steps at the same cost of energy, as schematically depicted below.





▲ Image created by graphic designers Sean McNaughton and Samuel Velasco for National Geographic.

Space Exploration Technologies

PEGASES a new promising electric propulsion concept

■ Ane Aanesland[1], Stéphane Mazouffre[2], Pascal Chabert[1] – DOI: 10.1051/epn/2011604

■ [1] Laboratoire de Physique des Plasmas (LPP), CNRS - Ecole Polytechnique, France – ane.aanesland@lpp.polytechnique.fr

■ [2] Institut de Combustion Aérothermique Réactivité et Environnement, CNRS, France

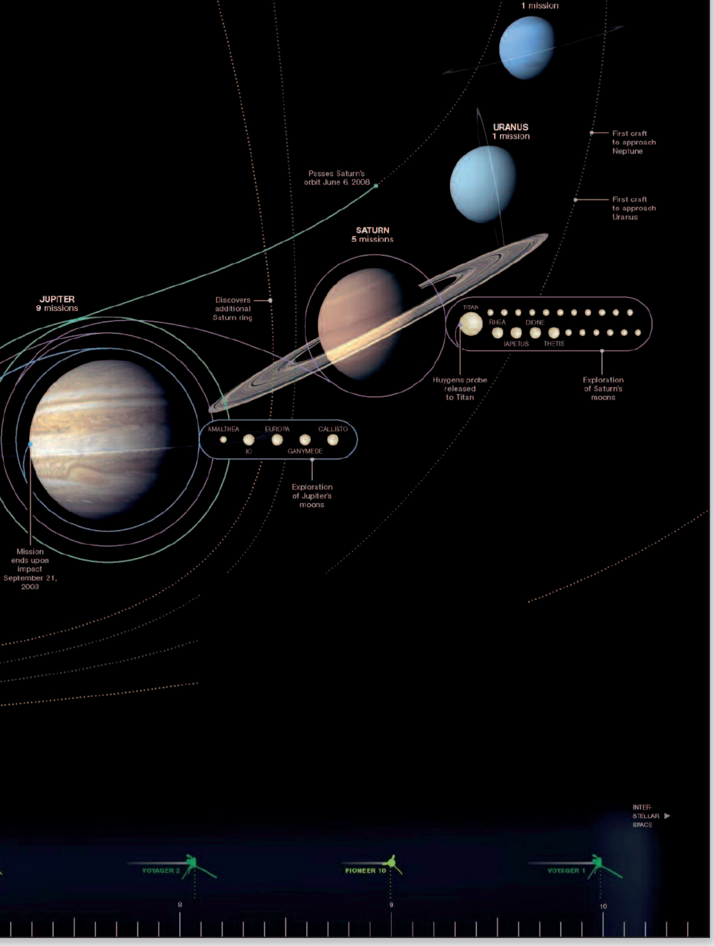
Space represents a unique vantage point for both exploring the universe and looking down onto our own planet, enabling major discoveries with regard to our origins and the environment we live in. To observe, communicate and explore, we need technologies that can control our movement in space. This article will give a short introduction into spacecraft propulsion and present a new promising electric propulsion technology.

Above is an artistic illustration of all the space missions carried out since the 1950s, and it shows our relatively short history in exploration and observation from space. We have done more than 70 missions to the moon, 9 to the sun, 40 missions to Mars, and several other missions to the far- reaching planets and their moons. Pioneer, launched in the 70s, was the first human- made spacecraft to cross the asteroid belt, and Voyager the first spacecraft to approach Uranus and Neptune. Voyager is now in the interstellar space (beyond the boundary of our Solar System), and more than 30 years after its launch it still transmits data back to earth.

How to move in space?

To allow exploration and observation in space, we need a control of the spacecraft position in space. On earth, friction and gravitation forces help us moving. In space these forces are negligible or non-existing: So how do objects move by pushing on nothing?

Isaac Newton gave the answer as early as in 1687 when he published the laws of motion, where the third law states that every action has an equal and opposite reaction. The Russian physicist Konstantin E. Tsiolkovsky (1857-1935) was one of the early pioneers in space rocketry and used Newton's laws to derive what we now refer to as the rocket equation:



$$T = m\frac{dv}{dt} = -\frac{dm}{dt}v_g$$

It shows that the force T (called thrust in the space community) acting on the spacecraft equals the rate of change of the spacecraft mass (dm/dt) times the velocity v_g of the ejected particles (v is the spacecraft speed).
The delivered thrust is one of the major performance values used to classify a thruster concept. There are many different ways to generate thrust. For example, a rocket uses a chemical reaction or combustion to give a large transfer of momentum to the propellant; the propellant then passes through a nozzle to accelerate the fluid to high velocities. A lot of mass is ejected during a very short period of time and even if the velocity of the ejected particles is not very high, the thrust values can reach up to hundreds of Mega-Newton. To escape earth, the thrust created by the propulsion system has to be bigger than the weight of the escaping body. Chemical propulsion, with its enormous thrust, is therefore very suitable for launching objects into space and is so far the only method to leave the Earth's gravitation field.

Specific Impulse and Propellant consumption

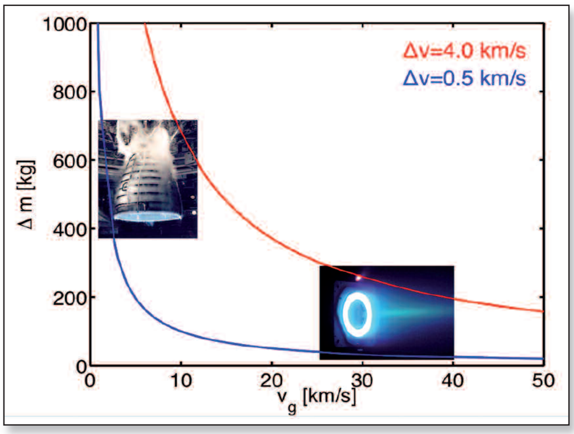
By integrating the rocket equation, we can find an expression for the required amount of propellant Δm, which also corresponds to the change in the spacecraft mass, as a function of the propellant velocity v_g. Figure 1 shows that high v_g leads to a strong reduction in the use of propellant. A thruster is therefore also evaluated depending on its propellant velocity, which in the space propulsion community is defined as the thruster's Specific Impulse $I_{sp} = v_g/g_0$, where g_0 is the gravitation at sea-level. The higher the I_{sp} the more propellant efficient is the system.

Chemical versus Electrical propulsion

Electric propulsion (or plasma propulsion) offers very high v_g. Contrary to chemical propulsion the amount of ejected propellant is low. As a result, only low thrust values can be achieved. Typically, current electric propulsion systems offer an I_{sp} of around 3000 seconds and a thrust of a few hundreds of milliNewton, in comparison to chemical propulsion systems that have typically an I_{sp} of less than 400 seconds but thrust values that can vary from 10 Newton to several Mega-Newton. If we take the example of an interplanetary mission that will need a velocity change Δv of 0.5 km/s (figure 1), to achieve the same maneuver one could go from a propellant mass of around 300-400 kg to only 25 kg by choosing electric rather than chemical propulsion. Yet, the duration to achieve the maneuver is very different due to the thrust level. Launchers (huge rockets using chemical propulsion) are used to get a spacecraft up into space. In Europe, Ariane V is one of the biggest and most powerful on the market and can for example bring two satellites of around 2-5 ton into space. To use this launcher costs about 14000 euro per kg that are brought up to GEO orbit [1]. The 300 kg saved in using electric propulsion would correspond to a budget reduction of 4 million-euro.
One would therefore expect that all spacecrafts or space probes would be driven by electric propulsion when they are in space. The first mission that used electric propulsion as a unique propulsion system was launched in 1989 with the Deep Space I program. This mission was very successful and showed its huge potential. Despite this fact, only a few percent of the space probes, commercial and military satellites, use electric propulsion today. WHY?
One of the reasons is due to "political inertia": The decision makers in charge of the mission are not ready to take the risk of using new technology, as it might not work and therefore jeopardize the whole mission. Another more fundamental reason will be clarified below.

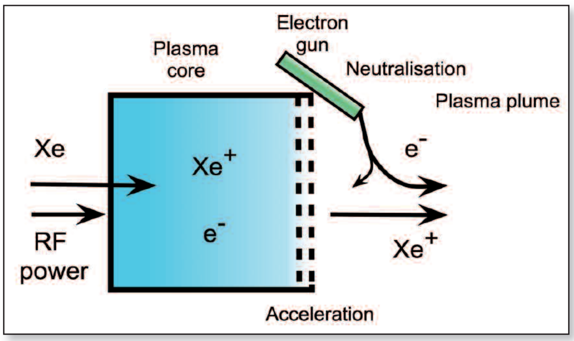
Principle of electric propulsion

Existing technologies for electric propulsion, illustrated in figure 2, uses electrostatic or electromagnetic fields to accelerate a beam of positively charged ions to generate thrust



◀ **FIG. 1:** Total propellant needed during a mission as a function of the ejected particle velocity. The example is given for a spacecraft with an initial mass of 2 ton. Δv is the total velocity change required for a certain mission; 4 km/s is required to change from Low earth orbits (LEO) to Geostationary orbits (GEO), while 0.5 km/s is more suitable for interplanetary missions.

▶ FIG. 2: Illustration of the existing electric propulsion concepts. High-density plasma is created, in which positive ions are accelerated and neutralized by electrons downstream of the acceleration stage. Usually Xenon is used, as it is heavy and therefore good for thrust and does not require much energy for ionization.



[2]. The ions are accelerated from a *high-density plasma*, consisting of positive ions, electrons and few neutrals. To ensure an efficient use of the propellant most of the ejected particles should be ions (and not neutrals).

In space, when a positive beam of ions leaves the thruster, the space vessel would charge negatively. This would lead to a charge separation and therefore an electric field that would cancel the acceleration field. To avoid this charge separation, the positive ion beam needs to be neutralized downstream of the acceleration stage. This is normally done by an electron gun feeding electrons into the positive stream. As a result a quasi-neutral beam leaves the thruster and provide thrust.

Two weak points in existing technologies

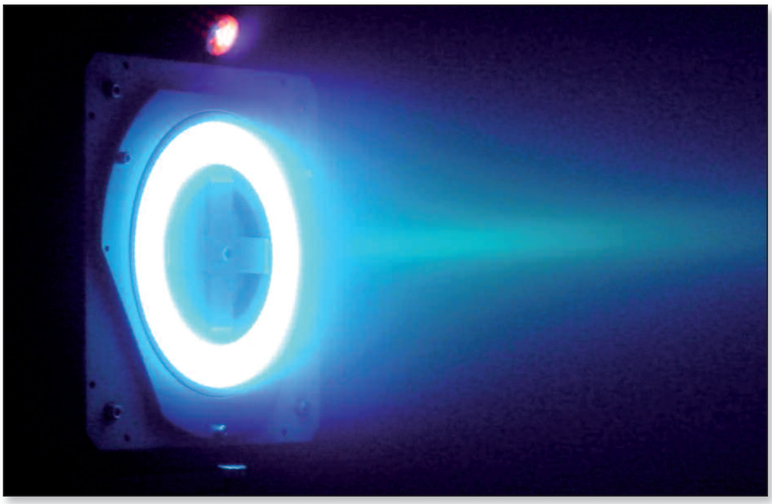
The lifetime and stability of the electron gun are very often critical, and might limit the lifetime of the thruster at high power operations. Much effort is put into improving these issues, and the evolution of the hollow cathode (the most advanced electron gun on the market) is improving rapidly.

The plasma plume outside the thruster, visible on figure 3, causes another more fundamental problem: The fast ions leaving the thruster have typically a speed around 20-40 km/s or larger. They escape from the spacecraft immediately. But some of these fast ions collide with the ejected neutrals before they escape, and in this collision they can exchange the charge. As a result a fast neutral escapes the thruster and a slow ion remains in the surrounding of the thruster. The plasma plume contains therefore the accelerated ions and neutrals from the thruster, the electrons ejected for neutralization, and the slow ions generated in the plume.

These slow ions can cause damage to the satellite/spacecraft. Since the spacecraft is typically not an equipotential surface these ions can backscatter which results in sputtering of the thruster itself, the solar panels and other external surfaces of the spacecraft.

This ion backscattering problem is probably the most reasonable argument for why electric propulsion is still not used excessively in the space industry. However, up to now there has been no mission failure due to ion-spacecraft interactions.

