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Nobel 2012: trapped ions and photons
Shocks in fragile matter
Sensitive magnetometers and dark states
Advances in radiotherapy
Paleomagnetic investigation of the Pyramids

43/6
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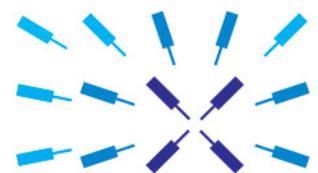
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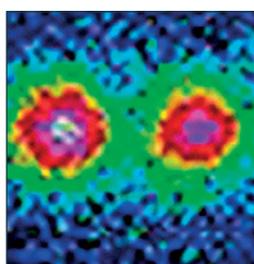
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Cover picture: Impact result from ball in liquid with burst of light.
See p.36 "Shocks in fragile matter". ©iStockPhoto



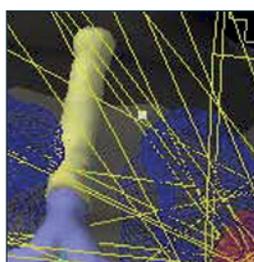
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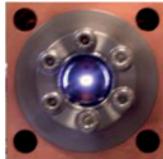
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UNESCO Executive Board supports International Year of Light

It is a tremendous pleasure to report that the proposal to establish 2015 as the International Year of Light has received enthusiastic support from the UNESCO Executive Board, which met in Paris from 13-18 October 2012.

The proposal has been the initiative of the European and African Physical Societies, on behalf of a global partnership of over 40 scientific societies, academies and other institutions. Endorsement by UNESCO is a vital step, which will now lead to placing a formal resolution before the UN General Assembly, the only body actually able to declare worldwide international observances of this sort.

The motivation for the International Year of Light is to highlight the importance of the theme of Light to science, development, education and culture, and these aims were described in more detail in an EPN Editorial last year (42/5, p.3, 2011). It has been a central project of EPS since 2009, and was formally launched in 2011 at a kick-off meeting *Passion for Light* held in Varenna (IT) in conjunction with the Italian Physical Society.

However, items for the agendas of UNESCO and the UN must be led by nations (and not societies). Thanks to our links with the African Physical Society based in Ghana, and with the Museum for Light and the University Nacional Autonoma de Mexico in Mexico, the nations of Ghana and Mexico led the initiative within UNESCO to create a broad consensus of international partner states. Highly active support prior to the board meeting came from many scientific partners of EPS, and special thanks go to our colleagues in China, Italy, New Zealand, Russia, Spain, Tunisia, and the USA, as well as the International Basic Sciences Programme of UNESCO

Highlight the importance of the theme of Light to science, development, education and culture.

headquarters in Paris whose help opened contacts with various national Embassies and Missions.

The finalized resolution for an International Year of Light in 2015 was placed before the Executive Board by Ghana, Mexico and the Russian Federation (Board Members), and New Zealand (UNESCO Member State). UNESCO delegates from Ghana and Mexico introduced the proposal to the Executive Board. The resolution was then adopted by the Executive Board joined by co-signatories from a further 28 Board Members: Angola, Bangladesh, Brazil, Burkina Faso, China, Congo, Cuba, Djibouti, Ecuador, Ethiopia, Gabon, Gambia, Kenya, Indonesia, Italy, Malawi, Nigeria, Peru,

the Republic of Korea, Saudi Arabia, Spain, Thailand, Tunisia, the United Arab Emirates, the United States of America, Venezuela, and Zimbabwe. Other Member States of UNESCO supported the initiative: Hungary, Serbia and South Africa.

Following this endorsement by UNESCO, EPS will work with the many other partners to begin detailed planning of outline activities for 2015 along with a formal request to the United Nations General Assembly. The most recent version of the project prospectus can be downloaded from the EPS website. ■

■ **John Dudley**
Vice-President of the EPS



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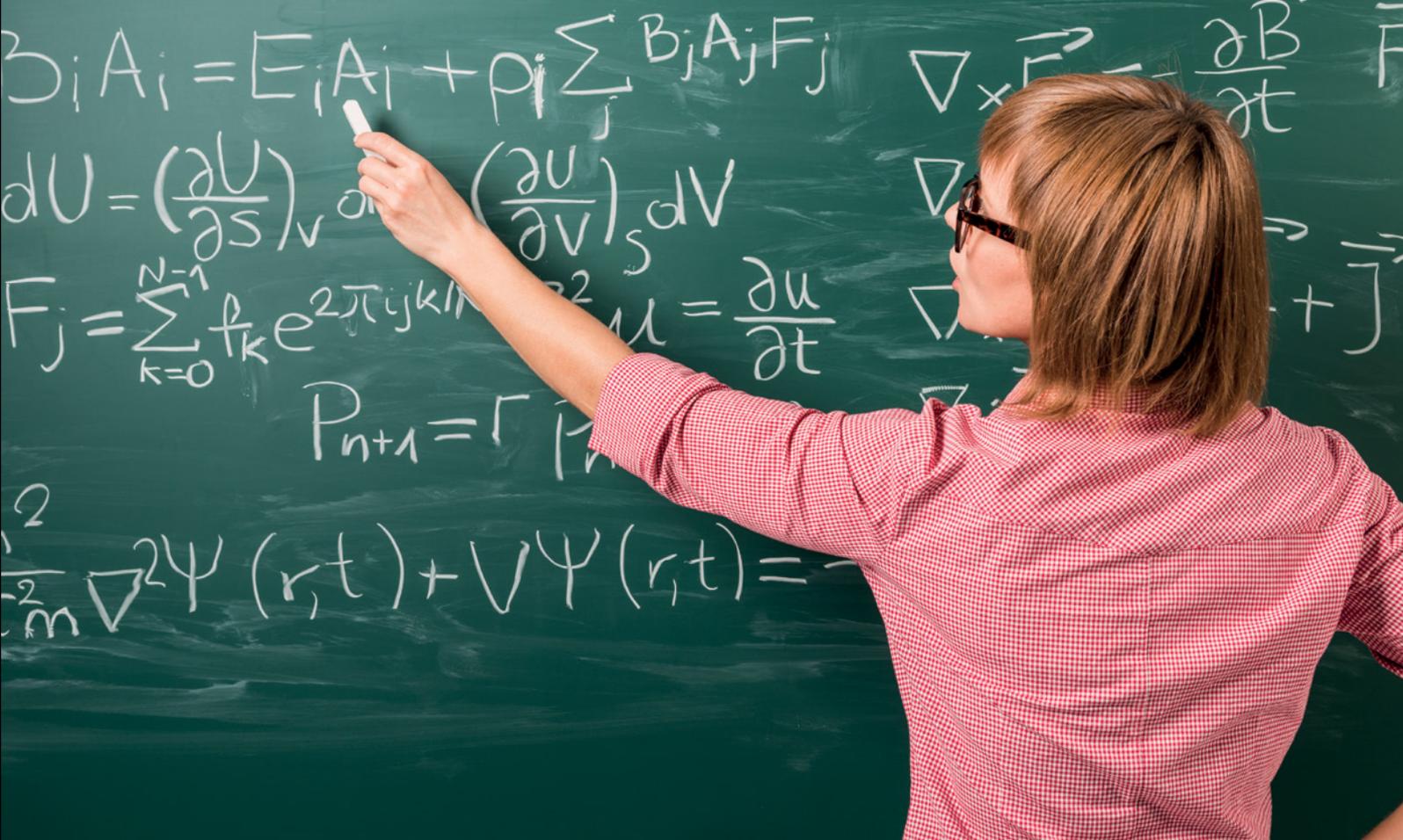
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Dépôt légal: November 2012

Executive Committee Meeting: **summary**

- The EPS Executive Committee met at the Ettore Majorana Scientific Centre in Erice, Italy, October 23-24.
- The ExCom met with the EPS' Technology and Innovation group, which held a kick-off meeting in its renewed form at the same location. The ExCom also discussed with the chair of the ERC scientific council, it shares ERC's concern about the Horizon2020 budget.
- The ExCom is proud to announce that the International Year of Light 2015, which has emerged from EPS, has received enthusiastic support by UNESCO's executive board (p.03).
- The ExCom was informed about different ongoing projects with international partners (APS, CPS, EuChems, EMS, SESAME, IAEA, ...). From 2013 on, an International Affairs Committee will focus on EPS' relations with partners outside Europe. As a follow-up of the 1st EPS Conference on Physics for Development, a Task Force North-South was created in order to coordinate future activities in this domain.
- The ongoing review of Action Committees has produced general rules for all standing committees, which are to be included in the revised terms of reference of each committee.
- The ExCom decided to merge the existing conference and grants committees into a single Conference Committee, which will be responsible for the distribution of all grants linked to conferences. All proposals for EPS' different honours (except divisional prizes) will be handled by the newly created Distinction and Awards Committee. The standard rules for ACs and the actual renewal process will be presented at council 2013.
- The ExCom together with the Equal Opportunities Committee will define a conference charter for all EPS conferences.
- The ExCom discussed recent evolutions of the Open Access process. It expressed concern about the implementation of the author-pays model, in particular during the transition period. EPL will not be part of the SCOAP3 consortium.
- The Physics Publishing Alliance (PPA-PER) is in its starting blocks, its launch is expected very early in 2013. EPL will appoint a new Editor in Chief before the end of the year.
- The ongoing study on "Physics for the Economy" includes data on 27 EU countries; a tentative publication date is January 2013.
- The mode of operation of the Forum Physics and Society, which constitutes an important think-tank for EPS, was discussed. FPS wants to be more pro-active in view of global challenges, various subjects have been proposed for its next edition scheduled for autumn 2013 in Serbia.
- A member questionnaire will soon be sent to IMs in order to make available better data on the involvement of members in different issues (outreach, European affairs, ...).
- The ExCom was informed about the (sound) state of the budget, and the evolution of salaries at the EPS secretariat (no pay-rise).
- The next ExCom meeting is scheduled for 1-2 February 2013 at the synchrotron facility Alba, Barcelona/Spain. Council 2013 will be held on 5 and 6 April in Strasbourg/France. ■

■ **Martina Knoop**
EPS Honorary Secretary



Position paper on physics education by the EPS Physics Education Division

Effective and inspiring education in all subjects and at all levels – school, university and lifelong – is important to the future of European culture, commerce and industry as well as to scientific research. In this context the Physics Education Division of European Physical Society (EPS PED) has identified effective physics education, as vital to ensuring adequate knowledge and skills for every citizen aspiring to active participation in democratic society, as well as to the supply, training and updating of a wide range of scientists and engineers.

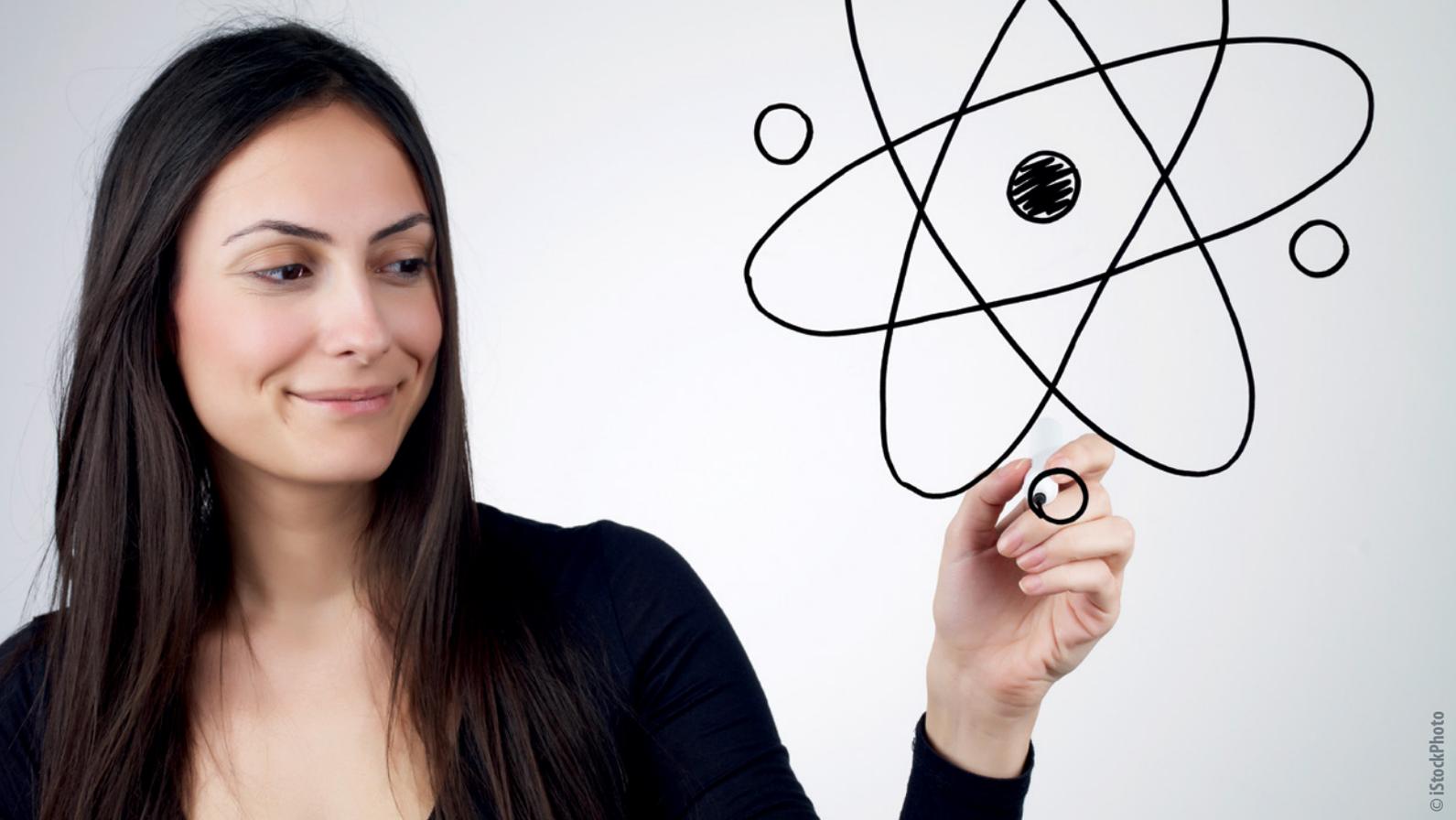
Despite the generally acknowledged importance of physics education, and the special attention paid to it in several European countries, there are a number of points of specific concern that the EPS PED wishes to highlight and draw to general attention.

First, with regard to physics education in schools: EPS PED is concerned

▲ Equations...
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that students in all European nations should be engaged in an accurate and useful introduction to physics, as a distinct discipline, by motivated and well-trained teachers. There are divergent views across Europe about the desirability of teaching the different scientific disciplines separately or together as a combined subject. However there is general agreement that it

is important for students to properly appreciate the differences in method that characterise the various sciences, particularly at the upper level. The solving of real-world scientific problems often requires a multidisciplinary approach but the strength of that approach frequently arises from the differences between the separate disciplines rather than their similarities. It



is for this reason that all those engaged in the teaching of physics, whatever their individual back-grounds, should display a robust understanding of physics knowledge that is broadly-based, authoritative and up-to-date. In particular, school students should appreciate that physics is not a disjoint collection of facts, rules and laws but rather a coherent approach to making sense of the physical world, utilising its resources and solving problems that range from the purely academic to the most pressingly practical. For this to be the case, it is vital that programmes for both the initial and the continuing education of teachers should be capable of attracting students of the highest quality, that they should fully reflect the latest developments in physics education research, educational technology and pedagogical methodology, and that they should be informed by the most recent advances and applications of physics. This emphasis on rigorous evidence, coherence, modernity and relevance should, of course, also be reflected in school curricula, syllabi and teaching specifications,

School students should appreciate that physics is not a disjoint collection of facts

which need constant attention and purposeful refreshment.

Second, with regard to universities: despite the currently buoyant situation regarding the recruitment of physics students, the proportion of students entering and continuing with university-level physics studies had previously been declining for almost two decades. Such a decline threatens the flow of physicists into industry, academic research and teaching, and thereby challenges future technological innovation and science-based economic development. Ensuring that such a decline does not recur calls for a range of ongoing measures but an important element is certain to be an improvement in educational physics. Against this background, EPS PED is concerned to note the relative lack of specialised university-level physics education research groups in Europe and the corresponding absence of a clear career path for those primarily interested in the evidence-based improvement of undergraduate and post-graduate physics education. This situation now puts Europe in sharp contrast to the US, where decades of

unbroken support for university-level physics education research by the National Science Foundation and other bodies has produced a highly active university-level physics education research community with clear routes of progression from graduate student to post-doctoral researcher to tenured faculty position, and equally clear impacts on the university curriculum and the methods used in university teaching. EPS PED urges that throughout Europe steps should be taken by those responsible for the funding of scientific research to ensure that opportunities are created for the establishment and support of high quality university-level physics education research groups with a mission to contribute to evidence-based innovation in the course structures and resources available for physics learning as well as the broader understanding of the nature and role of physics teaching and learning. This is a field of applied physics research in which Europe has demonstrated strength but will need additional programmes of targeted research funding and increased flexibility on the part of

many more university physics departments if it is to compete successfully in the international research arena.

Third, with regard to lifelong learning and public outreach; EPS PED is convinced that a proper understanding of physics, including the opportunity to gain insight into the nature and significance of the latest developments and their impacts on society and scientific culture, is a cornerstone of effective European citizenship, an important element of social inclusion, and crucial to meaningful participation in public discourse and decision making. EPS PED encourages those with the knowledge and talent to promote the public understanding of science to do so. It also encourages institutions to support that effort and to help remove whatever barriers stand in its way. Proactive public engagement is essential if informed public support for physics is to be sought and achieved. The EPS PED is particularly aware that many efforts to promote public understanding are limited in their impact by linguistic considerations. Consequently, EPS PED urges the harnessing of resources to enable the best and most effective outreach activities to be publicised throughout Europe and made available to the widest possible part of the European populace. Good ideas can transcend national boundaries even when good words cannot.

