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Executive Committee
Merging incompatible materials
EPS directory
Neutrinos… the last mixing angle
Magnetic Resonance Imaging

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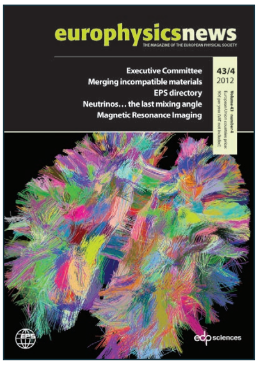

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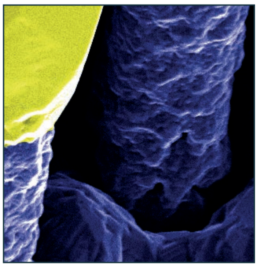
Cover picture: the main networks of the human brain white matter as extracted from RMI images. © CNRS Photothèque / Antoine Grigis, Vincent Noblet, Fabrice Heitz, Jean-Paul Armspach. See p. 26 " Magnetic Resonance Imaging, a success story for superconductivity"



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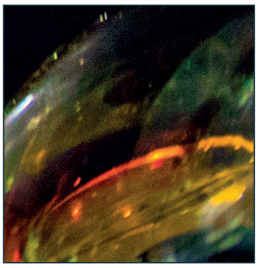

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It's the **economy!**

Physicists, when asked to justify their existence, routinely trot out a list of all the good things that unarguably they have contributed to society. These include x-rays, MRI scanners, semiconductors, lasers and GPS navigation to list just a few. The development of these, however, can take a generation or longer to reach fruition and furthermore their economic benefit is almost impossible to assess. As we are all aware, and especially in Europe, it is precisely this economic aspect that currently dominates political thinking and a society faced with pressing economic problems and rising unemployment. Physicists, however, can have a good story to tell here also. For example in the UK the Institute of Physics has in recent years commissioned several reports (see: www.iop.org/publications/iop/2007/page_42716.html) to study and quantify the role of physics-based sectors in the UK economy. These are defined as those in which the use of physics- based expertise or technology is critical for the sector to function and encompassed industries that are dependent on modern and advanced physics (for example, aerospace and telecommunications) but does not include those that are dependent on more basic physics such as mining and construction. These reports have clearly demonstrated the importance of physics to the UK economy. Physics-based business and industry has been shown to account for 5% of the UK workforce – a similar number of workers to that employed in the construction sector. Economic activity, measured in gross value added, is approximately 6.4% of the UK total – the same as for banking, finance and insurance.

The European Physical Society is currently funding a similar study to cover the European Economy (the 27 EU countries plus two EFTA countries - Switzerland and Norway - for which Eurostat data in the form of NACE codes is also available). Research and development, balance of trade impact and foreign investment in European physics-based industries will also be analysed. This study is being conducted by an independent body, the Centre for Economics and Business Research Ltd, which is a company of high repute specialising in this type of work – an important consideration if the report is to command high respect from outside the physics community. Although the report is aimed at European institutions, the data will be presented in a format that will enable physicists in individual countries to extract the relevant figures they require to enable them to inform and influence their own politicians and policy makers.

It is now increasingly appreciated that, for economic recovery, austerity must be accompanied by economic growth. This is, of course, stimulated by innovation much of which emanates from the application of physics in creating and advancing new technologies. It is hoped that the EPS report and the facts that it reveals can be used to maintain, indeed enhance, support for physics and physics-based industries thereby enabling them to drive growth and employment in the European economy. As the English philosopher, Bertrand Russell, optimistically commented, "a habit of basing convictions on evidence… would, if it became general, cure most of the ills from which this world is suffering". ■

Colin Latimer
Treasurer of the EPS

The new members of the EPS Executive Committee in 2012

Carlos Hidalgo (1956, Madrid, Spain)

➥ *Representing Divisions and Groups*

I received my PhD degree from the Madrid Complutense University in 1984 with my work on structural defects in solids and positron annihilation spectroscopy. My next area of research was related to plasma turbulence, transport and plasma diagnostics where I am currently leading the Experimental Plasma Physics Division at CIEMAT (Centro Nacional de Investigaciones Mediambientales y Tecnológicas).

I have worked in different international laboratories, initially as a PhD student [Technical University of Denmark (Denmark), Nuclear Research Centre of Grenoble (France), Technical University of Helsinki (Finland)] and later as a visiting scientist [Fusion Centre at the University of Austin (US), Oak Ridge National Laboratory (US), Joint European Torus (UK), Max Planck Institute (Germany), National Institute Fusion Studies (Japan)]. I have been leading different international research teams including the European Transport Task Force on Turbulence (1994 -2000) and the European Transport Topical Group (2008 -2010), involved in Advisory Committees, including the Science and Technology Advisory Committee of the European Fusion Development Agreement (2008-2012) and leading the Plasma Physics Division of the European Physical Society (2008-2012). Teaching experience, including my involvement at the Plasma Physics and Nuclear Fusion Erasmus Master, complements my research activity. ■

Goran Djordjević (1963, Niš, Serbia)

➥ *Representing Member Societies*

My scientific and pedagogical career started in 1989 at the Department of Physics, Niš, where I had also completed my BA. I obtained an MSc in Theoretical Physics at the University of Belgrade in 1995 and a PhD in 1999. A segment of my PhD research was at the Mathematical Institute Steklov Moscow. Between 2000 and 2003, I spent two years as a DFG visiting researcher at Ludwig-Maximillian University and Max Planck Institute for Physics in Munich. Much of my scientific work has been devoted to the theoretical and mathematical aspects of quantum models on Planck scale, including Cosmology, Inflation and Particle Physics.

From 1997 until 2011 I coordinated a project on a "Special grammar school class for gifted pupils in science and physics" in Niš. During that period I was also leader for a number of national and international UNESCO projects.

With strong support from Julius Wess and the WIGV Initiative I proposed then headed the Southeastern European Network in Mathematical and Theoretical Physics (SEENET-MTP) from 2003 to 2009. I am now its Executive director. It consists of 19 full-member institutions from 10 countries from the Balkans, 14 partner institutions and about 300 individual members all over the world. The Network has implemented 11 research-training projects and organized a series of schools and conferences in cooperation with UNESCO (Paris and Venice), ICTP and CEI Trieste, DAAD, CERN, EPS, the Serbia Ministry of Sciences and others.

The services I have performed at the Department of Physics, University of Niš, Serbian Physical Society, Balkan Physical Union and now the European Physical Society made me realize that cooperation between countries from the former Yugoslavia, the Balkans, Europe and beyond is the best way to strengthen personal and group capacities in research and teaching and best prepare a new generation of scientists in troubled times. ■

Jonathan Lister (1949, Purley, Great-Britain)

➥ *Representing Divisions and Groups*

With a degree in Physics from the University of Oxford, I carried out my PhD research at the University of London (Westfield College), working during the start-up of the Omega project at CERN. After this enriching experience, I changed fields and became a Research Associate at the Culham Laboratory in the UK, working on two fusion experiments and learning some plasma physics. Following this, I took up a 2-year post-doctoral post at the Centre de Recherches en Physique des Plasmas at the EPFL in Lausanne for the start-up of the TCA tokamak project just funded. I never left.

During these many years spent in fusion research, I have been able to work on a wide range of subjects, including plasma diagnostics, plasma heating, tokamak operation and tokamak control. I spent some time outside the CRPP, working briefly at General Atomics in California, at MIT, at the Japanese fusion centre in Naka, as well as numerous short visits to European centres. I was detached to work for just over 2 years (2006-2008) on the ITER controls challenges.

I have been more than lucky to follow a number of stimulating graduate students, and have given a regular Master course on fusion for many years.

My external service activities have included working with the Plasma Physics and Controlled Fusion editorial board, as Deputy Editor and now on the Advisory board. Having been a member of the EPS Plasma Physics Division board for some years, I had the honour of chairing the division from 2004-2008.

Given my strong view that we should return to others what we have been lucky to receive during our own careers, it will be a pleasure and honour for me to work together with similarly minded colleagues on the Executive Committee of the EPS. ■

James Hough (1945, Glasgow, Scotland)

➥ *Representing the IoP Member Society*

A graduate of the University of Glasgow, I became a Professor of Experimental Physics in 1986 and Kelvin Professor of Natural Philosophy for 2009-10. For close to 40 years I was involved in building up the UK effort aimed at the detection of gravitational waves and was Director of the University's Institute for Gravitational Research from 2000 to 2009. Having formally retired in 2010 I am now employed as a research professor in Glasgow. A Fellow of the Royal Society of London, the Royal Society of Edinburgh, the American Physical Society and the International Society for General Relativity and Gravitation, I was appointed to the Scottish Science Advisory Council in 2010, and, in the same year, to the core group of the Physical and Engineering and Science Committee of the European Science Foundation representing the relevant UK research councils.

I was elected to the Council of the UK Institute of Physics in 2011 and also took up a position as chair of the Education Committee for the UK Institute of Physics in Scotland in 2011.

From 1 May 2011 I assumed the role of Chief Executive Officer for the Scottish Universities Physics Alliance (SUPA) – a loose collaboration of eight physics departments.

In these roles I am taking a particular interest in how research alliances in the UK can interact with similar types of collaborations in continental Europe, and facilitate the further growth of collaborative research, education and innovative developments in multidisciplinary science in Europe for the benefit of the economy and quality of life.

I believe the European Physical Society has a pivotal role to play in such interactions and I hope to be in a position to help in this area, and with contributing to the delivery of the strategic priorities of the Society. ■

Sofoklis Sotiriou (1970, Athens, Greece)

➥ ***Representing the Divisions and Groups***

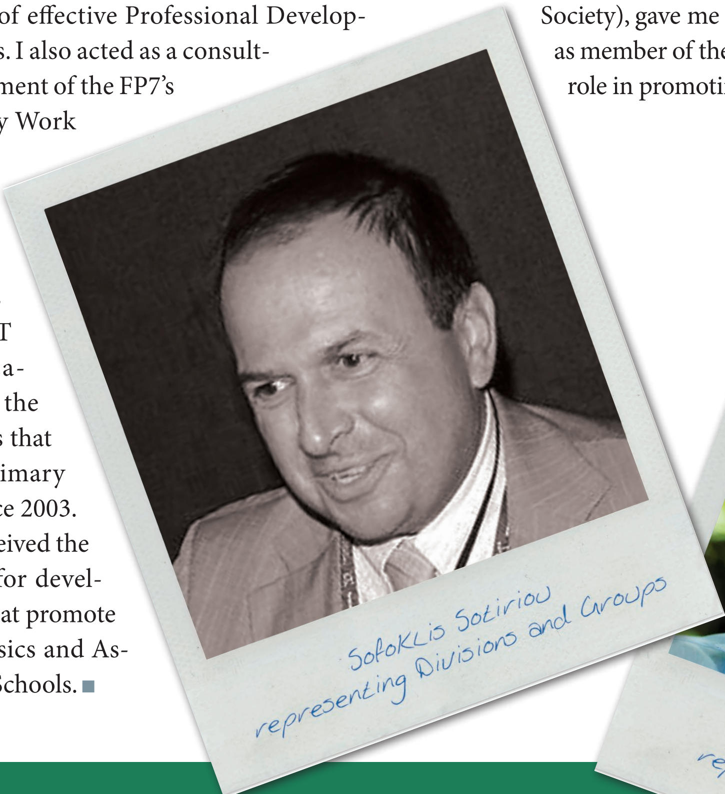
I have worked at CERN, at the National Centre for Scientific Research "DEMOKRITOS" in Athens and in the Physics Laboratory of Athens University and hold a first PhD in High Energy Neutrino Astrophysics and a second in Technology Enhanced Science Education.

As the Head of R&D Department of Ellinogermaniki Agogi, the first research department that operates in the school environment in Greece, I have been active in the co-ordination and development of research projects on implementation of advanced technologies (*e.g.* mobile applications, wearable computers, VR and AR applications, robotics) in science education and training. Since 2001, I am Director of the Ellinogermaniki Agogi Centre for Science Teachers Training. My main research field is the design, application, and evaluation of virtual and digital media environments that could bridge the gap between formal and informal science learning. I co-ordinated a long series of EC joint research and technology funded projects.

I am a member of the European Academy of Sciences (since 2003), member of the board of ECSITE – European Network of Science Centres and Museums (2004 - 2009) and member of the NAP (Network of Academics and Professionals) Executive Committee of EDEN – European Distance and eLearning Network. I have been appointed by the EPS to lead the design and development of the European Science Education Academy, which will support the effective integration of Inquiry Based and Problem Based approaches in the teaching, through the development of effective Professional Development Programmes. I also acted as a consultant to the development of the FP7's Science in Society Work programme.

Author of numerous articles, publications and teachers guides on the use of ICT in science education, I also wrote the Science Textbooks that are used in all primary Greek schools since 2003.

In 2011, I have received the EPS-HEP award for developing resources that promote High Energy Physics and Astronomy in High Schools. ■



Thomas Müller (1953, Wuppertal, Germany)

➥ ***Representing the DPG Member Society***

Since 1979 when I started my PhD Work at CERN as an employee of Bonn University, my research life focused on detector construction and on physics at highest energy hadron colliders. First experiment was UA5 at the SPPS Collider, where I made the first measurements of inelastic proton-antiproton collisions at 546 GeV. As a CERN fellow and staff I then researched on W and Z boson production at the UA1 experiment, supervised by Carlo Rubbia who won the 1984 Nobel prize for their discovery. In parallel I researched on novel detector concepts in tracking and warm liquid calorimetry.

In 1990 I became professor at UCLA, where I built up a research group at the CDF experiment at the Tevatron collider in Fermilab. This is where in 1995 the top quark was discovered. My research interest shifted from measuring W-photon couplings at high energies to searching for single top quark production, which was first observed in 2009.

Since 1995 I am professor and head of the institute IEKP at Karlsruhe (Institute of Technology). Here I founded a research group with the aim to carry out research at the Large Hadron Collider LHC at CERN. We contributed a large part of the CMS silicon tracker endcap and focused at the same time on top quark production and the search for the Higgs boson.