▼ FIG. 3: A picture of the PPSX®000-ML Hall-effect thruster operating in a test facility at the ICARE institute. The glowing plasma plume is beautiful, yet it can cause problems due to the slow ions backscattering towards the spacecraft. The electron gun is the red-glowing element on top of the thruster core.



PEGASES – a new promising concept for electric propulsion

With this in mind, we propose a new concept for electric propulsion [3-5]. This concept is called PEGASES and is an acronym for Plasma propulsion with Electronegative GASES. The concept is illustrated on figure 4.

Instead of accelerating only positive ions to provide thrust and use negatively charged electrons for neutralization downstream, in the PEGASES thruster both positively and negatively charged ions are accelerated and provide thrust. In this way the additional neutralization system is redundant and the issue related to the plasma plume is reduced. The PEGASES thruster operation can be separated into 3 stages:

Stage 1 is the ionization stage occurring in the plasma core (see figure 4). Here the external power is coupled to the electrons such that they get sufficient energy to ionize the gas and form the plasma. To be able to create both positively and negatively charged ions, the gas has to be electronegative. This means that the gas molecules have a high electron affinity and allow electrons to attach to the molecules, creating negatively charged ions. Electron attachment occurs when electrons of low energy collide with the neutral molecules. In contrast, if the electrons are more energetic the electron-molecule collision results in ionization. Electronegative gases are typically molecular gases containing halogens such as fluorine (F), chlorine (Cl), bromine (Br) or iodine (I).

Stage 2 is the electron filtering stage. Charged particles gyrate around magnetic field lines due to the Lorenz force. Since the electrons are much lighter than heavy ions, a magnetic field can be used to confine the electrons in the plasma core, but allow the ions (of opposite charge) to diffuse perpendicular to the field. The electrons can only move perpendicular to the field by collisions, and are therefore cooled down when diffusing in this direction. These colder electrons attach efficiently to neutrals forming negative

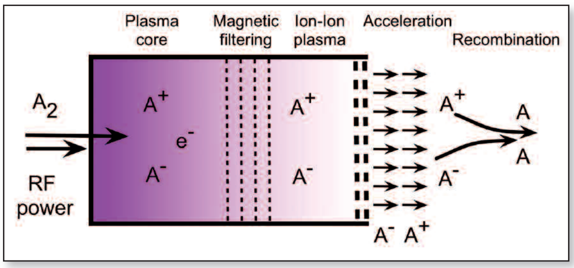
ions. As a result the plasma in the PEGASES thruster is segregated into two regions, i) a plasma core comprising positive and negative ions and electrons and ii) an ion-ion plasma region comprising only positive and negative ions. The ion-ion plasma is a new type of plasma, and currently much research is done on the fundamental physics of these plasmas. The ion-ion region is the heart of the PEGASES thruster and is a distinctive feature of this new concept.
Stage 3 is the acceleration stage. Due to the formation of the ion-ion plasma it is possible to accelerate both types of ions for thrust. The acceleration is obtained, similar to classical gridded thrusters, by two or more parallel grids polarized to generate an acceleration field between them. In the PEGASES thruster, one of the grids is alternately biased, changing alternately the acceleration field. As a result consecutive bursts of positive and negative ions are extracted and accelerated out of the thruster, and both the positive and negative charges provide thrust.

The PEGASES advantages

Since both positive and negative ions leave the thruster, there is no need for an additional neutralization system. This is a promising advantage for this innovative concept, but it is not the only advantage and probably not the most important one. As discussed above, with the current technologies a fraction of the plasma plume interacts with the spacecraft components. This plume exists because the recombination process between electrons and ions to form a neutral atom or molecule is a slow process, in particular between the fast ions and the neutralizing electrons. In the PEGASES thruster the only expelled charges are heavy ions, and their recombination process is often much faster than between electrons and ions. The plasma plume outside the PEGASES thruster will therefore transform quickly into a beam of fast neutrals with a significant reduction in the charge density. Remember that the problem with the plume is the creation of slow ions from collisions with neutrals. If the density of charged particles is reduced, also the production of slow ions will be significantly reduced and hence the backscattering problems will be solved.

Current state of the PEGASES development

The PEGASES concept was invented and patented at the Ecole Polytechnique in 2007 [3]. Since then a research team, comprising permanent researchers, post doctoral fellows, PhD students and engineers, have worked ambitiously towards a proof of concept [4,5]. Several prototypes for laboratory tests have been designed and built, and the results are promising for the future. The most recent prototype can be seen on figure 5. The estimated performances of power, mass and thrust efficiencies are comparable to the existing electric propulsion systems. The team aims to measure the thrust within the following year, and these results will show if PEGASES one day will fly in space. ■



◀ **FIG. 4:** Illustration of the innovative PEGASES concept, where both positive and negative ions are accelerated and used for thrust generation.

About the authors

Ane Aanesland, researcher at the CNRS, and in charge of the PEGASES project. PhD from the University of Tromsø, Norway, in 2004, and received a Marie Curie Intra European Fellowship in 2006. She was the EPS invited speaker at the ESCAMPIG in 2010.
Stéphane Mazouffre, researcher at the CNRS and head of the Electric Propulsion team at the ICARE institute. PhD from the Eindhoven University of Technology, The Netherlands, in 2001. He received the bronze medal of the CNRS in 2008.
Pascal Chabert, research director at the CNRS and head of the group Plasma Froid at the LPP laboratory. PhD from the University of Orsay, France, in 1999. He received the 2007 IUPAP Young Scientist Prize in Plasma Physics, and is the author of the textbook Physics of Radiofrequency Plasmas.

Acknowledgement

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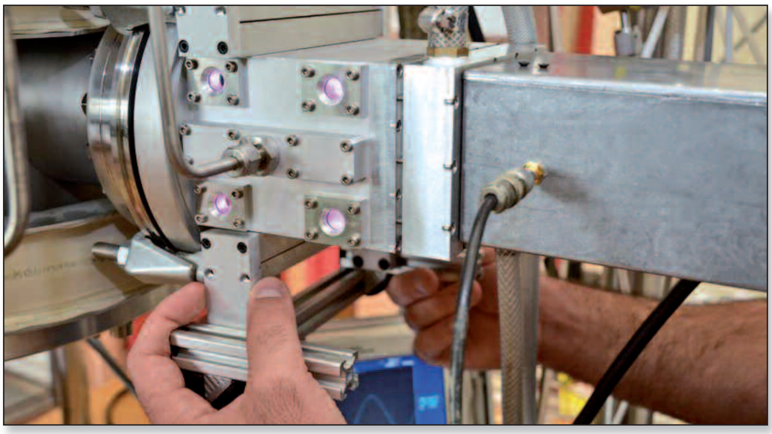
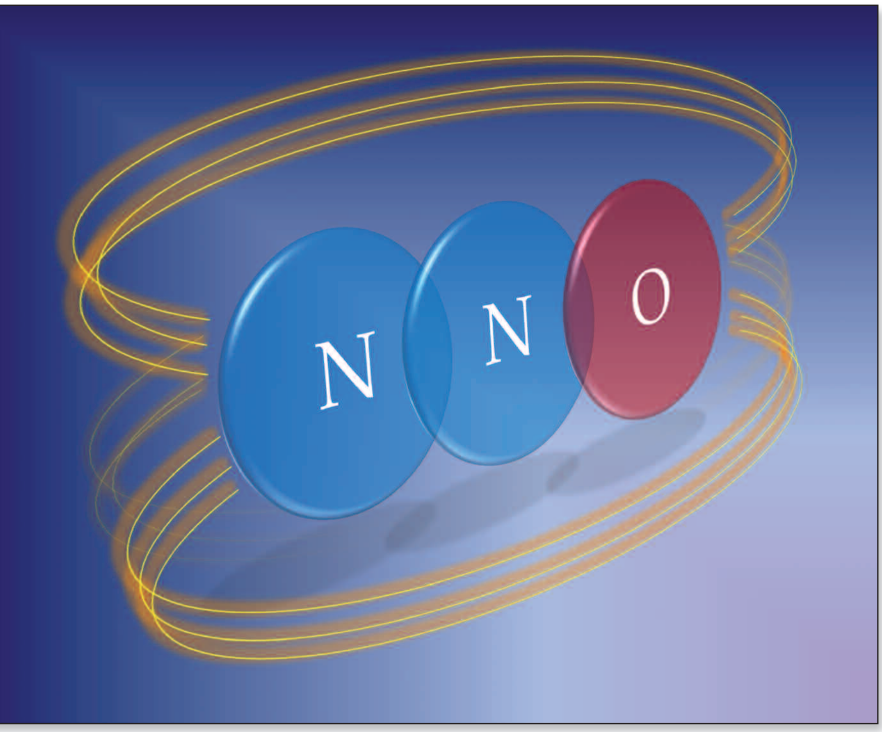
▼ **FIG. 5:** The PEGASES prototype, attached to a lager vacuum chamber in the LPP laboratory. Here the permanent magnets are positioned for optimal performance. Photo: P. Lavialle, Ecole Polytechnique.



A new class of spontaneously polarized materials



■ David Field, Oksana Plekan, Andrew Cassidy, Richard Balog and Nykola Jones
■ Department of Physics and Astronomy (IFA) and Institute for Storage Ring Facilities (ISA)
■ University of Aarhus, Aarhus 8000 C, Denmark
■ DOI: 10.1051/epn/2011605

Very large electric fields form spontaneously within films of seemingly prosaic chemicals such as nitrous oxide or propane. We describe how the discovery of this unexpected phenomenon took place and how we attempt to understand the nature of the new class of spontaneously polarized materials, resembling ferroelectrics, which these observations herald.

Materials have been a defining feature of the evolution of human culture and the electrical properties of materials are now at the forefront of this evolution. Advances occur both through the discovery of new electrical characteristics and through new devices based upon these discoveries. Here we describe a hitherto unsuspected electrical property of materials.

We have recently found that solid thin films of many common or garden molecules harbour very large electric fields [1]. These fields are a property of the film and appear spontaneously when films of species such as nitrous oxide or isoprene are laid down on a substrate. The fields point in a direction perpendicular to the surface and may exceed 10^8 V/m. The films can be as thin as ten monolayers for large electric fields to be established.

This new class of ferroelectric-like materials are of the order-disorder type, as opposed to displacive ferroelectrics such as the class of perovskites [2], in which fields are generated through small displacements of lattice atoms from their positions in the non-ferroelectric phase. We are hesitant to name the present films simply 'ferroelectric' since, while they satisfy the requirement that they harbour spontaneous macroscopic electric fields, we have not shown that these fields can be reversed by application of an external field. Note also that the films which we describe are not 'electrets', which possess a fixed charge or ordered dipole orientation induced by charge injection or an externally imposed electrostatic field.

The experimental method

The peculiar nature of films described below makes itself felt by the spontaneous appearance of a voltage on the surface. The experimental challenge is to measure this voltage without perturbing it significantly. The electric field within the film is then given by the measured voltage divided by the film thickness.