In all these concerns, the importance of evidence gathering and interpretation has been stressed. In the domain of primary and secondary education, where much work of this kind is already carried out, the investigative studies by the Programme for International Student Assessment (PISA, [1]) may be taken as exemplary. Also worthy of note are the efforts of the Eurydice Network and particularly its Eurypedia [2], which aims to make available the kind of information on European educational systems and policies that researchers need. At higher levels, initiatives such as the E.C. flagships 'Youth on the Move' [3] and 'Innovation Union'

[4] provide examples of thoughtful policy development with a potential to promote lasting action with positive educational impact. The EPS PED has had a direct involvement in this domain through the European Mobility Scheme for Physics Students, which started in the 1990s, and continue with its current efforts to support student and staff mobility. Complementing these are the EPS-backed investigations into the implementation and impact of the ongoing Bologna process on physics studies at the Bachelor, Master and Doctoral levels, and the corresponding 'EPS Specifications of University Level Physics Programmes' at the three levels [5]. In relation to outreach and public engagement, the EPS PED is again putting its principles into practice through its Forum Physics and Society, as evidenced by reports such as 'Science Journalism and Scientific Communication' [6]. Recently gathered evidence relating to a range of issues in educational physics may be found in the book 'Teaching Physics in Europe' [7] produced by the EU funded STEPS TWO project, which, like the EUPEN network that preceded it, has been consistently supported by the EPS. Welcome as this work is, its chief significance may actually be the indication it provides of the vast amount that remains to be done in developing, analysing and utilising a comprehensive, representative and up-to-date account of physics education on a European scale. Improving the quality of physics education at all levels is vital to the future of Europe; such activity sustains our ability to identify and address problems analytically and to develop solutions through the application of rigorous methodology.

EPS PED encourages those with the knowledge and talent to promote the public understanding of science to do so.

The initial and in-service education of teachers is an important part of this, as is the improvement of school curricula and the development and evaluation of new teaching methods. Also important is the improvement of university physics teaching, lifelong learning and outreach to the general public. Underpinning all this is the development of research in physics education, particularly that carried out in physics departments. EPS PED supports all these efforts and is especially active in helping to promote regular contacts between physics educators at all levels and those working at the frontiers of physics. It encourages others to recognize the importance of its efforts to improve European physics education and invites them to participate in achieving this goal. ■

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- [1] Programme for International Student Assessment (PISA): see www.pisa.oecd.org
- [2] Eurydice: see http://eacea.ec.europa.eu/education/eurydice/index_en.php and follow the link to the Eurypedia
- [3] Youth on the Move: see <http://ec.europa.eu/youthonthemove/>
- [4] Innovation Union: see <http://ec.europa.eu/research/innovation-union>
- [5] EPS Specifications for University Level Physics Studies: see the EPS website www.eps.org/?page=studies_reports
- [6] Science Journalism and Scientific Communication: see www.eps.org/resource/resmgr/activities/eps_fps_2010_communication.pdf
- [7] Teaching Physics in Europe: Edited by L. Tugulea *et al.*, Ars Docendi Press, 2011 ISBN 978-973-558-595-2 and available to download from www.stepstwo.eu

ERRATUM

We apologize for name exchanges in the pictures of three EPS Plasma Physics Division laureates at the lower part of pages 4 and 5, in the EPN 43/5 issue. See the pictures on the right. ■





EPS HISTORIC SITES

The Goldfish Fountain of the Physics Institute of Panisperna Street

Fermi Centre – Rome, Italy

On April 19-20, 2012 the 'Second Conference of Fermi Centre Projects' took place in Rome, Italy, in the temporary headquarter of the Centre (Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi"), presently located on the premises of the Italian Ministry of Interior.

The Conference focused on the presentation of the results and perspectives of advanced interdisciplinary and multidisciplinary research projects underway at the Centre. About 250 scientists, researchers and university professors, took part in this gathering, together with a number of high school teachers and students. Since its creation, under the presidency for over

10 years of Antonino Zichichi (also President of the European Physical Society in 1978-1980), the Fermi Centre has implemented important research projects, promoted the dissemination of scientific culture and given top priority to talented young scientists.

A plenary session took place in the morning of April 20, in the Conference Hall of the Ministry of Interior. The session

hosted a solemn ceremony designating the 'Fermi fountain' as an EPS Historic Site in the presence of the President of the Italian Republic, Giorgio Napolitano, and of the Minister of Interior, Annamaria Cancellieri, the Minister of Cultural Heritage and Activities, Lorenzo Ornaghi, and the Undersecretary of State for Education, University and Research, Elena Golini.

▼ The 'Fermi fountain', i.e. the goldfish fountain of the Physics Institute of Panisperna Street in Rome, presently under refurbishment, and in the foreground the EPS commemorative plaque (Image: David Lee/EPS)



The Fermi Centre is one of the youngest Italian scientific institutions and it will soon take up permanent residence in the former Physics Institute of Panisperna Street, in Rome, still embedded in the building complex of the Ministry of Interior, and presently under refurbishment. The 'Fermi fountain' is in the garden of this Institute and is the goldfish pond where Fermi performed his world famous experiment.

The plenary session was opened by Minister of Interior Cancellieri, and by the President of the European Physical Society and of the Fermi Centre, Luisa Cifarelli. A keynote speech illustrating the fundamental scientific research work by Fermi in Rome at the Institute of Panisperna Street in the thirties of last century was delivered by A. Zichichi. The crucial, symbolic importance of 'Fermi fountain' in the history of physics was highlighted in his address. Minister Cancellieri underlined how the involvement of the EPS, testifying the determination since 1968 of European scientists to strengthen the cultural unity of science in Europe, significantly enhanced the importance of the event. The morning session of the Conference – which had of course a very large media



▲ The entitlement of 'Fermi fountain', under heavy rain. In the foreground, the jet of the fountain; Under the awning, L. Cifarelli illustrating the plaque to the President of the Italian Republic G. Napolitano (on her left) in the presence of various authorities (partially hidden behind her, A. Zichichi). (© Image: David Lee/EPS)

coverage – ended up with a visit of the Head of State to the 'Fermi fountain', the restoration of which has almost been completed, and with the unveiling of a commemorative marble plaque sealing the fountain as Historic Site of the European Physical Society, with a brief but significant citation reading as follows:

Using the water of the goldfish fountain of his Institute, Enrico Fermi established for the first time, in the afternoon of 22 October 1934, the crucial role of

hydrogenous substances on neutron induced radioactivity, thus opening the way to the use of slow neutrons in nuclear fission chain reactions.

The 'Fermi fountain' was the first EPS Historic Site entitlement event since the beginning of this initiative (see EPN 43/3 2012, Editorial), the first example of 'scientific heritage' that the EPS would like to signal and stamp. ■

■ **Luisa Cifarelli**
President of the EPS



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UP 2012

XVIIIth International Conference on Ultrafast Phenomena (www.up2012.org)
9 - 13 July 2012, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

In the past ten years, the field of ultrafast phenomena has breathtakingly progressed, thanks in part, to the development of new sources of ultrashort pulses of electrons and light, such as high harmonic generation, few-cycle optical pulses, and large-scale sources of short wavelength radiation (synchrotrons or x-ray free electron lasers).

The spectral range of ultrashort pulses of radiation goes now from the Terahertz to the vacuum UV and the soft and hard X-rays. Together with the development of new methodologies, *e.g.* multidimensional spectroscopies from THz to UV, THz spectroscopy, electron-based techniques (EELS, PINEM, *etc.*), these great leaps forward are delivering an impressive degree of insight into phenomena both within and between atoms.

At the same time, the flexibility in methodologies has opened new perspectives for major applications in the fields of solar energy, photo-catalysis, molecular electronics, optoelectronic devices, biomimetic devices, *etc.* Last but not least, improvements in theoretical tools and in computational power bridge the gap in the description of small quantum systems and extended molecular systems up to nanostructured materials exposed to ultrashort light pulses. The Ultrafast Phenomena Conference (UPC) is the largest gathering of a multidisciplinary group of scientists and engineers involved with ultrafast science and technology.

The 18th UPC held in Lausanne last July clearly reflected these trends and provided an impressive show of recent achievements in all ultrafast phenomena. It was the largest so far with 580 submissions among which 28 programme committee¹ members selected 434: 12 invited talks, 173 oral and 249 poster contributions. The number of attendees reached 483 (64 women, 143 students), including 23 industrial exhibitors.



▲ Poster session at the 18th ICUP

7 plenary and 20 parallel sessions covered the areas of X-ray spectroscopy, attosecond spectroscopy, X-ray and electron diffraction, multidimensional vibrational and electronic spectroscopies, high-order harmonics pulse generation, X-ray free electron physics and nonlinear optics, along with ultrafast studies of solution chemistry, water hydration and interface dynamics, strong field effects in molecules, semiconductor and organic solids, biomolecules and photobiology, photosynthesis, metamaterials, spin, charge and lattice dynamics in highly correlated systems, and nanosystems. The posters stayed in place throughout the conference, providing a great stimulus for discussion in 3 sessions. Several contributions on instrumentation and applications of femtosecond laser technology were posted in the same area.

Finally, a post-deadline session was organised to present 8 “hot” papers out of 28. The closing lecture of the conference was given by the 1999 Chemistry Nobel Prize winner Ahmed H. Zewail, who presented his latest results on ultrafast electron microscopy, spectroscopy and diffraction. A book of Proceedings is in press by EDP-Sciences.

The conference was organised by the Ecole Polytechnique Fédérale de Lausanne, the Université de Lausanne and the European Physical Society. We acknowledge the support of these 3 institutions and of the various sponsors.

Pictures of the conference at: http://mediatheque.epfl.ch/modules.php?include=view_album.php&file=index&name=gallery&op=modload&set_albumName=albu06. ■

■ M. Chergui and A. Taylor,
General Chairs

■ R. de Vivie-Riedle, S. Cundiff
and K. Yamanouchi,
Programme Chairs

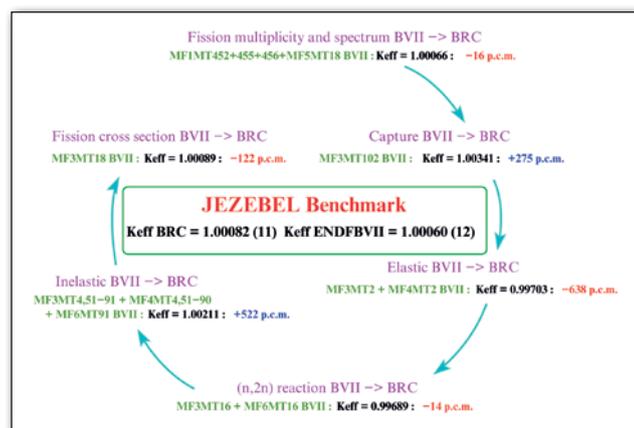
¹ R. de Vivie-Riedle, Ludwig-Maximilians Univ. of Munich, Germany, S. Cundiff, NIST, USA and K. Yamanouchi, Univ. of Tokyo, Japan, Programme Chairs.

Highlights from European journals

NUCLEAR PHYSICS

Coherent investigation of nuclear data at CEA DAM

A body of work accomplished by the CEA/DAM is reviewed to determine accurate nuclear reaction cross sections for use in neutron transport codes. This work integrates theory and modeling, experiment, computer simulation, and statistical analysis. It involves researchers who thrive on multidisciplinary work, and who are motivated to achieve realistic simulation predictions in nuclear technology applications. Not only has the group succeeded in creating databases of accurate cross sections, but, in every aspect of the work, significant progress has been made in the understanding of the underlying nuclear physics.



▲ Jezebel (a plutonium sphere) reactivity induced by components of the evaluated BRC09 and ENDF/B-VII.0 ^{239}Pu file, demonstrates that two different evaluated data sets predict the same K_{eff} criticality for different underlying reasons; one or more of them (probably both) are in need of improvements.

This unique analysis of advances in applied nuclear reaction physics, includes, notably: (1) Fission and inelastic scattering using detailed nuclear structure descriptions of actinides; (2) Integral simulations of critical assemblies that reveal compensating errors between different reaction channels (Fig) – this CEA discovery is now motivating the broader community to identify and eliminate deficiencies; (3) Identification of limitations on the applicability of the surrogate method for neutron capture. CEA/DAM contributes to the Joint Evaluated Fusion and Fission File (JEFF3.1), the database that is used widely in European nuclear technologies. It collaborates closely with related efforts in the USA (ENDF/B-VII) and Japan (JENDL). The authors show useful comparisons of their work against those based on ENDF/B-VII.0 and JENDL3.3-08, demonstrating the quality of these various capabilities. CEA/DAM strengths lie, in particular, in bringing microscopic theoretical insights in fission,

coupled-channel optical model, and inelastic scattering to advance the quality of their application nuclear databases. ■

■ E. Bauge plus 28 co-authors,

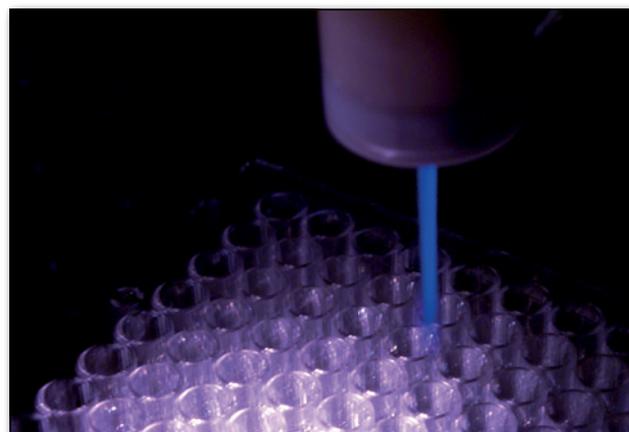
'Coherent investigation of nuclear data at CEA DAM: Theoretical models, experiments and evaluated data', *Eur. Phys. J. A* **48**, 113 (2012)

BIOPHYSICS

Plasma killing of Leukemia cells

Plasmas are ionized gases that contain a mixture of electrons, ions, and neutrals. Plasmas are generated by adding some form of energy to a neutral gas. The most common method to generate plasma is to subject a gas to high level of electrical stress, which initiates an electronic avalanche and thus generating electrons, ions, and molecular fragments such as radicals and other reactive species. Low temperature plasmas in particular produce chemical species including reactive oxygen species (ROS) and reactive nitrogen species (RNS). ROS and RNS exhibit strong oxidative properties and can potentially trigger signaling pathways in biological cells. For example oxidation of the lipids and proteins that constitute the membrane of biological cells leads to the loss of their functions. In such an environment, bacterial cells were found to die within minutes or even seconds. In eukaryotes, very low doses of low temperature plasmas were found to help the proliferation of some skin cells and at slightly higher doses, plasmas can induce apoptosis, or programmed cell death, opening the possibility to use plasma technology against cancerous cells. In this study, we investigate the effect of low temperature atmospheric pressure plasma towards the progression of

▼ Cell suspensions in multi-well plate being exposed to the low temperature plasma plume emitted by the Plasma Pencil.



cancerous human T-cell leukemia cells. The source of low temperature plasma is the plasma pencil, which utilizes short duration high voltage pulses. Our data shows that cell morphology and cell viability was affected in a dose-dependent manner after treatment with low temperature plasma. The outcome of this study revealed that the effect of plasma exposure was not immediate, but had a delayed effect and increasing the time of plasma exposure resulted in increased leukemia cell death. ■

■ **N. Barezki and M. Laroussi,**

'Dose dependent killing of Leukemia cells by low temperature plasma', *J. Phys. D: Appl. Phys.* **45**, 422002 (2012)

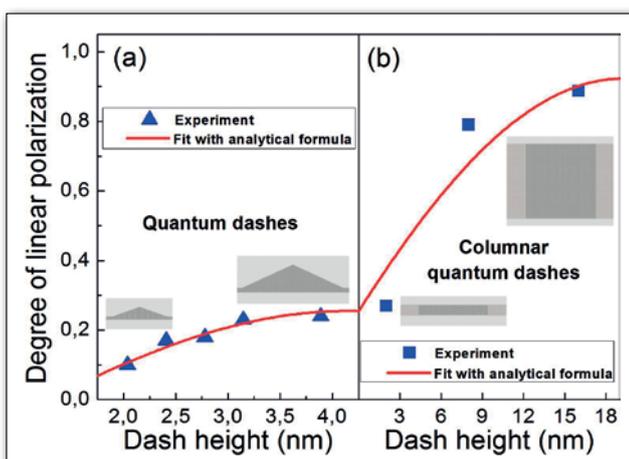
APPLIED PHYSICS

Polarization of the surface emission from quantum dashes

We propose a novel approach to control the polarization of surface emission from quantum-dot-like objects - an issue of great interest for optoelectronic applications where both fully polarized and polarization-insensitive gain is highly desired. The experimental study of strongly asymmetric In(Ga)As/InP nanostructures in a wide range of geometries verifies our theoretical modelling.

A simple analytical formula describing the dependence of the degree of polarization on the nanostructure height is established, which is of practical importance when aiming at fabricating structures with predictable polarization properties without sophisticated atomistic modelling. Furthermore, it shows that the observed changes in polarization are a consequence of the valence band states mixing. It appears that the surface emission is enhanced for the polarization along the in-plane larger dimension and sensitive to the lateral shape anisotropy. Its saturation for highly asymmetric geometries makes fully polarized emission unachievable solely by the lateral symmetry control.

▼ Degree of the linear polarization for standard (a) and columnar quantum dashes (b) versus their height (symbols); solid lines show a theoretical dependence. The respective cross-sections are schematically shown for reference.



Our study reveals very high sensitivity of the surface emission polarization to the object height and demonstrates its continuous height-driven enhancement up to 0.9 for so called columnar quantum dashes – a record value for any epitaxial system. It is possible only through the combination of a strong in-plane anisotropy and an enhanced nanostructure height – the condition shown to be essential to fully tailor the polarization properties of the surface emission. Moreover, it opens up a possibility to combine unpolarized edge emission and strongly polarized surface emission in one device via its active region engineering. ■

■ **Anna Musiał and 11 co-authors,**

'Height-driven linear polarization of the surface emission from quantum dashes', *Semicond. Sci. Technol.* **27**, 105022 (2012)

OPTICS

Statistical uncertainty in line shift and width

A general statistical analysis (classical statistics) is a common experimental procedure to determine the uncertainty of photon statistics in measuring a line shift and width. Given the importance of taking into account the background as well as the measured signal in any photon measurement, the paper describes both the perfect spectrometer measurements with a zero and nonzero background as well as the case of an imperfect spectrometer.

More complex line shapes are reviewed and the problems of their evaluation are discussed. The paper then addresses all situations when, instead of making continuous measurements, modern detection arrays with finite-width wavelength bins (pixels) are employed.