My professional life has been filled up with teaching, doing physics and administration. My experience with the latter (highlights are deputy Dean and Dean in Karlsruhe, chair of the advisory committee of the German ministry of science, member of various boards, at one stage of the council of the German Physical Society), gave me confidence that I will be able to contribute as member of the EPS executive committee to strengthen its role in promoting European Physicist's interests. ■

Zsolt Fülöp (1964, Debrecen, Hungary)

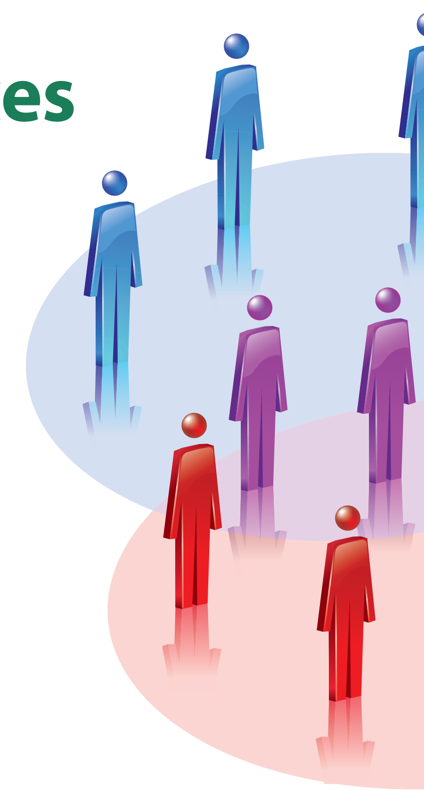
➥ *Representin g Divisions and Groups*

Having graduated in nuclear physics I soon learned the interdisciplinary nature of the field when I started my work in nuclear astrophysics, a borderline between nuclear and astrophysics in Atomki, one of the leading establishments in atomic and subatomic physics in Hungary. Nuclear astrophysics is an excellent example for the state of the art interdisciplinary research. Imagine: the origin of elements studied by geologists is modelled by astrophysicists using reactions measured by the nuclear physics community. Now, as the director of the Atomki institute and the recent chair of the EPS Nuclear Physics Division, I meet the fact day by day: physics is everywhere. So should be EPS!
My vision is to create and maintain a positive work atmosphere at EPS, leading to large scale success of European physics innovation, education and research. This calls for a personality that promotes ideas and boosts enthusiasm. I had the chance to learn these aspects not only through my professional carrier. As a father of five children I have learnt to keep the balance and promoting each and every advantage and as a long distance runner I know what endurance is, still keeping the obvious limits in mind. During my three-year-stay in Japan I have learnt to cope with the communication barriers between different societies. I not only promoted but actually practiced lifelong learning by attending recently a three-year MBA course. Instead of using the already existing opportunities I prefer to create them and share my vision and enthusiasm with my colleagues to reach aims that I believe in. The European Physical Society is one of the places where my contribution can have an impact and reinforce European added value. ■

EXECUTIVE COMMITTEE MEETING: SUMMARY (BY MARTINA KNOOP)

- The EPS Executive Committee met at the EPS headquarters in Mulhouse, France, in its new composition as result of the strategy plan 2011 and the elections in April 2012.
- EPS considers the opportunity to prepare a **statement on Horizon 2020**, explicitly consulting to this purpose D/G boards.
- The ExCom has started to review the composition and mode of operation of its various **Action Committees**. In order to strengthen the links to the ExCom, each AC will include a member of ExCom, mandates of all AC members will be of 2+2 years, the number of members will be limited. First proposals have been made for the Young Minds and the Gender Equality in Physics activities (this AC will be renamed as Equal Opportunities).
- The **Statement on assessment** has been circulated with all MS and D/G, the paper will be published in its final form accompanied by a press release, MS are encouraged to diffuse in their countries (see p.08 of this issue).
- Proposals of **historic sites** have been reviewed; inaugurations will eventually be linked to an important anniversary ceremony, in order to give large visibility.
- Progress on the study about **"The importance of Physics to the economies of Europe"** has been presented; a first draft version is expected for the end of August 2012 (see the editorial p.03).
- Nominations are open for the first edition of the **EPS Edison Volta Prize** (close 31 July 12, see p.09 of this issue).
- ExCom has endorsed the creation of two **new prizes by the QEOD**.
- The ExCom has discussed the case of the **membership of Bosnia-Herzegovina to EPS**, where two representative entities exist; EPS will offer help to find mean-term solutions.
- EPL continues its economic growth and has largely increased the number of institutions where it is present. **Call is open for a new EiC.** EPL has been invited for tender on HEP contents by SCOAP3.
- The **Physics Publishing Alliance** is preparing its portal for electronic reference (PPA-PER), a tentative date for online presence is autumn 2012.
- The chair of the **Physics Education** division, Gorazd Planinsic has presented the recent **position paper** of the PED board, which the ExCom has approved.
- The process for the endorsement of the **International Year of Light** by UNESCO is ongoing, and might eventually be successful before the end of the year.
- The new EPS website includes a **detailed member directory** as part of the member services. Michel Schlenker (IM delegate) has suggested further improvements; the legal framework has also to be respected.
- Different dates and places have been put forward for the next meeting in October. ■

On the use of bibliometric indices during assessment



Recent years have seen quantitative bibliometric indicators being increasingly used as a central element in the assessment of the performance of scientists, either individually or as groups, and as an important factor in evaluating and scoring research proposals. These indicators are varied, and include *e.g.* citation counts of individual papers published by researchers; the impact factors of the journals in which they publish; and measures that quantify personal research contributions over an extended period such as the Hirsch Hindex, and variants with corrections such as the G-index.

Although the use of such quantitative measures may be considered at first glance to introduce objectivity into assessment, the exclusive use of such indicators to measure science "quality" can cause severe bias in the assessment process when applied simplistically and without appropriate benchmarking to the research environment being considered. Funding agencies are aware of this, nevertheless experience shows that the reviewing of both individuals and projects on the national and European level is still relying excessively on the use of these numerical parameters in evaluation. This is a problem of much concern in the scientific community, and there has been extensive debate and discussion worldwide on this topic (see for instance [1]).

Since the very first applications of bibliometric indicators in this way, scientists and science organisations have taken strong positions against such purely numerical assessment. Various organisations in Europe have published studies on their potential adverse consequences on the quality of funded scientific research. A prime example is the publication of the *Académie des Sciences* of the *Institut de France* that has presented clear recommendations on the correct use of bibliometric indices [2]. Other publications have addressed the role of peer review in the assessment of scientists and research projects *e.g.* the European Science Foundation *Peer Review Guide* published in 2011 [3] with recommendations for good practices in peer review following an extensive European survey on peer review practices [4]. Other recent examples are a study of peer review in publications by the Scientific and Technology Committee of the House of Commons in the UK [5], the peer review guide of the Research Information Network in the UK [6] and the recommendations formulated at a workshop dedicated to quality assessment in peer review of the Swedish Research Council [7].

A common conclusion of these studies is the recognition of the important role of **peer review** in the quality assessment of research, and the recommendation to apply bibliometric performance indicators **with great caution**, and only by peers from the particular discipline being reviewed.

The European Physical Society recognizes and takes note of these recommendations for unbiased assessment procedures, and emphasizes in the following those aspects that are particularly important (in some cases unique) in the context of the assessment of the performance of the work of physicists, and of the quality and originality of physics research projects.

1. Evaluation should exclusively be carried out by peers, who must be independent and must have no conflict of interest with the evaluation process. They must strictly respect

NOTE OF THE EPS PRESIDENT

In this ongoing debate, the European Physical Society insists on the importance of peer review for all evaluation procedures. It takes position against a purely numerical assessment. Only the cautious application of bibliometric indices during a peer-review procedure can guarantee non-biased results. Rigorous but broader assessment procedures must take into account the research environment and particularities of the domain in the evaluation of the scientific content.

Luisa Cifarelli

a published code of conduct. Whilst recognizing the role of confidentiality in some forms of peer review, the names of evaluators should normally be made public, either before or after the assessment procedure as appropriate to the evaluation being carried out.

2. An unbiased assessment of the scientific quality of individual researchers or their projects using bibliometric indices must take into account many factors such as: the scientific content; the size of the research community; the economic and administrative context; and publishing traditions in the field. Publishing habits and traditions significantly vary between different fields of physics research, and are reflected for example in areas such as the name order in the list of authors and the particular choice of the journals in which to publish. A special example is publishing in the field of physics with large facilities where traditions are very different from many other fields. For example, accelerator physicists publish their work essentially in conference proceedings, while only a small percentage of their work appears in peer-reviewed journals. Another example is the publication policy of the large collaborations of physicists in the field of experimental particle and astroparticle physics. These collaborations apply strict procedures for the assessment and endorsement of results by every member of the collaboration prior to the internal publication of results. The external publication of results is also endorsed by the full collaboration. As a consequence of this policy, their articles in refereed journals often have long author lists published uniquely in alphabetical order.

the reviewing of both individuals and projects on the national and European level is still relying excessively on the use of these numerical parameters in evaluation.

3. The annually-published impact factors of refereed journals are averaged over many papers, and publishing in a high impact journal does not guarantee that every individual article is equally highly cited. Such quantitative measures based on the number of publications and/or citation statistics of researchers are one aspect of assessment, but they cannot and must not replace a broader review of researchers' activities carried out by peers. The European Physical Society, in its role to promote physics and physicists, strongly recommends that best practices are used in all evaluation procedures applied to individual researchers in physics, as well as in the evaluation of their research proposals and projects. In particular, the European Physical Society considers it essential that the use of bibliometric indices is always complemented by a broader assessment of scientific content taking into account the research environment, to be carried out by peers in the framework of a clear code of conduct. ■

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[6] Peer review, A guide for researchers, Research Information Network, UK, March 2010 (www.rin.ac.uk/our-work/communicating-and-disseminating-research/peer-review-guideresearchers)

[7] Swedish Research Council, Quality Assessment in Peer Review, 5 November 2009 (www.cm.se/webbshop_vr/pdfer/2011_01L.pdf)

THE NEW EPS-EDISON VOLTA PRIZE

The European Physical Society, the Centro di Cultura Scientifica 'Alessandro Volta', and Edison S.P.A. have established the 'EPS Edison Volta Prize' to promote excellent research and achievement in physics.
The EPS Edison Volta Prize is awarded to individuals or groups of up to 3 persons on a biannual basis. The Prize consists of a cash award of Euro 10,000 for the prize winner(s), as well as a diploma and a medal.
Nominations for 2012 Prize are now open. The nomination deadline is 31 July 2012. ■

Opinion: Leave it behind

Kevin Sheridan, Graduate Student,
Molecular Physics Laboratory, University of Sussex (UK)

Travel seems to be either a key ingredient or a natural result of a successful career in academic physics. Once, as an undergraduate, a casual chat with a post-doctoral researcher running a workshop session inevitably led to detailing the extensive list of places he had worked; an unlikely web of journeys which somehow brought him to my University. He summed it up with a smile explaining that it was physics, which had made him a world traveller. This resonated with me instantly. It was the first time that I thought about my work as being part of something larger than just my classroom or laboratory.

It is very challenging to acquire a perspective large enough to contain the entirety of something like an international physics community. As a young post-graduate working in a laser lab I often wondered what it would be like to work in other laboratories. Certain important experimental papers took on an almost religious significance, and it was difficult to try to believe that the authors of these papers were individuals not so fundamentally different from me working in laboratories nearly identical to the one I work in. For what must have been years I had grown accustomed with a singular way of working; perhaps even a singular way of thinking. Encountering another atomic physics laboratory for the first time was a unique experience. Spending time working in a foreign laboratory as a student was an invaluable opportunity to become acutely aware of the things that worked well in my home lab and the things that worked, let's say, less than well. Experiences like these helped me understand what my role, or potential role, is within the scientific community.

Physics relies upon collaboration and the European community is a fertile ground for growing successful collaborations. The European Union of fascinatingly varying cultures with close geographical contact and lax travel restrictions is, for me, a source of unending fascination. As a native outsider, it is amazing to be able to step from a jet after a mere hour of travel into a fundamentally different surrounding. This is perhaps an unfairly glamorous view of matters. Of course, the utility of travel is what ensures its existence. Foreign surroundings inspire new ideas and foster research opportunities.

Foreign surroundings inspire new ideas and foster research opportunities

I was fortunate enough last autumn to undertake a short-term scientific mission (STSM); a collaboration-building programme organized within the COST Action MP1001. I spent two months engrossed in a fascinating project in a new surrounding. I developed a fresh sense of confidence about my work and fostered useful contacts. Perhaps the biggest benefit of the trip came after returning home. There is no better way to add perspective to work than to leave it behind. Upon returning there is no option but to look upon it with a fresh perspective. These types of opportunities are not entirely common for PhD students, and certainly not as common as they should be. It was my PhD supervisor who initiated and organized my STSM. Reflecting on the overwhelmingly positive impact of my trip, I cannot help but wish that I had the initiative to organize it myself. To any current post-graduate researcher I would recommend an experience like an STSM for the potentially massive benefit to personal and professional development. ■

COMING EPS EVENTS

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

- **QFS2012**,
  International Conference on Quantum Fluids and Solids
  15-21 August 2012,
  Lancaster, UK
  www.physics.lancs.ac.uk/QFS2012/index.html

- **IWNET 2012**,
  6th International Workshop on Nonequilibrium Thermodynamics and 3rd Lars Onsager Symposium
  19-24 August 2012,
  Røros, Norway
  www.complexfluids.ethz.ch/cgi-bin/CONF/g

- **5th EPS-QEOD EUROPHOTON CONFERENCE**,
  Conference on Solid-state, Fibre, and Waveguide Coherent Light Sources
  26-31 August 2012,
  Stockholm, Sweden
  www.europhoton.org

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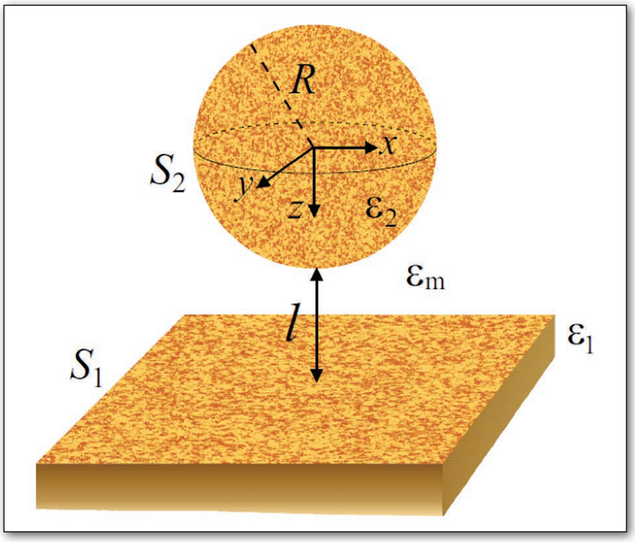
Highlights from European journals

BIOPHYSICS

Electric charge disorder: **A key to biological order?**

Electrically net-neutral objects are found to attract strongly if a small amount of charge disorder is present on their surface, holding the key to a possible understanding of biological pattern recognition. This article demonstrates that random patches of disordered, frozen electric charges spread throughout surfaces, which are overall neutral, can interact with the long-range twisting force strong enough to be felt across the whole mesoscopic scale and compete with Casimir-van der Waals forces.