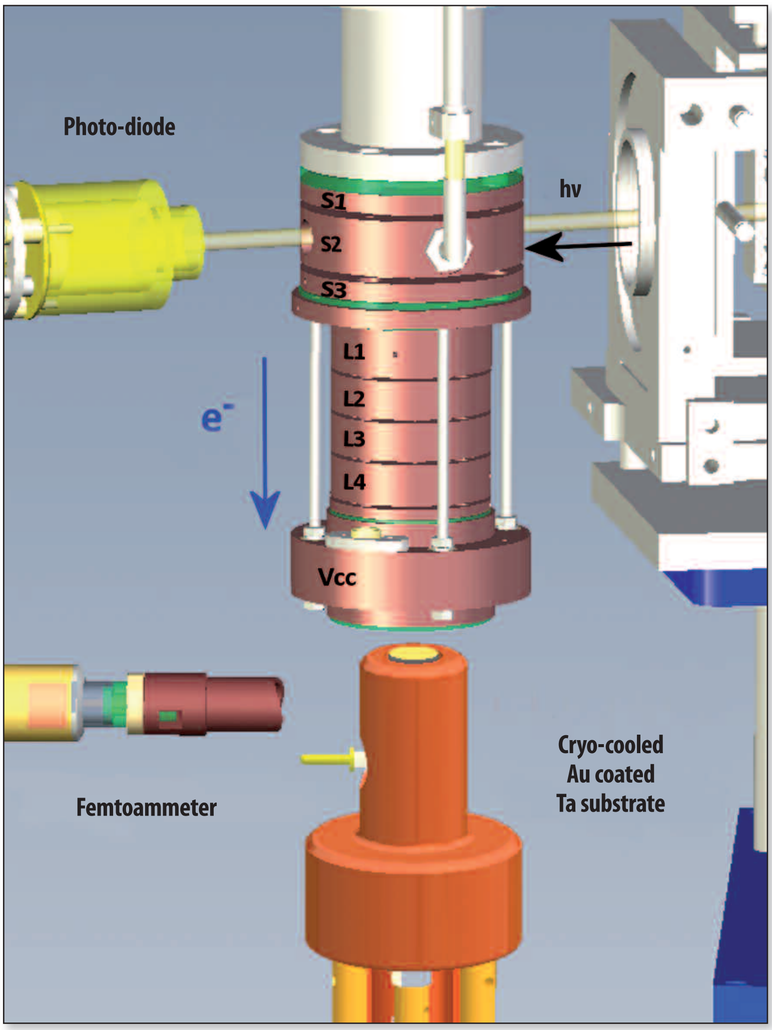
In our experiment this is achieved as follows. A beam of low energy electrons, formed by synchrotron radiation photoionization of Ar, travelling through vacuum at energies down to two to three meV with an energy resolution of 1.5 meV, is directed onto a film surface (figure 1). Electrons are formed at a nominal zero potential with an energy of a few meV and should therefore just be able to reach a target when the target is itself at a nominal zero. If the target were not at zero but rather, say, at +5 volts due to a spontaneous formation of an electric field within the film, then in order to ensure that the electrons only just reach the target it would be necessary to bias the target 5 volts negative. Measurement of the bias required to locate the onset of a measureable current, that is, 1 to 2 femtoamps, therefore gives the potential on the surface of the film, some small corrections apart. The necessary bias is measured by connecting a highly sensitive ammeter (a 'femtoammeter': figure 1) to the gold substrate on which films are laid down.

Ευρηκα

Our discovery of the electrical properties of our films was serendipitous. We had chosen to observe electron scattering at very low energy in a 40K film of N_2O, a molecule selected since it is one of the basic molecules of chemistry in the natural world. We found that a current was detected at the femtoammeter which remained a large proportion of the incident current when the film voltage was set equal to zero, the nominal potential at which the electrons were formed (see Figure 1). A negative bias was applied to the sample to attempt to reduce this current to zero. We discovered that we needed to apply more than 2 volts to achieve this. The apparatus was designed to measure millivolt shifts in order to record negative charging of the target due to electron capture in the film, as for example in water ice [3]. Here we required a bias of >2V and in the wrong sense, that is, negative rather than positive. Hence our surprise.

Our first thought was that our experimental apparatus was malfunctioning and was recording a leakage current through imperfect insulation to ground. A few simple tests showed that this was not the case; for example we found that increasing the thickness of the layer of N_2O increased the voltage on the surface of the film almost proportionally. In due course we found that 1253 monolayers (ML), equivalent to 0.4 μm, of N_2O laid down at 40K could support a voltage of 38.40 V. Here we stopped for fear of wrecking our femtoammeter. The measured voltages also showed a strong dependence on the temperature at which films were laid down, creating much higher voltages for lower temperatures for any given film thickness. This is shown in figure 2 for ten different temperatures between 38K and 65K. Electric fields were correspondingly stronger at lower temperatures. For example, a film laid down at 38K showed a field of $1.19 \pm 0.08 \times 10^8$ V/m in the N_2O film, dropping to $1.60 \pm 0.1 \times 10^7$ V/m at 65K (figure 3). Fields were calculated using 1 monolayer (ML) = 0.32 nm.

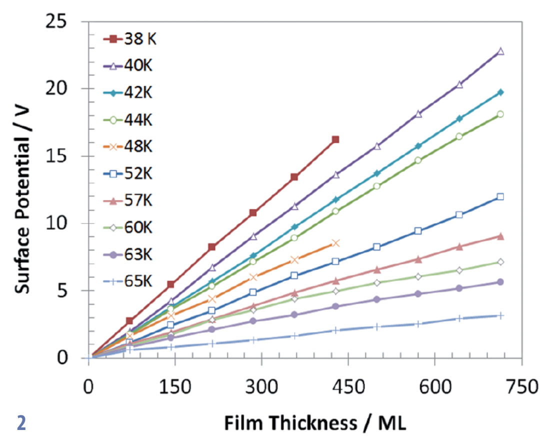
Why do films not break down electrically in the presence of such large electric fields? For comparison, the breakdown of dry air occurs at electric fields of a few times 10^6 V/m, while the field in a spark plug to ignite petrol in an internal combustion engine is around 2×10^7 V/m. However, in solids in general, breakdown fieldsiv vary between 10^8 V/m to 10^9 V/m, where electromechanical stress is induced by elastic deformation and electron cascade. The latter will be inhibited by inelastic scattering of electrons within solid films. Given that it is possible for such large fields to be present in stable solids, other issues come to mind. What is the nature of the interactions which give rise to such powerful electric fields within the medium? Have we stumbled upon a new class of materials of which N_2O is but one member? Is the nature of the substrate, polycrystalline gold in this case, of significance for the phenomenon to occur?



▲ FIG. 1: Detection of surface potentials using electron beams: electrons are formed in the gas phase through threshold photoionization of Argon at ~15.75 eV, using monochromatic synchrotron radiation 'hv' at a resolution of ~1.5 meV. Electrons are created at the potential of S2, which is set to a nominal zero, and directed under Ultra-high vacuum (UHV) conditions onto condensed solid films at temperatures of 38K and above. Current is detected with a femtoammeter. We use the ASTRID synchrotron radiation source at the University of Aarhus, where all the experiments described here were conducted. Radiation not absorbed by Argon is collected at the photodiode.

POSITIVE AND NEGATIVE

Films of different molecules can carry a positive charge on their surface (N_2O, isoprene, toluene) or a negative (propane, isopentane, CF_3Cl). The value of the electric field within the material may also differ greatly from case to case. Both features are illustrated by data in Figure 4.



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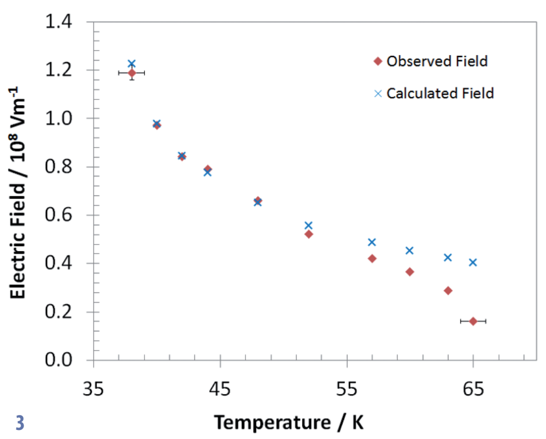
▶ FIG. 2: Surface potentials measured for films of N_2O as a function of thickness (in monolayers, ML), laid down at ten different deposition temperatures. Films were accumulated through successive depositions of 71 ML.



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▶ FIG. 3: Observed electric fields in N_2O (red diamonds) and calculated values (blue crosses) as a function of the temperature at which films of N_2O were laid down.

Film deposition temperature: a model

Our hypothesis is that the mechanism for the creation of electric fields in the film is due to a tendency of the molecular dipoles to line up, plus to minus, in successive layers of the material. At the surface-vacuum interface, the positive nitrogen end of N_2O, which has the structure (δ^+) N-N-O (δ^-), protrudes out of the surface and the resulting charge density on the surface gives rise to polarization and a positive voltage. Thus, polarization resulting from dipole alignment gives rise to the electric field, rather than free charges. This is a non-linear system since alignment of dipoles creates the field and the field itself creates dipole alignment. Since there is negligible charge within the film, Gauss' theorem requires that the field be constant.

The reason why a strong temperature dependence of the electric field on deposition temperature is observed (figure 3) is that dipole ordering is countered by a tendency to disorder through thermal motion. The control parameter of the physics is therefore the energy associated with the interaction of the dipole with the local electric field divided by the thermal energy.

The non-linear order-disorder problem may be solved by methods set out by Langevin, Debye and Landau, using so-called mean field theory. Solutions yield the average direction in which a dipole is pointing within the film, relative to the normal to the film surface, as a function of temperature. This in turn gives the amount of charge at the surface-vacuum interface per unit area - the polarization - and hence the electric field. Theoretical values are fitted to observed data of electric field versus temperature, using three temperature-independent parameters and yielding results shown as blue crosses in figure 3. The good agreement between this theory – albeit parameterized - and observations gives strong support to the hypothesis that dipole alignment is the cause of the unexpected electrical nature of the films. Note also that dipoles are not pointing vertically but rather are typically aligned at an angle of more than 80° to the normal.

CURIE POINTS

A critical temperature at which films lose their electric fields, can be observed for isoprene, isopentane and propane, for which spontaneous polarisation is lost by heating whilst the film survives. This makes the analogy with ferroelectric materials where a similar phenomenon is observed.

A new class of spontaneously polarized material

We have recently tested seven species for the presence of a spontaneous electric field, the only criterion of choice being that they should possess low dipole moments. Of these the first six, propane (dipole moment 0.08D), isopentane (0.13D), N_2O (0.167D), isoprene (0.25D), toluene (0.385D) and CF_3Cl (Freon-13; 0.5D) all form polarized films. The seventh, OCS, with a dipole moment of 0.7D, does not - nor does H_2O with a still larger dipole moment of 1.85D.

It appears a reasonably safe conclusion that all species with dipole moments between close to zero and 0.5D, and lacking hydrogen bonding, form polarized layers. We therefore suggest that we have discovered a new class of polarized materials. To emphasise the generality of the new phenomenon, N_2O has been laid down on 20ML of xenon. Exactly the same values of the electric field are found as for films laid down on amorphous gold.

Different molecules have, of course, different properties. The most striking difference is that some species carry a positive charge on their surface (N_2O, isoprene, toluene) and some a negative (propane, isopentane, CF_3Cl). The value of the electric field within the material may also differ greatly from case to case. This is shown in figure 4, expressing the electric field in terms of mV of potential increase upon the addition of 1 monolayer (ML).

The values shown in figure 4 are highly reproducible. However, we have found some complexity in the case of propane. Films are built up by successive deposition and for propane we found typically that thinner layers showed ~0.7 mV/ML whereas thicker layers of >3700 ML appeared to switch phase and yield 4.77 mV/ML. Both these values are shown in figure 4.

There is an optimum dipole moment for creation of polarized films, around 0.25D. No quantitative explanation can be offered for this value at present. At values of the dipole >0.5D the tendency of molecules to align with positive and negative ends close to each other overcomes the tendency to create order leading to net polarisation, at any rate in the absence of other influences such as hydrogen bonding. The result is then zero net polarization and zero electric field within the film.

Each of the species in figure 4 shows similar strong temperature dependence of the electric field as that found in N_2O. For example, a 280ML film of isoprene laid down at 40 K shows a surface potential of 9 V whereas if laid down at 70K the value is 1.80 V. Potentials may also be observed at high temperatures: for example toluene shows ~2V at 115K.

Polarized films are very robust to temperature stress. For example a 426 ML film of N_2O was laid down at 38K and heated in steps of 3.7K over a period of 90 minutes to just below the evaporation point at 75K. The surface potential was measured at each temperature. The potential drops by only 510 meV. This may be compared with data in Figure 1 where results for the fully relaxed state show a drop of 11.95 V between 38K and 65K. It has also been found that deposition above the Curie temperature and reduction of the temperature to below the Curie temperature does not lead to the establishment of an electric field within the layer.

