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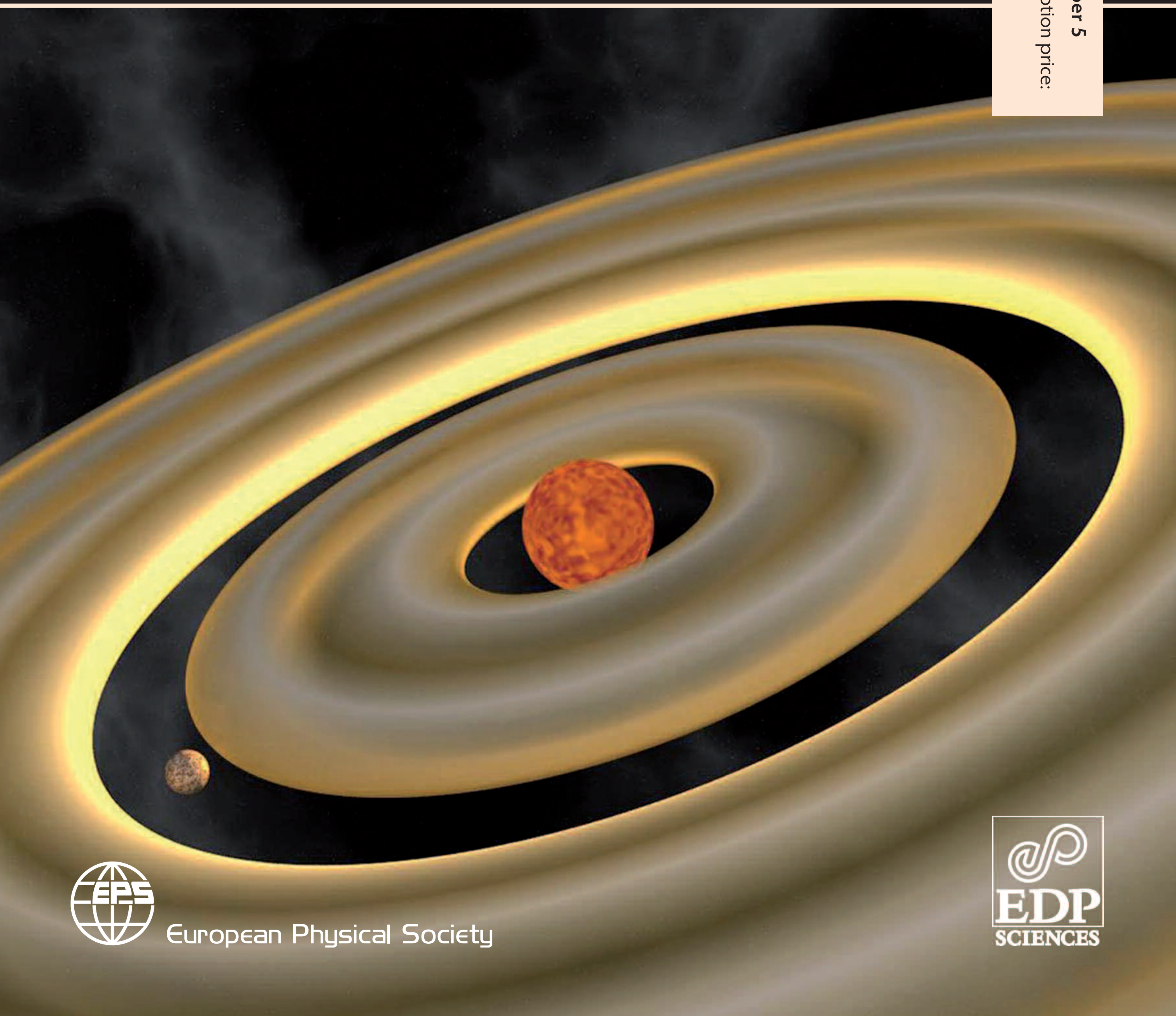

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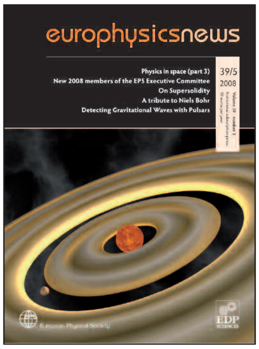

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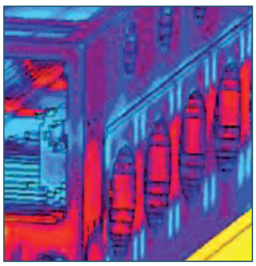
cover picture: Protoplanetary disk (simulation by Michael Kramer)
Figure from www.skatelescope.org - see article p.35



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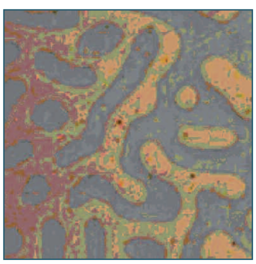
Thermophysical properties of materials



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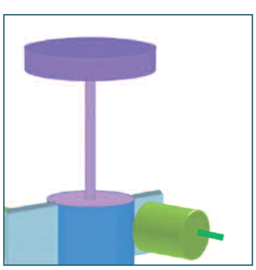
Materials solidification physics in space



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On Supersolidity

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SPECIAL: PHYSICS IN SPACE (PART 3)

EPS FINANCES ››› EDITORIAL

EPS made a healthy surplus in 2007! I had the pleasure of reporting this exceptional outcome to the Council Meeting in Mulhouse in March. Expenditure under all headings was close to the budget approved by Council in March 2006. This was a great achievement by our Secretary General David Lee and his staff, who were thanked by Council for their work.

Income was higher than budget because of increases in the numbers of Individual and Associate Members and higher contributions from the surpluses of EPL and the European Journal of Physics. But the real star of the year was the Conference Service section in Mulhouse, the staff of which dealt with more and bigger conferences than expected and produced a dramatically increased surplus. This is a great vindication of the decision taken many years ago to establish such an activity for the benefit of the research community and to provide some extra income for the EPS.

After setting aside funds to cover the possible costs of the 40th anniversary events and the General Meeting in Rome, Council was able to add the significant sum of 100 k€ to the Society's reserves. This is unlikely to be repeated in future years, especially since activity in the Conference service is lower in even years because of bi-annual conference activity.

There are important reasons for holding a reserve. First, small overspends arising from differences between budgeted and actual income and expenditure can be managed without over-conservative budgeting. Secondly and most importantly, with a reasonable reserve the EPS will be in a position to take advantage of new opportunities which might arise by providing pump-priming funds for new projects. Thirdly, an organisation such as EPS must be in a position to treat its staff correctly and manage its other commitments if subject to sudden major adverse shocks either to its income or to its costs. The Executive Committee accepts that the current reserve is about adequate for these needs provided that future budgets are not in deficit.

Despite the surplus in 2007 problems can be seen on the horizon for future years. When fee levels and structures for Individual and Associate Members and for Member Societies were revised in 2004 they were set at a fixed level (apart from an insignificant change in 2007) and EPS income now from these sources is still at the 2003 level. Naturally costs have risen with inflation and some additional projects have been undertaken such as Bologna Process studies, the Brussels newsletter, energy workshops and a new grants scheme. It is remarkable that it has proved possible to balance the books for so many years. But unless something is done growing costs will sooner rather than later overwhelm fixed income.

Faced with this prospect the Executive Committee will be considering during 2008 both the level and the structure of fees. The intention is to put a proposal before the 2009 Council for changes, beginning in 2010, which will underpin EPS finances for future years. Discussions will be held with interested parties, particularly the two largest Member Societies, DPG and IOP, on whose subscriptions EPS is so dependent, to develop a methodology which is fair to all concerned. It is the fee income, particularly that from Member Societies, that provides the basis for the core expenditure upon which all the activities of the EPS are built. My preference is to raise the fee level annually based on a suitable inflation index and so of order 3%. I do not want to see the EPS squeezed to death by a slow process of trying to manage with what is an effectively fixed income.

I see the main task of being Treasurer of the EPS as ensuring that there is a reliable foundation on which activities can be built both in the short and in the long term. David Lee and his staff manage the resources they are given extremely well but they must be given a stable platform on which to build the activities of EPS. I am sure that I have members' support in doing this. ■

John Beeby,
Treasurer of the EPS

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VIEWS FROM

PRESIDENTS WEAIRE AND WOLFENDALE »» 40YEARS OF EPS

EUROPE – THE GREAT ADVENTURE

Dennis Weaire (Ireland),
President of the EPS ,1997-1999

For those of us whose life-span is long enough to include experience of the aftermath of the Second World War - with rationing and visas in the West and an Iron Curtain sealing off the East - today's Europe is a great adventure. We are not easily disillusioned by petty bureaucracy or the sporadic resurgences of nationalisms. A trip on the Thalys, crossing national frontiers at seemingly relativistic speed, remains a thrill.

It is saddening however that, if the Thalys terminates in Brussels, we see that the central institutions of our great conglomerate continent present a rather dismal picture, and ample opportunities for ridicule by a hostile press. But look outside that inner circle of mutual distrust and you see the spontaneous emergence of many organisations that seek to stimulate rather than to regulate. The EPS is one such, and to occupy its Presidency was a unique privilege for me, especially as I came to it from the periphery of the continent.

Most new European societies of this kind struggle to survive. Up to a point this is a good thing: let those that are most effective survive. But too many of them remain precarious after several decades. They deserve some support from the centre, once they have proven their worth.

My years as President were the first after the move to Mulhouse. This was a survival tactic, dictated by finance, but location in an explicitly "European" region proved to offer symbolic value as well as economy. We have now taken firm root on the fine campus of the university. I have proposed to represent this rather literally by the planting of trees.

It was also the period during which David Lee joined us. We share a passion for rugby, so we were never short of a conversational topic, whenever we got tired of looking at the bottom line, or the necessary evil of our written constitution.

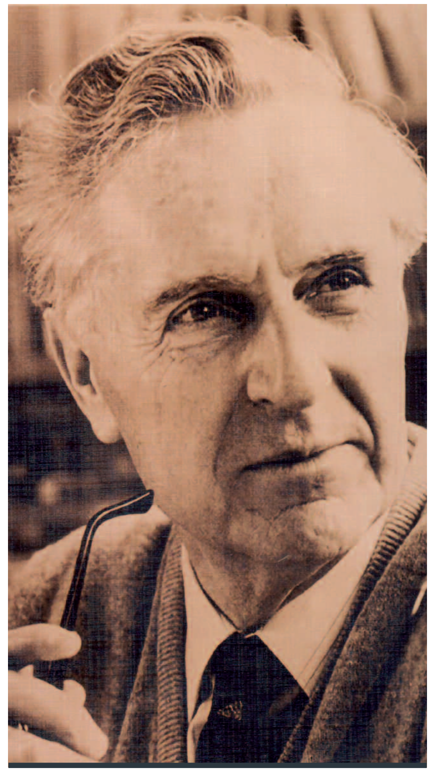
We agreed on one priority for development, which was conference organisation. This seems to have done well, but there is still more scope for ambitious plans in that area.

There is much to be done on behalf of our members. Many matters of public policy need our attention and advocacy. One has only to think of the rapid encroachment of new copyright legislation, eating away at our creative freedom, our precious time and perhaps eventually our funds as well. Who is speaking for its moderation in the academic world? It seems that the script-writers of Hollywood are more alert.

Having heaped praise on European integration, let me add the counterpoint: *que vivent les différences!* Just the other day, I was disputing a point in research with a German colleague in Paris. The problem is, I said, that a German says the bottle is half-empty while an Irishman says the bottle is half-full – and a Frenchman says *"Qu'est-ce que c'est qu'une bouteille?"*

REPORT ON 'THE MAIN ACTIVITIES'

Sir Arnold Wolfendale FRS (UK),
President of the EPS, 1999-2001



1. General Remarks

The period 1999-2001 was a busy one for the EPS, indeed all periods seem busy for our Society; it marked the last occupancy of the 'old' building in Mulhouse, before its transfer to the present purpose-built location.

I was blessed with a very impressive and co-operative set of colleagues on the Executive Committee and the office staff, under the inspired leadership of David Lee, worked incredibly hard.

From the multitude of activities I shall pick out just a few.

2. The Malvern Seminar, September 1999

Organised, very largely, by John Lewis, another stalwart of the EPS, we had 23 presidents of European Physical Societies and as many deputies or past-Presidents. A number of Working Groups were set up, dealing with such topics as 'the Public Understanding of Physics', 'Physics and the Human Condition', 'Physics and Wealth Creation', 'Physics Education' and 'Teacher Training'. The 'Report of the Malvern Seminar' was sent out to many individuals and institutions; indeed, it is still in demand. Contacts with other Presidents proved invaluable.

3. Position Papers

Considerable effort was put into the production of Position papers, on such topics as 'The Brain Drain', 'Nuclear Energy', 'Public Awareness', 'The funding of Physics'…. The first-mentioned was particularly important for our efforts to minimize the loss of scientific talent from Eastern and Central Europe; specifically we (Dalibor Krupa, from Bratislava, and I) recommended that the host country (usually the USA) should pay the donor country one million dollars per person. The funds so gained would be used to fund the educational base of the impoverished base and, hopefully – in that way – reduce the drain. Lest it be though too much I would refer to a (later) visit to Belgrade and the Tesla Museum where I learned that Tesla's transfer to the USA had benefited the US economy to the extent of some two billion dollars!

4. Central Europe

I made a number of visits to countries in Central Europe, (specifically, Romania, Lithuania, Croatia, Albania, Serbia and Germany), where I met groups of politicians, as well as physicists. I was impressed by the generally favourable attitude of politicians towards science, although disappointed by their lack of knowledge.

Particularly important here were our Position Papers on 'National Funding of Physics' and 'The role of Research Institutes'. With the downfall of Communism, many Research Institutes in Central and Eastern Europe (the old Soviet bloc) were at risk, and needed to change their lines or be affiliated to Universities.

Efforts to fund visits by young scientists to our Conferences, and for other purposes, were strenuously made.

5. The Einstein Year (2005)

At Council's meeting in Berlin in 2001 we were alerted to the fact that 2005 would be the centenary of Einstein's famous 1905 papers on Brownian Motion, the Photo-electric effect and the Special Theory of Relativity. The original idea came from the next President-to-be (Professor Martial Ducloy) and I was able to achieve unanimous agreement of those present. The idea was taken to UNESCO and approved. In the event, the Year was very successful.

6. The EPS Congress

A very successful Congress was held in London, adjacent to Westminster Abbey. The student posters were particularly fine and it was excellent seeing so many young physicists from Europe present as well as admire the quality of their presentations.

7. Funding

The provision of adequate funding was always a problem and much discussion was devoted to national subscriptions. Surprisingly, even the UK's Institute of Physics needed convincing of the European case.

8. Posters for schools

A cause of great personal regret was the fate of the large number of excellent posters produced by Dr Svetlana Erlykin. These related to the lives (warts and all) of great European physicists, and were prepared with the help of physicists from all over Europe. They were virtually complete when I finished my term of office but – to the best of my knowledge – were never transmitted to schools. A glorious opportunity for the subject, and publicity for EPS, lost. Perhaps it is not too late? ■

Conference announcements

XRMS-09

The next workshop on X-Ray Spectroscopy of Magnetic Solids (XRMS) will be held at the French synchrotron radiation source SOLEIL, Gif sur Yvette (France), 19-20 January 2009.
This workshop continues a series started eight years ago in Berlin (XRMS-00). The most recent one was held this year in Hamburg (XRMS-08).

›››**E-mail:**
conf-xrms09@synchrotron-soleil.fr

NANOMAGNET 2009

A European Workshop on Self-Organized Nano-magnets will be held at the CNRS Centre Paul-Langevin in Aussois (an Alpine winter sports resort, France), 29 March – 3 April 2009.

›››**Website:**
http://nanomagnets2009.neel.cnrs.fr

NEW EPS FELLOWS IN 2008 AND CALL FOR NOMINATIONS FOR 2009 »» INSIDE EPS

EPS is pleased to announce that the following were elected EPS Fellows at the Council meeting in Mulhouse in March:

• **Giuseppe-Franco Bassani, Italy,**
for his fundamental contributions to the theory of the electronic states of solids and to the explanations of their optical properties.

• **Alexander Marian Bradshaw, Germany,**
for his outstanding research in surface science, molecular spectroscopy and instrumentation development as well as for his engagement to the community, where as holder of many honorary offices he has promoted programmes for the public understanding of physics, advanced open-access publishing, prompted the discussion of future energy supplies and advised national and international science programmes.

• **Claude Cohen-Tannoudji, France,**
for ground-breaking, broad ranging scientific contributions to atomic physics and quantum optics and for the dissemination of scientific knowledge through books and lectures.

• **Martial Ducloy, France,**
for his excellent contributions to non-linear physics and laser spectroscopy and his outstanding contributions to the public understanding of physics through initiating and promoting the World Year of Physics 2005.

• **Paul French, UK,**
for pioneering achievements in femtosecond source development and applications in biophotonics, and for contributions to the European Physical Society.

• **Günter Huber, Germany,**
for his pioneering research of the growth, characterization and use of new solid-state laser-active materials, in particular transition-metal and rare-earth ion doped crystals.

• **Denis Jérôme, France,**
for remarkable achievements in solid state physics, including superconductivity in organic materials and for his contributions to the European Physical Society as editor in chief of Europhysics Letters.

• **Eberhard Keil, CERN,**
for his seminal contributions to numerous topics in accelerator physics and contributions to the design and performance of major accelerators.

• **Jürgen Meyer-ter-Vehn, Germany,**
for his outstanding contributions to plasma physics in fields of inertial confinement and laser-matter interaction and for his contributions to the European Physical Society.

• **Wolfram von Oertzen, Germany,**
for his outstanding contributions to the understanding of nuclear structure and nuclear reaction mechanisms, in particular through the concept of molecular orbitals of valence nucleons mediating the covalent binding of clusters within a nucleus.

• **Sandro De Silvestri, Italy,**
for his outstanding contributions to the field of ultrafast optical phenomena from the development of few optical cycle pulses to the generation of attosecond pulses in addition to his service to the international optics community and the Quantum Electronics and Optics Division of the European Physical Society.

• **Henryk Szymczak, Poland,**
for his contributions to solid state physics, his service to the physics community and his support for gifted and talented school children.

This brings the total number of EPS fellows to 36. Details of the 24 can be found on the EPS website.

Nominations are sought for EPS Fellows to be elected in 2009. Rules are on the website but are summarised below:

- The total numbers of Fellows at any one time should not exceed 5% of the total of Individual Members of the Society.
- Individuals whose achievements in physics, whether in research, industry or education and/or through commitment to the Society warrant specific recognition are eligible to become EPS Fellows.
- No one will be denied EPS Fellowship on the grounds of nationality, sex or religious beliefs.
- Normally only those individuals who have been Individual Members of the Society for at least five years are eligible as EPS Fellows. However, exceptions will be made for those who have made significant contributions to the running of the Society.
- Only EPS Members (Individual Members, Member Societies and Associate Members) may make nominations for EPS Fellows.
- No person can be nominated while that person is a member of the Executive Committee.
- No person may make a nomination while a member of the Executive Committee.
- No self-nominations will be accepted.
- Nominations may be made at any time. Nominations must be received no later than 15 January of the year of the Council meeting that will decide on the Fellows to be admitted that year.
- All nominations must be accompanied by the following documentation:
  - Support letters from at least three EPS Members, including the principal nominator. These support letters should not all come from the same country nor from the same institution.
  - A CV of the proposed Fellow.
  - A brief description (maximum one A4 page) describing why the individual deserves to become an EPS Fellow. This should include the achievements in research, industry, education and/or service to the physics community or the Society that justify the nomination.
  - A short citation.

Nominations will be made to the EPS Fellowship Committee (care of the EPS Secretary General). ■

NEW 2008 MEMBERS OF THE EPS EXECUTIVE COMMITTEE

>>> INSIDE EPS

MARCIS AUZINSH (1956, Riga, Latvia)

My place of birth is the city of Riga. In 1974 I graduated from high school - even though the school had a chemistry profile and provided special classes in chemistry, my fascination was physics. I regularly participated in national contests of high school students in physics and for three successive years was the absolute winner. That was the time when I got infected with passion for school physics. Every summer I still lead the national team of high school students from Latvia to the International Physics Olympiad that takes place regularly in different countries all over the world.

In 1979 I got my physics diploma from the University of Latvia. I obtained a PhD from St. Petersburg University in 1986. After that some time was spent as a postdoctoral student in Peking University, China, and subsequently in Western Ontario University, Canada.

Finally I settled down at my home University – University of Latvia, where in 1995 I acquired a full professorship. Since then I have been a visiting professor in different universities - University of Sussex (UK), University of Bielefeld (D), University of Oklahoma (USA) and several others. The highest point of my international visits until today was in 2005 when I was elected as a Miller visiting professor at the University of California, Berkeley.

