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The quest to understand the pioneer anomaly
A tribute to Boltzmann
Gravity's pull on arc lamp efficiency
The ANTARES telescope turns its gaze to the sky

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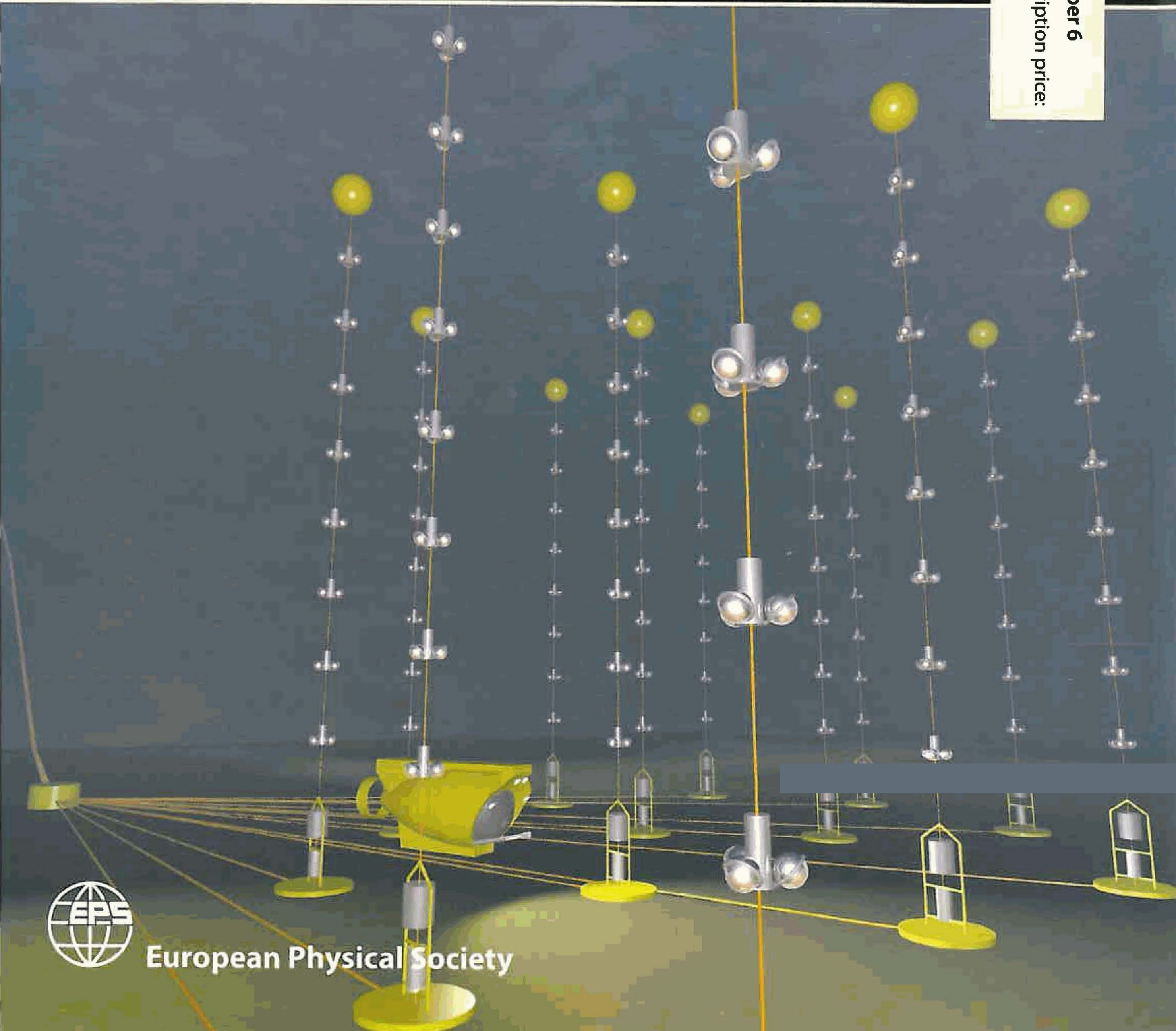

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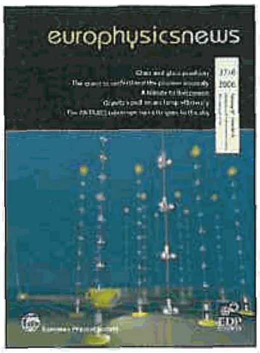

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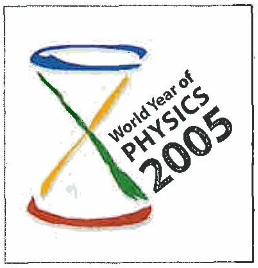
cover picture: Artist's impression of the ANTARES neutrino telescope on the sea floor.
See article p. 18 (© F. Montanet, CNRS/IN2P3 and UFJ)



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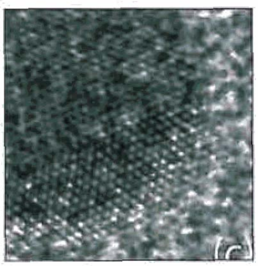
Report on the World Year of Physics 2005



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editorial

Forum Physics and Society: on physics changing relationship with society

The emergence of modern science as we know it today took place after the Second World War. Science and in particular physics and engineering had contributed decisively to the outcome through new technology, such as radar and nuclear weapons. The result was a blank cheque for physics research in the following 40 years, nurtured by space exploration and the cold war. This symbiosis came to a halt with the end of the cold war - luckily enough for physics, because the old partnership with society, although profitable, was on the dark side.

What came next was the new industry – science partnership. Physics was seen as an innovation driver and catalyst for economic growth. The large European Union Framework Programmes which began in the 80's and have gradually expanded over the last 20 years were not basically programmes to support science but rather supported society's investment in novel ways of creating new products and processes and to spur economic growth.

For physics this second phase in its interaction with society has never been a happy one. The reason is simple and straightforward. The linear innovation chain, valid in the first mode of interaction with society was no longer adequate in describing the value of basic science. The easy fix of unfettered serendipity and basic physics as a precursor for new technologies was no longer evident. The result was a reduced interest in physics as a research topic.

In the same period we have seen a reduced interest among students in studying the hard natural sciences (mathematics, physics and chemistry). Whereas the tertiary educational intake has grown 45 % during the last 20 years, the enrolment in the hard natural sciences has dropped, even relative to the population trends.

This is the challenge EPS and all its **39** member societies and members face. We need to turn this development around and create a new and enduring partnership with society. That society values this partnership was demonstrated at a recent ceremony in Brussels, where the European Economic and Social Committee selected EPS for its first prize for organized civil society under the heading of European identity as an essential cultural element for European integration.
www.eesc.europa.eu/sco/prize_civ_soc/index_en.asp

What is organized civil society? It is the web of very many organisations bringing people together under a well defined agenda.

Organised civil society is one of the most valuable and important elements that glues societies together. This is exactly what EPS is doing under the umbrella of physics education, physics research and physics as an innovative tool in value creation.

Over the last 40 years, organized civil society has undergone major changes. This same time span corresponds to the life of EPS activity and the development of Europe as we know it today.

In the early years much EPS focus was on collaboration in a divided Europe with restrictions on many of the freedoms that we enjoy today. Moreover science, technology and innovation are increasingly

At a meeting on 29 August chaired by EESC president Anne-Marie Sigmund an EESC panel of judges unanimously agreed on the winners of the Committee's 2006 prize for organised civil society. The first prize, worth 10 000 €, was awarded to the European Physical Society (EPS). A second prize was awarded jointly to the 'European Civic Forum and a Hungarian body, the Future of Europe Association, who each received 5 000 €. The inaugural 2006 prize was given for work or actions by civil society organisations that could help raise European citizens' awareness of the shared roots, values and goals of all the peoples united under the banner of European integration.

important drivers for economic growth and thus also an important precondition for social cohesion. However, beyond these observations, education stands out as the single most important theme to be developed further in Europe, where national educational systems often hinder a student in exploring other cultures.

EPS is committed to contribute substantially to this harmonization of the European educational system. We have developed our own educational platform within the overall framework of the Bologna process and are effectively disseminating these educational policies in all of our member countries.

This increased exposure to topics of great civil importance puts pressure on organized civil organizations such as EPS, entirely based on voluntarily contributions from members. EPS must position itself not only within the physics community but also outside physics, as a responsible player in society at large.

Put differently, EPS must enter civil society taking our part of the responsibility for the development of Europe with physics as our common background and our experience from being in ourself a strong and unified culture.

In order to live up to this challenge EPS needs new tools. Our Divisions play a strong role in the formulation of professional physics related issues, such as publication and conference activities. Our Groups work with subject specific issues of particular interest for physics such as mainstreaming, education and technology.

EPS needs an integrator for these activities working with the overall issues of relevance towards the wellbeing of physics in society and to underline the importance of physics as a discipline and as a strong and valuable culture in our societies. It is proposed to establish a Forum Physics and Society as a new unit in the family of EPS Divisions and Groups. Its main responsibility will be the overall representation of EPS as a strong policy making body in support of physics on a European scale.

The Executive Committee will discuss the matter this year with the aim of formally establishing the Forum at the next Council meeting in March 2007. It is proposed to use the EESC Prize money of 10.000 € as seed money in establishing the new unit. Those of you interested in joining are kindly asked to e-mail either opo@iha.dk or d.lee@eps.org.

Ove Poulsen, EPS President.

Iberian-Rmerican Federation of Physical Societies

Gerardo Delgado Barrio, President of FEIASOFI • IMAFF (CSIC)Madrid-Spain • E-mail: Gerardo@imaff.cfmac.csic.es

The Council of the "Federación Iberoamericanade Sociedades de Física" (FEIASOFI) was held in Madrid (Spain), from 20 to 22 of September. This was the first General Assembly, bringing together presidents and representatives from the physical societies of the Latin-American countries plus Portugal and Spain. Although representatives from the entire region were not present, e.g. the presidents of Brazil and Paraguay had an important problem just at the last minute, those present, from fourteen countries, were able to establish several agreements to start the normal life of the Federation. This meeting was supported jointly by two Governmental Spanish institutions: the Spanish National Research Council (CSIC) and the Spanish Foundation of Science and Technology (FECYT); and was also supported by a Spanish private institution, the BBVA Foundation.

The Federation is a not-for-profit association whose purpose is to promote physics and physicists in Iberoamérica. The first name of this federation was "Unión Iberoamericana de Sociedades de Fisica" (UISF), and it was created in 1996 by the president of the Federation of the Latin-American Physical Societies, and the presidents of the Spanish Royal Physical Society and the Portuguese Physical Societies. In September 2005, in La Plata (Argentina), the representatives of the different physical societies decided to approve a Constitution and they changed the name in order to stress the continuity of the Federation of the Latinomerican physical societies. The last meeting of UISF was held in Madrid in December of 2003, where also the president of EPS, Prof. Martin Huber and the International Coordinator of WYP2005 and past president of EPS, Prof. Martial Ducloy participated.

In this first Council of FEIASOFI, during the three days, we have accepted the creation of the first four divisions: Atomic, Molecular and Cluster Physics Division; Condensed Matter Division; Education in Physics Division; Statistical and Nonlinear Physics Division. We have decided also to establish the permanent seat in Montevideo (Uruguay) and it will be registered as a society in this country, but it will have also a second provisional seat in Madrid (Spain). Several scientific activities, such as schools, workshops and conferences will be supported and promoted by the Federation. In particular, a school in Medical Physics will be organized by the executive committee in Guatemala in 2007. FEIASOFI will also support several programs such as "Science on Stage": "New Talents in Physics" and the Iberoamerican Physical Olympiad. It was clear for all the participants, that a strong effort will be necessary to promote education in physics at all levels, because it constitutes an important step to strengthen physics in the region. Another important decision was taken about the official journal of FEIASOFI "Revista Iberoamericana de Física" that was first published in Madrid in 2005, and from now will continue to be published every six months.

A official presentation in the palace "Casa de America" in Madrid the 21st of September 2006. In the table from the left: Actual President of the Spanish Royal Physical Society, Prof. Antonio Fernandez-Rahada. Representative of the Spanish International Cooperation Agency, Dª Monica Ruiz. President of the FEIASOFI, Prof. Gerardo Delgado-Barrio. General Secretary of FEIASOFI, Prof. Raul Grigera and President of The Spanish Foundation of Science and Technology, Prof. Joan Comella.

All the Council meetings were held in the main building of the CSIC, apart from the official presentation of the Federation that was in the palace of "Casa de América" on the 21st, and the last session that was held in the seat of the BBVA Foundation on the 22nd. Several invited representatives of the CSIC, FECYT, and BBVA Foundation have also participated in the Council.

Finally, a very important goal for this Federation is to establish, not only a very strong collaboration among the physical societies in Iberoamerica, but also with APS and EPS. As a first step the federation has invited the APS and the EPS to participate in the Council.

◄ all the presidents and representatives of the physical societies that have participated in this 2006 General Assembly of the FEIASOFI, plus the representative of the EPS Prof. Victor Velasco and several members of the Spanish Royal Physical Society, in particular the Secretary of this Society Prof. Antonio Dobado.

The World Year of Physics 2005 (WYP 2005)

Martial Ducloy, Former President of the EPS

The origin of the World Year of Physics 2005 goes back to 2000. The idea originated in a set of discussions and conversations I had with physicist colleagues, during that year, about the apparent loss of attractiveness of physics to society and towards young people, as well as the decline of physics studies at the University level. Proposed at the EPS Executive Committee and at the Third World Congress of Physical Societies in December 2000, the initiative of a "World Year of Physics" similar to the 2000 World Mathematical Year was unanimously adopted. Year 2005 was proposed as it would be the 100th anniversary of the "*Annus Mirabilis*" of Albert Einstein in 1905 when he made his epoch-making contributions to physics and science by setting the bases of special relativity and the mass-energy equivalence, proposing the energy quantum of light and establishing the theory of the Brownian motion based on atomic theory. This initiative, in order to be implemented with success around the world, needed to be approved by international organisations. This took some time, more than expected: the General Assembly of IUPAP (International Union of Pure and Applied Physics) voted a motion along this line in October 2002; the same year, a WYP International Steering Committee was put into place, and the WYP logo was devised at the EPS Executive Committee during a memorable meeting in Mulhouse, in June 2002. In October 2003, the General Conference of UNESCO approved the WYP2005 initiative; and finally, the General Assembly of United Nations (UN), in June 2004, on a proposal made by Brazil, France, Lesotho, Monaco, Portugal, Singapore and UK, and defended by the Ambassador of Lesotho, unanimously designated 2005 as the "International Year of Physics'.

Objectives and preparation of WYP

The main objective of WYP was to improve the communication between science and society, and for this purpose, to encourage celebrations directed outside the physics community, toward the general public. Practical objectives were to decrease the gap between physics and society, to promote physics in its broad sense by demonstrating its major role in the socio-economical development and in every day life (health and medicine, energy, environment...), and to increase the interest of the general public, particularly of its youngest part, in physical sciences and scientific innovation. It implied a strong involvement of researchers and scientists to explain their motivations and share their enthusiasm.

To implement the WYP activities, a number of preparatory meetings have been held in Graz (July 2003), Montreal (March 2004) and Mulhouse (October 2004). These meetings, which on the average involved about 40 representatives of Physical Societies throughout the world, had been organised to insure the information transfer and the exchange of ideas between national coordinators, about activities and events which were planned for 2005. They also allowed scheduling and implementing international events, such as "Physics enlightens the world or "Physics talent search" (see below).

International events

They included WYP launch and closing events as well as other international events.

The WYP launch conference "Physics for Tomorrow" was organised at the UNESCO headquarters in Paris, on January 13-15, 2005, under the aegis of UN, UNESCO, IUPAP, EPS and SFP (French Physical Society). Over 1200 participants from over 80 countries attended, including many eminent scientific personalities and more than 500 young students. These students, aged 16 to 21, from over 70 countries, with 25% of females, had been selected among the best physics students of their countries (*e.g.* laureates of International Physics Olympiads...). Prestigious invited speakers, among them eight Nobel laureates, gave outstanding presentations for a general audience and participated in 'round table' discussions about physics and society questions. The accent was put on the impact of physics on daily life: development, life science, information technology, etc. (see the report in *EPN* 36-2 p. 66).

Many other international events were organized, among which: *"Physics enlightens the world"*, *"Physics talent search* an International Poster Contest (*"Physics across the World'*: organised by IoP-UK, with a final rating organised at EPS13 in Bern), "*Physics in School Architecture"* (PHYSARH, organised by Serbia-and-Montenegro), the *"International Physics Olympiads"* (Salamanca, Spain, July 2005), the IUPAP Conference on *"Women in Physics"* (Rio, Brazil, May 2005; see report in *EPN* 36-5 p. 175), the International Young Physicists Tournament (with 23 participating countries in Winterthur, Switzerland, July 2005 – see the report in *EPN* 37-1, p. 10), the International Conference of Physics Students (Coimbra, Portugal, August 2005) or the IUPAP World Conference on *"Physics and Sustainable Development"* (Durban, South Africa, November 05; see the report in *EPN* 37-4 p. 10).

One should note the fantastic success of the light relay organised around the globe (*"Physics enlightens the world')* during the night of 18 April 2005, for the 50" anniversary of Einstein's death. A light relay starting from Princeton went westward throughout the USA and Canada,

▲ Chris Rossel presenting the WYP logo

A Physics for tomorrow at the UNESCO headquarters in Paris on January 13-15, 2005.

and, after crossing the Pacific Ocean, ran through Asia and Europe, to get back to Princeton, 24 hours later. At the occasion of this light relay uniting participating countries under the banner of physics, and organised by Max Lippitsch (Graz, Austria), more than 100.000 people from over 40 countries participated in the various light shows organised during this "long night of physics". Taiwan, which had the highest participation number in relation to its population, was specially awarded at EPS13.

EPS13, the general conference of EPS, which has been organised in Bern in July 2005, was more directed towards physicists (570 registered); but it has been the occasion of numerous ceremonies and events for the general public, all related to the fact that Einstein was living in Berne in 1905: International Celebration day, Open day, special exhibit on Einstein's life and achievements at the Historical Museum, etc. (see the various reports on those events in *EPN* 36-5, and *EPN* 37-1 p. 31 for the museum exhibit).

Another successful international event organised for young pupils and students was the *"Physics Talent Search"* (organised by Beverly Hartline, USA). Its purpose was to create "enthusiasm, interest and participation in physics among young people (and their families)". Each participating country had to identify physics-talented girls and boys who should be rewarded for their excellence in physics. These "Physics Young Ambassadors", aged 10-18, were selected in each of the 22 countries participating to the event (Albania, Argentina, Austria, Belarus, Bulgaria, Cameroon, Croatia, Cyprus, Ghana, India, Indonesia, Korea, Nepal, Netherlands, Poland, Serbia and Montenegro, Slovakia, Switzerland, Taiwan, Trinidad and Tobago, Tanzania, United States). The national awardees received certificates for Young Physics Ambassadors, together with personal letters signed by Nobel laureates. They assembled in an "International Physics young Ambassadors Symposium" organized in Taipei, Taiwan, at the end of December 2005. This manifestation is to be renewed in 2006.

Finally, there has been numerous WYP closing events. Among them, such an international event as the *"Simpdsio de Encerramento do Ano Mundial da Física 2005"* organised in Recife, Brasil (December 05) should be mentioned, with the participation of Nobel laureate Claude Cohen-Tannoudji, of eminent speakers such as Dan Kleppner and Mildred Dresselhaus (MIT, USA), as well as of Sergio Rezende, Brazilian Minister for Science and Technology (and physicist from Recife). The choice of the location for this WYP closing Conference was not innocent because, by comparison with the kick-off conference in Paris, it set the emphasis on an emerging country, Brazil, and a particularly under-developed region of this country, "Nordeste" - but with a good physics community. Another well publicized closing eveht was a World Wide Webcast entitled *"Beyond Einstein"* and organized by CERN on the 1st of December. During 12 hours of live show, this webcast circled the globe, with direct links to physics laboratories and science museums across the world, from Europe to America, from Asia to Tasmania, up to Antarctica, and with the participation of several hundred physicists. The topics considered in this webcast were mainly centred on particle and theoretical physics, as could be expected from CERN organizers, but it also included emerging fields like nanotechnologies.