By providing detailed mathematical descriptions for the line width and shapes discussed with either zero or nonzero background subtraction, this work will be of considerable use for many researchers in assessing their experimentally obtained results. ■

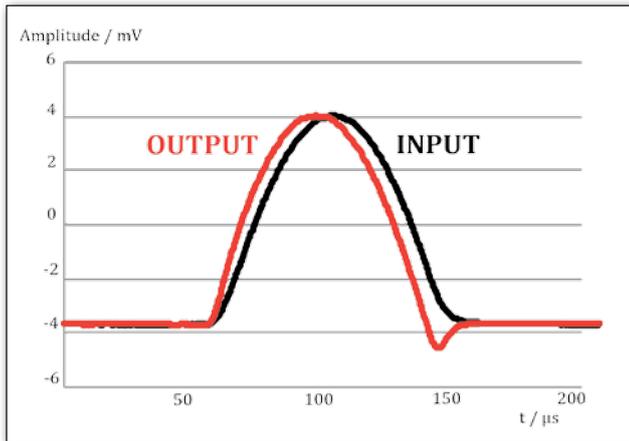
■ **I.H. Hutchinson,**

'Statistical uncertainty in line shift and width interpretation', *Eur. Phys. J. Plus* **127**, 81 (2012)

APPLIED PHYSICS

Giant negative group time delay by microwave mode adaptors

In 1960 Brillouin wrote a footnote in his famous book on 'Wave Propagation And Group Velocity' (p.79): "The negative parts of the (theoretical) group velocity have no physical meaning. A negative velocity shows the maximum of the group at the output before it has entered the input of a special medium". However, since 1985 several



▲ Input (black) of a pulse traversing 20 m adaptor cavity and its output (red). The adaptor cavity delay is ≈ 2200 ns and leads to a negative time shift.

physicists measured a negative delay and thus a negative group velocity at a sharp molecular resonance. Recently a giant negative group time delay was observed in a medium of two microwave mode adaptors separated by a 20 m long waveguide when they are not parallel aligned. Instead of +60 ns vacuum time $-2.2 \mu\text{s}$ were measured for the same distance. Such adaptors are used in communication technology to transform rectangular waveguide modes into circular waveguide modes, for instance, in the case of TV reception via satellite. The strange behaviour is based on a 90° shift of the linear polarization of the superimposed right and left circular wave modes in the case of a perpendicular adaptor orientation. Remarkably, the polarization shift of 90° takes place at each reflection and in this way makes the shifted adaptors to reflectors, whenever the distance between the adaptors equals a multiple of half the wavelength. ■

■ **A. Carôt, H. Aichmann and G. Nimtz,**
'Giant negative group time delay by microwave adaptors',
EPL **98**, 64002 (2012)

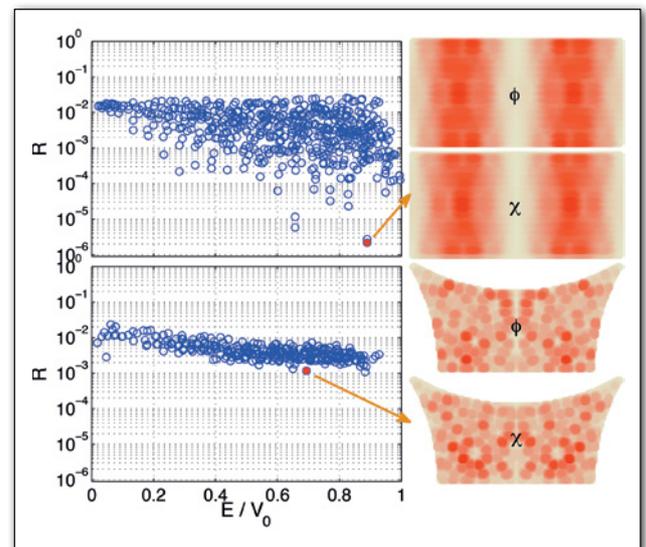
QUANTUM PHYSICS

Effect of chaos on relativistic quantum tunnelling

What can classical chaos do to a quantum system is a fundamental issue, which is highly relevant to a number of branches in physics. The field, named quantum chaos, has been active for at least three decades, where the focus has been on non-relativistic quantum systems described by the Schrödinger equation. With respect to relativistic quantum systems governed by the Dirac equation, Berry and Mondragon were the first to investigate the energy-level statistics of a chaotic neutrino billiard. The present work presents an astonishing case of how chaos may affect relativistic quantum tunnelling dynamics. By developing an efficient method to solve the Dirac equation in the setting where relativistic quantum particles can tunnel

between two symmetric cavities through a potential barrier, it appears that chaotic cavities can mostly suppress the spread in the tunnelling rate. Specifically, when the classical dynamics is integrable, the tunnelling rate for any given energy can assume values in a range that increases with energy (fig. upper panel). However, when the cavities allow fully chaotic dynamics, spread in the tunnelling rate is strongly reduced (lower panel). This suppression can be explained by the emergence of certain class of pointer states (fig.). A remarkable feature, which does not arise in non-relativistic quantum tunnelling systems, is that substantial tunnelling exists even when the particle energy nears zero. This is a consequence of the relativistic quantum phenomenon of Klein tunnelling. The authors found similar results in tunnelling devices made of graphene, implying that the field of relativistic quantum chaos can be highly relevant to the development of such devices. ■

▼ Tunnelling rates and local density of states for massless Dirac fermion in integrable and chaotic double-well systems where ϕ and χ are two components of Dirac spinor.



■ **Xuan Ni, Liang Huang, Ying-Cheng Lai and L.M. Pecora,**
'Effect of chaos on relativistic quantum tunnelling',
EPL **98**, 50007 (2012)

BIOPHYSICS

Giraffes are living proof that cells' pressure matters

This article presents a model that describes dividing cells within human tissues from the perspective of physicists, and could help further the understanding of cancer growth. It explores the relative impact of the mechanical pressure induced by dividing cells in biological tissues, and could have significant implications for the understanding of cancer growth.

The authors create a two-component mathematical model accounting for both the cells and the fluid caught in between.



▲ If homeostatic pressure within biological tissues were proportional to fluid pressure, giraffes could not exist.

On the one hand, cells are modelled as behaving like a dividing fluid subject to expansion. On the other hand, the interstitial fluid is akin to an ideal fluid that cannot be compressed. This model is designed to elucidate the nature of mechanical pressure exerted upon dividing cells by their surrounding tissues, referred to as homeostatic pressure.

It replaces a previous single-component model they developed last year. Its assumption: the homeostatic pressure is proportional to the fluid pressure within the tissue. If that were the case, very tall organisms such as giraffes could not exist, because the cells in their lower body would die under pressure.

Thanks to the two-component model, the authors find that it is the cells' pressure and not the interstitial fluid's pressure that influences the level of cell division. Going one step further, they pinpoint the range of fluid pressure required to drive cell flow within the body. Such models could help gain a greater understanding of the importance of the disruption of homeostatic pressure in biological tissues caused by cancer cells that are characterised by abnormal levels of cell proliferation. ■

■ **J. Ranft, J. Prost, F. Jülicher and F. J. Joanny,**

'Tissue dynamics with permeation', *Eur. Phys. J.E* 35, 46 (2012)

PLASMA PHYSICS

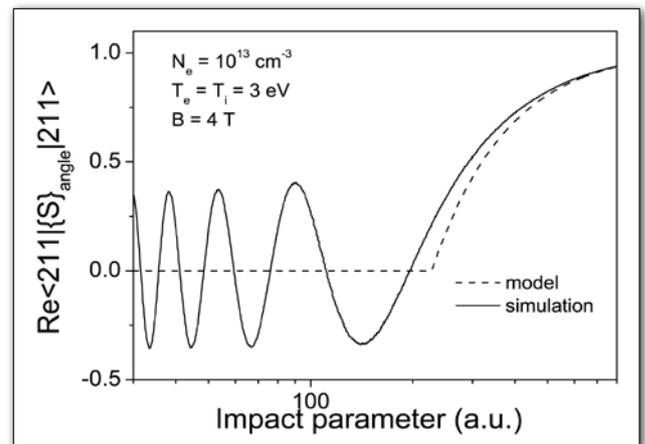
Probing thermonuclear plasmas with atoms

Controlling the plasma in magnetic fusion experiments remains a major challenge, in particular, with the advent of large-scale facilities such as the ITER tokamak (presently under construction in Cadarache, France). In order to support the operation of the machine, an extensive set of measurements is planned. Passive spectroscopy is a convenient diagnostic tool since it is non-intrusive and quite easy to implement experimentally. For instance, the hydrogen Balmer α line ($3 \rightarrow 2$ transition, visible range) is considered as a way to measure fluxes of the hydrogen

isotopes (H, D, T) in the divertor region (see "Progress in the ITER Physics Basis", *Nucl. Fusion*, special issue, 2007).

The plasma density in the ITER divertor will be large enough to make Stark broadening observable on the spectral lines of hydrogen isotopes. Such neutral particles survive in the cold and complex edge plasma and their spectra provide invaluable information on its conditions. We have shown that the case where the Stark perturbation can be associated with a series of binary collisions with ions (impact approximation, see the work of Hans Griem, Plasma Spectroscopy) may be adapted to conditions foreseen in ITER. This model is based on an estimation of the S-matrix for atom-perturber collisions using a series expansion for large impact parameters (weak collisions) and, on the other hand, using a cut-off accounting for the oscillating behaviour of the wave-function in the case of small impact parameters (strong collisions). Confrontations with computer simulations indicate that the model is a good candidate for accurate diagnostics in the ITER plasma. ■

▼ Computer simulations serve as a test of analytical line shape models. Here, we compare calculations of the angle-averaged S-matrix for a quasi-elastic atom-ion collision. The model and the simulation lead to the same line shape.



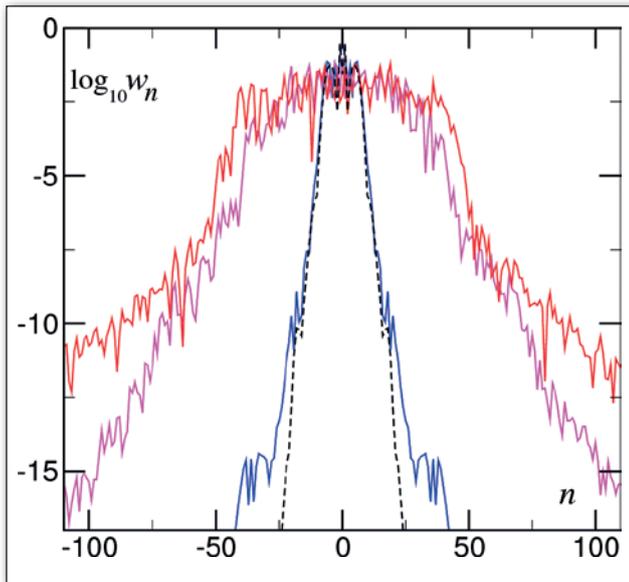
■ **J. Rosato, H. Capes, L. Godbert-Mouret, M. Koubiti, Y. Marandet and R. Stamm,**

'Accuracy of impact broadening models in low-density magnetized hydrogen plasmas', *J. Phys. B: At. Mol. Opt. Phys.* 45, 165701 (2012)

CONDENSED MATTER

Turbulences at a standstill

Energy flowing from large-scale to small-scale places may be prevented from flowing freely in specific conditions, similar to those found in disordered solids. In the present article, the author presents an exception he found in a model of turbulence, indicating that there are energy flows from large to small scale in confined space. Indeed, under a specific energy threshold, there are no energy flows, similar to the way electron currents and energy spreading are stopped in disordered solids.



▲ Probability distribution w_n over linear wave modes n in (2) at time 10^7 for $\beta = 0:0$ (dashed black), $0:05$ (blue), $0:5$ (magenta), 1 (red)'

The author relies on numerical simulations to study a kind of turbulence—known as Kolmogorov turbulence—that describes how energy flows from large to small scale in a confined space. According to this concept energy is introduced on large scales, e.g. by wind, and it is absorbed on small scales due to energy dissipation. This approach assumes that a small perturbation will make the system evolution chaotic as energy flows from large to small scales. However, the author finds that a phenomenon normally observed in disordered metals, called Anderson localisation, which implies that there is no energy flow from one side of the metal to the other, also occurs with the type of turbulences he is focusing on. As a result, energy flow from large scale to small scale does not happen under specific circumstances where the energy level is below a certain threshold level. This result is in keeping with our intuitive experience of a small wind not creating a storm, and that wind needs to reach a certain threshold before a storm can be created. ■

■ **D. Shepelyansky,**

'Kolmogorov turbulence, Anderson localization and KAM integrability', *Eur. Phys. J. B* **85**, 199 (2012)

BIOPHYSICS

Noise down, neuron signals up

A new model of background noise present in the nervous system could help better understand neuronal signalling delay in response to a stimulus. The authors present a biologically accurate model of the underlying noise present in the nervous system, which has implications for explaining how noise, modulated by unreliable synaptic transmission, induces a delay in the response of neurons to external stimuli as part of the neurons coding mechanism.

Neurons communicate by means of electrical pulses, called spikes, exchanged via synapses. The time it takes for brain cells to first respond to an external stimulus with an electric signal—commonly referred to as first-spike latency—is of particular interest to scientists. That is because it is thought to carry much more neural information than subsequent serial spike signals. The authors analyse the presence of noise in the nervous system detected through changes in first-spike latency. The noise is due to the large number of incoming excitatory and inhibitory spike inputs bombarding synapses. Previous attempts at noise modelling used a Gaussian approximation. Now, the authors have devised a noise model that is closer to the biological reality. It is shown that there is a relation between the noise and delays in spike signal transmission, caused by unreliable synapses. Yet, synaptic unreliability could be controlled by tuning the incoming excitatory and inhibitory input signalling regime and the coupling strength between inhibitory and excitatory synapses. Ultimately, this could help neurons encode information more accurately. ■

■ **M. Uzuntarla, M. Ozer, and D.Q. Guo,**

'Controlling the first-spike latency response of a single neuron via unreliable synaptic transmission', *Eur. Phys. J. B* **85**, 282 (2012)

APPLIED PHYSICS

Plasma screens enhanced as disorder strikes

A new study improves our understanding of plasma sources, a state of matter similar to gas in which a certain portion of the particles are ionised and which are used for example in plasma display panels. Under certain circumstances, plasma tends to form structures such as filaments of electric discharge akin to mini-lightning. The authors investigated the transition from a highly ordered filament pattern, which is arranged hexagonally, to a disordered system due to the reduction of the externally applied voltage.

To analyse the transition in the order of the discharge, the authors used two approaches. First, they used a method commonly employed to analyse spatial patterns, called 2D Fourier transformation. Then, for the first time, they applied an analysis tool typically used to evaluate dusty plasma discharges, known as triple correlation function.

The authors observed a pivot point in the voltage at which the decaying order started occurring. This information can ultimately be used to guarantee the quality of applications such as plasma screens. That is because the dissolution of self-organised electric discharge filaments in plasma matter enhances the homogeneity of the matter. ■

■ **R. Wild and L. Stollenwerk,**

'Breakdown of order in a self-organised barrier discharge', *Eur. Phys. J. D* **66**, 214 (2012)

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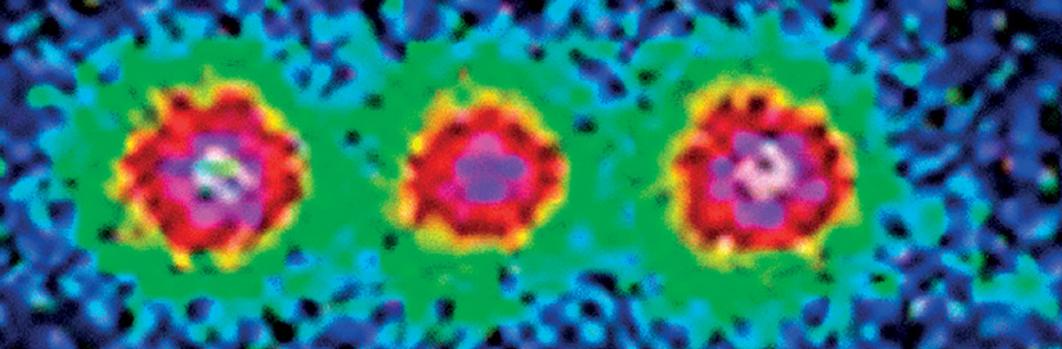
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Nobel 2012: Trapped ions and photons

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▲ This colorized image shows the fluorescence from three trapped beryllium ions illuminated with an ultraviolet laser beam. Black and blue areas indicate lower intensity, and red and white higher intensity.

NIST physicists used three beryllium ions to demonstrate a crucial step in a procedure that could enable future quantum computers to break today's most commonly used encryption codes.

Image courtesy: National Institute of Standards and Technology

The 2012 Nobel prize in physics has been awarded jointly to Serge Haroche (Collège de France and Ecole Normale Supérieure) and David Wineland (National Institute for Standards and Technology, USA) “for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems”.

What are these methods, why are they jointly recognized?

The key endeavour in the last century of quantum physics has been the exploration of the coupling between matter and electromagnetic radiation. For a long time, the available experimental techniques were limited to a large number of atoms and a very large number of photons. It was only in thought experiments that one envisioned the manipulation of well-controlled individual quantum systems, dreamed of experimenting with a single atom or a single photon.

For instance, Einstein and Bohr once imagined weighing a photon trapped forever in a box, covered by perfect mirrors. These gedankenexperiments and their “ridiculous consequences”, as Schrödinger once stated, played a considerable role in the genesis of quantum physics interpretation. The technical progress made these experiments possible. One can now realize some of the founding fathers' thought experiments. D. Wineland's ion traps and S. Haroche's Cavity Quantum Electrodynamics (CQED) have pioneered this domain, which is now thriving worldwide.

Wineland and his team at NIST trap ions in a Paul trap, in which a linear string of a few ions can be kept for weeks in electric fields. The collective ion motion in the trap is laser-cooled down to its quantum ground state. The ions internal states are manipulated by resonant laser beams and read out, 'seen' with a unit efficiency by laser-induced fluorescence. Finally, these internal states can be coupled, also via laser beams, to the joint quantum motion of the string in the trap, which acts as a 'quantum bus' interfacing the ions. Very complex manipulations of weird entangled quantum states have been realized.

Haroche and colleagues (including JMR and MB) work on a radically different system at Laboratoire Kastler Brossel (ENS, CNRS, UMPC, Collège de France). Instead of trapping matter particles, he traps individual microwave photons. This is even more challenging than trapping matter. Photons roam the Universe forever, but it is difficult to hold them for a long time in a modern equivalent of Einstein's "photon box". Haroche uses superconducting microwave cavities. Their long development led from a few μs storage time in the 90s to cavities that can now hold a photon for 0.13 s, a time interval in the macroscopic range. While stored in the cavity, the field is repeatedly probed by sensitive atoms (circular Rydberg atoms) crossing the cavity one at a time. These atoms carry away information on the field quantum state. They can be used to count photons in a Quantum Non Demolition way (to 'see' a photon without destroying it), or to create and probe weird quantum states of the field.

