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The critical Casimir effect
Over the rainbow
Construction of the Egyptian pyramids
Physics in Rome
Race to an new atomic kilogram

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2009
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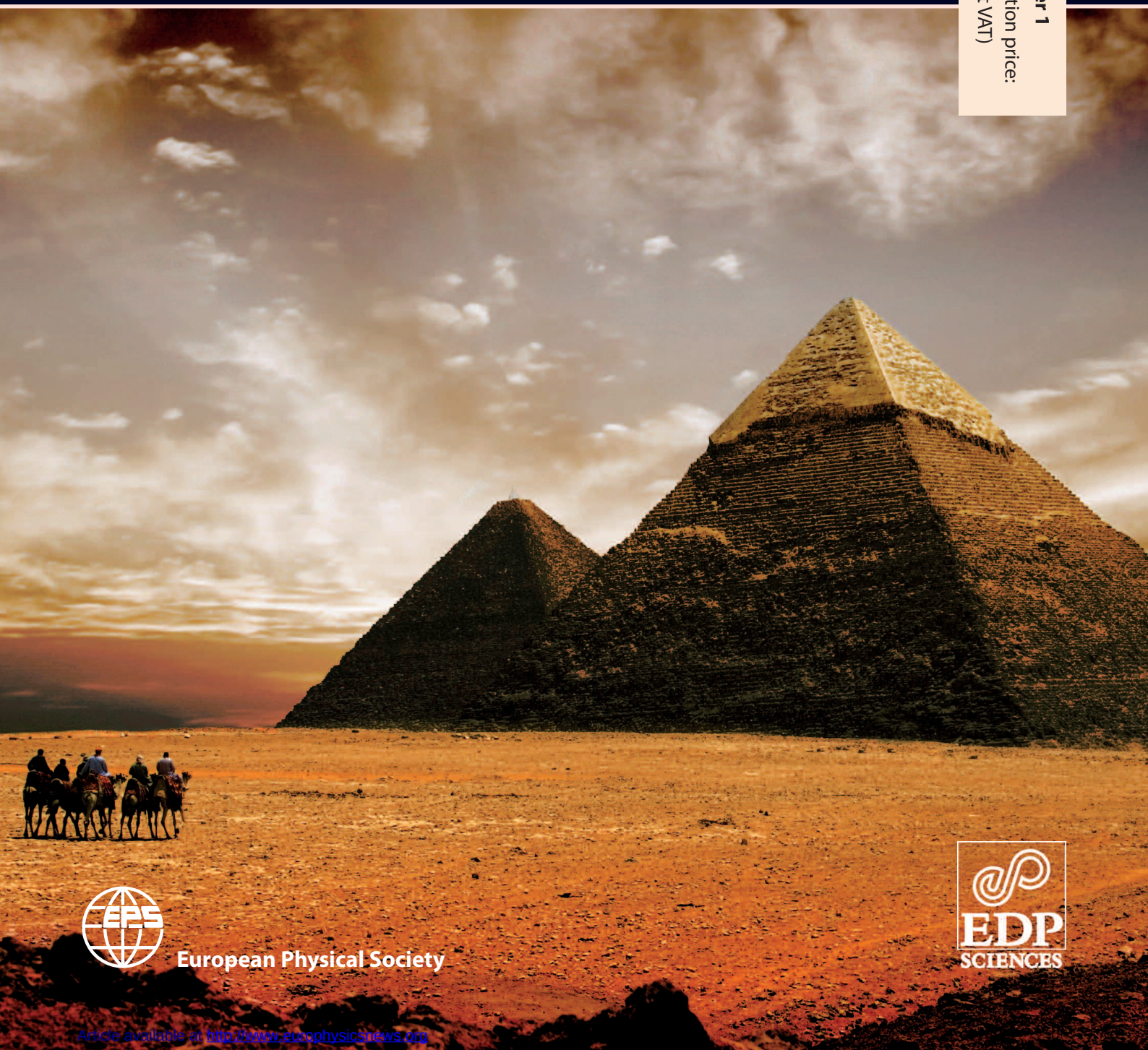

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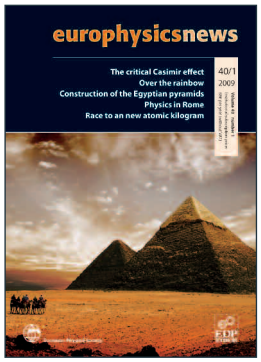

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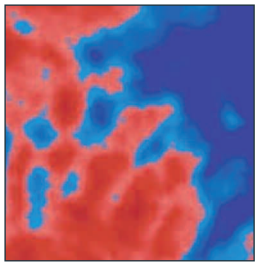
Cover picture: mysterious pyramides of giza



▲ PAGE 18

The critical Casimir effect

▲ PAGE 23

Race to a new atomic kilogram

▲ PAGE 27

Construction of the Egyptian pyramids

EDITORIAL

NEWS

HIGHLIGHTS

FEATURES

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EPL – TOWARDS A GLOBALLY COMPETITIVE LETTERS JOURNAL*

The journal *Europhysics Letters* was launched in 1986 through the merging of *Journal de Physique Lettres* and *Lettere al Nuovo Cimento*. At the time this was rightfully considered to be *"a milestone in the progress towards greater unity in Europe"* (G.H. Stafford). But in today's global science scene the label 'Euro' has become too restrictive.

As of 2007, therefore, the journal has been 'branded' EPL. This renaming coincided with the re-launch of the journal through a new publishing contract.

The new contract was drawn up with a 'vision' anticipating that:

- number of submissions increase from 1387 articles in 2006 to over 3000 articles in 2011
- acceptance rate for manuscripts decrease from 46% in 2006 to 33% by 2011

and, fully realising the limited value of ambiguous statistical data, that

- impact factor rise from 2.2 in 2006 to 3.5 for 2011.

When – in 2006 – the balance between fields in *EPL* was compared with other international broadband letter journals, the topical distribution of publications in *EPL*, for example, in condensed matter, was found to match the international pattern. In addition, *EPL* had strengths in both general physics and in interdisciplinary research topics. Several fields of physics, on the other hand, were under-represented in EPL. Promotional efforts aimed at mitigating imbalances have already met with success in some domains: the shares of letters pertaining to plasma physics and to geophysics are now approaching the international pattern. As an incentive to authors working in the domain of 'particles and fields' – another under-represented subject – *EPL* now offers open-access publication free of charge. This offer, introduced in November 2008, concerns theoretical as well as experimental work, and remains valid until the SCOAP (Sponsoring Consortium on Open Access Publishing in Particle Physics) agreement becomes operational and covers publication costs. Having widely publicised this opportunity for free open-access publishing, we may shortly expect rising submissions in these domains.

Unique features of *EPL* are the stature and role of the Co-Editors: well-known active scientists, who are autonomous in their accept/reject decision for each manuscript. They are free to ask for the number of reviewer reports they deem necessary; and this also means that they may accept articles without review by an external reviewer. As a result, *EPL* can accept exceptional papers in one day and publish online within about 10 days.

Given the central role of Co-Editors, the Editor-in-Chief takes great care in preparing appointments to the Editorial Board. The primary criterion for membership of this Board is scientific excellence. Recent expansions of the Editorial Board ensure appropriate coverage of under-represented domains, and increase the number of overseas Co-Editors. Following a suggestion by the Editor-in-Chief, former and current members of the Editorial Board have started publishing more of their own work in *EPL*, thus underlining the fact that *EPL*-promotion is a multi-facetted effort.

The number of articles submitted to *EPL* has increased between 2006 and 2008 by 34 % and the number of letters published has grown by 27 %. This is going in the correct direction, except that the acceptance rate should still decrease more strongly. Approaching the target value for the acceptance rate (33 %) remains a challenge for the Editorial Board. In general, however, we seem to be on the right track.

You, as reader of this Editorial, may also help in the promotion of *EPL*: please consider submitting your important research results of general interest to *EPL*!

The publishing process is rapid, and the services to authors are excellent. ■

Volker Dose, *EPL* Editor-in-Chief and
Martin Huber, Chairman of the Board of the *EPL* Association.

* More information on *EPL* page 4 of this journal and EPL website www.epljournal.org

WHO OWNS *EPL*?

EPL is owned by the Europhysics Letters Association – a consortium of 17 learned societies. Any earnings from the publishing exercise thus flow directly back into physics endeavours.

The *Europhysics Letters Association (EPLA)* consists of the four publishing partners who are the main shareholders (the so-called Category A members)

- the *European Physical Society (EPS)*, which bears the scientific responsibility for *EPL*,
- the UK *Institute of Physics (IOP)*,
- the *Société Française de Physique (SFP)/EDP Sciences* and
- the *Società Italiana di Fisica (SIF)*.

Further shareholders in *EPLA* (the so-called Category B members) are

- the Physical Societies of Austria, Germany, Hungary, Netherlands, Portugal, Switzerland and Turkey, a Pool of Scandinavian Physical Societies (Denmark, Finland, Iceland, Norway, Sweden), and the Institute *"Ruder Boskovic"* in Croatia.

In addition, there are two Associate Members, namely

- the Institute *"Josef Stefan"* in Slovenia, and the *Spanish Royal Society of Physics*.

EPLA is governed by an annual General Assembly, which often holds elections and makes decisions by e-mail. A Board of Directors (BoD) decides on the strategy and supervises the affairs of *EPLA*. The Board consists of representatives of the four Category A shareholders and one representative of the Category B members. The current Board is composed of Sir John Enderby (IOP), Martin Huber (EPS, Chair), Angela Oleandri (SIF), Jean-Marc Quilbé (SFP) and Markus Schwörer (member of the German Physical Society, DPG). The Editor-in-Chief, Volker Dose, the Executive Editor, Graeme Watt and the Staff Editor, Frédéric Burr are permanent guests of the BoD. The Business Manager, David Lee, is Secretary of the Board and is also responsible for finances and the day-to-day running of *EPLA*. The seat of *EPLA* is Petit-Lancy, a suburb of Geneva.

The Principal Tasks of the Publishing Partners

The *European Physical Society*, or rather the *EPS Executive Committee*, appoints the *EPL* Editor- in-Chief and the Co-Editors (whose tenure is 3 years, with the possibility of extension by a fourth year). EPS also runs the Editorial Office, which is located at the EPS Secretariat in Mulhouse. The Editorial Office currently consists of the Staff Editor and two Editorial Assistants. This Office receives the manuscripts, advises the most suitable Co-Editor with suggestions of potential referees, and then follows up the publication process: issuing reminders, where necessary, to minimise delays in the publishing process and addressing alternate Co-Editors or reviewers in cases of conflict of interest or other impediments.

The publishing office of the *Società Italiana di Fisica* in Bologna takes care of the final editing of the manuscripts, including figures and tables, and produces the articles in their final format for proofing by the authors.

Édition Diffusion Presse Sciences (EDPS) in *les Ulis* near Paris, the publisher for SFP, have responsibility for producing and distributing the printed version of *EPL*.

Institute of Physics Publishing (IOP Publishing) in Bristol, the publisher for *IOP*, hosts the on-line version of each article, which is freely accessible for 30 days from the publication date. *IOP Publishing* is also responsible for subscriptions, sales and marketing, and provides the Executive Editor and Product Manager, who maintain the statistics and promote the journal, in part by attending conferences.

Representatives of all the publishing partners form the *EPL Management Team*, which frequently resolve issues via e-mail or telephone and hold a once-a-year face-to-face meeting at one of the publishing locations. This Team, under the chairmanship of the Executive Editor, co-ordinates and streamlines the publishing process and elaborates assignments of the BoD.

From Submission to Publication — how much Time Does it Take?

In 2008 the median time for a paper from submission to acceptance was 91 days, or less than 52 days for manuscripts where no revision was required. Articles regularly appear online and in print, respectively, 31 and 42 days after acceptance. Letters of high scientific quality that have been flagged by a Co-Editor for fast-track publication are typically accepted in one day and published on line ten days later. ■

John Beeby

It is with great sadness that we inform you of the sudden death of John Beeby, the Honorary Secretary of the Institute of Physics and the Treasurer of the European Physical Society. He will be sorely missed for his deep commitment and his strong support of the EPS. John was a great physicist and a true European. An obituary will be published in the next issue of Europhysics News ■

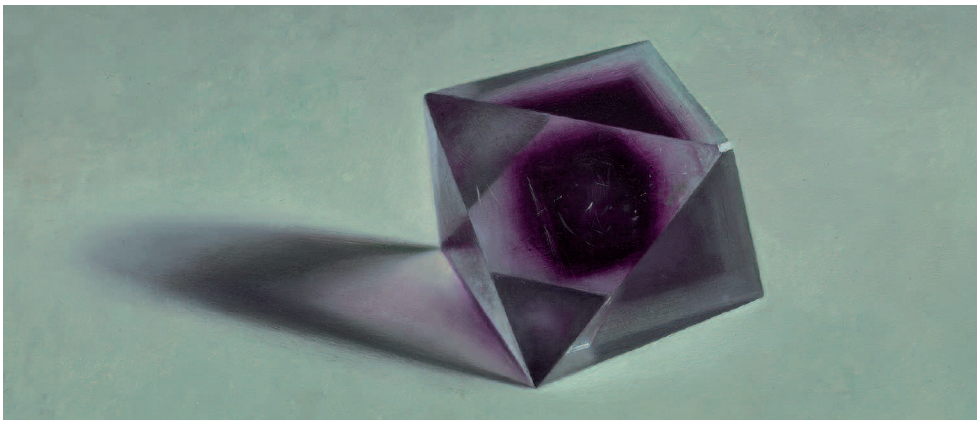
ALUM CRYSTAL CONTEST: A NEW RECORD

Since about 1980 annual competitions in growing your own single crystal are held in Belgium and the Netherlands.

The idea is to evoke the aesthetics of a fundamental scientific endeavour and to pay respect to a well-defined laboratory art, that of bringing substances to crystallize. The conditions are such that anyone is able to participate, with no risks for the environment: water is used as the solvent, a cheap and easily purchasable material as the solute. Tests revealed that alums are the most appropriate. Alums are double salts that crystallize, with inbuilt water, adopting an octahedral form. The most common form is aluminium alum, used as after-shave.

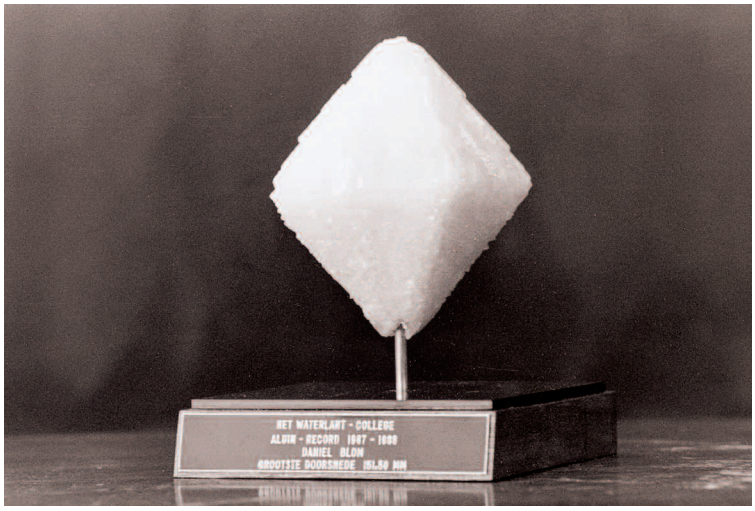
In the early years of the contest records were annually broken. In 1988, a more lasting record was set by Daniel Blom from Waterlant-College, Amsterdam (Figure 1). His crystal's longest diagonal measured 151,50 mm. Blom had taken 3 months for his achievement.

A new, really epochal record was set only recently by Rik Wagenaar (Pijnacker, NL). Wagenaar had started with chrome alum, to continue after a while with aluminium alum; whence the pink kernel of his product. Most remarkably, by steadily improving his technique (crystallization in the cold by slow evaporation) he succeeded in maintaining the water-clear state of the single crystal. This crystal will be the standard for assessing eventual future attempts. Its largest diagonal measures 162,5 mm, its mass being 1.299,23 gram. It took 10 (ten) winters to do the job. Painter Henk Helmantel, renowned for his impression of the Bernoulli globe electrical machine (2003)[1], reproduced the crystal in 2007 in oils on masonite. ■



▲ **FIG. 2:** Alum Crystal, Wagenaar new record (photo: Art Revisited, Marum).