National activities

The list of national activities developed for WYP2005 is impressive. It concerned more than 80 countries over all the continents. In some countries, the number of organised events was well over the hundred: for example, more than 500 registered events in France or UK, about 300 in Austria, over 100 in Poland, etc. Those activities included:

- Local and itinerant exhibitions on physics and its achievements
- Local events on physics in every day life
- Cultural events (theatre performances, symphonies...)
- Actions in schools, universities; open doors in universities and laboratories, etc.
- Competitions (poster competition, calendar competition)
- National physics Olympiads
- Physics in the street, in public areas: interactive experiments, revisiting of historical experiments
- Campaign of experiments at the national level (air pollution, natural radioactivity monitoring...)
- Interaction with local industry, technology parks, etc.
- Advertising material: articles in newspapers and specialised magazines, posters in public areas and transportation systems (train, buses, airlines), issues of special stamps, postcards, etc.
- Edition, or re-edition of books
- Special programmes on national and local TV channels and radios
- Conferences and seminars for a general audience, science bars...

▲ Physics enlighteens the world in Taiwan

Let us review some of these activities. Exhibitions have been numerous throughout Europe (in France, over 100) generally with a scientific character, but possibly integrating cultural and historical elements. Light has inspired many of these exhibitions, like *"La lumitre au sitcle des lumitres"* (Nancy, F), but obligated by the centenary, Albert Einstein has been the focal point of the majority of them. One should quote, among many exhibitions (like Seoul "Einstein" exhibition, over 300000 visitors; or an Einstein exhibition in Berlin), two outstanding ones, the first in Bern, "Albert Einstein": very complete and which encountered a noticeable success (more than 140.000 visitors in five months), and the other, very nice, at the Calouste Gulbenkian Foundation in Lisbon, *"A luz de Einstein"*, which indeed spanned 2500 years of science and physics, from early Greek science and Aristotle up to the modern view of physics and cosmos (over 70.000 visitors). Some of these exhibitions are itinerant and will continue to be presented in various countries. A French one *"Mosaïques de la physique"* composed of easily reproducible experimental kits has circulated in France, and has started to travel through North Africa and the Middle East.

Activities in schools have been a very important part of WYP2005, because ...

▲ Eratosthenes' measurement in the USA

... the young generation was one of the main targets of WYP. These activities can be classified along two main lines:

(1) Competitions, like national Olympiads (in many countries), science poster competitions (Poland, UK, Slovakia, etc), cartoon physics jokes, calendar competitions (WYP calendars with relevant events related with physics in Portugal, with final meeting chaired by the Portuguese President, etc.), scientific and technical contests (Eureka cup and Techniek Toernoi in the Netherlands, etc.), photographic contests...

(2) Networked-activities gathering schools at the regional or national level, and possibly internet-linked: environment or pollution monitoring such as ozone measurement in South-East France, radioactivity mapping (natural radon measurement in Italy, Serbia-and-Montenegro), water pollution (Serbia-and-Montenegro), air pollution by dust (140 schools all over Poland), traffic noise pollution (Poland, Serbia-and-Montenegro)...

In a number of countries (Australia, Czech Republic, Norway, Spain, United Arab Emirates, USA), school pupils have reproduced with modern means the famous Eratosthenes' measurement of the earth circumference (3rd century BC). Eratosthenes' approach, mixing geometry and geography, trigonometry and astronomy, rested on the comparison of the shadows of a vertical "gnomon" (stick) -at noon, on summer's first day - simultaneously in Alexandria and Syene (present-day Aswan).

One of Eratosthenes' major difficulties was to measure the Alexandria-Syene distance, which he realised via the counting of the number of camel steps in caravans connecting the two cities. The remake of this measurement has been for many years one of the emblematic projects of the *"La main a la pâte"* programme in French primary schools. In 2005, such a remake has been done at a continental scale in North America. Across Canada, USA and Mexico, 800 schools participated to the measurement to get an earth-circumference value accurate to within 5%.

Revisiting historical experiments like that of Eratosthenes has been performed in many countries in 2005. It includes the Foucault pendulum to evidence the earth's rotation (in the Netherlands, Slovakia or Belgium). Light velocity measurement using a modern version of the 1849 chopper wheel method of Fizeau has been performed using a green laser beam between the Paris Observatory and Montmartre. The two-hemisphere Magdeburg demonstration of atmospheric pressure (1654) has been redone in several countries (Croatia, Belgium, the Netherlands, Spain...). Most of those experiments have been performed in public places. Indeed street experiments have represented an important component of WYP events. They were organised in many different ways. Physics performances have been implemented in such varied public places as street markets, large department stores, shopping malls and supermarkets (Physics on the market, the Netherlands), railway stations (Physics at the Helsinki station, Finland), beaches (Energy Beach Tour, the Netherlands), etc. The idea was to go toward the general public where it stands. Railway stations are good places to reach the public – provided that the events are not organised on week days at the moment of the great 'rush hour' workday migrations. In the Netherlands, beach performances were devoted to renewable energy. In 2005, the unusually bad weather led to this project reaching far less people than it would have otherwise. However the idea is great, since people at the beach have free time, are more relaxed and accessible to unusual entertainment (stimuli). This should be renewed.

A way to make science experiments more mobile and take them to children across the country, has been to organise *"science buses'*: able to move freely in public locations and visit schools. This has been done in Estonia (a big success, with 100 schools visited), France (4 science buses *"Scientibus"*, in various provinces), UK (a fleet of 3 *"Lab in a Lorry"* vehicles, more than 200 schools visited in 2005). One of the Lorries crossed Africa from North to South, to reach South Africa and visit schools in townships, finishing its journey in Durban, at the IUPAP conference on Physics and Sustainable Development.

Another interesting approach has been to use public transportation to advertise physics and stimulate the interest of a wide diversity of people. In Slovenia, a very successful initiative has been to install posters in city buses. The idea was to provoke curiosity among the general public by displaying on posters provocative questions at the entrance to the bus, and providing short and clear answers later on at the exit doors of the bus.

► A monument to Einstein in Bulgaria

This initiative is being extended now by EPS, under the denomination "Science in Public Areas", to other countries like France, Mauritius Island, Philippines, China... (www.scienceinpublicareas.org)

In 2005, physics has been also the object of specific cultural events or of actions integrated in larger events. Theatre plays on science history or on the 'modern physics' revolution have been performed in several countries like UK, Japan, Serbia-and-Montenegro, France, Croatia, Bulgaria, Norway, etc. Dance and choreographic shows have been also performed in many countries: France, UK ("Constantspeed"-based on 1905 Einstein theories), etc. In Poland, a symphony "Sinfonia de *Motu*" has been especially composed for the World Year of Physics by the great Polish composer Wojciech Kilar. In South Africa, a funky song on Einstein's life ("Siyabonga Einstein" - "thank you Einstein!") has been composed and recorded on a DVD by junior school kids. Many monuments or sculptures centred around physics and Einstein were realized across the world, during 2005. Just a single example: on the 29 December 2005, in the Bulgarian city of Varna, on the Black sea, a monument to A. Einstein was unveiled.

One should note that, for some countries, in particular the smaller ones, all events and performances were concentrated in a short, and publicised, period of time, in order to better reach a larger audience: a 'physics week' in Croatia, Cyprus, Norway..., 'physics days' or "Journées de Physique" (Catalonia, Slovakia...). One also should underline that the problem of gender equity in science has been debated in a number of countries (UK, Cyprus, Ghana, Slovenia...), in addition to the IUPAP conference "Women in Physics" held in Rio, in May 2005.

Advertising material

Advertising material has been produced of a great diversity: calendars, stamps, postcards (Poland, China, Bulgaria, Slovakia, and Czech Republic), phone cards (Cuba, Slovenia...), lottery tickets (Spain), T-shirts... Commemorative stamps have been in the great majority of cases devoted to Relativity Theory and Albert Einstein (many countries including Cuba, Congo, Costa Rica, Fiji, Germany, France, Switzerland, Liechtenstein, Monaco, Israel, Romania, Serbia-and-Montenegro, Mali...), or to other physicists (India, Slovakia, Ireland). Fortunately some of the stamp-issuing countries did it especially for the World Year of Physics, and did not forget to include the WYP logo in the stamp, which makes its fame lasting forever! This includes Mexico, Macedonia, Tunisia, Turkey, Argentina, Portugal, Spain, Italy, Czech Republic, etc. (for more information, see: http://fizjlk.fic.uni.lodz.pl/RUT/Stamps/wyp/wyp2005.html

▼ Example of WYP's stamps and postcards

WYP overview: funding, media response, politicians...

The funding of WYP activities has been a key-point for their success. A financial support of 2.1 M€ has been given by the European Union, through the Science and Society Programme (Directorate C of DG XII), to 16 European countries (Albania, Austria, Belgium, Croatia, Estonia, Italy, Moldova, the Netherlands, Norway, Poland, Portugal, Serbia & Montenegro, Slovenia, Slovakia, Sweden, Switzerland) coordinated by EPS. This funding has been particularly important for smaller countries which otherwise would have had much d culty to implement their outreach activities. Bigger countries got their own funding directly from the physics societies and governmental agencies. France had a particularly important overall budget of ~ 5 M€, followed in importance by UK (~ 1 M£) and the Netherlands (1.1 M€), Austria (0.7 M€), Portugal (0.63 M€) Italy (0.42 M€) and Poland (0.4 M€). USA operated with a budget of 0.75 M$.

The response of the politicians was strongly dependant on the country. For relatively smaller countries, the contact has been often good: for example, in Portugal and Bulgaria, the President of the Republic, and in Slovenia the Prime Minister, participated to some of the WYP events, like launch events, school award ceremonies, etc. In larger countries, the response of politicians has been slower and more limited, but at the end, more or less adequate, with in general the participation of Science, Research, Education or Economy Ministers. It appeared that the cooperation with Industrialists was often easier - even excellent in some cases (the Netherlands). The Director General of UNESCO participated in the Launch Conference and in the International Celebration Day in Bern, along with the President of the Swiss Confederation.

The media coverage has been quite diverse region to region or country to country, often relatively more important in the smaller ones. It came mostly first from radio broadcast and press, and more at the regional level in big countries. In the press, the articles were mostly in the science pages of newspapers, instead of the front page. It has been in general difficult to interest TV channels, except for spectacular events like "Physics enlightens the *world*". In practice, the media and particularly TV were more interested in celebrating Einstein than in the achievements of physics and its importance in daily life.

Assessment of WYP impact

The impact of the World Year of Physics will need some more time to be analysed in terms of the changes brought to their approach to physics by the general public, and particularly by young people and school pupils, as well as its influence on student enrolment in scientific studies. However it is clear that a huge momentum •••

has been given to worldwide science communication and physics outreach in 2005. WYP organisation has involved thousands of scientists, physicists and teachers who have been mobilised in the many countries (over 90 across 5 continents) which have been checked to effectively participate into WYP2005. The mobilisation of physicists across the world will remain as one of the strongest messages of WYP. In this respect, one should not underestimate the impact of the resolution of the UN General Assembly which was eagerly anticipated by the physicists of smaller countries as a launch signal for their outreach programme. One could consider that the few countries directly concerned or the big countries (UK, Germany, Switzerland, France, USA...) would have anyway celebrated the 100th anniversary of Einstein's '*Annus Mirabilis*', but this would not have necessarily been the case for smaller countries. One also should note that the UN signal was indeed important for the larger countries. In a recent conversation with William Phillips (NIST, Washington), we both came to the opinion that even the USA would not have set up the same outreach programme in the absence of the international mobilisation which occurred in 2005.

Finally, with the benefit of hindsight, one can single out the most successful outreach activities:

- School events and hands-on activities. This particularly includes the collective school measurements (environmental monitoring, Eratosthenes, etc.) and itinerant science buses.
- Interactive "open-air" experiments (experiments and performances in the streets, department stores, beaches...). Science in the city buses, science cafés.
- Exhibitions: museum exhibitions, physics fairs, science shows...
- International events: Physics Talent Search, Physics enlightens the World, International Physics Olympiads, etc.

Prospects, follow-up: beyond 2005

The momentum acquired in science communication should be maintained along with the strong involvement of physicists in those activities. The scientists have to continue their involvement in physics outreach (this type of activity should be recognized in career promotion). All this, as well as the relations with policy-makers and media, has been debated in a *"Physics and Society"* Forum organised in Graz in April 2006 (see the report in EPN **37-3,** pp **3-4).**

However one cannot ask the same burden from physicists active in 2005, and organise a World Year of Physics every year - but why not trying to organise International Physics Days or Week?

Also, physics communication could be partly pursued during the forthcoming International Science Years: in 2007, there will be the International Heliophysical Year, in 2008, the International Year of Planet Earth, and 2009, the World Year of Astronomy

The successful outreach activities described above should be pursued whenever it is possible, like the school events or the exhibitions. The second round of "Physics Talent Search" is already programmed. Extension of the project *"Science in city buses"* to other countries is also in progress.

The importance of an international coordination, inside the scientific community, for public awareness of physics has been demonstrated in 2005, and it calls for "Physics and Society" Action Committees at several international levels: EPS, IUPAP...

Finally, it appears to be vital to continue to reflect on the teaching of physics, and to maintain the close links between researchers and teachers which has been established during WYP 2005.

Science on the Buses: a WYP project under the 6th Framework programme

Miha Kos, Luka Vidic, Božo Kos et al., Ustanova Hiša eksperimentov (The House of Experiments)

The objective of the Slovenian Science Centre called Hiša eksperimentov was to find a way to raise public understanding of science, with the emphasize on physics. We came out with the idea of making a set of provocative questions and answers in physics and to put them on display in the public transport – buses.

By the responses we got from the public the project was well accepted and we were encouraged to continue to take part in the process of educating the public and raising the public awareness of science.

A set of 50 everyday's questions and answers were composed among the team of the Science Centre – Hiša eksperimentov. After some discussions with the representatives of local transport companies we agreed to make the following setup:

We have put one question at the entrance of the bus (inside the bus) and the corresponding answer at the exit. In this way the passengers were told to move towards the bus exit in a scientific way.

One of the best illustrators and humorists in Slovenia - Božo Kos - was chosen to put an illustration next to each question and answer. By its humour and attractive illustration many people would notice the question and continue reading it. We are aware of the fact that humour is a very powerful tool in the process of education. Through laughter people's hearts and souls open and they are much more susceptible to acquiring new knowledge.

Local transportation companies in 6 major cities agreed to offer us their space for free, which is otherwise used for advertising.

▲ The project was a real success...

Approximately 350 buses were engaged as the carriers of knowledge.

A press conference was held on the bus while driving. The facts about the project were explained as well as the performance of an experiment that was explained on the bus. A balloon filled with helium was fastened through a thread on the floor. The balloon acted to oppose the rules of inertia in the no-inertial system – the bus.

The public found the displays on the buses very interesting. Such events as this help in building a knowledge-based society since it raises the public awareness of science and leads to a better public opinion of science, scientists and their work

During the project we also developed new ideas. One was the opening of the 'ceiling exhibition' in the science centre. All the questions and answers were fastened on the ceiling equipped with arrows. The visitor had to follow the arrow pointing from the question in order to find the answer. By that we wanted to show, that one has to put some effort in order to gain new knowledge, but gaining it is a straight way.

The visitors were also given double reflection mirrors to save their necks.

The exposition was opened by the European commissioner Dr. Janez Potočnik.

A book of all questions and answers was also printed. The exposition was named 'Science up High.'

Science in public areas

After the great success of the International Year of Physics in 2005, the European Physical Society developed, in collaboration with Hisa Eksperimentov, the project "Science in public areas" whose purpose is to promote science awareness within the wide public, through attractive series of questions and answers, displayed in public areas.

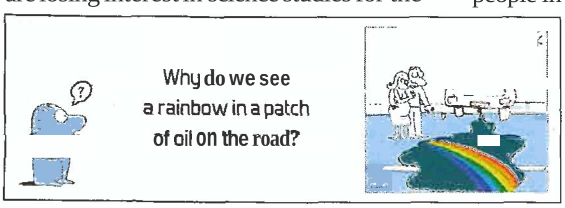
Project aims

Several studies confirm that young people are losing interest in science studies for the following reasons:

- science looks too hard,
- poor image of scientists
- lack of awareness of scientific careers.

The objectives are:

- to help rebuild the public impression of physics and physicists;
- explain simply and in an amusing manner some basic principles in physics;
- increase the awareness and excite the curiosity of the general public and young people in particular.



Posters with the physics questions and answers will be placed in public areas, such as theme parks, public transport, schools and science centres. The answers are short, attractive, informative and scientifically correct. They can give an answer to questions that are frequent among children. The questions and answering illustrations will draw the public attention. EPS provides you with the files: questions, answers as well illustrations in PDF formats.

Partners:

If you wish to display the posters, they are available in English, French, German, and Chinese, Arabic and Portuguese.

If your organisation wishes to contribute to the project or becomes an Associate Member of the EPS, your logo can be put on the posters.

For more information, please contact Mrs Ophélia Fornari, Project Leader for EPS activities, o.fornari@eps.org – or by phone +33 389 329 448.

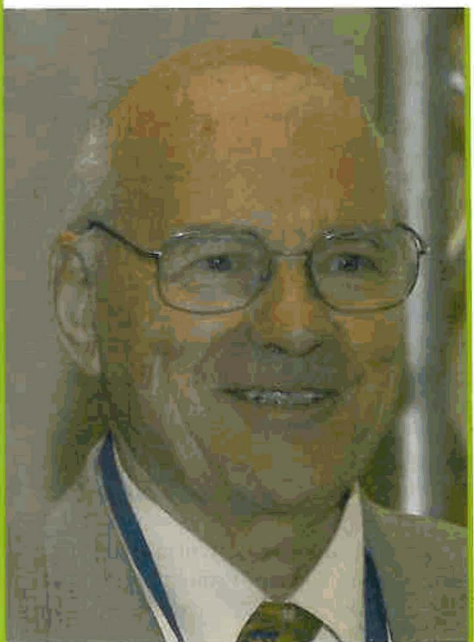
Plasma Physics Division: Conference report and annual Awards

Jo Lister, Chairman of the Plasma Physics Division

The 33rd annual conference of the EPS Plasma Physics Division was held in the Angelicum in Rome from 19-23 June 2006, organized by the Associazione EURATOM-ENEA sulla Fusione, Centro Ricerche Frascati, Italy under the chairmanship of Francesco De Marco. All aspects of Plasma Physics were treated in plenary and parallel oral presentations, as well as poster sessions, under the Programme Committee chairmanship of Prof. Boris Sharkov, Director of the Institute for Theoretical and Experimental Physics in Moscow. The conference was very well attended by 749 delegates from 37 countries. ITER physics was of course at the forefront of the magnetic confinement programme and the delegates welcomed Ambassador Ikeda, Director General Nominee of ITER to the opening ceremony. The Divisional conference continues to attract a wider participation, with increased numbers of delegates from Beam Plasma and Inertial Confinement, from Dusty and Industrial Plasmas, and from Basic and Astrophysical Plasmas, although the greatest participation is from Magnetic Confinement Fusion.

The divisional Hannes Alfvén Prize

It has been awarded to Dr. Paul-Henri Rebut. The laudation for this prestigious prize contains the following major points.



"Paul-Henri Rebut is one of the most successful physicists, engineers, machine-builders and managers in the history of magnetic confinement fusion. He has made pioneering contributions to many topics in magnetic confinement theory and in the design of tokamak devices, many of which are now implemented in the ITER design.

His career began in the early 60s introducing many original ideas in the field of plasma theory. His work rapidly turned to the design and operation of various magnetic confinement systems in the early years of the fusion programme. He soon concentrated on the tokamak as the most promising route to fusion, and in the late 60s, he designedand built the TFR tokamak in a very short time. In 1973 he was appointed head of the design team of JET. The enormous challenge he took on with this project is illustrated by the fact that the plasma volume of JET was about 2 orders of magnitude larger than any other tokamak operating at that time. He introduced several innovations in the design of the machine, among them the D-shaped cross section of the magnetic field coils, which simplified construction and allowed much higher plasma currents than originally foreseen, and a first wall with a controllable temperature up to 500°C.