At home I have held various positions. I am a head of the Chair of Experimental Physics, have been the director of the Institute of Atomic Physics and Spectroscopy, the head of the Department of Physics and the dean of the Faculty of Physics and Mathematics. Currently I am rector of the University of Latvia.

My research interests most precisely are reflected in the monograph co-authored with Professor Ruvin Ferber – *Optical Polarization of Molecules* (Cambridge University Press, 1995, 2005) ■

HENDRIK FERDINANDE (1940, Gent, Belgium)

Born in Brugge (Belgium), I received my first degree in Engineering Physics at Ghent University, then obtained an MS degree in EE from Stanford University. Back to Ghent, I completed my higher education with a doctorate in engineering physics in 1973. My main research was devoted to low and intermediate energy nuclear physics. During the academic year 1973/74 and in the summer of 1975, I have been fellow and visiting researcher at the National Research Council of Canada, Ottawa. Since 1992 I was senior lecturer in nuclear instrumentation at Ghent University, wherefrom I retired in 2005.

I have always been fascinated by the European idea and have contributed to that in the last part of my career. I have not only stimulated and advised mobility to a large number of physics and engineering physics students at my own university from almost the beginning of the ERASMUS programmes, but I was the coordinator from the start in 1993 of the large co-operation *'European Mobility Scheme for Physics Students'* (EMSPS) established by EPS. From 1996 till 2003 I chaired and co-ordinated the *'European Physics Education Network'* (EUPEN), linking more that 150 Physics Departments from 30 countries in Europe. From 2005 and on, this initiative runs under the project name *'Stakeholders Tune European Physics Studies'* (STEPS). Recently I accepted the co-ordination of the EPS project *'The implementation of the Bologna Process in the Physics Studies in Europe'*, supported by the LLL Jean Monnet Programme for 'European Associations active at European level in the field of Education and Training' and to be executed at the International Centre for Higher Education Research (INCHER) from the University of Kassel (Germany) by Prof. B. Kehm.

In the EPS Executive Committee I hope continuing to develop the harmonization of the Physics Studies in the spirit of the Bologna Process by offering a greater transparency and a clearer understanding of the study programmes, hence making periods of learning abroad more the rule than the exception. ■

ANDERS KASTBERG (1963, Uppsala, Sweden)

I took my education in physics at Uppsala University, and I also did my graduate studies there, working with laser spectroscopy on ion beams. After my graduation, I obtained a post-doctoral position at the National Institute for Standards and Technology in Gaithersburg, outside Washington DC. During that time, I reoriented my research towards laser cooling and trapping, and ever since, my scientific focus has been on cold atoms, and in particular on cold atoms in periodic potentials – optical lattices.

In 1995, I received funding for setting up my own activities in laser cooling in Sweden, and I started this at Stockholm University. When I was offered a senior position by Umeå University around 2001, I started to move my group to Umeå, in northern Sweden.

I have been an associate editor for the European Physical Journal D for almost 10 years, and a co-editor for EPL for two years. I have also edited special issues for various journals. Since 2007, I serve as President of the Swedish Physical Society, and in that capacity I have represented Sweden at the last EPS councils.

In light of my interest and experience in scientific publications, it is natural that I will devote a part of my work with EPS to these issues. I feel strongly that it is important that we have good physics journals in Europe, and I believe that an extended pan-European collaboration on publication issues is a necessity.

I think physical societies in general have an important role to play for physicists and for society. Moreover, I am a strong believer in European collaboration. I have been impressed by the work of EPS in areas such as *e.g.* education and promotion of scientific collaborations, and I think there is a potential for doing even more. I look forward to working for EPS and its members. ■

ANA I. PROYKOVA (1951, Sofia, Bulgaria)

After a Master Degree in Physics (University of Sofia, 1974) I prepared a PhD (1980, University of Sofia & the JINR-Dubna, USSR) on the scattering of Mössbauer conversion electrons in very thin films. Then I developed various mathematical models concerning muon capture by nuclei and electron emission. Back in 1995 from the University of Chicago (USA), I focused on small systems (atomic and molecular clusters, nanotubes). Self-organization and critical phenomena observed in finite-size systems in equilibrium and thermodynamics of chaotic systems are of my current interest. After establishing the Monte Carlo Group in 1996 for computational theoretical study of matter, I supervised many students and post-docs. In 2008 I was awarded the Doctor of Science degree for my work on finite-size systems.

Besides my teaching duties, I have been a visiting scientist and lecturer at several universities and research centres: Catholic University of Louvain (Belgium), University of Washington (USA), Nagoya University (Japan), University of Chicago, Cologne University, the Jacob Blaustein Institute for Desert Research (Israel), National University of Singapore, Paul Scherer Institute, Villigen, (Switzerland), ICTP-Trieste (Italy).

In 2004 I became a member of the programme committee of the Nano-Materials & Production, TP3 in Brussels. Since 2002 I am team leader of IUPAP Working Group on Women in Physics and, since 2007, national delegate to the ESFRI. Being a member of the National Council on Nanotechnology (1998 and on) I am Vice-President since 2005. I belonged to the Executive Board of the Union of Physicists in Bulgaria (2001-2004). Currently I am on the Board of Administration of the European Platform of Women Scientists.

Besides article reviewing, I am Editor of the *International Journal of Molecular Science*, Founder and Editor of the annual proceedings "Meetings in Physics @ University of Sofia" (since 1999) and Editor of Atomic and Molecular Physics, *Central European Journal of Physics* (since 2006).

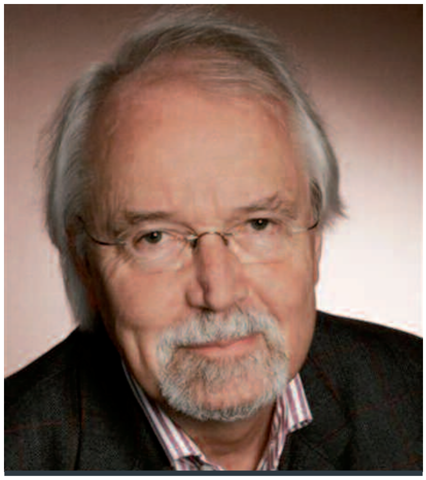
My goals as a member of Executive Committee of the EPS will be to encourage collaboration with and between national societies for the advancement of science, science education and the science community, particularly in physics; to help the physicists to create networks and clusters of research groups focused on multidisciplinary research; to work to establish gender balance at various levels including top positions in administration, professorships, and research councils. ■

KLAUS WANDELT (1944, Bonn, Germany)

After completing my higher education at the University of Hannover, Surface Science became the subject of my dissertation – and of the rest of my scientific career. I completed my PhD at the Ludwig-Maximilians-University (LMU, 1975) in Munich and then worked as post-doc at the IBM Research Lab. in San Jose, California. Back in Munich I did my habilitation (1981), again at the LMU, on electron spectroscopy of surfaces. Professor of physics at the LMU, (1983-86), I then moved with Gerhard Ertl, my former supervisor, to the Fritz-Haber-Institut of the MPG in Berlin. In1988, I became full professor and director of the Institute of Phyisical and Theoretical Chemistry in Bonn. My research interests include the whole spectrum of surface and interface science, from solid surfaces in vacuum over solid/liquid interfaces to epicuticular wax layers on green leaves.

Over the years I have been a visiting scientist and guest professor in Venezuela, China, Italy, Croatia, Australia, and California. I co-organized over 20 scientific conferences, workshops and symposia and edited as many conference proceedings, and I am Regional Editor of Surface Science since 1995.

From 1990 until 2002 I engaged myself in various positions in the German Physical Society (DPG), 5 years as the Chairman of the "Surface Physics Section", 3 years as Chairman of the "Condensed Matter Division", and 4 years in the Executive Committee, responsible for "Public Relations" (involved in the organization of the German "Year of Physics 2000" – and later of the German "Year of Chemistry 2001"). From 1992



until 1995 I was also Chairman of the "Surface Science Division" of the International Union of Vacuum Science, Techniques and Applications (IUVSTA), and since 1995 I am Chairman of the "Surface and Interface Section" of the Condensed Matter Division of the EPS, and as such I am also Chairman of Board of the annual "European Conferences on Surface Science (ECOSS)".

Since the creative minds of natural scientists are not only a good basis for our all our ecological and economic future survival, but together with their "common language" are also a good basis for creating mutual understanding and "common sense", the natural sciences deserve a better recognition in society. In order to claim and improve this public recognition, during my work in the EPS executive committee, I want to "provoke" more actions in the following directions:

- EPS should "become younger", and should in turn address more directly more young people. EPS should seek more immediate visibility at universities, *e.g.* by having a direct contact-person at each physics faculty in Europe, who, for instance, organizes colloquia occasionally under the explicit label "EPS-colloquium" in order to convey more directly the "spirit of a European Physical Society".
- Physics requires better "lobbying", as for instance chemistry. The closer contact between chemical societies and chemical industry (certainly in Germany) strengthens there common "lobbying", and reaches more attention in political decision making processes concerning education, ecology, economy, etc. ■

A LOOK AT THE IYPT ››› REPORT

IYPT, the International Young Physicists' Tournament, was invited to Croatia this year, to the beautiful coastal town of Trogir. We are grateful to our hosts for a wonderfully organized IYPT event. IYPT is a competition between teams composed of five pre-university students, accompanied by two team leaders, normally physics teachers. 21 teams were present two of which, namely China and Iran, for the first time. No less than six countries had sent observers, France, Macedonia, Serbia, Slovenia, Singapore and Thailand, implying that they may participate in the near future. As usual jury members were recruited among team leaders as well as university researchers and teachers.

The IYPT event starts with five qualifying rounds, so called physics fights, in each of which three teams compete by reporting their solutions to physics problems. There are 17 problems published about ten months before the actual event. Thus the students have time to prepare the solutions, by doing some research or by studying literature. In each physics fight, the teams takes on three different roles, as reporter, opponent or reviewer. The jury gives credits to each performance in the form of points. After the five qualifying rounds, the points are added, and the three top teams fight for victory in a final round. More details can be found at www.iypt.org

The best three teams were Germany, New Zealand and Croatia, with final ranking 1, 2 and 3. To give an idea of the type of problems discussed the German students had chosen the following:

Kaye Effect: When a thin stream of shampoo is poured onto a surface, a small stream of liquid occasionally leaps out. This effect lasts less than a second but occurs repeatedly. Investigate this phenomenon and give an explanation.

In the report they presented a video showing the effect; later a very good physics explanation was given where theoretical deliberations played an important role.

In July 2009 the 22nd IYPT event will take place at Nankai University in Tianjin, China.

On a personal note, I should like to add that since my first appearance in IYPT competitions, in 1995, I have been generously supported by EPS. Our association owes warm thanks to EPS also for help in establishing its legal site in Mulhouse. This happened in November 2007 after some years of negotiations with community authorities and writing Statutes. ■

Gunnar Tibell,
IYPT President 1998 - 2008

▼ **The acronym of IYPT made up of participants standing on a hillside in a Croatian national park.**

CELEBRATING 10 YEARS OF NEW JOURNAL OF PHYSICS

››› PUBLICATIONS

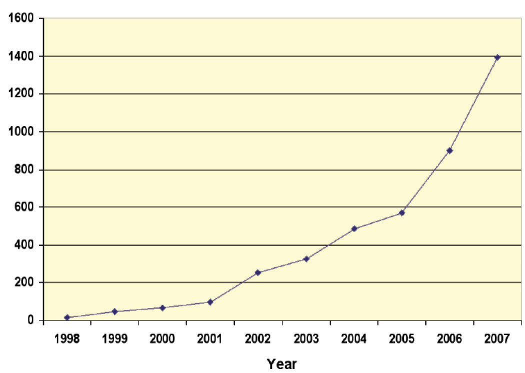
This year *New Journal of Physics* (NJP) celebrates its 10th anniversary of publishing permanently free-to-read, cutting-edge research for the benefit of all physicists. As the journal's current Editor-in-Chief it is my privilege to be involved alongside my other prestigious colleagues on the Editorial Board with one of the fastest growing and, I believe, most important journals in physics.

Launched by the Institute of Physics (IOP) and Deutsche Physikalische Gesellschaft (DPG) as a joint venture in 1998, NJP represented a truly innovative and compelling departure from the traditional, subscription-based journal's publishing model. Its ethos, based on an article publication charge model, to provide a free-to-read, electronic-only publishing outlet for physics research, charted a novel way forward towards addressing both the perceived spiralling journals "pricing crisis" and the then challenge of the Internet as the new electronic medium. All at a time before the term "Open Access" had been invented!

The original core objective for NJP was simple – to publish physics research of outstanding quality, and to remove financial barriers for all readers. In this way researchers across the world, regardless of financial means, would be able to access the kind of cutting-edge, *peer-reviewed* physics research that may previously have been unavailable to them. The journal's open-access model would also ensure the widest possible dissemination of an authors work, and through its electronic medium the vision was for NJP to offer rapid publication coupled with all of the advantages of online functionality.

The benefits of NJP to the reader are clear; permanently free access across the world to physics research of (we hope) the highest quality and impact. With a readership extending to over 190 countries, and amounting to more than 50,000 downloads each month, NJP is now established internationally as a journal that has proved able to achieve the widest and most effective delivery of its content.

Continuous and rapid growth in article submissions (see figure) also reveals how NJP has become an increasingly attractive journal for authors (amounting to a ten-fold increase in the number of published papers over the last 5 years). With guaranteed high article visibility (an NJP paper is downloaded, on average, more than 700 times within 12 months of publication), NJP authors and their work benefit from exposure to a new, wider audience, in addition to maximised citations and impact. NJP's current Impact Factor is 3.26 and in analysis that further underlines the journal's enhanced editorial stature, it has been repeatedly identified by *Thomson ISI* over the last two years as a '*Rising Star*' in physics – this being the journal that has achieved the highest percentage increase in total citations out of all physics journals. The culmination of this editorial growth over the last decade, coupled with modest increases in the article charge and growth in the proportion of authors willing and able to pay the publication fee, now means that this year NJP will achieve the key milestone for an open-access journal of becoming financially self-sustainable.



▲ **Growth in article submissions to NJP over the last 10 years.**

Receiving the backing of the community it serves is vital to any research journal and from the outset NJP and its open-access ethos has been fortunate to enjoy the support of large sections of the physics community through the journal's close links with national physical societies around the world. In Europe, this support has been underpinned through the formal endorsement of the European Physical Society (EPS) and eleven other physical societies (out of a total of eighteen worldwide) which, as NJP Associate Members, collectively underline the journal's strong European character.

I therefore take this opportunity to acknowledge the physics community in Europe as a whole for its vital contribution to the success of NJP. Over the last ten years you have been responsible for nearly 100 NJP editors, more than 1,500 referees, in excess of 1,300 published articles and over 900,000 article downloads. Thank you!

In summary, now ten years and more than two million article downloads on, NJP is firmly positioned not only at the forefront of the open-access movement, but also as a leading, internationally renowned, European-based physics journal in its own right. A proven editorial success, and one that is enjoying growing support from the physics community worldwide, NJP looks well placed to continue to play a pivotal role in scholarly communication in the years to come just as it has done in its first decade. ■

Eberhard Bodenschatz,
Editor-in-Chief, New Journal of Physics

Some of the article highlights published in NJP over the last 10 years are collected now at http://njp.org/10years.

THE EUROPEAN PHYSICAL JOURNAL (EPJ) CELEBRATES ITS 10 YEARS »» PUBLICATIONS

As Europe rightly celebrated the 50th anniversary of the Treaty of Rome last year, we are left to ponder what aspects of unification may have been overlooked so far. Scientific publishing plays a prominent role as it links economics with scientific and cultural issues and could thus be considered a good testbed for European "self-assurance" in this field. In the following discussion we shall restrict ourselves to the physical sciences, though many facets of this issue are readily transferable to other natural sciences.

By the 1960s it had become evident that the focus of scientific research and publishing in physics had moved from Europe to the US, still it took a long time to realize that the individual European journals would have to team up, in order to present a serious alternative to their efficient US based counterparts. It was only in 1986 that the first significant merger took place when the Lettere al Nuovo Cimento (Italian Physical Society, SIF) combined with the Journal de Lettres Physique (EDP Sciences/ French Physical Society) to form Europhysics Letters (EPL), under the scientific leadership of the European Physical Society (EPS).

The launch of EPL could only be the first step. In the 1990s, further negotiations began between a number of **national physics communities and publishers concerned by the prospect of a unified European publishing platform** to merge many, if not all of their physics journals. Eventually, in 1998, The European Physical Journal (EPJ, Fig.1) was launched as a merger of Il Nuovo Cimento (SIF), Journal de Physique (EDPS) and Zeitschrift für Physik (Springer). This represented the most important move yet in terms of combined size and impact. Indeed, ten years later, EPJ has succeeded in transcending its national roots, receiving high-level papers from all over the world (by now more than 3,000 per year) and conversely being distributed, mostly electronically, to some 4200 institutions worldwide with an enormous surge of visibility and usage… (Fig 2).

▶ FIG. 1: Logo of The European Physical Journal (EPJ) www.epj.org

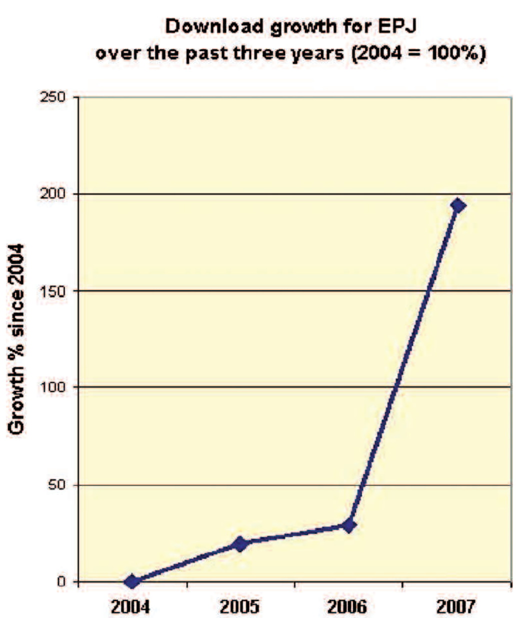
The combined archives of EPJ and of its predecessor journals contain an unparalleled treasury of 20th century physics publications [1]. As of today, EPJ is proud to present itself as a continuation of Acta Physica Hungarica, Anales de Fisica, Czechoslovak Journal of Physics, Il Nuovo Cimento, Journal de Physique, Portugaliae Physica and Zeitschrift für Physik. Yet, the European landscape remains fragmented, an issue that the European Physical Society plans to address in a larger context in the near future [2]. Meanwhile, EPL and EPJ (as well as other cooperating journals) are related to each other through an editorial transfer agreement, allowing the transfer of papers in relevant cases [3].

EPJ currently consists of seven distinct journals: EPJ A - Hadrons and Nuclei , EPJ B - Condensed Matter and Complex Systems, EPJ C - Particles and Fields , EPJ D - Atomic, Molecular, Optical and Plasma Physics, EPJ E - Soft Matter (since 2000), EPJ AP - Applied Physics and EPJ ST - Special Topics (since 2007).

The journal also experiments with new publishing models such as open-access publishing [4] and combines any modern approaches with the traditional careful and personalized evaluation of submitted work as well as thorough copy-editing of manuscripts.

Last but not least, EPJ is an excellent example of cooperation between learned societies and publishers. It is through the combination of their efforts that this platform can exist as an independent, high-quality and economically self-sustained part of the European science industry. ■

▼ FIG. 2: Rapidly increasing visibility and usage of EPJ



Maria Bellantone, **Christian Caron**, **Agnès Henri**, **Jean-Francois Joanny**, **Angela Oleandri**, **Angiolino Stella**
The EPJ Steering Committee

References

[1] Currently being built at www.epj.org/archives.html

[2] O Poulsen: Physics in Europe, *Europhys. News* 37/2 (2006)

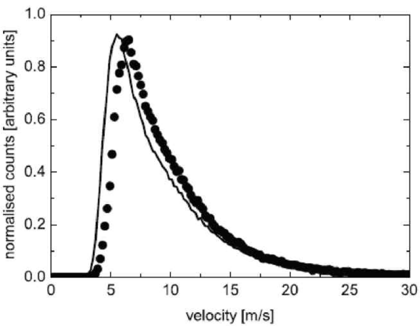
[3] www.epj.org/_pdf/transfer.pdf

[4] www.epj.org/open_access.html

HIGHLIGHTS FROM EUROPEAN JOURNALS

Neutron velocity distribution from a superthermal solid $^2H_2$ ultracold neutron source

Neutrons with velocities below ~ 7 m/s are termed ultracold. They are produced in non-equilibrium superthermal converters, *e.g.*, superfluid helium or solid deuterium, and can be stored in vessels with a storage time constant close to the neutron lifetime. They are used for the measurement of fundamental properties of the neutron, such as the electric dipole moment*, the lifetime of the free neutron*, and the gravitational interaction*. For an increased precision of these experiments, very intense new ultracold neutron (UCN) sources are in construction. The velocity distribution of the neutrons from a solid deuterium converter at 5 K is very important for the design of these new UCN sources.