▼ **FIG. 1:** Alum crystal, Blom 1988 record size (photo: John Melskens, Amsterdam).



Henk Kubbinga,
University of Groningen
(The Netherlands)

Acknowledgment

I am indebted to Jeff De Hosson for kind support.

reference

[1] Cf. *Europhysics News* **33-5**, 178 (2002) and, for the painting, *Physics Today* **59-9**, 104 (2006). See also: **www.helmantel.nl** and **www.artrevisited.com.**

PLASMA PHYSICS DIVISION:
CONFERENCE REPORT AND ANNUAL AWARDS, 2008

The 35th annual conference of the EPS Plasma Physics Division was recently held in the Creta Maris conference centre, Hersonissos, Crete from 9-13 June, under the local chairmanship of Paraskevas Lalousis of the FORTH institute, Heraklion.

The conference was hosted by the EURATOM-Hellenic Republic Association. The whole field of Plasma Physics was covered by plenary and parallel oral presentations, as well as poster sessions, under the scientific chairmanship of Dr Carlos Hidalgo, CIEMAT, Madrid. The conference attracted 751 delegates from 40 countries. The conference was combined with the 10th International workshop on Fast Ignition of Fusion Targets, repeating a successful co-organisation which had been tried in London, 2004.

Dr Paul Thomas, from the recently established "Fusion for Energy" organisation in Barcelona, the European Domestic Agency for the ITER project, gave the evening talk on ITER. Dr Thomas outlined the results and significance of the scientific and technical design review which had recently taken place, and presented the changes proposed and their impact on the project.

A second evening session was held on the well-recognised difficulties facing women working in physics, during which statistics and sociological studies were presented to underline these challenges. The principal speakers were Mrs Anne Pepin ("Mission pour la place des femmes au CNRS", France) and Mrs Cathrine Hasse (University of Aarhus, coordinator of the UPGEM project).

Our Cretan hosts provided an excellent social programme for accompanying persons to visit Crete, including the unique site of Knossos, and arranged a traditional village dinner outside the city for everyone to relax.

▲ Professor Liu Chen, presenting his Hannes Alfvén prize lecture during the conference opening session.

Hannes Alfvén prize

The 2008 divisional Hannes Alfvén Prize was awarded during the opening ceremony to **Professor Liu Chen** (University of California Irvine). The citation for this academic distinction reads as follows: "*…for his many seminal works on Alfvén wave physics in laboratory and space plasmas and his continuing contribution of new ideas, including: the theories of geomagnetic pulsations, Alfvén wave heating, fishbone oscillations, the formulation of the nonlinear gyrokinetic equations and fundamental contributions to drift wave instabilities and turbulence*".

The full laudation for the 2008 prize reads: *"Professor Liu Chen is awarded the 2008 Hannes Alfvén prize for his many seminal works on Alfvén wave physics in both laboratory and space plasmas, for his continuing contribution of new ideas which fostered creativity and promoted cross-fertilization in both these areas of research, and for his fundamental contributions in educating a new generation of researchers for which he is an example to emulate.*

Space plasma physics is the research field from where the outstanding career of Professor Chen started, then continuing with a metaphoric journey that brought him to develop his interest in magnetic fusion physics. Among his most significant scientific productions are the discoveries of kinetic Alfvén waves, toroidal Alfvén eigenmodes, and energetic particle modes; the theories of geomagnetic pulsations, Alfvén wave heating, and fishbone oscillations; the first formulation of the nonlinear gyrokinetic equations; and fundamental contributions to drift wave instabilities and turbulence.

Professor Chen is broadly acknowledged as one of the "fathers" of the physics foundations of burning plasmas, which are magnetically confined in toroidal systems. His pioneering research on fundamental aspects of burning plasma physics research is of crucial importance for problems to be investigated in the next couple of decades by ITER and its accompanying program. In this respect, Professor Chen can be considered to be among the handful of scientists who established the foundations for the understanding of the challenging new physics which will be the key to solving the controlled thermonuclear fusion problems and will eventually shed light onto the path to the first thermonuclear reactor.

The fact that many of Professor Chen fundamental contributions are in the area of Alfvén waves, of which he is one of the greatest experts worldwide, and for which he receives the prize named after Hannes Alfvén

▲ Dr Beatrice Annatarone presenting her research experience leading to the first EPS Plasma Physics Innovation Prize
▶ Dr Brendan Dromey receiving his PhD Research Award certificate from Dr Wolfgang Suttrop during the conference opening ceremony.

himself, is an appropriate demonstration that plasma physics in general, and fusion physics in particular, are still extremely lively and intellectually challenging research areas of both practical importance and rich in fascinating fundamental physics problems, which await solution by the new generation of researchers in plasma physics."

A new "Plasma Physics Innovation Prize"

Last year, the Divisional Board decided that the Division should create a plasma innovation award, to underline the importance of spin-offs of basic research in Plasma Physics into applications which have, or could have, significant industrial importance. A decision was made to award the *"2008 Plasma Physics Innovation Prize"*, jointly, to **Prof. John Allen** and **Dr. Beatrice Annatarone** *"…for their invention of a plasma heating scheme used in an RF plasma reactor, where the plasma heating is implemented using the plasma series resonance. This heating scheme is now used by several industrial companies since the concept presents many advantages. Extensive experimental and theoretical work led to the design and production of a material processing reactor, with single or dual frequencies, to produce denser plasma at low pressures. Such applications are strongly involved in many steps in the fabrication of a high performance commercial processor chip, which all depend on plasma processes.It is clear that this novel improvement has a very large impact on several industrial components."*

PhD Research Award

The traditional Plasma Physics Division PhD Research Award was judged by a committee comprising Daan Schram, Peter Mulser and Jan Weiland, who examined all the candidatures in a process managed by Wolfgang Suttrop. The jury nominated 3 award winners from an impressively high quality of candidates and the 2008 PhD Research Awards were presented to: **Dr Louise Willingale**, (Imperial College, London) for her thesis entitled *"Ion Acceleration from High Intensity Laser Plasma Interactions: Measurements and Applications"*, **Dr Ivo Classen** (TU Eindhoven) for his thesis entitled *"Imaging and Control of Magnetic Islands in Tokamaks"* and **Dr Brendan Dromey** (Queen's University, Belfast) for his thesis **"***Bright Soft X-ray Harmonic Radiation***"**. Besides receiving a modest financial reward, the recipients all made an oral presentation to the conference.

Itoh turbulence prize

Professor Sanae Itoh from Kyushu University continued to sponsor her *"Itoh Project Prize in Plasma Turbulence"*. The 2008 prize was awarded to **Dr S. Oldenbürger** (U. Nancy, France) for her thesis entitled *"Investigation of cross-field transport in a linear magnetised plasma"*. This award offers a trip to visit research groups at Kyushu, Japan. **Dr N. Ben Ayed** and **Dr S. Perri** were highly commended by the jury. In presenting this award, Professor Itoh combines her convictions of the need of international understanding in our field, and the great importance of understanding turbulence in magnetized plasmas.

PhD student poster awards

The Institute of Physics once again encouraged young physicists with the IOP Poster Prize. Yasmin McGlashan, Publisher of the journal *"Plasma Physics and Controlled Fusion"* presented the awards this year to 4 candidates: **Alessandro Biancalani** (U. Pisa, Italy), **Jan Psikal** (Czech TU, Prague), **Mierk Schwabe** (Max Planck Institute for Extraterrestrial Physics, Garching) and **Bogdan Teaca** (Brussels Free University, Belgium).

Last words

Jo Lister bowed out after 4 years as chairman of the EPS Plasma Physics Division. He underlined his belief that combining the previously more or less separated conferences on inertial fusion and beam plasma interactions with the larger conference on magnetised plasmas has now been widely accepted, and he played tribute to all those actors who have helped these communities to converge. He drew attention to the privilege of working with hundreds of people who have given their primary resource, namely their time, to the EPS Plasma Physics conferences over the last four years. Jo wished Dr Carlos Hidalgo (CIEMAT, Madrid) an enjoyable period as his successor as the Chairman of this lively Division. ■

Jo Lister,
(CRPP-EPFL, Lausanne),
chairman of the Plasma Physics Division

ICWIP-2008

Report on the Third International Conference on Women in Physics, 2008, Seoul (Korea)

Dr. Ana Proykova, Professor at the Sofia University (Bulgaria) and Dr. Angela Di Virgilio of INFN, Pisa (Italy), both members of the Executive Committee of the European Physical Society, recently returned from Seoul, Korea. They attended the Third International Conference on Women in Physics (ICWIP2008), which registered over 330 scientists from nearly 70 countries from all corners of the world. Delegates came from African, Asian, European, Latin American, North American, and island nations.

ICWIP2008 registered over **330 scientists** from nearly **70 countries** from all corners of the world

The meeting, held from 7 to 10 October was dedicated to celebrating the physics achievements of women throughout the world, networking toward new international collaborations, gaining skills for career success, and aiding the formation of active regional working groups to advance women in physics. Each country presented information about its statistics and its activities to increase women's participation.

Dr. Stoitchkova, a Bulgarian delegate who is the first year Assistant Professor at the Sofia University said *"Attending this conference has been hugely inspiring to me. I met so many women physicists who are incredibly successful. I am excited to follow in their footsteps. My research area – biophysics - is so important for helping society in fighting cancer and other diseases of the contemporary world"*.

Ana Proykova: *"The opportunity to network with potential colleagues has been valuable to me. It was exciting to learn from all the countries at the conference, and to see so many bright young physicists—both women and men—who are passionate about their research and committed to attracting girls to physics and advancing women"*.

A male-delegate from South Africa said *"I have never been at a physics conference with so many women. I learned a lot and will be helping make physics friendlier for women, because we need their ideas for the field, the country, and the world to thrive"*.

Worldwide fewer than 15% of physicists are women. More than 80% of the conference attendees were women. It was clear that the scarcity of women in physics, especially in leadership positions, is a problem for many countries. They cannot benefit fully from women's ideas and approaches to improve their economic competitiveness or solve difficult problems, such as energy, health, and global sustainability.

Women, men, institutions, and governments need to work together to encourage, educate, recruit, retain, advance, and promote more girls and women in physics and other science and technology professions. To that end, the conference participants unanimously approved a resolution presented at the 26th General Assembly International Union of Pure and Applied Physics in Tsukuba Japan on 15 October 2008.

Dr. Youngah Park, a physicist who chairs the conference organizing committee, was recently elected to the Korean National Assembly from her district. She told the assembled participants, *"I believe the positive effect of ICWIP2008 will go beyond the physics community and will have a strong effect on women leaders in all fields of science and technology"*.

The First International Conference on Women in Physics was held in Paris in 2002. The Second conference was hosted by Rio de Janeiro in 2005. Since the first conference most countries have made some progress in attracting girls to physics, increasing the proportion of physics degrees to women, and promoting women physicists. However, the proportion of physicists who are women is well below 20% in nearly all countries—too few to have maximum benefit for society. ■

▼ The attendees to ICWIP 2008 © ICWIP

Ana Proykova and **Angela Di Virgilio**

For more information:
anap@phys.uni-sofia.bg

ULYSSES ODYSSEY AND STATISTICAL PHYSICS

Report on the International Conference on Statistical and Nonlinear Physics, Kolympari (Crete), 2008

The international conference on Statistical and Nonlinear Physics took place this Summer in Kolympari at the Orthodox Academy of Crete.

This was the second edition of the so-called Sigma Phi conference (www2.polito.it/eventi/sigmaphi2008/) and the programme covered a wide range of topics from fundamental aspects of statistical physics, kinetic theory and quantum computation to applications in condensed matter, biophysics, geosciences, socio-econophysics, and networks. There were about 300 oral and poster presentations with 80 invited talks.

The conference also hosted a celebration in honour of Giorgio Parisi on the occasion of his 60th birthday. A special session was organized under the auspices of the EPS division of Statistical and Nonlinear Physics and chaired by the SNP division chairman.

A particular event took place when a chart with a text from Ulysses Odyssey was presented to the participants who were invited to sign the chart. The message of the chart is an illustration of the odyssey through the many islands visited by Ulysses as a metaphor of the many different areas where statistical physics can be applied. A copy was sent to Cyprus where the next Sigma Phi conference will take place, and the original chart is kept in Kolympari. ■

Jean-Pierre Boon, Chair of the Statistical and Nonlinear Physics Division

▼ The organizer of the conference, Giorgio Kaniadakis (right) and the SNP division chairman, Jean Pierre Boon shaking hands in front of the chart posted in the Academy of Crete.

New Secretary General at IUPAP

Bob Kirby-Harris, the chief executive officer of the Institute of Physics (UK) is the new secretary general of the International Union of Pure and Applied Physics (IUPAP).
He replaces **Judy Franz**, the chief executive officer of the American Physical Society. The financial and administrative responsibility of IUPAP passes to IOP this January. ■

PHYSICS **IN ROME**

Notes on the 22nd General Conference of the Condensed Matter Division of the EPS and the 14th General Conference of the EPS, August 2008

The 22nd General Conference of the Condensed Matter Division of the European Physical Society was held in Rome from August 25 till 29, 2008. It is the third General CMD-Conference, after those in Pisa and Baveno-Stresa, which was held in Italy. This year the forum of European Physicists, which gathered 589 participants, was organized by the Chair, Prof. **Lucia Sorba** and the Co-chairs, Prof. **Carlo Mariani** and Prof. **Eoin O'Reilly**.

As a cradle of our civilization, endowed with its heritage of Renaissance and Baroque, its history, architecture, art, culture in general, …Rome is a universal attraction pole. For us physicists the *Università di Roma La Sapienza* offered a unique meeting place in the *"Eternal City"*. The informal pictures of Enrico Fermi, Pontecorvo, Majorana, Segré …on the walls of some of the lecture halls set a most demanding standard.

Within this 22nd General Conference of the Condensed Matter Division, the 14th General Conference of the European Physical Society took place on the 27th of August 2008. EPS President F. Wagner devoted his welcome to the 40th anniversary of EPS. There was also a brief interlude with Congratulatory Messages on the occasion of the 40th anniversary of EPS.

The Symposium of the 14th General Conference of the EPS presented a very attractive program. The 2008-Europhysics Prize of the Condensed Matter Division was bestowed on **Andre Geim** and **Kostya Novoselov** (University of Manchester, U.K.). The citation reads *"for discovering and isolating a single free-standing atomic layer of carbon (graphene) and elucidating its remarkable electronic properties"*. An overview of their achievements *"Graphene: Magic of Carbon Flatland"* was presented by Andre Geim, who sketched the experimental work on graphene, especially its fascinating electronic and optical properties that are governed by relativistic-like equations. We could learn more about the stability and the dynamics of graphene in a special session. **Helmut Dosch** in his lecture *"2011 – A Nanospace Odyssey"* (which – for the first time at the General Conferences – was illustrated with 3D images) discussed challenges and trends of modern physics and emphasized the importance of the European Mega-facilities for explorations in the field of high-tech nanomaterials, which provide the building blocks of future technologies. Nobel Laureate **Klaus von Klitzing** in his truly fascinating and penetrating talk *"News from Quantum Hall Physics"* summarized the fundamental aspects of the Quantum Hall Effect (QHE) for important applications in metrology – as a resistance standard and for a novel definition of the SI basic units – and the most recent basic research on coupled QHE systems which reveal direct connections with exciton condensation and superfluidity.

The Plenary Talks at the General Conference in Rome covered a broad spectrum of cutting-edge research, in particular, on interdisciplinary topics, from the magnetic microstructure of magnetic microcrystals in bacteria to organic molecules at surfaces. In his Plenary Talk, **Albert Fert**, co-discoverer of the giant magnetoresistance effect and Nobel Laureate in 2007, gave us a brilliant overview of recent developments in the booming field of spintronics. He covered the use of magnetic switching by spin transfer for the next

generation of magnetic random access memory, the application to the emission of microwaves in the GHz range, and the trends towards hybrid systems, which associate magnetic materials with semiconductors or molecules and promise numerous applications in the fields of information technology and telecommunications. **Antoine Georges**, in his very clear Plenary Talk on ultra-cold fermions in optical lattices, analysed the analogy between the approaches and techniques used in the physics of cold atoms and the methods of condensed matter physics. An example is a recently proposed probe of quasiparticle properties of fermionic gases using stimulated Raman scattering, which is the analogue of angular-resolved photoemission spectroscopy in solids.