He was appointed as the director of JET in 1985, and under his leadership, JET produced plasmas with currents-up to 7MA, well above the extended design specification of JET and still stands as a world record. As a consequence, values for the fusion triple product rose from about 1110000th to 1/6th of the value needed for ignition.

The next major step was the Deuterium Tritium experiment on JET in 1991, resulting in the first controlled power production in the megawatt range from fusion reactions. His leadership and vision to implement all technical requirements to make this possible played a major role in the success of these experiments. They formed the essential basis of a second series of DT experiments, carried out under his successor, resulting in 16MW of fusion power. This corresponded to Q=0.7, very close to break-even,and again, still a world record. Consequently, the results of JET have largely contributed to the design of ITER. Dr. Rebut was appointed Director of ITER in 1992, and led the ITER EDA Outline Design.

It is especially appropriate and timely, in the year of the ITER Construction Agreement, to recognise the crucial contributions of Dr. Rebut."

◄ Dr. Paul-Henri Rebut receiving his prize

The PhD Research Awards

The Plasma Physics Division presented them for the second time. The Jury was most adamant that it should exceptionally award 4 prizes in 2006. These prizes were awarded to:

Dr Kristel Crombé, from the University of Ghent, for her "SpectroscopicStudies of Impurity Ion Dynamics on the JET and TEXTOR tokamaks" in which, through unprecedented care in calibration and accuracy, she was able to produce the first reliable measurements of the poloidal rotation velocity in JET, with results that will have profound significance for the understanding of plasma transport and the formation of the internal transport barrier.

Dr. Ben Liesfeld, from the Friedrich-Schiller-Universitat, Jena, for his thesis entitled "A Photon Collider at Relativistic Intensities" in which he introduced the use of counter-propagating extremely intense femtosecond laser pulses. The main result is the first demonstration of Thomson backscattering in the x-ray regime from laser radiation backscattered from laser generated electrons. Thus it is now possible to generate unprecedented bright, polarized and ultra short x-ray pulses with lasers of modest size and high repetition rate.

Dr. Stuart Peter David Mangles from Imperial College, London, for his "Measurements of Relativistic Electrons from Intense Laser Plasma Interaction" which constitute a key contribution step towards the realization of a laser-electron accelerator. For the first time he demonstrated the production of mono-energetic electrons of close to 100 MeV energy and showed the change in the dominating acceleration mechanism from wake field to direct laser acceleration at very high intensities.

Dr. Paolo Piovesan, from the University of Torino, for his "Experimental MHD Studies of Enhanced Confinement Reversed-Field Pinch Plasmas", in which he succeeded in particular, for the first time to measure the dynamo electric field in quasi-helical reversed field pinch states and to show the magnetic chaos healing effect of pulsed poloidal current drive by soft X-ray imaging of the plasma core.

Itoh Project Prize in Plasma Turbulence

This is another initiative to recognise budding young physicists, financed for the second year by Professor Sanae Itoh from Kyushu University. The prize was awarded to Dr. Paolo Angelino for his thesis entitled 'Plasma elongation and magnetic shear effects in nonlinear simulations of ITG-zonal flow turbulence', from the CRPP-EPFL, and allowed him to briefly visit Kyushu research groups in Japan. Strong recommendations were made to Rory Scannell, UKAEA, on 'ELM filament Studies using the edge Thomson Scattering Diagnostic on MAST', to Sambaran Pahari, IPR, India, on 'Experiments and Simulation in Small Aspect Ratio Toroidal Electron Plasma' and to Stefan Müller, CRPP-EPFL, on 'Real space statistical characterization of turbulence and transport in the TORPEX experiment'.

IOP Poster Prize

Finally, the Institute of Physics once again encouraged young physicists with this prize, awarded this year to 4 candidates: Sergey Bozhenkov, 'Observation of disruption mitigation experiments by an ultra fast framing camera', Nuno Lemos, 'Characterization of relativistic ionization fronts in gas jets', Eva Kovacevic, 'The Search for Interstellar Dust in Laboratory Plasmas' and Luis Gargaté, 'Large scale hybrid simulations of solar energetic particle acceleration'.

Report on the 38th annual conference of EGAS

A. Sasso Naples, Local chair of EGAS 38, H. Hotop, Kaiserslautern, Chair of EGAS

The 38th Conference of the European Group on Atomic Systems (EGAS - www.eps-egas.org) was held on the island of Ischia (Naples, Italy) from 7th to 10th June (local chairman Antonio Sasso, Department of Physical Sciences, University of Naples "Federico II"). The conference program consisted of 14 Plenary Lectures, 6 Progress Reports, 24 short oral presentations, and 2 poster sessions. The conference was attended by more than 200 delegates coming from about 40 countries.

4 Valentin Ostrovsky (St. Petersburg), a prominent colleague in theoretical atomic, molecular, and optical physics, was one of the speakers at EGAS 38. With sadness, we learnt about his untimely death on September 18, 2006.

The EGAS Conference Series (which started in 1969 at Orsay with support by Alfred Kastler) continues to provide an important opportunity to discuss advances in physics involving atomic systems, such as attosecond physics, antihydrogen, quantum dots and Bose-Einstein condensates. In addition, the traditional role of atomic physics, providing basic input for chemistry, astrophysics, plasma physics and applied disciplines, remains as important as ever. The vitality of atomic and molecular science including modern spectroscopy, with its many guises and applications, was impressively documented on Ischia.

The EGAS 38 Conference covered a wide range of topics. The meeting started with a lecture by 2005 Nobel Laureate Theodor Haensch on ultra-precise measurements of optical frequencies using octave-spanning frequency combs and their applications to the hydrogen spectrum and optical clocks. The programme also included a review on the role of precision spectroscopy of simple atomic systems in deducing some of the fundamental constants of nature. The recent progress in bound state quantum electrodynamics, the theory which underpins the high precision experimental programmes, was described. The use of cold molecules in searches for the electric divole moment of the electron was presented along with its role as a probe of fundamental symmetries and physics beyond the Standard Model. The use of Penning traps to make precision mass measurements was reviewed, as was some of the resulting science, such as the electron g-factor and aspects of neutrino physics. The contribution of atomic spectroscopy to the physics of halo nuclei was also discussed. Bound states of atoms and molecules with both positrons and electrons came under scrutiny, as did the reactions of cold, stored molecular ions. Continued progress in the trail from femto- to attosecond science was a prominent feature of the programme. The active control of quantum systems along preferred reaction pathways using femtosecond laser technology was discussed, including the new technique of near-field femtosecond nanoscopy. Further highlights included discussion of the coherent interaction between cold atoms and photons, quantum degenerate gasses in optical lattices and multiple ionization in ultra-short laser pulses.

The next EGAS conference will be held as part of ECAMP 9 (9th European Conference on Atomic, Molecular, and Optical Physics, 7-11 May 2007, Heraklion, Crete). www.iesl.forth.gr/conferences/ecamp9/

Highlights from european journals

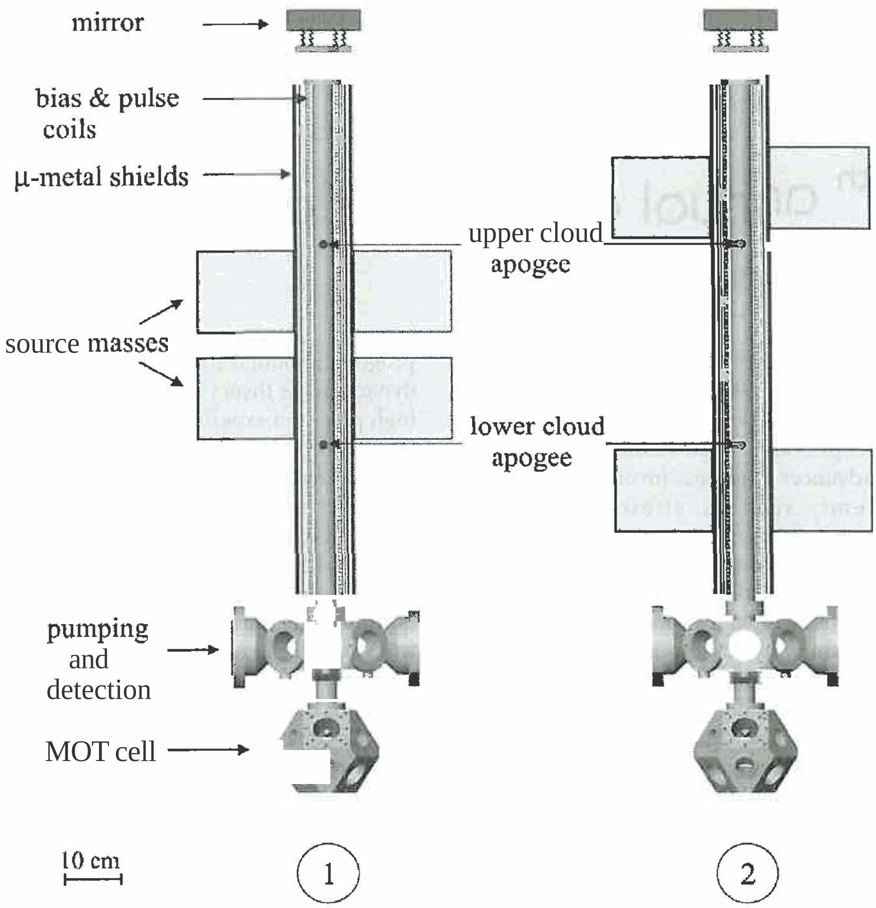
What is G at the atomic scale?

Experiments that mix gravity and quantum mechanics are rare. In a new experiment (MAGIA) conducted by Guglielmo Tino and colleagues in Firenze, laser-cooled rubidium atoms launched in an atomic fountain are used to measure the value of the Newtonian gravitational constant, G. The gravitational constant is not theoretically related to any other fundamental constant and its value is known with low precision. 200 years after the famous experiment of Henry Cavendish his result has been improved only by a factor of a hundred.

From the time of Cavendish, almost all G measurements performed up to now were based on torsion balance-like techniques, in which the restoring force of a twisted fiber balances the weak gravitational torque produced by the attraction between macroscopic test masses.

In the MAGIA experiment, supported by Istituto Nazionale di Fisica Nucleare, microscopic atomic probes and an atom interferometry detection scheme are used to measure this elusive fundamental constant.

Atoms are trapped combining magnetic fields and crossed laser beams in a vacuum chamber. By radiation pressure they can be precisely launched upwards and, as any body does, they feel the Earth's gravitational attraction and fall back down. During this free fall the position of the atoms is precisely measured at three different times by means of advanced atom-interferometry techniques. The use of two displaced Raman atom interferometers allows a dramatic common mode phase-noise suppression, so highly accurate gradiometric measurements are possible. By repeating the differential measurement for different configuration of the surrounding attractor masses systematic effects are strongly minimized. The gravitational attraction induced by 24 lead cylinders (12 kg each) was detected and a first value of G ($6.64(6)\times10^{-11}$ $m^3kg^{-1}s^{-2}$) was obtained. When using heavier (tungsten) masses a compensation of the Earth's gravity gradient will be possible and a great gain in accuracy will be obtained. The targeted accuracy is 100 ppm.



G.A. Bertoldi, G. Lamporesi, L. Cacciapuoti, M. de Angelis, M. Fattori, T. Petelski, A. Peters, M. Prevedelli, J. Stuhler and G.M. Tino, "Atom interferometry gravity-gradiometer for the determination of the Newtonian gravitational constant", *Eur. Phys. J.* D40, 271 (2006)

◀ Experimental set-up; 1) Attractor masses in; 2) Attractor masses out.

ABOUT THE EPS DIRECTORY

In future the full EPS Directory that is usually published in the Europhysics News last issue of the year will be found on the EPS website. This will allow it to be kept up-to-date in real time. A simple two pages information document limited to the membership of the Executive Committee and a listing of National Societies will be published in the Europhysics News first issue of 2007.

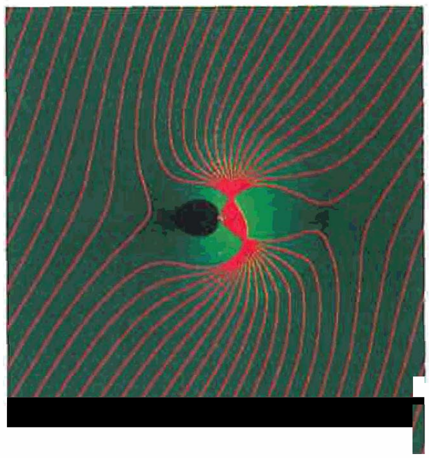
FROM THE EPN STAFF

It is with profound sadness that Europhysics News has learned of the sudden untimely death of Professor Jerzy Prochorow. We would like to express our sincere condolences to the family and colleagues of Professor Prochorow, and will remember him for his conscientious service on the Editorial Board of EPN and for his contributions to physics and to the European physics community.

Visualizing invisibility

The idea of invisibility has fascinated people for millennia and has inspired countless myths, novels and films, not to mention Harry Potter. Invisibility is not transparency: Herbert G. Well's Invisible Man has made himself transparent by inventing a recipe to make his refractive index uniform, to remove the causes of scattering or absorption of light in his body. In contrast, another fictitious character, the Invisible Woman creates a field that distorts space. Her field is cunningly designed to smoothly guide light around her. The less fictitious stealth technology of America's most advanced bombers is not invisibility. These planes are black, they are also black to radar and their aerodynamically challenging shapes are designed to bounce off radar in odd directions. In this way, the planes merge with the black radar sky lit by radar searchlights from below; they are camouflaged, not invisible.

The paper "Notes on Conformal Invisibility Devices" develops a realistic recipe for invisibility devices inspired by the strategy of the Invisible Woman. However, instead of distorting space itself, an optical medium should be employed that mimics a transformation from straight to curved coordinates. Light follows the curved coordinate lines and they may be designed to guide any light around a region of space. Anything placed there is invisible. In particular, the paper considers media that perform conformal maps. Since such media can be made with modern meta-materials, invisibility is about to become a reality. The paper uses the graphics capabilities of the New Journal of Physics to visualize the complex mathematics behind the scenes of invisibility devices, visualizing invisibility, and to show how invisibility is connected to many other fascinating subjects in theoretical physics and to some of Maurits C. Escher's surreal paintings and patterns used in Islamic Art.



Ulf Leonhardt,
"Notes on conformal invisibility devices"
New Journal of Physics 8, 118 (2006)

◄ Light propagation in a conformal invisibility device. The light rays are shown in red. The brightness of the green background inaicates the refractive-index profile.

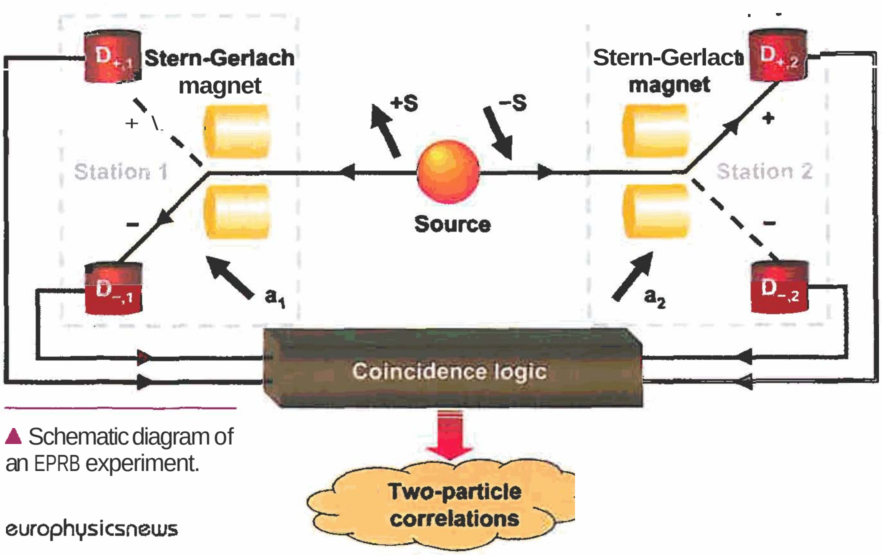
Where EPR is not what you may think

Many experimental realizations and quantum mechanical descriptions of the Einstein-Podolsky-Rosen (EPR) Gedankenexperiment adopt the model proposed by Bohm. In this model (see Figure), a source emits pairs of particles with opposite magnetic moments. The two particles separate spatially and propagate in free space to observation stations. As a particle arrives at a station, it passes through a Stern-Gerlach magnet. The Stern-Gerlach magnet deflects the particle, depending on the orientation of the magnet and the magnetic moment of the particle. As the particle leaves the Stern-Gerlach magnet, it generates a signal in one of the two detectors. The firing of a detector corresponds to a detection event.

The fundamental problem, first posed by EPR in a different form, is to explain how individual events, registered by the different detectors, exhibit the correlations of two $S=1/2$ particles in the singlet state, even though a measurement on one particle does not have a causal effect on the result of the measurement on another particle.

This paper presents a solution of this fundamental problem. Starting from the data gathering and analysis procedures used in EPR experiments with photons, the authors constructed an event-based computer simulation model in which every essential element in the experiment has a counterpart. The data is analyzed by counting single-particle events and two-particle coincidences, using the same procedure as in experiment. The simulation model strictly satisfies Einstein's criteria of local causality but does not rely on any concept of quantum theory or probability theory.

A mathematical proof is given that this model reproduces the correlations of the singlet state. This proof demonstrates that quantum correlations can be produced by two separate classical subsystems which have interacted in the past but do not communicate in the present and opens a path to ontological descriptions of quantum phenomena.



▲ Schematic diagram of an EPRB experiment.

K. De Raedt, K. Keimpema, H. De Raedt, K. Michielsen and S. Miyashita,
"A local realist model for correlations of the singlet state", *Eur. Phys. J.* B (2006)

The ANTARES telescope turns its gaze to the sky

T. Stolarczyk,
CEA Saclay, DSM/Dapnia/SPP • France

On Thursday, 2 March 2006, the first detection line of the ANTARES neutrino telescope, which lies 2,500 m below the surface of the sea, was connected to the shore station in La Seyne-sur-Mer by a remote-controlled robot. A few hours later, ANTARES looked up at the sky for the first time and caught sight of its first muons.

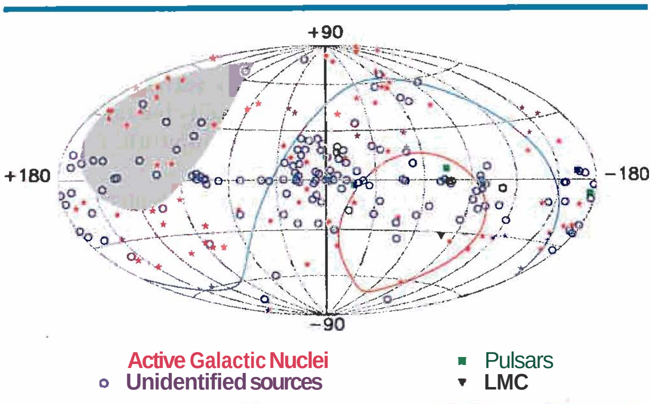
This connection marks the arrival of the ANTARES detector, the first deep-sea, high-energy neutrino telescope in the Mediterranean. The event rewards ten years of combined efforts by some 200 technicians, engineers and scientists from twenty laboratories (France, Germany, Italy, Spain, The Netherlands and Russia).

ANTARES is located about 30 kilometres off the French coast near Toulon. The detector when completed will consist of 12 vertical strings supporting 900 photomultipliers in total. The measurement of the Cerenkov light emitted by muons produced in muon-neutrino interactions in water and under-sea rock will allow the reconstruction of the neutrino direction with an accuracy of 0.3 degree above 10 TeV, thus justifying the term 'neutrino astronomy'.

Why a neutrino astronomy?

The sky has been observed from antiquity with photons. The second half of the last century has seen the birth of astronomy outside the visible light domain and in particular γ ray astronomy ($E > 10$ MeV). Each time a new wavelength has been used, unexpected phenomena were observed. Our view of the Universe today reveals objects such as supernova remnants, pulsars, micro-quasars in the Galaxy, extragalactic γ ray bursts and active galactic nuclei, all emitters of very high energy photons (see Fig. 1).