▲ **Neutron velocity distribution from the superthermal solid $^2H_2$ ultracold neutron source at TRIGA Mainz. Full dots: absolute velocity deduced from the TOF data. The line represents the velocity component parallel to the neutron beam axis.**

This velocity distribution has now been determined for the first time at the UCN source at the TRIGA reactor in Mainz* using the time-of-flight (TOF) method: (i) The neutron spectrum rises sharply above 4.5 m/s . After transport in an 8 m stainless-steel neutron guide, the distribution has a maximum around 7 m/s, and decreases approximately exponentially above this velocity. (ii) Though expected from, *e.g.*, deceleration in neutron optics*, this experiment confirms the recent first experimental verification of neutron acceleration by the material optical potential of a solid $^2H_2$ UCN converter*. As a consequence, the number of storable neutrons in an experiment can be increased considerably (by a factor of ~ 2) by placing the corresponding experimental setup outside the biological shielding about 1 m above the UCN converter. (iii) A solid $^2H_2$ UCN converter provides also 'very cold neutrons' for experiments. These neutrons have velocities above the UCN velocity range, *i.e.*, with 7 m/s < v_n < 25 m/s. ■

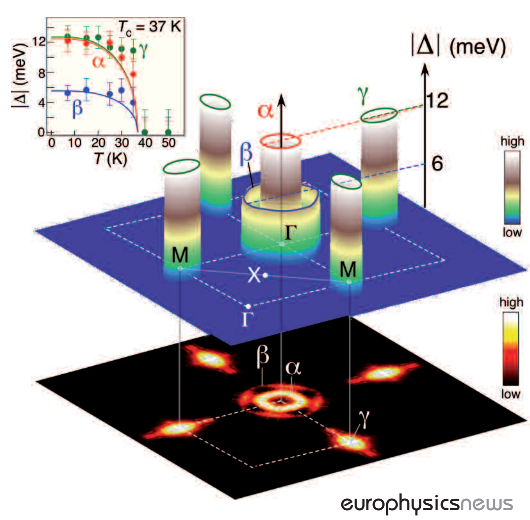
I. Altarev *et al. (16 co-authors)*, 'Neutron velocity distribution from a super-thermal solid $^2H_2$ ultra-cold neutron source', *Eur. Phys. J.* A, **37**, 9 (2008)

* References to be found in the original article.

Pairing symmetry of iron-based superconductors

The recent discovery of superconductivity in iron-arsenic compounds with a transition temperature (T_c) as high as 55 K, ended the monopoly of copper-oxides in the family of high-T_c superconductors. A critical issue in understanding this new superconductor is the symmetry of the superconducting pairing gap. An international team led by Dr. H. Ding of the Institute of Physics, Chinese Academy of Sciences has reported a direct observation of the superconducting gap, including its momentum, temperature, and Fermi surface (FS) dependence in single crystals $Ba_{0.6}K_{0.4}Fe_2As_2$ (T_c = 37 K) using angle-resolved photoelectron spectroscopy. They discovered two nodeless and nearly isotropic superconducting gaps around their respective FS sheets: a large gap (Δ ~ 12 meV) on the two small hole-like and electron-like FS sheets, and a small gap (~ 6 meV) on the large hole-like FS. Both gaps close simultaneously at the bulk T_c. The isotropic pairing interactions are strongly orbital dependent, as the ratio $2\Delta/k_B T_c$ switches from weak to strong coupling on different bands. The same and surprisingly large superconducting gap due to strong pairing on the two small FS sheets, which are connected by the (π, 0) spin-density-wave wave vector in the parent compound, strongly suggests that the pairing mechanism in the iron-based superconductors originates from the inter-band interactions between these two nested FS sheets.

H. Ding, **P. Richard**, **K. Nakayama**, **K. Sugawara**, **T. Arakane**, **Y.Sekiba**, **A. Takayama**, **S. Souma**, **T.Sato**, **T. Takahashi**, **Z. Wang**, **X. Dai**, **Z. Fang**, **G. F. Chen**, **J. L. Luo** and **N. L. Wang**, 'Observation of Fermi-surface–dependent nodeless superconducting gaps in $Ba_{0.6}K_{0.4}Fe_2As_2$', *EPL* **83**, 47001 (2008)



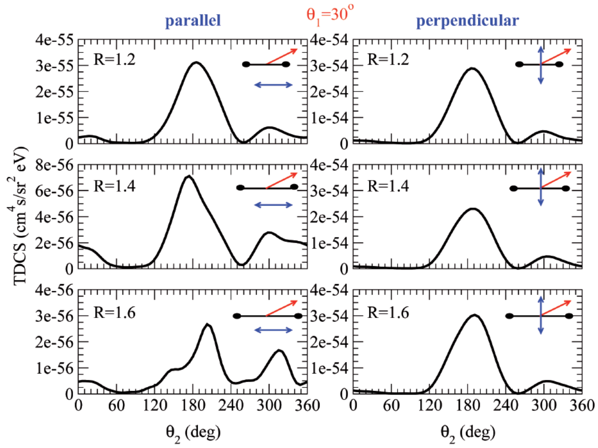
▶ **Three-dimensional plot of the superconducting-gap size (Δ) measured at 15 K on the three observed FS sheets (shown at the bottom as an intensity plot) and their temperature evolutions (inset).**

Two-photon double ionization of H_2

Recent advances in free-electron laser technology, allied with new detection technologies, have allowed experimental investigations of few-photon fragmentation of light atoms such as helium and neon. These exciting experimental advances have been matched by the application of powerful theoretical tools for exploring how atoms and molecules respond to XUV and X-ray light. Such tools have shown good agreement between experiment and theory for the removal of both electrons from He and H_2 by one photon, and recently investigated how the helium atom fragments after the absorption of two photons.

A recent communication has, for the first time, shown how H_2 responds to interaction with two photons, by directly solving the time-dependent Schrödinger equation for the outgoing electrons under the influence of the Coulomb field of the molecule and of the laser light. Some similarities are found with the analogous process in helium; the total probability for removal of both electrons is similar for helium and H_2.

When the molecule is oriented perpendicular to the laser polarization, the angular distributions of the outgoing electrons also show similarities to distributions arising from double ionization of helium. However, when the molecule is parallel to the polarization, the distributions are different from the atomic case. Moreover, these distributions show some dependence on the internuclear separation of the molecule at the time of ionization. Such sensitivity to the internuclear separation has also been found for the `parallel geometry' for double ionization of H_2 by a single photon and for photoionization of H_2^+. ■



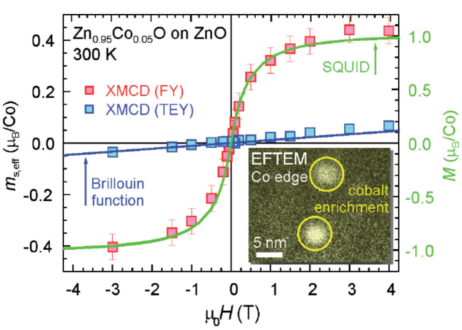
▲ Angular distributions for the double ionization of H_2 by two 30 eV photons. The internuclear separation is increased going down the panels; the left panels show the 'parallel geometry' and the right panels show the 'perpendicular geometry'.

J. Colgan, **M.S. Pindzola** and **F. Robicheaux**, 'Two-photon double ionization of the hydrogen molecule', *J. Phys. B: At. Mol. Opt. Phys.* **41**, 121002 (2008)

The nature of ferromagnetism in cobalt-doped ZnO

The rapidly emerging field of spintronics requires material systems combining ferromagnetism (FM) with the versatile electronic properties of semiconductors. Diluted magnetic semiconductors (DMS) such as Mn-doped InAs or GaAs are very attractive in this regard. Unfortunately, these well established DMS have Curie temperatures $T_C \leq 170$ K, preventing room temperature (RT) applications. In contrast, $T_C > 300$ K has been predicted for cobalt-doped ZnO and ferromagnetic behavior has been reported. However, there is an ongoing debate on whether this material is really a DMS or the observed behavior is caused by magnetic nanometer-sized precipitates of the Co dopant atoms embedded in a nonmagnetic ZnO matrix.

To unambiguously clarify the nature of FM in ZnO:Co thin films we have combined SQUID magnetometry, X-ray magnetic circular dichroism (XMCD), and AC susceptibility measurements with careful X-ray and high resolution TEM studies. We simultaneously recorded XMCD spectra in both the total electron (TEY) and the fluorescence yield (FY) modes, allowing for an element-specific distinction between surface and bulk magnetic properties. Our data provide clear evidence that our ZnO:Co thin films are not homogeneous DMS. Rather the observed RT magnetic behavior is caused by nanometer-sized superparamagnetic Co precipitates, which are directly evidenced by XMCD and energy-filtering transmission electron microscopy (EFTEM). Of course, our data do not prove that the realization of a DMS is impossible for ZnO:Co. However, more effort is required to unambiguously determine the nature of FM, and conclusions based on superficial studies should be considered with care. ■



▲ Effective spin magnetic moment $m_{s,eff}$ of Co in ZnO:Co, derived from TEY and FY XMCD measurements. The FY data follow the sample magnetization M. The TEY data fit well to a Brillouin function for paramagnetic Co^{2+} ions. The inset shows an elemental map of Co obtained by EFTEM, displaying Co enriched regions.

M. Opel, **K.-W. Nielsen**, **S.Bauer**, **S.T.B. Goennenwein**, **J.C.Cezar**, **D. Schmeisser**, **J. Simon**, **W. Mader** and **R. Gross**, 'Nanosized superparamagnetic precipitates in cobalt-doped ZnO', *Eur. Phys. J. B* **63**, 437 (2008)

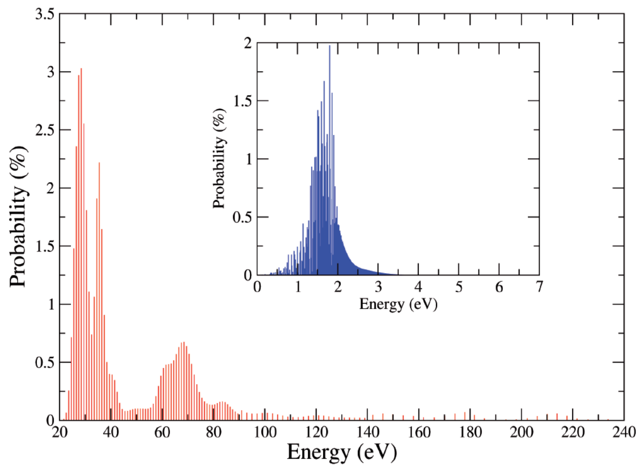
Excitations to the electronic continuum of $^3HeT^+$ in investigations of T_2 β-decay experiments

Recent measurements both using solar neutrinos and ground based experiments have demonstrated conclusively that neutrinos have a mass. However so far only upper bounds exist for this fundamental parameter. Several laboratory-based experiments have attempted to measure the mass of a particular flavour of neutrino based on careful measurement and analysis of the energy distribution of ejected beta particles. These end point experiments are difficult and previous ones have been bedevilled with systematic errors due, at least in part, to difficulties with the complete understanding of all the physical processes important in the experiment.

The KATRIN (Karlsruhe Tritium Neutrino) experiment aims to make a significantly more accurate measurement of the mass of the electron antineutrino; the planned precision is 0.2eV. KATRIN will analyse the endpoint of ß-decay of cool, gaseous triterated hydrogen molecules, T_2. The decay process under scrutiny will therefore be: $[T_2 \rightarrow {}^3HeT^+ \, e^- + \overline{\nu}_e]$ To model the shape of the endpoint distribution correctly it is necessary to have a detailed, reliable knowledge of the final state probability distribution of the resulting $^3HeT^+$ molecular ion.

This paper presents calculations of the final state probability distribution for excitations to the electronic continuum of $^3HeT^+$. The R-matrix method is used to treat explicitly resonance states of $^3HeT^+$, allowing for nuclear motion, and implicitly the background continuum. When combined with previous studies of other energy ranges, 99.94% of the decay probability is recovered, a significant improvement on previous results. ■

N. Doss and **J. Tennyson**, 'Excitations to the electronic continuum of $^3HeT^+$ in investigations of T_2 β-decay experiments', *J. Phys. B: At. Mol. Opt. Phys.* **41**, 125701 (2008))



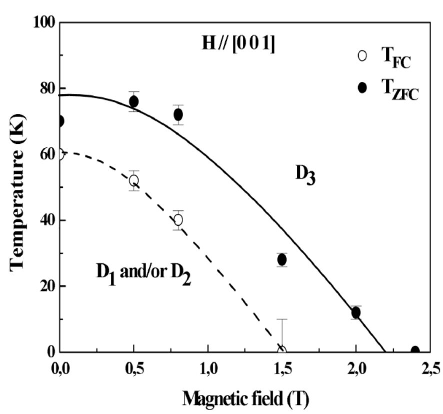
◀ Final state probability distribution of the electronic ground state (inset) and the electronically excited states and electronic continuum (main graph) of $^3HeT^+$ resulting from the ß-decay of T_2. The probability distribution is presented in a discretized form, using energy bins of 0.01 eV for the ground state, 1 eV bins for the excited states and the electronic continuum up to 90 eV, 2 eV bins from 90-140 eV and 4 eV bins from 140-240 eV.

Magnetic ordering in (110) Eu films in a magnetic field

Below its ordering temperature (90K), bulk bcc Eu has a helical magnetic state with propagation vectors along the three equivalent <100> directions. In contrast, epitaxial (110)Eu films exhibit a unique magnetic ordering : the domain with a magnetic helix propagating along the in-plane [001] direction vanishes on cooling (below T_d), at the expense of other domains with helices propagating along [100] and [010]. In addition, the two remaining propagation vectors continuously rotate towards the [110] growth direction. Both the temperature T_d and the rotation of wave vectors exhibit a pronounced dependence on film thickness, as a consequence of a thickness- and temperature- dependent lattice clamping effect that distorts the Eu lattice at low temperature.

The helix propagating along the [001] direction can be restored by the application of an external field along this direction. On the contrary, when a magnetic field is applied along an intermediate direction, $[\bar{1}10]$, the domain with a helix propagating along [001] is suppressed. Both effects depend on film thickness. They are explained if one considers that, because of the low magnetic anisotropy of Eu, a helix with a propagation vector parallel to (or close to) the applied magnetic field is energetically more favorable than cycloidal structures with unchanged propagation vectors. Finally, the amplitudes of the propagation vectors and their directions do not vary under magnetic field. ■

S. Soriano, **C. Dufour**, **K. Dumesnil** and **Ph. Mangin**, 'Magnetic ordering in (110) Eu films in an applied magnetic field', *Eur. Phys. J.B* **63**, 469 (2008)



▲ Magnetic field temperature diagram for a 375nm thick (110)Eu film when the magnetic field is applied along [001]. Empty symbols correspond to T_{FC} the temperature of vanishing of D_3 (the domain with a helix propagating along [001]) when decreasing temperature. Filled symbols correspond to T_{ZFC} the temperature of appearance of D_3 when increasing temperature. D_1 and D_2 are respectively the magnetic domain with an helix propagating along [100] and [010]. Continuous lines are guides for the eyes.

Magnetic interactions of cold atoms with surfaces: Material engineering meets atom optics

Experiments with ultra-cold neutral atoms trapped in potentials generated by micro-structures integrated on a nearby surface (atom chips) are evolving rapidly and may soon enable robust quantum devices. This decade has seen atom chip based coherent manipulation (interferometry) of both internal and external atomic degrees of freedom.

The promise of the atom chip platform may, however, be hindered by thermal noise originating from the nearby "classical environment", specifically the motion of finite-temperature electrons present in the surface. The coupling of this noise radiation to the atoms results in atom loss, heating and decoherence. Slight imperfections in the fabrication of this nearby environment also lead to static corrugations of the trapping potential, which can cause a variation of the atoms' density in traps, as well as lead to localization in guides and perturb quantum phase evolution in interferometry. This paper describes the implications of using novel materials on the atom chip for the micro-structures creating the trapping and guiding potentials and specifically electrically anisotropic materials. Using such materials, decoherence and heating rates can be significantly reduced, even for room temperature atom chips. In addition, the amplitude of the static potential corrugation can be reduced, as typical electron scattering patterns within the imperfect wires can be controlled. Materials, fabrication, and experimental considerations are discussed. ■

T. David, **Y. Japha**, **V. Dikovsky**, **R. Salem**, **C. Henkel** and **R.Folman**, 'Magnetic interactions of cold atoms with anisotropic conductors', *Eur. Phys. J. D* **48**, 321 (2008)

Time-independent theory of ionization and breakup reactions

Under the stimulus of advances in experimental techniques and methods of numerical calculation, numerous theoretical investigations have recently been undertaken of the process of single ionization of an atom (or breakup of a nuclear target) by impact of a charged projectile. Encouraged by such advances, more ambitious programs, involving multiple ionization and nuclear breakup reactions, are now being undertaken. The theoretical basis for such calculations is rather less firm than it is for single ionization. One looks for refinements in the basic formulation of the problem to allow for more effective numerical investigations.

A rigorous theory of non-relativistic time-dependent multiparticle collisions was developed (by J. D. Dollard) quite some time ago, in which the effect of long-range Coulomb forces was accounted for by a modification of the standard wave operator, describing propagation of particles in initial and final states, that appears in treatments of neutral-particle scattering. While it establishes the existence of the scattering matrix, that theory provides no specific procedure to be used for the calculation of the transition probability.

In order to have available a method more amenable to numerical calculation, this time-dependent theory is converted, in the present work, to a time-independent form, with the wave-operator modification replaced by the use of Coulomb-modified plane waves in the construction of the wave packets that appear in the formalism. This provides a convenient basis for the development of approximation techniques in configuration space, including the use of variational methods of calculation, based on integral identities for the transition amplitudes. In many cases oscillatory divergences appear in integrals representing the ionization or breakup amplitudes; this disturbing feature is intrinsic to the theory. A rigorously justified method for removing such divergences by an averaging of the integrand at great distances is here defined. ■

L. Rosenberg, 'General time-independent theory of ionization and breakup reactions', *J. Phys. B: At. Mol. Opt. Phys.* **41**, 155203 (2008)

The "footprints" of irreversibility

The reversibility paradox stated by Loschmidt in response to Boltzmann's H-theorem illustrates the apparent incompatibility of the time reversal symmetry governing the dynamics of microscopic processes and the second law of thermodynamics ruling their macroscopic behaviour. One century later, exact equalities, referred to as work and fluctuation theorems, reveal that the very same time-reversal-symmetry puts strong constraints on the *probability distributions* of work, heat and entropy in non-equilibrium experiments involving small scale devices. These equalities are compatible with the second law of thermodynamics, but provide no extra information on the actual value of the entropy increase. Even more recently, Kawai, Parrondo, and Van den Broeck [*Phys. Rev. Lett.* **98**, 080602 (2007)] have derived from Hamiltonian dynamics the exact value of the entropy production, relating the mean work dissipated in an arbitrary non-equilibrium experiment directly to the statistical difficulty of distinguishing whether a snapshot of the microstate of the system pertains to an experiment carried out forward or backward in time.

This statistical indistinguishability is quantified through a concept from information theory: the relative entropy or Kullback-Leibler distance between two probability distributions.

Now, Gomez-Marin, Parrondo, and Van den Broeck have extended the previous result to the relative entropy between the distributions of paths or trajectories. Furthermore, by combining the mathematical properties of the relative entropy with the work theorem, they have been able to identify the relevant information to exactly evaluate the entropy production along an arbitrary process connecting two equilibrium states. Their conclusion is striking: the only relevant variables are those containing the statistical information about the work performed in the experiment. Any further information does not improve the discrimination of the arrow of time. Therefore, such variables provide, without the need of other microscopic information, the "footprints" of irreversibility. ■

A. Gomez-Marin, **J.M.R. Parrondo** and **C. Van den Broeck**, 'The "footprints" of irreversibility', *EPL* **82**, 50002 (2008)

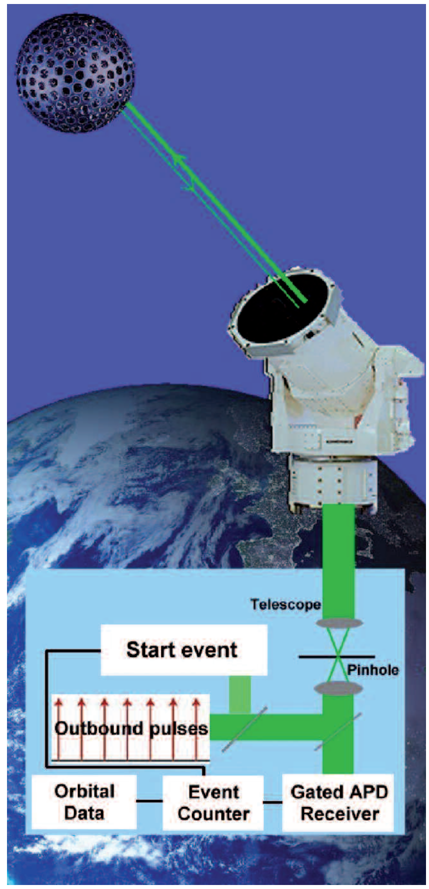
Feasibility of a quantum channel between space and Earth

Our goal was to establish a link between an orbiting source of single photons and a ground telescope, as the first step in the communication space-ground or space-space and based on the coding of the bits of information in the quantum state of a photon, or qubit. Our experiment also demonstrated that present technology is mature enough for this purpose, and the crucial crossing from the theoretical predictions and the experimental demonstration was possible. However, a combined effort from different expertises was needed from classical optics, to satellite laser-ranging for geodesy, to quantum optics, to advanced electronics.