From a vast variety of topics addressed at the sessions on Surface, Interface and Low-Dimensional Physics, which constituted the largest part of the program, I mention: the synthesis of molecular surface structures stabilised by strong covalent intermolecular bonds in ultra-high vacuum, novel chiral switching mechanism in those molecular surface structures, efficient organic-inorganic coupling in novel hybrid materials, experimental study of surface states in self-organized nanostructured surfaces by angle-resolved-photoemission spectroscopy and scanning tunneling spectroscopy, the use of curved crystals and of nanopatterning by surface reconstruction for nanotemplates. An intriguing presentation dealt with experimental evidence for a Peierls transition, fluctuations and phase separation typical for quasi-1D correlated systems, which were found using diversified tools: variable-temperature scanning tunneling microscopy (STM), angle-resolved photoemission and low-energy electron diffraction. Among the other topics, which provoked lively debate here, were: the novel magnetic and catalytic properties of surface-supported metal-organic networks, STM-based resolving of charge states and the interface band structure of thin organic films, the new method of chiral purification of crystals using Ostwald ripening, control of the structural and optical properties of metallic nanoparticles using the influence of capping-layer effects and nanostructured surfaces as well as a striking finding that the field-induced diffusion of adsorbates to the STM tip can significantly enhance the experimental magnetic resolution.

▲ Via Panispernia boys "Enrico Fermi, with his students- , who called him "God" -, was very present in the lecture Halls of La Sapienza during CMD22".

The programme on Semiconductor Physics included attractive presentations devoted to the quantum Hall effect in bilayers and multilayers, an analysis of low-energy excitation modes in quantum Hall liquids, as well as the theoretical description of quantum transport in two-dimensional systems, including the spin Hall effect in a two-dimensional electron gas with magnetic couplings. Key themes at the 22nd General Conference CMD-EPS were nanophysics and the physics of low-dimensional systems. Among those works, which drew much attention, I mention: transport in quantum dots and in graphene studied using novel experimental techniques; an experimental demonstration of the possibility to merge THz quantum cascade lasers with microwave and telecom technologies; computer-simulation-driven understanding of the structure and functioning of self-assembled organic and organometallic nanomaterials; the construction of quantum logic gates on the basis of quantum dots using spin qubits. Fascinating structural, electronic and optical properties of 0D

▼ The organising team and the future president of the EPS. Left to right: C. Mariani (La Sapienza, co-chair), L. Cifarelli (President SIF), M. Kolwas (Vice-President EPS), L. Sorba (La Sapienza, chair), A. de Virgilio (Executive Committee EPS, Pisa) and E. O'Reilly, chair CMD, co-chair, UK)

and 1D semiconductor structures were discussed during an *ad hoc* "Invited Focus Symposium" as well as at the Semiconductor Physics sessions.

Superconductivity and Highly Correlated Systems were among the central topics of this Rome General Conference of CMD. The appealing presentations on high-T_c superconductivity and new materials with strong correlations included results related to the electronic and magnetic excitations of cuprates, the existence of two energy scales in the superconducting phase of strongly correlated systems, superconducting pairing through spin resonance, non-Fermi liquid behaviour in the 2D Hubbard model and in the periodic Anderson model. Discussions also centered around: electron-phonon effects on transport and one-particle properties of two-dimensional electron Rashba-gases; the observation of an extraordinary Hall effect at liquid helium temperature in a two-dimensional electron gas in heterostructures implanted by a rare earth using ion beams. The observation of multiple order parameters from the measured temperature dependence of the superfluid density in cuprate superconductors as well as the works on the generation of single photons in superconducting nanocircuits and the effect of hole-phonon coupling on angle-resolved photoemission spectra of high-T_c superconductors were among the topics which induced vivid discussions.

Magnetism was another key subject of the Conference. Among the topics of interest here were: the properties of magnetic tunnel junctions, a possibility to reach ferromagnetism with extremely high Curie temperature in oxides without magnetic impurities, experimental studies of current-induced domain-wall dynamics, the use of magnetic nano-particles in magnetic hyperthermia experiments aimed to evaluate possible therapies on unicellular organisms, the fabrication of novel ferromagnetic materials by the rare earth implantation, magnetic anisotropy of individual Fe and Co single atoms and clusters on a Pt surface investigated using inelastic scanning tunneling spectroscopy, the characterization of magnetic nano-particles and nano-wires, an analysis of field-induced spin mixing instabilities in antiferromagnetic molecular wheels, the magneto-capacitance effects due to the strong spin-charge-lattice coupling in transition metal oxides.

The sections Materials as well as Liquids, Disordered and Off-Equilibrium Systems provided similarly well-attended presentations. Talks which attracted good attendance, were focused on the integer quantum Hall effect and generation of terahertz radiation in graphene, electronic properties of functionalized single wall carbon nanotubes (SWCNTs), the behavior of SWCNTs during electrochemical doping, kinetics of the carbon nanotube synthesis, dynamics of quasicrystals, new results on multiferroics, mutual relation of jamming and glass transitions in amorphous solids, applications of analytical approaches and supercomputer simulations to quakes in the off-equilibrium response of aging thermal systems and the aging dynamics of 3D spin glasses, the creation of ideal foam morphologies, topological changes in liquid crystals and self-assembled vesicles, the prospects of the use of the European Synchrotron Radiation Facility to address major research areas relevant to nanosciences, life-sciences, energy, transport and environment.

The Rome-2008 General Conference of CMD-EPS offered a magnificent view of recent developments also in other fields, where the methods of Condensed Matter Physics have found potentially important and sometimes unprecedented applications. Sessions with such cross-border investigations dealt *i.a.* with Socio-Economic and Complex Systems and attracted also non-specialists. Other sessions were devoted to the three-dimensional reconstruction of starling flocks, unveiling the nature of the mutual interaction between individuals. Further examples: the usage of phone

▲ Nobel Prize laureate A. Fert during his talk

◀ Attendees in front of the Conference building

◀ General opening of the 14th General Conference of the EPS. Left to right: E. Molinari (chair "Massimo Sancrotti Award", Italy), G. Martinelli (Rector, LaSapienza), F. Wagner (President EPS, Germany), G. Ruocco (Science Faculty Head, La Sapienza) and L. Cifarelli (President SIF, Italy)

Surface, Interface and **Low-Dimensional Physics** made the **largest part** of the programme

records to construct a proxy for the network of interactions at societal level; statistical models able to account for the emergence of a shared set of linguistic conventions in a population of individuals; a synthetic market forecast on the future stock price volatility. A very attractive session was devoted to the application of innovative and powerful physical methods for the conservation and non-destructive exploration of cultural heritage, with as a beautiful example the understanding of the composition of Leonardo Da Vinci's *sfumato*.

This Rome-2008 General Conference of CMD convincingly demonstrated how recent advances, particularly in molecular biology and nanotechnology, to some extent blur the traditional boundaries between biology, chemistry, physics, engineering…. The presentations at the sessions Biological Physics & Life Sciences joined with the Polymer Physics sessions have provided numerous examples of successful applications of experimental physical methods and computer simulations in studying biological structures and various processes in them as well as in the investigation of the intricate dynamics of various polymer systems (films, polymers confined in microchannels, swollen networks, polymer melts…).

The 22nd General Conference of the CMD-EPS was dedicated to the memory of the late Co-chair **Massimo Sancrotti**. His active life and his scientific achievements were recalled by Prof. Carlo Mariani. The **Associazione Italiana di Scienza e Tecnologia** (AIV) established three Massimo Sancrotti young scientists' awards, which were presented on the last day of the conference to **Ofer Yuli** (Jerusalem) for the talk *"Enhancement of the superconducting transition temperature in $La_{2-x}Sr_xCuO_4$ bilayers: role of pairing and phase stiffness"*; **Christian Ertler** (Regensburg) for the talk *"Self-sustained magnetoelectric oscillation in magnetic double barrier structures"* and **Carlos Escudero** (Madrid) for the poster *"Non-standard dynamic scaling on Riemannian Interfaces"*. The best poster prize of the 22nd General Conference of CMD-EPS established by the EPS was given to Manuela Lunz (Dublin) for her presentation *"Theory of Förster resonant energy transfer in two dimensions applied to a mixed quantum dot monolayer"*.

Professor **Lucia Sorba**, Chair of the Rome-2008 General Conference of CMD, together with her co-chairs Prof. **Carlo Mariani**, Prof. **Eoin O'Reilly** and the local committee did a wonderful job and deserve our thanks and congratulations! The website of the conference was very precise, user-friendly and helpful. Participants were able to follow up their submissions in a convenient way. The cultural embedding of our conference in Rome helped to establish a highly creative atmosphere at the conference. The participants were very happy with the organization.

Finally, we wish our Polish colleagues, who will be organizing the next 23rd General Conference CMD-EPS in 2010, a successful continuation of the traditions of this series of General Conferences. ■

Jozef T. Devreese,
Universiteit Antwerpen (Belgium)

Acknowledgement

The author thanks professors Vladimir Fomin, Fons Brosens, Lucia Sorba, Eoin O'Reilly and Claude Sébenne for valuable discussions.

Conferences and Schools announcements

5th Optoelectronic and Photonics Winter School
A thematic school on *CMOS Photonics* organized within actions initiated by the *HELIOS European project*, will be held at Trento (Italy), 15-21 March 2009.
Website:
http://portale.unitn.it/events/cmosphotonics

European School on Magnetism
The school will be held in Timisoara (Romania), 1-10 September 2009. The session belongs to a Series organized every other year and will be dedicated to "Models in magnetism: from basics aspects to practical use".
Website:
http://esm.neel.cnrs.fr

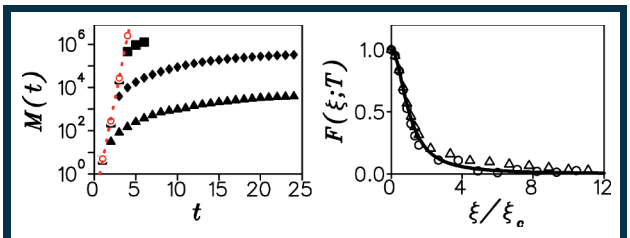
XAFS 14
The 14th X-ray Absorption Fine Structure Conference will be held in Camerino (Italy), 26-31 July 2009.
Website:
http://www.xafs14.it

How well a **chaotic quantum system** can retain memory of its initial state?

It is well known that unrestricted exponentially fast structuring of the phase space distribution and exponential sensitivity of classical chaotic dynamics to any weak external perturbation result in rapid loss of memory of the initial distribution and, as a consequence, to practical irreversibility of the chaotic classical motion. On the contrary, the degree of structuring of the quantum Wigner function is restricted by the quantization of the phase space. It is of great importance from the general scientific as well as practical (having, in particular, in mind the problem of quantum computing) points of view to ascertain how this fact influences stability and reversibility of quantum dynamics of classically chaotic systems.

Using the number M(t) of Fourier harmonics of the Wigner function as a measure of complexity of the quantum state, we have shown that this number grows beyond the semi-classical domain not faster than linearly, Fig. (left). It is in striking contrast with the classical dynamics, where the number of harmonics of the phase space distribution growths exponentially. We then established a quantitative connection between complexity of the quantum Wigner function and the degree of reversibility of the quantum dynamics of classically chaotic systems. This degree remains, contrary to the case of the classical dynamics, high enough (see Fig. (right)) as long as the intensity ζ of an external perturbation applied at some arbitrarily chosen reversal time T does not exceed some critical value $\zeta_c(T) = 2\,[M(T)]^{-1/2}$ determined by the number of harmonics developed by this time during the forward evolution. Thus the relatively strong stability of quantum evolution discovered before in numerical simulations gains a quantitative analytical treatment. ■

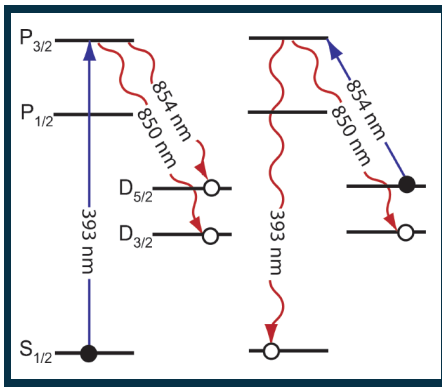
V.V. Sokolov and **O.V. Zhirov**,
'How well a chaotic quantum system can retain memory of its initial state?', *Eur. Phys. Lett.* **84**, 30001 (2008).



▲ Left: the number M(t) versus time: exponential in classical chaos (red circles), and linear in quantum case (closed points); right: the power-like decay of the overlap of the initial and reversed quantum states (Peres fidelity) against the ratio ζ/ζ_c

Precision measurement of decay branching fractions in Ca II

Absorption and emission lines of low lying dipole transitions in Ca^+ have been used in many astrophysical observations, such as of galaxies, interstellar clouds and dust disks surrounding stars. For a proper interpretation and modelling of these observations, an accurate knowledge of transition frequencies and oscillator strengths is required. On the theoretical side considerable effort is devoted to precise structure calculations of singly charged alkali earth ions such as Ca^+. For comparison to theory precise measurements of branching ratios and lifetimes are needed.



◄ Level scheme of Ca^+ showing part of the pumping scheme employed. The $4P_{3/2}$ level can decay to $4S_{1/2}$, $3D_{5/2}$ and $3D_{3/2}$ with measured branching fractions: 0.9347(3), 0.0587(2) and 0.00661(4).

In laboratory experiments, Ca^+ is studied for a physical implementation of quantum information processing and the construction of optical atomic clocks. In these experiments, single Ca^+ ions are trapped and manipulated routinely. However, precision measurements of lifetimes and branching ratios in literature are often based on experiments in ion beams or trapped clouds of ions.

This paper reports on precision measurements of the branching fractions of the $4P_{3/2}$ decay in a single trapped Ca^+ ion. The use of a single ion allows for high fidelity state preparation and detection while eliminating errors due to depolarizing collisions. The precision is further improved by a new technique based on repetitive pumping to the $4P_{3/2}$ state. The branching fractions are determined with sub-percent precision and a forty-fold improvement with respect to previously known values. These experiments demonstrate that single trapped ions are perfectly suited for precision measurements of branching fractions. ■

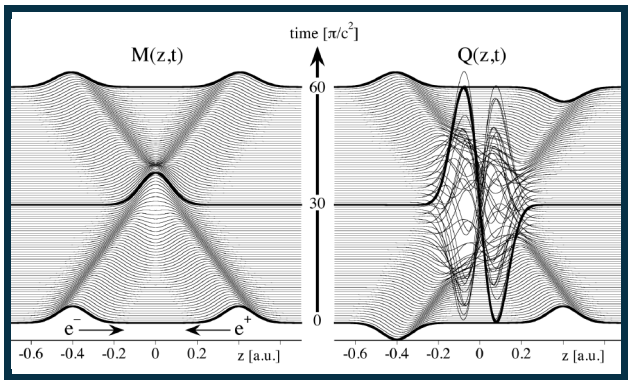
R. Gerritsma, **G. Kirchmair**, **F. Zähringer**, **J. Benhelm**, **R. Blatt** and **C. F. Roos**,
"Precision measurement of the branching fractions of the $4p^2P_{3/2}$ decay of Ca II", *Eur. Phys. J. D* **50**,13 (2008)

Vacuum-induced **high-frequency oscillations** in the charge density

In classical electrodynamics the total charge density of two colliding particles is normally given by the simple sum of the individual densities associated with each particle. This intuitive view changes in quantum field theory, where the presence of the matter vacuum can lead to high-frequency oscillations in the resulting charge density. Numerical solutions to the time-dependent Dirac equation for the electron-positron field operator predict violent oscillations (of the order of 10^{-21} sec) if a two-particle state of an electron and positron is in a superposition with the vacuum. In contrast to the usual quantum mechanical interference effect for two indistinguishable particles, the amplitude of these oscillations can exceed the individual amplitude of each particle by arbitrary factors. Consequently, one cannot simply view the total charge density of two particles as the sum of the individual densities in situations where the electrons and the positrons were spontaneously created from the vacuum but the vacuum has not yet decayed completely.