Tremendous progress has been made during the last century in understanding these new objects, helped in that by the fact that many of them are detected in several wavelength domains and in particular at higher and higher energies. However, photon observations have their limitations. Because of their interaction with the infrared or cosmological diffuse backgrounds or with intergalactic matter, they cannot travel more than 10 Mpc above 10^{14} eV (The visible universe is $\sim$ 5 Gpc, where 1 pc $\sim$ 3.2 light year $\sim$ 3 10^{13} km).



▲ **Fig. 1:** High energy γ ray sources (E>100 MeV) from the 3rd Egret catalogue (Instrument operated on the CGRO satellite between 1991 and 1995). This map presents 271 sources in total among which 170 are not identified. Only the grey area is never seen by a neutrino detector in the Mediterranean. Most of these sources may emit high energy neutrinos. The source concentration in the middle of the map corresponds to the galactic Centre.

Another view of the sky is given by cosmic rays. This is particularly true with the new generation of ground observatories that will detect particles up to 10^{20} eV. They could help to elucidate the origin of cosmic rays on which scientists have been debating for tens of years. However, here again, the fact that protons are subject to interaction with diffuse photon backgrounds on their path to the detector limits the observation depth to 50 Mpc at 10^{20} eV. Moreover, being deviated by intergalactic magnetic fields, they are of little help in point-source searches at lower energies.

The neutrino appears to be an excellent candidate for high energy astronomy: it is neutral and insensitive to magnetic fields. It essentially does not interact with matter. It makes the Universe totally transparent over a wide energy range. As an example, although from a lower energy domain, photons produced in the core of the Sun during fusion reactions become visible light and reach the Sun outer layers after one million years. On the other hand, neutrinos that are produced in the same reactions escape immediately from the star and reach the Earth after 8 minutes. This example shows how neutrinos can give unique information on the core of a source.

High energetic photons are usually interpreted as being the result of electron acceleration. High energy neutrinos should be produced from the interaction of accelerated protons on the surrounding matter ($p + A/\gamma_{amb} \rightarrow \pi^0 + \pi^\pm + \ldots$ followed by $\pi^\pm \rightarrow \mu\,\nu$, and $\mu \rightarrow \nu_\mu \nu_e e$, where A represents the surrounding matter and γ_{amb} the ambient low energy photon field). Under these assumptions, part of the high energy photon flux could also be due to proton interactions from the $\pi^0 \rightarrow \gamma + \gamma$ decays.

Possible sources of high energy neutrinos in the Galaxy are binary stars with a neutron star or a black hole accreting matter from its companion. The accretion process creates plasma waves in the strong magnetic field of the compact object, leading to stochastic acceleration at high energies. The interaction of these particles with the accreting matter or the companion star would then produce high energy neutrinos.

Explosions of massive stars in the Galaxy (supernovae) produce an expanding shell of matter which is known from radio observations to accelerate high energy particles. Protons inside supernova shells can be accelerated by a first order Fermi mechanism (diffusion of charged particles on magnetic field inhomogeneities inside moving plasmas). The interaction of these protons with the shell gives neutrinos.

Active galactic nuclei are the most powerful objects observed in the Universe. They are galaxies hosting a super massive black hole (10^6 to 10^{10} solar masses) accreting matter at a rate of a few solar masses per year. Part of the absorbed energy is then released in a jet of accelerating electrons, these electrons being further able to give energy to ambient photons (the inverse Compton process). Electrons are accelerated by the Fermi process that should apply to protons.

Gamma ray bursts are the most violent phenomena in the Universe. The energy released in the few tens of seconds of the emission is estimated to be up to 10^{45} J. A possible interpretation of such an event is that a compact object emits matter that further expands relativistically in the surrounding medium. This would naturally produce high energy neutrinos.

Up to now no high energy neutrino source has been discovered. Detecting neutrinos from already known sources would help to understand better the origin of the high energy phenomena. Because neutrinos make the universe transparent, sources with no photonic counterpart could also be discovered. The discovery of such neutrino sources would imply the presence of proton acceleration and help in answering the long standing question of the origin of the high energy cosmic rays.

Detection principle

Their very weak interaction with matter makes neutrinos hard to detect. This problem can only be overcome by using the largest detectors, shielded against the cosmic radiation which constantly bombards all sites on the Earth and generates significant and continuous background noise. Neutrino telescopes are mainly sensitive to the 1 TeV-1000 TeV energy range.

The principle of neutrino telescopes is based on the detection of the very faint trails of light that upward going muons leave behind in a large instrumented volume of water or ice. These upward going muons result from the interaction of neutrino-muons with the Earth's crust. The typical path of a high energy muon in the rock is a few kilometres so that even a relatively modest sensitive volume (100 m being a typical scale) can indirectly detect the neutrinos from the much larger interaction volume (of a 10 km scale) below the detector. The phenomenon can be observed because of the total darkness at these abyssal depths.

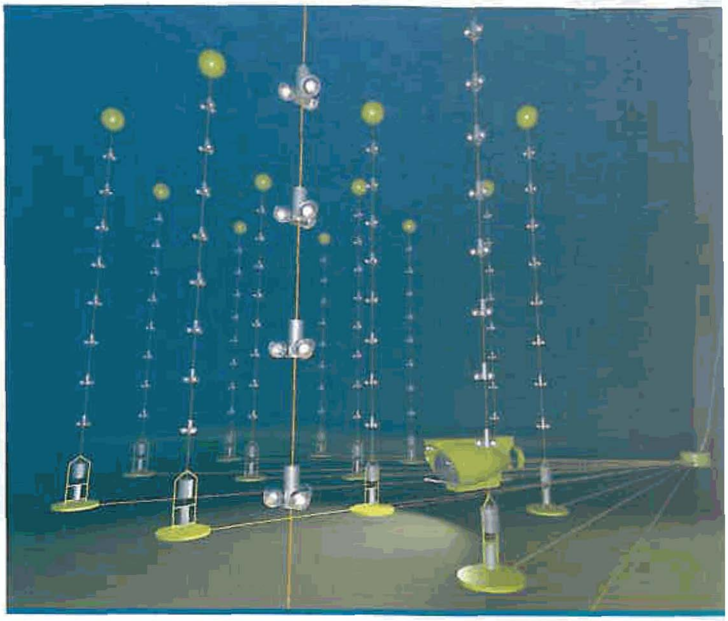
The ANTARES detector, being placed at 43° N in the Mediterranean, observes the sky in the southern hemisphere through the Earth (see Figure 1). It covers a complementary region compared to the South Pole neutrino detector IceCube [1]. In particular it includes the Galactic Centre, a region that reveals high energy phenomena as recently shown by the Hess high-energy γ observatory [2].

ANTARES could also give information on the dark matter problem. First revealed 70 years ago, this problem is now a central question in cosmology. Most of the content of the Universe – 95% of its mass – is still mysterious: it is expected to consist of at least two components called dark matter and dark energy. Dark matter might be composed of particles known as weakly interacting massive particles or "wimps". The physics theory referred to as supersymmetry predicts their existence, but their demonstration is now needed. According to this theory, wimps, which can be both particle and anti-particle, would eventually annihilate, producing jets that include neutrinos. ANTARES could observe the low-energy neutrinos (10 to 100 GeV) produced from the annihilation of wimps gravitationally trapped at the centre of the Earth, the Sun or the Galaxy.

The interaction of cosmic rays in the atmosphere creates showers of particles among which only muons and neutrinos are penetrating enough to reach the detector. The downward atmospheric muon flux is a potential background although reduced by order of magnitudes by the water above the detector. Interactions of atmospheric neutrinos coming from above give a negligible contribution to the downward muon flux. By contrast, those produced at the antipodes mimic the cosmic signal. Fortunately they have a harder spectrum and they become rapidly negligible as their energy increases, usually above 10 TeV.

An extra background is the continuous faint light coming from two distinct origins: firstly the Cerenkov light of MeV electrons resulting from ^{40}K beta-decay in the sea water; secondly the contribution from the bioluminescent abyssal fauna.

ANTARES is also a multidisciplinary underwater-science infrastructure continuously recording various types of data for studies relating to oceanography – including observation of the deep marine environment and bioluminescent phenomena – and geophysics. One example of this is the seismograph installed there, which has been recording Earth tremors for the past year.



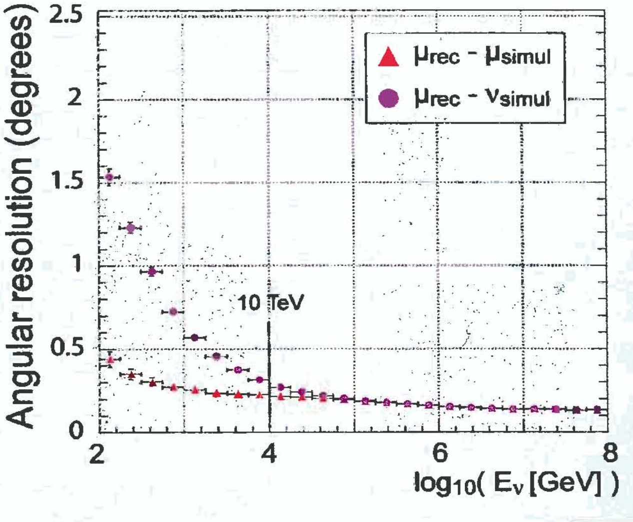
▲ **Fig. 2:** Artist's impression of the ANTARES neutrino telescope on the sea floor, showing the detector lines, the seabed interlink cables, the junction box and the cable to the shore. In this illustration for clarity, the number of storeys per line is reduced and many items are not drawn to scale (© F. Montanet, CNRS/IN2P3 and UFJ).

The detector

An artist's impression of the layout of the ANTARES neutrino telescope is shown in Figure 2. The detector consists of 12 lines spread over a 200 x 200 m^2 area and spaced by around 65 metres, at a depth of 2500 metres. Each line has a total height of ~450 m. They are weighted to the sea bed and held nearly vertical by a buoy at the top. A line has a total of 25 storeys each comprising 3 optical modules. They consist of 10 inch photomultipliers housed in glass spheres that detect Cherenkov light. They are oriented 45° downward to increase the sensitivity to upward going tracks [3][4]. The first storey is 100 metres above the sea bed, and the spacing between storeys is 14.5 metres. Each storey comprises a titanium electronic container where the analogue electrical outputs of the photomultipliers are digitised in a custom built microchip. The signal is then treated in real time by a data acquisition card. The result is finally sent to the bottom of the line through optical fibres.

Each line anchor is connected to a junction box on the seabed via an electro-optical cable. In the junction box the outputs from up to 16 lines are gathered onto a 40 kilometre electro-optical submarine cable and sent to the experiment shore station in the town of La Seyne-sur-Mer, in France. Since no filtering is made offshore, the data stream is mainly composed of background hits. On shore, a computer farm selects from the data the periods of time containing storeys in coincidence, suspected to contain physical tracks. These events are stored on disks for further selections and analysis. The knowledge of the fired photomultiplier positions and the arrival time of the Cerenkov photons allow the reconstruction of the muon track thus giving information on the parent neutrino.

The lines are flexible and so move in the sea current, with movements being 5 metres at the top for a typical sea current of 5 cm/s. ▸



▲ **Fig. 3:** Left: Angular resolution of the ANTARES detector as a function of the energy of the incident neutrino
Right: picture of the second storey of the mini-instrumented line during its deployment in March 2005 (© ANTARES collaboration).

••• The positions of the optical modules are measured with an acoustic positioning system with components at discrete positions on the line and on the sea bed, together with tiltmeters and compasses on each storey of the line. The positioning system gives a real time measurement, typically once every few minutes, of the position of every optical measurement with a spatial precision better than 10 cm.

During the extensive trials carried out in the R&D phase (1996-1999), the properties of the selected site have been carefully studied. Absorption and scattering lengths are of about 60 and 300 metres in the blue wavelength, and of about 26 and 100 metres in the UV wavelength, respectively [5]. The loss in transmission due to biological fouling and sedimentation deposits on the surface of the optical modules is less than 1.5% per year [6]. The optical background was also monitored. The 10 inch ANTARES photomultipliers have a continuous rate of 60 to 100 kHz on top of which some short bursts are due to episodic fauna activity [7].

Measured and expected performances

In March 2005 a so-called mini-instrumented line equipped with three storeys was deployed [8]. Its primary goal is to monitor the environmental parameters and to illuminate the full detector by means of several optical beacons. These beacons are able to emit flashes of light of a few nanoseconds in duration thus allowing the time calibration of the full detector. Moreover a seismometer is linked by a 50 metre cable to the instrumented anchor. Since its deployment, it has registered many earthquakes all round the world.

The anchor holds a laser beacon and an acoustic positioning receiver-transmitter. The bottom storey lies 100 m above the sea bed and is equipped with an optical beacon, a conductivity-temperature probe, an apparatus for light transparency monitoring and a hydrophone acting as an acoustic positioning receiver. The middle storey, located a further 15 metres above, comprises 3 optical modules and a sound velocimeter (see Figure 3, right). Finally the top storey, at a further 50 metres above, has another optical beacon and an acoustic Doppler current profiler.

The measurement of the sound velocity is important to convert time measurement with the acoustic positioning system into distances. The sound velocimeter records a value of about 1545 m/s with a very good stability. The sound velocity depends on the temperature, pressure and conductivity which are independently monitored. The temperature on site is 13.2°C with variations of 0.1°C at most on a monthly scale.

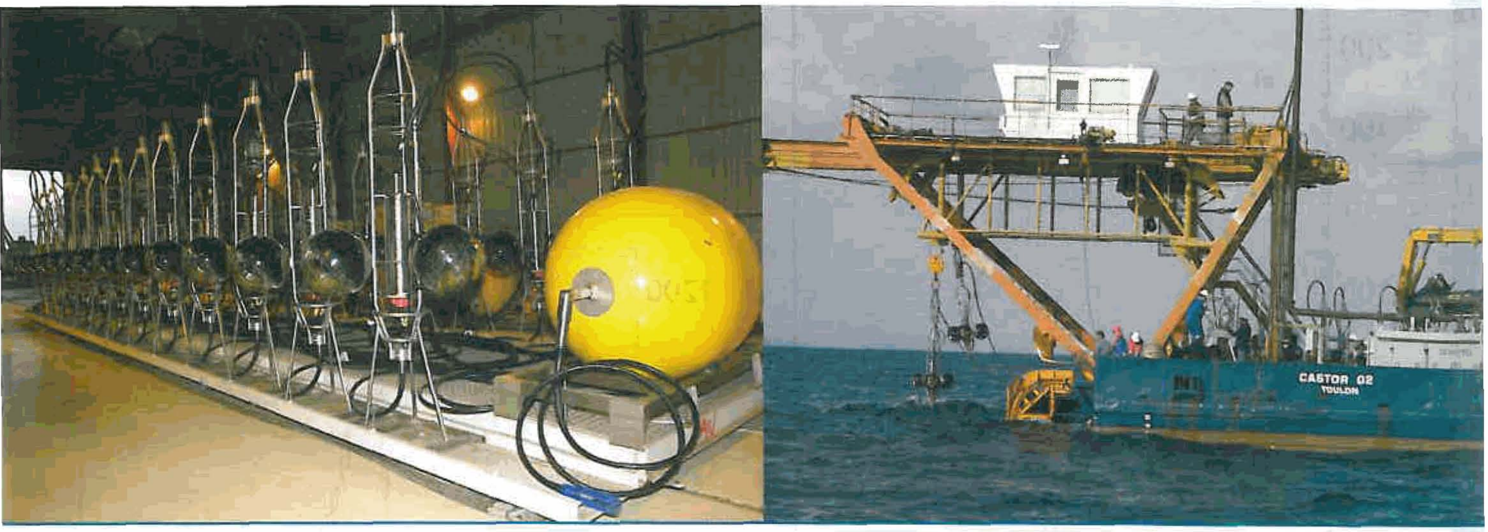
This line allowed the measurement of some key performance figures in real conditions. In particular it was possible to check the timing precision of the apparatus at various stages. As an example the relative timing resolution of the photodetectors was obtained by illuminating the three optical modules on the middle storey with high amplitude signals from the optical beacon in the first storey. The distributions of the time differences between the three optical modules and the internal photomultipliers of the beacon, after subtraction of the light propagation offset, have a width of the order of 0.5 ns.

A number of other specifications were also shown to have been attained. For instance measurements of the distance between the bottom of the line and an emitter at 180 metres on the sea bed have shown a stability of a few centimetres.

These measurements show that the timing precision in ANTARES, for which the detector concept was designed, is only limited by the transit time spread in the optical modules (1.3 ns) and the light scattering in water. This shows experimentally that the ANTARES telescope should be able to reach a 0.3" angular resolution above 10 TeV.

Figure 3, left shows the evolution of the angular resolution (the difference between the reconstructed and Monte Carlo generated angles) for muons and neutrinos versus the neutrino energy. At lower energy, the neutrino angular resolution deteriorates because the emitted muon is no longer collinear with the incident neutrino. Above 100 TeV the resolution is better than 0.3" for both muon and neutrino and is mainly limited by the light diffusion in water and the discrete energy loss of muons.

The event rate is related to the neutrino cross section and the efficiency to reconstruct muon tracks within a certain pointing accuracy. It can be quantified by the effective detector surface which is the ratio of detected muons per unit of time, divided by the incident neutrino flux. It increases with energy as the neutrino cross section does, and also because the muon range in the rock below the detector and the light produced by muons in water both increase with energy. However, because of the very small neutrino cross section, this area is very small: it reaches 1 m^2 for vertical



▲ **Fig. 4**: Line 1 on its transportation frame in La Seyne-sur-Mer **(left)**, and during the deployment from the boat (right).
Both photographs are under copyright of L.Fabre/CEA

upward going neutrinos at 100 TeV. It then starts to decrease due to the fact that the neutrino interacts early in the Earth and leads to a muon stopped before the detector (higher energy domains can be reached with nearly horizontal muons). The rates which are expected in ANTARES are of the order of 10^7 per year for downward going atmospheric muons, and 10^4 per year for upward going muons induced by atmospheric neutrinos. The high energy neutrino event rate predictions vary from a few to a hundred per year after background rejection.

Because neutrinos are hardly absorbed, the contribution of all neutrino emitters in the Universe, that is the high energy neutrino diffuse flux, is one of the first physical goal that should be achieved. Since most theoretical models predict a high energy neutrino emission to have an E^{-2} energy dependence (Fermi acceleration), the key point is to fight against the upward going atmospheric neutrino background, consisting of events with a softer spectrum ($E^{-3.7}$). Above 1 TeV, the muon energy loss rate becomes correlated with its energy and it can be estimated from the detected light and the muon visible path. The energy can then be obtained to within a factor 2 or 3 from this estimation, and the high energy signal can be isolated from the lower energy background.