More in detail, in this experiment we have simulated a quantum communication source onboard a satellite, and showed how the very dim signals could be detected. Such a quantum source has to fulfill the particular requirement, that only one single photon per pulse is emitted. In this work this is realized by sending a rapid sequence of weak laser pulses towards a Japanese satellite (Ajisai) that is equipped with retroflectors, (*see the figure*) The main challenge was to detect the very few reflected photons amongst a huge background signal which is exactly the same situation as would be if we had the real quantum communication system.

The next step of our work would be placing of an active source of single photons and a measurement system for the photons state into space. This will realize quantum physics experiments over much larger distances than possible on ground. This will push the limits of fundamental physics tests to longer distances, and also allow the quantum key distribution on a global scale, probably the only secure method for the exchange of cryptographic keys. In addition, novel methods for exchange information as quantum teleportation will be possible. ■

P. Villoresi, **T. Jennewein**, **F. Tamburini**, **M. Aspelmeyer**, **C. Bonato**, **R. Ursin**, **C. Pernechele**, **V. Luceri**, **G. Bianco**, **A. Zeilinger** and **C. Barbieri**, 'Experimental verification of the feasibility of a quantum channel between space and Earth', *New J. of Phys.* **10**, 033038 (2008)

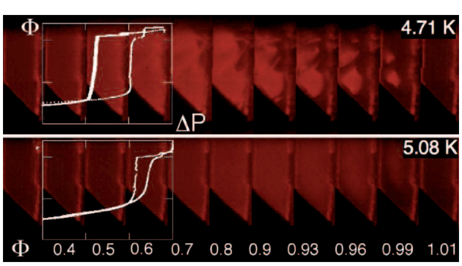


▶ The MLRO telescope linked to a SRL satellite. An avalanche photodiode (APD) detects the gathered photons, that are then correlated with the outgoing pulses.

Phase transition in the condensation of ^{4}He in aerogels

Although widely studied, capillary condensation of fluids in disordered mesoporous media is not fully understood. A central question is the origin of the hysteretic behaviour, as a function of pressure, of the adsorbed amount of fluid. It has been recently proposed that this hysteresis could result from the disorder of the porous media. A specific prediction is the existence of a disorder-driven transition similar to that occurring in the random field Ising model. At a given disorder, this transition implies a change of shape, from smooth to steep, of the hysteresis loop as the temperature is decreased below a critical value.

Our experiments support this view. Condensation of helium in different silica aerogels, synthesised at Montpellier and Northwestern universities, has been studied using combined optical and thermodynamic measurements below the bulk critical temperature (5.2 K). Silica aerogels of large porosity (95% to 98%) provide a natural realisation of dilute disorder, while the small index of refraction of helium makes it possible to image the condensation process, at the macroscopic and microscopic scales. As illustrated in the figure for one of the aerogels studied, the adsorption branch becomes steeper at low temperatures, associated with a change in the morphology of the condensation process. Together with the first evidence in favour of the new theory, these experiments illustrate the power of studying helium in transparent porous glasses to address the problem of condensation and evaporation of fluids in porous media. ■



◀ Condensation in a base-synthesised aerogel of porosity 95%. The white curves show the condensed fraction F plotted versus the distance ΔP to the bulk saturation pressure. Between 5.08 K and 4.71 K, the adsorption isotherm becomes steeper. Correlatively, the condensation process changes from homogeneous to heterogeneous. These modifications are an evidence for a disorder-driven transition.

F. Bonnet, **T. Lambert**, **B. Cross**, **L. Guyon**, **F. Despetis**, **L. Puech** and **P.E. Wolf**, 'Evidence for a disorder-driven phase transition in the condensation of ^{4}He in aerogels', *EPL*, **82**, 56003 (2008)

[PHYSICS IN SPACE]

THERMOPHYSICAL PROPERTIES OF MATERIALS

››› DOI 10.1051/epn:2008501

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For a wide range of new products in the industrial production chain, solidification processing of metallic alloys from the melt is a step of uppermost importance. Such advanced products are usually complex and made up of many components. Examples are:

- turbine blades for land-based power plants and for jet engines sustaining high temperatures and high stress levels,
- low-emission energy-effective engines for cars and aerospace,
- so-called supermetals (amorphous metal alloys) such as thin sheets for electronic components with ultimate strength to weight ratio,
- high-performance magnets,
- biocompatible medical implants such as hip replacements,
- new semiconductors for solar cell applications,
- fine metallic powders to catalyse chemical reactions,
- new low-weight and high-strength materials for space exploration and future space vehicles.

Accordingly, to produce materials that meet ever-higher specific requirements, in particular to save energy by reducing weight or for use at high temperature, the solidification processing of structural materials has to be controlled with ever-increasing precision. This aim is most efficiently achieved by means of predictive quantitative numerical simulations of grain-structure formation using sophisticated integrated software, to improve casting quality and reproducibility, yield strength, creep resistance and other properties (Figure 1).

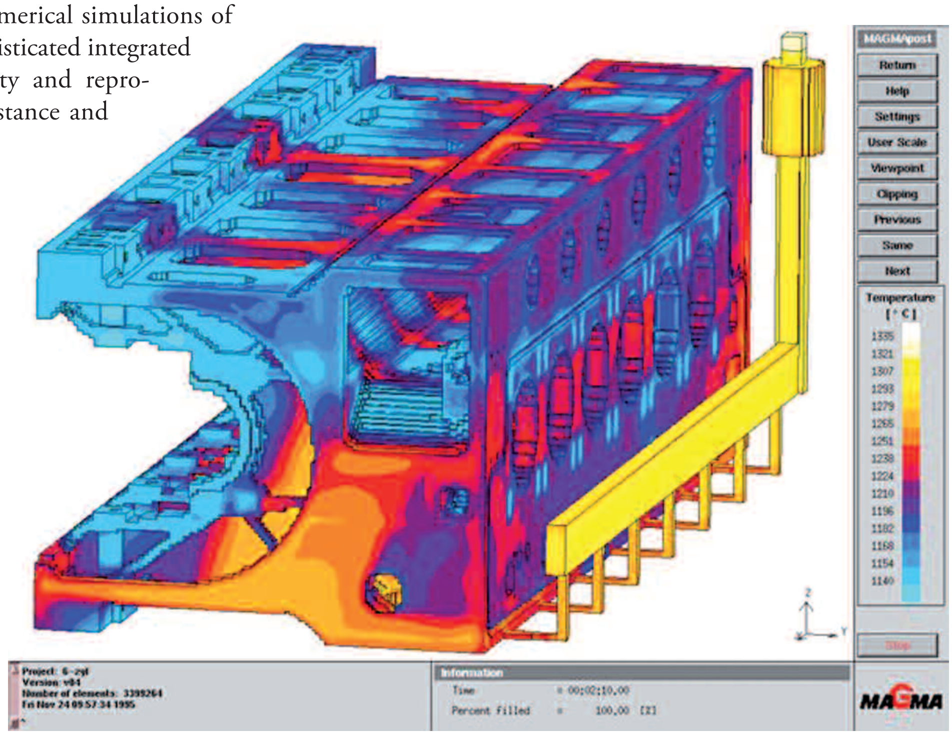
Current limitations

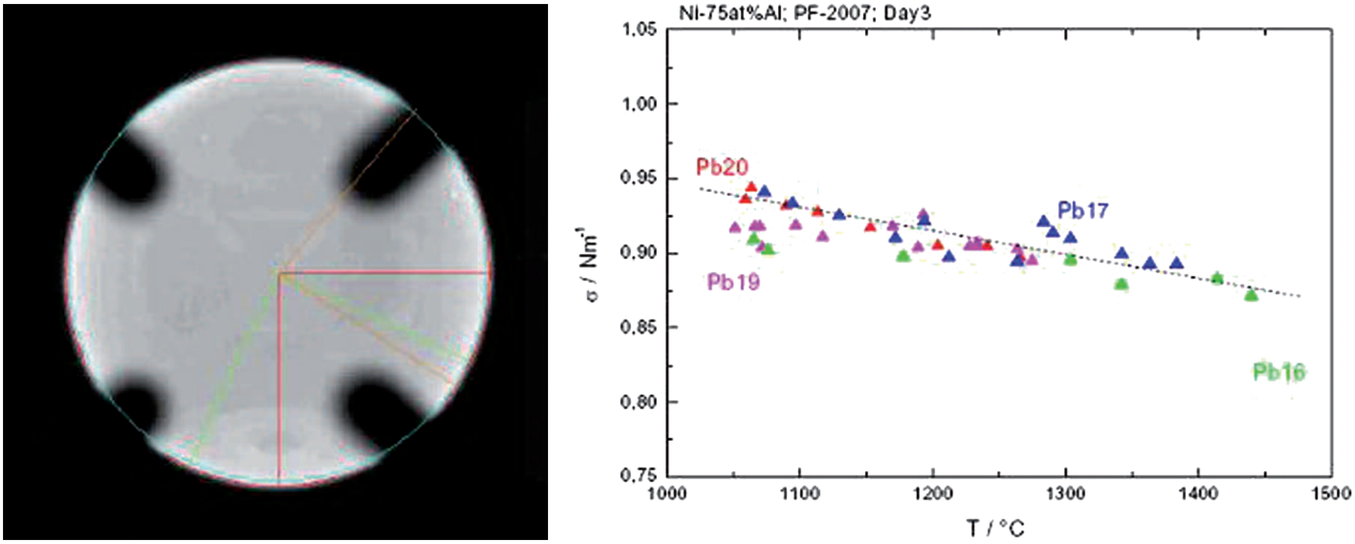
The application of such numerical tools is generally hampered by the lack of reliable thermophysical property values of the relevant liquid metals and alloys, needed as input parameters for the computational models [1,2]. In this respect, there is a discrepancy between the ever increasing sophistication of the numerical models and computer power, and the availability or accuracy of the thermophysical property data for the liquid phase. The paucity of data is generally owed to the high chemical reactivity of most metallic alloys in the liquid phase. This holds in particular for high-temperature alloys such as *Ti* alloys and *Ni*-based superalloys, but also for some lower-temperature light weight alloys such as the *Mg* and *Li* alloys. These are of interest to the automotive and aerospace industries. The current space-related research projects were conceived to improve this situation by combining conventional thermophysical property measurements with advanced containerless processing techniques of hot melts on ground and under reduced gravity conditions.

Levitation of hot metallic drops in space

Levitation of molten metals and other materials has been developed to solve a series of practical issues [1]. First, high-temperature chemical reactivity between liquid and container is often rather devastating (*e.g.* silicon in contact with graphite). The resulting sample contamination then drastically falsifies the measurements of thermophysical properties. Second, heterogeneous nucleation of solid phases easily occurs at the container wall. This makes deep undercooling and growth of metastable ▸

▼ **FIG. 1:** MAGMASOFT® numerical simulation of the surface temperature distribution over a car engine block immediately after mould filling





▲ **FIG. 2: Left panel: Spherical droplet of a molten Ni-75%Al sample (8 mm diameter) obtained in a parabolic flight. Video images allow measurements of the surface tension and viscosity as a function of temperature. Right panel: surface tension between 1050 and 1450 °C (the symbol Pb denotes the number of parabola performed during a single flight day)**

▸ phases unattainable. Conversely, without a container undercooling levels of several hundreds °C below the melting point can be achieved.

A reduced gravity environment adds further key merits to containerless levitation processing [1], namely:

- Achievement of perfectly spherical drop shape
- Levitation forces required to hold the samples are much lower than at 1-g conditions, resulting in improved temperature control (within 0.1 K) and sample stability
- Improved control of sample environment (excellent vacuum conditions)

Furthermore, segregation and sedimentation effects become negligible, such that uniform mixing is achieved. Finally, the samples that can be levitated are much larger than on earth. Such experiments are, however, not exactly straightforward in microgravity where residual gravity and capillary forces at fluid surfaces are still at work. For example, everyone has seen on TV astronauts playing to catch large, freely floating drops of water. Nevertheless, stable sample positioning, which must be ensured to enable laser heating or pyrometry measurements, is possible with higher precision than on earth. In addition, it requires weaker electromagnetic fields. For more than twenty years, space agencies are thus developing levitators using electromagnetic forces, or alternatively acoustic waves or electrostatic forces. The ElectroMagnetic Levitator (EML) is taking advantage of well-known phenomena following from Maxwell's equations. High-frequency alternating fields are generated by passing a current through an assembly of coils shaped for positioning and heating. The applied electromagnetic field induces eddy currents in the metallic sample placed between the coils. This will heat, and may even melt, the sample, due to the Joule effect. The coupling of these currents with the applied electromagnetic field is used to impose a lifting force on the sample, which is concomitantly undergoing fluid flow driven by the electromagnetic forces when molten.

Parabolic flight measurements

Parabolic aircraft flights provide about twenty seconds of reduced gravity. This duration is sufficient for melting, heating into the stable, uniform liquid, and cooling to solidification of most metallic alloys of interest. It is thus well suited for the measurement of the surface tension and the viscosity by the oscillating drop method. In this method, surface oscillations are excited by a pulse of the heating field, and the surface tension and viscosity are obtained from the oscillation frequency and damping time constant of the oscillations, respectively. The process is implemented in an inert gas atmosphere that is circulated in order to enhance sample cooling and assure solidification at the end of the microgravity phase. This results in cooling rates between 30-50 Ks^{-1}.

Using the Electromagnetic Levitator, surface oscillations of the liquid hot drop with diameter of 8 mm (Fig. 2a) can be for instance introduced by an electro-magnetic pulse and the results analyzed by a high-speed high-resolution video camera [5,6,7]. Among the results, Figure 2b shows the surface tension as a function of temperature in the range 1050 – 1450 °C of liquid *Ni* - 75 at% *Al* processed under low gravity in 4 parabolas with 10 seconds of processing time each.

Critical technologies

Therefore, one of the key ISS facilities under development is the ESA/DLR ElectroMagnetic Levitation (EML) device. This advanced EML will permit containerless melting and solidification of alloys and semiconductor samples, either in ultra-high vacuum or high-purity gaseous atmospheres over long time periods. Furthermore, the EML is equipped with highly advanced diagnostic tools which permit accurate measurements of thermophysical properties, as well as direct observation of the experiment during flight by high-speed high-resolution video analysis (see Figure 3).

Summary and outlook

Cast materials are common objects in everyday life (car and jet engines, metallic skeleton of buildings, dental or hip implants…). The latest developments have been achieved through solidification processing from the melt on earth **and** in space in order to improve casting facilities, and also by gas atomization and powder production for the catalytic activation of chemical reactions.

Ultimately, a reliable database of thermophysical properties of liquid metals and alloys over a wide range of temperatures will be established, including the following properties needed for numerical simulations and improvement of casting quality for new and advanced materials:

- density – using video observation techniques in the coil's axial and radial directions
- thermal expansion – also from video observation
- viscosity – using the oscillating drop technique
- surface tension – also by drop oscillation
- total hemispherical emissivity – using modulation calorimetry and measurement of external relaxation times
- specific heat – also by modulation calorimetry
- electrical conductivity – using inductive methods to measure the impedance of a pick-up coil surrounding the sample
- thermal conductivity – using the Wiedemann-Franz law that relates the electrical and thermal conductivity
- alloy melting range and fraction solid – using modulation calorimetry

In order to achieve these goals on a reliable basis sophisticated computer models have been recently favoured in Europe. These will, in all aspects of industrial materials processing, add to the long-term sustainability and technology leadership sought for in the worldwide competition. On this basis ESA together with national space agencies in Europe has set up a strong scientific programme to utilise space as a complementary crucial tool to ease and accelerate the development of new products through knowledge-based designs using the timely fundamental advances acquired from parabolic flights, sounding rockets and, in the near future, the International Space Station. ■

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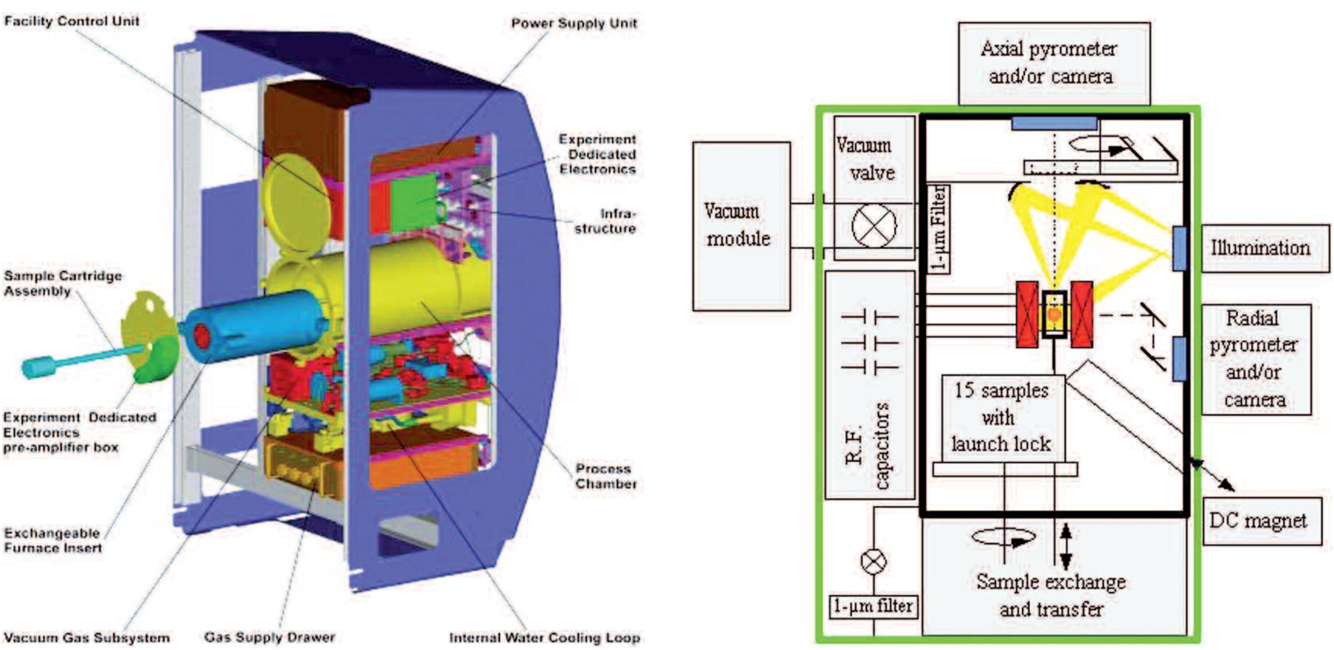
▼ FIG. 3: Schematic diagrams of the Materials Science Laboratory, MSL (Left panel) and of the ElectroMagnetic Levitator, EML (right panel) both of which will be accommodated onboard the International Space Station.



[PHYSICS IN SPACE]

MATERIALS SOLIDIFICATION PHYSICS IN SPACE

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One of the major unresolved problems in solidification physics and its industrial counterpart, the foundry industry, reads simply: the effect of fluid flow on the microstructure of cast products. As "cast" is just another word for "forced flow" and casting of alloys is an art and engineering technology of a few thousand years old, it might appear peculiar that the interplay between an advancing solidification front and fluid flow in the molten alloy still remains to be understood.