Historically, fast time scale oscillations of the order of $(2mc^2)^{-1}$ have been associated with the term Zitterbewegung. However, the position of a free electron does not jitter. Unphysical oscillations in the expectation value of the electron's position operator point to a misuse of the single-particle interpretation of the Dirac equation for those situations where the multi-particle framework of quantum field theory is required. The Zitterbewegung-like charge oscillations in the electron-positron-vacuum superposition are consistent with quantum field theory. ■

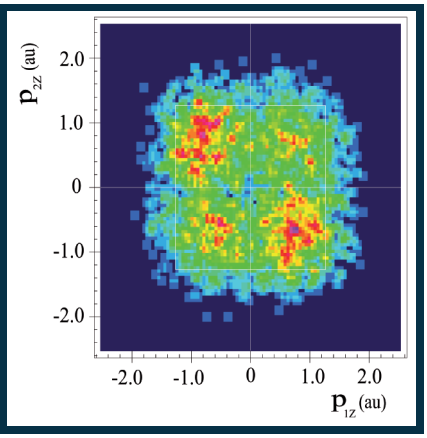
T. Cheng, C.C. Gerry, Q. Su and **R. Grobe**, "Vacuum induced oscillations in the charge density of distinguishable fermions", *EPL* **84**, 50004 (2008)



▲ Space-time evolution of the quantum field theoretical mass density M(z,t) (left) and the total charge density Q(z,t) (right) for an electron (moving to the right) and passing through the positron (moving to the left).

Anticorrelated electrons from **weak recollisions** in non-sequential double ionization

Non-Sequential Double Ionization is accepted to occur primarily through recollision, where the oscillating laser field ionizes one electron but then impels it back to the core, where energy can be shared through collision. Recent experiments by Liu *et al.* [*Phys. Rev. Lett.* **101**, 053001 (2008)] in J. Ullrich's lab at the Max Planck Institute in Heidelberg revealed that for conditions in which the maximum energy of the returning electron is well below that needed for direct ionization of a second electron, doubly ionized electron pairs were more likely to be detected on **opposite** sides of the nucleus (*i.e.*, $p_{1z}p_{2z}<0$, where p denotes final momentum and z the laser polarization axis).



► Final momentum along the laser polarization axis for one electron vs the other. Significant populations in quadrants 2 and 4 indicate a net anticorrelation in electron direction. From Haan et al.

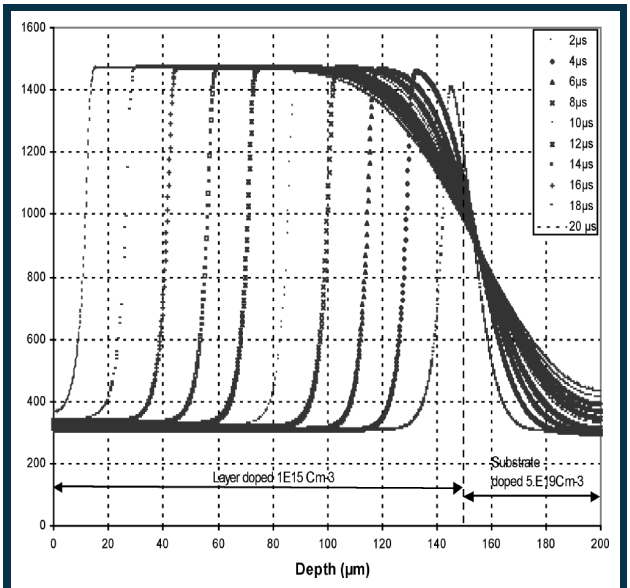
The theory group of Haan *et al.* [2], employed a 3D fully classical two-electron model for below-threshold conditions, and also found a majority of oppositely directed electrons. They found that most often the final recollision—there could be more than one—resulted in a doubly excited state in which the electrons had unequal energies. The more energetic electron would usually ionize fairly early during the first barrier suppression after collision, the other slightly later. If the second electron ionized too late in the first suppression, the laser could push it back into the opposite direction. The second electron would also drift opposite from the first if it ionized early during the second suppression after recollision. These two scenarios were sufficient to give the electrons a net anticorrelation. ■

S.L. Haan, Z.S. Smith, K.N. Shomsky and **P.W. Plantinga**, 'Anticorrelated electrons from weak recollisions in nonsequential double ionization', *J. Phys. B: At. Mol. Opt. Phys.* **41**, 211002 (2008)

Theory of laser **heating of thick layers**

In this paper we investigate theoretically a mode of heating thick layers using a laser beam where the temperature of the layer propagates in a steady-state self sustained fashion from the bottom of the layer towards the surface and may exhibit a very steep front. The propagation of the thermal front happens at a constant speed, related to the intensity of the power flux. To achieve this heating mode the absorption coefficient of the layer has to remain low at low temperatures and to increase rapidly as a function of temperature at higher temperatures. Additionally, a significant temperature increase must be generated to trigger this propagation mode, for example through the presence of a strongly absorbing layer beneath the transparent layer. The mode is well suited to semiconductors, especially silicon . The theoretical approach is confirmed by a simulation in the case of a low doped silicon layer 150 µm thick above a highly doped substrate ; the low doped silicon is heated homogeneously at 1476 K by a 2 10^6 W/cm^2 CO_2 laser beam throughought the entire thickness in a timescale of 20 µs. Examples of applications are proposed. ■

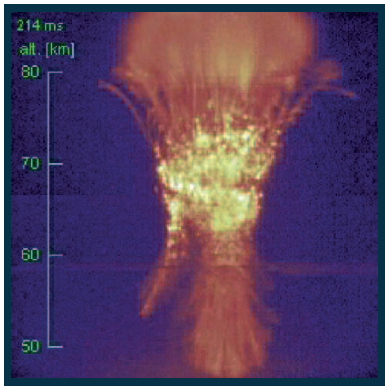
Michel Bruel,
'Laser heating of thick layers through a backwards, self-sustained propagation of a steep, steady state thermal front', *Eur. Phys. J. Appl. Phys.* **45**, 10304 (2009)



▲ Numerical simulation of the evolution of the temperature profile of the structure defined in the summary by a laser flux of 2 10^6 W/cm at the wavelength of 10.6 µm. The profile is represented at time intervals of 2 µs.

High time-resolution sprite imaging

Sprites are optical emissions high above thunderstorm activity triggered by lightening strikes in the clouds below. They typically only last for a few tens of ms, which makes them very difficult to observe visually. The figure shows a big sprite recorded at 1000 frames per second and the altitude scale indicates the size. The colors have been added for emphasis. But even



◀ The upward going streamers tend to end in a diffuse top as also seen here

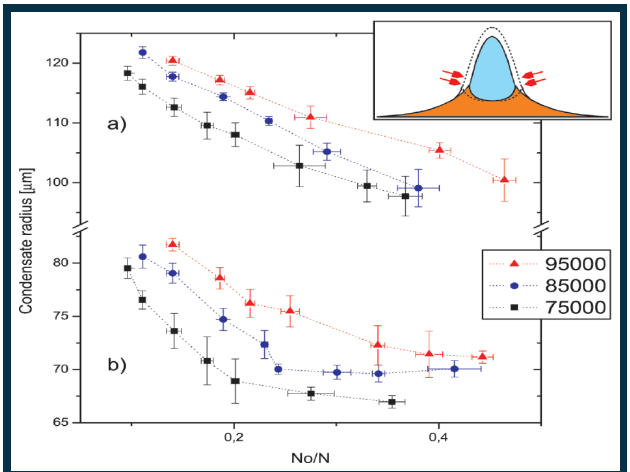
ms time resolution does not resolve the temporal development. Actually, the long strands of luminosity going up and down from the central bright structures around 70 km altitude are formed by small, but very bright, and rapidly propagating streamer heads. A paper published in *J. Phys D: Appl. Phys* in November 2008 presents a review of images and analysis of recordings made at 10,000 fps over the last 3 years. The streamer heads revealed in the images appear to be small, 100 m or less, but they can be brighter in the images than planet Venus. They also move very fast; up to half the speed of light, creating the tendril structures in the figure reaching down to 45 km altitude. In other examples they reach down to the cloud tops. The upward going streamers tend to end in a diffuse top as also seen in the figure. The streamer development appears similar to laboratory discharges; in fact, when scaled for atmospheric density the sprite and laboratory imagery appear similar. This indicates that the large laboratory based literature can be applied to sprite research, and conversely, sprite observations can be evaluated as vacuum lab discharges, but without detrimental laboratory wall effects. The volume affected by the sprites can be large (~10,000 km^3 in the case of figure 1), but it is still uncertain if the chemistry plays a role in the larger atmospheric system. If so this may have 'Global Change' implications. ■

H.C. Stenbaek-Nielsen and **M.G. McHarg**,
'High time-resolution sprite imaging: observations and implications', *J. Phys. D: Appl. Phys.* **41**, 234009 (2008)

How does BEC mix **with thermal atoms?**

At low but finite temperatures, free expansion of a diluted Bose–Einstein condensed gas results in a spatial separation of the thermal and condensed phases. So far, most of experiments on the condensed gases concentrated on samples with a large number of atoms at very low temperatures (Thomas–Fermi, TF) regime. Close to T_C, however, the number of atoms in the condensate fraction is small and so is the condensate internal energy as compared to its kinetic energy. The effective potential of the collisional self-interaction vanishes and the TF approach does not properly describe the Bose–Einstein condensate. Consequently, the condensate dynamics departs from the familiar hydrodynamic behaviour of TF condensates. The measurements performed in the Polish National AMOP Laboratory (KL FAMO) show that the behaviour of the condensate part depends on both the number of condensed atoms and its interactions with thermal atoms. They also prove that the thermal cloud compresses the BEC. At equilibrium, the shell of thermal atoms surrounding the condensate in a trap exerts a force towards the trap centre, thereby compressing the BEC. In free fall this compression results in a faster expansion in all directions, which is well evidenced by the condensate radii dependence on the condensate fraction. ■

M. Zawada, R. Abdoul, J. Chwedeńczuk, R. Gartman, J. Szczepkowski, L. Tracewski, M. Witkowski and **W. Gawlik**, 'Free-fall expansion of finite-temperature Bose–Einstein condensed gas in the non-Thomas–Fermi regime', *J. Phys. B: At. Mol. Opt. Phys.* **41**, 241001 (2008)



▲ The radial and axial radii of the condensate versus the condensate fraction (N_0/N) with constant number of atoms in the condensate phase, N_0) for N_0 = 75000, 85000 and 95000 atoms. Inset illustrates the compression effect with the spatial distributions of the thermal shell (orange) and BEC (blue).

Leibinger Research Prize 08* **to Pr. Xiaolang Sunney Xie**

[PRESS RELEASE]

One of the world's leading researchers in molecular imaging and single-molecule dynamics at Harvard's Department of Chemistry and Chemical Biology, Professor **Xiaoliang Sunney Xie** has been selected to receive the prestigious Berthold Leibinger Zukunftspreis for outstanding research milestones in applied laser technology.

Professor **Xiaoliang Sunney Xie** is one of the founding fathers of single-molecule biophysical chemistry, specifically single-molecule enzymology. For his valuable contributions to high-resolution optical imaging techniques, Xie has been selected to receive the Berthold Leibinger Zukunftspreis for outstanding research in applied laser technology. Jury member Professor **Theodor Hänsch** at an award ceremony in Ditzingen, Germany has presented the prize to Xie on September 15, 2008. Worth 20,000 euro, the prize is being awarded for the second time. The first recipient was Professor Jeffrey H. Kimble of Caltech, in 2006, for his work on Cavity Quantum Electrodynamics.

A recent success of the Xie group at Harvard's Department of Chemistry and Chemical Biology is a real-time molecule-by-molecule movie of protein production in live cells. The direct observation of single fluorescent molecules in single cells is of great importance in probing gene expression. This generation of proteins according to the genetic codes in DNA is a core process of live regulation in cells. A better understanding of this process will enable scientists to develop new strategies to fight against many diseases. Sunney Xie is also well known for his development work on CARS (coherent anti-Stokes Raman Scattering) microscopy. Due to his relentless efforts, CARS microscopy has become one of the most important developments in light microscopy. Xie not only first recognized the full potential of CARS in biological imaging, but eliminated most of its technical challenges as well. Unlike fluorescence microscopy, CARS can be used when the observed material cannot be tagged with or is intolerant of fluorescent markers. Xie's team has demonstrated the use of CARS microscopy to identify tumors and monitor metabolism. ■

source: **www.leibinger-stiftung.de**

* The Berthold Leibinger Zukunftspreis is an international research prize awarded biennially by the German non-profit foundation Berthold Leibinger Stiftung. Together with the Berthold Leibinger Innovationspreis awarded biennially since the year 2000, these prizes support research and innovations on laser sources and the applications of laser light. An international jury of laser experts, medical doctors and former business executives selects the prizewinners.

THE CRITICAL CASIMIR EFFECT

UNIVERSAL FLUCTUATION-INDUCED FORCES AT WORK

A. Gambassi [1,2], C. Hertlein [3], L. Helden [3], S. Dietrich [1,2], and C. Bechinger [1,3]

DOI: 10.1051/epn/2009301

▲ The demixing of water and the solvent 2,6-lutidine (seen here in false colours), is Hertlein and colleagues' laboratory for measuring the critical Casimir force. © C. Hertlein *et al.*

It is well known that nothing comes from nothing. In physics, however, this is not always the case. Surprisingly indeed, two electrically neutral conducting metallic plates placed in vacuum about half a micrometer apart attract each other, even at zero temperature, due to a force which was theoretically predicted in 1948 by the Dutch physicist Hendrik Casimir [1]. This force originates from the quantum mechanical fluctuations of the electromagnetic field in vacuum - so, apparently, from nothing.

In the absence of the plates, these fluctuations are the same everywhere. But if the plates are introduced, a distance L apart, the fluctuation modes need to have a node at the plate surfaces, so that only waves with wavelength $\lambda=nL/2$ and integer n are permitted in the gap between the plates. Outside, instead, there is no such restriction. As a consequence the total field outside the gap produces a pressure on the plates which is higher than the one produced from inside, so the surfaces are pushed together by a force F. The force per unita area A of the plates takes the form

$$\frac{F}{A}=-\frac{\pi^2}{240}\frac{\hbar c}{L^4} \qquad (1)$$

for distances L large compared to a characteristic microscopic length $L_c \approx c/\omega_p$. The value of L_c is roughly set by the material-dependent frequency ω_p above which the actual metal is no longer conducting ($L_c \approx 0.1\mu$m for copper).

The asymptotic expression of this long-ranged force has a universal character in that it depends only on the speed of light c and on Planck's constant $\hbar$ but not on the material properties of the plates which determine only the actual value of L_c. The absence in Eq. (1) of such material parameters, which might be sources of experimental uncertainties, makes its experimental verification a particularly stringent test.

The first attempts to verify Casimir's prediction date back to 1958, but a sufficiently accurate measurement of F at the micrometer scale has been accomplished first only in 1997 [2] due to the relative weakness of the force: Two plates of area A=1mm^2 at a distance L=1μm attract each other with a force of 10^{-9}N. Nonetheless, this effect is responsible for the stiction (static friction) occurring in currently available microelectromechanical systems (MEMS), in which different device parts cling together, hampering their functioning [3].