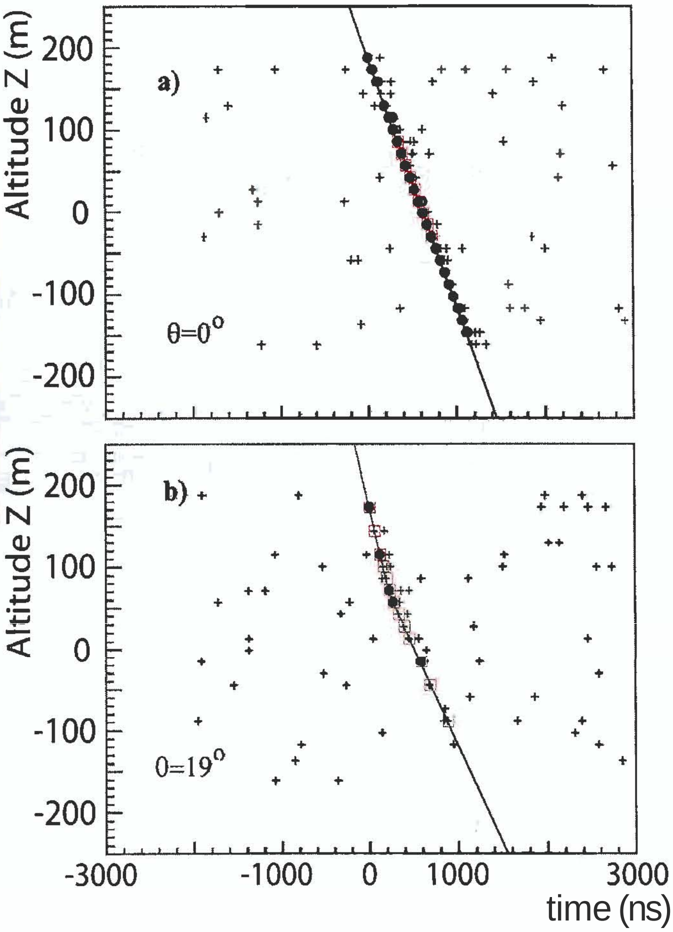
First muons detected with the first line

On February 14th 2006, the first line of the ANTARES detector was deployed (Cf. Figure 4). It was connected to the junction box on March 2nd, using the remotely operated Ifremer submarine, Victor. Although the detector is designed to observe upward going muons from neutrinos which transverse the Earth, the angular acceptance of the photomultipliers is such that downward going muon tracks from cosmic ray interactions in the atmosphere can be observed as well. The neutrino telescope is designed to reconstruct muon tracks which in general have hits on a number of lines and the reconstruction with only one line suffers from geometrical ambiguity and reduced angular resolution. For instance a single line gives a very poor sensitivity to the azimuth angle. Moreover, downward going muons belong to bundles that contain more than one muon. So the performance expected is far below what will be obtained from a multi-line detector for which upward going single-muon reconstruction and downward going multi-muon rejection are known to be efficient.

The trigger condition applied in the present online computer farm is to require at least 5 pairs of optical modules to have signals coincident within 20 ns which could be causally connected with the same source, consistent with muon and light propagation speeds. This essentially suppresses the random hits due to the optical background. Figure 5 shows a display of two typical muon events together with their reconstructed fit. The display shows the recorded hits at the different heights (Z) along the line with the measured times relative to an arbitrary zero. All the hits within a 1 μs time window are displayed as crosses and those used in the event fit are surrounded by a red square. Black dots correspond to hits in coincidence as defined above. The muon track reconstruction is simplified in this case and consists of a simple least-square minimisation based on time and altitude of the hits and on the properties of the Cherenkov light (propagated as a coherent conic wave-front with an angle of about ≈ 42° with respect to the track).

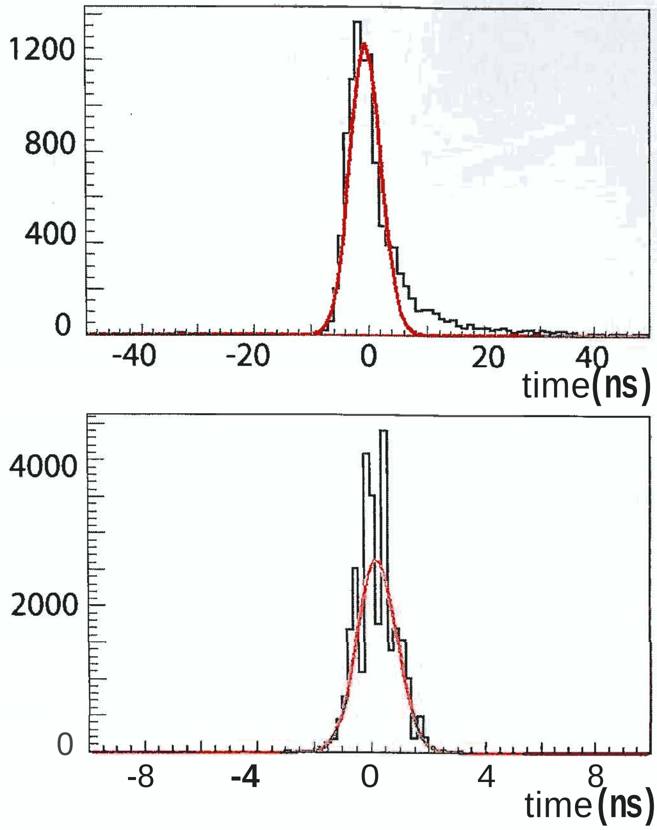
The optical background conditions at the bottom of the sea can vary significantly: there was a period of relative calm just after deployment in March; this was followed by two months of high bioluminescent activity, making data taking difficult. This optical background increase was previously observed last year and during the operation of a prototype in 2003. It seems related to higher sea currents and is a seasonal effect which was unexpected and is not well understood. From the end of May the optical background has fallen to a level that has allowed data taking, tuning of the detector and muon reconstruction.

Beside the success of reconstructing physical particles with the first line of the detector, the performance previously obtained with the mini-instrumented line deployed in 2005 has been reproduced. In particular, the line was illuminated by the optical beacon located on the first floor of the mini-instrumented line and gave the time resolution shown on Figure 6. The left plot shows the width of the time differences in the coincidence found between the optical beacon and the storey of the detection line at the same altitude. The distance between the two storeys is 70 metres. The distribution is basically Gaussian and has a width of 0.7 ns. The right plot is obtained in the same conditions with a storey at higher altitude on the detection line. The distance between the emitter and the optical modules is now 150 metres and the influence of the light scattering is visible in the distribution.



▲ **Fig. 5:** Examples of reconstructed tracks using the data from the first ANTARES line: a) vertical downward going muon; b) downward going muon at 19 degrees from the zenith.

▼ **Fig. 6:** The time differences in the coincidence found between the optical beacon on the instrumented line and two storeys of the first detection line. **Upper:** storey at a higher altitude (distance of 150 metres). The Gaussian width is larger (2.6 ns) and the influence of the light scattering is responsible for the tail at larger times. **Lower:** storey at the same altitude (distance of 70 metres). The Gaussian width is 0.7 ns.



What next?

After ten years of continuous efforts, from site surveys to prototype deployments, the ANTARES collaboration has recently taken up the challenge of deploying a particle detector deep under the Mediterranean sea. The installation of the lines of the detector has now started with the deployment and operation of the first line since March, the deployment of the second line at the end of July and its connection on September 21st. Muons are now detected with both lines. Two more lines will be deployed by the end of the year, 4 more next spring, and the last 4 in autumn 2007. The operation of the detector is then planned for 5 years.

Beside the successful installation of ANTARES with many years of exciting results to come, the ANTARES collaboration is involved in the so-called KM3NeT design study[1] to define the next kilometre-scale generation of neutrino telescoves in the Mediterranean. (More information on the experiment: http://antares.in2p3.fr)

[1] KM3NeT is a consortium of European laboratories among which are those involved in the ANTARES experiment and on two other projects NEMO and NESTOR. This consortium is funded by the European FP6 over the period 2006-2009 with the objective of producing a design study for a Mediterranean kilometre-cube neutrino detector. More on www.km3net.org.

About the author:

Thierry Stolarczyk received his PhD in 1990 for work on the Gallex experiment (solar neutrinos), then joined the NOMAD collaboration in 1994 (neutrino oscillations), and ANTARES in 1998. He is now Head of the CEA/Dapnia ANTARES and KM3NeT groups. From 1993 to 2001 he was a member of the French Physical Society Executive committee.

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Glass and glass products *

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It was apparently by chance that, about 4000 years ago, glass as an artificial material was discovered. Actually natural glass exists in nature and has been used since a very long time. Fulgurites, produced by the impact of a lightning on sand seems never to have been used, but obsidian, of volcanic origin has been used by men to make arrows tips, and by women to make mirrors... supposed to reflect also the soul!

But it was when natron blocks, a sodium carbonate largely used in antiquity to desiccate the body in the process of mummification, were put by accident in contact with sand in the preparation of a meal, that is with a fire, that the fusion point of silica (actually sand) was sufficiently lowered as to obtain the melting of this mixture, and with its further solidification to realise the first man-made glass. One may say that the whole glass industry started from this event.

Pure silica, SiO_2, exists under two different atomic structures: quartz, a trigonal crystal also found in nature and vitreous silica the structure of which is disordered, that is "amorphous" or glassy".

This article does not examine the exact nature of the amorphous structure. This is a complex issue, still not completely understood by physicists. In its February 2005 issue, the "journal du CNRS" put the "obscure nature of glass" amongst the 10 main enigmas of physics! Neither shall the industrial processes for making glass and glass products be described. They are actually in constant improvement, thanks in particular to the progress in mathematical modelling [1]. This article will concentrate on industrial glass products, and on the trends in these technological developments.

As opposed to silica, a pure material (SiO_2), glass has a complex composition. A composition of 8 to 10 different oxides gives it its properties: fusion point, viscosity at high temperature, mechanical properties, surface hardness, chemical stability, colour, etc.

When comparing ancient compositions with some modern glasses, actually glass bottles, it appears that they are surprisingly similar (over 16 centuries, SiO_2 went from 70.5 to 72.5%, Na_2O from 15.7 to 13% and CaO from 8.7 to 9.3%, the other oxides, K_2O, MgO, Al_2O_3 and Fe_2O_3, changing only slightly their small proportions) although some properties have been enormously improved throughout time. That is the case with transparency: the first glasses were relatively opaque due to a high level of impurities. In the 17th century, the secret of making transparent glasses in order to make mirrors was a monopoly of the Venetians, and to protect the secret the glass manufacturers were installed on the island of Murano, in the Laguna of Venice... where they still are. To break this monopoly, Louis XIV and Colbert, his minister, decided to establish in 1666 the "Manufacture Royale des Glaces de Miroir", to become the "Compagnie de Saint-Gobain". The secret was eventually stolen from the Venetians by means that would certainly not be considered fully ethical today [2]. More recently, silica glasses used to make optical fibres have been subject to the necessity to extend the transparency of this kind of glass to such an extreme value that they are as transparent over tens, or even hundreds of kilometres, as a window glazing over a few millimetres! (Fig. 1)

But let us examine the parameters on which one may play to develop new glass products. We shall examine five of them, although there may be many more:

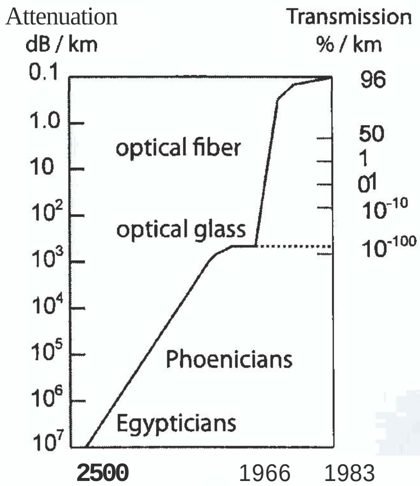
- The composition of glass
- The structure of the glass matrix
- The surface of glass
- Thin films deposition on this surface
- Complex glass products

We shall only consider a few examples in each of these categories.

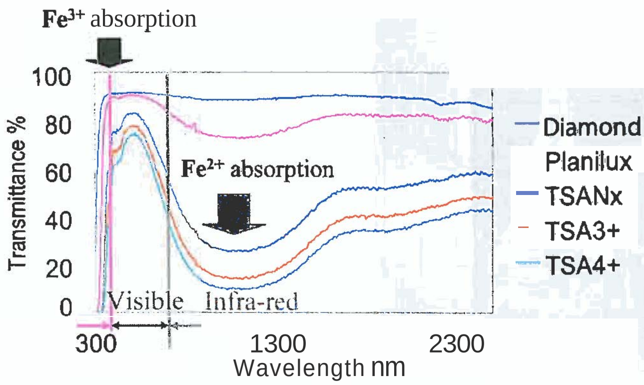
Glass composition

A glass composition is so complex that it is extremely difficult to predict by mathematical simulation the actual properties of a given glass. However the long experience of the glass makers gives them the ability to have a good idea, at least for the most classical compositions, of what will be the properties and how they will change with small modifications of a given constituent. This is part of the "art" of glass making.

A good example of this mastery of the art is what has been an issue for the past ten years for the producers of glass wool for thermal and acoustical insulation: The fact that this product is made of short fibres of small diameters (a few micron of diameter and a few millimetre of length), has raised the question of their behaviour in the lung in case of inhalation. However, from the beginning it was known that contrary to asbestos, a crystallized silicate, the glass used to make these fibres was more or less soluble in

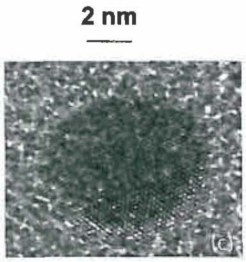


◄ Fig. 1: Improved glass transparency through centuries



▼ Fig. 2: Transmittance of various glasses versus wavelength. Compositionnal . changes by adding Fe induces a wide Fe^{2+} absorption band in the near infrared (900-1200 nm), and a Fe^{3+} absorption shoulder near 450 nm.

* A French version of this article has been published in the review of the French Physical Society, Bulletin SFP, 150, 4 (2005)



ruby glass bottle (Murano) Fahrenheit bottle Cu cluster

A Fig. 3: (a, b) Two examples of colored glasses. (c) Nanometric Cu clusters inducing the red color in the fig. 03b glass.

the pulmonary liquid. This solubility depends, however, on the precise composition of the glass. The glass initially used for this application disappears totally from the lung after a few months, whereas asbestos fibres are still present 30 years after their imposition. By playing on very small changes in composition (a standard glass becomes bio-soluble by decreasing its Al_2O_3 from 3.4 to 2.2±0.2%, Na_2O from 15.75 to 15.5% while MgO is increased from 3.0 to 3.2%), it has been possible to produce glass wools which, although perfectly stable in the humid air of the walls of a house, are dissolved in the lung, an acid medium, in a few weeks or even a few days. A very large number of tests, as well as epidemiological studies, have now been conducted that have led to the official conclusion that this glass wool is totally safe in term of the risk of cancer.

Another example of progress made by simply changing the composition of glass is that of the simple window glazing. A window-is mostly supposed to isolate from the exterior, while being as transparent as possible. However, if the transparency in the visible is indeed what is desirable, infrared transparency brings in a few inconveniences: On one hand the near infrared is transporting most of the solar energy and heat, therefore in summer it may heat up too much the interior of a building or of a car. Conversely in winter, the black body radiation of the interior of a building, at 20°C has a peak energy around 10 microns, in the far infrared, and if this radiation can also go through the windows, generally by a process of absorption-reemission inside the glass, it gives rise to a high wastage of heat from the interior of the building and therefore to excessive heating energy and discomfort near the window. What are the solutions? The first one is to develop glass compositions as transparent as possible in the visible, but absorbing in the near and in the far infrared. Figure 2 shows the progress made recently. The "TSA 4+" composition is almost perfect, its transparency being strictly limited to the visible spectrum. However, the "ideal" window should be still perfectly transparent in the visible, but reflecting rather than absorbing in the infrared to insure both summer comfort, by reflecting out the heat of the sun, and winter comfort, by reflecting back the blackbody radiation at 10 microns. We shall see later that this has become actually possible by the deposition of complex coatings on glass.

▲ **Fig. 4:** Example of mass engraved glass using focussed laser pulses.

Glass structure and nano-particles

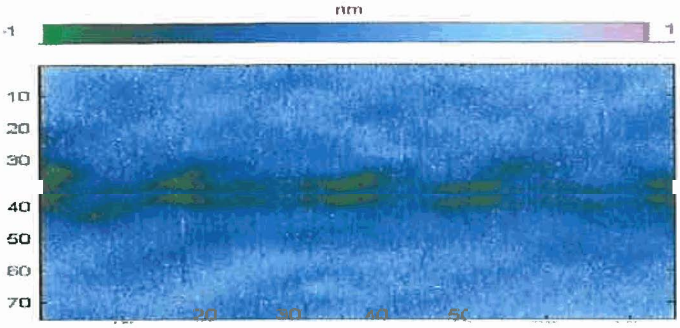
The molecular structure of glass is in itself a complex issue: What does it means to be a disorderly medium? Is there a short distance order, and which one? What is the homogeneity of a composition, at short and medium distance? ...etc. It actually happens that under specific conditions of annealing or illumination, some phenomena of demixing may take place right inside the volume of the glass, and this modifies deeply the local structure. It is the case in the well-known "photochromic" effect in which an ultra-violet illumination induces the dissociation of nanometric aggregates of silver halides, created during the initial annealing of the glass. When the illumination is turned off, the atoms, which did not have the possibility to fly very far from one another, recombine, and the coloration due to atomic silver fades out.

Another well known example is that of the "ruby" glass of the Murano glass blowers. Its very specific red colour (figure 3a) is due to small gold clusters formed during the heat-curing of the glass. A modern version of this colour, due to a plasma resonance of aggregates, is the perfume bottle "Fahrenheit" (for men), the degraded red colour of which (figure 3b) is due to a differential heat-curing along its height, producing copper or copper oxide aggregates of different sizes (figure 3c). The absorption frequencies of their plasma resonances give to the glass the complementary colours.

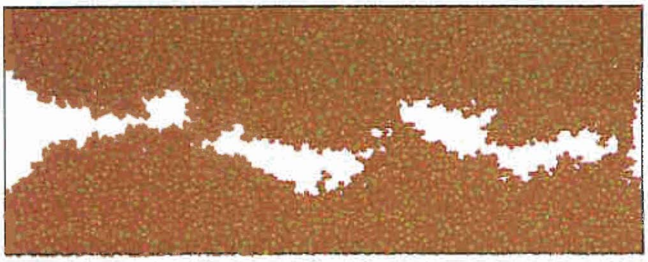
Finally, over the last few years several laboratories in the world have become interested in the engraving of shapes inside the glass matrix. This can be done by focusing a laser picosecond pulse on successive spots inside the glass, which induces very local changes in structure. The exact nature of these changes (micro-cavities, micro-crystallites, local changes in composition...) is still to be studied precisely. Used today to make decorative objects (figure 4), this technique is also studied with a view to making three-dimensional optical memories.

What can one say about the surface of glass?

The surface is in a way the "Achilles heel" of glass. Indeed, it is the propagation of micro-cracks along the surface that eventually ends up with the fracture of the glass piece. It is therefore from the surface that the brittleness of glass comes, a material which on the other hand has a very high tensile strength modulus. The way that these cracks propagate, at the beginning extremely slowly, is now better understood. The role of water vapour is important, the water molecules being located at the bottom of the crack, therefore leading to the breaking of covalent bonds in the glass. It is well known that the ancient glass workers, to break a piece of glass, would first make a crack with a diamond (which is still actually done, even on industrial lines), and would then spit on this crack to increase its speed of propagation and help the rupture of the glass. Recent experiments using atomic forces microscopy have permitted one to produce a "movie film of the propagation of a crack [3] (Figure 5a). Mathematical modelling has, on a simplified model material, shown a similar behaviour, and in particular the formation of cavities appearing in front of the crack head itself. [4, 5] (Figure 5b).



(a) AFM image



(b) computer simulation

A Fig. 5: **(a)** Atomic force microscope view of a nanocrack propagation. On top, color code to get the cavity depth. (b) Computer simulation of a crack propagation.

In addition, glass manufacturers are observing complex, or even paradoxical, phenomena. For example, it is mostly the quality of the external surface of a glass bottle which implies its resistance to internal pressure (which is important for champagne bottles!), and it is the quality of the internal surface which governs the shock resistance, which is important during the transport and filling of the bottles.

Thus, a glass product to be strong would require a perfect surface, which is quite hard to maintain in practical situations. It is, however, already almost the case for glass fibres used to strengthen composite materials, the rupture coefficient when it comes out from the bushing being about 3.5 10^9 Pascal, close to the theoretical value for a defect-free silica of 10 to 15 10^9 Pascal. A more realistic approach, which can be generalized, is to block the propagation of the cracks. This can be achieved by different approaches: Tempering is a good way to do it by putting the surface in compression. Thermal tempering is largely used but has a limited performance. Chemical tempering, in which the glass piece is immersed into a hot bath of potassium salts, is far more expensive. The sodium ions of the glass are partially substituted by bigger potassium ions, therefore inducing a compression of the surface, which eventually makes the glass practically unbreakable. Two swords blades made for the uniforms of two members of the French "Institut de France": that of Yvan Peyches, R&D Director of Saint-Gobain from 1944 to 1966 and a member of the Academy of Sciences, and that of Commandant Cousteau, elected in 1988 at the prestigious "Académie Française", have been made by Saint-Gobain in chemically tempered glass!