▲ Sphere rotating next to a planar substrate, both carrying random charges on their surfaces.

The twisting forces acting on a randomly charged sphere mounted on a central axis, which is next to a randomly charged flat substrate, are investigated. Because small amounts of positive and negative charges are spread in a disordered mosaic throughout both surfaces, they induce transient attractive or repulsive twisting forces, regardless of the surfaces' overall electrical neutrality. These forces' fluctuations are studied using statistical averaging methods.
It appears that the fluctuations' root-mean-square value grows in proportion with the total area of the two apposed surfaces. By contrast, it only decreases in inverse proportion to the distance separating the sphere from the substrate. This counter-intuitive result suggests that the long-range twisting force, created by virtue of the disorder of surface charges, is expected to be much stronger and longer-ranged than the elusive Casimir-van der Waals forces. This could have implications for biological pattern recognition, such as lock and key phenomena based on attraction between biological macromolecules leading to pre-alignment prior to their interaction. ■

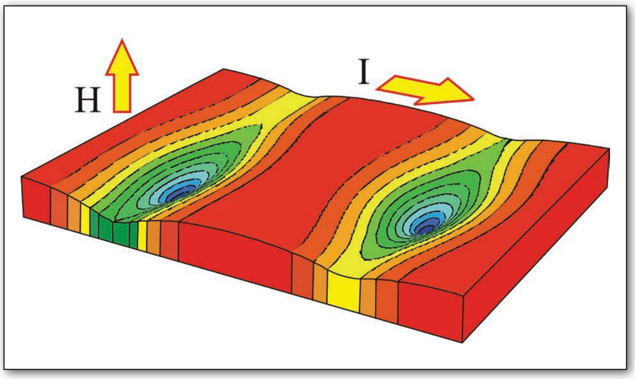
■ **A. Naji**, **J. Sarabadani**, **D.S. Dean** and **R. Podgornik**, 'Sample-to-sample torque fluctuations in a system of coaxial randomly charged surfaces', *Eur. Phys. J. E* **35**, 24 (2012)

CONDENSED MATTER

Superconducting strip: an ultra-low-voltage sensor?

Minute-scale interactions govern superconductors' electronic behaviour with potential applications for voltage measurement techniques.
Studying a superconducting strip, an intermittent motion of magnetic flux carrying vortices inside the regularly spaced weak conducting regions has been observed. These vortices resulted in alternating static phases with zero voltage and dynamic phases characterised by non-zero voltage peaks in the superconductor. One knows that superconductors subjected to sufficiently strong magnetic fields feature vortices carrying quantized amounts of magnetic flux. The authors relied on the Ginzburg-Landau theory to study the dynamic of the nanometric to millimetric-scale-width superconducting strip, which was subjected to a magnetic field applied at a right angle and a current applied alongside its length.
It is found that increasing magnetic field also increases the density of mutually-repelling vortices, which in the presence of an external current stimulates vortex motion across the strip. At the same time, the barrier for vortex entry and exit on the strip boundaries is also dependent on the magnetic field.

▼ Moving vortices inside the weak conducting links carved into a current-carrying superconducting strip.



This interplay of magnetic-field-dependent barriers and vortex-vortex interaction results in an on/off vortex motion in increasing magnetic fields.
Eventually, these findings could be applicable in gate devices used to control various modes of on/off states in electrical systems operating in specific windows of temperature, applied magnetic field, current and voltage. ■

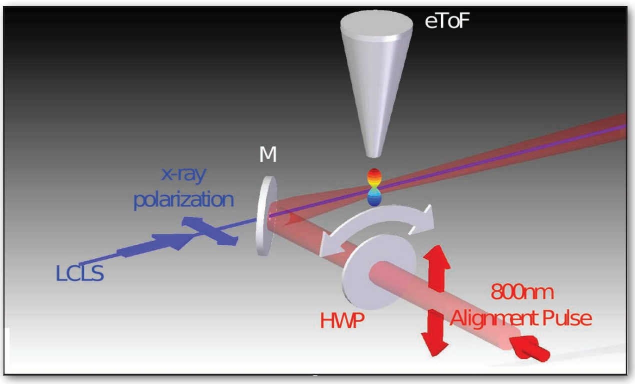
■ **G.R. Berdiyorov**, **A.R. de C. Romaguera**, **M.V. Milosevic**, **M.M. Doria**, **L. Covaci** and **F.M. Peeters**, 'Dynamic and static phases of vortices under an applied drive in a superconducting stripe with an array of weak links', *Eur. Phys. J. B* **85**, 130 (2012)

ATOMIC AND MOLECULAR PHYSICS

Auger electron energy spectrum from N_2: new visit

This article presents a study of electronic relaxation of core-excited molecules. Relaxation occurs through the Auger process where a valence electron fills the core vacancy, created by x-ray ionization, and a second valence electron is released from the molecule. The kinetic energy of this second electron then depends on the final state of the core-relaxed molecule. The Auger electron energy spectrum can therefore be viewed as a kind of fingerprint for molecular composition.
In this study, an infrared laser pulse was used to align an ensemble of nitrogen molecules relative to the laboratory frame. We then photo-ionized the molecules with a ~60 fs x-ray laser pulse. Rotating the polarization of the infrared laser, as shown in the Fig., changed the orientation between the aligned molecules and the laboratory frame electron detector. In this way we measured the angular pattern of the entire Auger electron spectrum in the molecular frame.
This experiment demonstrates a new way to measure the molecular-frame angular emission pattern for every Auger electron feature. Adding angular information to the spectral information allows incorporating electronic symmetry in feature identification. These findings suggest reordering some previous Auger feature assignments in the seemingly well-known N_2, showcasing the power of this method to measure transient changes in electronic symmetry as a molecule undergoes a chemical reaction. ■

▼ Experimental setup

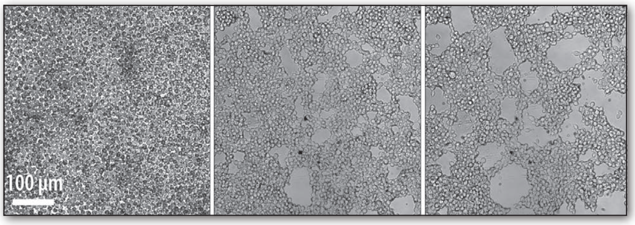


■ **J. P. Cryan**, **R. N. Coffee** and **32 co-authors**, 'Molecular frame Auger electron energy spectrum from N_2', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 055601 (2012)

BIOPHYSICS

Make or break for **cellular tissues**

Models developed to study liquids are used to investigate the mechanics of cellular tissues, which could further our understanding of embryonic development and cancer.



▲ Living cells monolayer change upon time (left to right: after 0s; 9500s; 13000s)

The present study demonstrates that the behaviour of a thin layer of cells in contact with an unfavourable substrate is akin to that of thin fluid or elastic films. Understanding the mechanism by which a thin layer of cells splits into disjointed patches, thus breaking the layer's structural integrity, bears great significance because the human tissue, or epithelium, covering organs can only fulfil its role if there are no holes or gaps between the cells.
Thanks to the analogy between the cellular layer examined and the well-understood behaviour of thin liquid films, the authors devised a model of the layer's evolution. They considered it as an active, amorphous material made of a continuum of cells. Because it is subject to a constant competition between neighbouring cell-cell and cell-substrate adhesion, it can either maintain its contiguous structure or break.
The authors investigated the layer's stability when subjected to chemical and physical disturbances. In particular, they scrutinised how the cellular layer reacted to a non-adhesive substrate with little chemical affinity with the cells. They also subjected the cell to a physical disturbance by laying them in substrates with low stiffness, such as soft gels.
So, the so-called de-wetting phenomenon has been observed, whereby the cellular layer is ruptured leading to islands of cells interspersed with dry patches. The de-wetting phenomenon is therefore due to the cells' distinctive sensitivity to the nature of its substrate, particularly to its decreased stiffness. ■

■ **S. Douezan** and **F. Brochard-Wyart**, 'De-wetting of cellular monolayers', *Eur. Phys. J. E* **35**, 34 (2012)

ASTROPHYSICS

A note on Pöschl-Teller **black holes**

An interesting feature of black holes is the existence of quasi-normal modes, arising because the system has a peak in the wave potential (scalar, electromagnetic, or gravitational waves). The quasi-normal mode is excited when a disturbance is put in the field near but outside the black hole, (like a wave packet roughly in a circular orbit near the peak).

The excitation then propagates outward and inward and decays. An excitation "mode" has a definite complex frequency: a given oscillation rate in time, and a corresponding decay rate. For gravitational radiation from a spherical (Schwarzschild) black hole, the least damped mode is: $e^{i\,0.747t/t_H}\, e^{-0.178t/t_H}$ with t_H the time for light to travel a distance equal to the radius of the black hole [S. Chandrasekhar and S. Detweiler, *Proc. Roy. Soc. London* **344**, 441 (1975)].

To calculate these modes is typically a computational problem, with attendant difficulties in controlling errors and convergence. A partial step to ameliorate these difficulties has been to substitute the black hole potential (long range, polynomial decay to infinity), with more localized potentials decaying exponentially at infinity. Pöschl and Teller [G. Pöschl and E. Teller, *Z. Phys.* **83** ,143 (1933)] suggested one such potential in another context: $1/\cosh^2 a(r- r_0)$.

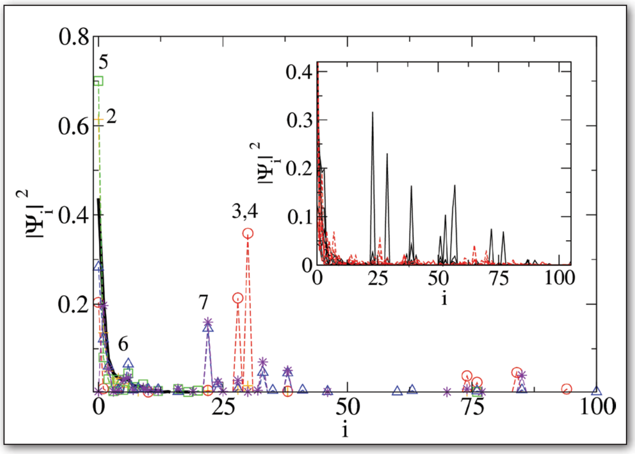
This is much simpler – and decays more rapidly – than the correct gravitational potential, but to date even this potential has required numerical/computational treatment. Now, however, S. Zarrinkamar, H. Hassanabadi, A.A. Rajabi and P. Ghalandari Eskolaki have found an ingenious analytic transformation of the Pöschl-Teller wave equation with immediate solution in terms of Jacobi polynomials. Jacobi polynomials are well studied and characterized classical "special functions". Thus questions of accuracy and convergence are now under control, and the authors have completely solved the quasi-normal mode problem for the Pöschl-Teller black hole. ■

■ **S. Zarrinkamar**, **H. Hassanabadi**, **A.A. Rajabi** and **P. Ghalandari Eskolaki**,
'A note on Pöschl-Teller black holes', *Eur. Phys. J. Plus* **127**, 56 (2012)

STATISTICAL PHYSICS

The game of go
as a complex network

The study of complex networks attracts more and more interest, fuelled in particular by the development of communication and information. It turns out that such networks can also modelize many important aspects of the physical world or of social interactions. However, they have never been used in the study of games.



▲ Moduli squared of right eigenvectors of the 7 largest eigenvalues of the Google matrix for the first 100 most frequent moves, showing that each eigenvector is localised on specific moves.

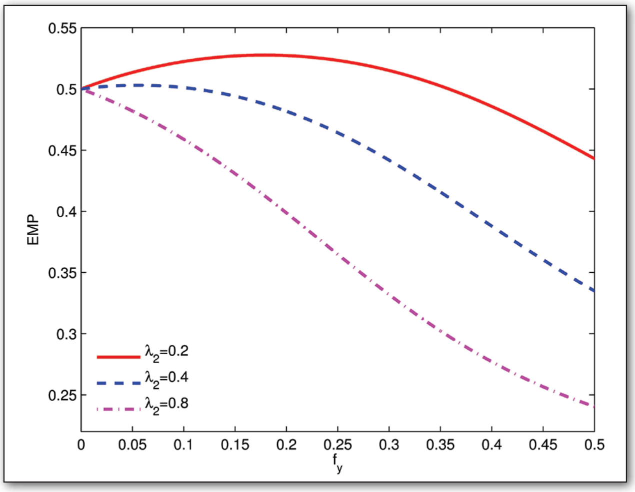
Games have been played for millennia, and besides their intrinsic interest, they represent a privileged approach to the working of human decision-making. They can be very difficult to modelize or simulate: only recently were computers able to beat chess champions. The old Asian game of go is even less tractable, as no computer program has been able to beat a very good player. The paper presents the first study of the game of go from a complex network perspective. It constructs a directed network, which reflects the statistics of tactical moves. Study of this network for datasets of professional and amateur games shows that the move distribution follows Zipf's law, an empirical law first observed in word frequencies. Differences between professional and amateur games can be seen, *e.g.* in the distribution of distances between moves. The constructed network is scale-free, with statistical peculiarities, such as the symmetry between ingoing and outgoing links distributions. The study of eigenvalues and eigenvectors of the matrices used by ranking algorithms singles out certain strategic situations (see figure), and vary between amateur and different professional tournaments. These results should pave the way to a better modelization of board games and other types of human strategic scheming. ■

■ **B. Georgeot** and **O. Giraud**,
'The game of go as a complex network', *EPL* **97**, 68002 (2012)

MATERIAL SCIENCE

Molecular machines
with continuous phase space

Molecular motors exploit the free energy released in the hydrolysis of energetic molecules like ATP to perform work useful for the cell. It is therefore important to know the efficiency of this process, *i.e.*, the ratio between the performed work and the released free energy. The efficiency could reach 100% if the motor worked reversibly, *i.e.*, infinitely slowly, but then its output power would vanish.