Concluding comments

The discovery of this new class of spontaneously polarized materials opens up a wide field of possible applications. These may arise rather generally in nanoxerography and voltage-patterned surfaces could for example be employed to create very high-density biosensor arrays. Moreover, it turns out to be possible to manipulate these films very readily to create a broad range of electric field structures. Presently we seek materials which can be used under less extreme cryo-conditions and this will be one focus of future research. Other future areas may be effects of rate of deposition of films, dilution of the active material in xenon and the creation of more complex electrical nanostructures. We have also very recently found that some higher dipole moment species such as methyl formate (1.75 D) and 2,5, dihydrofuran (1.53 D) can spontaneously form polarized films. This is under further investigation. ■

About the Authors

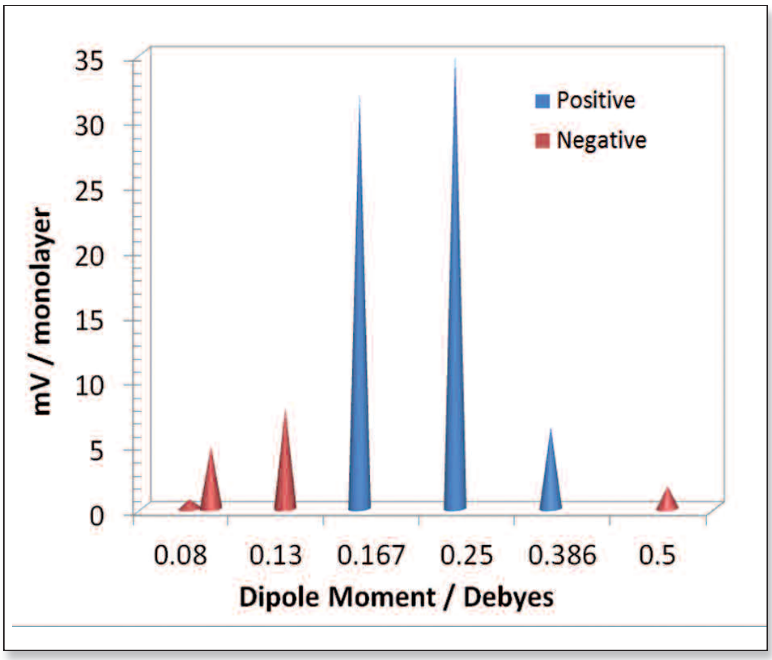
David Field has been a professor of Physics and Astronomy at Aarhus for the last decade or so and is scientific director of the Institute for Storage Ring Facilities (ISA).

Oksana Plekan is an experienced post-doc, funded by the Danish Research Council, who worked for several years at the Elettra Synchrotron in Trieste before coming to Aarhus.

Andrew Cassidy is a young researcher (post-doc), previously in Cambridge (UK), now funded by the LASSIE EU Network (FP7).

Richard Balog is an ex Marie-Curie and Lundbeck fellow now a post-doc at Aarhus funded through the ERC.

Nykola Jones is a beamline scientist working on the ASTRID synchrotron storage ring at Aarhus.



▲ FIG. 4: The electric field in terms of mV of potential increase upon the addition of 1 monolayer (ML) of different compounds. Values given are for layers laid down at 40K. Here 0.08D refers to propane, 0.13D to isopentane, 0.167D to nitrous oxide, 0.25D to isoprene, 0.385D to toluene and 0.50D to CF_3Cl. Two figures are given for propane (see text). Red cones represent a negative potential on the surface, blue a positive potential.

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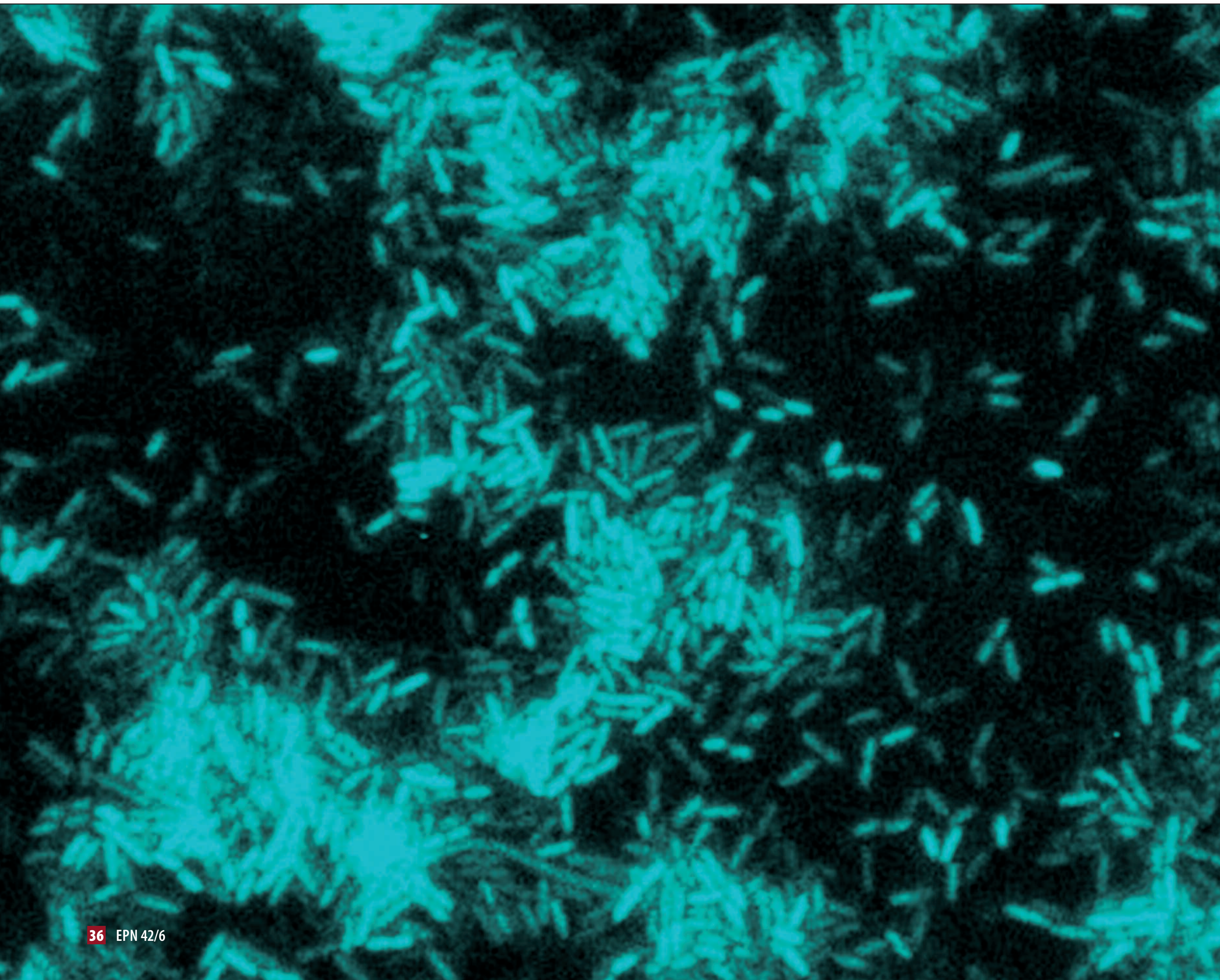
QUANTUM WELLS

Quantum wells can be can be readily assembled. A 33ML layer of N_2O was laid down at 40K generating +800mV at the film surface. Subsequently, 183 ML of isopentane was laid directly on top of the N_2O and created precisely -800 mV, bringing the potential on the film surface back to zero, forming a 2D triangular quantum well. The possibilities are manifold: for example, Xe spacers can be used to form flat-bottomed wells. With standard masking techniques a wide range of nanostructures could be formed, for example quantum dots.

Fluctuations importance and control in biological systems

Bahram Houchmandzadeh and Irina Mihalcescu - DOI: 10.1051/epn/2011606
Université Grenoble 1 / Centre National de la Recherche Scientifique,
Laboratoire Interdisciplinaire de Physique, Unité Mixte de Recherche 5588, Grenoble, F-38041, France

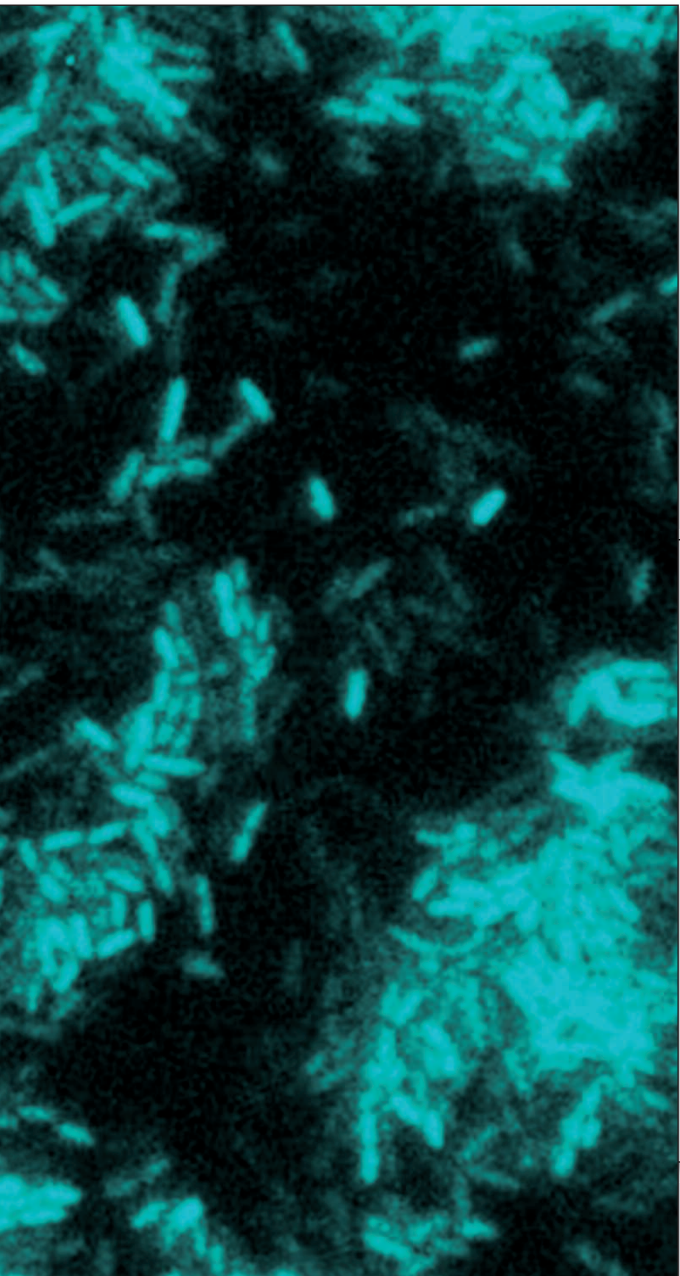
Living cells are miniature chemical 'factories'. Unlike their macroscopic counterparts, due to the small number of molecules involved, the reactions that take place are not fully deterministic. 'Probability' management is part and parcel of cell life and leaves its mark at all length scales of living matter. We review some aspects of 'stochastic noise' management, which has profoundly changed our vision of living systems during the past ten years.



A deterministic machine will always give the same output in response to a given input, while a probabilistic machine will give different outputs more or less widely distributed around a mean value (Figure1). The standard deviation of the output values divided by their mean is what we call the noise amplitude in this article. If this noise is small, the machine is considered deterministic. This is the case for macroscopic chemical reactions, and the usual differential equations of chemical kinetics are sufficient to describe the evolution of concentrations.

When the number of molecules is small, fluctuations are large and the mean value of the molecules number is not a good description of the reaction. Often, in bacteria, chemical reactions are controlled by very low numbers of proteins (Figure 1). A typical example is the bacterium *Escherichia Coli* (a host of our intestine): 80% of its genes produce proteins with less than 100 copies/cellular cycle. The noise amplitude for these proteins is in the range of 5% to 65%. Looking at a collection of bacteria, we have to expect that the same reaction will have different outcome in similar individuals (see an example in the introductory picture).