Solidification physics in general deals with the evolution of microstructures during the solid-liquid phase transformation. The term microstructure here relates to crystalline patterns developing from a complex interplay between heat and mass transport in the melt and the solid, where the solid-liquid interface morphology is defined in the process. In castings, the solidification process always starts with the nucleation of crystals in a region of the melt that is below its equilibrium temperature. This usually occurs at the surface of the mould. As growth of these nuclei is unstable, *dendrites* grow as trees with primary trunks and side branches parallel to fairly well-defined crystallographic directions. Their selective growth leads to dendritic patterns which are called columnar, since they look like columns or pillars growing parallel to the thermal gradient. The growth of these columnar dendrites can be arrested by the nucleation and growth of dendritic grains forming in the bulk liquid ahead of the columnar dendrite tips. These grains that exhibit dendritic arms growing in different radial directions are called equiaxed and the transition is the Columnar-to-Equiaxed Transition (CET). In practice, this transition is either avoided or triggered to proceed as quickly as possible in order to obtain samples with homogeneous microstructure. The region where dendrites, whether columnar or equiaxed, develop and are still in contact with the liquid is called the *mushy zone*. An illustration of the CET and the dendritic microstructure is given in Fig. 1.

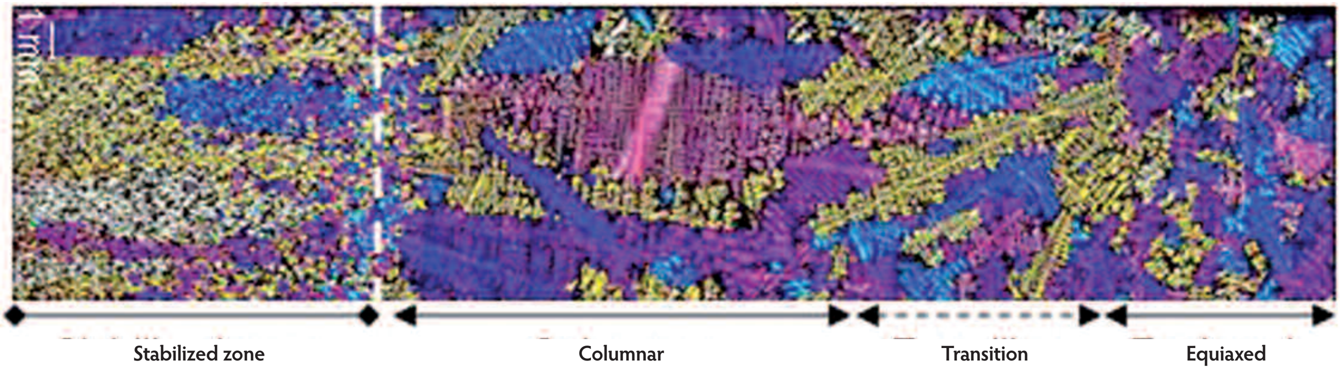
Convection

Despite several models for the CET, the influence of convection is still an open question in solidification physics. Numerous theoretical and experimental papers have been published and a few important mechanisms seem to be responsible [1]. The European programme "Columnar to Equiaxed Transition in SOLidification processing (CETSOL)" aims to investigate this transition and to identify the underlying mechanisms. Microgravity processing on sounding rockets, essential to avoid buoyancy induced fluid-flows, reveals that CET in directionally solidified Al-7wt%Si alloys occurred earlier than in the corresponding ground environment.

The growth of dendrites in metallic alloys depends on many parameters, such as alloy composition, cooling rate, interface velocity, temperature and solute gradients at the solid-liquid interface, thermophysical parameters such as concentration – and temperature – dependent diffusion coefficients, interfacial energy, kinetics of atoms attachment at the solid-liquid interface etc. [2, 3].

The development of physically-based models of the evolution of microstructures is the core of solidification physics. This is especially the case with respect to engineering alloys used, *e.g.*, in crankcases or cylinder heads, turbine blades and cooking pans or as an ingot for sheet metal production. The microstructure as retrieved from the mould is decisive for many properties, including mechanical, electrical, thermal, corrosion resistance,

▼ **FIG. 1: Columnar-to-equiaxed transition (CET) in Al-7wt%Si alloy solidification carried-out in space. The structure develops from left to right. Starting from a fine equiaxed structure in the stabilized zone, selective growth leads to columnar patterns which end in equiaxed grains. The transition from columnar-to-equiaxed structure is of utmost importance for the foundry industry.**



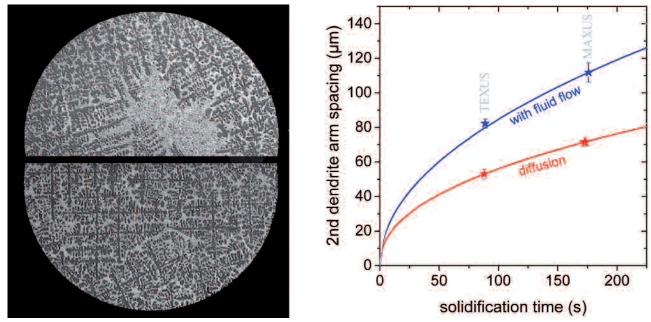
friction and wear, formability and welding properties. Since approximately five decades, the classical foundry practice gradually evolved into solidification physics. Numerous papers and books describe essentials of microstructure evolution under so-called diffusive transport conditions for heat and mass.
Important theoretical milestones are in this respect the discovery of the Mullins-Sekerka instability, marginal stability and microscopic solvability theories providing a basic understanding of dendrite formation. A critical test of these theories was performed with microgravity experiments by Glicksman and coworkers in which established flow-free conditions of heat transfer [4-6] allowed a careful validation of theoretical models.

The same approach is presently under development for *modelling of solidification processes with microstructural features*. Computer simulations have enabled one to model complex processes better than ever before by combining momentum, heat and mass transport equations for multiple phases. However, the predictive power of such approaches is dependent on benchmark experimental validation.

Forest-like

The main difficulty lies in the flow interactions with the mushy zone in a way similar to winds or storm interacting with a forest. Does the strong wind above the tip of the trees permeate to the forest soil? Or is it damped considerably before it reaches the ground? This depends essentially on the permeability of the mush. There is no reliable measurement of mush permeability or validated theories for it. The problem is old, and numerous attempts have already been made to solve at least a few issues. Papers have been published investigating the effect of flow on the growth of primary dendrite trunks, the evolution of side branches, the entrainment of solute in the mush [7], the effects of artificial flow induced by rotating or alternating magnetic fields on cast microstructures [8]. However, the understanding of fluid flow on the liquid-to-solid transformation is rather in its infancy and tremendous progress is expected from comparison of simulations with results provided by space experiments.

Therefore, European teams have defined experimental programs under free-fall conditions using short time experiments in parabolic aircraft flights (20 seconds low gravity), sounding rockets (3-12 minutes) and of course the Materials Science Laboratory, MSL, on board the International Space Station, ISS. Here not only diffusive conditions of heat and mass transport can be established but also controlled fluid flow by means of rotating magnetic field devices. A few examples of on-going space projects and first results will illustrate the benefits of experimenting under reduced gravity conditions.



▲ **FIG. 2: Solidification of Al 6wt%Si alloys in microgravity. Without fluid flow, a dendritic network develops that is well distributed across the sample (bottom left picture). Fluid flows generated by applying a rotating magnetic field in space result in an enrichment of solute towards the centre of the specimen (top left picture) and also in a different kinetic of the evolution of the dendritic network in the periphery. The right panel depicts the microstructure features of samples processed in pairs in space, one with magnetic convection (curve "with fluid flow") and one without (curve "diffusion"). Experiments were performed on two consecutive missions (Texus and Maxus) providing for the evolution with time in both the flow and no-flow cases. These results from space experiments are coherent with those from laboratory experiments on ground, which are always influenced by a slight natural convection.**

New kinetic laws

The European team of the MICAST project focuses on a systematic analysis of flow effects on dendritic microstructures in Al-base cast alloys starting from academic binary to industrial multi-component systems. Besides extensive laboratory research, experiments on sounding rockets were performed; further experiments will be performed in the MSL. The mush interaction with defined artificial fluid flow induced by rotating magnetic fields was analysed in sounding rocket experiments in the last years. The result shows that new kinetic laws have to be developed to describe the dendrite side branch spacing. Figure 2 shows a result together with a micrograph illustrating the effect of fluid flow: compositional inhomogeneities by segregation of solute on the scale of the cast object. Careful analysis of such microstructures gives the graph to the right. Under purely diffusive transport conditions, the spacing varies with the cubic root of the solidification time. Analytical, simplified models are available for this and implemented in all modern casting software tools. Fluid flow of a few mm/s above the mush induces instead a square root-like behaviour, for which first simplified models are just being developed.

Using again the analogy of a dendritic mush with a forest one now might ask, does the interaction of the forest with the wind generate branches, fragments that are taken away with the wind? Such a possible mechanism of fragmentation leading to ▸

equiaxed crystals transported into the melt above the mush is beautifully illustrated by in situ synchrotron X-ray radiography during directional solidification of thin films of an Al-Cu alloy, showing how dendrite branches melt off and buoy upwards against gravity due to their lower density [9]. If a sufficient number of fragments accumulate above the mushy zone, columnar solidification is no longer possible (movies are available at http://tinyurl.com/3zytrk). These and similar investigations have led to the definition of a European project, XRMON, that aims to develop an X-ray radiographic facility for sounding rockets, thus permitting the study of various solidification phenomena without any disturbances by convection.

New microstructures in bronze

The casting of steel, done every day on a million-ton basis, is characterised by a so-called *peritectic reaction-transformation*. This means that below a certain temperature, a new phase nucleates and grows at the *periphery* of the already formed dendrites under normal solidification conditions. Although practised for thousands of years (this reaction occurs also in bronze and brass castings) the formation of peritectic microstructures has received comparatively little attention. For example, at very low growth rate, novel microstructures were predicted as early as the sixties but were not observed until recently. In particular, under certain conditions, it was anticipated that the primary and the peritectic phases could grow side by side with a planar front instead of one forming around dendrites of the other. This growth morphology, typical of *eutectic* alloys, is called *coupled growth*.

The European project METCOMP is focused on the directional solidification at very low speed of peritectic bronze alloys [10]. During this project, coupled growth in Cu-Sn alloys was observed for the first time as shown in Fig. 3. This transverse cross section taken at two regions of a single specimen exhibits various coupled growth morphologies, with the (primary) α-phase in light yellow-brown and the (peritectic) β-phase in grey. On the left, the α-phase is continuous and the β-phase is either in the form of lamellae or fibres. On the right, this is the opposite, the β-phase is continuous and the α-phase is in the form of fibres or short lamellae. These morphologies, which are quite similar to recent 3D multi-phase field computations performed by M. Plapp for various eutectic alloys [11], clearly show that the tin composition was not uniform in this specimen. Indeed, both the α- and β-phases reject the lighter Sn element ahead of the α-β coupled front, thus inducing solutal natural convection and variations in the local composition. Although convection was reduced in this case by the use of fairly small specimen sizes, it is essential to perform similar directional solidification experiments in a microgravity environment, in which the convection and the associated macrosegregation are decreased substantially.

The upcoming possibilities to experiment in the Materials Science Laboratory onboard the ISS gives the chance to perform systematic experiments in reduced gravity to clarify many aspects of flow effects on pattern formation in solidification. ■

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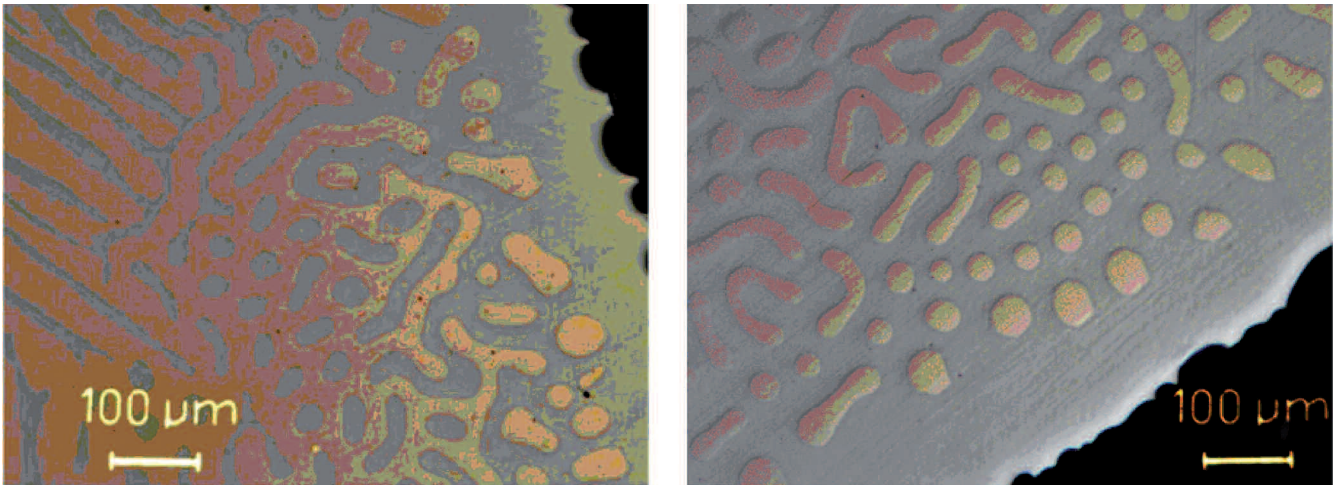
▼ **FIG. 3: Labyrinth-like lamellar microstructure observed in cross sections of a Cu-21wt%Sn sample directionally solidified at 0.58 µm/s in a thermal gradient of 20 K/mm. Left panel: Continuous α-phase (in yellow-brown) with either lamellae or fibres of β (in grey). Right panel: Isolated short lamellae and rods of α in a continuous β phase [10].**



[PHYSICS IN SPACE]

AGGREGATION AND CRYSTALLISATION IN SPACE

DOI 10.1051/epn:2008503

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Aggregation and crystal nucleation phenomena are among the subjects in condensed matter physics that still deserve a strong experimental effort to be fully grasped. This is in particular the case for macromolecular solutions or to dispersions of particles in the colloidal size range. Self-assembly, spontaneous ordering, structural organization on mesoscopic scales, are moreover key concepts for the design of nanostructured materials with specific functional properties. Although ground-based experiments performed on model systems have already shed light on many aspects of the latter phenomena, the presence of gravity often plays a noxious role. Density gradients induced by fast settling of large aggregates, or convective effects associated with the depletion zone around growing crystallites are just two well-known examples. But gravity often yields additional and rather unexpected effects.

To investigate these issues, ESA has recently promoted three distinct, related space projects. They are related, respectively, to the formation of synthetic zeolites, the aggregation and crystallisation of model colloidal systems, the nucleation and growth of protein crystals. These studies will benefit from the already planned development of a versatile light scattering (LS) setup to be installed on the International Space Station (ISS), allowing the use of novel sophisticated optical techniques. Further investigation methods such as confocal microscopy are also foreseen on the ISS, the implementation of rheological and particle manipulation would be an invaluable addition.

Zeolites

Synthetic zeolites are crystalline porous silicates with invaluable importance in a sustainable industrialised world. Zeolite adsorbents and catalysts are workhorses of petroleum and natural gas processing. They are also used in large volumes as detergent enhancer and as drying agents. Applications extend into a wealth of new areas including environmental protection, production of fine chemicals, serving as *e.g.* pharmaceuticals, nutriceuticals, fragrances, flavours, agrochemicals, and further as sensors, electro-optical devices, etc.

The industrial synthesis of zeolites is a slow process involving the lengthy hydrothermal conversion of a silicate-based hydrogel into crystalline material. Depending on the synthesis composition and the presence of structure directing agents (templates) in the form of cations or organic molecules, different pore topologies are obtained. How a specific structure is formed and why the crystallisation takes so long is presently poorly understood. Improved insight into the basic molecular mechanisms during zeolite formation is indispensable for the design and synthesis of tailor-made materials for numerous potential applications awaiting the development of an appropriate zeolite.

Zeolite formation is a complex interplay between silica, templates and solvent. The synthesis mixtures react very sensitively on changes in composition, pH, and convection. This circumstance makes *in situ* observation mandatory. The so-called clear solution synthesis, where no gel-formation occurs, is an ideal model system to study the processes leading up to crystalline zeolites. Specifically the formation of Silicalite-1 from tetraethylorthosilicate, tetrapropylammoniumhydroxide and water has been studied in detail by a number of research groups. Very early in clear solution formation 2-4 nm sized particles appear, which are thought to be precursors for the final zeolite structure [1,2]. They consist of a silica core enclosed by a template shell [3]. Over time silica-template interplay leads to successive structure optimization within these precursors. Suitable building units now start to aggregate into crystals. Such a process is a classical example of self-organisation on different time- and length-scales. Experiments under free-fall conditions aboard sounding rockets and the ISS clearly demonstrated that the nanosized precursors are already affected by the absence of gravity which is a manifestation of long range phenomena [4]. These results prompted an intensive on-ground study of the system focussing on the colloidal interactions which lead to the local enrichment of suitable building units for aggregation in so-called ordered liquid phases (OLPs). With this concept it was possible to re-direct the self-organization by addition of a secondary structure directing agent towards the formation of a new class of hierarchical porous materials [2].

Even though the understanding of zeolite formation has significantly progressed over the last few years, many open questions remain. Especially the initial organization of unstructured silica into specific precursors and the following integration into crystals needs attention. Space experiments are necessary to understand in detail the multi-scale aspects of the formation of precursors and their role in the overall aggregation mechanism. Future experiments are planned to answer these questions. The formation of precursors, their optimisation, enrichment and aggregation will be followed *in situ* aboard the ISS.

Biological macromolecules

The difficulties found with protein crystallisation by the end of the last century motivated many attempts to conduct protein crystal growth in space. Crystallisation of proteins in space has been a large effort since 1982, overwhelmingly based on the "serendipity" approach. Overall, from various evaluations, about 20% of the space-grown crystals showed improvements in diffraction quality, larger crystal volume, more regular visual morphology, or all of the above. Poor reproducibility of conditions, ambiguities in the meaning of "quality improvement" and large scattering of results make this improvement figure not fully reliable and render ambiguous most claims about the benefit of experimenting in space and the reasons for the expected/observed quality enhancements

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Besides the serendipity approach, attempts have been made to understand how a reduction in gravity might improve either the protein crystal quality or our basic knowledge on the operation and implications of the processes involved in protein crystal growth. This rational effort was much more limited in terms of number of experiments, but it brought about much better insight into the protein crystallisation. Fundamental research of biological macromolecule crystallisation reveals that these crystals grow by mechanisms similar to those known for small molecule crystals grown from solution, and contain defects similar to those existing in them. On top of this classical lattice disorder, intramolecular disorder (such as conformation variations or orientation misalignment of the molecules) [5] may be the most important factor limiting the quality of diffraction data and, therefore, the most interesting one for studies on crystal quality and space relevance.

Central to any study of the space relevant aspects of crystal growth is the recognition of the processes that could plausibly explain a different growth behaviour or crystal quality in microgravity. All intermolecular interactions are about 32 orders of magnitude stronger than that related to gravity. Also, Brownian motion velocity of protein molecules is sqrt(3kT/m) ≈ 3-30 m/s at room temperatures for molecules having a molecular weight of 10^4 -10^6 Da. These Brownian velocities are orders of magnitude larger than the 0.1 mm/s that we can assume as a maximum value for the bulk terrestrial convection. Therefore, only the macroscopic mass transport of protein molecules to the growing crystal surface and the interrelation of this transport with the protein incorporation processes at the crystal interface may explain any difference in growth behaviour or in crystal quality.

During the last 20 years, some European initiatives focused on the study of protein crystallisation in space on the basis of a rational understanding of the crystal growth physics. Currently the Topical Team on Solution Crystal Growth and the Science Team of the project selected in ESA's ELIPS programme are active in this direction. So far, these initiatives have concentrated on two main hypotheses on the gravity-dependent processes involved in crystal growth that can influence the quality of the crystals:

1. Protein depletion zone (PDZ) & low supersaturation growth [6, 7]: The rate at which the crystallising protein is transported, via pure or convectional diffusion, to the growing crystal surface may be comparable with the rate at which this protein is incorporated into the crystal lattice on this surface. Then, the supersaturation immediately at the crystal surface is lower than that in the bulk solution and steady, which is known to be beneficial for the quality of crystals grown from solution.

2. Impurity depletion zone (IDZ) & diffusion purification [8]: Impurity concentration trapped by the growing crystal is often larger than that in the surrounding mother solution. Therefore, a crystal just nucleated in solution purifies this solution around itself. The further portions of this crystal grow from a cleaner solution, and will also be cleaner (at the expense of its core). This means diffusion purification: each impurity molecule may reach the crystal surface only after filtering through the IDZ.

Nucleation has been more rarely studied. Interactions driving nucleation of macromolecular crystals are controlled by the precipitant concentration that in most cases turns out to be inhomogeneous due to macroscopic mass transport of the precipitant. Consequently, macroscopic solubility gradients exist, corresponding to concentration (*i.e.* density) gradients that are subject to buoyancy convection. Recent results on the amplification of concentration fluctuations at diffusion fronts in the absence of gravitational effects (GRAdient-Driven FLuctuation EXperiment onboard Foton-M3 mission) demonstrated the relevance of nucleation studies in space and triggered new efforts in this direction.