▲ EMP for a tightly coupled motor as a function of the chemical driving force, for different values of the asymmetry. Note the regime in which the EMP exceeds 50%.

Thus the relevant quantity is the Efficiency at Maximum Power (EMP). It has been shown that the EMP reaches 50% when the motor operates in the linear regime close to equilibrium. However, it has only recently been investigated further from equilibrium in models describing the motor as a discrete random process.

One can provide a more fundamental model of a molecular motor as a Brownian particle evolving in a two-dimensional continuous space, in which one coordinate represents its spatial position on the substrate and the other coordinate the advancement of the ATP-hydrolysis reaction, subject to a periodic "egg-carton" potential, whose tilt in the direction of the chemical coordinate expresses the free-energy imbalance. We have evaluated the EMP for such a model, with special choices of the potential, and found that it reaches the highest values when the displacements in the spatial and chemical coordinates are tightly bound: in this regime, efficiencies larger that 50% can be reached sufficiently far from equilibrium. When the binding is not tight, the EMP decreases since the motor can perform a chemical hydrolysis cycle without advancing. Our formalism thus allows us to gain a deeper insight into the connection between the mechanics and the thermodynamics of molecular motors. ■

■ **N. Golubeva**, **A. Imparato** and **L. Peliti**,
'Efficiency of molecular machines with continuous phase space', *EPL* **97**, 60005 (2012)

NUCLEAR PHYSICS

The neutron-rich superheavy **element 116 confirmed**

The synthesis of a superheavy element with the proton number Z=116 has been studied at the velocity filter SHIP of GSI in Darmstadt using a ^{48}Ca beam on radioactive ^{248}Cm targets. At excitation energies of the compound nuclei of 40.9 MeV, four decay chains were measured, which were assigned to the isotope $^{292}116$ produced in 4n channel, and one chain, which was assigned to $^{293}116$ produced in 3n channel. All chains are terminated by spontaneous fission decays of either ^{277}Hs or ^{284}Cn isotopes on the shoreline of the neutron-rich superheavy island.

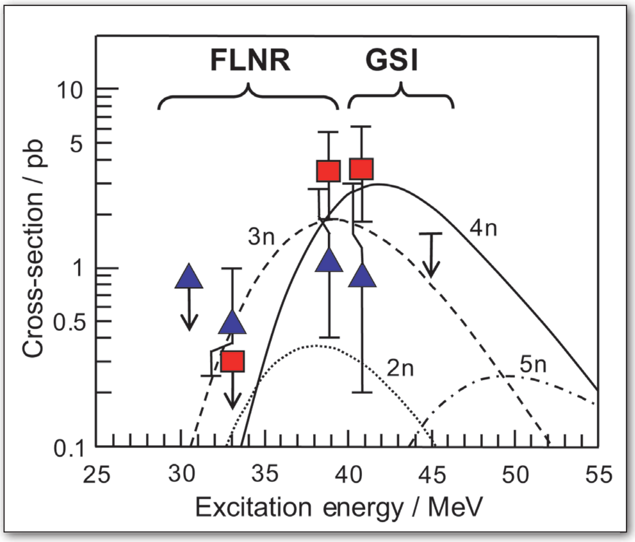
Measured cross-sections of 3.4 pb and 0.9 pb, respectively, and decay data of the chains confirm previous data at the Flerov Laboratory of Nuclear Reactions (FLNR) in Dubna. As a new result, one alpha-decay chain was measured, which terminates after four alpha decays by spontaneous fission. The alpha energies of the second to fourth decay are considerably higher than those measured for the alpha decays of $^{289}114$, ^{285}Cn, and ^{281}Ds and the spontaneous fission half-life is significantly longer than that of ^{277}Hs measured in previous experiments.

Possible assignments and role of isomeric states are discussed in the frame of excited quasiparticle states of nuclei populated in the decay chain from $^{293}116$.

The experience gained in this experiment will serve as a basis for future experiments aiming to study still heavier elements at the velocity filter SHIP. For this purpose, related very detailed experimental study of sources of background fission events was also carried out and published in a related article. Here it was shown that such events occur mainly in connection with transfer reactions leading to target-like residues having half-lives similar to the ones of superheavy isotopes from respective fusion reactions. ■

■ **S. Hofmann *et al.* (38 co-authors)**,
'The reaction $^{48}Ca + ^{248}Cm \rightarrow ^{296}116^*$ studied at the GSI-SHIP', *Eur. Phys. J. A* **48**, 62 (2012) and
■ **S. Heinz *et al.* (9 co-authors)**,
'The source of "background" fission events in experiments on superheavy elements', *Eur. Phys. J. A* **48**, 32 (2012)

▼ Cross-sections and cross-section limits of the reaction $^{48}Ca + ^{248}Cm \rightarrow ^{296}116^*$ measured elsewhere and in this work. The data for synthesis of $^{293}116$ (3n channel, triangles) and $^{292}116$ (4n channel, squares) are shown. The experimental data are compared with results of theoretical calculations.



STATISTICAL PHYSICS

Mitigating disasters by hunting down Dragon Kings

Scientists aim at forecasting natural or economic disasters by identifying statistical anomalies in complex systems that deviate from behaviour obeying traditional power laws. This article and the special issue it comes from, present the many facets of Dragon Kings in a review alongside nineteen other contributions exploring to which extent this emerging field of statistical analysis could become further established.
Dragon Kings are events akin to catastrophes. They don't belong to the same power law regime as the more standard events. For example, they can be found in financial market bubbles ending in crashes and neuron-firing cascades leading to epileptic seizures.

▾ Dragons Kings stem from a combination between the supernatural powers of dragons and the anomaly of a king's wealth relative to that of his subjects. © Anek Suwannaphoom / photos.com.

This review focuses on elucidating how Dragon Kings are created and can be detected. It also gives an overview of their empirical evidence in abnormal rainfall, hurricanes, and sudden events such as landslides and snow avalanches. The authors also outline the limitations of this sort of statistical analysis. For example, despite being sometimes interpreted as featuring characteristic events of Dragon Kings, great earthquakes may not be formally confirmed as such. Finally, the authors share their views on the importance of devising prediction models that could become the basis for Dragon Kings simulators. These could be designed to help interpret the warning signs of complex systems evolving out of their safe equilibrium into extreme events such as the subprime crisis, and to steer them into sustainability and ultimately avoid such crisis. ■

■ **D. Sornette** and **G. Ouillon**,
'Dragon-kings: mechanisms, statistical methods and empirical evidence', *Eur. Phys. J. Special topics* **205**, 1 (2012), (Discussion and debate issue: from black swans to dragon-kings - Is there life beyond power laws?)

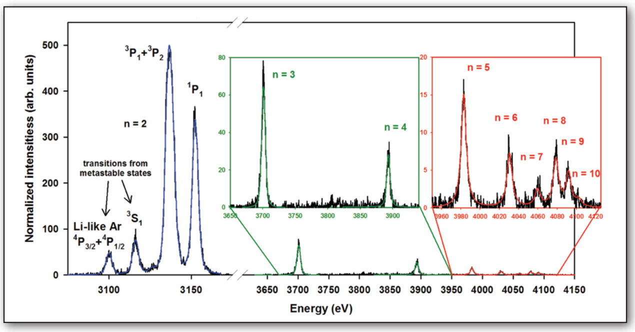
ATOMIC AND MOLECULAR PHYSICS

Astrophysics in lab via collisions of heavy systems

Collisions between slow highly charged ions and atoms are one of the most common fundamental processes in space. The consequent emitted light is used to diagnose the relative abundance of constituents in intergalactic clouds and comets. During the collision, the projectile-ions capture, in a highly excited-state, from one to many target-electrons. By a series of atomic cascades the electrons "tumble" from the very high atomic levels onto the ground state through multiple and complex pathways. These cascades lead to photon and/or electron emissions. The accurate analysis of the light (from UV to hard X) emitted during the interaction provides direct insights into the early stages of capture mechanisms.
Until now, for systems involving a large number of electrons, only low-resolution X-ray spectra recorded with solid state detectors were available. In the present work, the contribution of single-electron capture from multiple-capture processes in the X-ray emission have been successfully disentangled for an Ar^{17+} projectile colliding with N_2 or Ar gaseous target at v=0.53 a.u. Thanks to an accurate calibration of the spectrometers and a complete determination of the ion beam-gas target overlap, absolute X-ray emission cross section has been extracted with a significant improvement in uncertainty. Using a mosaic crystal spectrometer, 2 orders of magnitude in resolving power have been reached. The whole He-like Ar^{16+} Lyman series from n = 2 to 10 has been resolved as well as the fine structure of $1s2\ell \rightarrow 1s^2$ transitions. The role of single-electron capture, leading to transitions from n = 7 to 10 levels, has been clearly discriminated from multiple capture processes that populate lower lying states. Furthermore, a precise determination of the influence of metastable states emphasizes that transposition of the measurements via 'laboratory ion-atom collisions' towards interpretation of astrophysical spectra should be made with caution. ■

■ **M. Trassinelli *et al.* (8 co-authors)**,
'Investigation of slow collisions for (quasi) symmetric heavy systems: what can be extracted from high-resolution X-ray spectra', *J. Phys. B* **45**, 085202 (2012).

▾ High resolution X-ray spectra of $Ar^{17+} \rightarrow Ar$



STATISTICAL PHYSICS

Brain capacity limits online data growth

Study of internet file sizes shows that information growth is self-limited by the human mind. It is found here that it is the capacity of the human brain to process and record information –and not economic constraints – that may constitute the dominant limiting factor for the overall growth of globally stored information. The authors first looked at the distribution of 633 public internet files by plotting the number of videos, audio and image files against the size of the files. They chose to focus on files hosted on domains pointing from the online encyclopaedia Wikipedia and the open web directory dmoz.

▲ The human brain limits global information load

The absence of exponential tails for the graph representing the number of files indicates that economic costs were not the limiting factors for data production. Instead, it appears that underlying neurophysiological processes influence the brain's ability to handle information. For example, when the individual attributes a subjective resolution to an image, their perception of the quality of that image matter. Their perception of the amount of information gained when increasing the resolution of a low-quality image is substantially higher then when increasing the resolution of a high-quality photo by the same degree. The analysis shows that this relation, known as the Weber-Fechner law, is also obeyed by file-size distributions. This means that the total amount of information cannot grow faster than our ability to digest or handle it. ■

▮ **C. Gros**, **G. Kaczor** and **D. Marković**, 'Neuropsychological constraints to human data production on a global scale', *Eur. Phys. J. B* **85**, 28 (2012)

APPLIED PHYSICS

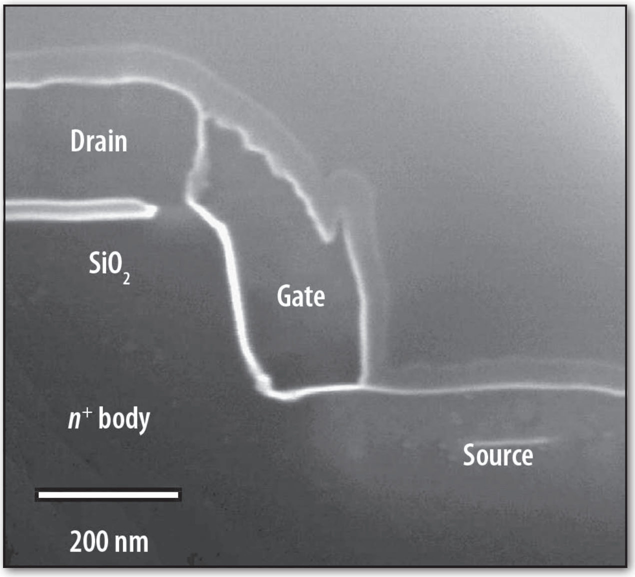
Improvement in 3D device performance

Microelectronics researchers and engineers are finally running into the fundamental physical limits of silicon and are trying to find innovative ways around these limits. Three-dimensional (3D) integration technology is emerging and has drawn attention as a viable solution to extend the fundamental limits of complementary metal–oxide–semiconductor (CMOS) scaling because 3D technologies allow reduction in chip size, delay time in interconnections and power dissipation. In order to fully benefit from the 3D architecture, the development of vertical MOS field-effect transistors (FETs) is essential, especially for memory and radio frequency applications.

In this work, the authors investigated a vertical MOSFET incorporating an epitaxial channel and a drain junction in a stacked silicon-insulator structure. An oxide layer near the drain junction edge (referred to as a junction stop) acts as a dopant diffusion barrier and consequently a shallow drain junction is formed to suppress short channel effects. A simulation study in the sub-100 nm regime calibrated to measured results on the fabricated devices was carried out. The use of an epitaxial channel delivers 50% higher drive current due to the higher mobility of the retrograde channel and the junction stop structure delivers improvements of threshold voltage roll-off and drain induced barrier lowering compared with a conventional vertical MOSFET. These results suggest that this device architecture allows CMOS scaling to be extended. ■

▮ **T. Uchino**, **E. Gili**, **L. Tan**, **O. Buiu**, **S. Hall** and **P. Ashburn**, 'Improved vertical MOSFET performance using an epitaxial channel and a stacked silicon-insulator structure', *Semicond. Sci. Technol.* **27**, 062002 (2012)

▼ SEM image of a device cross sectional view



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Singing glasses, musical mugs

Everybody knows how to make a wineglass sing. Just run a wet finger around the rim of a clean glass. It is a well known after-dinner trick, but as physicists we may ask: what exactly makes the glass squeak, and what mode of vibration are we inducing? Let's first look at the mechanism. It is the same 'stick-slip' motion that is used to play the violin, or the cello and the bass. Without probably realising it, when we run our finger around the rim of the glass we are making use of the fact that dynamic friction is lower than static friction. Whenever our finger sticks for a split second, the glass is slightly stretched, but once our finger gets moving again, the glass surface slides back easily, returning to its original state.

Now what kind of vibration are we inducing in the glass? Given the relatively loud noise that we can produce using this trick, we suspect that it must be a transverse vibration, so that the side of the glass transmits the noise to the surrounding air. Moreover, we guess that we are exciting the simplest possible vibrational mode: the fundamental.