Casimir, in collaboration with D. Polder, actually had already derived Eq.(1) by showing that the interaction potential $V(R)$ between two neutral atoms at a distance R, due to their fluctuating electric dipole moments, is affected by the finite speed of light c (retardation). As a result $V(R)$ changes from the London-van der Waals behaviour $1/R^6$ to $1/R^7$ as R increases. Equation (1) actually reflects this asymptotic behavior for large R. Surprised by the fact that the final result of their lengthy calculation for $V(R)$ was so simple in the limit $R\rightarrow\infty$, Casimir (following a suggestion by Niels Bohr) looked for a simpler derivation focussed on

affiliations

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vacuum fluctuations. This kind of focus has far-reaching consequences when carried over to cases in which fluctuations of a different nature occur. Casimir's line of argument, indeed, does not rely on the fact that the fluctuating quantity is actually the electromagnetic field of the vacuum and that its fuctuations are of *quantum* nature. What really matters is the presence of any such a quantity and a mechanism by which physical boundaries modify the spectrum of its allowed fluctuations, so that the corresponding total free energy depends on the distance between the boundaries. Due to this dependence, as Casimir pointed out, the boundaries experience an effective, fluctuation-induced force. These basic requirements are so modest that indeed one encounters such kind of fluctuation-induced forces in a wide range of circumstances, well beyond the context of quantum electrodynamics, ranging from cosmology to statistical physics, making the subject really fascinating (see, *e.g.*, Ref. [4]).

Thermal fluctuations at work: the critical Casimir effect

In the following we focus on *thermal* fluctuations which occur in statistical physics, in particular close to continuous phase transitions where their effects are particularly pronounced, such that their confinement leads – in analogy to the Casimir force – to the so-called critical Casimir effect.

In statistical physics fluctuations are due to the thermal motion of atoms and molecules. Therefore they typically occur on a molecular scale ξ_0.

Consider the case of a liquid which is kept at room temperature T. If one sets out to measure its density from a sample of volume 1 mm^3 there is no chance to detect appreciable fluctuations around its average. In order to observe such fluctuations one has to decrease the volume to a few nm^3, corresponding to the typical spatial linear scale ξ_0 at which fluctuation of the density of a fluid occur under normal conditions.

All fluctuation effects, including possible Casimir-like forces, are relevant at this scale and disappear at larger ones. In addition, one cannot expect these forces to be characterized by universal laws such as the one derived by Casimir, because the physical phenomena at the molecular scale are dominated by the specific microscopic details of the fluid.

There are instances, however, in which the fluctuations become relevant and detectable even at scales ξ much larger than the molecular ones, *i.e.*, $\xi \gg \xi_0$.

This emerges upon approaching a second-order phase transition point (also called *critical point*, located at specific values T_c and P_c of temperature and pressure, respectively) which is characterized by the fact that due to the emerging collective behavior of the molecules, fluctuations in the density are correlated across the so-called *correlation length* ξ which increases with a power law for $T \to T_c$. At scales large compared with ξ_0 the resulting physical behavior of the system turns out to be largely independent of its microscopic details (giving rise to the concept of "*universality*"). In a certain sense, a critical point acts as a magnifying glass for the fluctations which occur in any case at the molecular scale. Critical points are present in the phase diagrams of a wide variety of microscopically different systems, ranging from classical and quantum fluids (for example ^{4}He close to the superfluid transition) to nuclear matter. In each case the relevant quantity – called *"order parameter"* –, the thermal fluctuations of which are magnified upon approaching the critical point, has a different physical nature but plays the same role in determining the free energy density of the system.

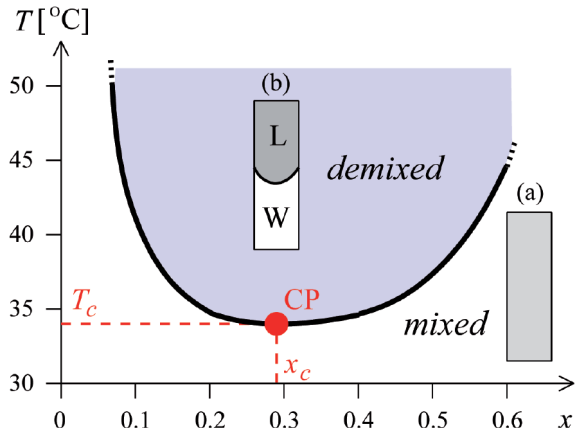

FIG. 1: Schematic phase diagram of the liquid mixture of water with the oily liquid 2,6-lutidine (dimethylpyridine, C_7H_9N). At ambient pressure, the relevant thermodynamic variables are the temperature T and the mass fraction x of lutidine in the mixure. The schematic side view of a vertical test tube filled with the binary liquid mixture is shown by (a) and (b). In (b) W and L indicate the water- and the lutidine-rich phase, respectively.

The effective force resulting from the confinement of the fluctuations of the order parameter is called *"critical Casimir force"* [5] and was first discussed in 1978 by Michael Fisher and the late Pierre-Gilles de Gennes in their study of the behavior of a binary liquid mixture made up of two components and confined between two plates [6]. (An independent field-theoretical analysis was carried out by Symanzik [7].)

The phase diagram of a binary liquid mixture, for example water and lutidine (a clear oily substance), is depicted in Fig.1: For a fixed lutidine mass fraction x, the mixture forms a mixed solution at low temperatures (as indicated by the inset (a)), whereas it separates into a water-rich (W) and a lutidine-rich (L) phase if the solution is heated above the transition line (inset (b)).

At the critical point $T_c \cong 34$°C and $x_c \cong 0.286$ (CP in Fig.1), the two phases do not form abruptly, like water solidifying into ice. Instead, at the critical concentration and below the critical temperature, fluctuating areas form in the mixture which contain more water or more lutidine. The closer the temperature gets to the critical point, the

larger these fluctuating areas grow and the longer they remain intact. Actually, the typical size of these correlated fluctuation diverges as $\xi \approx \xi_0 |1-T/T_c|^{-\nu}$, where $\nu \cong 0.63$ characterizes the type of critical point. The order parameter for this mixture is the difference between the local concentration of water and lutidine compared with their average values and therefore it increasingly fluctuates upon approaching the critical point.

If two plates at close distance are introduced in the mixture, analogously to the quantum Casimir effect, each of them sets boundary conditions by preferring to be in contact with one of the two components of the binary mixture. The corresponding boundary conditions are referred to as (++)(or (−−)) if the two plates prefer the same component of the mixture and (+−)(or (−+)) if they have opposite preferences.

The resulting critical Casimir force F on the plates of area A, a distance L apart, is theoretically expected to be largely independent of the microscopic details of the fluctuating medium and of the boundary conditions. Indeed, for $\xi, L \gg \xi_0$ it takes the form

$$\frac{F}{A} = \frac{k_B T}{L^3} \Theta(L/\xi) \qquad (2)$$

where k_B is Boltzmann's constant and $k_B T$ the thermal energy. In contrast to the quantum Casimir effect, the range of the force F is now set by the correlation length ξ of the critical fluctuations, which can be controlled by the temperature T. The function $\Theta(u)$ is *universal* in that it depends only on certain gross features of the critical behavior of the system and on the kind of boundary conditions imposed by the plates on the order parameter, *i.e.*, (++) or (+−) for a binary liquid mixture of classical fluids. Most of the details about the molecular structure of the fluid and its microscopic interactions with the atoms constituting the plates are of no importance in determining F as long as the correlation length ξ and the distance L are much larger than the microscopic length scales of the system.

The force we have measured can be easily turned from attractive to repulsive by suitable surface treatments

This universality allows one to determine the function $\Theta(u)$ by studying a slab of the Ising model with surface fields. For the type of fluid under consideration such a study has been recently carried out via Monte Carlo simulations [8]. It turns out that the force F can be made repulsive by changing the boundary conditions from (++) to (+−). Such a possibility is still debated for the quantum Casimir force. A rough estimate of F reveals that at room temperature, for two plates with A=1mm² and at a distance L=1μm, the expected force is about 10^{-9}N. Due to this weakness its experimental detection is particularly difficult. Indeed, only in 1999 the first indirect experimental evidence was provided by capacitance studies of wetting films of liquid ^{4}He close to the superfluid transition [9] and by X-ray studies of wetting films of a binary liquid mixture in 2005 [10]. Close to the corresponding critical points, the thicknesses of these liquid films change and this phenomenon can be succesfully explained by the occurrence of critical Casimir forces.

In order to measure directly the force acting on an object, the simplest approach is to attach to it a suitable dynamometer and then read off the result from the scale. This approach would suggest the use of the cantilever of an atomic force microscopy, capable to measure forces with pico-Newton resolution (1 pN = 10^{-12}N), but this turns out to be still too difficult.

The measurement of the Casimir force is actually easier if, instead of considering the force acting between two parallel plates immersed in the fluctuating medium, one considers the force acting on an immersed spherical particle of radius R when it approaches the wall of the container of the mixture. As in the previous cases both the wall and the sphere impose boundary conditions on the order parameter and as a consequence a critical Casimir force F acts on the sphere. If the distance of closest approach z between the sphere and the wall is much smaller than the radius R, the potential $\Phi_c(z)$ of the critical Casimir force takes the form

$$\frac{\Phi_c(z)}{k_B T} = \frac{R}{z} \vartheta(z/\xi) \qquad (3)$$

where the function ϑ can be expressed in terms of Θ [11] and it shares the same qualitative and universal properties. With this change in the geometrical setting the experimental challenge is to determine the force acting on the sphere. In order for the effects of F to be detectable on a sphere floating in the mixture, its magnitude has to be comparable with the typical forces at play. This suggests the use of micrometer-sized polysterene particles, *i.e.*, *colloids*.

A femto-Newton dynamometer

The sensitivity necessary to directly measure the critical Casimir force can be achieved by total internal reflection microscopy (TIRM [12], see Fig.2) which actually is capable to measure forces with femto-Newton resolution [13] (1 fN = 10^{-15}N).

A laser beam is totally reflected at the silica wall of the container of the mixture, so that an evanescent wave penetrates into the mixture with an intensity $I_{ev}(z) \propto \exp(-\kappa z)$, which decreases exponentially upon increasing the distance z from the wall, with a decay length κ^{-1}. When the colloidal particle approaches the wall with surface to

surface distance z, it scatters light off the evanescent wave and the scattered intensity is proportional to $I_{ev}(z)$. A single photon counter measures the scattered intensity $I_{sc}(z)$, from which one infers the distance $z=-\kappa^{-1}\ln[I_{sc}(z)/I_{sc}(0)]$. An optical tweezer provides the lateral force which avoids the drift of the particle out of the objectives of the microscope. The colloid is actually so small that it is sensitive to the collisions with the molecules of the fluid which cause it floating randomly in the mixture as in the celebrated Brownian motion. As a result, the distance z randomly changes in time and this is actually detected by the single photon counter which measures a randomly varying scattered intensity I_{sc} as a function of time (see Fig. 2(b)). From this signal one determines the probability distribution function $P(z)$ that characterizes the erratic motion of the particle. In thermal equilibrium $P(z)$ is given by the Boltzmann distribution associated with the total potential $\Phi(z)$ to which the particle is subjected: $P(z)\propto \exp\{-\Phi(z)/(k_BT)\}$. This theoretical relation allows one to determine the potential $\Phi(z)$ from the apparently meaningless random signal $I_{sc}(t)$ associated with the Brownian motion of the colloid.

With this technique at hand one can study the onset of critical Casimir forces on the colloid as the temperature T of the binary mixture is increased towards its critical value T_c, at fixed critical concentration $x=x_c$.

First we consider the case of an hydrophilic colloid of radius $R=1.2\mu m$ and a hydrophilic wall, corresponding to (−−) boundary conditions. (With reference to the water-lutidine mixture we indicate by "+" and "−" the preferential adsorption of lutidine and water, respectively.) Far from the critical point the measured potential $\Phi(z)$ (apart from the contribution of buoyancy and of the optical tweezer, which are subtracted from the data presented in Fig.3) is given only by the electrostatic repulsion between the colloid and the wall, as shown in Fig.3(a) for T_c-T=0.30K.

Upon heating the mixture, however, an increasingly deep potential well develops, which is due to the attractive Casimir force providing a negative contribution $\Phi_c(z)$. As expected theoretically, the spatial range ξ of this contribution increases upon increasing T. The set of measured $\Phi_c(z)$ can be compared with the corresponding theoretical prediction (Eq. (3), solid lines in Fig.3(a)), resulting in a remarkable agreement. The maximum of the attractive force measured in this case is about 600 fN.

If one exchanges the hydrophilic colloid with an hydrophobic one (of radius $R\cong 1.8\mu m$), the corresponding boundary conditions change from (−−) to (+−) and on theoretical grounds one expects repulsion. Indeed, in this case, areas rich in water form at the wall, whereas those rich in lutidine stay close to the colloid. Since it takes free energy to make contact between these water- and lutidine-rich regions, the sphere is repelled. As in the previous experiment, far below the critical point, $\Phi(z)$ consists only of the electrostatic repulsion, as in Fig.3(b) for T_c-T=0.90K. Upon heating the mixture, the repulsive part of the potential curves shifts towards larger values of z due to the fact that, as expected, repulsive Casimir forces are acting on the particle and yield a positive contribution $\Phi_c(z)$ to the total potential $\Phi(z)$. As in the case of Fig.3(a), one finds a remarkable agreement with the corresponding theoretical prediction (Eq.(3), solid lines in Fig.3(b)).

By changing the adsorption preference of the silica wall from hydrophilic (−) to hydrophobic (+) via a suitable chemical surface treatment, attraction is recovered (data not shown). In contrast to the smooth onset of the critical Casimir force, in mixtures with $x\neq x_c$ and (−−) or (++) boundary conditions one observes the abrupt formation of a potential well upon approaching the transition line. This occurs only on the side of the phase diagram where the mixture is poor in the component preferentially adsorbed by both surfaces and is due to the sudden formation of a liquid bridge which spans the space between the particle and the wall and is rich in the component preferred by the surfaces [11].

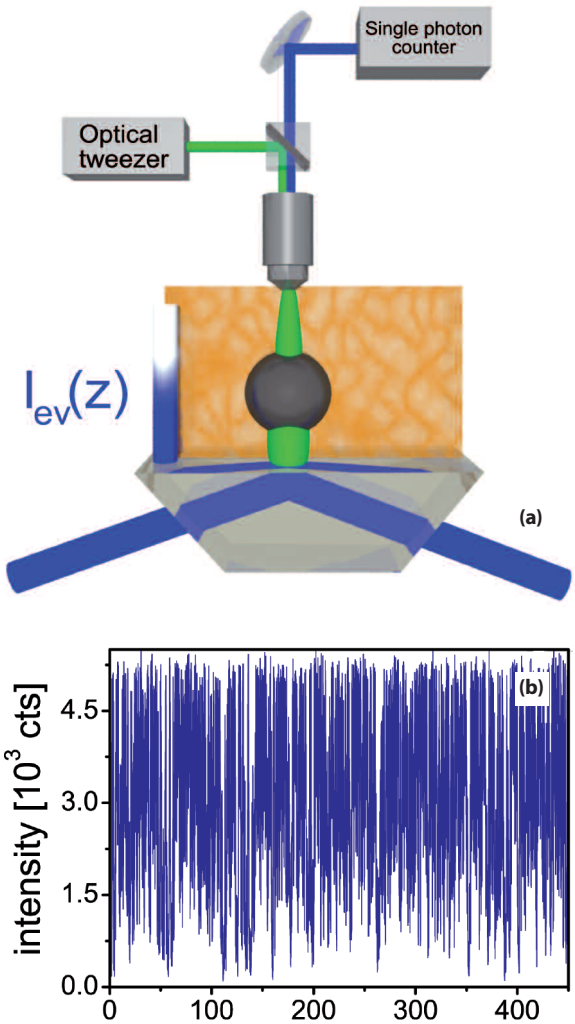

FIG. 2: The femto-Newton dynamometer. (a) Scheme of the TIRM set-up. A colloidal particle undergoes thermal motion in the evanescent field I_{ev} created by a totally reflected blue laser beam and scatters light, whose intensity $I_{sc}(z)$ is measured by a single photon counter. The lateral diffusion of the particle is prevented by a vertically incident green optical tweezer. (b) I_{sc} as a function of time, reflecting the random motion of the particle in the vertical direction. (Taken from Ref.[11].)