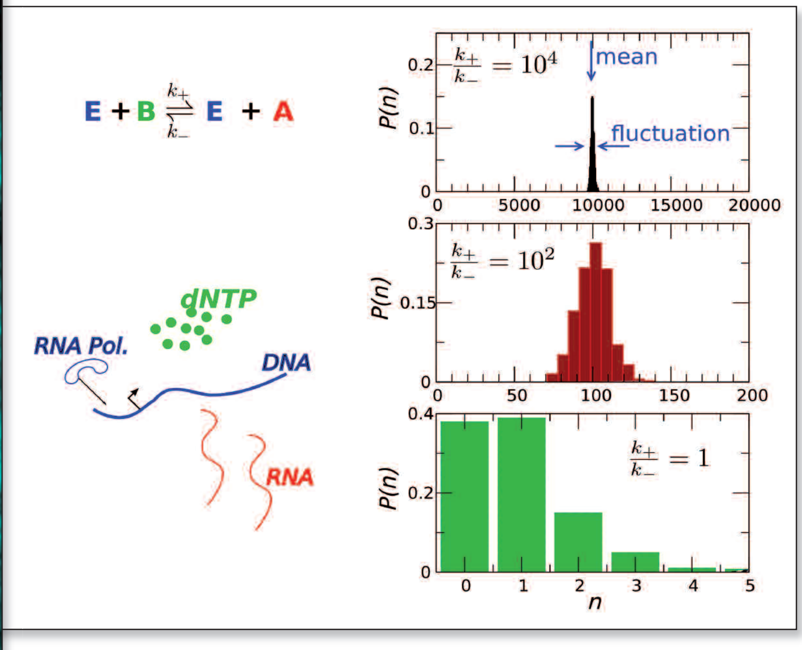
One of the first experiments to show a "non genetic individuality" was performed by Novick and Weiner in 1957, when none of the fine molecular tools of today were available and scientists had a very crude notion of what was going on inside a cell. By observing a population of *E. Coli*, genetically identical and in the same bath, they showed two distinct behaviours: some were able to digest the sugar lactose, and some were not. Even more troubling: this behaviour, related to the presence of the enzyme β galactosidase, was inherited by the offspring of each bacterium. We now know that the concentration of this enzyme, initially under DNA control, can have *two* stable states of concentration. This bistability is due to the presence of regulatory positive feedback loops. The bacterial chemical *reactor* falls into one of the two states by random fluctuations, remains there and the offspring inherits this *metabolic* state.



“In order to function, an organism has to ensure the fidelity of its response to a given stimulus.”

◀ Bioluminescence images of rod shaped marine bacteria V. Harveyi (1.5 µm x 0.5 µm). These bacteria are naturally bioluminescent upon addition of an inducer to the medium.

▼ **FIG. 1:** Schematic representation of the transcription chemical reaction. **Left panel:** the probability of observing *n* molecules produced in a simple chemical reaction at ≈steady state, as a function of the strength of the chemical reaction k_+/k_-, where k_+ and k_- are the forward and backward reaction rate, respectively; the mean number of molecules and the fluctuation amplitude can be read directly on the chart. When $k_+/k_- \approx 1$, the average number of molecules is small and the fluctuations are dominant. **Right panel:** RNA production from DNA substrate (transcription). *E* symbolizes both the enzyme RNA-polymerase (Pol) and the DNA substrate (in blue) ; *B* is for nucleic acids (dNTP, green) ; finally, *A*, the product of the reaction represents the RNA produced (in red).



The technical advances in molecular biology and the discovery of fluorescent markers brought the subject of fluctuations to the forefront in the 90's. In these techniques, the gene encoding a normal protein is forced to contain also the gene of a fluorescent protein (such as GFP -Green Fluorescent Protein). Whenever the protein is produced, its presence is directly detected in living cells by fluorescence (see Figure 2). It soon became clear that the variability in cell behaviour was not an exception but the rule in a wide variety of systems: from protein production in bacteria and eukaryotic cells (such as our red blood cells) to more complex system such as the oocytes maturation mediated by progesterone, embryonic development, social behaviour. The fluctuations are the combined result of many factors, like the available enzyme in the whole cells (*e.g.* RNA polymerase in Fig.1) and the characteristic noise of each chemical reaction. Scientists were able to perform clever experiments to distinguish these different sources of noise and propose a general mathematical framework for them [1].

Controlling fluctuations

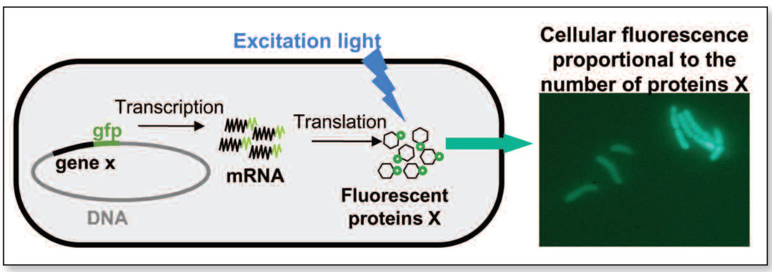
In order to function, an organism has to ensure the fidelity of its response to a given stimulus and keep the amplitude of the fluctuations in check. A large set of cell genetic and metabolic regulatory circuits are dedicated to this task and we understand the general principles for the simplest cases. For example, human engineers use negative feedback loops for high fidelity amplification of a signal. This mechanism is also widespread in the living world, and bacteria have an important number of genes that are self-regulated like that. When very high precision is needed, one can witness "living" engineering gems of high fidelity. A recent example is the circadian clock in cyanobacteria (a two billion years old organism which generated the rise of the atmospheric oxygen). Widespread in the living world, result of the adaptation to the night/day terrestrial cycle, the circadian clock is a self-sustained biochemical oscillator with an approximately 24hr period. In cyanobacteria this oscillator has a strong temporal stability: it keeps the phase of oscillation constant during many *months* [2] in the absence of any outside cue, like light or temperature (see Figure 3). For a long time, it was thought that this precision is due to communication among bacteria, raising the effective number of molecules of the subsequent chemical reactions. We have shown that this is not the case: each bacterium, using a small number of molecules, is capable of keeping its phase, a fact which seems to defy the rules of thermodynamics [3].

Another example is the embryonic development where different groups of cells progressively specialize from stem cells into tissues. It is vital for an animal to maintain a high precision in the size, and especially in the proportion of different tissues. The generic program used for differentiation is the following. A spatially varying concentration of a signalling molecule is built across the embryo (or part of it). Each cell "reads" this signal, and selects a binary fate according the local concentration of the signal at its position. Each differentiated cell can become itself a producer of a new signalling molecule and so on. This cascade converts a crude initial gradient into a fine genetic positioning system, where each cell, according to its position in the embryo, receives precise instruction to differentiate. This program, however, is too sensitive to noise and unable to ensure proportion fidelity. The generic program has to be completed by many additional correcting circuits, which indeed ensure better fidelity than one-cell fidelity. We can measure the extreme efficiency of these additional circuits, even though we don't completely understand their blue-print [4].

Using Fluctuations

The living world also exploits random fluctuations. The best known example is of course the Darwinian evolution, which is the founding principle of biology: the very act of duplication of an organism is subject to noise and produces a small proportion of mutants, which can be selected if they are better adapted to the environment.

Darwinian evolution, based on the noise at the level of the genome, happens over long time scales. The same mechanism, at the level of gene products, can produce adaptation on short time scales. This was recently brought to the forefront in the bacterial persistence problem of the *E. Coli*: in a given population of bacterial clones, a small proportion can resist anti bacterial agents for a long time. It was shown by N. Questembert-Balaban that this bacterium has two metabolic states, switching randomly between them. In the favourable state, the bacteria are strong importers of their resources from the outside world and duplicate fast, at the expense of an increased sensitivity to antibacterial agents easily imported inside the cell. In the unfavourable state, the bacteria seldom communicate with the outside world, at the expense of very slow division. The random switch between the two states insures that a small proportion of the population is always maintained in the unfavourable state, and can repopulate the ecological niche after the end of a cataclysmic antibacterial event. In a more general framework, it appears that in fluctuating environment, a gene whose products show some variability can give an advantage to its bearer.



▼ FIG. 2: Optical measurement of protein concentrations. **Left panel:** the gene *x* encoding the studied protein is fused into the fluorescent protein gene by "cut and paste" molecular biology tools. The molecular machinery will read this DNA sequence, then transcribe it into messenger RNA and translate it into new chimerical proteins X which will contain a supplementary fluorescent domain. **Right panel:** Cells producing this protein will be fluorescent and the level of this fluorescence is proportional to the quantity of protein inside, which can be measured under a microscope. Measuring a few hundred cells allows quantifying the variability of the cell's response when producing the protein X.

Fluctuation at large spatial scales

Fluctuations at the individual level can have consequences at the ecological level and over large spatial scales. One important example is the clustered distribution of species in natural environment: individuals of a given species are not homogeneously distributed in space. This phenomenon was first observed for plankton at ocean's surface. Since then, reviews of more than thousand species in different kingdoms have shown that the clustered distribution is a general rule of ecology. One obvious cause of the distribution heterogeneity is geography itself: lakes, mountains, quantity of available sun… This changes the local carrying capacity and should have an effect on the number of individual inhabiting the place. There is, however, a deeper cause, which is the randomness and asymmetry between birth and death: a new individual always appears close to its parent, but can die everywhere. This asymmetry favours short distances between individuals despite their random movement. We have recently shown that indeed, in a controlled ecological experiment on amoebae, in the absence of any outside clue, the spatial distribution of individuals becomes extremely clustered after a few generations (see Figure 4). In addition all statistical properties of the distribution are predicted by a probabilistic theory taking into account random birth, death and diffusion [5]. The clustered distribution in natural communities therefore should indeed be the rule, and *not* a source of surprise.

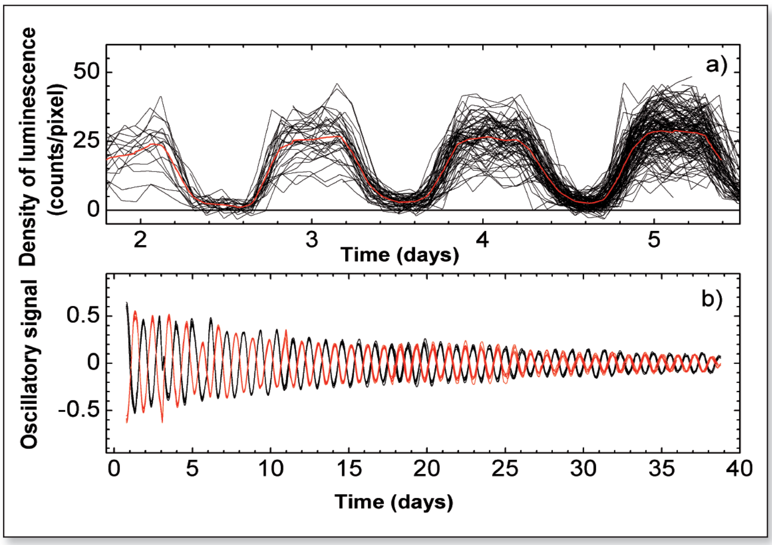
Conclusion

Stochastic fluctuations have come to the forefront of biology, thanks to active collaborations between on the one hand physicists, who contributed by their culture of statistical physics and the methods used there and, on the other hand, biologists who brought their knowledge of the complexity of the living world and their mastering of molecular biology tools. The cell is no more considered as a deterministic machine, but possesses a non-genetic individuality provided by amplified fluctuations and maintained by multistable chemical reactions.

Much has been achieved in the understanding of these phenomena but much more remains to be understood. We know many specific genetic circuits inside the cell dedicated to noise management, but we lack a general view on their design principles and their fundamental limitations. We are only just beginning the journey into this field. ■

About the Authors

Bahram Houchmandzadeh is *directeur de recherche* at CNRS. He graduated in statistical physics, and first dedicated his interests to out-of-equilibrium physical systems. He then became interested in biological systems, and worked in various areas like the structure of mitotic chromosomes, embryonic development, population structure in ecology and Evolution.



▲ **FIG. 3: Synchronous oscillation of individual bacteria and their progeny. (a) In the cyanobacterium *Synechococcus elongatus*, the circadian clock adds a periodic component to all protein production. To follow this oscillation we use a bioluminescent reporter. Each black curve represents the signal emitted by one bacterium and the red curve their average. (b) The normalised circadian oscillation of two populations of cyanobacteria (shown in red and black) with opposite initial phases, conserves its phase over many weeks (for each phase 8 to 12 experimental curves are superimposed). Note that only the phase information is relevant as the amplitude is sensitive to metabolic variations along the experiment ([3] and [4])**

Irina Mihalcescu is Professor at Grenoble University. Junior member at the Institut Universitaire de France from 2005-2010, she studies the fluctuations in biological systems like the circadian clock, the quorum sensing and the stress response network. She graduated in semiconductor physics and first inquired into the fluorescence mechanisms in porous silicon.