Other techniques are presently being developed to prevent the cracks from propagating, thanks to appropriate coatings.

Coatings on glass

This brings us naturally to a few considerations on glass coatings. A large variety of functionalities are brought to glass products, especially glazing for windows, by the deposition of simple or complex coatings. As was mentioned earlier, a first target is to realize a "perfect" glazing, transparent in the visible and reflecting in the near and far infra-red.

This can be achieved by deposition of a carefully calculated multilayer interference filter at the surface of the glass. It must not only insure one or both of these properties of reflection and transparen-

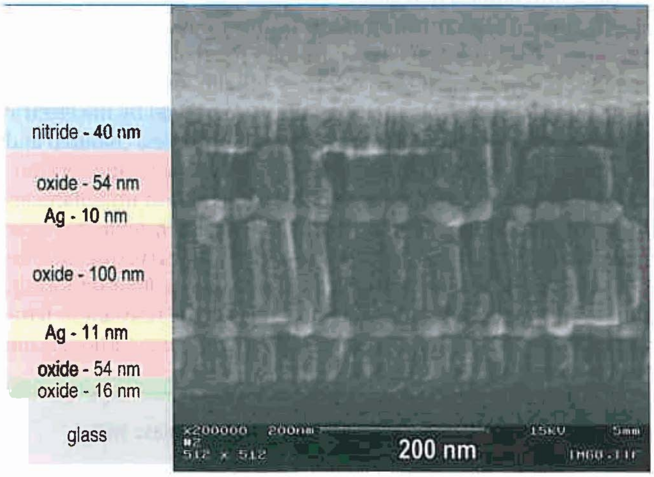
cy, [illegible] the glass be manipulated safely while introduced into a double glazing, in which it is eventually protected. And this must be realized at moderate cost. The main technique used to make these coatings is vacuum deposition by sputtering, which gives the possibility to deposit several layers, the structure and thickness of which being perfectly calculated and controlled. The simplest coated glasses would have half a dozen layers, with thicknesses going from a few nanometres to a few tens of nanometres (figure 6). The cost in this case remains low enough to be accepted in the construction market. The most complex may have more that twenty layers. This is the case for example for solar protective glass for car windshields, which reflects the near infra-red while being perfectly transparent in the visible, and able to stand without damage the cycle of heating and cooling necessary to realize the complex shapes of modern car windshields.

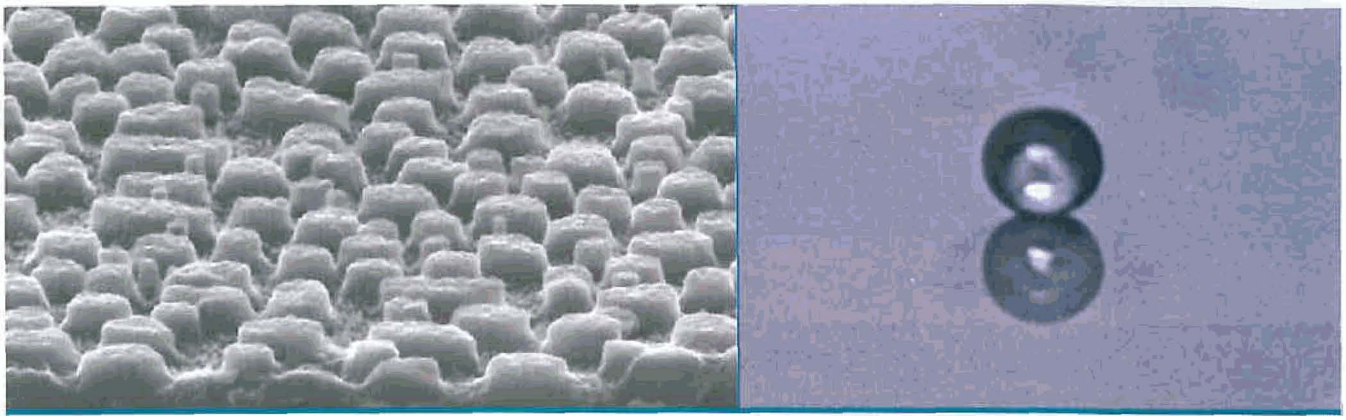
Mastering the various techniques of glass coating gives the possibility of many other functionalities: antireflective, hydrophilic or hydrophobic, antifrost... etc. Hydrophobic layers, especially, automatically assembled organic layers, are already used for airplane windshields, and for some lateral car glazing. The strong constraints imposed, however, by the necessity of keeping the wipers, make it still unsuitable for application in car windshields.

An interesting property that has also been studied is that of "super-hydrophobia": Studies of the hydrophobic property of the leaves of water lilies, which never get wet even under a heavy rain, have shown that this is due to a structure of the surface on a scale of a few hundred nanometres. Reproduced at the surface of a glass piece, it gives rise to a spectacular hydrophobic effect [6] (figure 7).

The latest glass product enriched by thin film deposition is the self-cleaning glass: in this case the cover is a thin coating of titanium oxide TiO_2. In the crystalline phase, called "anatase", it dissociates the greasy dust by a photo-catalytic cracking effect, the cleaning being further assisted by the rain flowing on this coating which is also hydrophilic (figure 8). Such products are now available commercially. Depending on the exact nature of the film they are efficient under UV radiation, or even under ordinary visible light.

▼ Fig. 6: Micrograph of the section of a multilayer cover





▲ **Fig. 7:** Micrograph (left) of a super-hydrophobic glass surface. The efficiency of the wetting decrease is shown (right) by the water drop (R=100 micrometres) which remains nearly spherical.

Complex glass products

The next step in term of glass products is to make complex, glass-based products. Two examples will illustrate this approach. They both are in the category of "electricity-driven" products.

The first example, the "Privalite", a commercialised product, is such that it commutes instantaneously from a transparent to a translucent state (figure 9). While not absorbing the energy of the light, it provides privacy, keeping the inside of a room out of sight from the outside. The applications of such a glazing are in offices, meeting rooms, hospitals (care rooms), etc. Its principle is the following: between two pieces of glass, each one covered by a transparent conductive film (in most cases SnO_2 doped with fluorine), is laminated a plastic film in which are imbedded small droplets of liquid crystal. The whole structure is such that when they are oriented by the electric field produced under an applied voltage, the droplets have, in the direction perpendicular to the glazing, an index of refraction equal to the index of the plastic sheet in which they are embedded. The system is therefore transparent. In the absence of electric field, the droplets are disoriented, presenting a variety of indexes of refraction in a direction perpendicular to the glazing. Their sizes being of the order of the wavelength of the visible light, a fraction of a micron, the light is diffused and the glazing becomes translucent. The commutation time is fast, of the order of a millisecond. Considering the nature of the liquid crystal molecules, this kind of product is not very resistant to ultra-violet radiation, and is therefore mostly used in the inside of buildings and not for outside windows. In the translucent state, it can become an excellent screen for optical projection.

Far more complex to realize is a large-sized "electrochromic" glazing (figure 10) : Electrochromism is nothing but a battery between two glass plates. It is actually a thin solid film battery of which the mobile electrical charges are protons or lithium ions. Depending on the battery layer in which these charges are pushed by the electric field, the system, while still transparent, is more or less coloured and absorbing. The migration of ions being a slow process, the commutation time is slow and progressive. If it seems almost instantaneous for a small rear mirror in a car, it can reach several minutes for a car glass roof of 0.5 m^2. The difficulties of manufacturing such an object of this size are considerable. It must change colour uniformly, for a large number of times without aging, and be resistant to temperatures up to 100°C and to intense W light...etc. Although the principles have been known for several decades, it has required about 20 years of development by Saint-Gobain to put the first electrochromic car roof on the market! The applications of such a product in the building industry are very promising, in terms of permanent control of the energetic and luminous transmission through windows. However, the large size necessary and the cost issues specific to its construction make it still a product for the future.

Where will the future progress of glass come from?

In the first instance from the composition itself. We have shown a few examples above, but the number of possible compositions is practically infinite. Only a microscopic fraction of the multidimensional space of possible compositions has actually been explored. In just the Aubervilliers research laboratory of Saint-Gobain alone, 200 new compositions are formulated and tested each year. More systematic methods of exploration, inspired by "combinatory chemistry": give today the possibility to greatly increase the number of compositions explored. In addition, the modelling by molecular dynamics, in association with the huge amount of empirical knowledge accumulated by the glass makers over several centuries, should dramatically improve our ability to predict the properties of a glass of a given composition. Then new glassy materials will be developed, either with better performance in existing applications, or adapted to rapidly expanding new applications such as substrates for flat panel displays for television, or in photovoltaic cells. Other applications, such as micro-fluidic or biosensors, may also use glass substrates in the future. To take but one example, the glass used for active matrix liquid-crystal flat TV screens is quite different from the one used for Plasma displays.

► **Fig. 8:** Compared transparencies of an ordinary glass and a self-cleaning one, after one year.

Mastering the surface of glass is the next big challenge. If we are now beginning to really understand the phenomenon of crack propagation, we have very few practical ways of blocking this propagation, at least at an acceptable cost. On the other hand we have seen that by structuring the surface of the glass, it becomes possible to give it new properties such as super hydrophobia, and this can be done locally, opening the door to new elaborate substrates. The propagation of surface waves also gives the possibility to make touch-sensitive glasses, identifying precisely the position where it has been gently pressed.

As for the structure of glass in the bulk itself, exciting new possibilities are opening up. It has been known for a very long time how to grow aggregates or micro-crystallites inside some glass matrices. We have also seen that it is possible to "write" inside the glass by using focused laser pulses. This opens the way to the realisation, inside the matrix, of elaborate patterns giving rise to new optical properties, comparable to those actually obtained by complex thin-film deposition, or to write information with a view to making three dimensional memories, or even to include inside the glass matrix molecular species which could be later released in a controlled way.

Another approach for new materials is that of material "construction" at the molecular level. Hybrid materials in which inorganic and organic molecules are combined to create an amorphous network begin to be developed. Such materials have at the same time the mechanical and thermal properties of minerals, and functionalities which can be brought by organic molecules. It appears to be a very promising approach.

The biocompatibility of glass, or even the bio-solubility of some compositions, opens the way to medical applications. Already, glass micro-spheres, full or empty, are being tested to bring in situ, by ingestion or injection, therapeutic or radiation treatments, or simply to block the circulation of the blood in micro-vessels nourishing a tumour.

In summary,

- the infinite variety of compositions that offer the possibility at best of adapting the glasses to applications that exploit its basic characteristics,
- the mastering of the surface structure and the deposition of thin layers,
- the beginning of an industrial approach to structuring the bulk of the glass,
- the realization of the first truly hybrid materials and
- the making of complex products in which glass is the main component,

▲ **Fig. 9:** Electrocontroled glass wall: opaque **(left)**, transparent (right)

all ensure a brighter and brighter future for this ever expanding material.

The importance of active, ongoing fundamental research on glass must also be stressed, to better understand what is actually an amorphous material, what happens at its surface, how to predict its properties by molecular dynamics, how to realize hybrid materials, how to structure in a controlled way its volume, etc..

Finally, being a physicist who has become modestly a glass manufacturer, I cannot but mention in closing the fascination that this material holds, for its beauty and the diversity of the products that can be made with it.

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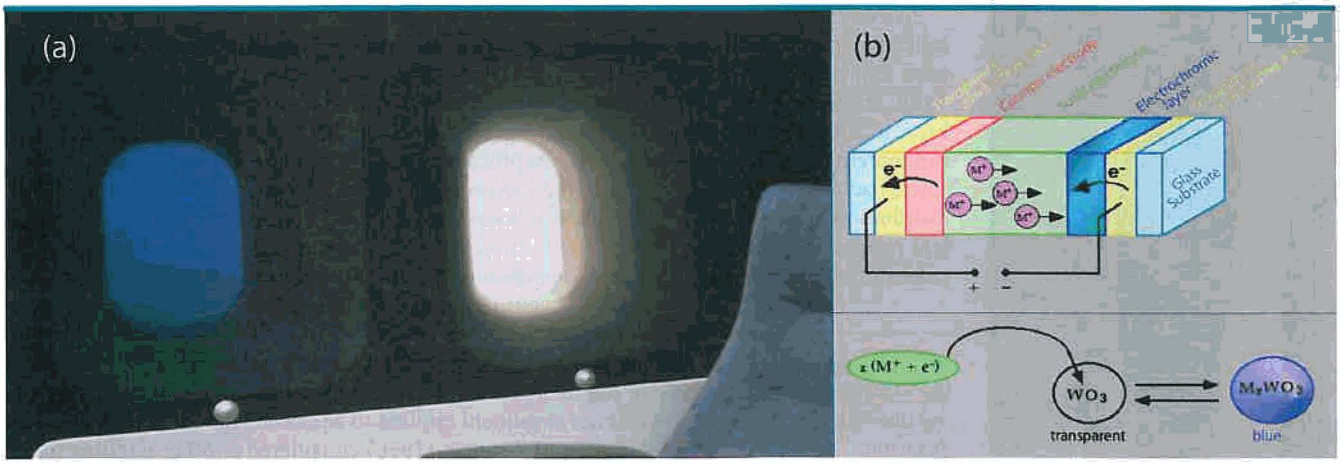
▼ **Fig. 10:** (a) Example of electrochromic glass; (b) Changing the ion distribution modifies the optical absorption.



A tribute to Boltzmann

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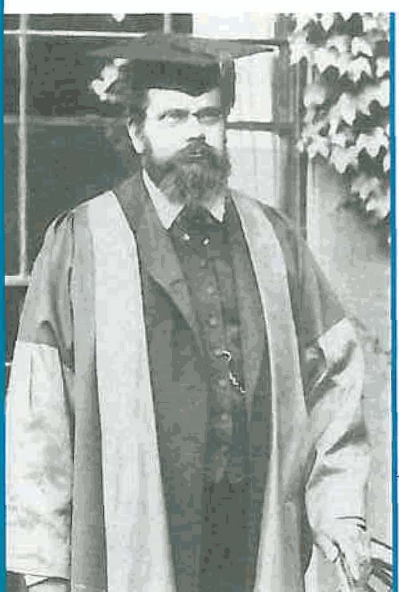
The name of Ludwig Boltzman is at the heart of modern science. The constant carrying his name, k, is as old as quantum physics. It was introduced by Max Planck in the epochmaking paper read, on 14 December 1900, before the *German Physical Society*, in Berlin, and called after him, following Boltzmann's death [1]. Boltzmann embodied at once brilliant physics, an acute sense of humour, and pure human tragedy.

Boltzmann was born in 1844. In 1863 he enrolled as a student of physics in the Faculty of Science of Vienna. Under Josef Stefan he passed the MSc, the PhD and the 'Habilitation', the latter early in 1868. The swiftness may indeed surprise. It should be realized, however, that, before 1872, no dissertations had to be submitted for degrees in academic Austria. So he could be nominated in 1869 as professor of mathematical physics at the Karl-Franzens University of Graz. In his new position, he set out for a trip to Hermann von Helmholtz. in Berlin. In Helmholtz' laboratory the implications and consequences of Maxwell's brand new electrodynamics were being considered in detail. One of these, the relation between the dielectric constant, ε, the diamagnetic constant, μ, and the refraction index, n, proved crucial. Initially, the idea was that of Maxwell, n being considered as the geometrical mean of ε and μ, hence $n = \sqrt{\varepsilon\mu}$. For insulators such as sulphur (colophonia, paraffin wax, ..) μ would be equal to that of air, that is unity. So Maxwell's formula (1865) reduced to $n = \sqrt{\varepsilon}$. For sulphur, *e.g.*, a platelet was made by allowing a melt to cool down slowly, a process that gives the monoclinic form. For the resulting platelet, ε was measured as the relative capacitance of a Kohlrausch plate condenser ($C_{sulphur}/C_{air}$): $\varepsilon = 3.84$ or $\sqrt{\varepsilon} = 1.96$. The refraction index for monoclinic sulphur was known from the literature: $n = 2.040$. The agreement – not too bad, given the tricky nature of the experiment – could be considered as a confirmation (an early one: 1872 !) of the postulated equivalence of light and electromagnetism [2]. Boltzmann closely followed the further developments in this domain. Early in 1887 he was one of the first to replicate the revolutionary findings of Heinrich Hertz of the winter before, that is, the production and registration, at a distance, of electromagnetic phenomena of an obviously wave-like nature [3]. Arrhenius and Nernst, as young guests, were among the eyewitnesses.



◀ Ludwig Boltzmann as honorary doctor (1894) of the University of Oxford (from [6]).

In a way Clerk Maxwell called the tune. The Scotsman had introduced, in 1860, statistics into the kinetic theory, another fundamental innovation. There had to be a random distribution in the numerical properties of molecules in the gaseous state. In Maxwell's view this concerned not so much the mass or the diameter, but only the translation velocity. Boltzmann generalized this approach, taking the kinetic energy as the essential variable. The link with thermodynamics was a direct one. When Clausius proclaimed in 1865 that 'The energy of the world is constant; the entropy strives to a maximum', he in fact summarized the First and Second Law. But *entropy* appeared hard to nail down, even for the gaseous state. Boltzmann's colleague Josef Loschmidt, for instance, suggested that since matter, or more particularly a gas, was indeed a huge collection of speedy molecules of ever increasing entropy, then one could reasonably expect at some time in the future the end of the world, a vision with Biblical connotations. The ongoing dissipation of energy would result in what came to be known as the *heat death*. However, since there are evident examples of entropy *decrease* in our environment, there must be some kind of *reverse* mechanism, contradicting Clausius' version of the Second Law. This seemed indeed paradoxical, at least at first sight, as Boltzmann showed in 1877 [4]. The new statistics revealed the answer, though its details were hard to grasp for the, as yet, inexperienced physics community. The probabilities of particular states were the clue: they could be weighted by applying permutation theory, using a discrete model for the energy. For a particular quantity of energy L divided into a great, though finite, number of 'energy elements' ε (say h, such that $\lambda\varepsilon = L$) and distributed over, say, N molecules, a particular number of well-defined distributions would be possible, each of these distributions being realisable in a particular number of ways; each of these ways was called a *complexion*, a wonderful word. Hence, the relative probability W of a particular distribution could be defined as its number of *complexions*, P – that is, its *permutability* – divided by the *total* number of *complexions*, J ($= \sum P$) :

$$W = \frac{P}{J} \qquad (1)$$

A given quantity of a gas, in a closed vessel and left to itself, will be in thermal equilibrium. When two (isolated) vessels containing the same gas at the same pressure though at different temperatures are connected, they will tend to straighten out the T difference. Considering all the possible distributions over the two vessels, it is evident that the initial state has but a poor probability. There are, of course, states of still lower probabilities, *e.g.* those with greater T differences. Such a state of greater ΔT could of course be attained, at least in principle: Maxwell considered, in 1868, the intervention of an imaginary creature, a *demon*, quick enough to open the stopcock between the vessels when one of the speediest molecules of the colder gas was heading that way. Boltzmann, however, realized that the probability of such an event was very small. He argued that in the succession of molecular events (translation; collisions) the whole is bound to develop in the direction of the most probable distribution, for the simple reason that the number of the latter's *complexions* is by far the greatest. So Loschmidt's argument could be countered: former situations could indeed eventually occur, but the probability of such events was so small, at least in comparison to the overwhelmingly great number of *complexions* of the *most probable* state, that of thermal equilibrium. The same counter-argument applied to Maxwell's demon. Later, Poincaré (1890) and Zermelo (1896) considered another paradox in the same vein, that of ***recurrence***, implying the regular reappearance of particular states and, implicitly, the periodicity of natural phenomena, more or less in agreement, let's say, with the succession of the seasons. Boltzmann argued that, given the state of thermal equilibrium of the universe as a whole it is doubtless so, that when we, in our corner of low entropy, observe an apparent ***increase*** which determines our idea of ***time***, there will be elsewhere in the universe ***decreases*** in entropy and a corresponding idea of ***time***. The universe considered as a whole, then, tends nonetheless, irreversibly, into the direction of thermal equilibrium. Boltzmann describes all this in terms of his H-theorem, H being a rather arbitrary function which, qualitatively, mirrored more or less Clausius' entropy: H strives to a minimum, where S tends to a maximum.