Concluding remarks

We have observed and measured the fluctuation-induced critical Casimir forces between a colloid and a wall [11]. Based on the general argument presented above, one expects them to act also between two or more colloidal particles immersed in a near-critical mixture, with interesting many-body phenomena due to the non-additivity of these fluctuation-induced forces. In contrast with other types of interactions which are typically acting among colloids (*e.g.*, electrostatic) the critical Casimir force exhibits a striking temperature dependence which can be exploited in order to control the phase behaviour of such particles via minute temperature changes. This fact could be used, for example, in order to control the aggregation of colloids, which is a central problem in many areas of materials science where colloidal particles dispersed in a solvent form the basis of diverse substances such as milk or paints. The force we have measured can be easily turned from attractive to repulsive by suitable surface treatments. This property might be used in order to compensate the attractive quantum mechanical Casimir force which brings MEMS to a standstill. If these machines would work not in a vacuum, but in a liquid mixture close to the critical point, the stiction could be prevented by coating the machine parts so that the critical Casimir force has a repelling effect.

Our combined experimental and theoretical approach demonstrates that the minute forces which result from random thermal fluctuations at the sub-micrometer scale can be harnessed to serve dedicated purposes. ■

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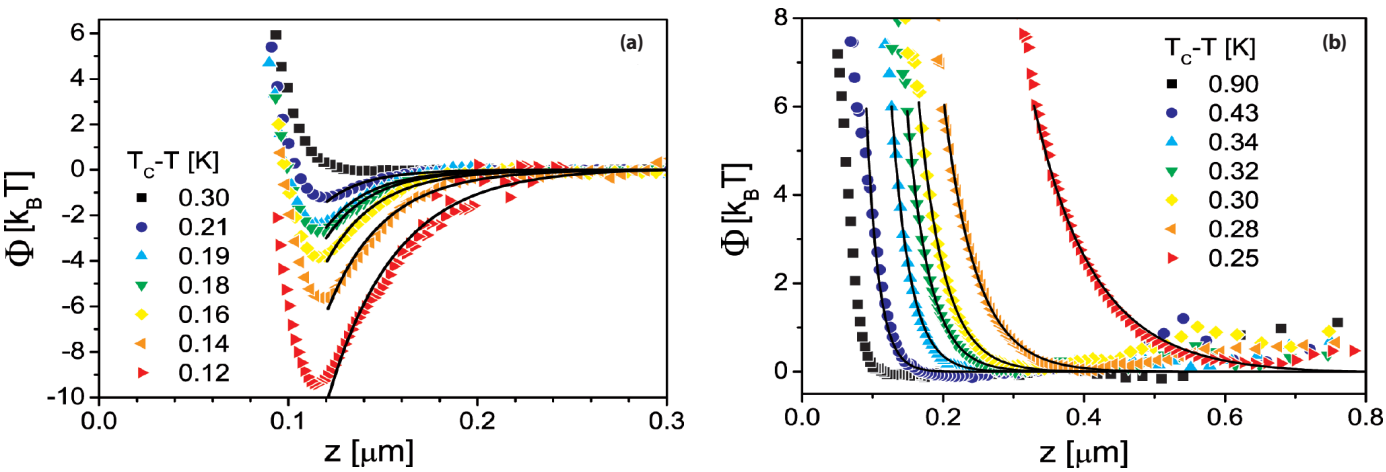

▲ **FIG. 3: Critical Casimir potentials for a colloidal particle in a water-lutidine mixture and close to an hydrophilic wall (from Ref. [11]). Upon approaching the critical point, an attractive Casimir force is observed with an hydrophilic particle ((−−) boundary conditions, (a)), whereas with an hydrophobic particle ((+−) boundary conditions, (b)) the force is repulsive. The solid lines in (a) and (b) correspond to the theoretical predictions for the Casimir potentials.**

THE MARATHON RACE TO A NEW ATOMIC KILOGRAM

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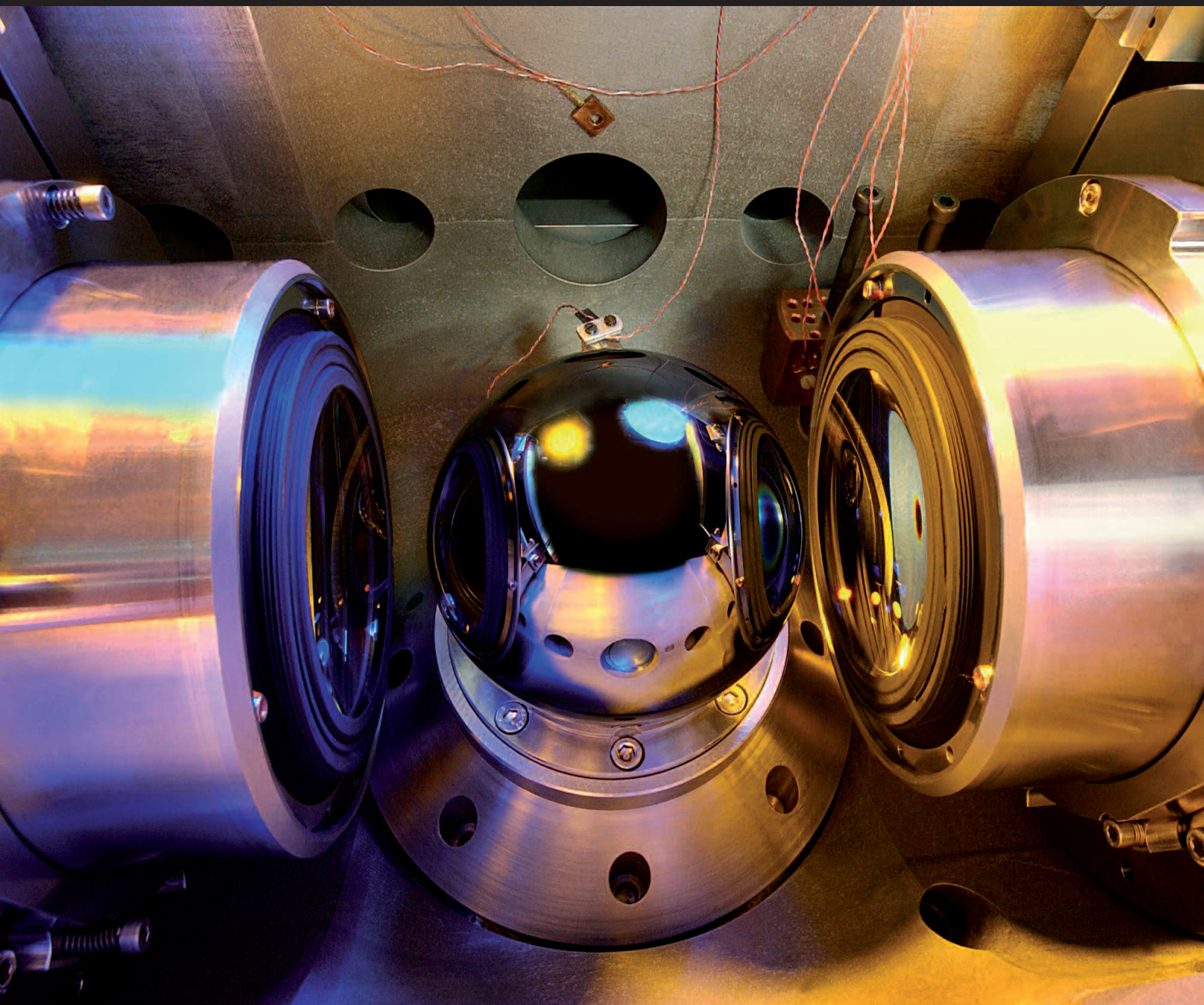
Almost all of the base units of the International System of Units (SI) have meanwhile been defined by atomic constants or fundamental constants of physics. Only the kilogram is still represented by a prototype, the prototype kilogram. For a long time now, experiments to also link the kilogram to fundamental constants have been running worldwide. Metrologists worldwide have advanced an important step with their so-called Avogadro experiment.



"The kilogram is the unit of mass; it is equal to the mass of the international prototype kilogram." This prototype, a platinum-iridium cylinder, has been stored since 1875 in a safe of the International Bureau of Weights and Measures in Paris (Figure 1). Only at this site is it possible for the national metrology institutes to assure themselves that their national mass scale is still correct – a disadvantage of this unit. A further disadvantage of this definition is the "vulnerability" of this prototype. As a result of frequent use and interaction with the environment, it changes its mass. Furthermore, it has been demonstrated in the last hundred years that the mass differences between the prototype and the various national copies have not remained constant [1].

Other base units of the SI have meanwhile been defined by atomic constants or fundamental constants of physics. Thus, the meter is linked to the second via the speed of light in vacuum. The second, in turn, is defined via the frequency of a hyperfine transition in the caesium atom.

Since about the beginning of the 1970s, test facilities have been set up in order to also link the kilogram to a fundamental constant. The objective of such an experiment for a redefinition is to attain a relative measurement uncertainty of a few times 10^{-8}. A recommendation of the CIPM, the *Comité International de Poids et Mesures*, where a redefinition of the kilogram, the ampere and the Kelvin is envisaged by 2011 in case the experimental measurements are indeed acceptable, has initiated a "race" among the national metrology institutes to tie the kilogram to a constant of nature. The general idea is to link this unit to exactly known values of the Planck constant or the Avogadro constant, which defines the number of atoms in a molar volume. The Avogadro Project, too, has its origins in the 70s, when it proved possible for German researchers to determine for the first time the lattice spacing in a silicon crystal X-ray interferometrically, without needing to know the X-ray wavelength used [2]. Thus it was possible to link the kilogram to the atomic mass unit. The Avogadro constant N_A, which specifies the number of atoms in one mole, serves as a link between a macroscopic mass and the mass of an atom:

$$N_A = M_{mol} / m_{Si} = (M_{mol}\, V) / (v_o\, m)$$

where M_{mol} is the molar mass, m_{Si} the mass of an atom, V and m are volume and mass of a silicon sphere, and v_o is the space taken up (the 'volume') of an atom.

In order to determine N_A, first V and m are determined. Then from specimens of the same crystal, the molar mass M_{mol} and the volume v_o of an atom are measured. When N_A is known, then it is easy to infer the number of atoms in a kilogram of the same material. All of the measured quantities must naturally be traced back to the existing Si base units.

P.23 ▶ **FIG. 2:** Optical characteristic of the Fizeau interferometer for determining the diameter of a sphere made of enriched silicon.

▼ **FIG. 1:** The prototype kilogram in Paris: the unit of mass.

Volume

The volume of the silicon sphere is determined by measuring the diameter of the sphere with a double ended Fizeau interferometer. The interferometer mainly consists of two optical surfaces in the form of spherical segments - the concave faces facing each other and so building a spherical etalon (Fig. 2). In order to fit the wave fronts of the interferometer to the curvature of the sphere, light beams from a fibre exit are first collimated by high-precision collimators and then transformed to spherical waves by means of special Fizeau objectives also containing the reference faces of the etalon. All rays of the beam therefore hit both the spherical reference plates and the surface of the sphere perpendicular to it, such that equidistant interference fringes are formed. Using a camera which can be switched to low spatial resolution (128x128 pixel) about 16000 optical phase values are measured simultaneously. For the diameter

measurement of the sphere two consecutive interferometric measurements are to be performed: first, the empty etalon is measured, yielding the inner diameters D. Then the sphere is inserted. Two new interference systems evolve now between the left arm reference face and the corresponding part of the sphere and accordingly between the right arm reference face and the opposite segment of the sphere. After measuring these distances d_{right} and d_{left} the diameter of the sphere d can be calculated from $d = D - d_{right} - d_{left}$. About 30 measurements at different orientations have to be performed to get a complete map of the diameters of the sphere (Fig. 3). For the best spheres they vary about 30-50 nm. The volume is then calculated from about 400 000 diameters. Measurement uncertainties of less than 1 nm for the diameter measurements could be achieved.

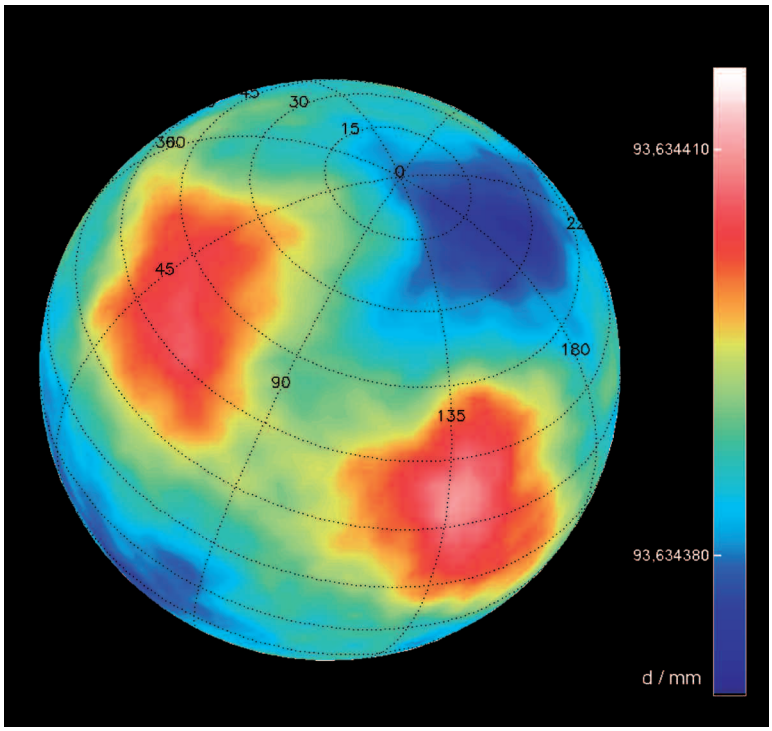
The spheres were polished in the Australian Centre for Precision Optics (ACPO). In the polishing process, the silicon sphere is overlaid with a thin oxide skin of some few nanometres, whose chemical structure and density also must be characterised. Its thickness is mapped by ellipsometry, giving a narrow net of the relative thickness. At some locations the relative values were combined with absolute layer thickness measurements by X-ray reflectometry measurements, thus providing uncertainties for the oxide layer thickness of some tenth of a nanometre.

Mass

The mass of the silicon sphere is linked to the prototype kilogram by weighing. Since the two materials have different densities, extensive buoyancy corrections are necessary. Volume and mass determinations must then still be adjusted in terms of the oxide layer.

Lattice spacing

The atomic volume is determined from the lattice plane spacing a of the crystal lattice with the aid of an X-ray scanning interferometer. The X-ray interferometer consists of three thin crystal lamellae with rows of atoms well orientated with respect to one another. The X-ray beams reaching the entrance surface of the third lamella form a periodic X-ray standing wave-pattern, reproducing the lattice period. Moving this lamella perpendicularly through the pattern results in a sinusoidal intensity modulation behind the interferometer. Measuring the travel distance using the metre as the unit of length (for instance by optical laser interferometry) and simultaneously counting the X-ray intensity maxima leads to a calibrated - mean - silicon lattice parameter a, averaged over the cross-section of the X-ray beam. Assuming the unit cell to be cubic in shape and to always contain eight atoms, the atomic volume is $v_0 = a^3/8$, with a the edge length of the cubic unit cell. Sufficient knowledge of the contaminations and of the crystal construction defects is a necessary precondition for this purpose.