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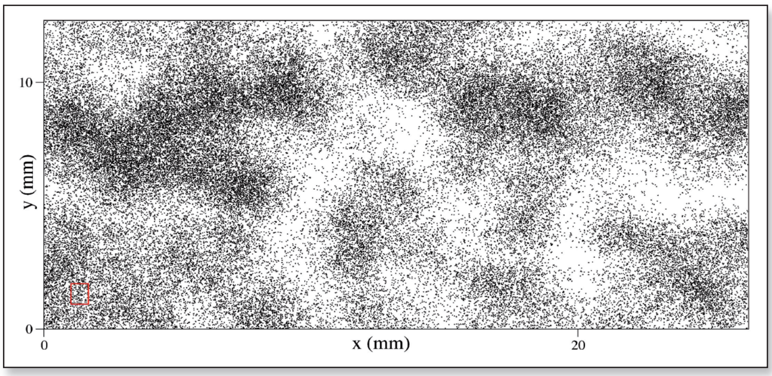
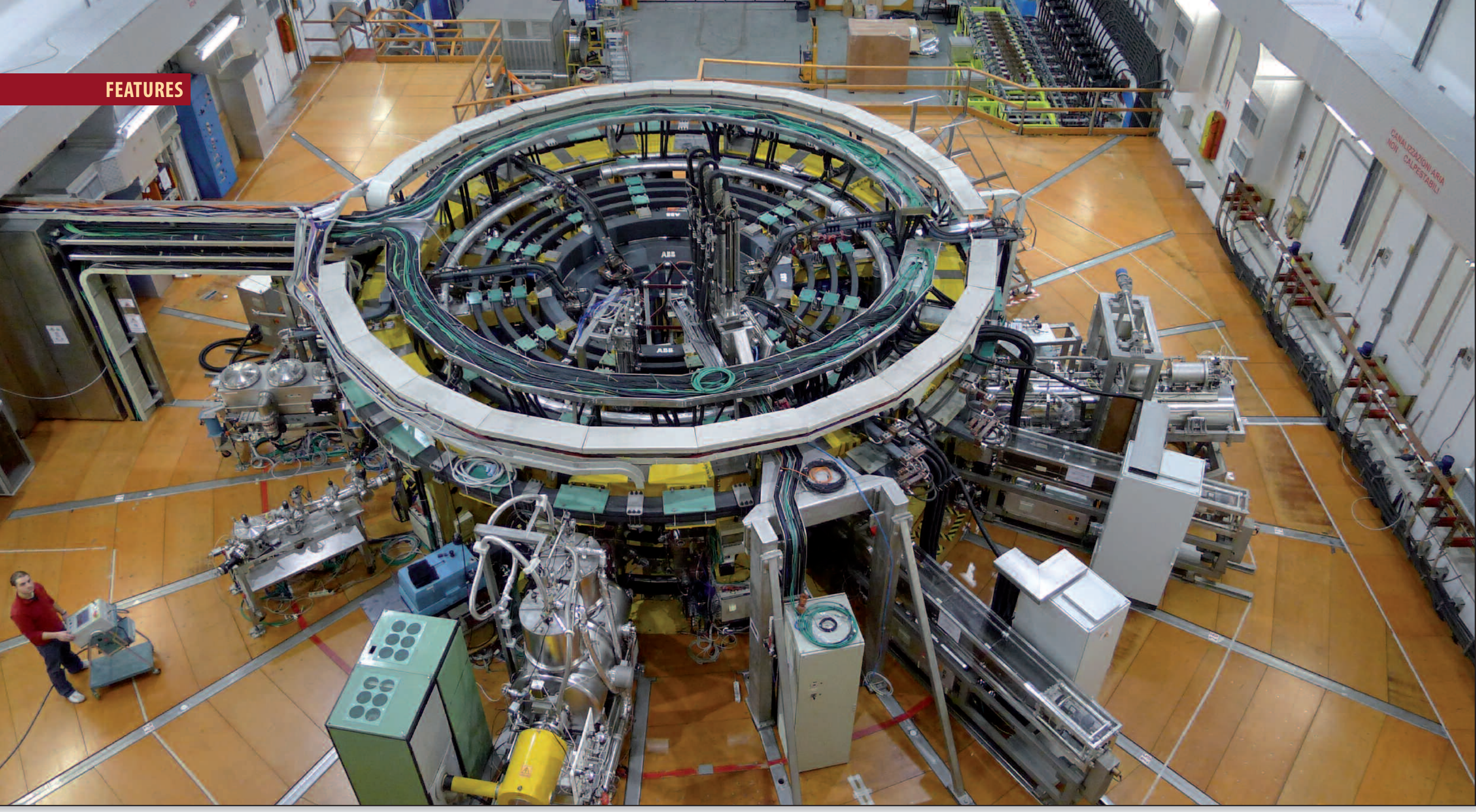
▼ **FIG. 4: The clustered spatial distribution after 9 generations, beginning with a homogeneous initial distribution. Each amoeba (*D. Discoidum*) has been detected at high magnification and represented here by a dot. Each birth, occurring close to a parent, increases the number of "short" distances. The Brownian motion tends to dilute short distances, but cannot overcome "short distance" creations at two dimensions [5].**





Feedback control in magnetic nuclear fusion

■ Piero Martin - piero.martin@igi.cnr.it - DOI: 10.1051/epn/2011607
■ Dipartimento di Fisica "G. Galilei", Università di Padova and Consorzio RFX-Associazione EURATOM-ENEA sulla fusione, Padova, Italy

Feedback control is part of our everyday experience. From the simple ambient thermostat in our homes to ABS in our cars, from the brightness self-adjustment of notebook screens to the more sophisticated cruise control systems in modern jetliners, feedback control is a ubiquitous ingredient of modern technology. Indeed, feedback control is a key process for life itself. It is therefore not surprising that a challenge like that of producing energy from controlled thermonuclear fusion strongly relies on feedback control for its success.

▲ The RFX-mod reversed-field pinch device. RFX-mod is equipped with the most complete system of coils for active control of MHD stability ever realized for a fusion device.

Living organisms, like humans, require feedback control mechanisms for maintaining internal stability in spite of environmental change. This ability is called homeostasis. It is, for example, responsible for maintaining blood pH or body temperature within rather narrow ranges – which, if trespassed, may lead to fatal consequences. Feedback control is also central for many technological tools, which are familiar to our daily life: from the simple one, like thermostats in our living rooms, to the more sophisticated like the Anti-lock Braking System (ABS) in the automobiles, or the control system in modern civil airplanes.

It may not be very surprising that one of the more ambitious scientific and technological challenges of mankind for this century, *i.e.* producing energy from controlled thermonuclear fusion, strongly relies on feedback control for its success.

The challenge of thermonuclear fusion

To produce energy with fusion, a hot plasma made by two hydrogen isotopes, deuterium and tritium, must be confined for a sufficiently long time within a reaction chamber. One possibility to achieve these conditions is using magnetic fields to confine the plasma (made by moving charged particles) within doughnut-shaped, toroidal containers. This is magnetic confinement fusion. For it to be successful, 'hot and dense' means orders of magnitude that for temperatures are ≈200 million °C and for densities ≈10^{20} particles per cubic meter (which corresponds to less than one millionth of the atmospheric density).

The ITER experiment [1] (ITER means "the way" in latin) is one of the largest science projects ever in the human history and is the front-runner in this challenge. ITER is supported by accompanying experiments in many countries of the world, which are necessary for its success. ITER is a 17 meters high, 830 m^3 plasma volume device, which is under construction in Cadarache, France as a joint project between China, European Union, India, Japan, Korea, Russia and USA. Its goal is to demonstrate the scientific and technological feasibility of fusion by producing 500 MW of fusion power. Its main parameters are listed in Table I.

Reliability and performance: key to success

R&P, reliability and performance: these are two keywords to make fusion a successful story. Reliability is clearly a must for a commercial plant, which should be available 24/7 – except for short maintenance periods – and fault-proof. And performance, too: the quality of confinement is a basic requirement for fusion to happen, and to keep cost of electricity as low as possible. Getting R&P together is in general a challenge, as it is often easier to have one at the expenses of the other. Airplanes are typical examples: commercial attractiveness and social acceptance requires reliability and safety. In fact, intrinsic stability is one of the main drives for passenger aircraft design. But if performance is the prime requirement – as happens for example for military aircraft, where maneuverability and speed often define the metrics of performance – constraints on stability are relaxed, even to the point of relying completely on active stability control ("fly-by-wire") to fly intrinsically unstable airplanes. Part of the challenge for fusion is to simultaneously optimize both reliability and performance.

Reliability and performance in fusion plasmas are linked to stability. A key dimensionless parameter to define the metric of performance in magnetized fusion is β, which measures the ratio between kinetic pressure stored in the plasma (*i.e.* the product of density and temperature) and the magnetic pressure needed to confine the plasma [2]. Higher β means better performance (both in terms of fusion gain and capability of maintaining steady state conditions). But at higher β the plasma is more prone to instability [3]. Plasmas for magnetic confinement fusion are in fact systems with built-in free energy: pressure gradients, magnetic field, population of fast ions are all sources of free energy, which could give rise to unstable behaviour. Instability means either performance degradation or, in the worst case, severe threat to device integrity. A large part of plasma stability is described within the magnetohydrodynamic (MHD) model, which treats the plasma as a magnetized conducting fluid and uses mass, momentum and energy conservation equations. A number of these instabilities can be avoided by appropriately "navigating" the operational space, *i.e.*, by proper selection of the plasma regime to avoid "more dangerous" parameter regions. But navigation might not be enough to achieve the desired performance in the burning plasma if it is restricted to passively stable regions. Moreover, it may not protect against dangerous off-normal events. Therefore, active control is an essential ingredient for safe navigation beyond conventional stability limits, which would bring significant benefit in terms of performance and efficiency.

Plasma major radius	6.2 m
Plasma minor radius	2.0 m
Plasma current	15 MA
Toroidal field at 6.2 m radius	5.3 T
Plasma volume	830 m^3
Fusion power	500 MW
Fusion power gain Q	≥10 (for 400 s inductively-driven burn)

▲ TABLE 1: ITER parameters [1] (more information at www.iter.org)

Examples of feedback control

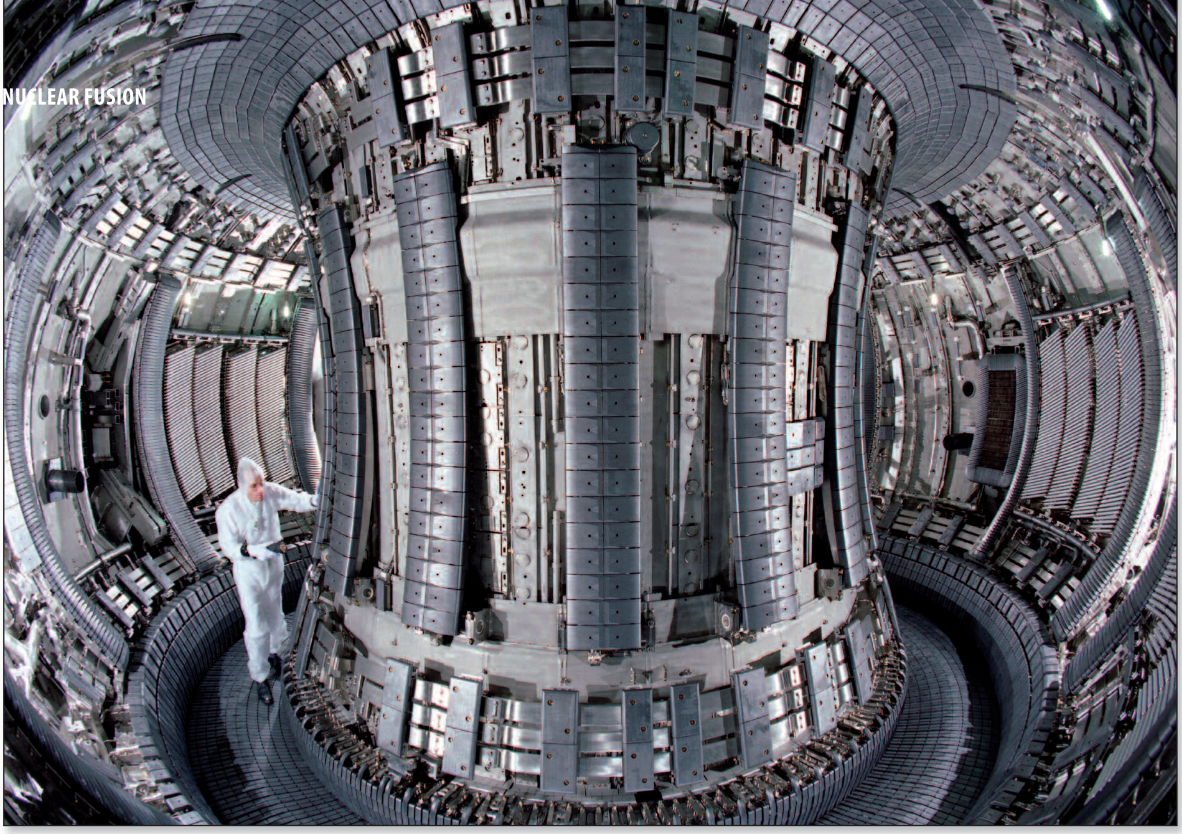
With clear awareness of the challenge, present-day fusion experiments are developing a successful program on feedback control of plasma stability, with a high level of integration and synergy between different approaches, all studied in view of applications to ITER and next generation of experiments. Interestingly enough, as we shall see, the science and technology of plasma control is being efficiently advanced in devices, which do not necessarily need to be tokamak, as ITER is.