Indeed, if we tap the glass at its side using a spoon, we notice that the frequency – or pitch – of the sound produced is the same as the one we get by running our finger around the rim. This strongly suggests that we are exciting the fundamental in both cases. In other words: if we tap, say, the North side of the glass, we should expect antinodes also at the South, East and West sides of the glass, and nodes at the four positions just in between.

There is an elegant way to prove us right. Just replace the glass by a mug that has a handle. If there is a choice, take a thin-walled mug made of good-quality pottery. Put it in front of you on the table with the handle towards you, pointing South, so to speak. Now take a spoon and tap. If you tap at the opposite side (North), or East or West, you produce a tone that is distinctly lower than if you tap at positions in between. This confirms that it is the fundamental vibration mode that we are exciting: it is the handle's extra mass that makes the frequency lower if it is positioned on an antinode. Look at it as a simple variation on the harmonic oscillator theme, for which we remember the frequency to be determined by $\sqrt{(k/m)}$, with k the force constant and m the mass.

Further evidence for the fact that we are dealing with the fundamental is obtained by holding the mug by the handle and repeating the experiment. If we tap the mug at the side opposite from the handle, the (lower) tone that we get is distinctly more damped than the one we get if we tap in between (the higher tone).

So, should your next formal dinner turn out a bit dull, physics may come to the rescue and bring some unexpected entertainment. Provided, of course, that there is wine. And coffee cups with a reasonable quality... ■

Merging
incompatible materials

Hans von Känel - DOI: 10.1051/epn/2012402

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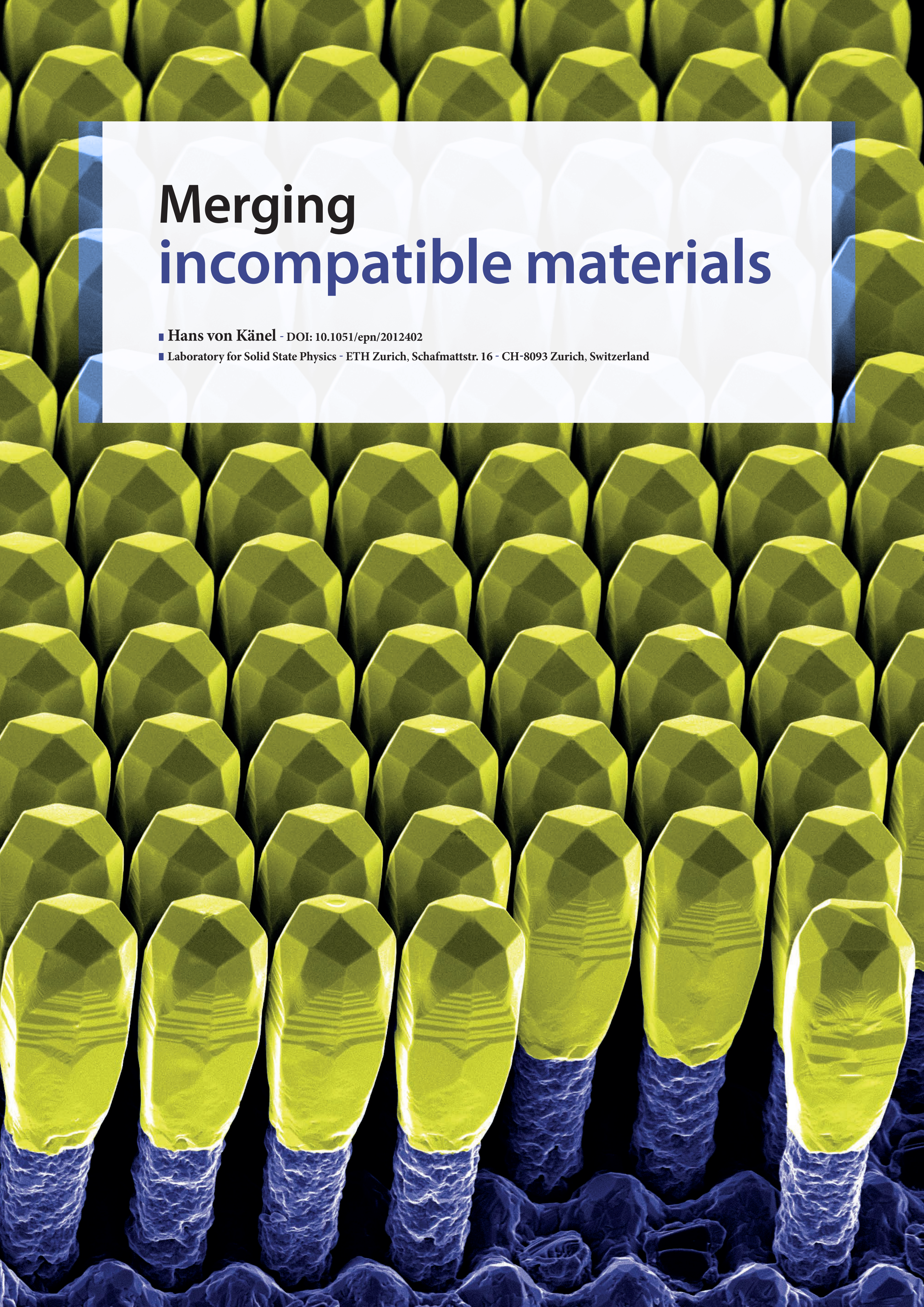


Highly perfect epitaxial semiconductor layers form the basis of many low-dimensional quantum structures and are used for ultrafast transistors, solid state lasers and detectors. Keeping epitaxial structures defect-free becomes difficult, however, when materials differ in lattice parameter and thermal properties. This often results in crystal defects, wafer bowing and cracks, unacceptable to any device application. These problems are solved by forming space-filling arrays of individual semiconductor crystals rather than continuous films.

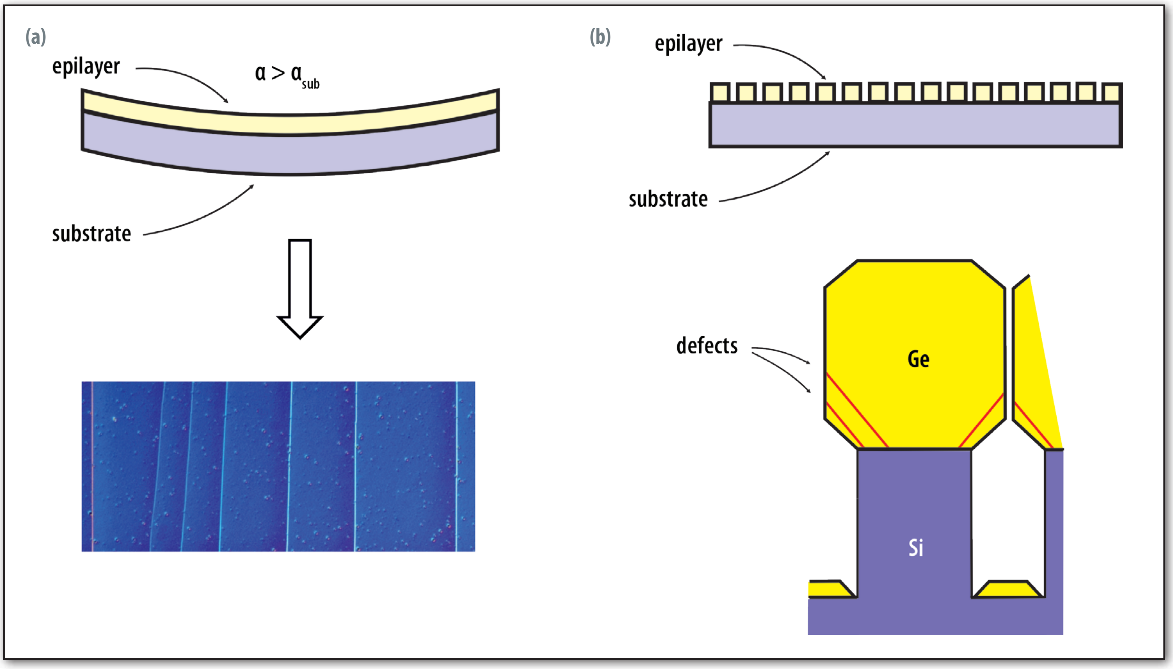
◂ Perspective-view scanning electron microscopy image of 8-µm-tall germanium crystals, epitaxially grown on a silicon wafer, patterned in the form of 8-µm-high and 2-µm-wide pillars, separated by 2-µm trenches.

Ever since the pioneering invention of molecular beam epitaxy (MBE) in the late sixties by Arthur Cho [1], the tailoring of semiconductor properties by stacking different layers has been pivotal both for advances in fundamental research [2] and for the development of new semiconductor devices [3]. While much of the early work was focused on lattice-matched heterostructures, more and more use has been made lately of the additional degrees of freedom for band structure engineering offered by the misfit strain. Nowadays "strained-silicon" forms an integral part in most state-of-the-art microprocessors [4]. Many applications, such as high-brightness light-emitting diodes, power transistors, or multiple-junction solar cells, require rather thick epitaxial layers for which any misfit strain is totally relaxed at the growth temperature. Such layers may nevertheless become strained if their thermal expansion coefficients differ from the one of the substrate.

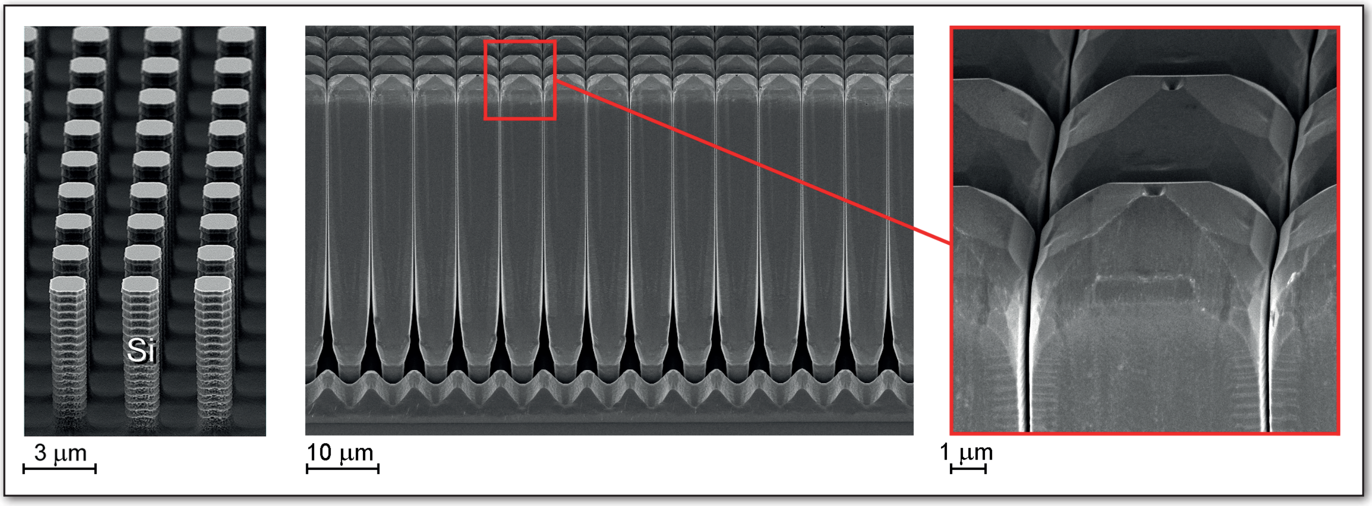
The role of lattice and thermal misfit

Irrespective of the technique by which an epitaxial layer is formed, complications arise whenever substrate and layer materials differ significantly in lattice parameter. According to theoretical studies originated by Frank and van der Merwe [5] the misfit across the interface is accommodated by misfit dislocations as soon as a critical thickness is reached. Unfortunately, in practice these dislocations are present not only at the interface. Misfit segments are rather terminated by threading dislocations extending throughout the epitaxial layer [6]. Since threading dislocations negatively impact performance whenever they penetrate an active region of a device, decades of intense work has sought to eliminate these defects or at least to minimize their density [7][8].

Since in addition to the lattice misfit, different semiconductors usually have different thermal expansion coefficients, wafers may bend upon cooling to room temperature. Very often layers even crack (Fig. 1(a)) when their thickness exceeds a few micrometers [9]. Wafer bending and layer cracking are hence of major concern, especially when multiple- junction solar cells, high-brightness light emitting diodes and power electronic devices are to be grown onto cheap Si substrates. Here, I shall discuss another extreme case, namely an X-ray absorber monolithically integrated on a Si-CMOS (Complementary Metal Oxide Semiconductor) chip [10]. Because of its higher atomic number germanium is considered to be a viable candidate for replacing Si as the absorbing material.



◂ **FIG. 1:** (a) Wafer bending and crack formation because of thermal expansion coefficients of Si-substrate and Ge-layer differing by about 130%. (b) Concept for Si(001) substrate patterning and epitaxial growth to eliminate wafer bowing and cracks by avoiding a continuous film to form. Defects lying on {111} planes are expected to escape to the surface of the Ge crystals.



▲ FIG. 2: Si-pillars etched by deep reactive ion etching into Si(001) (left), subsequently overgrown with 50 µm of Ge (right). Note the finite gap between neighboring Ge crystals.

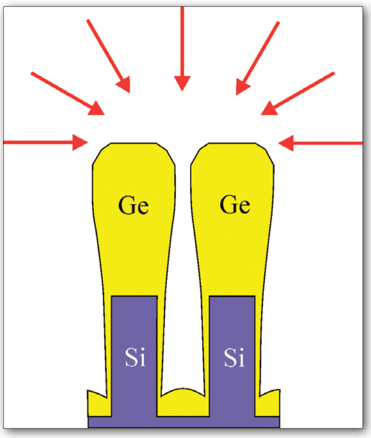
In contrast to compound semiconductors such as CdTe, it is compatible with Si processing. In order to efficiently absorb X-rays, a Ge layer must, however, be dozens of microns thick! How could one hope to grow such Ge layers crack-free and dislocation-free onto a Si substrate, which, moreover, is to remain flat, in view of thermal expansion coefficients differing by as much as 130%?