It was Max Planck who put the intuitively more appealing entropy on a privileged basis. He was to elaborate on Boltzmann's original 'permutation' theoretical approach. In order to account for the ***additivity*** of entropy, probabilities being multiplicative, the entropy S shows up, with Planck, as a function of logW. Since logW is dimensionless, then, a proportionality constant k is in the game, giving S the dimension of energy per degree K:

$$S = k \log W \tag{2}$$

This form was proposed in 1900. It allowed Planck to assess the radiation curves of black bodies, which looked like statistical distributions and behaved as such: what Willie Wien (1896) had summarized in his law ($\lambda_{max} \cdot T = c$) was, conversely, what could reasonably be expected for velocity distributions of a gas at varying temperature. It is fascinating to see how, in various ways, ***molecularism*** guided Wien and Planck in much the same way: the idea, that is, that the physics and mathematics of the essentially molecular gaseous state may be applied in other domains where discrete entities are at stake. As is well-known, another law, one found empirically by Stefan and claiming that the radiated energy of a cooling body was as the fourth power of its absolute temperature, had been deduced theoretically by Boltzmann (1884).

Boltzmann was a great European scientist, long before Europe became a concrete reality. Broadly educated, he was at ease at the piano – as a pupil of the famous composer Bruckner – and thoroughly familiar with German poetry (Schiller !), occasionally even refering to ancient Greek authors. As a physicist he taught at various universities in Austria-Hungary and Germany. He was otherwise an upright man, on which the socio-political delusions of the day apparently had not the slightest grip. Moreover, his humour and wit are well-documented: the report, for instance, on the ***Journey of a German professor into Eldorado, California*** is a cheerful case in point. His life, though, ended in a tragedy: on September 5th 1906 he took his life while on a medical leave with his family at Duino, near Trieste, Italy His motivation has puzzled generations of physicists. How could a prominent scientist, member – if not ***honorary*** member – of the most distinguished Societies of both Europe and the United States, do such a thing ? We may add, from this place, that he was nominated several times for the Nobel Prize for Physics, inter alia by Planck for those of 1905 and 1906 [5]. There have been rumours about the role of the obstruction with which Boltzmann had had to cope as to his kinetic theory, but, all things well-considered, these were wholly unfounded. The most probable reason were his successive depressions combined with a seriously detoriating health. He was, for instance, scourged by asthmatic-attacks and cartarrh of the nose, and about 1906 his eyes had become so bad that he could hardly read any more: at home, servants were paid for reciting books and the like. On the brink of a new academic year – Boltzmann was to return to Vienna the next day, September 6th – his despair apparently overruled all common sense. His body was repatriated and buried at Vienna's *Zentralfriedhof*. In 1933 a monument was erected, consisting of a bust made by Gustinus Ambrosi in white marble and featuring the entropy formula in the then current form.

About the author

Henk Kubbinga is a historian of science and technology in the University of Groningen. He passed the PhD (1983) and the 'habilitation' (1996) at the Ecole des Hautes Etudes en Sciences Sociales at Paris. Both theses were published as L'Histoire du concept de « molecule » (Springer Verlag, 2001). An abridged Dutch version appeared in two volumes (Verloren Publishers, 2003-2005); an English version, referred to below, is forthcoming.

Acknowledgment

Ilse Fasol-Boltzmann and Karl-Heinz Fasol (Vienna; University of Bochum) generously allowed me to reproduce Figure 1 and 2. I am otherwise indebted to Karl Grandin (Royal Swedish Academy of Sciences, Stockholm) for kind permission to consult the nomination letters by Max Planck.

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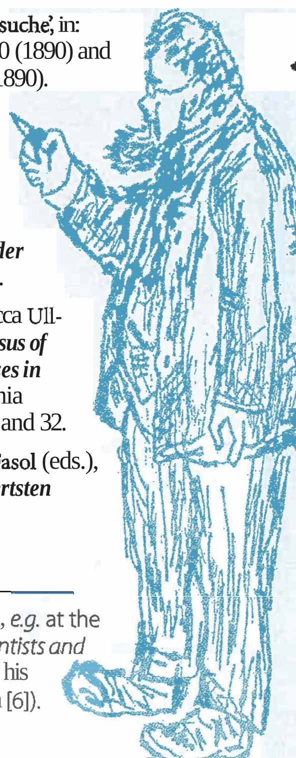

▶ Boltzmann preaching the molecular gospel, *e.g.* at the Lubeck congress *of the German Society of Scientists and Physicians* (1896), according to a caricature by his student Karl Przibram (1878-1973; 1905) (from [6]).

The quest to understand the Pioneer anomaly

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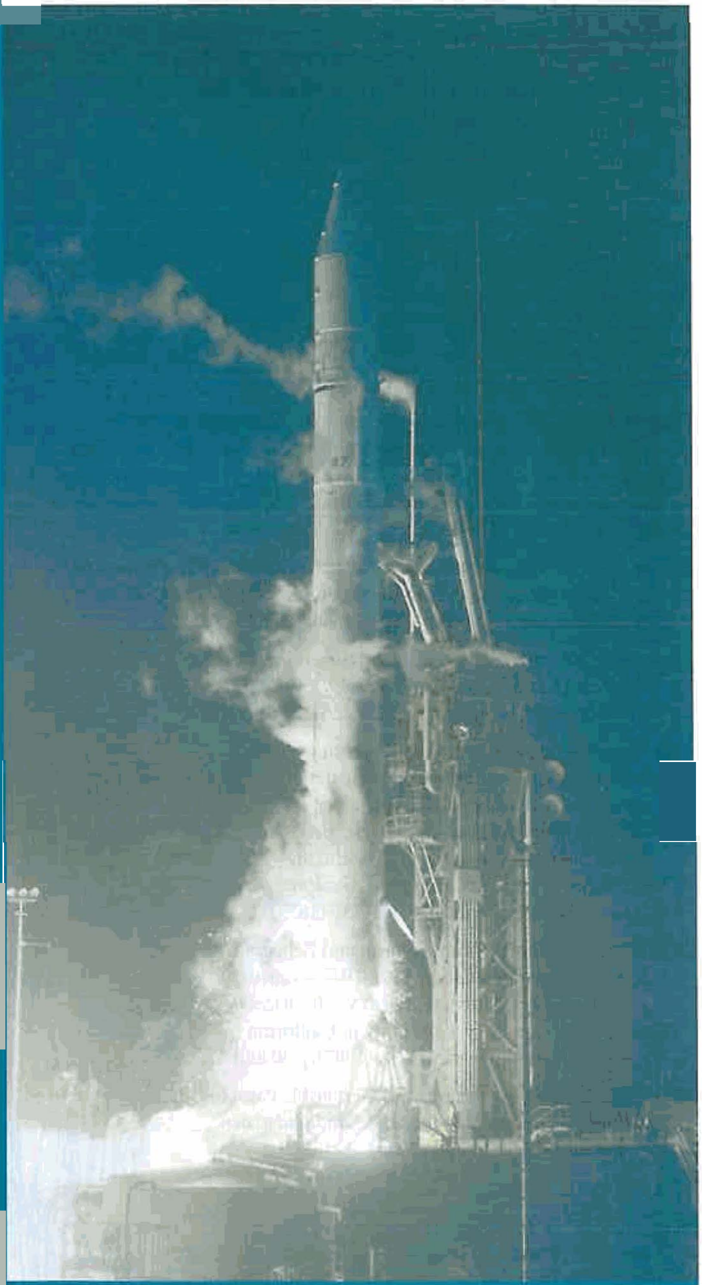
During the 1960's, when the Jet Propulsion Laboratory (JPL) first started thinking about what eventually became the "Grand Tours" of the outer planets (the Voyager missions of the 1970's and 1980's), the use of planetary flybys for gravity assists of spacecraft became of great interest. The concept was to use flybys of the major planets to both modify the direction of the spacecraft and also to add to its heliocentric velocity in a manner that was unfeasible using only chemical fuels. The first time these ideas were put into practice in deep space was with the Pioneers.



A Fig. 1: Pioneer 10's launch on 2 March 1972.

Pioneer 10 was launched on 2 March 1972 local time, aboard an Atlas/Centaur/TE364-4 launch vehicle (see Fig. 1). It was the first craft launched into deep space and was the first to reach an outer giant planet, Jupiter, on 4 Dec. 1973 [1,2]. Later it was the first to leave the "solar system" (past the orbit of Pluto or, should we now say, Neptune). The Pioneer project, eventually extending over decades, was managed at NASA/AMES Research Center under the hands of four successive project managers, the legendary Charlie Hall, Richard Fimmel, Fred Wirth, and the current Larry Lasher.

While in its Earth-Jupiter cruise, Pioneer 10 was still bound to the solar system. By 9 January 1973 Pioneer 10 was at a distance of 3.40 AU (Astronomical Units[1]), beyond the asteroid belt. This in itself was a happy surprise, as the craft had not been destroyed passing through. With the Jupiter flyby, Pioneer 10 reached escape velocity from the solar system. It was then headed in the general direction opposite the relative motion of the solar system in the local interstellar dust cloud or opposite to the direction towards the galactic center.

Pioneer 11 followed soon after with a launch on 6 April 1973, cruising to Jupiter on an approximate heliocentric ellipse. This time during the Earth-Jupiter cruise, it was determined that a carefully executed flyby of Jupiter could put the craft on a trajectory to encounter Saturn in 1979. On 2 Dec. 1974 Pioneer 11 reached Jupiter, where it underwent the Jupiter gravity assist that sent it back inside the solar system to catch up with Saturn on the far side. It was then still on an ellipse, but a more energetic one. Pioneer 11 reached as close to the Sun as 3.73 AU on 2 February 1976.

Pioneer 11 reached Saturn on 1 Sept. 1979. The trajectory took the craft under the ring plane on approach and it came within 24,000 km of Saturn. After encounter, Pioneer 11 was on an escape hyperbolic orbit. The motion of Pioneer 11 is approximately in the direction of the Sun's relative motion in the local interstellar dust cloud (towards the heliopause). Its direction is roughly anti-parallel to the direction of Pioneer 10.

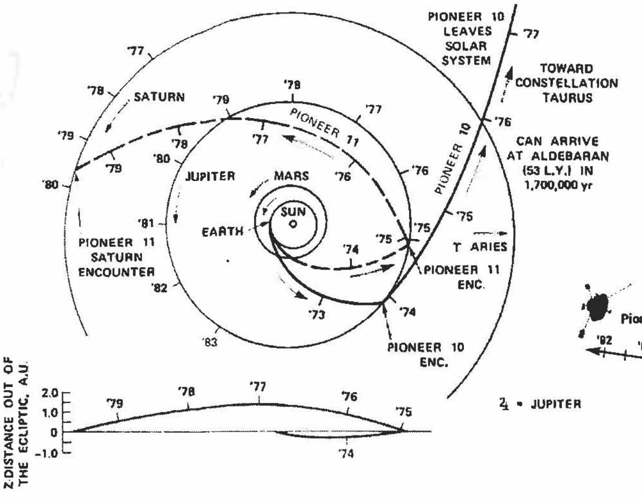
In Figure 2 the trajectories of the Pioneers in the inner solar system are shown. In Figure 3 the trajectories of the Pioneers and Voyagers over the entire solar system are shown.

The Pioneer Navigation

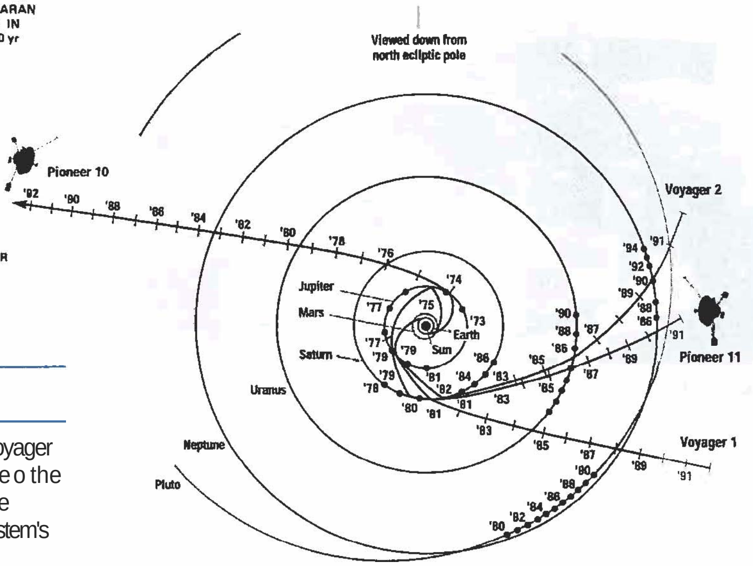
The navigation to Jupiter was carried out at the Jet Propulsion Laboratory using NASA's Deep Space Network (DSN). It was ground-breaking in its advances and fraught with crises. To succeed the navigation team needed to modify the codes with real-time fixes. (See Fig. 4). But the team succeeded.

The navigation used a Doppler signal. An S-band signal (–2.11 Ghz) was sent via a DSN antenna located either at Goldstone, California, outside Madrid, Spain, or outside Canberra, Australia. On reaching the craft the signal was transponded back with a (240/221) frequency ratio (–2.29 Ghz), and received back at the same station (or at another station if, during the radio round trip, the original station had rotated out of view). There the signal was de-transponded by (2211240) and any Doppler frequency shift was measured directly by cycle count compared to an atomic clock The idea was to determine the velocity as a function of time and from this calculate a trajectory, a procedure that is done iteratively to improve the accuracy.

[1] An Astronomical Unit is the mean Sun-Earth distance, about 150,000,000 km.



▲ **Fig. 2:** The Pioneer orbits in the interior of the solar system.



► **Fig. 3:** Ecliptic pole view of the Pioneer 10, Pioneer 11 and Voyager trajectories. Pioneer 10 is traveling in a direction almost opposite o the galactic center, while Pioneer 11 is heading approximately in the closest direction to the heliopause. The direction of the solar system's motion in the galaxy is approximately towards the top.

However, to obtain the spacecraft velocity as a function of time from this Doppler shift is not easy. The codes must include all gravitational and time effects of general relativity to order $(v/c)^2$ and some effects to order $(v/c)^4$. The ephemeredes of the Sun, planets and their large moons as well as the lower mass multipole moments are included. The positions of the receiving stations and the effects of the tides on the exact positions, the ionosphere, troposphere, and the solar plasma are included.

Given the above tools, precise navigation was possible because, due to a serendipitous stroke of luck, the Pioneers were spin-stabilized. This is contrary to, for example, the later Voyagers which were 3-axis stabilized. With spin-stabilization the craft are rotated at a rate of ~(4-7) rpm about the principal moment-of-inertia axis. Thus, the craft is a gyroscope and attitude maneuvers are needed only when the motions of the Earth and the craft move the Earth from the antenna's line-of-sight. With 3-axis stabilization, there are continuous, semi-autonomous, small gas jet thrusts to maintain the antenna facing the Earth. This yields a navigation that is not as precise as that of the Pioneers.

The Pioneers were the first deep spacecraft to use nuclear heat from ^{238}Pu as a power source in Radioisotope Thermoelectric Generators (RTGs). The RTGs were placed at the end of long booms to be away from the craft and thereby avoid any radiation damage. (See Fig. 5) Thus, the craft had to be spin-stabilized. Especially in the later years, only a few orientation maneuvers were needed every year to keep the antenna pointed towards the Earth, and these Could be easily modeled.

Even so, there remained one relatively large effect on this scale that had to be modeled: the solar radiation pressure of the Sun, which also depends on the craft's orientation with respect to the Sun. This effect is approximately 1130,000 that of the Sun's gravity on the Pioneers and also decreases as the inverse-square of the distance. It produced an acceleration of -20×10^{8} cm/s^2 on the Pioneer craft at the distance of Saturn (9.38 AU from the Sun at encounter). (For comparison, the gravitational acceleration of the Sun at the Earth is 0.593 cm/s^2). Therefore, any "unmodeled force" on the craft could not be seen very well below this level at Jupiter. However, beyond Jupiter it became possible.

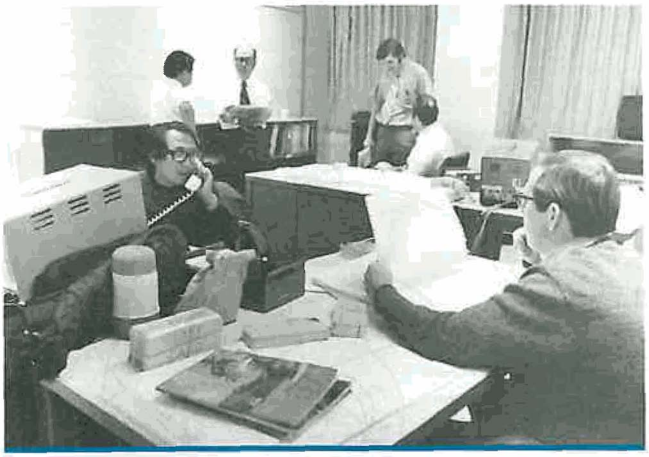
Discovery of the Anomaly

One of the main experiments on the Pioneers was radioscience celestial mechanics. In 1969 John Anderson became the PI of this program, remaining so until the official end of the extended mission [3] in 1997. Working with Eunice Lau (who also later joined the Pioneer anomaly Collaboration), the Pioneer Doppler data going back to 1976 for Pioneer 11 and 1981 for Pioneer 10 (but also including the Jupiter flyby) was archived at the National Space Science Data Center (NSSDC), something that later was extremely helpful.

Part of the celestial mechanics effort, working together with the navigation team, was to model the trajectory of the spacecraft very precisely and determine if there were any unmodeled effects. Around Jupiter none could be found. But over time, a number of approximately 6-month to 1-year averages of the data were taken from both Pioneer 10 and Pioneer 11 and by 1987 it was clear that an anomalous acceleration appeared to be acting on the craft with a magnitude $\sim 8 \times 10^{-8}$ cm/s^2, directed approximately towards the Sun. (See Fig. 6).

For independent reasons, in 1994 the current author contacted Anderson about gravity in the solar system. When the anomaly came up its magnitude was a great personal surprise. The result was an announcement in a 1994 Conference Proceedings. The strongest immediate reaction was that the anomaly could well be an artifact of JPL's Orbital Data Program (ODP), and could not be taken seriously until an independent code had tested it. So Anderson put together a team that included two former Pioneer co-workers (see Fig. 4) who were then associated with The Aerospace Corporation. These two used the independent CHASMP navigation code they had developed to look at the Pioneer data. To within small uncertainties, their result was the same.

The Pioneer anomaly Collaboration's discovery paper appeared in 1998 [4] and a final detailed analysis appeared in 2002 [5]. The latter used Pioneer 10 data spanning 3 January 1987 to 22 July 1998 (when the craft was 40 AU to 70.5 AU from the Sun) and Pioneer 11 data spanning 5 January 1987 to 1 October 1990 (when Pioneer 11 was 22.4 to 31.7 AU from the Sun). The result, after accounting for all known systematics, was that



A **Fig. 4:** Members of the JPL navigation team working on the day of Pioneer 10's launch. In the foreground are Tony Liu and Phil Laing, who later became part of the Pioneer anomaly Collaboration. In the background are Sun Kuen Wong, Jack Hohikian, Steve Reinbold, and Bruce O'Reilly. Note the stack of computer program cards labeled "LAST CARD," the large format computer printout paper, and the Tektronix scope, evidence of the technologies used then.

... there is an unmodeled acceleration, directed approximately towards the Sun, of

$$a_P = (8.74 \pm 1.33) \times 10^{-8}\ \mathrm{cm/s^2}.$$

Meaning of the anomaly

The decision to use modern data in the final analysis was motivated by a number of reasons. i) It was easily accessible and in modern format, ii) the craft were then further away from the Sun (greater than 40 and 20 AU, respectively, for Pioneers 10 and 11) so solar radiation pressure was a smaller complicating factor, and iii) further out there were fewer antenna Earth-reorientation manoeuvres that had to be modeled. To the accuracy of the analysis, the anomaly was constant, but this accuracy was only ~15%.