There is a beautiful duality between Wineland's and Haroche's experiments. In the former, trapped quantum matter is probed by light. In the latter, trapped quantum light is probed by matter. Both have the same goal: testing the most intimate features of quantum mechanics. Both have reached, sometimes simultaneously, similar achievements. For instance, both prepared in 1996 mesoscopic quantum superpositions. For the ion, it is a motional state in which the ion moves in two directions at the same time. For the field, it is a superposition of two semi-classical coherent states with opposite phases. These superpositions are quite reminiscent of the Schrödinger cat, discussed in another famous thought experiment. Studying how these superpositions are rapidly transformed into a statistical mixture by decoherence sheds light on the transition between the quantum and classical worlds.

What are the applications of Haroche's and Wineland's achievements? This is naturally a quite frequent question from the media. It is to some extent irrelevant. Both experiments are

exploring the most fundamental quantum features. This understanding of the quantum world is utterly important, even if practical applications do not follow on a short time scale. All applications of the quantum so far (lasers, transistors...) were developed long after the corresponding conceptual tools. The most fascinating outcome on the long term might be quantum information processing, but the road to a quantum computer is still a long one. In the way, the exquisite control achieved in ions experiments, for instance, led already to the most precise atomic clock ever.

These achievements, recognized by the Nobel Prize, did not appear out of the blue. They rely on a long-term development led by teams of experienced researchers working in close connection for extended periods. Wineland created his atomic-clock team at NIST 37 years ago, after his post-doc with Hans Dehmelt. Haroche started his work on Rydberg atoms at ENS in 1973 after his PhD work on the dressed atom approach supervised by one of us (CCT), and a post-doc with A. Schawlow. This fundamental research develops thus on a long time scale of tens of years, much longer than the duration of ordinary grants and funding plans. It requires a lot of efforts for teaching to generations of students the basic concepts of quantum physics. It is also clear that nothing would have been possible without the regular funding and support from institutions recognizing the importance of fundamental, curiosity-driven research.

In Haroche's case, the stimulating atmosphere created by the two founders of the laboratory, Alfred Kastler and Jean Brossel, was also an essential element. It allowed this laboratory to be awarded by three Nobel Prizes, in 1966 for Alfred Kastler, in 1997 for one of us (CCT) and, finally, in 2012 for Serge Haroche. ■



▲ © Christophe Lebedinsky/CNRS

A Tribute to Max von Laue

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DOI: 10.1051/eprn/2012602



19 C 67

Just an idea: take a crystal, surround it with photographic plates, and direct a pencil of X-rays at it, perpendicularly. It was one of those thrilling ideas that made new science. Max Laue was the proponent, in April 1912. The experiment as such had been tried out before by Röntgen himself, but without avail. Friedrich and Knipping, however, took their time and waited long enough. Overnight, the *atomic* variant of lattice theory—which had worked its way at the outskirts of crystallography—became fashionable. And, not to forget, X-rays proved to be wave-like indeed.

Max Laue originated from Pfaffendorf, a village now part of Koblenz. After his *Abitur* he enrolled at the university of Strasbourg, moving on, in 1899, to Göttingen, the place to be for theoreticians. Optics became his favourite subject. Waldemar Voigt and Otto Lummer showed the way to go. His PhD subject brought him to Berlin to study with Max Planck. In 1903 Laue defended a thesis about the diffraction which occurs during interference caused by plane parallel plates. It was Planck who asked him, in 1906, to become his assistant. Laue's *Habilitation* assessed the entropy of interfering pencils of rays. It was the time that one Albert Einstein's freshly appeared paper 'Zur Elektrodynamik bewegter Körper' was favorably discussed by Planck in a lecture at the Colloquium of Berlin's Physical Society.

Relativity: theory and experiment

Laue was in the audience. It took some time, but his conversion was unconditional. He went to see Einstein in Switzerland, soon after his *Habilitation*, to discuss details. His was one of the first experimental arguments if not proofs (1907), in the sense that he identified Einstein's 'addition theorem' with a formula derived by Fizeau (1851) for the velocity of light in flowing water. Fizeau, it is recalled, first established (together with Foucault) that in denser media light is slowed down—in conformity with the wave-theory—while the motion of some such medium may be used to move an interference pattern: the fringes produced by coherent light led through the two arms of a water circuitry slightly shifted when the flow direction was changed. Fizeau did not insist and left others the task to improve his method. It was Michelson and Morley who did so in 1887. There were some problems with the turbulence of the flowing water and Pieter Zeeman, therefore, used a movable glass stick instead. Laue produced the first general account of the recent developments in *Das Relativitätsprinzip* (1911) and succeeded in familiarizing many an estranged physicist with the broad context—and the paradoxes—of what came to be known as *special* relativity. In 1920 he would publish, as a supplement, a similar account of Einstein's latest breakthrough, *general* relativity.

Rays and rays and... X-rays

At the turn of the XIXth and XXth century a whole series of seemingly distinct, though more or less related radiation phenomena disputed each other's priority in the physicists' attention. One of the most enigmatic was, without doubt, the one revealed by Wilhelm Röntgen in the fall of 1896. For the general public, however, it had been overshadowed, by some natural rays, spontaneously emitted by materials that could be concentrated by chemical means. Laue got involved in 1909 when he entered, as a *Privatdozent*, in the service of Arnold Sommerfeld, at the University of Munich. Sommerfeld himself had been nominated a few years before to provide the theoretical background to Röntgen's rays. Röntgen was still around, but left Sommerfeld and the latter's students free to use his instruments, among which a 50 cm Rühmkorff-inductor and a whole collection of bulbs.

Lattice theory in crystallography

The 19th century had lived with the rise of lattice theory. Crystals had been conceived of, by René-Juste Haüy (1743-1822), as well-ordered 'assemblages' of polyhedral

◀ P.18: Blende (ZnS; covered with calcite) from Trepca (Serbia). Aquarelle by Claus Caspari (1911-1980). Reproduced from H. Schröcke and K.I. Weiner, *Mineralien* (Hamburg: E. Cramer, 1967).



◀ FIG. 1: Max von Laue (1920; courtesy Nobel Foundation).

molecules composed of the atoms of the elements. Those of pyrite, for instance, were presented as 'assemblages' of cubic FeS_2 -molecules. Such 'assemblages' could take the form of a cube or orthogonal parallelepiped, naturally, but also that of a dodecahedron or octahedron, depending on the regularities during the growth. It was a personal triumph for Haüy not only that the interfacial angles could be calculated in advance, but also that they agreed closely with those measured on natural crystals, for instance, in the case of dodecahedral pyrite. His successors gradually replaced the molecules by their centres of gravity. In this way the crystal became an abstract point lattice whose symmetry properties defied the imagination of men like Delafosse, Bravais and Jordan. Particular compounds, like the alums, though, suggested the existence of *superimposed* molecular lattices: after all, the crystal water of these so-called hydrates could be easily separated from the rest, while a crystal of the original form emerged on evaporating a solution. It was Leonhard Sohncke (1842-1897) who concluded, in 1888, that any crystal could be considered as an array of as many lattices as there are atomic species in it. In the 1890's

the exact number of a priori possible *atomic* lattices (230) was rigorously deduced by mathematicians like Evgraf Fyodorov and Arthur Schönflies. When Laue arrived in Munich Sohncke's spirit was still in the air, while the latter's lattice models had survived and were regularly used in classes. There was a third lucky coincidence.

Encyclopedia of the mathematical sciences

Felix Klein and Sommerfeld had launched, in 1896, the great *Encyclopedia of the mathematical sciences*, which became the indispensable toolkit for any physicist, let's say, together with the ever growing *Physikalisch-Chemische Tabellen* of Landolt and Börnstein. Once established in Munich, Laue was chartered to assess the theory and practice of wave-optics and had, naturally, amongst many other things, to assess interference phenomena [1]. That wave-optics was part of volume V of the *Encyclopedia...*, which for all kind of reasons—*i.a.* the Great War—would not appear in print before the 1920's. The text, it is true, only assessed line gratings, but during its preparation Laue had become familiar with experiments with crossed gratings, when square arrays of identical spots show up, square spots, that is. The stage was set.

Crystals and X-rays

Having finished his *Encyclopedia...* contribution, it occurred to Laue, early in 1912, that something interesting might happen when a pencil of X-rays would be directed at a crystal, the more so since the estimated wavelength of Röntgen's rays (on spectral grounds: 10^{-8} - 10^{-9} cm) was equal if not smaller than the interatomic distance (10^{-8} cm). An exchange of ideas, in February 1912, with Paul Ewald triggered a wider discussion at the Institute. An experiment, then, was staged, by Walther Friedrich and Paul Knipping. In a search for effects an easily grown copper sulphate crystal (triclinic) was first bombarded with X-rays, with photographic plates at various positions around it (Figure 2). They found that a plate *behind* the crystal manifested distinct black spots suggesting some kind of regularity. It was a small step, then, to replace the raw crystallized copper sulphate crystal by a thin 001 platelet of highly symmetric zinc sulfide (thickness: 0.5 mm; Figure 3). The result was a breathtakingly regular pattern of spots, manifesting the same symmetry elements as those deduced earlier for the crystal itself (Figure 4): a fourfold main rotation axis and four twofold rotation axes (four planes of symmetry). On enlarging the distance between the crystal and the photographic plate (say, P_5 instead of P_4), the spots kept their bigness and form, though the scale of the pattern was enlarged in the same proportion: apparently a parallel beam of rays was responsible for each spot. In the publication Laue would show how the distance between the centres of gravity of two neighbouring ZnS -molecules could be calculated, using the density $\rho = 4.06 \text{ g.cm}^{-3}$, the molar weight $M = 97.4 \text{ g}$ and Avogadro's constant, $N_A = 6.17 \times 10^{23}$:

▼ FIG. 2: The original set-up as used by Friedrich and Knipping to see the effect of X-rays on a copper sulfate crystal. From left to right on the table: Röntgen bulb (too low here), first diaphragm (lead foil), collimator, round turntable with the crystal at its centre and an enveloped photographic plate. A huge wooden tripod is used to rise and reset a shielding cover of lead foil. Since 1921 this set-up is part of the collection of the Deutsches Museum, München (courtesy: Deutsches Museum).



$[97.4/\{4.06 \times (6.17 \times 10^{23})\}]^{1/3} = 3.38 \times 10^{-8}$ cm. This would be the lattice constant. It brought Laue, Friedrich and Knipping instantaneous fame. In 1913 and, again, in 1914, Laue was nominated for the Nobel Prize for Physics. There were but few nominations, it is true, but these were enough for the Selection Committee to decide in 1914 in favor of Laue.

In the 1930's Laue, in his position of chairman of the German Physical Society and deputy director of the Kaiser-Wilhelm Institute for Physics, got involved in politics, like any other German. His fierce struggle against the nomination of Johannes Stark, a fervent Nazi, at various powerful positions became emblematic for civil courage. These were also the days that he favoured the development of a new, extremely promising visualisation technique for submicron entities: the electron microscope. After the war this technique would feature among the first subjects to be launched in the new German physics. ■

Acknowledgment

It is a pleasure to thank **Wolfgang Schmahl** (Director of the Crystallography Department of Ludwig-Maximilians-Universität, Munich) and **Wolfgang Heckl** (Director of the Deutsches Museum) for their hospitality and technical support. I am obliged to **Karl Grandin** (Director of the Archives of the Royal Swedish Academy of Sciences) for kindly allowing me to consult the nomination letters for Laue.

About the author

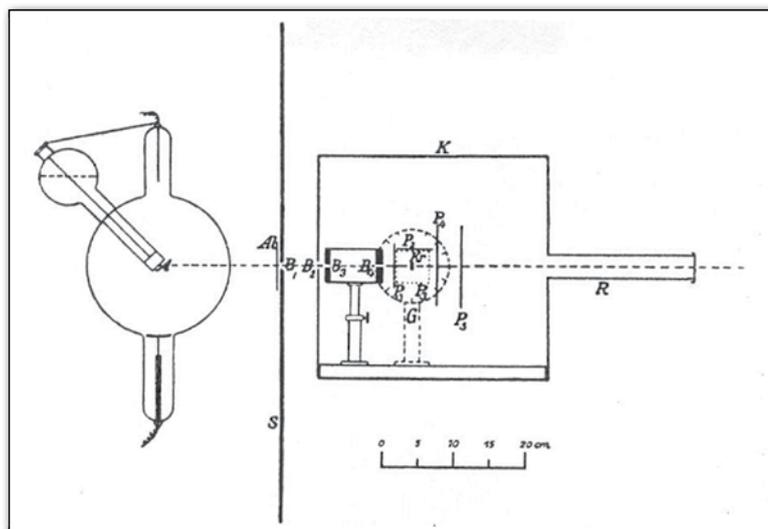
Henk Kubbinga is a historian of science at the University of Groningen and member of the EPS History of Physics Group. He is currently editing *The Collected Papers of Frits Zernike (1888-1966)*, the first two volumes of which were recently published by Gröningen University Press (ISBN 978-90-814428-3-1).

Notes and References

For the broad context see *Acta Crystallographica A* **68** (1) (2012) and *Zeitschrift für Kristallographie* **227**, 1 (2012), a joint issue edited by Wolfgang Schmahl and Walter Steurer.

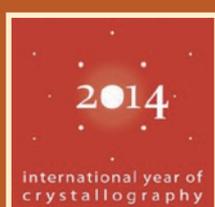
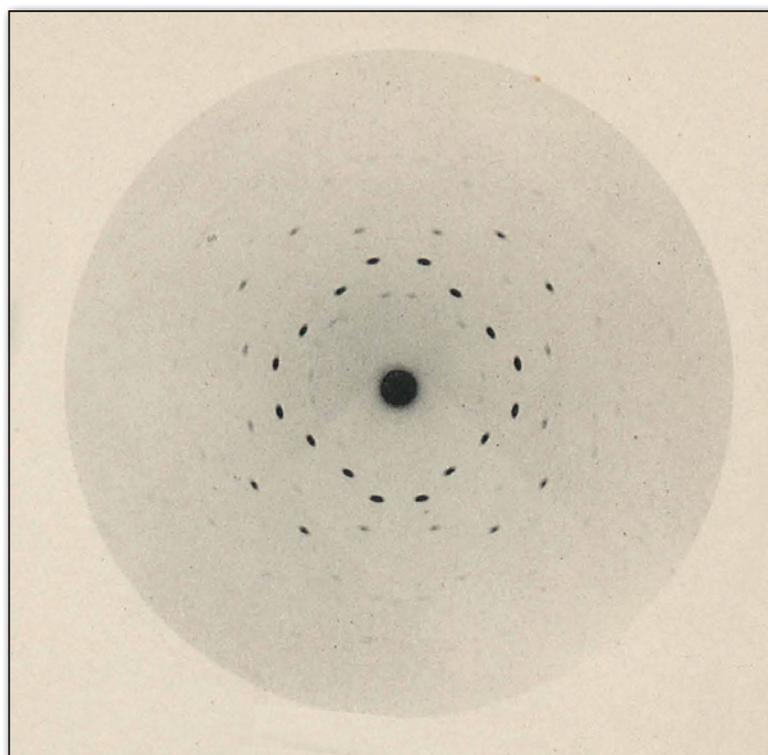
[1] M. Laue, 'Wellenoptik', in: F. Klein and Sommerfeld (eds.), *Encyklopaedie der mathematischen Wissenschaften, mit Einschluss ihrer Anwendungen*, Leipzig: Teubner, 1898-1926, volume V.3, 362 (finished by July 1915).

[2] W. Friedrich, P. Knipping and M. Laue, *Sitzungsberichte* (München) 1912, 303.



▲ FIG. 3: Final set-up of Friedrich, Knipping and Laue as used for the 001 platelet of ZnS. The Röntgen bulb is now watercooled. The platelet is glued at Kr on a finely tunable round turntable G (seen from above; interrupted line), with photographic plates at P1-5. Successive diaphragms, B1-4, narrow down the beam coming from anti-cathode A; R is a tube-of-no-return (from ref.[2]).

▼ FIG. 4: The first photograph of an 001 platelet of ZnS as made by Friedrich, Knipping and Laue (from ref. [2]).



2014: INTERNATIONAL YEAR OF CRYSTALLOGRAPHY

The UN decision was announced on 4 July 2012 by the International Union of Crystallography (IUCr), which since several years has been proposing to mark with an International Year the centenaries of

the discovery of X-ray diffraction by Max von Laue in 1912 and of the formulation of Bragg's Law in 1913. For more information, see the Website of the IUCr: www.iucr.org ■

DARK RESONANCE



Sensitive magnetometers based on dark states

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So-called Dark States provide another example of fundamental research which yields unexpected applications. Here is an all-optical magnetometer that can detect tiny fields even in an unshielded environment. As an obvious application a human magneto-cardiogram (MCG) has been recorded. And there are more promising applications.

▲ The first observation of dark resonances (marked by a star) in dye-laser-induced fluorescence of Na atoms, caused by a spatially inhomogeneous magnetic field along the laser beam.

In recent years interest has been growing into the fascinating properties of dark resonances. Most of the experiments have been carried out in alkali atoms due to their favourable level structure and the commercially available diode lasers, resulting in numerous applications. Teams from Siena and Sofia developed an all-optical magnetometer based on such dark resonances. The dark-state effect was discovered in 1976 by G. Alzetta, A. Gozzini, L. Moi and G. Orriols [1], while they were working on optical-pumping experiments with a multimode dye laser. They wanted to make the observation of multi-photon radio-frequency resonances in sodium atoms easy, *i.e.*, observable by the naked eye. To this end, they introduced a magnetic field (MF) that was constant in time but spatially inhomogeneous along the laser beam, so as to produce Zeeman splitting of ground-state hyperfine levels (Fig.1a, left). In this way, an applied

radio-frequency field was resonant only if it matched the Zeeman splitting. As a result, a bright radio-frequency resonance appeared (Fig.1a, right).

During these experiments, besides the bright resonances, a new “dark” resonance was observed, which does not require any radio-frequency field. In the introductory illustration only the dark resonance is shown. The new dark state (DS) effect appears in a position along the laser beam where the frequency difference ($\omega_{10}-\omega_{20}$) between two optical frequencies is equal to the frequency splitting ω_{12} between two Zeeman sublevels (Fig.1b, left). This is the resonant condition for the stimulated Raman transitions between the two long-living ground levels. Theoretical studies described the dark resonance as a coherent superposition of two long-living ground levels prepared by the bi-chromatic laser field, and ‘atomic population trapping’ was introduced, leading to the term Coherent Population Trapping (CPT) [2].