A series of papers showing our last results and the advances made in the definition of X-ray data quality, the PDZ effect, and the diffusion purification of impurities is in press [9].

Colloidal suspensions

Colloidal suspensions have been very successful model systems for testing basic predictions in statistical mechanics and condensed matter physics [10]. Many of the open questions in colloid science concern *solidification*, *i.e.*, the origin, formation, and dynamics of structures displaying a yield stress, such as colloidal crystals, glasses, and gels. Moreover, stress-yielding suspensions play a crucial role in many processes related to the food, oil, adhesive, paint, environmental, and pharmaceutical industry, as well as in making nano-structured materials such as photonic crystals and electro-rheological fluids, and even in biological structures.

Gravity may strongly influence the structural properties of colloidal suspensions: illustratively, experiments done in space have recently shown that gravity plays an important and not yet fully understood role even in the aggregation of nanometric colloids. The influence of gravity is even more important in colloid solidification, because gravitational stress can propagate on macroscopic length scales, therefore dictating not only the local properties, but also the global, macroscopic behavior of a sample. For dispersion of particles made of a dense material, the need for free-fall conditions is self-evident, since interesting structures such as loose colloidal gels cannot sustain gravitational stress. Yet, even when the density mismatch with the solvent is much less severe, gravity strongly affects colloidal aggregation. For instance, intriguing findings have been made concerning the growth of fractal aggregates of density-matched polystyrene particles, which has been found to be still limited by gravity on earth. By contrast, in space larger aggregates are obtained, whose size is ultimately limited by the stress due to thermal fluctuations.

We shall therefore take advantage of μ-gravity conditions to investigate some areas that are at the forefront of the current research on colloidal solids, such as the glass transition in hard-spheres systems, the dynamics and ageing of colloidal gels and glasses, the crystallisation of colloidal mixtures, and the behaviour of suspensions of anisotropic particles.

Our main approach relies both on using sophisticated optical methods, and on performing experiments on new particle systems presenting interesting structural or optical properties. Besides more 'traditional' colloidal systems, we shall indeed investigate colloidal suspensions of particles with complex geometries (ellipsoids, dumbbells, and rods), or exploit the peculiar optical properties of partially-crystalline colloids. As for the experimental methods, LS techniques possess many unique features that make them an extremely valuable tool for studying colloidal structure and dynamics. In particular, when compared to optical microscopy, LS is sensitive to motion on smaller scales (as small as a fraction of a nanometer for experiments in the highly multiple scattering limit, the Diffusing Wave Spectroscopy), allowing the study of smaller particles. Since all relevant dynamic time scales decrease with decreasing particle size, smaller particles are a premium when studying the very slow dynamics and aging of super-cooled or glassy suspensions. As stated before, besides already "standard" scattering methods, the new LS setup planned for the ISS will include novel techniques, such as Depolarized Dynamic Light Scattering [11], which allow the rotational dynamics of anisotropic particles, or spherical particles with an optically anisotropic composition, to be studied, and Time Resolved Correlation [12], which provides time and space-resolved information on the dynamics, yielding crucial information for structurally and dynamically heterogeneous samples such as gels or glasses.

However, direct visualization of colloidal structures, allowing one to track the coordinates of individual particles and their time evolution with a resolution of the order of a few tens of nanometers [13] would also be extremely useful. We are therefore investigating the possibility of having on board the ISS a confocal microscope, equipped with optical tweezers (to manipulate individual particles), a "dielectrophoretic bottle" (allowing one to tune the local volume fraction of a dispersion by the application of an inhomogeneous electric field), and a flat plate-shear cell, where the relative speeds of the upper and lower plate can be individually set, creating a plane of zero-velocity for optical observation.

Space experiments exploiting novel experimental methods and systems will then very likely increase our understanding of colloid solidification in relation to fundamental physics and biology research, industrial applications, and the preparation of new advanced materials. ■

Acknowledgements

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EDITOR'S NOTE

This is the third and last set of articles on "Physics in space". Europhysics News is grateful to J.P. Boon, Å. Kvick and O. Minster who organized and edited the whole series (see their general introduction in EPN 39/3, p.25). Related to this, the EPS would like to call the attention of the readers to its Position Paper entitled 'The Need for Space Flight Opportunities in Fundamental Physics'. This Position Paper appeared during the World Year of Physics 2005. The Position Paper can be downloaded from the EPS web site as a pdf file (www.eps.org → 'about us' → 'position papers' → 'Fundamental Physics in Space').

ON SUPERSOLIDITY

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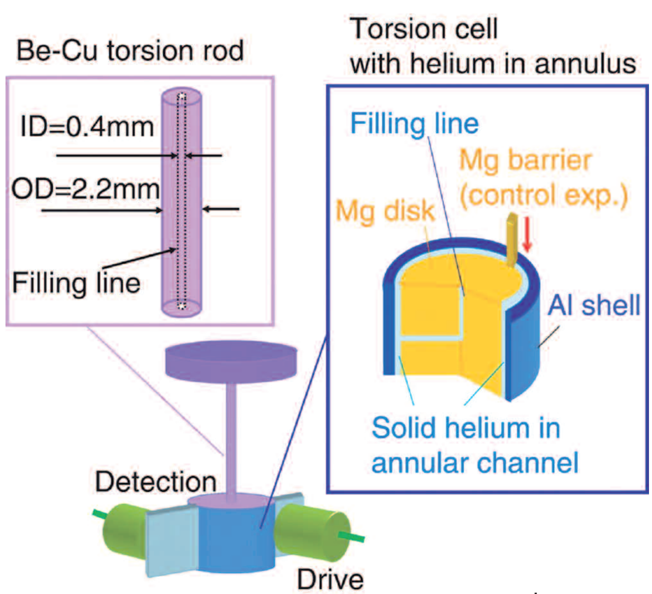
In the last few years a new term has become fashionable, supersolidity and again helium is at the centre of stage. With supersolidity one means a solid that displays some form of superfluidity, for instance that when you put in rotation a container filled with a solid sample, not all of this solid rotates but a part of it is not dragged along by the container and remains stationary with respect to the laboratory (this is called non-classical rotational inertia: NCRI). At first sight this seems at odds with common sense. A solid is a piece of matter that has its own shape, which resists shearing. Superfluidity means that a system can flow like a fluid but the "super" means that it is so prone to flow that it can do it without any dissipation. Notice the difference with a superconductor. Here the flow without dissipation is due to electrons. On the other hand a superconductor is a solid piece of matter but its solidity is due to a different kind of degrees of freedom, the ions. So in this case two different kinds of particles are responsible for the two aspects, the electrons for the flow and the ions for the solidity.

In a supersolid the situation is different: the same entities, neutral atoms, have at the same time to give the framework, which stands at the basis of solidity, and to give the particles that flow. Classically this is difficult to conceive but when Quantum Mechanics and indistinguishability of particles come into play this is not impossible. In fact supersolidity was suggested theoretically almost forty years ago [1,2] and the proposed mechanism was attributed to the possibility that the ground state of a quantum solid might contain a finite concentration of vacancies. This would mean that the probability of occupation of a unit cell of the crystal is less than unity. Often such a state is called an incommensurate crystal, in contrast to a commensurate crystal in which there is an integer (one) number of atoms in each cell of the crystal. If the atoms are bosons also, a vacancy, the absence of an atom, obeys the same statistics so at low temperature a Bose-Einstein condensation (BEC) is expected with the presence of some form of superfluidity.

The most likely candidate for such a state was identified in solid ^{4}He. ^{4}He atoms, due to the low atomic mass and very weak interatomic interaction, are very reluctant to solidify and, even at the lowest temperatures, they do so only if a substantial pressure is imposed. Nevertheless, when crystalline order is observed, solid ^{4}He is unique among all other solids in that the mean square oscillation of an atom around the equilibrium position is a very large fraction of the lattice parameter, of the order of 25%. All solids at finite temperature contain a finite concentration of point defects like vacancies but this concentration in a classical solid vanishes exponentially fast in 1/T, the inverse absolute temperature, as T goes to zero. In a quantum system a vacancy could tunnel to a neighbouring site, *i.e.* the vacancy becomes intrinsically mobile thus lowering its energy and it could even happen that the crystal with a vacancy has a lower energy than the crystal without vacancies. If this is the case, an incommensurate crystal would represent the ground state of the system and BEC should be present. This is a possible way to the supersolid state but not necessarily the only way. Since BEC implies off-diagonal order in the one-body density matrix, in such a state two different orders should be present at the same time: in real space (the crystalline order) and in momentum space (corresponding to the off-diagonal order). In any case for many years experiments did not find anything anomalous in the properties of solid ^{4}He so the interest in the supersolid faded away as a theoretical dream.

The situation abruptly changed in 2004 when Kim and Chan [3a] reported data on a torsional oscillator containing solid ^{4}He (Fig. 1). Below a temperature of a few tenths of a Kelvin the frequency of the oscillator dropped below the value at higher temperature, implying that the moment of inertia decreased below the value corresponding to a rigid rotation of the system (Fig. 2). The fact that there was a critical velocity effect (at large amplitudes of the oscillator no missing inertia was present), and that the effect was suppressed by the presence of a plug in an annular container or when the boson ^{4}He atoms were replaced by the fermions ^{3}He, all this led the authors to interpret these results as the manifestation of the long sought NCRI associated with the supersolid state in which about 1% of the ^{4}He atoms did not respond to the imposed oscillation of the container.

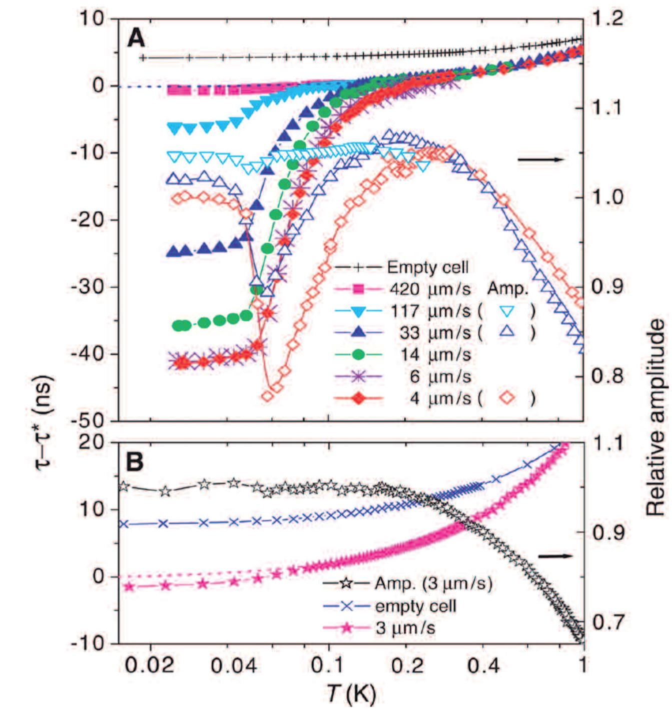
▼ FIG. 1: Schematic torsional oscillator: The cylindrical drive puts into oscillation the cylindrical torsion cell and this oscillation induces an ac voltage on the detection electrode. A lock-in amplifier enables the oscillation to be kept in resonance. ^{4}He is introduced via the filling line and ^{4}He in the annular channel solidifies if a large enough pressure is applied. In the control experiment a barrier in the annular cell is present. (Figure from ref. 3a)



These results spurred great excitement and many investigations, both experimental and theoretical, were launched. While in other laboratories NCRI was observed, these experiments made the situation very confusing. If the temperature range in which the NCRI effect was seen is common to the different experiments, this is not so for the superfluid fraction ρ_s. The value of ρ_s, which represents the fraction of atoms not responding to the torsional oscillator, differs by more than three orders of magnitude in different experiments; ρ_s is sensitive to annealing, to the cell geometry and composition, to even a minute concentration of ^{3}He impurities. Even in a single crystal, or almost so, it was found that ρ_s can differ by a large amount if the material of the container is changed. It is clear that defects have to play an important role in the phenomenon. Since the early measurements were performed in highly polycrystalline solids, grain boundaries were suspected to play a role. The fact that also single crystals gave NCRI [3b] implies that other defects have to be important and dislocations are reasonable candidates since it is known that even in a single crystal the concentration of dislocations can vary by a large amount depending on experimental details. This major role of defects on NCRI of solid ^{4}He led even to the conviction that the whole issue of supersolidity of ^{4}He was exclusively due to the presence of extrinsic defects that any real solid sample contains.

This position received a strong motivation also from theoretical results that in the meantime were obtained. If an ensemble of ^{4}He atoms represents a strongly interacting system, which is very difficult to study analytically, its boson nature makes the many-body problem much easier than the fermion case because there is no 'sign' problem here, at least for an equilibrium state, and this quantum system can be treated by robust simulation methods. Thus essentially exact results for bosons can be obtained from quantum simulations, even if one has to be careful that the results are with reference to a finite number of particles, usually less than a thousand, with periodic boundary conditions. Path-integral Monte Carlo methods have been widely used to study solid ^{4}He at finite temperatures and the result of such computations is that a perfect commensurate solid is not supersolid, at least in the temperature range of the simulations, a range that has some overlap with the one where NCRI is experimentally observed [4]. On the other hand, if some disorder is introduced, the simulations show that the system does become supersolid.

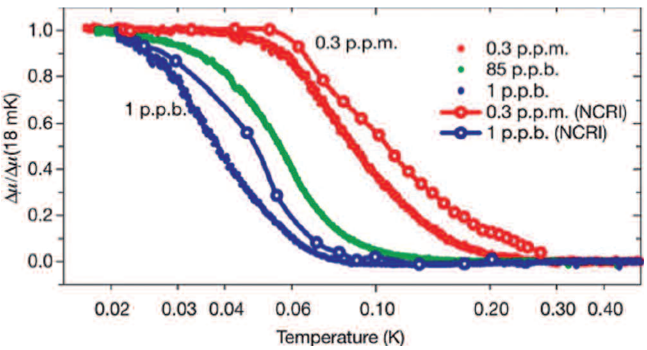
Liquid ^{4}He in the superfluid state has a number of peculiar properties in addition to NCRI. Obviously also in solid ^{4}He other signatures of superfluidity have been looked for, for instance flow without pressure drop, but none has been found so far. On the other hand, recently a new anomaly has been found in solid ^{4}He [5]. The elastic shear modulus has been measured and an anomalous stiffening of the solid has been observed at



▲ **FIG. 2: Resonant period (left axis, filled symbols) and amplitude (right axis, open symbols) of oscillations as a function of temperature (note the logarithmic scale) for the unblocked (A) and blocked (B) cell and for different maximum velocities as given in the legend. The period readings are shifted by v*, the resonant period at 300mK that is of order of 10^6. The resonant period of the empty cell at 300mK is about 3000 ns smaller than the filled cell volume due to the smaller moment of inertia of the empty cell. For the filled cell there is a drop of ν at temperatures smaller that 300mK and this drop does not depend on velocity at low ν. This drop is interpreted as due to a drop in the mass of ^{4}He coupled to the cell and this allows the superfluid fraction ρ_s to be extracted. The effect is drastically reduced for the blocked cell. (Figure from ref. 3a)**

low temperatures. The behaviour of the shear modulus has a remarkable similarity with the one of NCRI (Fig. 3). It has been proposed that this anomaly is due to dislocations, the same kind of disorder that has been invoked for NCRI, with dislocations being immobile at low temperature and becoming mobile at higher T. On the other hand this seems counterintuitive: the ability to move without dissipation seems at odds with a stiffening of the solid. The discovery of this stiffening is important new information on the system but we are far from an understanding of it and of the relation, if any, with NCRI.

If the establishment of NCRI represents a true phase transition one should expect to find some signature in the specific heat. It is important that very recently a peak in the specific heat has been reported at the temperature of the NCRI phenomenon [3c]. This is a very difficult experiment and it will be important to have an independent confirmation of this finding.



▲ **FIG. 3: Shear modulus μ of solid ^{4}He has an anomalous increase of about 11% going from 300mK to 18mK. The variation Δμ=μ(T)-μ(300mK) normalized to the 18mK value is plotted as a function of T for samples with different concentration of ^{3}He impurities (filled symbols). Open symbols represent similarly scaled NCRI ρ_s data from torsional oscillator measurements. (Figure from ref. 5)**

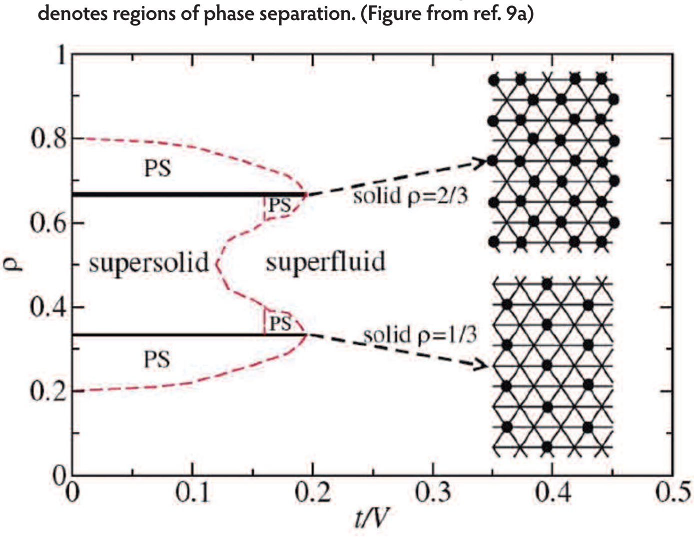
Some aspects of NCRI of solid ^{4}He, such as the value of the critical velocity and some observed metastability phenomena, are consistent with a vortex view of this state [6]: basic entities are assumed to be quantized vortices, possibly in a condensate which might correspond to the presence of BEC. However if the ground state of solid ^{4}He is commensurate, theory tells us that no BEC can be present. One possibility is that all "supersolid" phenomena in solid ^{4}He are due to the presence of some disorder induced by external conditions such as the condition of crystal growth. If this were the case this would be of interest per se but of course not as interesting as if supersolidity were an intrinsic property. In other words there is no doubt that defects have a very important role in NCRI but what happens if a more and more perfect crystal is grown? Will NCRI go away or will some remaining effect persist, i.e. the ground state of solid ^{4}He is qualitatively different from that of a normal solid?

As already mentioned there is strong theoretical evidence that a commensurate solid is normal, so the question is if some intrinsic form of disorder is present in the ground state. This leads back to from where we started forty years ago: are there vacancies in the ground state? My interpretation of experiments is that they exclude the presence of vacancies at a concentration of 1% or above but they cannot exclude the presence of vacancies at a lower concentration. Some argue that the presence of ground state vacancies is excluded by some theoretical computations giving a finite positive energy for the formation of a vacancy. To others such argument does not seem so convincing and they believe that the question of whether vacancies are present in the ground state of solid ^{4}He is still open both theoretically and experimentally [7]. But we should also be open to the possibility that intrinsic BEC and supersolidity might be associated not so much with vacancies but to some other kind of defects that, in any case, would make solid ^{4}He different from the textbook picture in which each atom occupies a crystal cell. We know for sure that the solid is periodic, this is demonstrated by the observation of Bragg peaks in the scattering of neutrons or of X-rays, but how the atoms populate the crystal cells might offer some surprise.

Looking in perspective, solid ^{4}He has turned out to be much more complicated than what was expected and we do not yet have a clear overall picture of the properties of this system. All attempts to explain the behaviour of solid ^{4}He in more conventional terms have failed so far and the presence of a non-conventional state appears to be the most likely explanation. But what this non-conventional state should be is unclear. Whether such a non-conventional state is only due to extrinsic defects or if it is an intrinsic property of the quantum solid is a fundamental question awaiting an answer. An argument in favour of the intrinsic nature of the state is the following. While, as already mentioned, the value of ρ_s changes by many orders of magnitude depending on the experimental details, the transition temperature is almost unaffected by such details. If supersolidity were entirely due to extrinsic defects it is difficult to understand how it can be that the transition temperature is almost unaffected when the amount of defects varies by many orders of magnitude. Consider now the other possibility. If the underlying ground state has BEC, associated with ground-state vacancies for instance, the system would have its own transition temperature but perhaps the intrinsic value of ρ_s could be very small. The presence of extrinsic defects might have an amplifying effect on ρ_s without necessarily affecting the transition temperature, *i.e.* extrinsic defects might act as leverage on ρ_s without much affecting the other properties of the system.