Let's have a look at some examples, just to show what we mean by plasma stability control and its interplay with plasma performance. Due to space limitations, this is clearly not intended as a complete coverage of such a broad field.

The most mature problem in plasma control is controlling plasma shape and position. Both need to be controlled in a fusion device. The plasma has to be kept in the containment vessel, without having direct contact with it. Moreover, the particle outflow needs to be directed to a specific region, called divertor, where exhaust power

▼ TABLE 2: JET DESIGN parameters (more information at www.efda.org)

Major radius	2.96 m
Minor radius	2.10 m (vertical) 1.25 m (horizontal)
Toroidal magnetic field on plasma axis	3.45 T
Plasma volume	~ 90 m^3
Plasma current (max)	4.8 MA

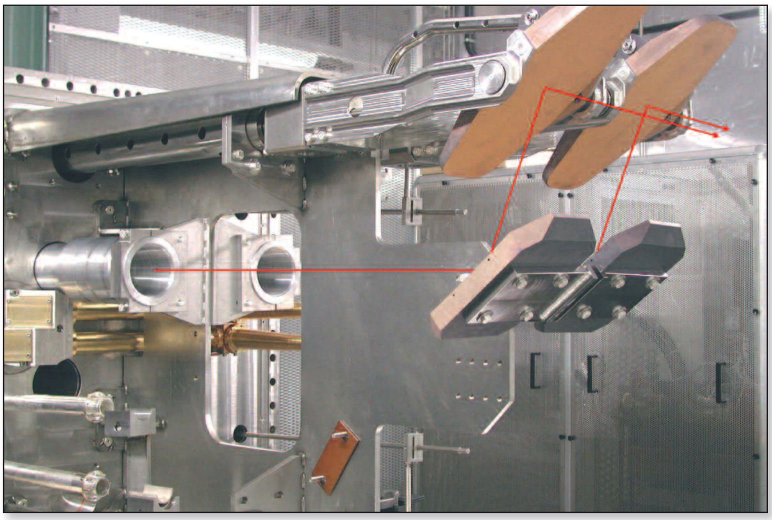


▸ FIG. 1: Internal view of the JET vacuum vessel (image courtesy of EFDA JET)

loads are managed. In addition, the poloidal plasma cross-section of a tokamak needs to be appropriately shaped to achieve higher performance. This means that the optimal cross-section is not circular, but vertically elongated. However, an elongated shape happens to be unstable against small vertical displacements, which are amplified and may lead to plasma termination. Therefore, also the vertical plasma position has to be controlled. Position and shape control is realized by acting on the plasma with external magnetic field.

The largest tokamak nowadays in operation, the European Joint European Torus (JET) device (see Figure 1 and Table II), works routinely with the eXtreme Shape Controller (XSC) [4]. This is a model-based, multivariable control system. Plasma shape is defined by 32 geometrical descriptors, which are basically distances (gaps) between the plasma and the wall and positions of particular plasma points. Magnetic sensors evaluate these descriptors. For each desired shape a set of such descriptors is preset. In real-time the differences between the actual and the preset optimal values of the descriptors are fed as input in the controller. Outputs are the voltages applied to coils, where a current flows to produce the required magnetic field to shape the plasma. The eXtreme Shape Controller calculates the smallest currents needed to minimize the error on the overall shape. It works efficiently also in presence of significant variations of other plasma parameter, not directly controlled by it, which may also influence shape. The eXtreme Shape Controller works very reliably, and allows for significant improvement in JET plasma operation. As an example, the average error on the 28 controlled plasma-wall distances is reduced down to 1 cm, to be compared with the larger radius of the D-shaped JET cross section, which is 2.10 m. The extreme Shape Controller is a valuable example to show the importance of having a good model of the process to be controlled, as the model used in the XSC. An accurate model can be either "ab initio", *i.e.*, based on a physics description of the process, or a "black-box", *i.e.*, identified by experimental data.

▾ FIG. 2: The real-time controlled mirror system in ASDEX (Axially Symmetric Divertor EXperiment) Upgrade. Mirrors are tilted real-time to focus a radio-frequency beam directly on the region where instability has to be cured. The pattern of the beam is also shown. (image courtesy of Max-Planck IPP)



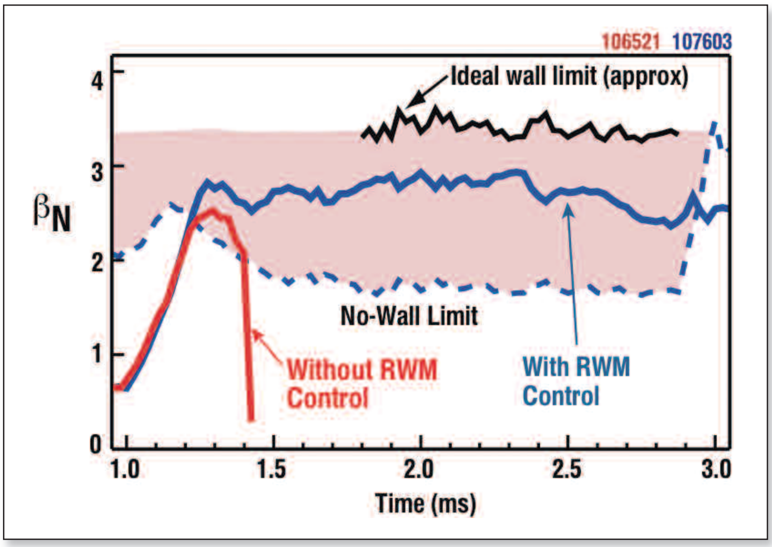
On the subject of plasma shape, a smaller tokamak device like the *"Tokamak à Configuration Variable"* "TCV" at the École Polytechnique Fédérale de Lausanne (EPFL) in Swiss [5] is explicitly designed to study the influence of shape on performance and stability.

As plasma performance is pushed, more free energy is available (in the kinetic pressure, for example) as a potential drive for instabilities. Active control provides a very efficient tool to overcome this problem, too. One option is to target directly the plasma current density and pressure, in order to tailor them in real-time in a more stable shape. The Tore Supra Tokamak at the Cadarache Center of the French *Commissariat à l'Energie Atomique et aux Energies Alternatives* (CEA) realized several successful experiments on this topic [6]. Another successful example is provided by Neoclassical Tearing

Modes control. Neoclassical Tearing Modes are instabilities driven by plasma pressure, which cause the growth of nested sets of magnetic field lines within the main plasma, called islands. Islands may degrade plasma performance or cause its termination. Targeting them with beams of Radio Frequency (RF) waves, which resonate at the electron cyclotron frequency, was found to be an efficient method to heal them in tokamaks.

An example is provided by ASDEX Upgrade, a tokamak at the Max-Planck Institut für Plasmaphysik in Garching, Germany [7]. Here a system of mirrors – shown in Figure 2 – is controlled in real time with a typical response of 10-20 ms to track the target island and allow launching in it RF waves. These RF waves are produced by 6 gyrotrons with a total installed power of 6 MW (with 4 of them deliverable for up to 10 s). RF-based real-time feedback systems have been developed also for TCV [5] and for the TEXTOR experiment [8], operated in Jülich, Germany under the Trilateral Euregio Cluster. In TEXTOR the system combines an electron cyclotron emission diagnostic for detecting the instability in the same sight line with a steerable RF antenna. Event-triggered RF wave injection has also been demonstrated to be a powerful tool to avoid dangerous disruptions in the FTU tokamak in Frascati, Italy [9] or to control core instabilities like the so-called sawtooth (see [10] for a recent review).

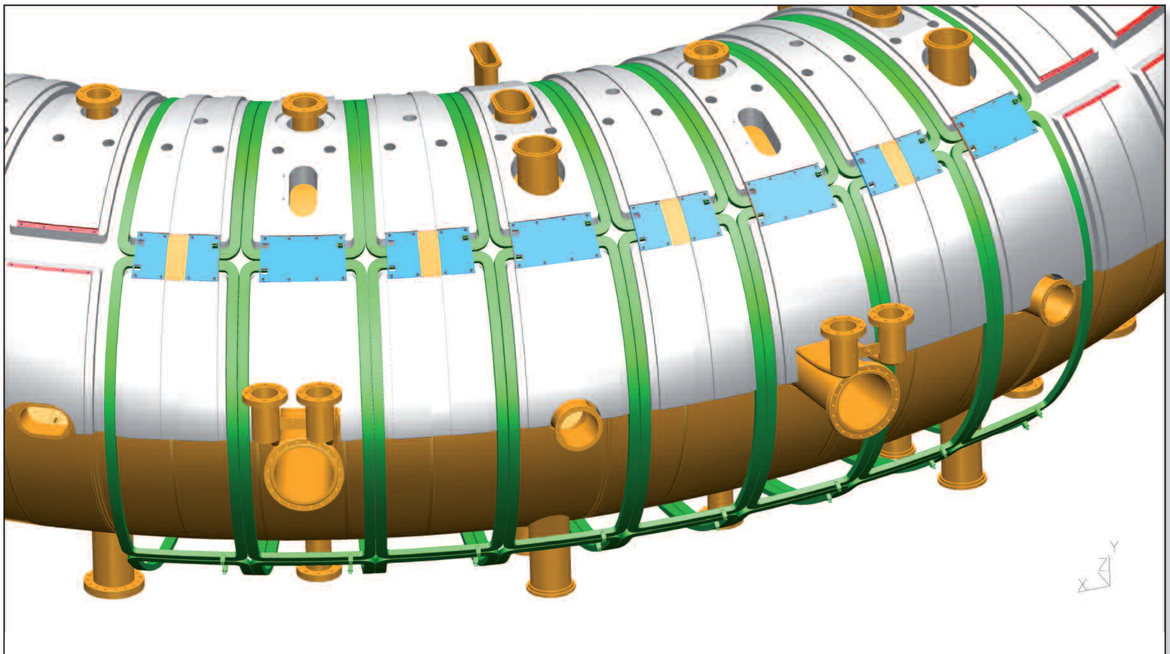
If one pushes performance even further, plasma instabilities known as Resistive Wall Modes perturb the equilibrium magnetic field. These perturbations can be sensed and used as input signals in a feedback loop, where the real-time actuators are a set of coils located at the plasma edge. These coils produce in fact a magnetic field, which cancels the perturbation. The technique is rather robust, and allows for running a tokamak plasma beyond passive stability limits. This was shown, for example, by the DIII-D tokamak [11], in operation at General Atomics, San Diego, California, see Figure 3. DIII-D is equipped with 18 feedback-controlled external coils, which have a key role in controlling magnetic field errors and perturbation caused by gross distortion of the plasma column, eventually leading to very high values of the plasma thermal content. RWM studies are conducted also in the NSTX device in Princeton, US. A new experiment, JT-60SA presently under construction in Japan under a joint programme between Japan and EU [12], will be particularly equipped with an active system to explore operation in high-performance, passively unstable regimes.