A striking property of the DS is that its spectral width is only 10 to 100 Hz (see Fig. 1b, right). This is because it is determined mainly by the long lifetime of the two ground levels, so the much larger spectral width of the excited level is not involved. Thus, the CPT resonances can be extremely narrow features allowing performances both at the level of basic physics experiments and of practical applications. Recently a complete suppression of fluorescence in narrow resonance has been realized exciting all ground-state Zeeman sublevels of sodium [3]. Different approaches have been adopted to observe CPT resonance. Most frequently Zeeman sublevels of the two hyperfine ground levels (with $\omega_{12} \sim 2 \div 9$ GHz for different alkali atoms) are coupled by two coherent optical fields [4], commonly obtained by diode laser frequency modulation around ω_{12} that requires relatively high modulation power. To reduce this problem, we proposed [5,6] to shift laser modulation to the kHz region by coupling Zeeman sublevels of the same ground-state hyperfine level, where ω_{12} is a few hundred kHz in earth and lab MFs. In addition, the involvement of a single hyperfine transition in the CPT preparation leads to observation of a new narrow resonance of enhanced absorption [6,7]. The recently expanding interest in the topic is due

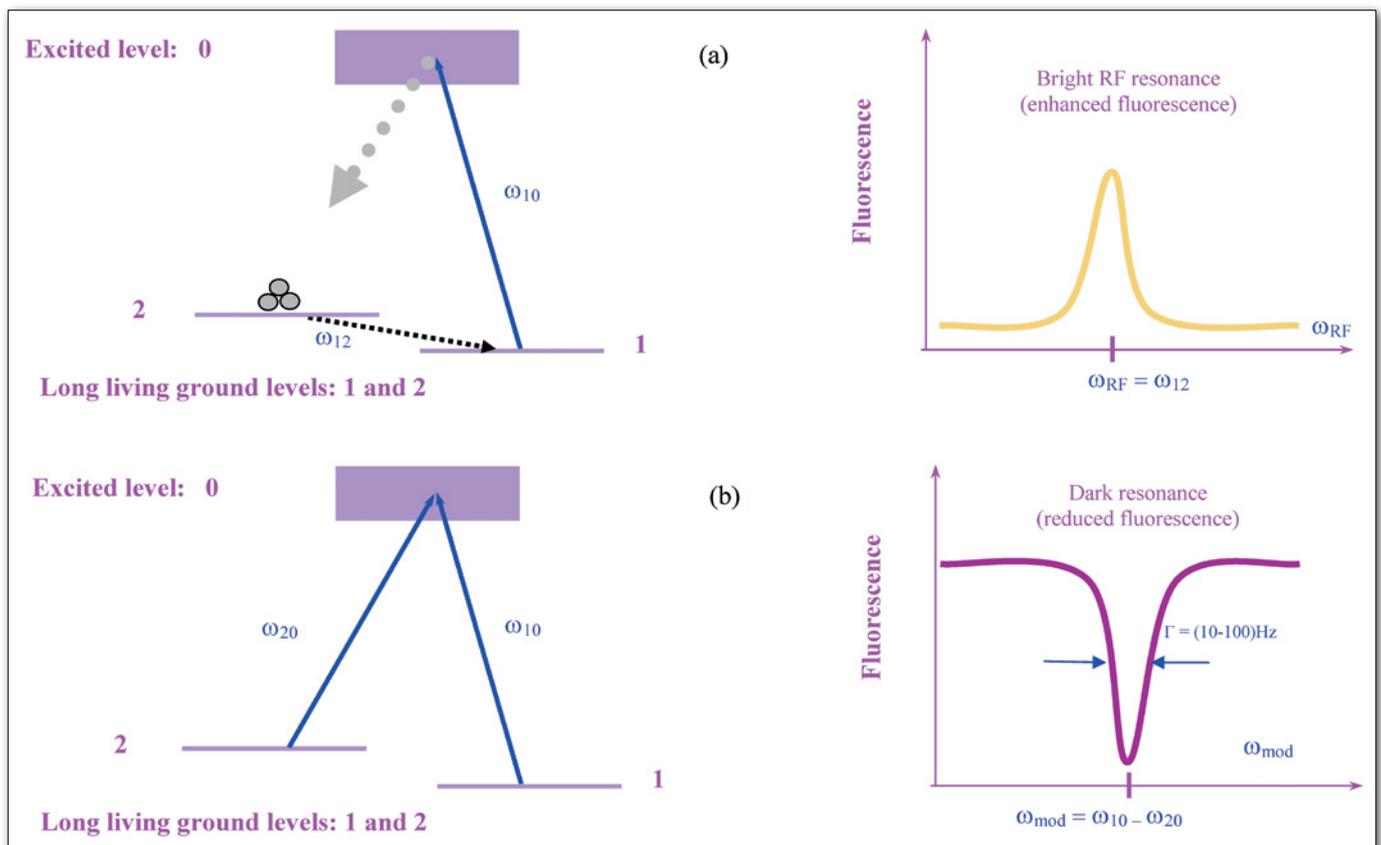
not only to the fascinating physics involving quantum coherence but also to the fact that there are many potential applications with relevance for fundamental studies, such as slowing of light, STIRAP, velocity-selective CPT and quantum information storage, as well as for development of new techniques/devices like atomic clocks/magnetometers.

Here we describe the development of an all-optical magnetometer based on the DS, which is promising for realization of low-cost and easily-operated practical devices for weak MF measurement.

Scheme for magnetic field (MF) measurements

In the developed approach (Fig. 2), bi-chromatic/poly-chromatic coherent optical fields couple Zeeman sublevels within a single hyperfine level, resulting in observation of DS resonance with $\Gamma < 100$ Hz, in a magnetically unshielded but partially compensated environment. The CPT resonance observed as a function of the modulation frequency makes absolute measurement of the MF value possible. Constant earth and lab MFs shift the resonance center at $\omega_{\text{mod}} = B/k$ without causing its broadening. The first step of the measurement is to find this point and to determine

▼ FIG. 1: (a) Formation of bright optical pumping resonance. (left) Due to fluorescence decay, a light field of frequency ω_{10} , resonant with the 1-0 transition, produces optical pumping (accumulation) of atoms in the ground level 2, non-interacting with the light. Consequently, the population in level 1 decreases. (right) As the splitting (ω_{12}) between levels 1 and 2 is determined by the applied magnetic field, the radio-frequency field (with $\omega_{\text{rf}} = \omega_{12}$) will couple the ground levels if $\omega_{\text{rf}} = \omega_{12}$, repopulating level 1 and producing enhanced absorption and a bright resonance (enhanced fluorescence). (b) Dark-state resonance formation: (left) basic scheme for Coherent Population Trapping (CPT) - only two optical fields are used, i.e., no radio-frequency field is involved in the CPT preparation; (right) when the two optical fields (ω_{10} and ω_{20}) are components of a modulated laser field separated by modulation frequency $\omega_{\text{mod}} (= \omega_{10} - \omega_{20})$, the dark resonance is centered at the modulation frequency determined by the ground level splitting $\omega_{12} = \omega_{10} - \omega_{20}$.



B. At the second step, the modulation frequency ω_{mod} is fixed and the small magnetic field to be measured (in the interval $\Delta B = k\Gamma$) is switched on. Thus, the resonance profile enables precise measurement of small MF fluctuations



This MCG measurement is passive (no radiation imposed to subject), completely non-invasive and contact-free.

in time, superimposed on a large magnetic background. In this way, the requirements for earth and lab MF shielding are strongly relaxed, which is a significant advantage because the shielding is about an order of magnitude more expensive than the

magnetometer. Note that other techniques performing the most precise measurement of MF fluctuations around zero value require expensive MF shielding.

First human magneto-cardiogram (MCG) in unshielded environment

In 2007, an encouraging result was obtained [8] with an experimental apparatus based on CPT and aimed at detecting a MCG in a magnetically compensated but unshielded surrounding. The system was suitable to compensate for some dc components of the environmental MF and the first order MF inhomogeneities, thus reducing the resonance line width to few tens of Hz. Environmental noise was cancelled by making use of a differential measurement. Synchronous data acquisition with a reference signal (electro-cardiogram/pulse-meter) improved the signal-to-noise ratio by off-line averaging. The setup has the significant advantages of working at room temperature with a small-size magnetic sensor, and the possibility of fast adjustments

of the dc bias MF, which makes the sensor suitable for detecting a biomagnetic signal of any orientation and in any position on the patient's chest.

This all-optical technique does not require coils in the proximity of the sensor cell to produce direct radio-frequency magnetic excitation. The sensor consists of a glass cell containing alkali vapor, and the laser light is brought to and from the cell by optical fibers.

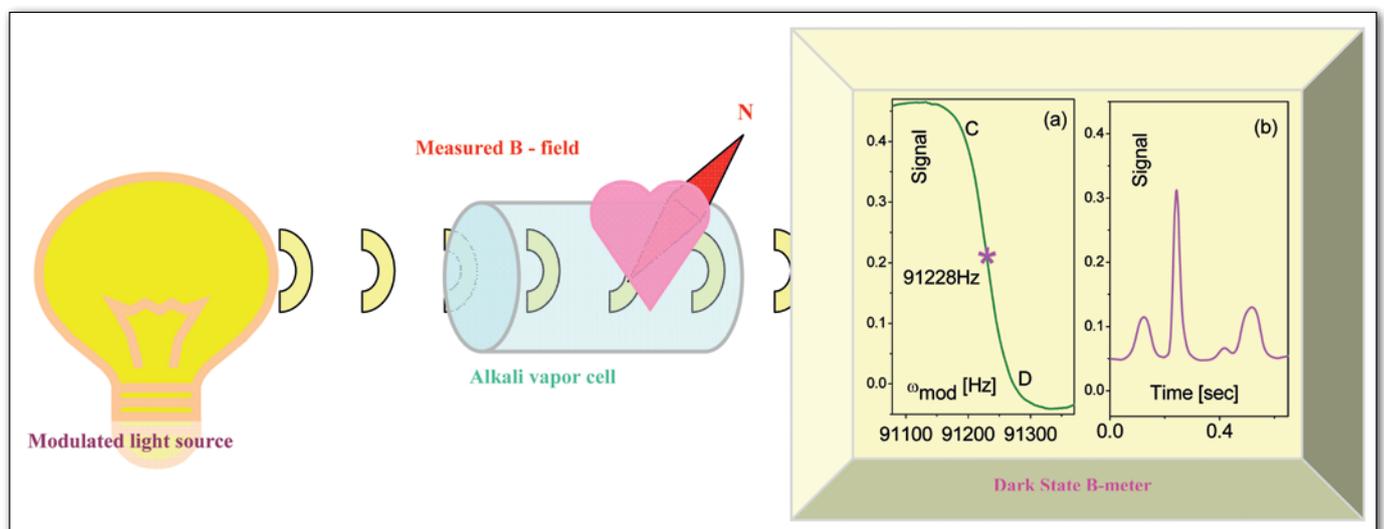
The potential of the magnetometer for magnetocardiographic applications in unshielded environments is illustrated by Fig. 3. Multiple MCG traces are averaged, in order to improve the signal-to-noise. The signals are filtered with a single low-pass filter and the deterministic noises (e.g., originating from the main supply and its harmonics) are subtracted off-line.

The simplicity of the method, its low cost, and the low cost of maintenance may be crucial factors for its dissemination in clinical applications. Note that this MCG measurement is passive (no radiation imposed to subject), completely non-invasive and contact-free.

Other promising applications

A dual-channel self-oscillating approach has been developed, based on a wide frequency modulation of the pump laser and registration of the nonlinear magneto-optical rotation of the probe laser [9]. The self-oscillating operation makes the magnetometer insensitive to the slow drifts of the MF (of several nano-Tesla), thus making possible long time records up to the duration of the working days. The sensor was used for the nuclear magnetic resonance (NMR) registration, detecting both the dc magnetization and the nuclear spins precession of remotely polarized

▼ FIG. 2: Principle scheme of an all-optical DS magnetometer. The modulated light (with components separated by ω_{mod}) is effectively produced by direct modulation of a diode laser current. The measured magnetic field B splits levels 1 and 2 of alkali atoms (Fig.1) at frequency ω_{12} related to the MF by $B = k\omega_{12}$, where k is determined by atomic constants. In unshielded and partially-compensated environments, the light produces a dark resonance, centered at $\omega_{12} = 91228\text{Hz}$ (denoted by asterisk), which is the modulation frequency (ω_{mod}) of the laser. The dark-resonance spectral width is $\Gamma \sim 90\text{Hz}$; its first derivative is shown by curve (a). The resonance corresponds to a MF variation $\Delta B = k\Gamma$. If the modulation frequency is kept constant ($\omega_{\text{mod}} = \omega_{12} = \text{constant}$), the obtained linear dependence CD (within the resonance profile) allows measuring MF fluctuations less than ΔB , based on the registration of the transmitted light intensity with time – shown in the curve on the right (b). In unshielded and partially-compensated environments the value ΔB is less than B by several orders of magnitude.



hydrogen nuclei in water samples. The optical magnetometer reaches a sensitivity of $100\text{fT}\cdot\text{Hz}^{-1/2}$ worsened to $2\text{pT}\cdot\text{Hz}^{-1/2}$ due to MF gradients in an unshielded environment. To facilitate averaging of bias-MF-dependent signals and to improve the signal/noise ratio in unshielded environment, an automatic system has been developed [10] for active compensation of time-dependent earth and urban MFs using the dual channel scalar magnetometer. The system made possible to stabilize the bias field within a bandwidth of several tens of Hz, counteracting MF fluctuation with attenuation levels exceeding 40dB. Developed optical magnetometers have been successfully tested for monitoring of earth MF variations, showing that the approach is quite robust against urban electromagnetic noise [11].

A lot of effort has been put by US scientists for the development of practical chip-scale atomic clock and magnetometer, based on the DS. More recently a special care has been taken to avoid electrical connections to the sensor, *i.e.* making the sensor head largely non-magnetic and its performance free of internal MFs [12].

Outlook

The Siena group, lead by V. Biancalana, is presently involved in a project for the magnetic characterization of magneto-nano-particle hydrogels. Further campaigns are foreseen in MCG as well as in ultra-low-field NMR, including collaboration with researchers involved in developing unconventional techniques for nuclear pre-polarization. The Sofia team is involved in studies of miniaturized optical magnetometer based on DS and in the improvement of its signal/noise.

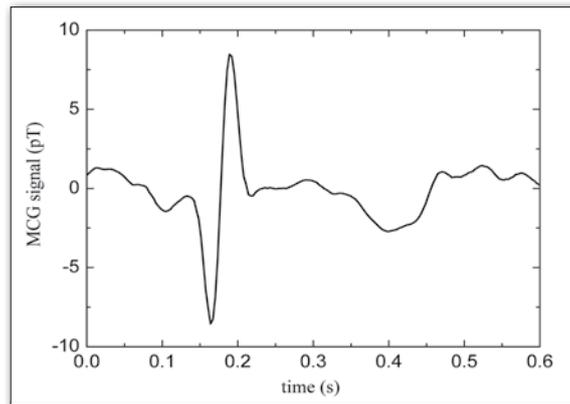
Conclusion

The DS magnetometer is a versatile device offering the possibility to build up non-magnetic sensors: no internal MFs perturb the field to be measured. This is an important issue when multichannel sensors are developed. Absence of coils minimizes the size and optical fibers may easily address each single detection point. It can be used also for remote control or work in hostile environment. ■

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Both authors are strongly indebted with the colleagues from Pisa, Siena and Sofia for their fundamental contributions to the studies of the dark/bright state phenomena. Many thanks to G. Alzetta, A. Gozzini great scientists and teachers in optics, as well as to S. Gozzini, F. Renzoni, E. Arimondo, V. Biancalana, Y. Dancheva, J. Belfi, G. Bevilacqua, E. Mariotti, C. Marinelli, E. Breschi, S. Gateva, E. Alipieva, G. Todorov, D. Slavov, C. Andreeva, T. Karaulanov, E. Taskova for fruitful and nice collaborations.

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◀ **FIG. 3:** MCG signal (83 averages) of an 8 year old boy recorded in an unshielded environment. Note that signals of order 10^{-12} tesla are detected. This result is kindly provided by V. Biancalana (unpublished).

About the Authors



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Paleomagnetic investigation of the great egyptian pyramids

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The great Egyptian pyramids present one of the greatest mysteries of mankind. Despite continuous scientific investigations, these monuments of antiquity still hide many secrets. Unresolved remains the question regarding the material and building technology of the pyramids. There are two opposing views.

It is generally accepted that they were constructed from cubic blocks of natural limestone, transported from the quarries in the surroundings of Giza. However, during the last century, several authors advocated the supposition that the cubes might have been produced from the mud of the Nile *in situ* in special wooden containers filled with a liquid called natron, a salt mixture from dry lake beds. In this way, a rocky concrete, called geopolymer, had been produced which, after having dried out, has properties similar to the natural limestone.

This technology has been described in detail by Demortier [1]. If we assume that this method is plausible, then paleomagnetism can be one of the instruments to verify this.

Method

Each rock, volcanic or sedimentary, acquires its remanent magnetic polarization during its formation. Ferromagnetic grains fix their magnetic orientation (volcanites when they pass through the Curie point and sediments during the sedimentation process) in the geomagnetic field. The resulting direction of the rock magnetic moment is parallel to the direction of geomagnetic field. The same process is active during the production of thermally produced artifacts from rock material like bricks, ceramics, *etc.*

In paleomagnetic research, rock samples are collected and the direction of their characteristic magnetic polarization is determined. Such paleomagnetic records find applications particularly in geology. However, since rocks or rocky artifacts may have been affected during their history by different agents (*e.g.*, heat, pressure, chemical reactions), a parasitic secondary magnetic polarization might have been acquired, and hence the so-called magnetic cleaning of the samples is necessary. During this cleaning, the secondary polarization is eliminated and the original magnetic characteristic is recovered. Thermal demagnetization is the most frequently used cleaning technique, in which the sample is step-wise heated to a temperature above the Curie temperature of any ferromagnetic material.

The sample is subsequently cooled in a nonmagnetic environment after each thermal increment (*e.g.*, 50°C) and the direction and intensity of its magnetic polarization is recorded. Soft secondary magnetic polarization is usually relieved at lower temperatures, while the hard original polarization undergoes demagnetization only at higher

temperatures. In addition to the direction and intensity of the magnetic polarization, the magnetic susceptibility is also recorded. If the magnetic susceptibility does not change during demagnetization, then no phase change of the magnetic material has occurred (rock keeps its original composition). By contrast, rapid changes in susceptibility with temperature indicate that the rock material underwent phase changes, and further measurement is irrelevant.