I believe that the issue of supersolidity will still be at the centre of attention in time to come. We have learnt something but much more has to be found out. And this topic will be at the centre of attention in another direction, that of trapped cold atoms. Cold atoms in a periodic potential is common trade nowadays and beautiful experiments [8] have shown how the system changes from superfluid to localized as

▼ **FIG. 4: Zero-temperature phase diagram of hard core bosons on the triangular lattice in the density-interaction parameter t/V. t is the nearest neighbour tunnelling amplitude and V is the nearest neighbour repulsion energy. At low value of t/V there is a supersolid region for intermediate densities whereas the system is superfluid for larger values of t/V. PS denotes regions of phase separation. (Figure from ref. 9a)**



the tunnelling probability of an atom from one site to the next decreases. Therefore the system is periodic and at the same time it can be superfluid. This however is not a true supersolid state because the periodicity is just the one imposed by the external field, for instance by a standing light beam. Theoretically there is strong evidence that bosons in a lattice can have a supersolid state [9]. Under certain conditions (Fig. 4) the spatial order of the atoms is not the simple one corresponding to that of the external potential but a more complex one resulting from the interplay between interatomic potential and external potential. Such complex spatial order can coexist with superfluidity so we can say now that supersolid order is present. At the moment this is a theoretical finding but we look forward to its experimental implementation with cold atoms. ■

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PHYSICS IN DAILY LIFE:

THE WAY WE WALK

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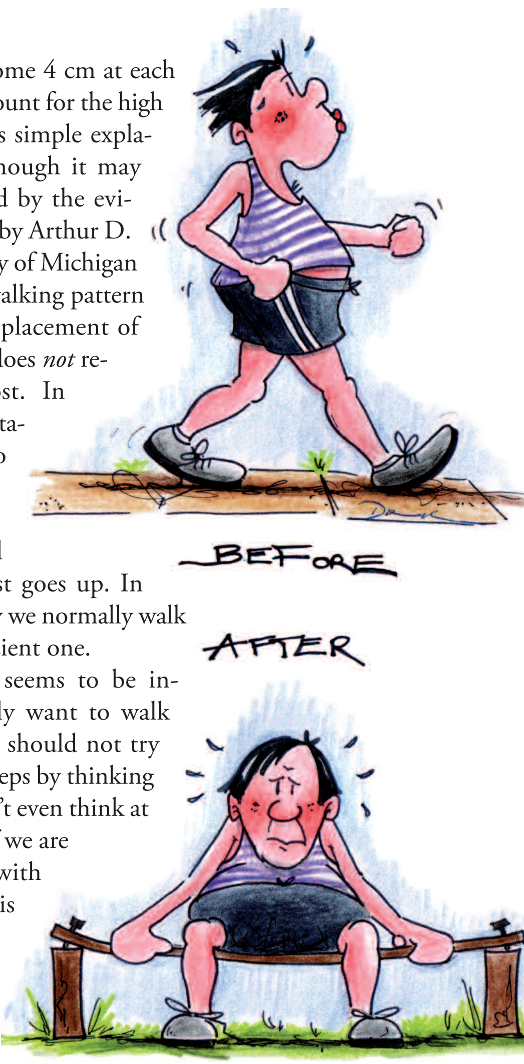
Centuries of evolution have given mankind plenty of time to learn how to walk. Walking is a reasonably efficient way of getting around, although not nearly as efficient as riding a bicycle. A few obvious features help us to walk efficiently: we move our arms and legs in antiphase, thus keeping the total angular momentum more or less zero. And we swing our legs at almost the natural pendulum frequency, which is around 1 Hz for adults. Indeed, traditional military marches proceed at 120 steps per minute: exactly 1 Hz. Given a standard step length of 83 cm, the corresponding marching speed is almost exactly 100 m per minute. Beautiful! This fact does not serve to illustrate the superiority of the metric system, but it sure is handy to know when hiking.

Energetically speaking, walking on a horizontal surface is a special case. We have no external force to overcome, in contrast to climbing the stairs, for example, where we have to fight gravity to increase potential energy; or to rowing and cycling, where we have to overcome drag from water or air. Walking is different: even aerodynamic drag is negligible (remember that it is proportional to the square of the speed). All energy that we produce is dissipated by our own body.

One may wonder why walking costs any energy at all. In fact, experiments show that the metabolic cost of walking, derived from oxygen consumption and carbon dioxide production, is about 2,5 W per kg of body mass. This is roughly 200 W for an adult. Why is that still so much? It is because human walking is mechanically complex. It involves the activity of numerous muscles, and various theories are being developed to arrive at a comprehensive description.

As innocent physicists we may offer an obvious clue: the effective displacement may be horizontal, but our centre of mass must be raised by some 4 cm at each step. Could that account for the high metabolic cost? This simple explanation, tempting though it may be, is not supported by the evidence. Experiments by Arthur D. Kuo at the University of Michigan have shown that a walking pattern that reduces the displacement of the centre of mass, does *not* reduce metabolic cost. In fact, it makes the metabolic cost go up. Also when the step length is varied beyond our natural step length, the cost goes up. In other words: the way we normally walk is also the most efficient one.

The conclusion seems to be inevitable. If we really want to walk more efficiently, we should not try to improve on our steps by thinking physics. We shouldn't even think at all, just walk. And if we are still not satisfied with the result, there is only one alternative: go home and pick up our bicycle… ■



A TRIBUTE TO NIELS BOHR

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It is hard to imagine, in 2008, the attraction exerted in the 1920's and 1930's by the Institute of Theoretical Physics, at Blegdamsvej 17, Copenhagen, an institute conceived and created by Niels Bohr, the young professor in the newly created chair of theoretical physics of Copenhagen University. Even before it opened its doors, the inventor of the new atomic model, in which J. J. Thomson's electrons, Rutherford's nucleus and Planck's quanta had been merged together to explain the line spectra, was a celebrity who attracted young physicists anxious to make the physics of the future. Hans Kramers from Leiden was the first to come to see Bohr and to join forces in the exploration of the atomic structure; many would follow.

The student

Niels Henrik David Bohr was born in 1885 as the second child of the physiologist Christian Bohr, the professor-in-chief of the Medical Faculty, and Ellen Adler, a banker's daughter and former student of Christian. There was an elder sister, Jenny, and a younger brother, Harald: Jenny was to become a teacher of Danish and history, Harald grew to become Denmark's most distinguished mathematician. From his youth onwards Niels Bohr was the practical man of the family. He loved working wood and metal and put together mechanical constructions, at a special bench with tools – at home – and equipped with a lathe. His father promoted an English way of life – with strong German literary accents – and so it came that 'football', a most recent novelty, became part of the extra-curricular student activities; his own boys were to excel at it, Harald, it is true, more than Niels. The two closely followed each other: in 1910, Harald expanded in his thesis on the theory of Dirichlet series; Niels passed his doctorate on the electron theory of metals. Typically, Harald preferred working alone, whereas Niels was always searching for company to discuss scientific subjects and, eventually, to dictate the texts of publications. Indeed, for some of his later guests it was an unforgettable experience to serve as the writer – pencil or fountain pen and paper, at hand – of the often exasperating number of successive drafts of a publication. Bohr's kind jovialty, though, in a way more than outweighed his barely hidden inclination to dictate.

The doctor

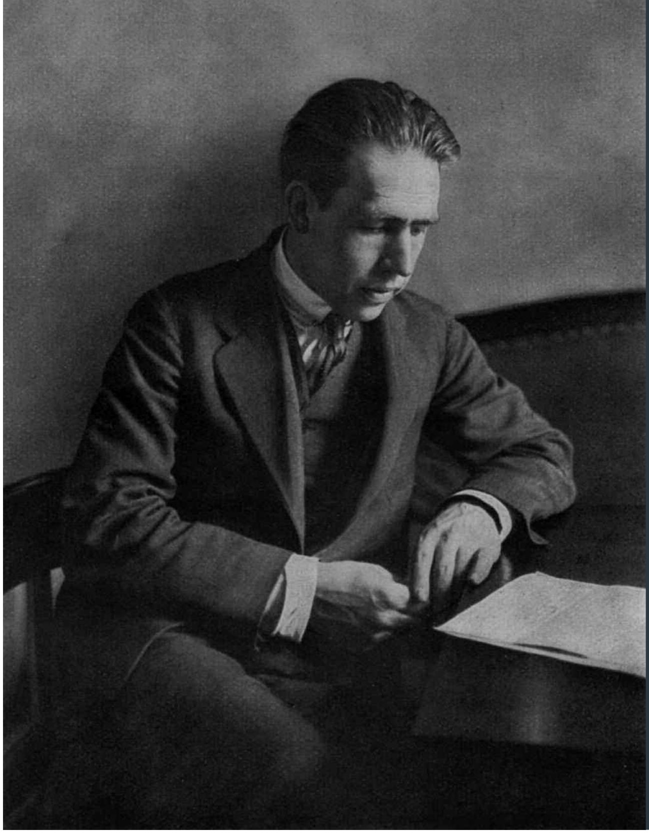
Armed with a provisional translation of his thesis, Bohr left for Cambridge in order to try to win J. J. Thomson's support for his novelties. Bohr's electron theory was built upon that of Lorentz, in which the velocities of the electrons obeyed a normal distribution. The statistics involved was that of the kinetic theory of gases, the electrons taking the place of the molecules of Maxwell and Boltzmann. Thomson himself, however, went not that far; assuming a steady velocity he had calculated in 1908, roughly, the velocity of those electrons: about 100 $km.sec^{-1}$. A metal was conceived of as a rigid structure of metallic atoms enclosing, as a porous container, the 'gas' of electrons moving hither and thither. The encounter with Thomson was much of a disaster. Bohr himself later acknowledged his awkwardness: it had perhaps not been really the best first move to try to convince his host of errors in the latter's publications. The youthful Bohr, renowned for his frankness, had to acquire some diplomatic skills, and so he did. At Cambridge he made the acquaintance of Ernest Rutherford, who had come over from Manchester for a talk. In moving on to Manchester, Bohr was made familiar with the latest trends in atomic physics, more specifically the assumption of a tiny *nucleus* at the heart of the atoms, a carrier of a huge positive charge, huge enough to cause the backscattering of α-particles, 1 out of every 20.000. A thin foil of e.g. gold thus was somewhat like a 2D grid of nuclei and electrons. Rutherford himself had referred to the Saturn-like system, formerly suggested by the Japanese physicist, Nagaoka; others had followed. In 1912, a flat system of electrons circling around the nucleus was in the air.

Atomic spectra and structure; professor

The simplest atom of all was claimed to have just one such electron. Crucially, its emission spectrum was renowned, since a long time, for its simplicity: four razor-sharp lines, hinting at four discrete light emissions. The numerical relationship had been analyzed by the mathematicians Balmer and Rydberg: the latter had translated the former's formula in terms of wave-numbers (cm^{-1}), σ (= 10^8.ν/c):

$$\sigma = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \qquad (1)$$

In a flash of genius, Bohr realized its bearing on the atomic structure, when the energy of the emitted light was considered, in Planck and Einstein's way, as the product of Planck's constant, h, and the light's frequency, ν. When the normal hydrogen atom is considered as having its electron in an orbit of lowest energy, states of higher energy could be imagined as brought about by the electric current through the gas discharge tube. The four lines of the hydrogen spectrum, then, correspond to discrete losses of energy stemming from electrons 'falling' from orbits of higher energy to that of lowest energy. The 'energy' of an orbit could also be expressed as $h\omega$, in which ω is the frequency of revolution. The kinetic energy of an electron in an orbit, then, corresponds to $½h\omega$. Supposing the occurrence of a series of orbits determined by τ = 1, 2, 3, .. their kinetic energies correspond to $\tau(½h\omega)$. The normal, 'permanent' state of an atom, then, is that for which τ = 1. On the other hand, the



◀ **FIG. 1:** The newly created Nobel laureate (about 1923) (courtesy and ©: Emilio Segrè Visual Archives of the American Institute of Physics).

kinetic energy of an orbiting electron equals its potential energy: $\frac{1}{2}mv^2 = eE/r$ (= W), in which $v = 2\pi r\omega$. So, the frequency of revolution, ω, may be expressed as:

$$\sqrt{\frac{2}{m}}\cdot\frac{W^{3/2}}{\pi eE} \qquad (2)$$

With $W = \tau(\frac{1}{2}h\omega)$ one obtains expressions for the atom's radius, r, and the frequency of revolution, ω, while W_τ , the energy of a particular orbit is fully determined. The energy difference between two orbits, $W_{\tau 1}$ - $W_{\tau 2}$, that is, the energy of the light emitted, thus leads to:

$$\nu = \frac{2\pi^2 me^4}{h^3}\left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2}\right)$$

Considering the symmetry of formulae (1) and (3), Rydberg's constant R, rewritten as $c/10^8$ times its original value, may be calculated as $3{,}1.10^{15}$ s^{-1}, an outcome that accurately verifies Rydberg's own: $3{,}290.10^{15}$ s^{-1}.

In this way Bohr succeeded in linking the various spectral lines of hydrogen (12 experimental, and 33 stellar). For the 33rd line of the stellar spectrum, the radius of the hydrogen atom would correspond to $1{,}2.10^{-5}$ cm, in magnitude corresponding to the mean distance between molecules in a gas at 2.10^{-2} mm Hg. All kinds of phenomena were at once explicable, among which the photoelectric effect and the production of X-rays and canal rays. In two following articles Bohr went on to assess more complex atoms – to begin with helium, lithium and beryllium – and molecules.

Drafts of his papers, meant for *Philosophical Magazine*, were submitted to Rutherford who advised to cut them down, but Bohr insisted. In order to fully convince his mentor Bohr took leave and went directly to Manchester. Rutherford was won over in the end and the first instalment appeared in the May issue of 1913. From then onwards the Bohr-Rutherford atomic model went irresistibly its own way. Van den Broek's suggestion, used by Bohr, was confirmed that very autumn by Moseley. In chemistry the new model was elaborated by Walter Kossel, a student of Sommerfeld, who stressed the importance of the noble gases as possessing stable electronic configurations. Sommerfeld himself addressed the splitting of spectral lines under magnetic and electric influence, known as the Zeeman and the Stark effect. Sommerfeld's *Atombau and Spektrallinien* (1919) became the manifesto of the new atomic theory.

Nobel Prize 1922

At home, Bohr's success led to his nomination, in 1916, as professor of theoretical physics. Unfortunately the material circumstances were extremely poor and Bohr started thinking of mobilizing public funds in order to create an Institute worth that name. The Carlsberg Foundation, which had previously funded his travels to Cambridge and Manchester, became interested. Bohr's association with the greatest physicists of the time, already Nobel laureates or soon to become, paid itself out. He was among the invités of the Belgian philantropist Ernest Solvay, during the first post-War Conference on Physics, that of 1921, where 'Atoms and electrons' featured on the agenda, Bohr's subject, that is. Because of ill health Bohr was unable to attend, but his friend Ehrenfest was kind enough to read his report on 'The application of the quantum theory to atomic problems'. Already in 1917 Bohr was proposed for the Nobel Prize [1]. It was to be that of 1922. In his conference on that occasion he could report on the very-latest success of his theory, a hot find that had been cabled from Copenhagen to Stockholm. It concerned the identification of number 72 of the elements by his guests Hevesy and Coster, an element to be baptized *hafnium*, after Denmark's capital. It concerned an analog of zirconium and not the rare earth that others had postulated. For the European community of physicists Bohr's credentials were unsurpassed and countless PhD students and senior scientists flocked to the Institute of Theoretical Physics. It is important to realize that 'theoretical', with Bohr, just meant 'fundamental', embracing both theoretical and experimental studies, in which physics and chemistry alternated in the most fruitful of interdisciplinary labours. Backed by the Carlsberg Foundation, Bohr became a model of scientific hospitality. In 1929, he received George Gamow from Odessa who had come, on a wild card, just to shake hands, and procured him a fellowship for a year. In much the same way Hendrik Casimir, a student of Ehrenfest, came over. Bohr's magnanimity is reflected in the open-mindedness of his guests. It is told, for instance, that on a warm summer evening Casimir, in trousers and waistcoat, took the trouble to swim across the Sortedams Sø, one of the lakes-in-a-row crossing Copenhagen, in order to check that it was indeed the shortest way. In so doing he won a bet made with Georg Placzek [2].

Compound nuclei; the drop model 1936-1937

Early in the 1930's Bohr tended to drift away in a more speculative direction, but the discovery of *artificial* radioactivity put atomic, more particularly nuclear, physics again on his agenda. Up until then the 'nucleus' had been regarded as a solid-like close packing of α-particles, protons and electrons. Rutherford had suggested, in 1920, the involvement of neutral particles, composed of a proton and an electron. His was a new physics, with a wholly new terminology centering on 'bombardments' with 'projectiles', mostly α-particles, the 'cross-sections' of 'beam' and 'target' defining the probability of atomic and nuclear reactions. Chadwick, his experimental confidant, had deduced, in 1932, the very existence of such neutral particles, slightly heavier than a proton, escaping from $^{9}Be_{4}$ when bombarded with α-particles. The context was the following. Bothe and Becker had studied, at Berlin-Charlottenburg, the effect of a polonium-preparation through silver foil upon a platelet of beryllium on top of a counter [3]. This powerful source of (almost) exclusively α-particles was expected to liberate protons from Be, the free protons, so to speak. Instead Bothe and Becker noticed a highly penetrative radiation, apparently unusually hard γ-rays. When lead through paraffin wax, this radiation was sufficiently energetic to liberate high-speed protons, as Irène Joliot-Curie, at Paris, established (speeds of at maximum $3{\cdot}10^{7}$ m.s^{-1}) [4]. However, what Joliot-Curie interpreted as an extremely energetic variant of the Compton effect was, in Chadwick's view, more probably the consequence of a classical collision of particles, that is of *neutral* particles capable of expelling protons, recoil protons, energy and momentum being conserved [5]. These *neutrons* appeared not to produce tracks of their own in Wilson's expansion chamber, but revealed their presence through abruptly emerging tracks, that is, tracks without an origin.

Bohr had followed, from a certain distance, the debate on the Be-radiation and the later findings of the Joliot-Curies and Fermi. In 1936 he proposed a model of his own for the mechanism of nuclear reactions. In essence, Bohr claimed the production, by the impact of a projectile, of an 'intermediate state', a 'compound nucleus', as he called it. This 'compound nucleus' would have a rather long lifetime: the entering projectile would hit one or more of the nucleons, its energy and momentum being spread over all of them. It could be considered as an 'excited state', in the classical atomic way. After a while, then, one of the nucleons obtained sufficient energy and escaped. What Bohr described in his characteristic mechanical way, could of course also be translated in the new quantum mechanical terms, a job carried out by Gamow [6]. Gamow took the nucleus as featuring a potential well, allowing for the nucleons a whole range of quantum states: outside the well the Coulomb field of the nucleus reigned, inside something new of a short-range, whose nature was left to be determined. If the entrance of a neutron is unhampered, the later ejection of a recoil particle is a matter of statistics, a tunneling process through the well. In 1937, Bohr would propose, together with Kalckar, the celebrated drop model, presenting the nucleus as behaving like a liquid, with modes of surface and volume oscillations of its own, ready to become excited isotopes by incoming neutrons. With this in mind the nuclear 'fission' of uranium-nuclei by slow neutrons, as deduced in 1938 from the appearance of barium, was nothing short of a confirmation of Bohr's drop model.

◄ **FIG. 2: 'And now our honoured guest will give his famous lecture on chain reactions', cartoon by B. O. Bøjensen, in: Politiken (1958) (courtesy and ©: Niels Bohr Archive, Copenhagen).**

Science and policy

From the very beginning of his career Bohr sought the stance of a scientist-statesman, displaying his responsibility whenever necessary. In the 1920's, he was the host who provided many of his guests from all over Europe with Carlsberg fellowships. In the 1930's he became the elder scientist who actively engaged in procuring safehavens for sacked German physicists. After the invasion of Denmark, Bohr remained at his post, as the embodied symbol of Danish academic non-collaboration who refused whatever honours his former student Werner Heisenberg had in mind. On 29 September 1943, though, he had to flee himself, via Stockholm to Great Britain and the United States. His appeals to Churchill and Roosevelt revealed his last great moves, this time as the distinguished statesman-scientist, second only to his friend Albert Einstein. ■

Acknowledgement

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DETECTING GRAVITATIONAL WAVES WITH PULSARS

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Einstein's theory of General Relativity predicts that accelerating masses will produce gravitational radiation: ripples in space-time that propagate outward at the speed of light and carry energy away from the source. The effect of this energy loss in the first-discovered double neutron star system was unambiguously detected by Joseph Taylor, Russell Hulse, and collaborators in the 1980's and garnered the Nobel prize in physics for them in 1993. But, the direct detection of gravitational waves (GW) from cosmic sources remains one of the great quests of modern physics, and groups around the world are using a variety of techniques in the search.