The main idea

Faced with the problem of fabricating an X-ray imaging detector monolithically integrated on a Si CMOS chip, we soon realized that the conventional means for thermal stress relief, such as very slow cooling or introducing stress-compensating interlayers, would never work. The only feasible way appears to be replacing a continuous layer by a dense array of individual crystal blocks [10]. *But this has to happen spontaneously during crystal growth, since after cooling down it would be too late, as by then the layer would already have cracked!*

The basic idea is outlined in Fig. 1(b). In a first step the Si substrate is patterned by photolithography and deep reactive ion etching, preferably in the form of tall pillars a few microns in width, separated by several µm wide trenches. What happens now when Ge is epitaxially grown onto such a patterned Si surface? Clearly, any growth carried out close to equilibrium would tend to flatten the surface and inevitably lead to a continuous film. Growth must therefore proceed far from equilibrium in a kinetic regime. Loosely speaking, this means using high deposition rates and low substrate temperatures. Our method of choice has been low-energy plasma-enhanced chemical vapor deposition (LEPECVD) [11], a method permitting growth rates of several nm/s, far above the ones of thermal CVD at substrate temperatures around 500° C. Under such conditions Ge atoms diffuse short distances before being incorporated into the growing crystal, typically on the order of 100 nm.

▼ FIG. 3: Shielding of particle flux arriving at the surface of closely spaced Ge crystals.



Space-filling epitaxial crystal arrays

The combination of deep substrate patterning and epitaxial growth far from equilibrium does indeed produce the desired result to a surprising extent. According to Fig. 2, the Ge crystals nucleating on the top of the Si pillars at first exhibit both vertical and lateral growth. Their lateral expansion comes to a complete standstill, however, once the Ge crystals reach a certain height, depending on the spacing of the Si pillars. The final gap amounts to about 50 nm and seems to persist to virtually arbitrary height as exemplified by the 50 µm tall crystals. High-resolution X-ray diffraction measurements show that the thermal strain of the Ge crystals is completely relaxed as opposed to the unpatterned parts on the same substrate where the cracked Ge layer is under a residual, thermally induced, tensile strain. Inclined surface facets are known to deflect threading dislocations towards the sidewalls of growing crystals [12]. We have indeed found no evidence for dislocations at the top of fully faceted Ge crystals, neither by high-resolution transmission electron microscopy nor by chemical etching and etch pit counting.

The mechanism for the unusual mode of epitaxial growth, leading to the space-filling crystal arrays of Fig. 2, has been studied by theoretical modeling [10]. The main ingredients of the model are a negligibly small surface diffusion length and mutual flux shielding by neighboring crystals. This can be understood from the scheme of Fig. 3, depicting the flux of activated species incident on the growing crystals. This flux is composed of a vertical and an isotropic component. The closer the crystals approach each other as growth proceeds, the more the sidewalls are shielded from the isotropic component and the more their lateral expansion is reduced.

Concept of an X-ray imaging detector

How can the Ge crystal arrays of Fig. 2 be used in an X-ray imaging detector? Our concept of such a detector is schematically depicted in Fig. 4. Here, the absorber layer is made from lightly p-doped Ge crystals grown onto the backside of a thinned, lightly n-doped Si wafer.

The readout CMOS circuits will be fabricated on the front side of the wafer in implanted p-wells. The p-doped Ge crystals and the n-doped substrate together form heterojunction p-n diodes, which, under a reverse bias voltage, permit the separation of electron-hole pairs generated by X-ray photons absorbed in the Ge. The Ge crystals are mutually isolated electrically by an oxide coating on the Si pillars. The heterojunction diodes can thus be characterized individually inside a scanning electron microscope. Ohmic contacts to the Ge crystals are formed by focused ion beam deposition of platinum. An example of a current-voltage curve, obtained by contacting a Ge crystal by a tungsten tip, can be seen in Fig. 4. The reverse current of the order of 1 mA/cm^2 at -15 V is comparable to commercial Ge p-i-n diodes of much larger size.

Diffraction measurements show that the thermal strain of the Ge crystals is completely relaxed

In principle, individual contacting of Ge crystals a few microns in width may be imagined to give rise to an imaging detector with enormous spatial resolution. In practice, however, X-ray photons impinging at an oblique angle are expected to be absorbed by several crystals. This, together with the finite thickness of the Si substrate, will degrade the spatial resolution. For this reason the pixel size of the actual detector is defined by the spacing of the n^+ implants rather than the size of the Ge crystals. This has the advantage that only one single metal contact is required on the absorber side.

What next

A high-resolution X-ray imaging detector based on epitaxial Ge crystals monolithically integrated on a CMOS chip is but one of the applications enabled by the new mode of substrate patterning and epitaxial growth. The extension of the concept to other material combinations is currently under way in the areas of high-efficiency solar cells and power electronic devices. ■

About the author

Hans von Känel is a lecturer at the ETH in Zurich and former full professor of physics at the Politecnico di Milano. His fields of interests comprise phase transitions, interfaces and surfaces, scanning probe techniques, and epitaxial growth. Besides his activities in the academic world he has been involved in technology transfer and the founding of start-up companies.

Acknowledgment

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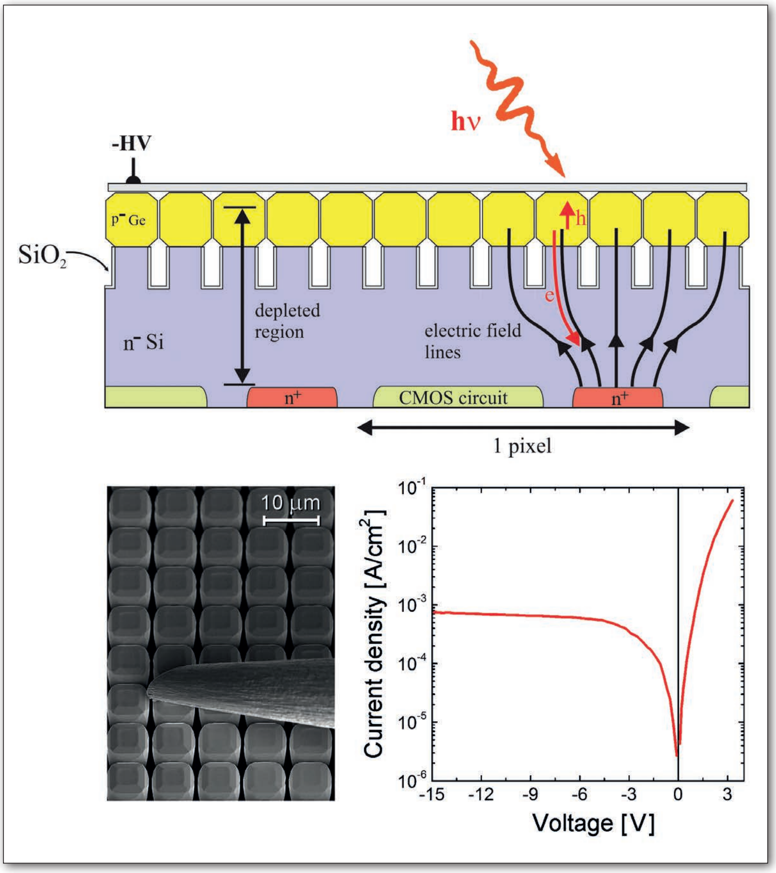
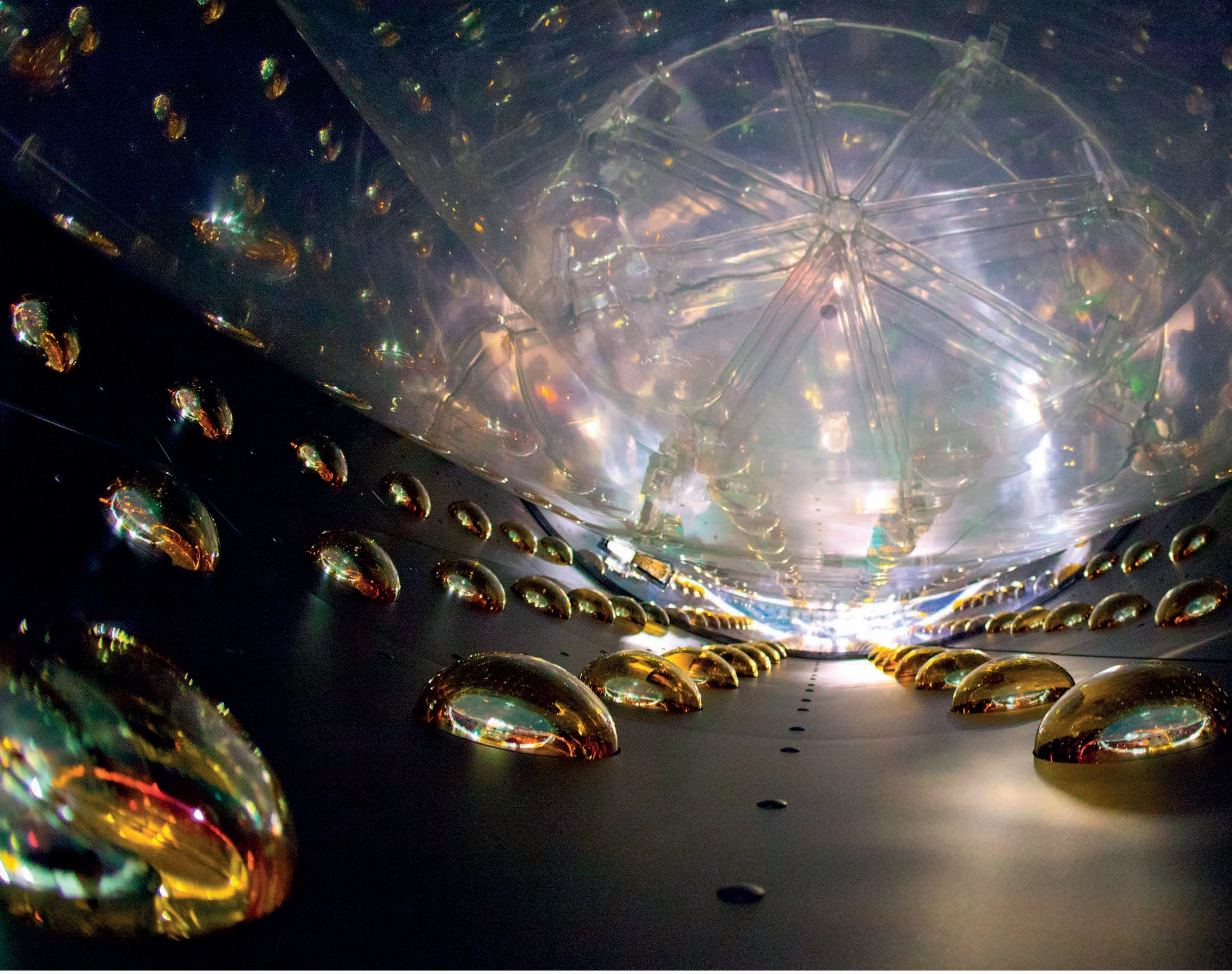
▼ **FIG. 4:** Concept of an X-ray imaging detector with a monolithically integrated Ge-absorber on a CMOS chip and current-voltage curve of a single Ge/Si(001) heterojunction measured inside a scanning electron microscope.





Neutrinos and the hunt for the last mixing angle

Tommy Ohlsson - KTH Royal Institute of Technology, Stockholm, Sweden - **DOI: 10.1051/epn/2012403**

Neutrinos are the Universe's second most common particles after the photons. During their journey through space-time, the elusive neutrinos can change types. Now, researchers at the Daya Bay experiment in China have determined the coveted final mixing angle for this phenomenon, known as neutrino oscillations.

▲ Picture of one of six detectors in the Daya Bay reactor neutrino experiment. The detector captures faint flashes of light that indicate antineutrino interactions. It consists of lines with photomultiplier tubes, and is filled with scintillator fluids. (Photo by Roy Kaltschmidt, Berkeley Lab Public Affairs)

A neutrino is an elementary particle that belongs to the same family of particles as, for example, the electron. These particles are called leptons, and consist of electrons, muons, taus as well as the three associated neutrinos, which below will also be called the three flavor states. There is even speculation that there could exist so-called "sterile neutrinos", but I will not consider such hypothetical particles in this article. Neutrinos are electrically uncharged, interact only via the weak interaction, and have very small masses; hence they are extremely difficult to detect. Neutrinos are produced *e.g.* in the soil, in the atmosphere, in the Sun, in supernovae, and in reactions at accelerators and reactors. Among other things, neutrinos are important for the processes that allow the Sun to shine. Although neutrinos are, indeed, very elusive, one has been successful in detecting them (Fig. 1).

Massive and mixed neutrinos

Until June 1998, it was believed that neutrinos were massless, but the results from measurements of atmospheric neutrinos with the Super-Kamiokande experiment in Japan showed that they are most likely massive and mixed (see below for a description of what "mixed" or "mixing" means), which in turn means that oscillations among the different neutrino flavors may occur [1]. The fact that neutrinos are massive and mixed further means that the physical model describing elementary particle physics (the so-called Standard Model) must be modified to include massive and mixed neutrinos. The masses of neutrinos and their mixing angles as well as their ability to oscillate implies that we have evidence for physics beyond the Standard Model.

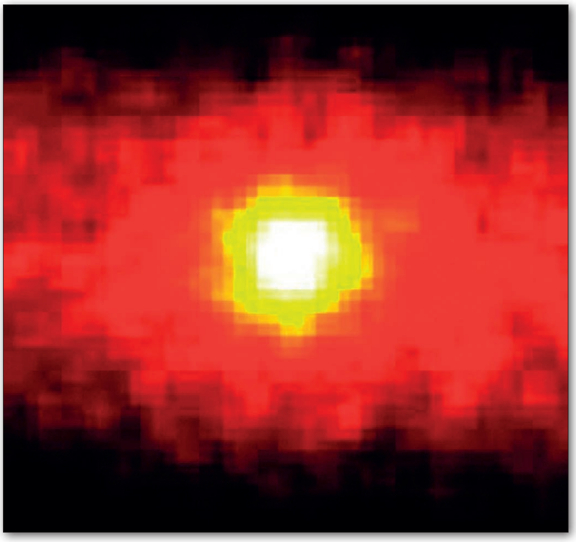
Neutrino oscillations

The phenomenon of neutrino oscillations arises as a sort of "beats" between the various flavor states, like the beats between two adjacent tones in music. However, this is a genuine quantum mechanical interference phenomenon, which means that the three types of neutrinos oscillate among the three flavor states as they travel through space-time. Mathematically, one can express it so that the three flavor eigenstates are mixings of the three mass eigenstates, where each flavor state is made up of parts of all mass states, and vice versa. This mixture of neutrinos can generally be parameterized by three so-called 'mixing angles' and three so-called 'CP-violating phases', whose importance will be discussed below. Note that CP-violation means 'broken' CP-symmetry, which is a combination of C-symmetry (charge conjugation symmetry) and P-symmetry (parity symmetry) and states that the laws of physics should be the same if particles and their antiparticles are interchanged (C-symmetry) and left and right are replaced with each other (P-symmetry).