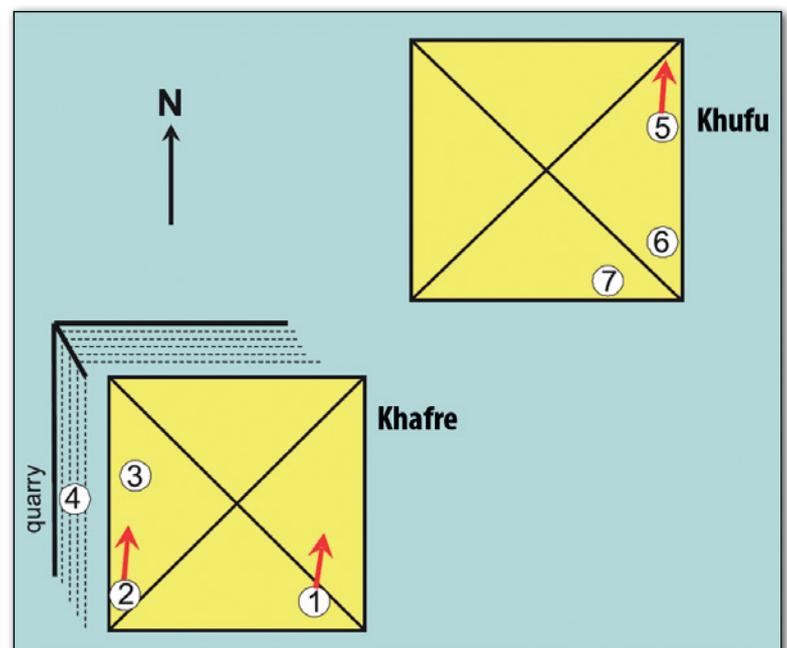
Our paleomagnetic investigation of the two great Egyptian pyramids, Kufu and Khafre, is based on the assumption that if the blocks were made *in situ* by the concrete technique [1] described above, then their magnetic moments would all have been parallel, oriented approximately in the north-south direction. However, if the pyramids were constructed from blocks transported from the nearby quarries, having been rotated randomly during transport and construction, then the directions of their magnetic moments would be oriented randomly.

Results

Samples were collected from 6 locations in the two pyramids, 3 from Khufu and 3 from Khafre (Fig. 1). Demortier [1] admits that even if the concrete technique was used,

◀ Egypt. Cairo - Giza. General view of pyramids from the Giza Plateau (from left - the Pyramid of Menkaure, Mykerinos; Khafre, Chephren and Chufu, Cheops - known as the Great Pyramid and three small pyramids popularly known as Queens' Pyramids on front side). The Pyramid Fields from Giza to Dahshur are on the UNESCO World Heritage List. ©iStockPhoto

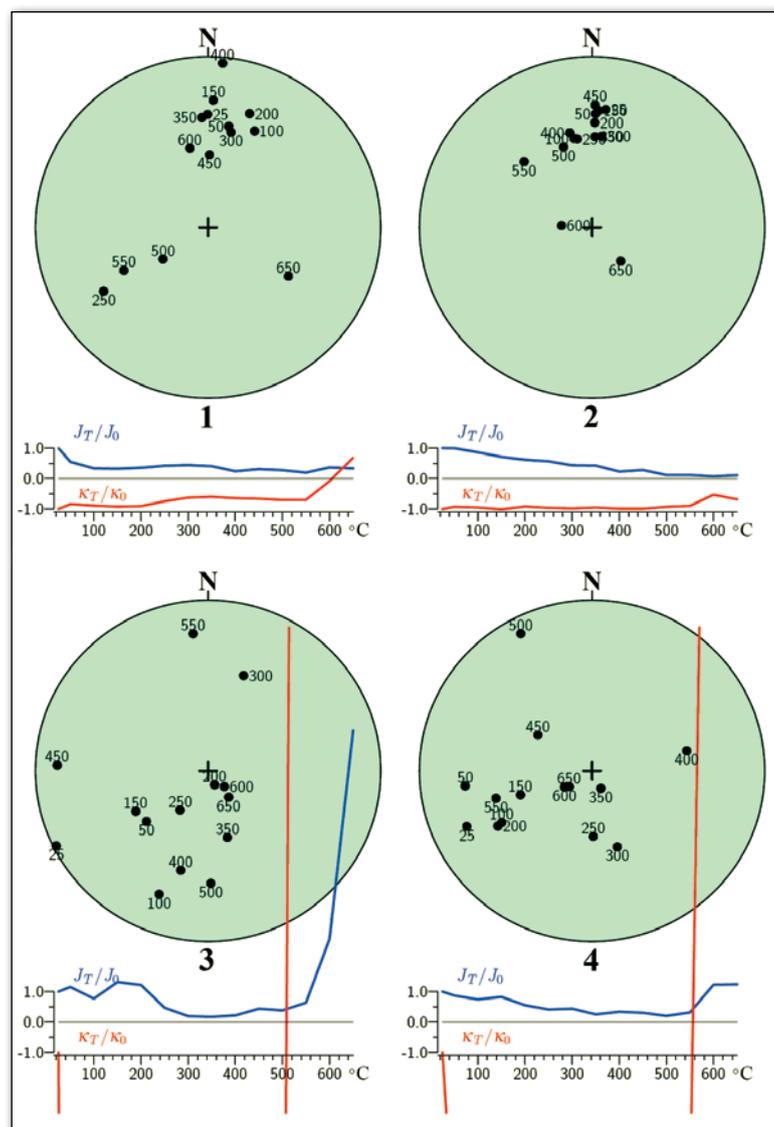
▼ Fig. 1: Sampling locations on the Khufu and Khafre pyramids and in the adjacent quarry. N = geographic North. Red arrows indicate the directions of magnetic polarization vectors (paleodirections) in the samples taken from locations 1, 2 and 5.



The results of this project have proved the usefulness of paleomagnetic methods

it is most probable that there might be a combination of artificial and natural blocks. We find (Fig. 1) that the Khafre pyramid lies partly in a small quarry forming the base of the pyramid. It is highly probable that blocks cut from this quarry were used to build the pyramids. This opinion was visually verified. The rock material from the quarry is very similar to the blocks material in the adjacent parts of pyramid. Therefore, in addition to the 3 sampling positions described above, other samples from the quarry at the position marked 4 in Fig. 1 were collected for comparison. Note that at least two samples were obtained from each position.

▼ Fig. 2: Thermal demagnetization of the samples from locations 1, 2, 3 and 4 (see Fig. 1). N = geographic North. The dots inside the big circles indicate the directions of the magnetic polarization vectors in the samples (see the main text) after heating to the temperature values specified by the numbers. Curve J_T/J_0 : magnetic polarization (J_T) of the samples, heated to temperature T, divided by its initial value (J_0). Curve κ_T/κ_0 : magnetic susceptibility (κ_T) of the samples after heating to temperature T, relative to its initial value (κ_0).



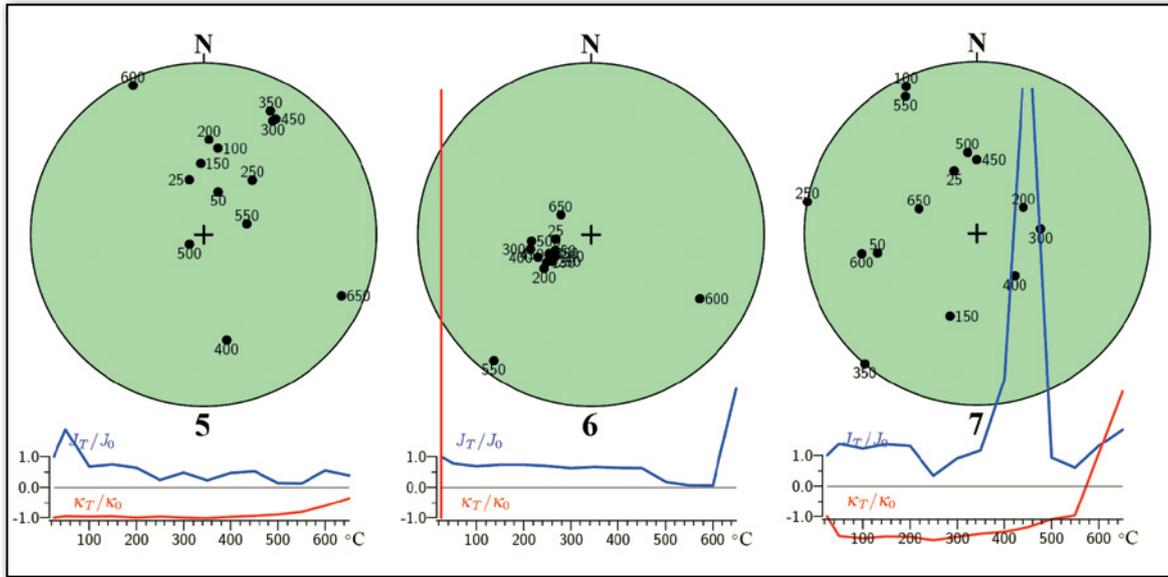
The measurements were performed in the Paleomagnetic Laboratory at the Geophysical Institute of the Slovak Academy of Sciences in Bratislava. The method of thermal demagnetization, together with adequate tests of paleomagnetic stability [2], were applied, and the results are presented in Figs. 2 and 3. Here, the dots represent projections of the tips of the magnetic polarization vectors onto the surface of a unit sphere, with the polarization vectors originating in the centre of the sphere. The big circles represent the projections of the unit sphere onto the horizontal plane. The symbol N denotes the direction of the true geographic North. The angular differences between direction of the true geographic North and the directions represented by the dots indicate declination. Furthermore, the distances between the centre of the big circle and the dots indicate the inclination of the geomagnetic field which magnetized the rocks in the locations where the sampling took place. (The inclination at the equator of the geomagnetic field is zero; the corresponding dot would lie on the circumference of the big circle. The inclination at the pole of the geomagnetic field is 90°; again the corresponding dot would project onto the centre of the big circle.)

The curves represent the thermal dependence of magnetic polarization (J) and magnetic susceptibility (κ) of the samples measured. Both quantities are normalized to their original values and shown in the plots as demagnetizing curves.

In the stereoprojections (Figs. 2 and 3) we can see that for samples from locations 1, 2 and 5, the north-south direction of their magnetic moments prevails.

We see that the samples from locations 3 and 4 have qualitatively similar demagnetizing curves. In both samples, a steep change in the magnetic susceptibility at about 400°C can be seen, which suggests that the samples contain the same magnetic material. It is impossible to identify any preferred direction from the range of directions in their magnetic polarizations. As described above, the material from locations 3 and 4 are very similar in nature. Together with the similarity in their magnetic characteristics, we may infer that the block from location 3 has its origin in the quarry near the pyramid (Fig. 1).

The samples from locations 1, 2 and 5 exhibit the same demagnetizing characteristics and their paleodirections (the average direction of magnetic polarization vectors) are nearly identical, as seen from Figs 2 and 3. This indicates that the blocks from which these samples were cut have identical carriers of magnetism and probably also identical rock material – perhaps the artificial limestone (geopolymer) prepared by the concrete technique described above. The paleodirections of the samples considered are presented in Fig. 4. In principle, they correspond to the declination and inclination of the geomagnetic field in Egypt.



◀ Fig. 3: Thermal demagnetization data, analogous to Fig. 2, of samples from locations 5, 6 and 7 (see Fig. 1).

The sample from location 7 shows demagnetizing characteristics similar to those from locations 3 and 4. This suggests that the block from which the sample was taken comes also from the quarry near the Khafre pyramid. Although the sample from location 6 allows one to determine the preferred magnetic direction, the rapid change in magnetic susceptibility at low temperatures (see Fig. 3) makes this paleodirection irrelevant. Therefore, we conclude that the rock material of the block from location 6 is different from that of blocks at other locations. The arrows in Fig. 1 indicate the calculated paleodirections.

Conclusion

The aim of paleomagnetic investigation of the rock material of the great Egyptian pyramids, Khufu and Khafre, was to find out the directions of the magnetic polarization vectors of their building blocks. This is one of the possible ways to verify the hypothesis according to which the blocks were produced *in situ* by a concrete technique. The analysis of a limited set of paleomagnetic samples provided the following results. The paleodirections of three sampling locations (2 from Khafre and 1 from Khufu pyramid) exhibit the common north-south orientation, suggesting that they may have been produced *in situ* by a concrete technique. The block from one sampling location of the Khafre pyramid is of natural limestone and evidently comes from the adjacent quarry. It is likely that the block from one sampling position of the Khufu pyramid comes also from the same quarry. Finally, we conclude that even if the concrete technique was used, the pyramids were constructed from a mixture of natural and artificial limestone blocks.

The results of this project have proved the usefulness of paleomagnetic methods. A more thorough investigation would provide further insight into the building material and the construction technology of the great Egyptian pyramids. ■

About the Authors

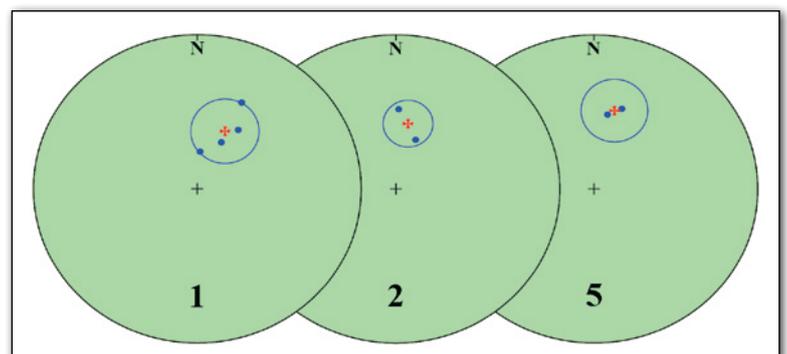
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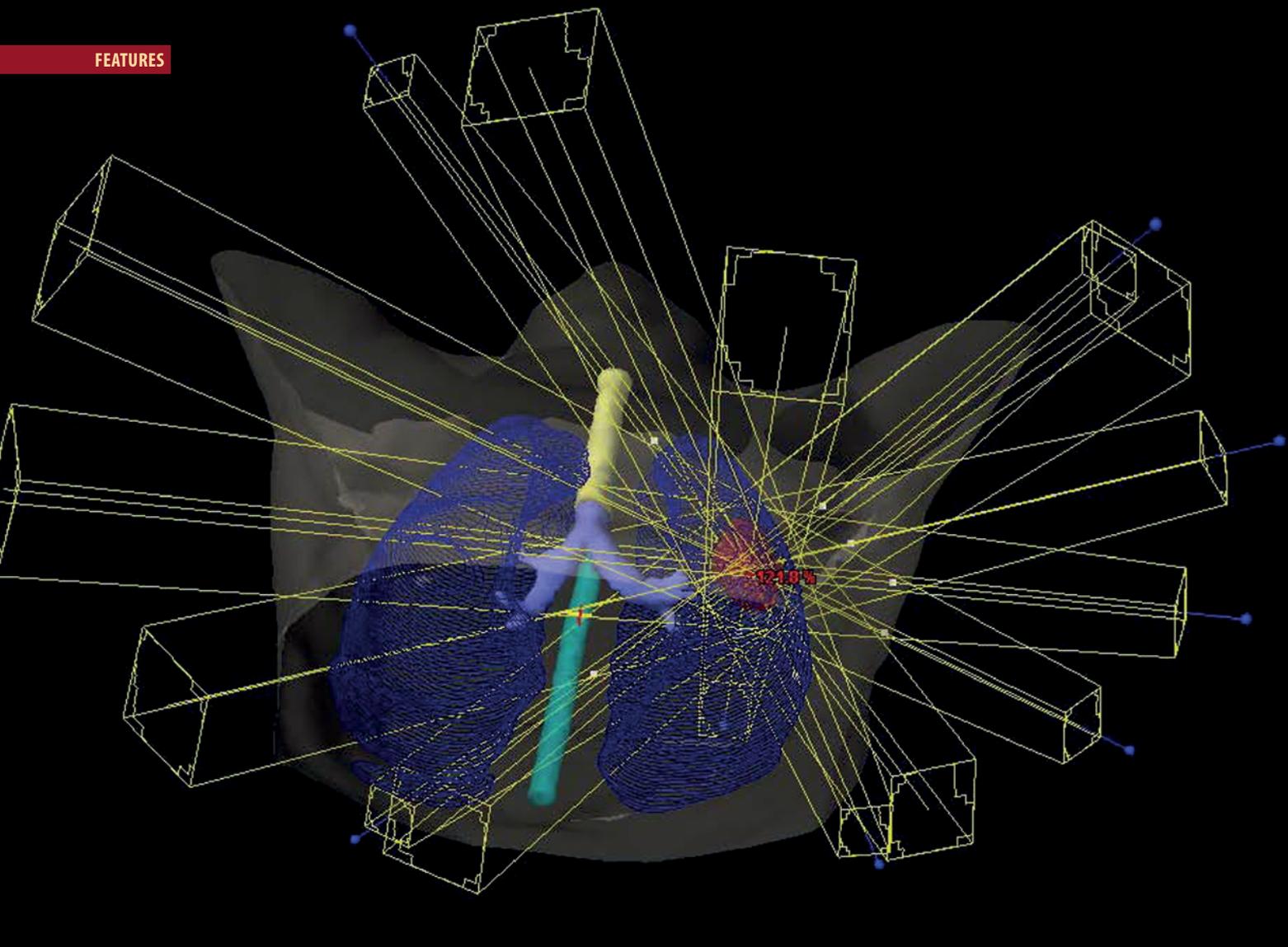
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▼ Fig 4: Directions of the characteristic magnetic polarization vectors of samples from locations 1, 2 and 5 (see Fig. 1). N = geographic North. Dots: directions of specimens from the same location. The cross symbols represent the mean directions. The blue circle indicates the region in which the polarization vector projection falls with 95% probability.





Advances in radiotherapy with external beam X-rays: from 3D to 4D

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Radiotherapy (RT) is the medical use of ionizing radiation, generally as part of cancer treatment to control or kill malignant cells. About 50 to 60% of all cancer patients in Europe receive RT either as curative therapy alone, or as an adjunct to surgery and/or chemotherapy, or as palliative therapy.

▲ Illustration of radiotherapy treatment in which the dose is concentrated on a small piece of lung tissue (so-called stereotactic body radiation therapy) (Image from HSCSP).

The goal of radiotherapy is to deliver a high dose of radiation to the tumour volume while keeping the dose to healthy tissue as low as possible. If the dose is too high the complication rate increases, but if it is too low the probability of tumour control decreases. This paper explains the process of RT, focusing on the current standard technique, which is called 3-dimensional conformal radiation

therapy (3D-CRT) using external-beam X-ray RT, and its technological improvements.