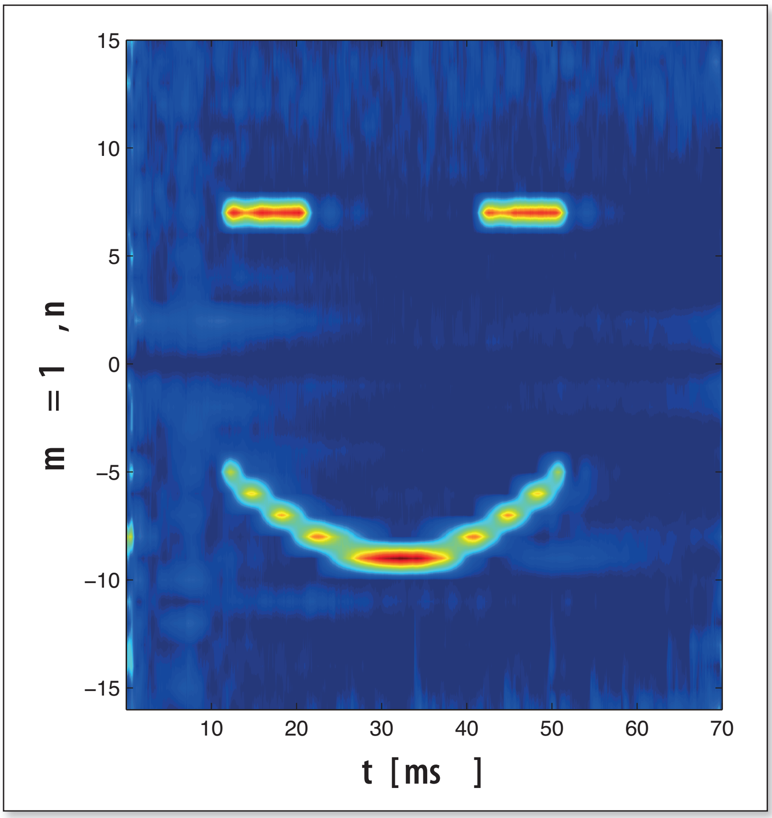
▲ **FIG. 3:** Time evolution of the β parameter (kinetic pressure divided by magnetic pressure, see text), here expressed with its normalized version β_N, in the DIII-D tokamak, with and without real-time control of magnetic stability. The dashed blue curve shows the boundary of the passively stable region: when a β-value higher than set by the passive stability boundary is reached, an instability called Resistive Wall Mode may grow and spoil plasma performance. This is shown by the red curve, where no active control was used. When real-time RWM control is used (solid blue curve) the plasma is actively kept stable and safely runs with higher performance. (Data taken from ref. [11]). Image courtesy of General Atomics-DIII-D

Coils: a robust tool for diverse experiments

Interestingly enough, flexibility in present devices is such that the same kind of coils are used in several tokamaks, like for example JET, DIII-D, ASDEX Upgrade, MAST ▶



◀ **FIG. 4:** In RFX-mod 192 saddle coils (some of them are shown in green) cover the whole plasma surface and are each independently controlled (image courtesy of *Consorzio RFX*) (at CCFE in Culham, UK) and TEXTOR, to actively produce appropriate magnetic perturbation which allow for the control of edge-localized instabilities and for a better mitigation of the plasma-wall interaction (see *e.g.* [13,14]). While plasma control is a challenging task, huge steps have been taken in recent years. Control tasks, which seemed unbelievable only a few years ago, are now performed. A good example is the experience of the European reversed field pinch devices, EXTRAP T2R [15] and RFX-mod [16]. Reversed Field Pinch (RFP) shares similarities with the tokamak, but is confined by a much smaller magnetic field. This has advantages – like an easier technology for coils – but also poses some issues in term of stability. RFPs are at the leading edge in the field of feedback control of plasma stability. For example, RFX-mod, in operation at *Consorzio RFX* in Padova, Italy, is equipped with 192 active coils, which cover the whole plasma surface (Figure 4). This system has allowed a significant improvement of the performance and in particular the discovery of the Single Helical AXis state [17]. Each of the coils is independently driven and feedback controlled, which allows enormous flexibility and control of several three-dimensional instabilities at the same time. The EXTRAP T2-R Reverse Field Pinch in Sweden is also contributing high leverage results (Figure 5). Reverse Field Pinches are providing a working example on how a complex control system can be designed, realized and used reliably. In addition, they prove the value of diversity, since flexible experiments, when cleverly designed, can provide key contribution to the tokamak main line even if they are not tokamaks.



▼ FIG. 5: A playful example of the capability of MHD real-time control in 'Reversed Field Pinch': the figure shows, as a function of time (*x*-axis), the Fourier spectrum (*y*-axis, toroidal mode number) of a magnetic perturbation deliberately imposed with external coils in the EXTRAP T2R device (image courtesy of EXTRAP T2R group, KTH, Stockholm).

Thanks to all this experimental and modeling effort the knowledge in this field is rapidly expanding, with a growing and cross-fertilizing interaction with control engineering world (see for example [18]), which also attracts new students in the field. ITER and the next generation of experiment will then be able to run in much safer condition and with higher performance. 3,2,1…take off. We are ready to fly! ■

About the Author

Piero Martin (1962) is full professor of physics at the Physics Department of the University of Padova, Italy, and head of the fusion science program of the RFX-mod experiment at *Consorzio RFX*. Since 2008 he is leading the Topical Group on "MHD stability and its active control" for the European Fusion Development Agreement (www.pieromartin.it). He is EPS Member and fellow of the APS.

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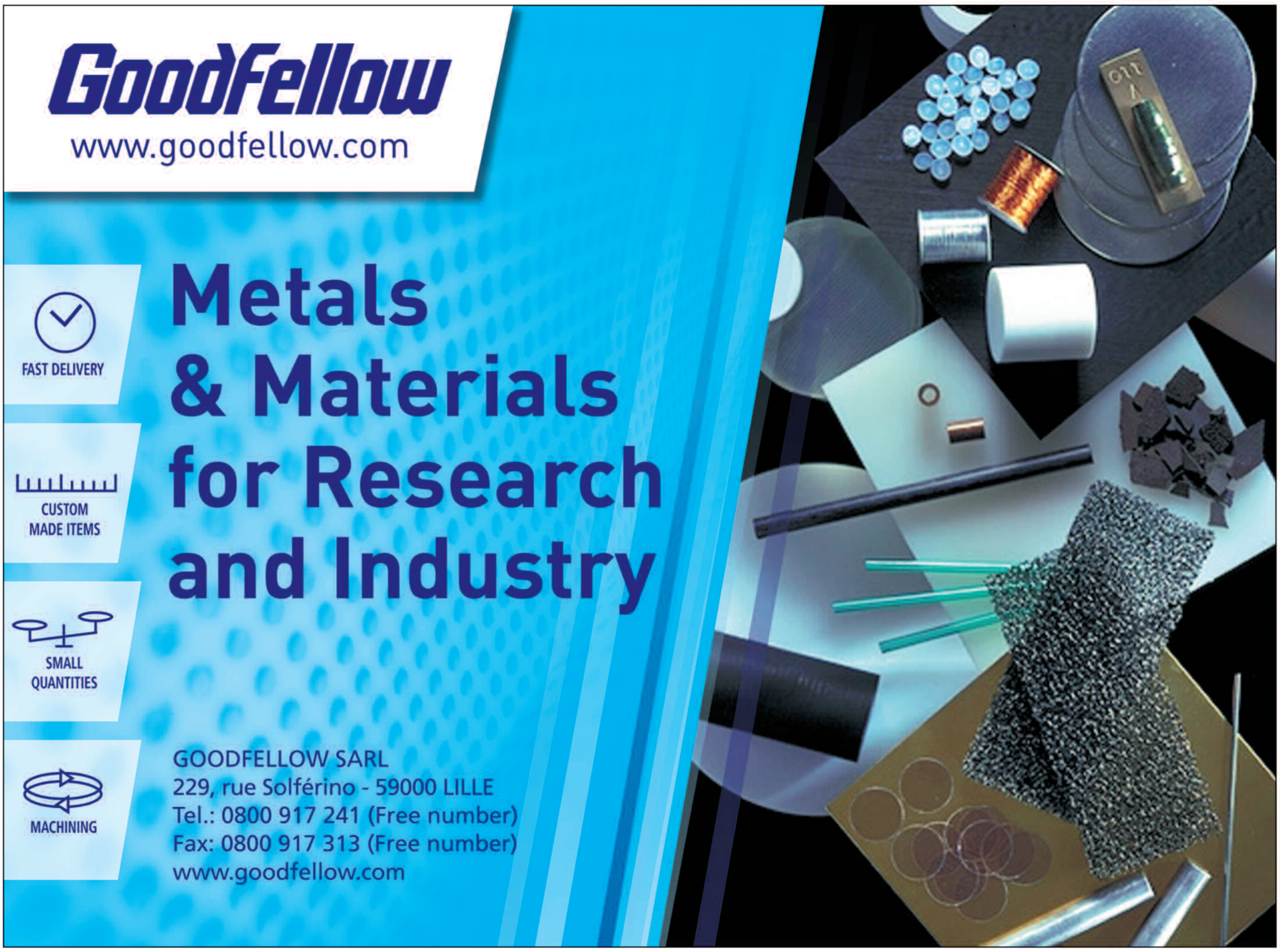
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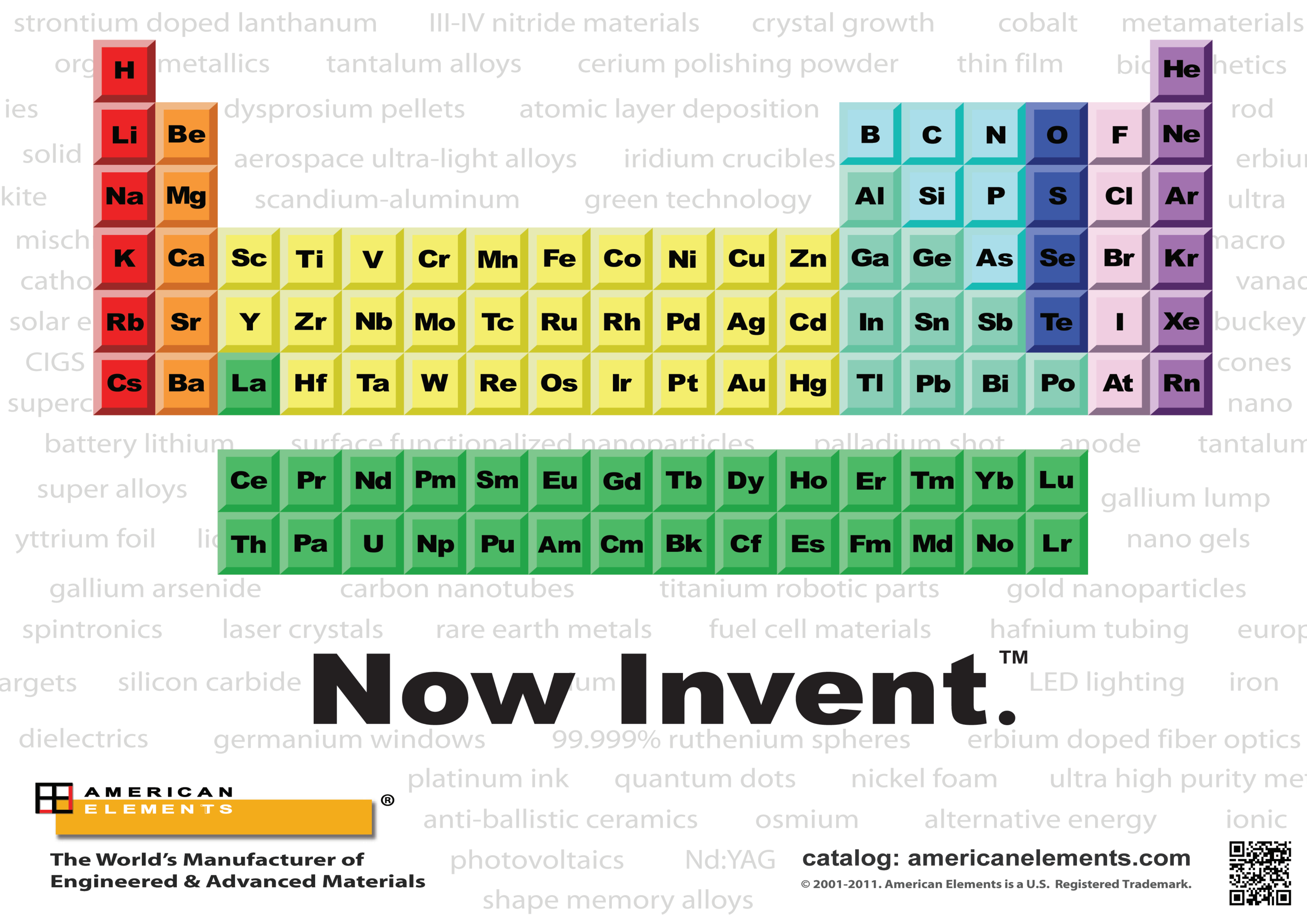
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