For example, detectors such as the European-based VIRGO and GEO600 and the US-based LIGO use powerful lasers directed down orthogonal arms several kilometers long to attempt to detect the passage of a GW by sophisticated extensions of Michelson interferometry [1]. These detectors are sensitive to gravitational waves with periods comparable to the light travel time across the array: tens of microseconds. Various techniques to lengthen the response time plus the fact that many sources of gravitational waves are expected to rise in spectral power at lower frequencies produces a peak sensitivity around 0.1 s or f ~ 10 Hz. A proposed space-based array, LISA, the Laser Interferometer Space Antenna, based on the same Michelson interferometer principle but with lasers directed between free-flying stations 5×10^6 km apart in a one year orbit around the Sun, would have a peak sensitivity around f ~ 10^{-3} Hz. (A precursor LISA Pathfinder mission is an approved ESA project with an expected launch in 2009.)

Pulsar timing — a complementary technique

Pulsars – rotating, highly magnetized neutron stars – are themselves the product of dramatic gravitational collapse of massive stars and provide another means to detect gravitational waves directly. The technique uses electromagnetic radiation from a group of pulsars to search for GWs, but the technique is not interferometric in character. Rather, radio astronomers search for slight disturbances in the arrival time of the pulses from these 'radio lighthouses' to signal the presence of gravitational waves. This technique is most sensitive to gravitational waves with frequencies about equal to the inverse length of the data record, which is tens of years in the best cases. This results in sensitivity to GWs in the nanohertz range, complementary to the much higher frequency range probed by the interferometric techniques.

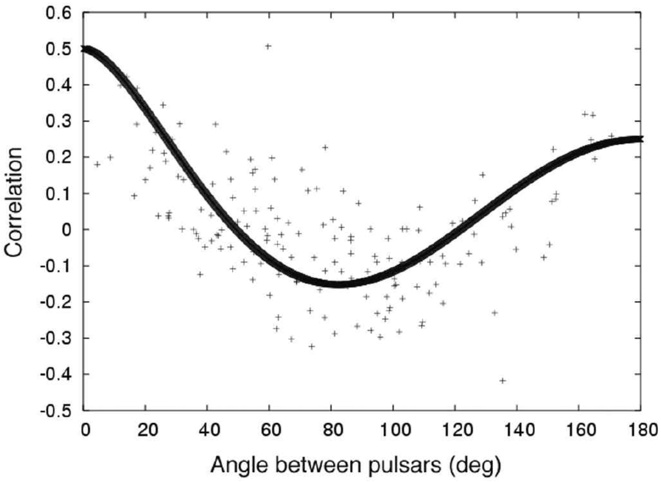
The discovery in 1982 of a class of rapidly rotating yet very old (~ 10^9 yr) "millisecond pulsars," revolutionized the prospects for gravitational wave detection with this method. Millisecond (or recycled) pulsars have gone through an accretion-induced spin-up phase that leaves many of them with rotational periods less than 10 ms. Not only do these pulsars have a timing precision 100 – 1000 times better than the more numerous longer-period objects, but their relatively old ages and small spindown rates (*i.e.*, slowing down of rotation) makes them less prone to the minor rotational irregularities that are present in younger pulsars.

The observations do not track the exact phase of the electromagnetic waves (as in Michelson interferometry) arriving from the pulsar at distance of hundreds to thousands of light years, but the rotational phase of the pulsar is measured instead. Since the width of the pulsar radio beam can be as narrow as 40 µs, high signal-to-noise ratio observations with the world's largest radio telescopes (Fig. 1) can determine the arrival phase of the pulse to a precision as good as 0.1 - 0.2 µs in the best cases.

Gravitational waves and pulsar timing

What effect do cosmic gravitational waves have on this electromagnetic link? The passage of a gravitational wave past the pulsar at the time the radio waves are emitted causes an effective Doppler shift in the repetition frequency of the pulses of order $(\nu\text{-}\nu_0)/\nu_0 \approx h$, where h is the dimensionless strain that characterizes the GW. This shifts the observed pulse phase by a slight amount, $\delta t \approx hT$, where T is the duration of the disturbance: weeks to years to decades in the cases of interest here. Similarly, the presence of a gravitational wave at the Earth at the time of reception of the e-m wave will introduce another slight time shift into the measurement. Surprisingly, the presence of gravitational waves along the hundreds to thousands of light year journey through the Milky Way galaxy does not affect the signal at all. This immunity to disturbances along the travel path arises because of two properties shared by electromagnetic waves and gravitational waves: they are both transverse, and they both travel at c in a vacuum. This leads to a cancellation of effects along the propagation path, and even the slight changes in propagation speed of the e-m wave because interstellar space is a dilute plasma are not enough to produce a detectable GW signal due to metric variations along the path. So, it is simply the metric disturbance (value of h) at the pulsar at the time of emission and, similarly, of the Earth at the time of reception that determines the net value of δt in the pulsar timing observation. There are, of course, additional complications (two independent polarizations of the GW, geometrical factors, etc.), but this is the essential physics [2,3].

▲ **FIG. 1: The Arecibo Observatory in Puerto Rico (left) and the Parkes Observatory in Australia (right) figure prominently in the search for gravitational waves using pulsars. Arecibo, the world's largest radio telescope, has unsurpassed sensitivity and discovered the first binary pulsar in 1974 and the first millisecond pulsar in 1982. The Parkes radio telescope can observe many of the millisecond pulsars that form the basis for a pulsar timing array (PTA) and is used in the best-developed PTA effort.**



▲ FIG. 2: **Half the timing irregularities due to a background of gravitational waves will be correlated around the sky because the gravitational waves are "jostling" the Earth, causing a retardation or advance of the observed pulsar rotational phase. The curved line in this plot shows the expected correlation as a function of angle between the pulsars. The plotted points are a simulation of the pair-wise timing correlations of 20 pulsars spread around the sky and represent one kind of signal that a PTA could detect [9].**

There is one important caveat. Unlike the case of spectral lines in atomic physics, the undisturbed rotation frequency of the pulsar (ν_0) and its first derivative because of pulsar spindown are not known *a priori*. Hence, the arrival phase of the pulse must be fit by a model that includes terms linear and quadratic in the observation time, t. Other parameters of the system must also be fit for such as the exact position of the pulsar on the sky, its motion across the sky, and multiple parameters of a binary companion, if one exists – and many millisecond pulsars are in binary systems. This reduces the sensitivity of the data in ways that must be carefully modeled [4,5].

How can this behaviour be used to detect gravitational waves with a pulsar timing array (PTA)? Consider a stochastic background of gravitational waves permeating the Galaxy. The effect on each of the pulsars being monitored will be independent since their GW-induced motion will be uncorrelated due to the large distances between them. However, half of the GW-induced timing noise in each pulsar-Earth link will be due to the effects of the GW on the Earth, and these effects will be correlated with a correlation coefficient that depends on the angular separation between the pulsars (Fig. 2) [3,6].

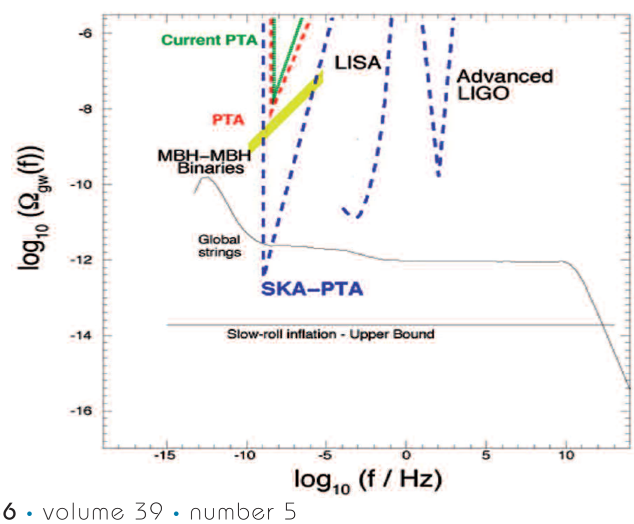
Sources of nanohertz gravitational waves

Take an electric charge and shake it back and forth. You will produce a kink in the electric field that will propagate away as an electromagnetic wave. The same would be true if you took a mass and shook it back and forth. Unfortunately from the standpoint of detecting gravitational waves, there are no hands out in the universe shaking massive objects back and forth. Instead, massive objects accelerate because of the presence of other massive objects. But, General Relativity postulates that, locally at least, all forms of mass-energy accelerate at the same rate. The static gravitational field itself, being a form of such mass-energy, then accelerates in the same fashion as the object that is producing it. Thus, massive, accelerating objects are very inefficient at introducing kinks into the field that surrounds them. It is only the non-local (*i.e.* tidal) aspects of the field that give rise to gravitational waves [7].

What might produce gravitational waves in the nanohertz frequency range? Collisions between galaxies and the ultimate coalescence of the massive black holes (MBH) at their centres are expected to emit strongly in this frequency range, but the signal from any one merging event is weak. However, the incoherent sum of thousands of such ongoing events form a stochastic background of gravitational waves that should be detectable by pulsar timing efforts in the next five to ten years [8,9].

Early-universe phase transitions and the emergence of various topological defects should also produce a stochastic background of gravitational waves [10,11]. However, there is a much wider range of model predictions in the case of a primordial GW background than for a background of MBH binaries; hence, a particular observational limit on a GW background affords more "wiggle-room" for these models.

A periodic or chirped signal from a single orbital system can be characterized by the strain amplitude h and the frequency of the wave f, both of which change with time during a gravitational coalescence event. However, for a stochastic background of gravitational waves it is conventional to express the spectral power as a fraction of the closure density of the universe. The fractional energy density per unit logarithmic frequency interval is $\Omega_{gw}(f)=(2\pi^2/3H_0^2)f^2h^2$, where H_0 is the Hubble factor. A variety of possible sources of a GW background and the instrumental sensitivities, achieved and anticipated, are plotted in Fig. 3.



◀ FIG. 3: **The power in a gravitational wave background as a function of GW frequency for a variety of sources relevant to PTAs. Power is shown as the ratio, per logarithmic frequency interval, of the stochastic gravitational wave power divided by the critical energy density of the universe. PTA refers to a generic pulsar timing array. Both current limits and five year projected improvements are shown. SKA-PTA is the pulsar timing array possible when the Square Kilometer Array is built in the 2015 – 2020 time frame. The most promising candidate for a stochastic GW source in this frequency range is due to massive black holes (10^7 – 10^8 solar masses) that in-spiral and coalesce as galaxies collide (shown as a yellow bar). Stochastic backgrounds produced by cosmic strings or in an inflationary era are also shown. Projected sensitivity limits are shown for LISA and Advanced LIGO, but the astrophysical sources most relevant to those detectors, binary combinations of stellar mass black holes and neutron stars, are not indicated. [The original figure, modified here, is courtesy of G. Hobbs.]**

Pulsar Timing Arrays: present and future

There are several, partially overlapping, efforts underway to detect a GW background with pulsars. The Parkes Pulsar Timing Array (PPTA) is the oldest and most fully developed collaboration [8, 9]. Their goal is to make multi-frequency timing observations of 20 of the brightest millisecond pulsars observable with the Parkes 64-m radio telescope on an approximately bi-weekly basis. This well-established observing and analysis program is publishing results on several scientific fronts related to the ultimate goal of detecting a GW background. The European Pulsar Timing Array (EPTA) takes advantage of three existing large-aperture telescopes: Jodrell Bank Observatory (UK), the Westerbork Synthesis Radio Telescope (the Netherlands), the Effelsberg Radio Telescope (Germany), and will be joined by the Sardinia Radio Telescope (Italy) when it is completed [12]. The North American collaboration, NANOGrav, uses data from the Arecibo Observatory, the largest radio telescope in the world, and the Byrd Green Bank Telescope [13]. All three collaborations share techniques, some data, and they have overlapping lists of personnel. Lamentably, both the Parkes Observatory and the Arecibo Observatory are dealing with severe budget cutbacks despite the crucial role they play in this forefront effort.

The longer-term future of pulsar-based gravitational wave searching will be focused on the Square Kilometer Array (Fig. 4), a world-wide effort with headquarters at the University of Manchester. When completed near the end of the next decade, this huge array of detectors/telescopes in a radio-quiet site in either Australia or southern Africa, will revolutionize all areas of radio astronomy. The discovery of an estimated 1000 or so millisecond pulsars and the ability to time 10 or 20 of them at a level of precision of 100 ns or better, will lead to a sensitivity level for this PTA of as much as a factor of 10^4 over existing efforts [14,15].

Status of Results and Prospects

As is evident in Fig. 3, pulsar timing is rapidly approaching a detection or falsification threshold for a GW background from coalescing massive black hole binaries. The latest upper bounds, using 8 years of data, place a limit of $\Omega_{gw} \leq 4 \times 10^{-8}$ on this source of a background and similar limits on that due to either relic gravitational waves from quantum era fluctuations or from the decay of cosmic strings [5].

The effort to use pulsars to detect individual GW sources or, more likely, a stochastic background of such sources is well underway using the world's largest radio telescopes. The nanohertz frequency range being probed is complementary to the higher frequencies being observed with Michelson interferometers on Earth and, ultimately, in space. Detection of a GW background due to thousands of merging galaxies in the detectable portion of the universe may be less than a decade away. The advent of the Square Kilometer Array will almost certainly lead to such a detection and the ability to characterize the spectrum and single out the few brightest sources for further study. All of this is being done with multi-purpose radio telescopes that are also being used for a wide variety of other investigations. Which will hit the gravitational wave jackpot first: a laser-powered Michelson interferometer or a Pulsar Timing Array? ■

About the author

Dan Stinebring has been observing pulsars since 1976 and worked in Joe Taylor's group at Princeton from 1985 -1990. Since 1990 he has been a professor at Oberlin College. In 2006-07, he spent a sabbatical year at Leiden University

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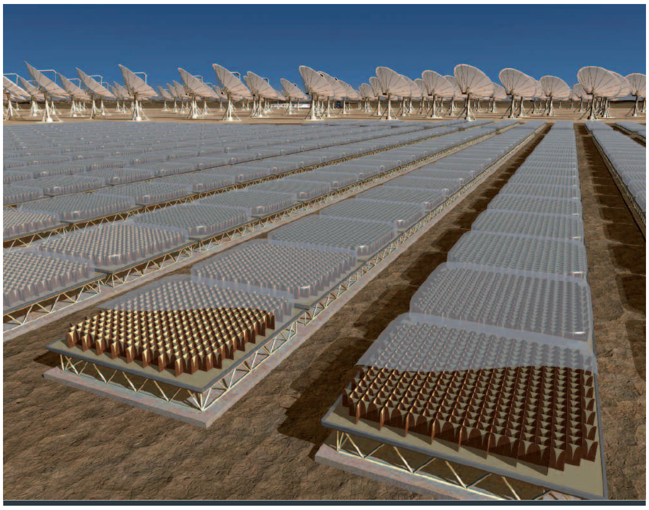

▲ FIG. 4: **Artist's rendition of the central portion of the Square Kilometer Array. This fundamental instrumentation advance in astronomy will have a total collecting area of about 10^6 m² consisting of innovative electronic tiles and parabolic dishes, concentrated in a central core but extending in a hierarchical fashion out to many thousands of kilometers. It will be built in either western Australia or southern Africa, with construction commencing in 2011, first science in 2014, and completion around 2020. [Figure from http://www.skatelescope.org]**

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Application forms are available on request or on the web site: **http://ghmfl.grenoble.cnrs.fr**
Scientists of EU countries and Associated States* are entitled to apply under the European Programme to obtain a financial support according to rules defined by the EC.

* Iceland, Israel, Liechtenstein, Norway, Switzerland, Turkey

Please contact: Dr. E. Mossang, Grenoble High Magnetic Field Laboratory
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2009 - Call for proposals on the CLIO infrared FEL

CLIO/ELYSE facility- LCP - Orsay, France

CLIO Performances

CLIO is a pulsed free-electron laser continuously tunable between 3 and 120 µm. It has a double pulsed structure: "macro-pulses" 10 µs long (at 1 to 25 Hz) contain "micro-pulses", of length adjustable from 0.3 to 5 ps (with Fourier transform spectral width). The micropulse interval is 16 ns. CLIO can lase simultaneously at 2 different, independently tunable frequencies, allowing 2-colours pump-probe experiments.

Spectral range	3 to 120 µm
Polarization	linear
Minimum spectral width $\Delta\lambda/\lambda$	0.2 % to 1 %
Stability in λ	0.1 %
Macropulse length	1 to 9 µs (tunable)
Micropulse "	0.3 to 5 ps (")
Peak power	10 à 100 MW
Max.average power	1 W (25 Hz, 16 ns/micro-pulses)
2-coulours FEL	tested up to 26 µm
OPOs	2 - 8 µm

User facility

A vacuum beam line transport the optical beam to 5 user rooms (another set of 3 is being built). They include various equipment : mirrors, detectors, optical mounts, monochromators, cryostats, etc. The users have computer control of the laser wavelength and spectral scans. In addition, 4 different set-ups are available. 3 of them are operated by permanent scientists, and include OPOs (2 – 8 µm) in parallel with the FEL :

- A surface sum frequency ("SFG") experiment, spectroscopy of molecules adsorbed on surfaces or interfaces.
- Several FT-ICR-Mass spectrometers for molecules in gas phase spectroscopy by multiphoton dissociation
- A near-field infrared microscope with spatial resolution < 100 nm capable of local spectroscopy
- A pump-probe and photon echo experiment (no permanent scientist)

In addition a pulsed magnetic field is being developped (45 T) and should be available by mid-2009

Information is available at: http://clio.lcp.u-psud.fr/clio_eng/clio_eng.htm

Call for Proposals

The proposals are reviewed by an international Programm Committee. Under the 7th PCRD of the European Union, the use of CLIO is free of charge for researchers from the academic community; travel and living expenses can be refunded for a researcher if he is normally working in one of the Member States of the Community or Associated States.
For the experiments to be performed in 2009 proposals must be submitted by:

December 31, 2008

on forms which can be obtained (as well as general information) from : http://clio.lcp.u-psud.fr/clio_eng/proposalNewang.html

More information for applications can be obtained at
Laboratoire CLIO/LCP
Centre Universitaire Paris-Sud
Bât. 201 Porte 2
91405 ORSAY
Tel. 33 (0)1 69 15 32 94 - **Fax.** 33 (0)1 69 15 33 28

Research Associate Positions

for Fundamental Studies of Magnetism at the Atomic Level

In the framework of the **ERC Advanced Grant "FURORE"**, the Department of Physics at the University of Hamburg is seeking outstanding and enthusiastic young researchers with a strong record of creativity and achievements in the area of atomic- and nanoscale magnetism for the following positions:

- **Research Associate**
  for combining low-temperature spin-polarized scanning tunneling spectroscopy (SP-STS) with ultrafast spectroscopy techniques, thereby achieving ultimate spatial-, temporal-, energy-, and spin resolution simultaneously.

- **Research Associate**
  for atomic-scale studies of magnetic molecules on surfaces by SP-STS at mK temperatures and high magnetic fields.

- **Research Associate**
  for atomic-scale studies of diluted magnetic semiconductors by low-temperature SP-STS.

- **Research Associate**
  for atomic-scale studies of surface spin structures of magnetic insulators by Magnetic Exchange Force Microscopy (MExFM).

- **Research Associate**
  for atomic-scale studies of spin excitations at surfaces of magnetic insulators using magnetic damping force spectroscopy with true atomic resolution.

- **Research Associate**
  for combining Magnetic (Exchange) Force Microscopy with ultracold quantum gases to study the coupling of the spin degrees of freedom between solid state and quantum optical systems.

Appointments are initially for one year with possible renewal up to a maximum of five years. Starting dates are negotiable, but some appointments can begin as soon as possible. Evaluation of applications will begin immediately. To apply, send a resume including a statement of research experience and interests, and a list of publications and presentations to:

Prof. Dr. Roland Wiesendanger
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Jungiusstraße 11, D-20355 Hamburg, Germany, EU
Email: wiesendanger@physnet.uni-hamburg.de
Web: www.nanoscience.de

The University of Hamburg is an equal opportunity employer and welcomes applications from all qualified individuals. It aims at increasing the representation of women among the staff and therefore explicitly encourages applications from female scientists.
Disabled persons are given priority over applicants of equal suitability, qualification and degree of specialized knowledge.

March 23 – April 02, 2009 **Geilo, Norway**

NATO Advanced Study Institute

Order, Robustness and Instabilities in Complex Systems

Topics of lectures:
- complexity in nature and society
- emergence of order
- financial instability
- fracture and crack propagation
- instabilities in networks
- managing complexity
- predictability in complexity
- robustness and adaptability
- self-organization
- sensory systems

Topics will cover both experiments and theory aiming at physicists, biophysicists, biologists and social scientists. Open to participants from all countries. Deadline for application: **January 9, 2009**

Information:
Trine Løkseth, Dept. of Physics, Institute for Energy Technology, POB 40, N-2027 Kjeller, Norway. Tel: +47 63 80 60 75, fax: +47 63 81 09 20, e-mail: fysikk@ife.no

Information about this NATO ASI and the application form can be found on: **www.ife.no/geilo**