External-beam X-ray RT

In most centres today, external-beam radiation treatment is delivered to the patient by means of an electron linear accelerator, known as “linac”. Linacs deliver radiation beams from different angles around the patient. These

beams pass through the patient delivering the dose along their path. The combination of various shaped beams of radiation concentrates the dose in the tumor while surrounding healthy tissues receive the lowest possible dose. Treatment in RT involves multidisciplinary professionals such as radiation oncologists, medical physicists and technicians, and requires their close collaboration to be safe and effective. The process for treatment generally covers the following steps (see figure 1):

1. Dose prescription. The radiation oncologist prescribes the total dose of treatment to the tumour and the dose constraints to adjacent healthy organs, called organs at risk. The total treatment dose depends on the type of tumour. It usually varies from 40 to 80 Gy and is administered in several fractions, usually from 1.8 to 2 Gy per session. The number of sessions ranges from 20 to 40, depending on the planned total dose. Overall treatment time is approximately 4 to 8 weeks.

2. Treatment planning. Treatment planning is currently based on 3D images taken using X-ray computed tomography (CT). To obtain these images, patients are placed in the same position in which they will be treated daily in the linac, and the same immobilization devices are used. CT images have a high contrast resolution to discriminate between values of tissue densities that differ up to 0.1% and a high spatial resolution (on the order of 1-2 mm). They make possible to determine ('delineate') the volume to be irradiated and the organs at risk. When supplementary information is needed in regions of the body such as lung, head and neck, images are taken by magnetic resonance (MR) or positron emission tomography (PET) and combined with these CT images. PET has a high contrast resolution, but its anatomic resolution is limited. Using images of both PET and MR we can distinguish the most resistant areas in a tumour and treat these with higher doses. In general, PET and CT are used for planning in lung and head and neck cancers, while MR and CT are used in tumours such as those in the brain or prostate. By better defining the target volume with data acquired from PET or MR we can deliver a larger dose to the patient and reduce damage to surrounding healthy tissue.

4D CT imaging

Respiratory motion is one of the major challenges in RT in thoracic and abdominal cancers. Movement of the tumor can lead to uncertainty in delineating the volume to be irradiated and therefore affect the treatment dose delivery. Conventional RT does not take this respiratory motion into account when planning the target volume. To compensate for this, a uniform margin is added to the tumour volume. Tumour motion is anisotropic and it varies from patient to patient. The magnitude of the movement depends not only on each patient's respiratory cycle but

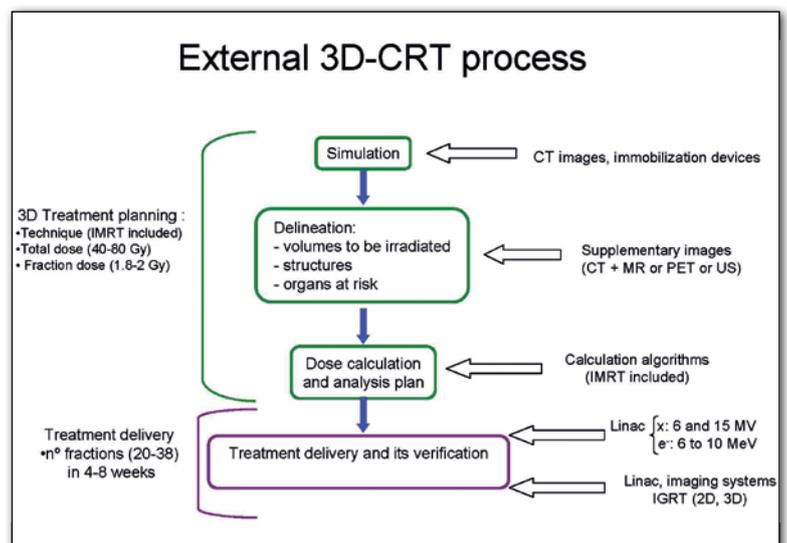
also on the size and location of the tumour. Displacement of tumour motion may vary significantly depending on the direction of the patient (superior-inferior, lateral and anterior-posterior) [1].

To analyse respiratory motion, 4D CT imaging is used. 4D CT images can only be obtained with new-generation CT scanners. These machines have faster data acquisition and yield dynamic CT images of the thoracic region. 4D CT imaging collects time-varying scans of the lungs. The first step is to record the patient's respiratory cycle. 4D CT imaging can only be used when patients have a regular and reproducible respiratory cycle. The breathing cycle is divided into distinct phases, and data sets of CT images are acquired for each phase and in every position of interest. After the scan is taken, images are sorted and correlated based on the corresponding breathing phase signals. Thus, many 3D CT sets are obtained, each corresponding to a specific breathing phase. Together, they constitute a 4D CT series of images that covers the whole breathing cycle. The radiation oncologist may choose to work on the images of a single phase or the images of the whole cycle. This 4D CT process allows the radiation oncologist to better delineate the target volume and reduce the volume of normal tissue to be irradiated.

Because 4D CT provides detailed visualization of the lung movements it implies considerable progress in treating tumors of the chest and upper abdomen.

3. Dose calculation. The dose contribution from each beam is calculated by a treatment-planning system using CT images of the patient and a mathematical model of how the linac will deliver doses in different tissues. The shape of each beam is controlled by collimators or multi-leaf collimators (MLC). Multi-leaf collimators consist of two sets of individual "leaves" (from 20 to 160 leaves per set) that can move independently in and out of the path of a beam to block it. One or several beams can be used, depending on the disease and the patient's needs.

▼ FIG. 1: External 3D-Conformal Radiation Therapy process



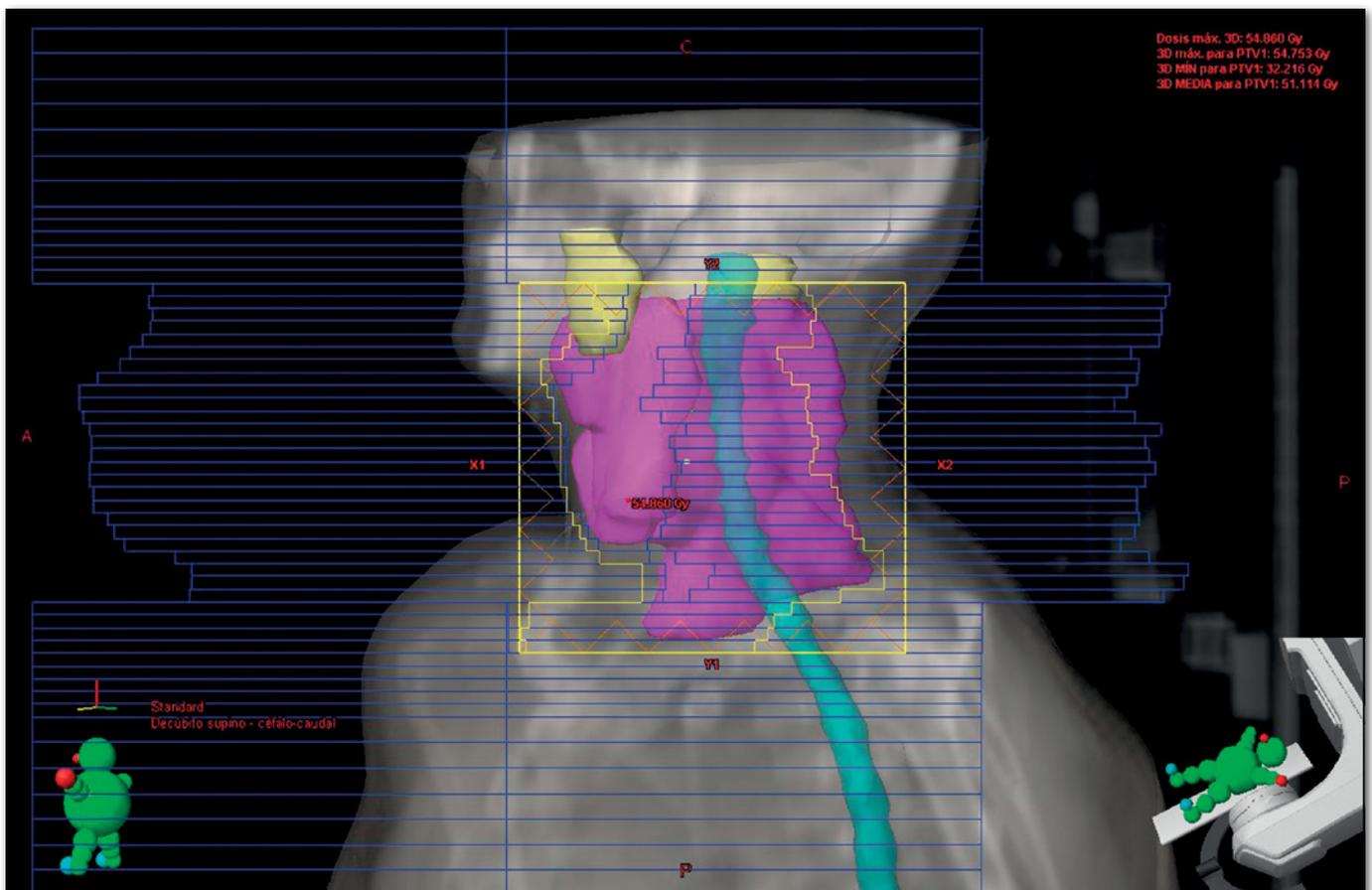
Some treatments need radiation fields that have non-uniform spatial intensity distributions. To obtain the desired dose distribution in the tumour target volume we need to combine several beams with a non-uniform dose so as to spare nearby critical structures. This procedure is called intensity-modulated radiotherapy (IMRT). IMRT is an advanced step of 3D CRT. IMRT uses multi-leaf collimators that can move dynamically during the treatment session when the beam is on, or between exposures. The process of dose calculation is the responsibility of the medical physicist. The radiation oncologists analyse the treatment plan and if they agree with this, it is approved and forwarded to the treatment unit for delivery (see figure 2).

▼ FIG. 2: A snapshot of the multi-leaf collimators (MLC) during a head and neck treatment using dynamic intensity-modulated radiotherapy. The main collimator is shown as a yellow rectangle. The yellow lines show the start and final positions of the MLC. The blue lines show an instantaneous position of the MLC. (Image from HSCSP).

4. Treatment delivery. The dose is delivered in a linac, as mentioned above. Linacs can be designed to produce monoenergetic photons with fixed energy (usually 6 MV), or multi-energetic photons (6 to 15 MV) and electrons (6 to 20 MeV). It is important that the radiation is delivered to the correct anatomic site. To verify the patient setup in the treatment position, traditional films have now been replaced by electronic portal imaging devices attached to the gantry of the linac and aligned with the beam. 3D CRT, intensity-modulated radiotherapy (IMRT) and other recently developed techniques have reduced the alignment error tolerance for targets that move and deform during treatment. However, these techniques are

complex. To deal with these challenging treatment scenarios, linac manufacturers have introduced image-guided radiotherapy 3D and developed and integrated X-ray imaging systems (see figure 3) to improve and facilitate 3D visualization of the patient's internal anatomy. This enables efficient positioning of these anatomical structures in relation to the linac. Most of these systems use CT-based technology.

With these technological improvements, a new RT procedure has emerged, called stereotactic body radiation therapy. It is highly effective for small lesions (<6 cm) in the abdominopelvic and thoracic region. The main feature separating stereotactic body radiation therapy from standard 3D RT or IMRT treatment is that large doses (6 – 30 Gy) are delivered in a few fractions (1 – 5) over a relatively short time (2 weeks), resulting in a high biological effective dose. To minimize normal tissue toxicity, it is essential to confine these high doses to the target and achieve rapid fall-off of the doses away from the target. So-called 'Stereotactic body radiation therapy' integrates simulation, treatment planning and dose administration and requires a high level of confidence in the accuracy [2]. Due to the rapid adoption of stereotactic body radiation therapy and other modalities of IMRT, specific linacs have been developed, with single photon energy of 6 MV. These new linacs incorporate different systems of image-guided 3D depending on the manufacturer. They may be based on CT, dual radiographic x-ray imaging, and/or fluoroscopy.



4D Treatment delivery

4D treatment delivery is analogous to 4D CT imaging discussed earlier. It means that respiratory motion is taken into account during RT treatment. The recommendations to apply 4D in the treatment of patients with thoracic, abdominal, and pelvic tumours affected by respiratory motion can be summarized if either of the following conditions are met [3]: when a range of motion greater than 5 mm is observed in any direction; or when significant normal tissue sparing can be gained through the use of a respiration management technique.

There are several methods to reduce the impact of respiratory motion in RT, but one of the most widely accepted modes by the radiation oncologists is real-time tumour tracking. Under ideal conditions, tracking can eliminate the need for a tumour-motion margin in the dose distribution, while maintaining a 100% duty cycle for dose delivery. For this tracking to be successful, four criteria must be met:

1. the tumour position must be identified in real time;
2. tumour motion must be anticipated to allow for time delays in the response of the beam-positioning system;
3. the beam must be repositioned;
4. dosimetry must be adapted to allow changes in lung volume and the location of critical organs at risk during the breathing cycle.

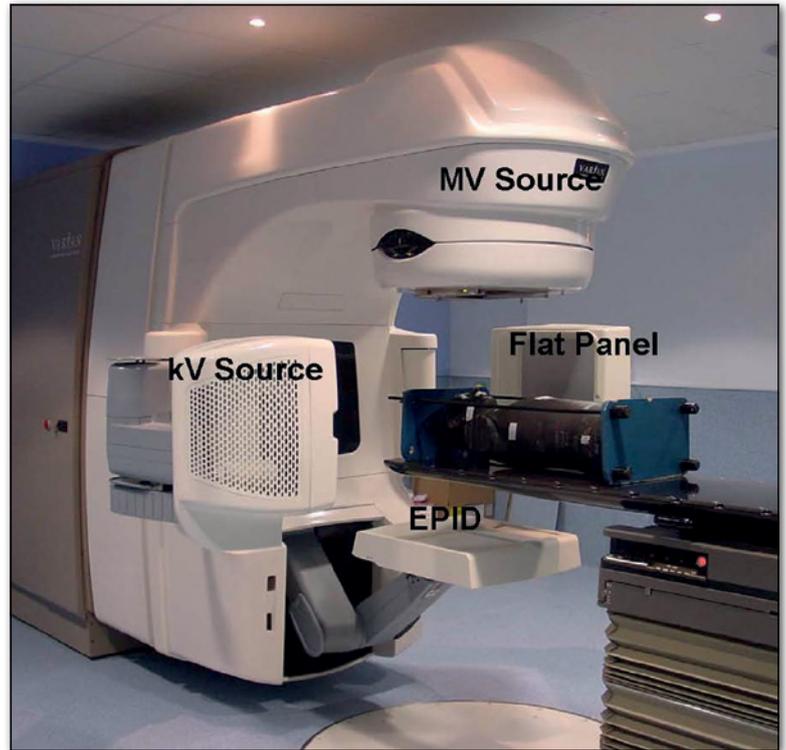
Only a few brands of linacs currently offer tracking. Research is ongoing in the field to improve or incorporate "tracking" in the linacs, adjusting the dynamic movements of collimators or multi-leaf collimators.

As management of respiratory motion requires the use of highly specialized technology it is recommended that a qualified medical physicist be present throughout the entire process for each patient, from the treatment-planning imaging sessions to treatment delivery.

Adaptive RT

Adaptive RT is the optimization of treatment planning based on information acquired during the course of fractionated treatment. RT is a dynamic process. Patient outcome depends on four variables: the location of the dose in each session; the variation of dose administration over time; the anatomical geometry of the tumour; and, the biological response of the tumour and normal tissue. As advances in RT allow a higher dose of RT to the tumour and lower dose to organs at risk, correct patient alignment and knowledge of changing internal anatomy is critical.

Until recently, all treatment was planned before the first fraction was delivered to the patient, and no further changes were made throughout the course of therapy. However, a new concept is now being introduced as a result of advances in current technology. Adaptive radiotherapy (ART), also called adaptive radiotherapy 4D, is



▲ FIG. 3: Linac with integrated X-ray imaging systems. (Image from HSCSP).

the explicit inclusion of the temporal changes in anatomy during the imaging, planning, and delivery of radiotherapy [4]. Adaptive radiotherapy 4D allows the radiation oncologist to modify treatment in cases of weight loss, tumour shrinkage or growth, or volumetric or dosimetric changes in the tumour. The tools and methods to perform such modifications are under continuous development and present results strongly suggest that ART will replace 3D CRT in the near future. ■

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Shocks in fragile matter

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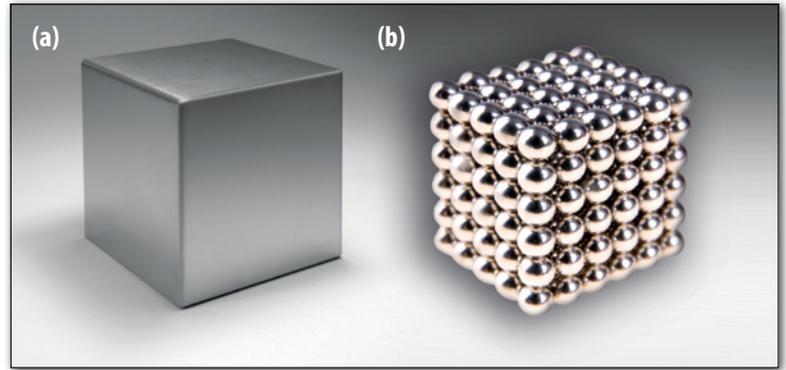
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In ordinary solids, only the most violent impacts lead to acoustic shocks. Soft materials, such as granular media, are different. They can be prepared in a state of vanishing rigidity, where even the tiniest perturbations create shock waves. Such materials are not just soft, they are *fragile*.



When a jet breaks through the sound speed barrier, it releases a great amount of energy in the form of non-linear sound waves often visible as a condensation cloud of the cooling air (see introductory illustration). This spectacular phenomenon, reminiscent of an explosion, is called a sonic boom and is a striking example of an acoustic shock. What about acoustic shocks propagating through a solid?

Sound speeds in metals are much higher than in air. A bullet would need to move faster than 6000 m/s into a solid block of steel for it to create an acoustic shock (see Fig. 1a). This is clearly a situation of scarce relevance to



everyday life. However, if, instead of a solid block, one considers a loose packing of steel balls (see Fig. 1b), a distinct physical property emerges: fragility. Such loose packings of balls or other particles are called granular media (sand, cereal, sugar). Granular media can display vanishingly small sound speeds, even if the particles are made of steel. When the sound speed is lowered to zero, linear sounds waves become irrelevant: every applied perturbation, no matter how tiny and slow, propagates supersonically, in the form of shock waves. How does this happen?

▲ Fig. 1: (a) A solid block of steel has a sound speed of 6 km/s, while a granular material, such as packings of steel balls (b), may exhibit a vanishing sound speed.