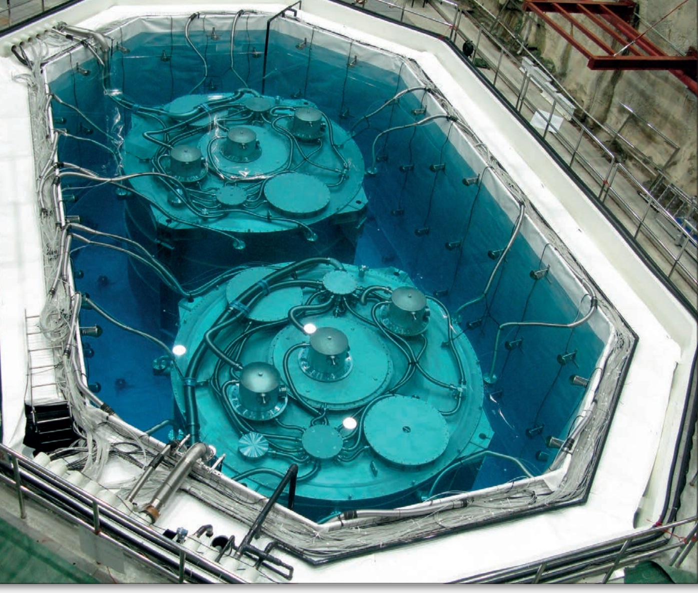
Leptonic mixing parameters

In a simple extended version of the Standard Model, the masses of the three neutrinos and the leptonic mixing parameters (*i.e.*, the three mixing angles and the three CP-violating phases) should be added to the already 19 existing parameters contained in the Standard Model. In what follows, I will only discuss the three mixing angles, often referred to as θ_{12}, θ_{13}, and θ_{23}, where θ_{ij} is a measure on the relative mixing between mass states i and j in the different flavor states. Historically, the three mixing angles θ_{12}, θ_{13}, and θ_{23}, were called the solar mixing angle, the reactor mixing angle, and the atmospheric mixing angle, respectively, but these names are somewhat misleading, as we will see below.

Using the results from the Super-Kamiokande experiment, but also measurements on accelerator neutrinos, one can determine an almost certain value of the mixing angle $\theta_{23} = 45°$ [2], which means that the mass states 2 and 3 are maximally mixed. Furthermore, one can use data from solar and reactor neutrinos to determine a relatively certain value of the mixing angle $\theta_{12} \approx 34°$ [3], saying it is large, but not maximal as is the case for θ_{23}. Until very recently, there has been only an upper limit on the third mixing angle θ_{13}. This upper limit, which restricts θ_{13} to a maximum



◂ **FIG 1:** The Sun in "neutrino light". The Sun as seen by the Super-Kamiokande detector, which is located in an old gold mine a few kilometers below the surface of the Earth. Sun light will never reach the detector, but solar neutrinos will. [Astronomy Picture of the Day (June 5, 1998), NASA. Credit: R. Svoboda and K. Gordan (LSU)]



▲ **FIGS 2, 3, AND 4:** Pictures of the Daya Bay, Double Chooz, and RENO detectors. (Credits: Daya Bay, Double Chooz, and RENO Collaborations)

of about nine degrees, was a result from the CHOOZ experiment in France in the late 1990's and was featured in a final article by the CHOOZ Collaboration in 2003 [4]. Thus, one has determined two large mixing angles θ_{12} and θ_{23} and one small mixing angle θ_{13} for the neutrinos. These results differ considerably from the values of the corresponding mixing angles in the so-called quark sector, which says that all mixing angles in that sector are small.

The hunt for the third and last mixing angle

The urge to know the values of the parameters of the Standard Model in general and the mixing angles for the neutrinos in particular has spurred particle physicists to also measure and determine a value of the third mixing angle θ_{13}. A non-zero value for θ_{13} would open up a window to eventually be able to measure the above-mentioned CP-violating phases, which provide information about the existing matter-antimatter asymmetry in the Universe.

In the search of θ_{13}, global fits to all available neutrino data to indirectly determine the mixing angles belong to the efforts [5]. Of course, one has also examined various theoretical models that predict values for these mixing angles. Many models lead to so-called tribimaximal ($\theta_{12} \approx 35.3°$ and $\theta_{23} = 45°$) or bimaximal ($\theta_{12} = 45°$ and $\theta_{23} = 45°$) mixing, but both mixing patterns provide $\theta_{13} = 0$. Therefore, one has also discussed models that predict so-called bilarge mixing, which means large, but not necessarily maximal values for θ_{12} and θ_{23} and no restriction on θ_{13}. Examples of such models are also found in the literature [6].

“This could have implications for the matter-antimatter asymmetry in the Universe.”

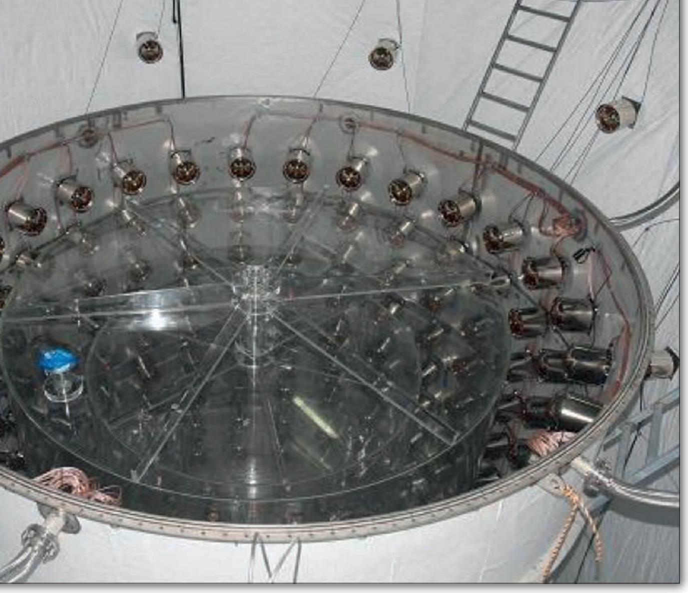
The hunt for θ_{13} has mainly been taken up by three neutrino experiments: the Daya Bay experiment in China, the Double Chooz experiment in France at the Franco-Belgian border (which is the successor to the CHOOZ experiment), and the RENO experiment in South Korea (see Figs 2, 3, and 4, respectively). All three are reactor neutrino experiments, which examine electron antineutrinos from nuclear power plants to directly determine the value of θ_{13}. For example, the Daya Bay experiment consists of six reactors and six antineutrino detectors at distances of 0.5 to 1.5 kilometers from the reactors.

It should be noted that in early 2011 two experiments, the T2K experiment in Japan and the MINOS experiment in the United States, found results which indicated that the hypothesis that θ_{13} equals zero is not true. At last, in November 2011, the Double Chooz experiment came with its first result: the value of the third mixing angle is probably just in between eight and nine degrees [7]. However, it was a result of great uncertainty, since it was not possible to exclude that the result was a statistical fluctuation. So, in March 2012, the Daya Bay experiment presented its initial findings in an article [8]. With good statistical significance, they measured $\sin^2(2\theta_{13}) = 0.092 \pm 0.017$ (see Fig. 5), which gives $\theta_{13} \approx 8.8°$, *i.e.*, just below the upper limit originally determined by the CHOOZ experiment. Thus, the Daya Bay experiment has won the hunt for the third mixing angle!

A month after the Daya Bay experiment, also the RENO experiment came with its first result (with even better statistical significance than the Daya Bay experiment), $\theta_{13} \approx 9.8°$ [9], which is slightly larger than the value of the Daya Bay experiment. There are now three independent measurements from three different experiments, Daya Bay, Double Chooz, and RENO, which all indicate that the value of the third mixing angle is about nine degrees. Thus, the value of θ_{13} is distinct from zero, but small. Therefore, both the tribimaximal and bimaximal mixing patterns are ruled out by data. At the "Neutrino 2012" conference in Kyoto, Japan, three experiments reported on updated best-fit values: $\theta_{13} \approx 8.7°$ (Daya Bay), $\theta_{13} \approx 9.4°$ (T2K), and $\theta_{13} \approx 9.6°$ (Double Chooz).

The CP-violating phase and the matter-antimatter asymmetry in the Universe

One of the three CP-violating phases, the so-called Dirac CP-violating phase δ, can be measured using neutrino oscillation experiments. This phase appears only in combination with the third mixing angle in the leptonic mixing matrix as $\sin(\theta_{13}) \exp(\pm i\delta)$. Thus, a non-zero value of θ_{13} means that it is, in principle, possible to determine δ. As a matter of fact, accelerator-based neutrino oscillation experiments will provide the most promising



opportunity to observe CP violation [10]. In order to measure CP violation, such experiments will study both neutrino and antineutrino oscillations. If antineutrinos do not oscillate in the same way as neutrinos do, then this is a signal of CP violation, and in turn, this could have implications for the matter-antimatter asymmetry in the Universe. For example, note that the lepton asymmetry in the mechanism known as leptogenesis [11] depends on the Dirac CP-violating phase [12]. Especially, the oscillation channels between electron and muon neutrinos (or antineutrinos) are best suited to study CP violation, since it is easier to create and detect such neutrinos compared to tau neutrinos. In fact, two neutrino oscillation experiments, the NOνA experiment [13] between Fermilab and Ash River, Minnesota, USA and the NuMI experiment [14] between Fermilab and the Soudan mine, Minnesota, USA, will search for muon neutrino-electron neutrino oscillations as well as muon antineutrino-electron antineutrino oscillations to measure CP violation in the neutrino sector. In addition, the NOνA experiment may be able to provide a measurement of the neutrino mass hierarchy – another important neutrino parameter. For the future, there exist proposals for the Long-Baseline Neutrino Experiment (LBNE) [15], which aims to find out if neutrinos are the reason why we exist (since their interactions could explain why matter is more abundant than antimatter), and a so-called Neutrino Factory that will be the ultimate producer of precision neutrino data.

Summary

In summary, the measurement of θ_{23} by the Super-Kamiokande experiment resulted in one of the first indications of physics beyond Standard Model, the measurement of θ_{12} was the first precision measurement in neutrino physics, and the hunt for the value of the third and final mixing angle θ_{13} was the beginning of the end of the measurements of the mixing angles for the neutrinos, but the beginning of the continuation of measurements of the remaining neutrino parameters. ■

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About the author

Tommy Ohlsson is a full professor in theoretical physics at the KTH Royal Institute of Technology in Stockholm, Sweden. His research field is theoretical particle physics, particularly neutrino physics and physics beyond the so-called Standard Model. He is an author of around 80 scientific publications and one textbook "Relativistic Quantum Physics" published at Cambridge University Press. He has also written a popular science text about the theory of special relativity at Nobelprize.org. You can find more information on: www.theophys.kth.se/~tommy/.
Picture taken by **Mats Wallin**.

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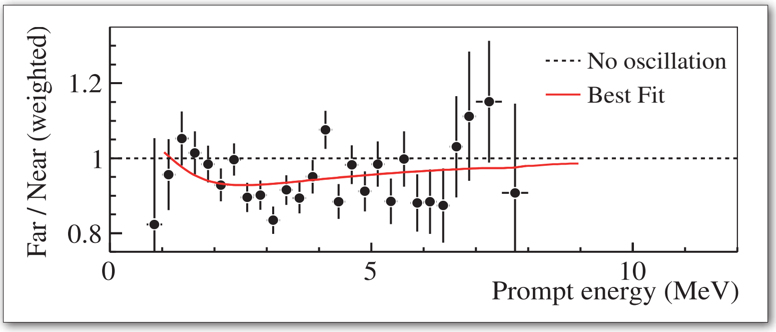

▼ **FIG 5:** The ratio of measured and predicted no-oscillation spectra. The red curve is the best-fit solution with $\sin^2(2\theta_{13}) = 0.092$ obtained from the rate-only analysis. The dashed line is the no-oscillation prediction. This figure has been adapted from Ref. [8].

Magnetic Resonance Imaging

a success story for superconductivity

René Aarnink[1] and Johan Overweg[2] - DOI: 10.1051/epn/2012404

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Superconductivity is at the heart of MRI scanners, helping to give doctors an unprecedented view of structures deep within the human body. Nevertheless, challenges still exist in realizing the full potential of this important imaging modality, some of which relate to physics and some to economics.

▲ Working screen for Magnetic Resonance Imaging

Without superconductivity, one of today's most important medical imaging modalities would not be possible. Magnetic Resonance Imaging (MRI), which depends on being able to align the weak magnetic moment of the protons in a patient's body with a magnetic field, requires the use of magnetic field strengths in excess of 1T. This can only be achieved practically through the use of superconducting electromagnets.

The field strength generated by a current-carrying conductor can be calculated using Ampere's Law. If the MRI magnet were a simple long solenoid with uniform winding density, this would reduce to:

$$B = \mu_0 I N/L$$

where B = field strength in Tesla; I = current per turn; N = number of turns; L = coil length and μ_0 is the permeability

of free space (to a close approximation, equal to that of the patient/air within an MRI scanner).
This simple formula works out at approximately 1×10^6 ampere-turns (around 10,000 turns of wire driven with 100 amps) for a typical MRI magnet length of 1.2 metres and a field of 1 tesla. For several reasons, practical MRI magnets actually have around 5 times as many ampere-turns. Firstly because of their small length-to-diameter ratio; secondly because of the increasing turns density needed towards the ends of the coil to make the field homogeneous; and lastly because of the need for active stray-field compensation (the magnet consists of two concentric coil sets with opposing polarity, shaped in such a way that the outer coil to a large extent cancels the external magnetic field of the inner coil).
Without the use of superconducting materials such as Niobium Titanium, cooled with liquid helium to below their critical temperature, the energy loss in such coils would make modern MRI scanners impractical. Thanks to these materials, however, MRI scanners are already commonplace in hospitals, providing superior soft-tissue imaging to assist doctors in the diagnosis of a wide range of diseases, including cancer, Alzheimer's, stroke, trauma injury and Parkinson's disease.