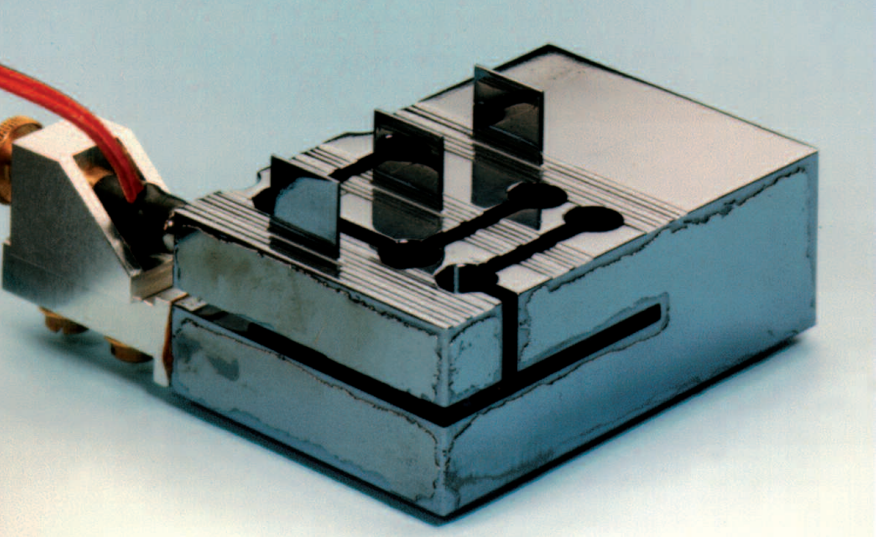


▲ **FIG. 3:** Diameter topography of a 1 kg sphere, peak to valley difference 40 nm

The molar mass

The molar mass M(Si) is obtained from the measurement of the isotope abundance ratios $Ri/28$ of the three stable Si isotopes ^{28}Si, ^{29}Si, and ^{30}Si which are then combined with the molar mass values $M(^{i}\mathrm{Si})$, all available with an uncertainty $< 10^{-8} \cdot M(^{i}\mathrm{Si})$, for ^{28}Si with $< 10^{-9}$: $M(\mathrm{Si}) = \Sigma f(^{i}\mathrm{Si}) M(^{i}\mathrm{Si}) = [\Sigma M(^{i}\mathrm{Si}) R_{i/28}] / \Sigma R_{i/2}$. The atomic masses of the silicon isotopes are linked to the mass of the carbon isotope ^{12}C by means of Penning traps. To calibrate the measurement of $R_{i/28}$, synthetic mixtures prepared gravimetrically from highly enriched ^{30}Si, ^{29}Si, and ^{28}Si were used. These were kept in the form of $BaSiF_6$, carrying the isotope amount ratios $n(^{i}\mathrm{Si})/n(^{28}\mathrm{Si})$ synthesized gravimetrically. The abundance ratio measurements are performed by means of an isotope ratio gas mass spectrometer, which compares the number of atoms of the various isotopes with each other through precise measurements of the ratios of the ion currents of the isotopes. In order to apply this method, the single crystals are converted to the gaseous compound SiF_4.

The idea is to **link the kg** to exactly **known values** of the **Planck** constant or the **Avogadro** constant



▲ **FIG. 4:** A scanning x-ray interferometer for nanometre calibration

In the case of natural silicon, however, technical limits were encountered in determining the molar mass. Therefore some years ago, the investigations of the Avogadro constant were stopped at an attained measuring uncertainty of approx. 3×10^{-7}, which was not sufficient for a redefinition of the kilogram however [3]. Unfortunately, in addition to the insufficient accuracy, also the observed difference of the measurement value of approx. 1×10^{-6} relative to other fundamental constants caused the researchers to rack their brains. Had they miscounted or are there hidden inconsistencies in the system of the physical constants?

The Avogadro Project received a new incentive with the possibility of using enriched ^{28}Si on a large scale for the production of large samples. Assessments had yielded, namely, that in this way the problems in measuring the isotopic composition, which is carried out in the European Institute for Reference Materials and Measurements (IRMM) in Geel near Brussels, were distinctly reduced. However, it was necessary to also repeat all other tests with this material.

An international Avogadro coordination IAC was agreed between national metrology institutes of Japan, Italy, Germany, Australia, Great Britain, USA, the IRMM and the BIPM, the *Bureau International des Poids et Mesures*, to bundle the existing capabilities and knowledge for the race finish. In a cooperation with research institutes in Russia in 2003, the IAC started the ambitious plan to have approx. 5 kg of highly enriched ^{28}Si (99.99%) produced as single crystal and to attain a measuring uncertainty until 2010 of approx. $2 \cdot 10^{-8}$. Meanwhile, the production of the material was successfully concluded with the growing of a perfect dislocation-free single crystal at the *Helmholtz Institute of Crystal Growth* in Berlin, see Figure 3. Two ^{28}Si spheres, each weighing one kilogram, were already polished in the Australian ACPO and arrived at the metrology laboratories of Germany and Japan in April last year. Here they will be measured in the hope of attaining the objective of a more accurate determination of the Avogadro constant within the prescribed time span. In the process, it should also be possible to uncover the cause of the observed difference with other fundamental constants.

A first inspection of the material has been started and the following characteristics of the material have been checked: impurity, vacancy and void contents, isotope enrichment, lattice parameter and density differences, presently compared with silicon of natural composition. All data measured so far meet the expectations of the scientists. For example, the carbon and oxygen content in the Avogadro crystal – usually the dominant impurities in commercially available FZ crystals – is astonishingly small.

The Avogadro constant is not the only candidate in the running for a redefinition of the unit of mass. The so-called watt balance experiments, which are being set up at several metrology institutes, *e.g.* in the USA, England and Switzerland, are determining the Planck constant and are given better odds in expert circles of winning the competition. But matters have not progressed so far yet. ■

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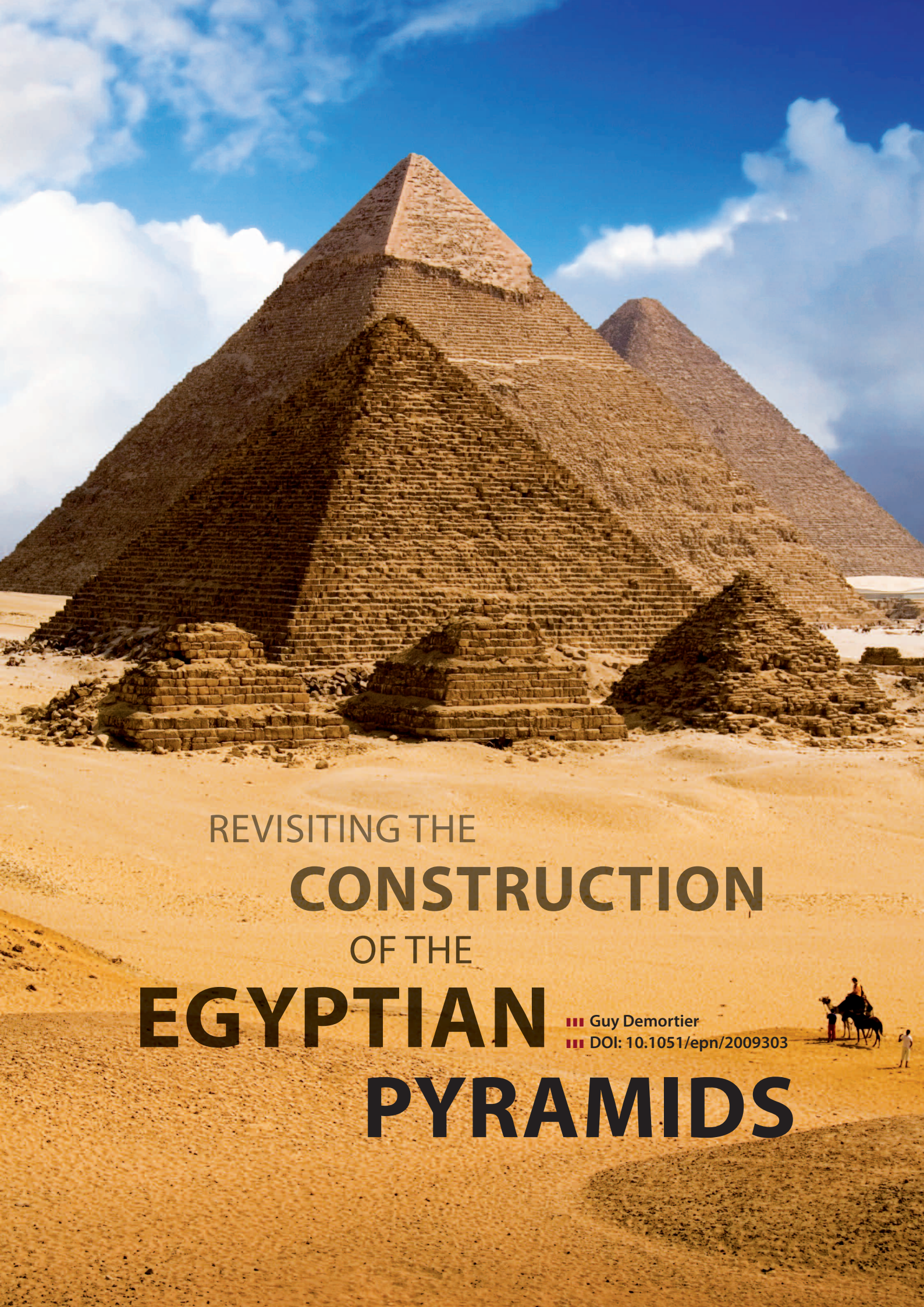
▲ **FIG. 5:** The highly enriched Avogadro ^{28}Si single crystal



REVISITING THE CONSTRUCTION OF THE EGYPTIAN PYRAMIDS

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The Kufu pyramid, with a volume of 2,7 10^6 m^3, was completed over a period of 20 to 30 years. From this one can estimate a daily rhythm of 300 to 400 blocks, each having an average volume of 1 m^3. This means one block put at the right place every 2 minutes. To achieve this goal, 1 m^2 of block face would have to be hewn every 20 seconds! What a performance, with tools made of stone or with soft copper! The construction of the pyramid of Kufu took 2,5 10^{12} J. In other words, 1m^3 of material was to be lifted up by 1m every 3 seconds! This assumes an efficiency of 100% (but who would guarantee that every small lift was never repeated?). Hoisting huge blocks of more than two tons with rudimentary means at this rate, even with 1200 teams of 15 men working simultaneously on 1200 blocks at the 60 000 m^2 surface of the monument, is an impossible task. Remember that wheels and pulleys did not exist at the time.

When looking (fig. 1a) at the vertical faces of the blocks visible today (but initially underlying the casing blocks which were totally removed), one sees irregularities in the shapes but a remarkable close fit. It is surprising that these blocks have been so "poorly cut" but are so perfectly joined. This close fit would have been more easily achieved if the blocks had been hewn with perfect parallelepipedal shape! Furthermore, great precision in this juxtaposition seems useless because these blocks were originally hidden under the casing anyway. The blocks also appear more porous at their top part than at their bottom, but this feature cannot be explained by some erosion of natural limestone. Surprisingly, when the Kufu pyramid is seen from the air (especially from a helicopter which blew the dust when flying close to the top of the pyramid- fig. 1b), one clearly sees that the horizontal surfaces of the blocks are flat. Presently, casing blocks are only present at the top of the Kafra pyramid (fig. 2).

In many books on Ancient Egypt, no distinction is made between techniques used in the Ancient Kingdoms (4500 years B.P) and the New Kingdoms (3000 years BP). During the New Kingdom and later, big monuments were made with moderate-size stones kept close to each other by dovetails (fig. 3). Nothing similar is visible on the pyramids. Compared with the 147 m of the Kufu pyramid, the height of the monuments of the New Kingdom does not exceed 20 m. We have calculated that the construction of the pyramid would have required 20 times more work than the Ramesseum (built 1200 years later). The Ramesseum and the Kufu pyramid cover the same surface at ground level, and thus they would require the same number of workers to make the comparison pertinent. Considering that the works on monuments at different periods are so different and that the structures of the block assembly are very different, we conclude that the materials could be also different.

In 1978, the French chemist Joseph Davidovits rejected the generally accepted technique of carving and hoisting stones. He proposed that the building method involved the moulding on site: blocks were made of a kind of concrete whose basic binding compound was natron: a sodium carbonate extracted very close to the site of Giza. The binder was obtained by some chemical reaction leading to a geopolymer (a name given by Davidovits). It is a poly-sialate containing an alkaline nucleus: sodium from natron. Natron, lime and water form caustic soda, which reacts with aluminous limestone to yield the basic geopolymer [1].

▼ **FIG. 1a:** Irregular vertical faces of the blocks of the Kufu pyramid

▶ **FIG. 1b:** Flat horizontal faces of the blocks of the Kufu pyramid

▲ **FIG. 2:** Casing blocks at the top of the Kafra pyramid

Ion beam Analysis of the material

X-ray fluorescence and X-ray diffraction [1] have shown that the blocks consist of limestone (85 to 92%) associated with a binder. Additional analyses were performed by PIXE (Particle-Induced X-ray Emission), PIGE (Particle-Induced gamma-ray Emission) and by NMR-Spectroscopy for structural characterization [2] in laboratories of Namur and Lecce. One of the pyramid's samples appeared to be made of a central compact structure embedded in a material of different composition. The central part is identified as natural limestone but the outer part contains a large amount of F, Na, Mg, Al, Si. The concentration ratios in the binder relative to the core are 7,5 for F, 8,5 for Na, 12 for Mg, 2 for Al and 21 for Si. Furthermore, a significant signal of As in the outer part may be attributed to some additional ore which could be scorodite. This mineral ore containing arsenic was added to produce sodium arsenate acting as an activating ingredient that could have been used in various concentrations to control the speed of the hydraulic setting. Recent measurements at the Tandetron of the University of Lecce on a large number of samples confirm the previous results and, for several samples, a very high content of P, S and/or Cl (up to 10%). The high concentrations of Na P, S and Cl are attributed to the use of natron and the presence of Mg, Al and Si to the use of the Nile alluvium to obtain the binding medium.

We have also fabricated the binder based on the geopolymer formula. The NMR-Spectra of Al and Si on this modern synthetic material shows typical resonances assigned to $Si[Si(OSi)_4]$ and Al-tetrahedral in this synthesized material which is chemically highly basic (pH = 10 - 11). The NMR spectra of several samples of Kufu pyramid indicate that the tetrahedral Al content is 10-15% of that obtained for the pure synthetic mixture. Si-NMR leads to the same conclusion. This binder exhibits a very fine adherence with small gravels.

More recently, Barsoum, Ganguly and Hug [3] compared a number of pyramid samples with six different limestone samples from quarries of their vicinity. The pyramid samples contain micro-constituents with appreciable amounts of Si in combination with Ca and Mg, in ratios that do not exist in any of the potential limestone sources. The intimate proximity of the micro-constituents suggests that, at some time, these elements had been together in a solution. Furthermore, between the natural limestone aggregates, the micro-constituents (with chemistries reminiscent of calcite and dolomite which are not known to hydrate in nature) were hydrated in the pyramid samples. The ubiquity of Si and the presence of submicron silica-based spheres strongly suggest that the solution was basic. Transmission electron microscope confirmed that some of these Si-containing micro-constituents were either amorphous or nano-crystalline, which is consistent with a rapid precipitation reaction.

Many additional arguments are in favour of a mode of construction based on agglomeration. These include: **(a)** the chaotic organisation of shells in the blocks, with respect to their parallel alignment in natural stones in the quarries around Giza, **(b)** the high water content measured by the transmission of electromagnetic waves, **(c)** traces of mortar, mostly at the base of the blocks.

The walls of narrow channels, with a cross section of 20 cm x 20 cm, starting from the Queen's chamber and investigated by R.Gantenblink's robot [4], clearly indicate that they were not carved: There is no gap between the walls and the ceiling of this conduit, and there are no protrusions in the walls and the ceiling. The only irregularities have a hollow (concave) shape. A carving procedure would have given both convex and concave irregularities in equal amounts. When thinking about a moulding procedure, the apparent cavities could be understood by some loss of material during the de-moulding.