The Sonic Vacuum

Individually, steel balls are neither soft nor fragile. Collectively though, granular packings are fragile and soft. The root cause of this lies in the non-linear, Hertzian interaction law, which governs the elastic deformations of spheres in contact (see Box 1). According to this law, when you push two elastic balls together, the deformation δ varies with the force f as $f \sim \delta^{3/2}$. If the contact law would have been linear, as you might have expected, doubling the force would double the deformation, but Hertzian contacts get stronger the more you compress. And, conversely, they get weaker and weaker the less you compress. More precisely, when many such balls are arranged along a chain, the effective spring constant, k_{eff} , is not really a constant anymore! Instead $k_{\text{eff}} \sim df/d\delta \sim \delta^{1/2} \sim f^{1/3}$ can be tuned by varying the compression δ , and vanishes when the confining force goes to zero. This has a crucial effect on the speed of sound of the chain: $c \sim k_{\text{eff}}^{-1/2}$. So, while the sound speed within the particles, v_p , is very large and independent of compression, the weak contacts lead to a vanishing collective sound speed when the overlap δ tends to zero. Such a state of vanishing rigidity and sound speed is called the *sonic vacuum* [1].

The sonic vacuum state of a Hertzian chain reminds us of the Newton's cradle, a toy composed of pendulum balls just touching so that $\delta=0$, see Fig. 2. When the leftmost ball strikes its neighbour with speed u_p , a propagating pulse of mechanical energy is generated, despite the vanishing sound speed. But, if the sound speed is zero, what excitations can propagate through this fragile mechanical system? And what sets their speed v_s ? Nesterenko first answered these questions in his pioneering investigation

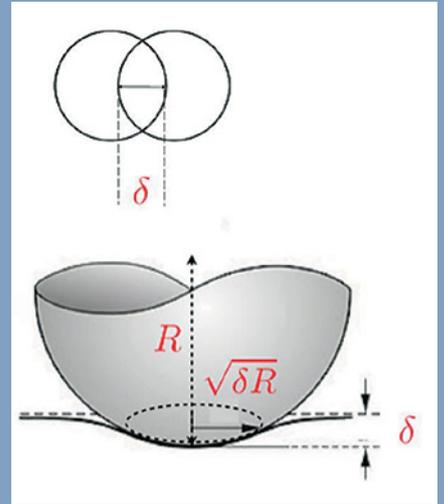
◀ A jet breaking through the sound barrier produces a shock wave, made visible by a condensation cloud. © iStockPhoto



BOX 1: HERTZIAN CONTACTS

When two macroscopic objects are brought into contact an elastic deformation δ is generated, as illustrated in figure. If a ball of radius R is squeezed against a flat wall, it is compressed in the *longitudinal* direction and expands in the *transverse* direction. Simple geometric considerations reveal that the radius of the area of contact is approximately $(R\delta)^{1/2}$ (see figure). That means that, in the contact area, the deformation (or strain) γ can be estimated by dividing the longitudinal deformation δ

by this radius: $\gamma = \delta / (R\delta)^{1/2} \sim \delta^{1/2}$. According to linear elasticity, the stress σ is proportional to the strain γ so that $\sigma \sim \delta^{1/2}$. The corresponding force f is obtained by multiplying the stress by the area of contact, which is proportional to $R\delta$, see the dashed circle in the Figure. The Hertzian law of interaction then follows: $f \sim \delta^{3/2}$, where only the dependence on δ has been tracked explicitly. Note that despite the linear stress-strain relation for the balls material, their interaction force is non-linear. ■



of one-dimensional granular chains [1]. He demonstrated that non-linear sound propagates with speed $v_s \sim u_p^{1/5}$ in the form of solitary or shock waves – note that v_s is larger than the sound speed in the chain c but lower than the speed of sound v_g within each ball. Recently, these insights have inspired technological advances ranging from tunable acoustic diodes to non-linear acoustic lenses [2].

Shocks in Sand

However, much remains to be understood about common granular materials such as sand. The confining pressure P is perhaps the most accessible experimental parameter, and it controls the *average* grain-overlap δ . As the confining pressure is lowered to zero, the sound speed vanishes [3]. However, granular packings are not simply one-dimensional and they are clearly *amorphous*. Will disorder destroy the Nesterenko solitons?

We have simulated the response of two-dimensional amorphous packings of Hertzian particles to the impact of a rapidly moving piston [4], see Fig. 3. The piston compression leads to the formation of a front that separates two states: behind the front we find a compressed region

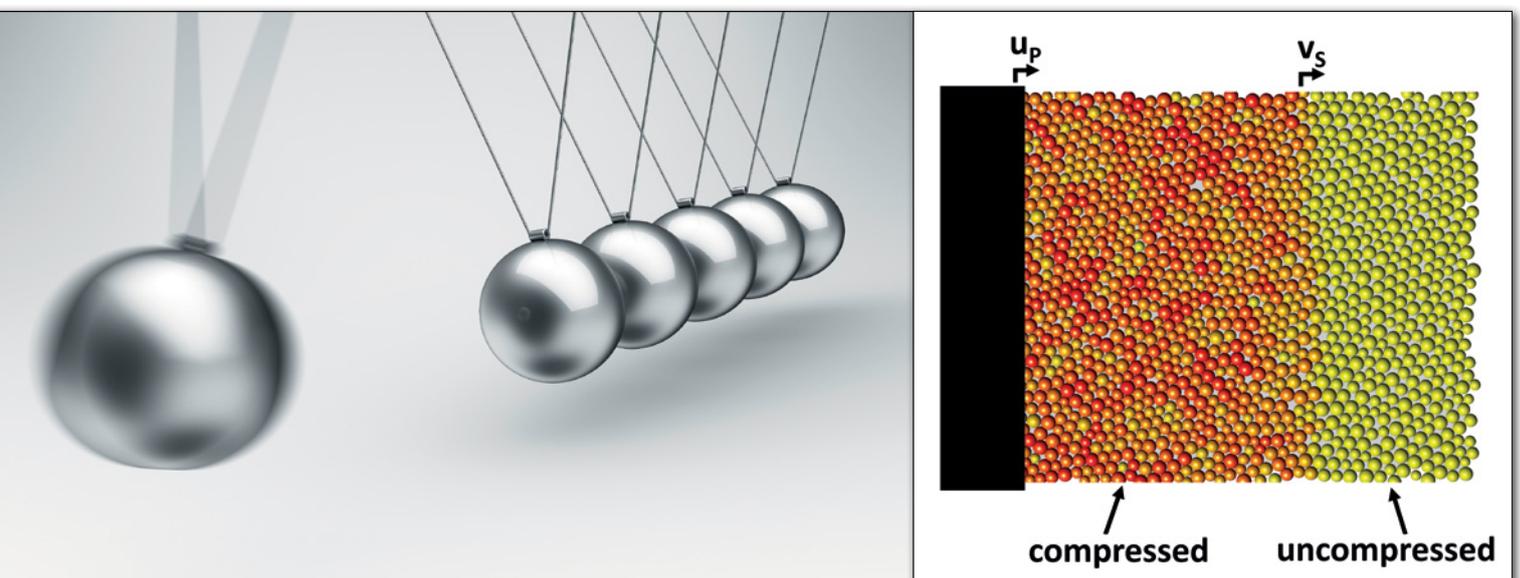
in which the particles are moving on average with the piston speed u_p , and ahead of the front we find an uncompressed region where the particles are at rest. Despite the strong disorder in the packings, the resulting fronts are smooth and stable, see Fig. 3. One finds two distinct types of fronts, depending on the initial pressure of the packing, and the speed of the piston. For large pressure and small piston speeds, the front speed is simply the linear sound speed, which varies with pressure but is independent of the piston speed. In contrast, for large piston speeds or small pressures, one finds more rapid shock waves, whose velocity is set by the piston speed only – much like the Nesterenko solitons (see box 2).

Extreme Mechanics of Fragile Matter

How general are such phenomena? The vanishing of the rigidity and sound speed of granular media for small pressures is just one example of fragile materials arise. For example, network glasses such as chalcogenides are made of covalent bonds (see Fig. 5). Yet, they can still be fragile if the average valence falls below a certain threshold [5]. In this case, the energy cost of microscopically

▼ Fig. 2: Newton's cradle: a sonic vacuum. © iStockPhoto

► Fig. 3: Simulations reveal supersonic shock waves travelling at a speed v_s in response to piston compression of a model granular medium with constant speed u_p .



deforming a bond is harmonic: the origin of fragility cannot be traced to non-linear interatomic forces. This *global* sonic vacuum state is generated by the weak connectivity of the network. It is the network topology that matters, not the strength of the individual bonds.

Similarly, shock waves are just one example of the intrinsically nonlinear phenomena that arise when soft materials become fragile. Other examples include nonlinear elasticity and nonlinear flow behaviour [6-7].

A common theme thus emerges. First, a wide class of materials, such as granular media, emulsions, wet foams, weakly connected biopolymer networks and covalent network glasses [6-8] can all be prepared in a fragile state. Second, all of these materials exhibit a vanishing range of linear response in their fragile state. As a consequence, tiny perturbations can elicit extreme mechanical responses in the form of shocks, rearrangements, yielding and flow [6-10]. It is tempting to ask whether, similar to shock waves in granular packings, all of these complex phenomena can be described by simple scaling relations. ■

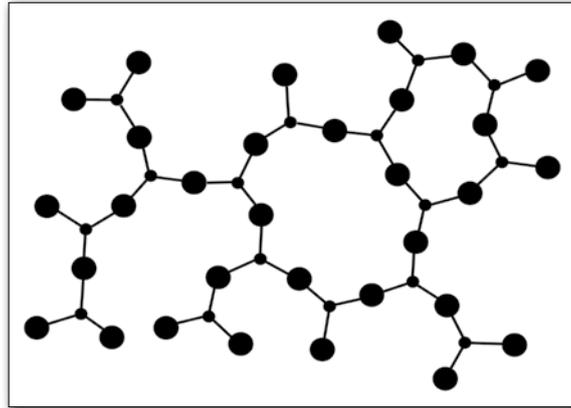
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◀ Fig. 5: Network glasses such as chalcogenides, illustrated here, can become fragile too.

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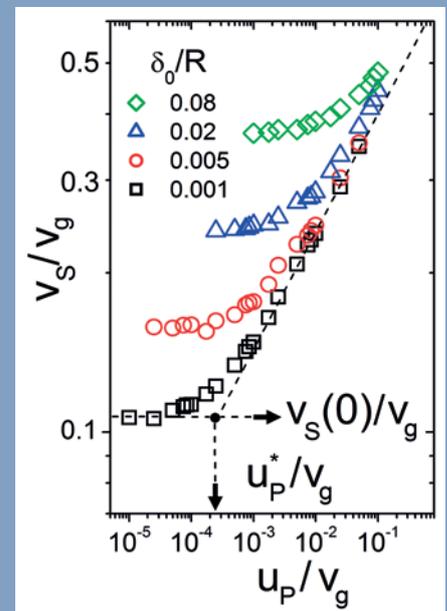
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BOX 2: SCALING

If a granular medium is compressed, once transients have died out, the front propagates with constant speed v_s whose dependence on piston speed u_p is illustrated in Fig. 4 for different values of the applied pressure P [4]. Here, both v_s and u_p are measured in units of the speed of sound v_g in the individual grain. For low u_p , the front speed v_s is nearly independent of u_p - in this (quasi)linear regime, v_s is simply controlled by the initial pressure P . In contrast, for high impact intensity, the nonlinear shock wave regime is reached, where $v_s \sim u_p^{1/5}$, but does not depend on P . The physical origin of the shocks can be grasped by means of intuitive arguments

and scaling. Even if the grains are not in touch to start with, the propagating front itself will generate a compression δ and a corresponding increase in the kinetic energy. Combining mass conservation through the shock with the assumption that the kinetic and potential energies are of the same order in the regime behind the shock, one obtains a scaling relation for the shock speed; $v_s \sim u_p^{1/5}$. This scaling relation, plotted as a dashed line in Fig. 4, is clearly consistent with the numerical data. ■

► FIG. 4: Scaling plot revealing the relations between the shock speed v_s , piston speed u_p , overlap δ and sound speed within the material, v_g .





Opinion: Research integrity in a competitive context

Michèle Leduc, *president of the Ethical Committee of CNRS, France*
Physicist at Laboratoire Kastler-Brossel, École Normale Supérieure, Paris

The value and the benefit of the research activity are fully dependent on the scientific integrity of all people involved. This is all the more needed since scientific advances are key contributors to societal issues such as health, national security, environmental protection, as well as economic development. Research misconduct could have a severe negative impact on the perception of the scientific enterprise, and eventually spoil the image of science itself within the public opinion.

These matters are timely as the context is rapidly changing with the many missions assigned to the researchers, potentially pushing them to deviate from strict integrity in the laboratories. The competition between them has become more and more severe. The pressure has increased for a share of the research funds, which are always too meager, and for personal careers, which are essentially dependent on scientific publications. The pressure is very large to perform at the level of excellence, with the implicit necessity to publish in high-impact journals as well as the requirement to come up with innovations and patents.

In such a competitive context, individual or collective inappropriate behaviour could easily take place, covering a broad spectrum of misconduct types. The most detrimental ones deal with the fabrication or falsification of data. Plagiarism also occurs, made particularly easy by modern digital techniques, which publishers also use to find copied text. More frequent and less severe

Misconduct could eventually spoil the image of science itself within the public opinion

cases refer to the misuse of research data and to publication-related misconduct, in particular regarding authorship – a very sensitive issue. In addition, personal behaviour in a research team can be inappropriate, revealing poor mentoring of students, harassment or inadequate leadership. There is no general definition of integrity. Different countries deal differently with the problem of scientific misconduct, which is recognized as a true obstacle to international collaboration. A world conference was held in 2011 in Singapore which put forward a statement now accepted by a large number of research institutions such as CNRS in France. The so-called Singapore Statement on Research Integrity makes 14 recommendations based on four basic principles dealing with “honesty in all aspects”, “accountability in the conduct of research”, “professional courtesy and fairness”, “good stewardship on behalf of others”. These are just universal values and “soft ethics” prescriptions.

There are no concrete rules along these lines enforcing a general code of conduct at the European level, not even at the national one. Each research institution and university has its own rules. Of course, sanctioning measures are requested in extreme cases, publicized with enough transparency while respecting confidentiality and avoiding conflicts of interest. More important in my view is that they should be preceded by pedagogical efforts aiming at preventing research misconduct in the first place, installing a responsible practice to young researchers from

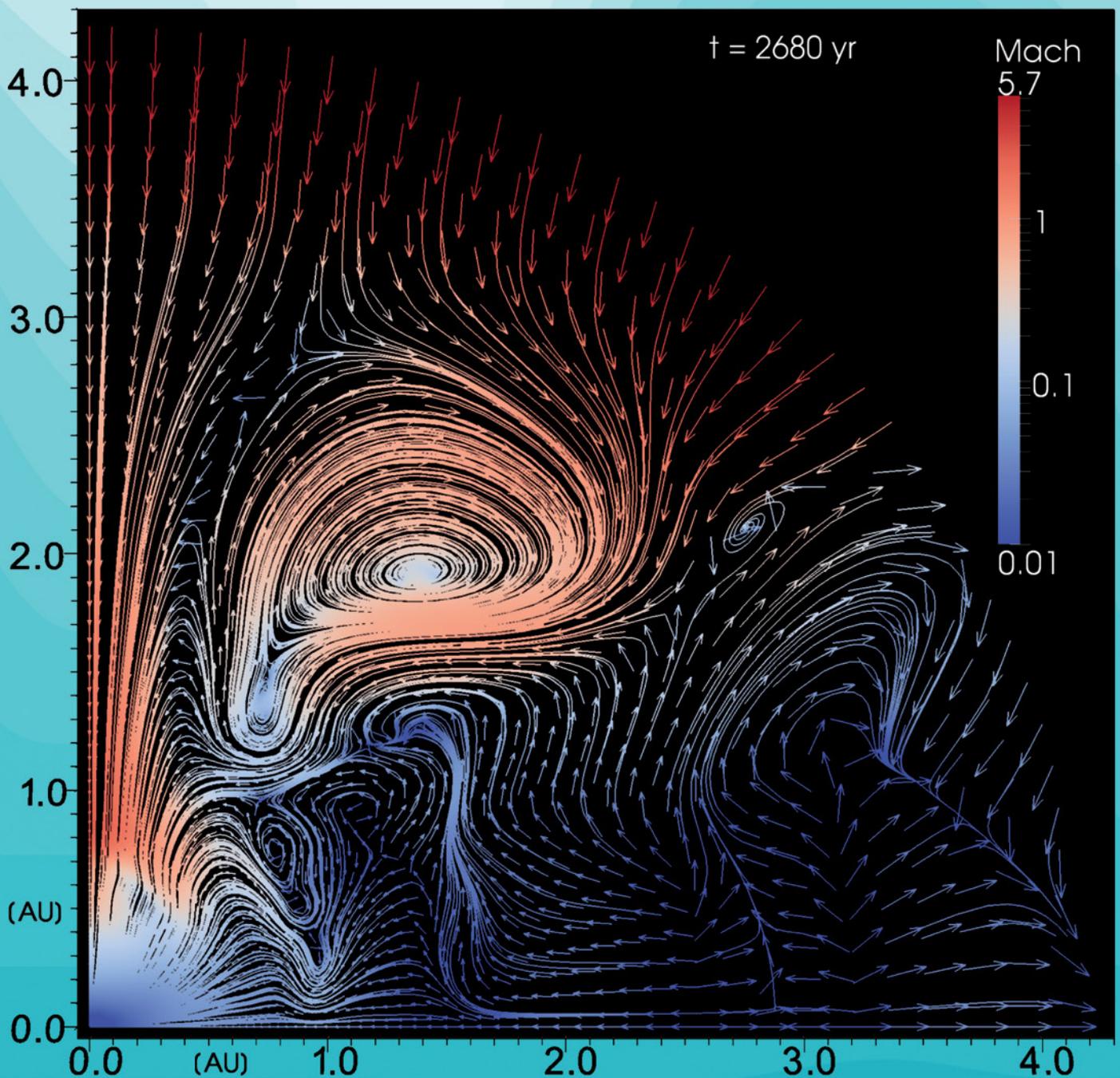
the very beginning of their life in the laboratory. Also, generally speaking, a less crazy rush for publications and a second thought given to evaluation methods by research institutions might bring back more serenity in our laboratories. ■

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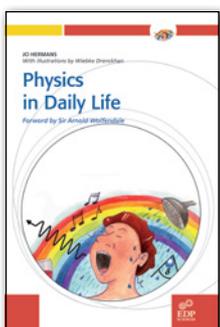




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