Field strength and uniformity

The characteristics of the magnetic field generated by an MRI scanner have a significant impact on its performance. The field strength has to be very uniform in the imaging volume (typically the cross-section of the human body, with a spherical volume of around 45 to 50 cm diameter in the center of the magnet) and it has to remain extremely stable during the scan. In addition, the proton polarization, which determines the strength of the NMR signal, increases linearly with field strength. High field strengths therefore enable increased signal-to-noise ratios and better image quality. They also allow shorter scan times, increasing patient throughput and reducing patient discomfort. There is therefore a trend toward higher field strength scanners, with 3T MRI scanners already being used in routine clinical care and 7T machines being used in (pre-)clinical research.
However, 7T MRI scanners are extremely expensive and will probably remain so, in particular because the current-carrying capacity of the superconductors employed decreases rapidly above 5T, leading to a disproportionate increase in the amount of conductor needed. In addition, the electro-magnetic (Lorentz) forces that have to be contained become a real problem, increasing with the square of the field. The main problem with Lorentz forces on superconducting conductors is that they can lead to motion of the conductors, which causes friction heat. It only takes a few microjoules of heat energy to raise a small piece of the superconductor above its critical temperature (the heat capacity at 4K is extremely small) and if this non-superconducting zone starts to propagate through the coil, the entire stored energy of the magnet (many megajoules) is dumped into the liquid helium cooling the magnet (this is known as a quench). MRI magnets are designed to survive such an event without permanent damage, but re-cooling and bringing the magnet back to the required field strength is time consuming and costly.

> **"Zero boil-off magnets are now state of the art"**

Cryostat design

In most of today's MRI magnets, the superconducting coil is enclosed in a helium tank containing approximately 1000 litres of liquid when full. Magnets are usually cooled down and filled only once, in the factory where they are made, and remain cold for their entire life (typically 10 years).

HOW MRI WORKS

When a person is in an MRI scanner, the hydrogen nuclei (i.e., protons, found in abundance in the human body as water) align with the strong magnetic field. A radio wave at just the right frequency for the protons to absorb energy pushes some of the protons out of alignment. The protons then snap back to alignment, producing a detectable rotating magnetic field as they do so. Since protons in different areas of the body (e.g., fat versus muscle) realign at different speeds, the different structures of the body can be revealed.
Gradient fields in the three dimensions allow the scanner to work only with protons from a 'slice' at a time, allowing the creation of a whole volume that can be looked at in three dimensions.
Contrast agents may be injected intravenously to show enhancement of blood vessels, tumors or inflammation. Unlike CT scanning, MRI uses no ionizing radiation and is generally a very safe procedure. Patients with some metal implants and cardiac pacemakers are prevented from having an MRI due to effects of the powerful magnetic field and powerful radio waves.
MRI is used to image every part of the body, but is particularly useful in neurological conditions, disorders of the muscles and joints, for evaluating tumors and showing abnormalities in the heart and blood vessels. ■

source:
www.websters-online-dictionary.org/definitions/Magnetic+resonance+imaging

Any heat leak into this cold mass causes helium to evaporate (at a rate of around 1.4 litres per hour per watt of thermal load). If the cold mass is enclosed in a high-vacuum space and the magnet's suspension system has a low thermal conductivity, the single biggest contributor to this heat load is thermal radiation. Older MRI magnets relied on two refrigerator-cooled shields in the vacuum space to reduce the heat load to less than 50 mW (the radiated heat decreases with the fourth power of the surface temperature of the shield seen by the cold mass), resulting in a loss of less than 1 litre of helium per day. More modern refrigerators have about 1W of cooling power at 4K, allowing boil-off from the helium tank to be stopped completely. These zero boil-off magnets are now the state of the art. The rapidly increasing cost of helium more than justifies the extra cost of such a refrigerator. However, it takes about 7 kW of electrical power to drive the refrigeration system.

One of the challenges in magnet design is therefore to make these refrigeration systems more efficient and reliable so that the loss of helium due to planned and un-planned downtime of the refrigeration system is minimized. When the magnet is being shipped or temporarily stored before installation, the refrigerator is also kept running whenever possible.

With the escalating cost of helium, which is a by-product of natural-gas extraction, another important challenge for the future is minimizing the helium content of the magnet. A few hundred litres of liquid helium or less would actually be sufficient to keep the magnet superconducting, so the main challenge in developing magnets without a large helium buffer volume is to make the refrigeration system so reliable that it never fails, or so efficient that it can re-cool the magnet without using much external helium after a failure.

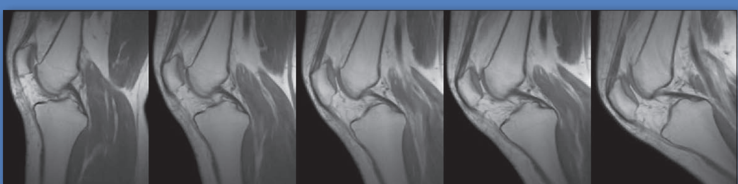
INCREASED PATIENT COMFORT AND ACCESS

Some patients feel very claustrophobic in the bore of a conventional cylindrical magnet MRI scanner, and the sudden loud noises emitted by the scanner when the gradient coils are activated often worsens this feeling and can cause the patient to move suddenly. Such movements can degrade image quality, so sedatives and/or ear plugs are often used to calm the patient and minimize the effect.

▲ The Panorama HFO, Philips' high-field, wide open system, offers outstanding clinical versatility with leading solutions for all clinical applications. And it is preferred by patients because of its comfortable space and wide open bore.

In an attempt to increase patient comfort and provide clinicians with better access to the patient, for example to perform MRI-guided clinical interventions, open-magnet MRI scanners have been developed. However, such designs are very challenging, since the C-shaped magnets used in these scanners are less efficient than cylindrical magnets; the mechanical forces generated are less symmetrical and therefore more difficult to control; and the split cryostat required becomes more complicated. Field strengths much in excess of 1T are therefore impractical. However, because open-magnet designs facilitate better receive-coil layouts, a 1T open-magnet scanner such as the Philips Panorama 1.0T illustrated above can achieve the same imaging quality as a 1.5T cylindrical magnet design. ■

▼ The Panorama HFO's open design provides space for dynamic imaging of joints in different positions.



High-temperature superconductors

One way of eliminating the need for helium in MRI scanners completely would be to use high-temperature superconducting materials such as Yttrium Barium Copper Oxide (YBCO) tape. This material remains superconducting at temperatures above 77K, although for a practical magnet an operating temperature of about 40K to 50K would be ideal. Being able to run the magnet at 40K to 50K instead of 4K would allow a simpler and therefore more reliable refrigerator to be used, and the electrical energy required to keep the magnet cool could probably be reduced to around 1kW. The problem, however, is that YBCO tape is currently 200 to 300 times more expensive than Niobium Titanium wire, which means that its use in MRI scanners does not at the moment make economic sense.

Clinical applications

Challenges may still lie ahead for the future of MRI, but the good thing is that in forty years it has turned from an experimental device to a highly effective tool for the diagnosis of disease. Compared to other commonly used imaging modalities such as X-ray CT, it provides far superior soft-tissue imaging and poses no threat to patients or operators in terms of exposure to potentially harmful ionizing radiation.

Despite this, one of the early expectations for the Nuclear Magnetic Resonance (NMR) principles on which MRI is based has still not been realized. MRI can visualize lesions deep within the human body, but it cannot on its own determine whether or not they are malignant. Differential diagnosis still has to be done by biopsy. Nevertheless, advances are being made that could allow MRI to reveal some of the functional characteristics of malignant tumors, turning it from a purely anatomical imaging modality into a functional imaging modality. MRI is already being used as an imaging tool to perform brain scans, where its ability to generate contrast images that distinguish oxygen-rich blood from oxygen-depleted blood is used to spatially localize brain metabolism. This same ability is also being used to provide an indirect measurement of the angiogenesis (the proliferation of blood capillaries) and increased tissue metabolism associated with malignant tumors. Contrast agents, based on biocompatible paramagnetic materials such as chelated organic gadolinium complexes, that are injected into the blood stream, are another means of using MRI to functionally image vascular structures. Enhancing this procedure using antibody complexes that bind specifically to the surface of tumor cells could also allow paramagnetic molecules to be used to highlight tumors.

Since diagnoses based on functional imaging often require the capture of dynamic behaviour, functional MR imaging could benefit from the use of scanners with high temporal resolution, *i.e.*, short image volume capture times. Unfortunately, the physics of MRI scanners means that spatial resolution and temporal resolution have to be traded off against one another. One way of achieving both is to move to higher magnetic field strengths. Despite their higher cost, 7T scanners may therefore find clinical applications in specialist diagnostic centers once appropriate clinical approvals are granted. At the moment they are only approved for research applications, typically with a focus on cardiac, oncology and neuro applications. Because of their excellent soft tissue imaging and the absence of ionizing radiation, MRI scanners could also provide clinicians with the real-time imaging needed for minimally invasive interventional procedures such as catheter-based heart valve replacement. However, they would preferably need to be open-magnet designs that provide clinicians with unhindered access to the patient. Philips is already collaborating with researchers at the University Medical Center Utrecht (Utrecht, The Netherlands) to combine an MRI scanner with a linear accelerator in order to investigate the benefits of MRI-guided radiotherapy.

Despite the fact that the technology underlying MRI scanners is relatively mature, with the result that they are now routinely used in radiology, there is clearly much that can still be done to exploit the full potential of this important imaging modality. The quest for higher resolution images, better temporal resolution and improved functional imaging will continue to resolve unmet clinical needs in imaging-based diagnostics. ■

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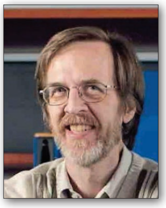

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LOW-FIELD-STRENGTH MRI

There are some applications where low field strengths could be an advantage. For example, patients with implants that contain ferromagnetic materials cannot currently be placed in an MRI scanner. The proton relaxation modes in low field strengths can also generate some interesting image contrasts. The main problem at low field strengths is that the RF signal generated by nuclear magnetic resonance is weak and the signal-to-noise ratio is therefore poor. One way of overcoming this could be to pre-polarize the protons rather than relying only on the magnetic field to do it. The transfer of nuclear spin polarization from one nuclear spin population to another via cross-relaxation (the Overhauser Effect) is being investigated, but because one spin population would probably need to be free electrons, which act in the body like free-radicals, biocompatibility could be a major problem. Research is also being done on contrast agents that can be pre-polarized before injection. However, the required pre-polarization is difficult to produce and its lifetime is only a few minutes. ■

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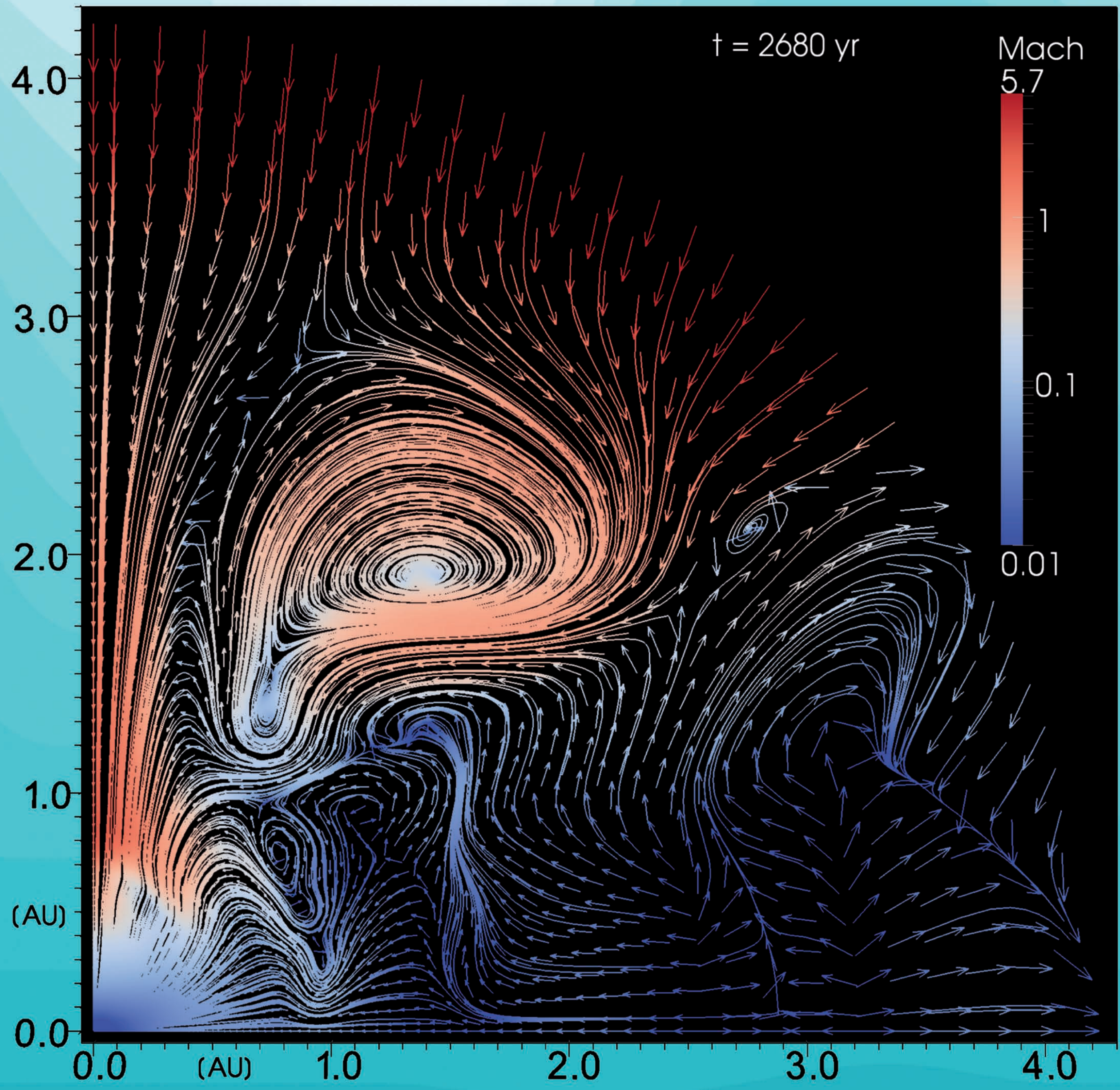

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