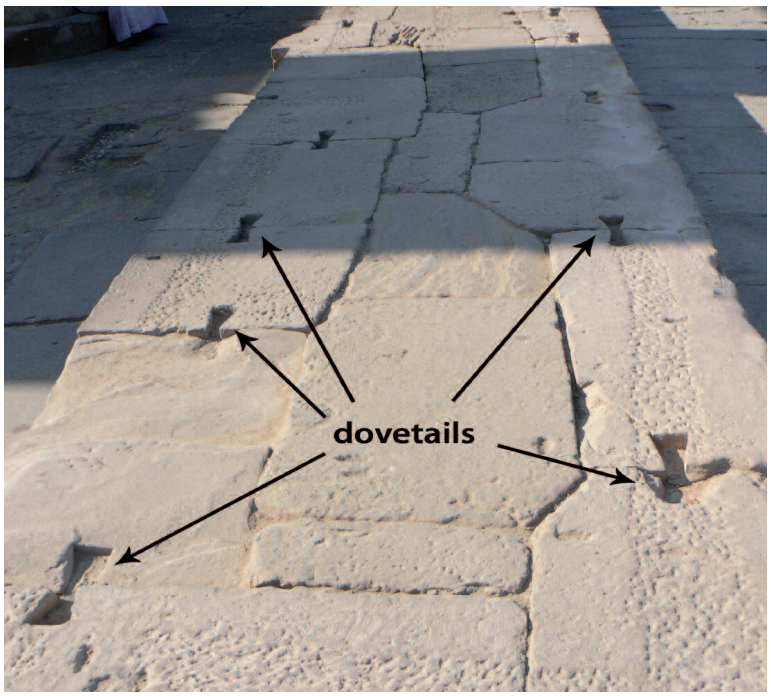
1 m³ of block material would have to be **lifted up** by **1m** every **3 seconds!**

Manpower for the construction of the pyramid

The moulds could have been made of grooved small boards fitting into one another (fig. 4). These boards have probably the width of an Egyptian palm (1/7 of cubit, about 7,5 cm). The construction of the moulds with a definite number of small boards explains the modular width of the blocks of the Kafra pyramid as reported by Davidovits [1]. The irregularity on the blocks in the Kufu pyramid would be due to possible "accidents" during the removing of the planks of the mould after the solidification of the liquid binder. We could imagine that these 'accidents' in de-moulding were intentional, to favour the link between the adjacent blocks with no need of dovetails. The height of a single block depends on the height of the shortest plank of the mould. The upper surfaces of the blocks are flat, as can be seen in fig. 1b. The modular width of the blocks depends on the number of small planks constituting the board.

The solid ingredients, brought in bow nets, were poured into the mould that had been made waterproof by the application of a mortar to waterproof the base of the mould. Instead of having teams pulling blocks weighing several tons, the workers transported the ingredients by small loads (25 kg) not requiring wide ramps. These hypothetical ramps would have badly supported the extensive heavy carriages during more than twenty years at a rate of 300 to 400 huge blocks per day. With the moulding technique, workers saved their energy by only bringing loads upwards, passing them from man to man on successive pyramid levels, without having to climb the monument. Thus, lifting the ingredients could be achieved with an optimal efficiency. By contrast, in the case of heavy hewn blocks the efficiency would have been extremely low, due to the necessary up and down movements when manipulating heavy charges. In addition, the fabrication of (static) moulds requires much less wood than the fabrication of (moving) hard sledges. Indeed, wood is rare in Egypt.

To complete the whole construction in 25-30 years, six workers would transport 1 m³ of small pieces of limestone each day from the quarries to the building site; one worker would lift 40 kg of ingredients every minute (limestone rubble, water, binder) to the height of one single step (1m or less), two workers were dedicated to the supervision of each mould and kneading during the pouring of ingredients. No more than 2300 workers would be present simultaneously on the surface of the pyramid. The distribution of the manpower is illustrated in fig. 5 [2].



▼ **FIG. 3:** Dovetails on external blocks of monuments of New Kingdom

The procedure was described in ancient reports.

Herodotus (Vth century B.C.) reports:

"This pyramid was made, as I am going to say, in terraces that some name steps, and others small altars. When the base had been built, the rest of stones were raised by means of machines fabricated with ***short*** *wooden pieces…* ***The summit of the pyramid was finished before the rest;*** *and afterwards they completed the parts in the following tier, and one ended by the lowest, by the one that touches the ground. It was written in Egyptian characters, on the*

pyramid, how much was spent ***for garlic, onions and parsley*** *for the workers. As I well remember it, the text (that the interpreter explained to me) means that the sum amounts to sixteen hundred talents of silver (58 tons of silver!). If these things cost so much, what did they spend in metallic tools, in foods and in clothes…"*

This description supports the following explanations:

a) Short wooden pieces cannot be associated with long beams of levers necessary for the lifting, but could be the planks of the mould,

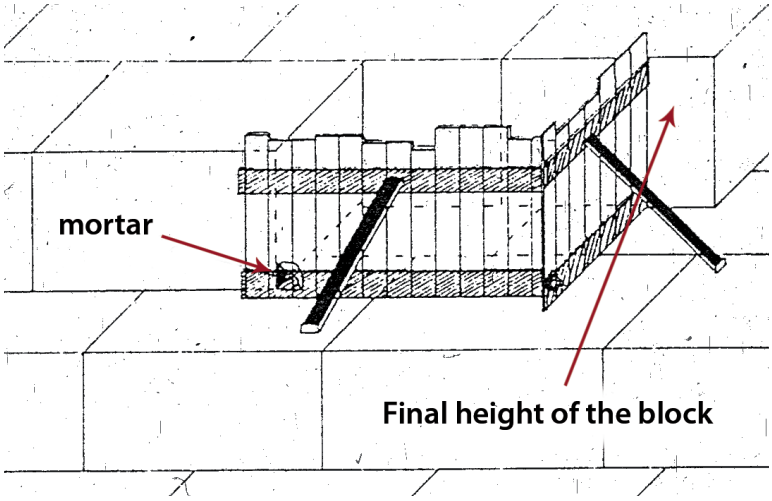
b) The completion of the pyramid began with the installation of the **facing blocks at the summit**. In order to make sure he would be well understood, Herodotus adds in the next sentence that the builders continue on the following floor, downwards, to end with the one that touches the ground. These facing blocks are still present today at the top of Kafra's pyramid (fig. 2) and they hold firmly together even after more than four millennia. They have obviously been put in place at the top first.

c) Garlic, onion and parsley cannot be understood as food supply for the workers. A comment on the cost of these ingredients provides us with a hint on the nature of the materials used for the building and not for food. In the sentence which closely follows this statement, Herodotus argues about the supplementary cost for food, tools and clothes. Garlic and onion, then, must have a direct link with ingredients occurring in the manufacture of blocks.

According to J. Davidovits two of the three ingredients appear in the text of the Famine Stele, dedicated to Pharaoh Djezer and its architect Imhotep [1]: "hedsh" (disaggregated stone smelling like **onion**) and "tem-ikr" (mineral containing arsenic identified by our PIXE measurements) which has the characteristic smell of **garlic**.

Recent and future investigations

On April 2, 2008, an announcement appeared in the Boston Globe to prove once again that the cement pyramid theory is not going away. Linn Hobbs (professor of materials and nuclear sciences at MIT) and his students have tested the theory by making a "Mini Great Pyramid". **"In fact, the very idea has been so controversial that you can't get research funding, and it's difficult to get a paper through peer review"**. Building a small-scale model of the pyramid using the materials and methods the Egyptians may have used is far more than just an educational exercise for the students. "Like any other investigation of ancient technologies, you can only get so far by speculating, and even only so far by looking at evidence. To go the rest of the way, you have to do the thing yourself. You have to get acquainted with the materials." says Linn Hobbs.



▲ **FIG. 4:** Mould model

The enigma is certainly not completely solved and our next investigations would include: **(a)** dating of straw in mortars by C^{14}accelerator mass-spectrometry, **(b)** comparison of plants growing on the pyramid and in quarries: differences would appear if some basic ingredient is used for the moulding, **(c)** investigation of the differences between the perfectly preserved blocks of the edges of the casing blocs of the pyramid of Kafra and the more damaged ones in the central part… if we have some opportunity to obtain the required material. ■

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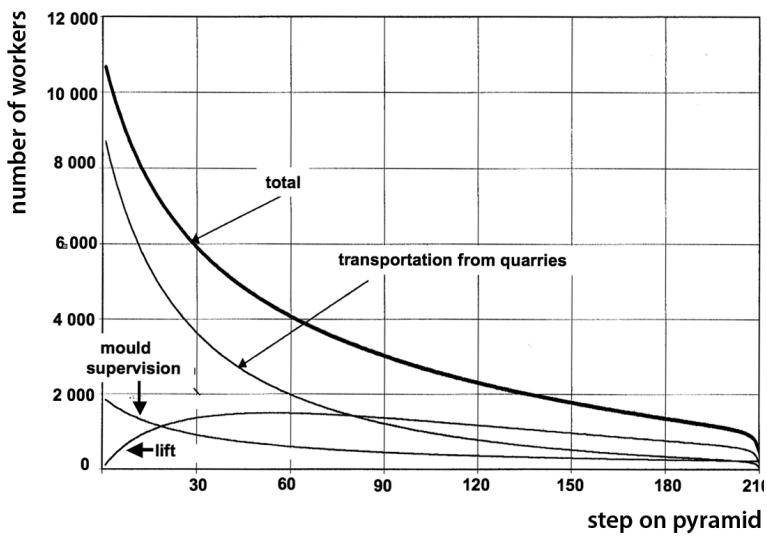
▼ **FIG. 5:** Step on pyramid



PHYSICS IN DAILY LIFE:

OVER THE RAINBOW

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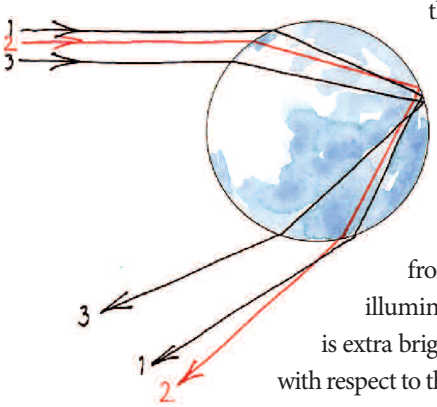
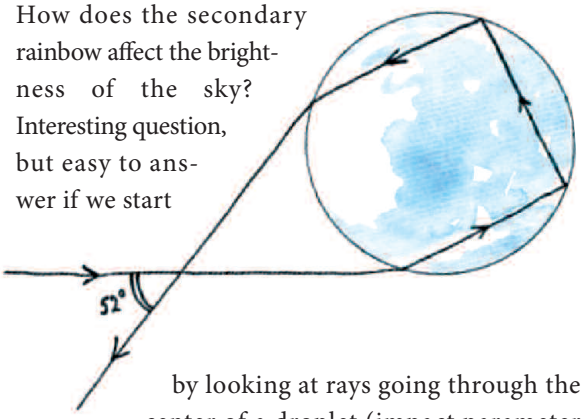
Everybody knows the rainbow, and most physicists know its optical background.

But there is one question about rainbows that even most physicists cannot answer off-hand: What about the brightness of the sky above and below the rainbow? In order to find the answer, let us first remember how the rainbow itself comes about. Geometrical optics will do, if we assume the size of rain droplets to be large compared to the wavelength of light. The key is that light rays making one internal reflection inside a raindrop have an extreme in their deviation as a function of 'impact parameter' if we put it in molecular collision language. That is, outgoing ray no. 2 in the figure makes the largest angle with respect to the horizontal, although it has incoming neighbours at either side (a fact that can easily be demonstrated by slowly moving a cylindrical glass of water through a laser beam). Consequently, when we turn away from the sun and look at a rain cloud illuminated by the sun, the reflected light is extra bright at this angle of about 42 degrees with respect to the sun's rays: the *rainbow angle*. Due to dispersion, the angle is different for each colour, and we see a colourful cone of light: the rainbow.



So far for the rainbow itself. Now what about the brightness of the sky next to it? From the figure it is obvious that there is also light reflected at angles *smaller* than 42 degrees, but not at larger angles. Conclusion: the sky is brighter inside than outside the rainbow.

But wait: this was only about the primary rainbow. What if there is also a secondary rainbow, having an angular radius of about 52 degrees? We recall that the secondary bow is caused by the extreme in the deviation of rays which leave the droplets after **two** internal reflections. It has inverted colours since the light rays have turned the other way around inside the droplets. How does the secondary rainbow affect the brightness of the sky? Interesting question, but easy to answer if we start by looking at rays going through the center of a droplet (impact parameter zero, or a 'head-on collision'). After two internal reflections, such a ray continues to move along its original trajectory. With increasing impact parameter, the outgoing rays will gradually move over toward the incoming direction until they reach their extreme: the (secondary) rainbow angle of 52 degrees. Consequently, they will not reach the 'dark' area in between the two rainbows. So the conclusion emerges that the sky is brightest inside the primary and outside the secondary bow. Complicated though it may seem, it reminds us of a well-known song. The sky is bright, *somewhere over the rainbow*. But not *everywhere*. ■



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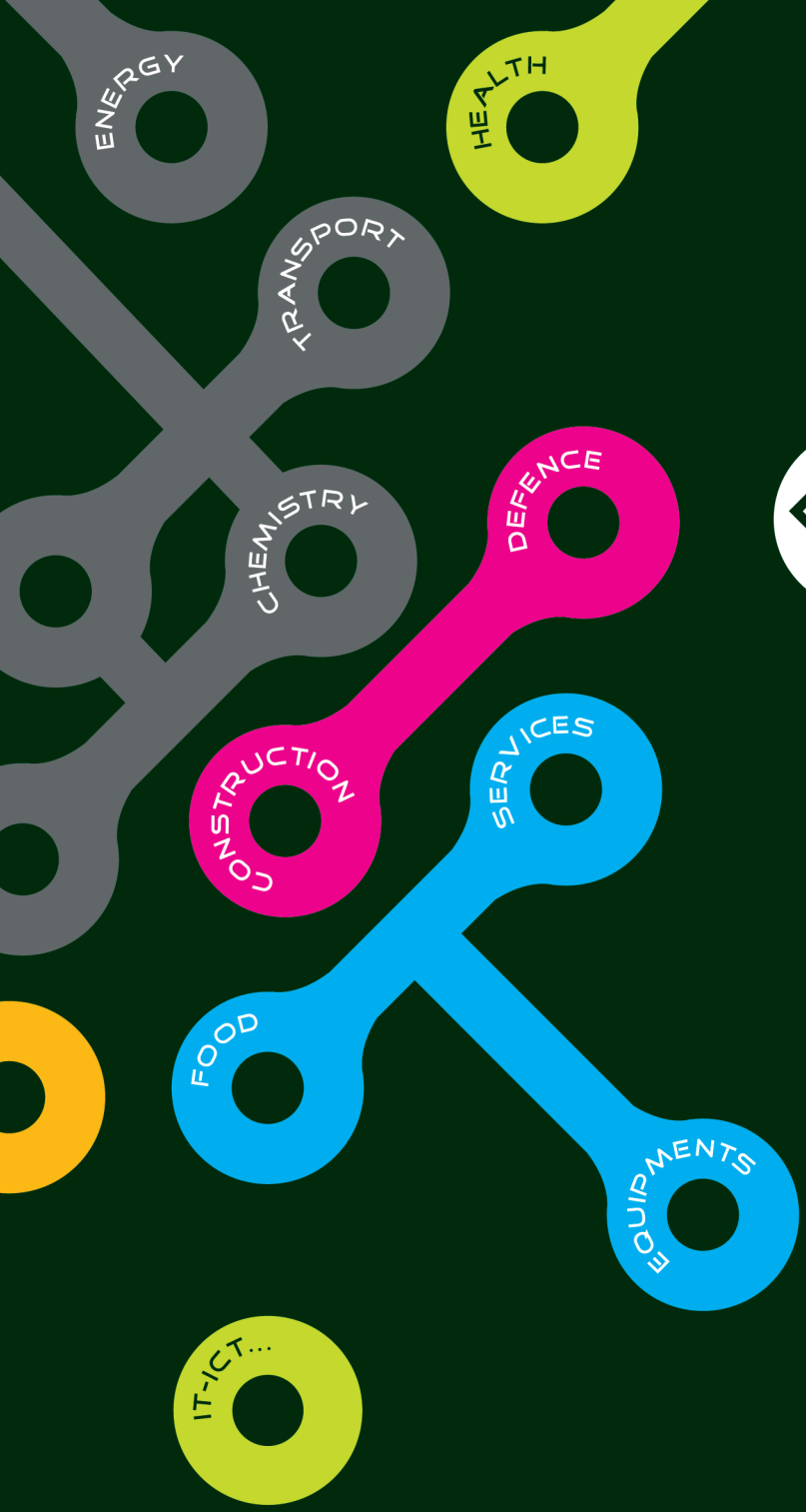

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