This brings up the problem of heat radiating out from the craft in a non-isotropic manner. Since at launch there were 2500 W of heat coming from the RTGs and only 63 W of directed power could cause the effect, it is tempting to assume this must be the cause. However, even though admittedly this is the most likely explanation of the anomaly, no one as yet has been able to firmly tie this down, despite heated controversy [6]. The craft was designed, again serendipitously, so that the heat was radiated out in a very fore/aft symmetric manner. Further, the heat from electric power went down by almost a factor of 3 during the mission. Heat as a mechanism remains to be clearly resolved.

Drag from normal matter dust as well as gravity from the Kuiper belt have been ruled out. Also, if this is a modification of gravity, it is not universal; i.e., it does not affect planetary bodies in bound orbits. It could, in principle be i) some strange modification of gravity, ii) drag from dark matter or a modification of inertia, or iii) a light acceleration. (Remember, the signal is a Doppler shift which is only *interpreted* as an acceleration). In such circumstances the true direction of the anomaly should be i) towards the Sun, ii) along the craft velocity vector[2], or iii) towards the Earth. (If the origin is heat the acceleration would be iv) along the spin axis).

[2] Technically it is along the vector sum of the spacecraft velocity and the dark matter's change in velocity.

Finding the origin of the anomaly

a) Using all the data.

If all the Doppler data, from launch to last contact, were to be analyzed together a number of things would be obviated [7]. First, it would be easier to see if the anomaly is truly a constant or rather if it exhibits a half-life corresponding to the 87.74 years of ^{238}Pu. Also, if the effects of solar radiation pressure and many manoeuvres that occur close in to the Sun could be disentangled, one might be able to do 3-dimensional tracking precisely enough to determine the exact direction of the anomaly. Perhaps most intriguingly, by closely studying the data around Pioneer 11's Saturn flyby (and Pioneer 10's Jupiter flyby) it could be determined if, indeed, there was an onset near these transitions to hyperbolic-orbits.

The Doppler data archived at the NSSDC and the data used in the summary analysis [5], as well as other pieces obtained elsewhere have recently been reacquired, translated and compiled in modern format. Analyses will soon start [8]. The Doppler data holds the possible key to finding an origin to the anomaly.

Due to the foresight of Larry Kellogg of Ames in retaining obsolete telemetry files, the engineering data has also been reacquired [8]. In the long run the telemetry might be most useful. From the beginning the Collaboration has observed that, even if the anomaly turns out to be due to systematics, the anomaly inquiry would still result in a win. One would obtain a better understanding of how to build spacecraft for very deep space and how to model and track craft there.

b) The New Horizons mission to Pluto

On 19 Jan 2006 the New Horizons mission to Pluto and the Kuiper Belt was launched from Cape Canaveral (Alan Stern of the Southwest Research Institute is PI). Although it was not designed for precision tracking, it might be able to yield useful information.

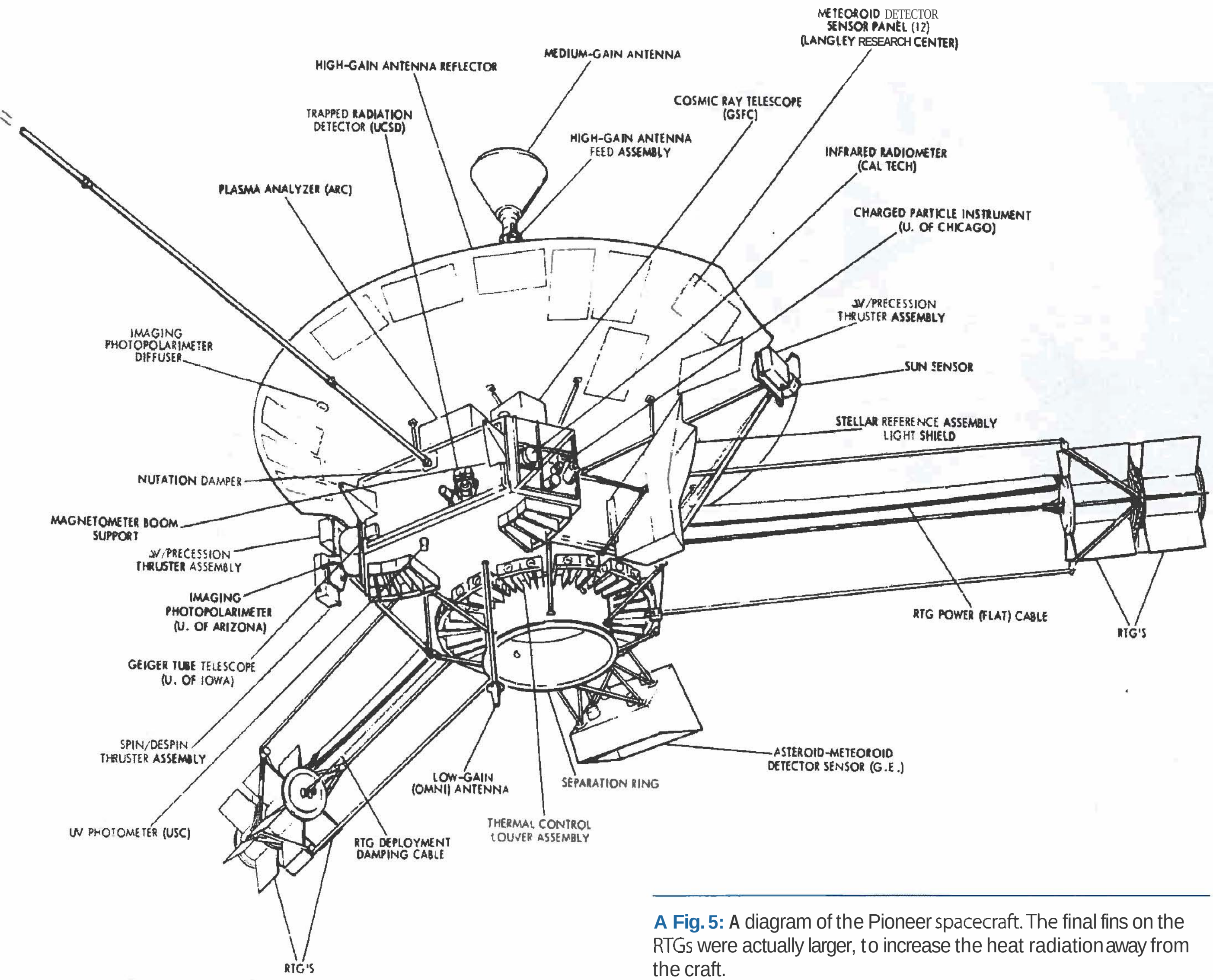
The first problem will be the on-board heat systematics. The large RTG is mounted on the side of the craft, and produced ~4,500 W of heat at launch. A rough calculation shows that a systematic of ~20 cm/s^2 or larger will be produced. Since the post-launch modeling of heat systematics is notoriously difficult, this makes this systematic an important problem to overcome.

A saving grace may be that soon after launch a 180 degree "Earth acquisition manoeuvre" rotation was performed, to aim the main antenna at the Earth. The difference in the Doppler shift immediately before and after the rotation can in principle yield a difference measurement of the heat acceleration which would be pointed first in one direction and then in the opposite. But a determination may be difficult because of the high solar radiation pressure (which will vary somewhat in the two orientations) and the relatively small data set before the manoeuvre.

More gratifyingly, New Horizons will be in spin-stabilization mode for about the six months before the Jupiter observing period (January-June, 2007, with encounter on 28 Feb. 2007). It also will be spin-stabilized for much of the period after June 2007 until soon before the Pluto encounter on 14 July 2015. This is designed to save fuel so it can be used to aim later at a Kuiper Belt Object. With luck the Doppler and range data from these periods will supply a test, at some level, of the Pioneer anomaly, especially since the velocity of the craft before (~21 km/s) and after (~25 km/s) the Jupiter encounter will be significantly different that those of the Pioneers (~12 km/s). Perhaps something can be learned from the New Horizons data by 2008.

c) ESA's Cosmic Vision

As discussion on the anomaly was proceeding, in Europe there independently arose an international interest in the problem. In



A Fig. 5: A diagram of the Pioneer spacecraft. The final fins on the RTGs were actually larger, to increase the heat radiation away from the craft.

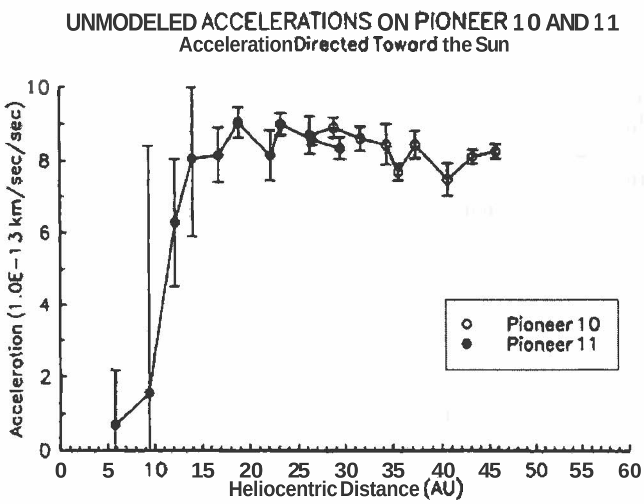
May 2004 a meeting was held at the University of Bremen to discuss the anomaly, and from this an international Pioneer Explorer Collaboration was formed to propose a dedicated test of the anomaly [9], with Hansjoerg Dittus of Bremen as PI. Institutions from all over Europe, including from France, Germany, Great Britain, Italy, Netherlands, Portugal, and Spain, have joined.

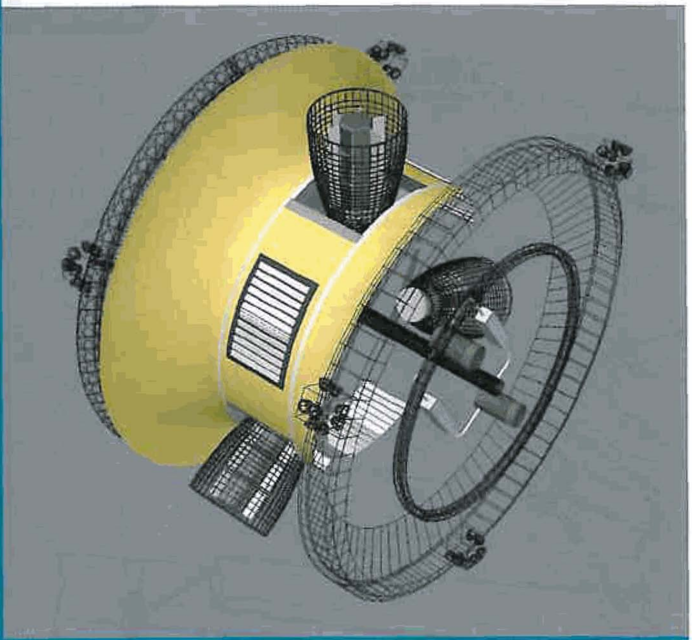
The proposal is a Theme for ESA's Cosmic Vision program, with launches to occur during the period 2015-2025. As such it's timing would be perfect if the two investigations described above indicate that a dedicated test of the anomaly is called for. A driving consideration would be new technology. The mission would take insight from knowledge of what allowed the Pioneer craft to be navigated so well and add to it.

The concept would be to determine accurately the heliocentric motion of a test-mass utilizing 2-step tracking with common-mode noise rejection[3]. A state-of-the-art Ka-band tracking system, using both Doppler and range, could be used to track the main ►

[3] Another concept would be an autonomous probe that would be jettisoned from a main vehicle, such as the Interstellar Probe. This would happen further out than at least the orbit of Jupiter or Saturn. The probe would then be navigated from the ground.

▼ Fig. 6: A JPL Orbital Data Program (ODP) plot of the early unmodeled accelerations of Pioneer 10 and Pioneer 11, from about 1981 to 1989 and 1977 to 1989, respectively. This graph first appeared in JPL memos from the period 1992.





▲ **Fig. 7:** A schematic, cut-away drawing of the Pioneer Anomaly Explorer concept. The side facing away contains the radio antenna to communicate with Earth. On the facing side are the canisters that will emit corner-cube covered spheres and the mW laser. (Drawing courtesy of Alexandre D. Szames).

••• satellite to an accuracy approaching 0.1×10^{-8} cm/s^2. Then, from the forward side facing away from the Earth, a "formation flying" system would send out small corner-cube covered spheres to be tracked from the main satellite with mW laser ranging. The passive spheres would be at a distance of order >500 m from the main satellite, which satellite would utilize occasional manoeuvres to maintain formation. This final step could yield an acceleration precision approaching 10^{-10} cm/s^2. On board one could also carry sensitive drag-free DC accelerometers, which are being developed.

The craft would be spin-stabilized. The design would be extremely fore/aft symmetric as far as heat/power-radiation were concerned, to reduce heat acceleration of the craft. (The heat would be radiated out in fore/aft and axially symmetric manners). In Figure 7 we show a schematic cut-away preliminary model. The side exterior surfaces is curved to symmetrically reflect and radiate heat from the side of the bus. (Heat from inside the equipment bus would come out of louvers located between the RTG extensions). This surface also symmetrically reflects heat from the RTGs which are in parabolic Winston cone reflectors. The RTGs could be extended out on booms after launch. One can also see where the spheres would be extruded and the central location of the laser.

The test masses would not be released until the main craft would undergo no further acceleration manoeuvres, be it from a final stage chemical rocket, a planetary flyby, or even a jettisoned solar sail. This would probably be at a distance of 5-10 AU, when the craft hopefully had a velocity of >5 AU/yr. From then on, and especially at distances of 25-45 AU, when solar radiation pressure is reduced, precise data could be taken.

Conclusion

That the Pioneer anomaly is a physical effect is no longer in doubt. The only question is its origin. Here the anomaly's discovery and the growing interest and efforts to understand it have been described. The latter include, in order of possible completion, a) an analysis of (almost) the entire Pioneer Doppler data set, b) the possibly fruitful analysis of the tracking data from the ongoing New Horizons mission to Pluto, and c) a dedicated ESA mission. Understanding the anomaly will yield, at the least, improved navigational protocols for deep space and, at the best, exciting new physics.

Finally, given this opportunity, I wish to more directly address the current audience with a political question that Europe must face. Up to now Europe has not ventured into deep space alone. Its greatest triumph, Huygens, necessitated a piggy-back on a RTG-powered NASA mission, Cassini. Why is this? Because of the political mine-field about anything nuclear.

There is simply no way, given any foreseeable near-term technology, that even a medium-sized spacecraft (few hundred kg) can go into deep space (>5 AU) in a short time (less than a few years) without some form of on-board nuclear power (the simplest being RTGs).

However, it is my experience that the elder statesmen of Europe are very hesitant to even discuss the matter. (Recall that they reached maturity during the anti-nuke era). On the brighter side, I have found that young post-docs have much more of an "of course" attitude towards using RTGs. At the least, I hope that the Pioneer Explorer proposal will help stimulate discussion on the matter. If there is not a shift in the European paradigm, then Europe will end up abandoning deep space to the rest of the world. That would be extremely sad. ■

About the author

Michael Martin Nieto is a Laboratory Fellow at Los Alamos National Laboratory. He received a BA with highest honors from the University of California, Riverside and a PhD from Cornell University. He has worked on exactly solvable quantum systems, particle physics, and tests of gravity (with some history of physics included). He is a Fellow of the American Physical Society and received an Alexander von Humbolt Senior Research Award.

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Gravity's pull on arc lamp efficiency

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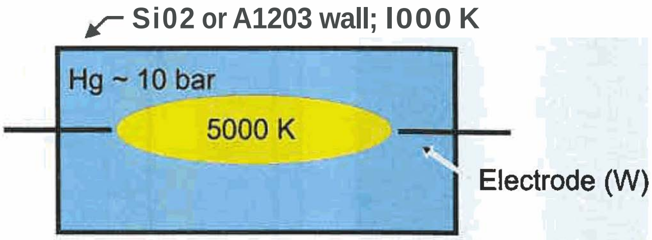
Wherever humans are present artificial light is used. It allows us to live and work indoors and outdoors at any time of the day. In densely populated areas, this literally lights up our planet as is clearly seen from outer space in figure 1. The 30 billion lamps operating worldwide are certainly a great commodity, but they come at a price. Not only do they cause serious light pollution, disturbing animal and plant life, they also have a huge energy need. Of the annual world electricity production, which is more than 10^{13} kWh, about 15-20 % is used for lighting applications [1]. A medium- to large-sized electricity plant has a production capacity of about one GW. An easy calculation shows that a few hundred electricity plants are operating continuously solely to supply the power for our lamps. Apart from depleting fuel reserves, this also results in an annual CO_2 emission of about a billion ton and the attendant effects on ecology and climate. Obviously, lighting has a large social, economical as well as ecological impact.

The best known lamp type is the incandescent lamp, where an electrical current heats a wire until it lights up. More than 100 years after Edison's invention, modern incandescent lamps are still not very efficient. Incandescent lamps produce only about 3% of all light whereas they consume 20% of the power needed for lighting. Discharge lamps are about 5 to 10 times more efficient. They can be grouped into two large families based on operating pressure. Tubular fluorescent lamps, commonly used in offices, are the best-known example of low pressure lamps. High pressure lamps are commonly used if much light is needed, such as outdoor lighting. About 97% of all artificial light on Earth is produced using plasma technology [1, 2]. Evidently, plasma lamps are essential in lighting, and any increase in their efficiency, even by as little as 1%, has a large impact on preserving our natural resources and environment.

The metal halide lamp is a high-pressure gas discharge lamp with a very high efficiency. Despite the fact that the lamp is widely used in outdoor lighting there are still several technological and scientific problems limiting its applicability. Some of the problems are related to a poor understanding of the physics of the gas discharge. Color separation, discussed here is one of them. But before describing the problem and discussing some experiments one should first review the basics of a metal halide lamp.

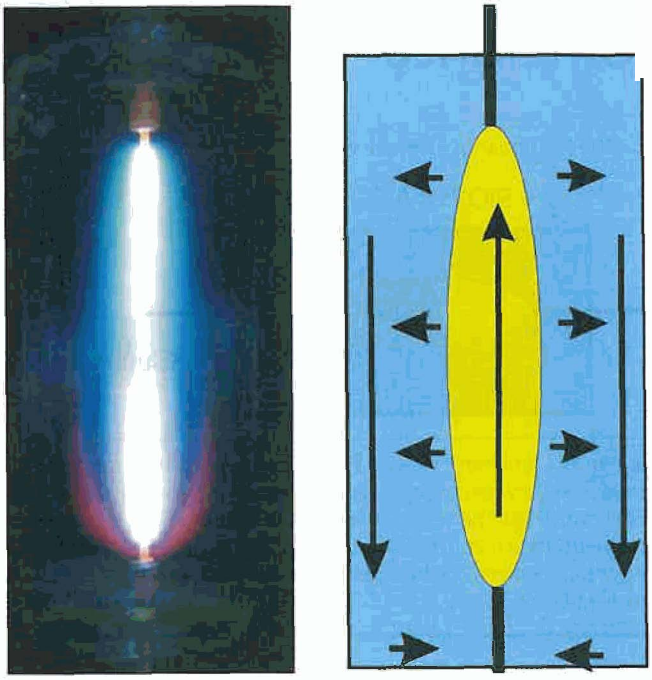


▲ Fig. 2: A schematic view of a metal halide lamp. The arc is produced between two tungsten electrodes in a mercury buffer gas of about 10 bar. The arc is confined inside an SiO_2 or Al_2O_3 burner. Furthermore, a metal halide salt like NaI, DyI_3, ScI_3, or TlI is added. After evaporation and dissociation, the excited metal atom is the main radiation source.

Metal Halide Lamps

A metal halide lamp is derived from the better known mercury high-pressure arc discharge [2]. A schematic picture is shown in Fig. 2. An electric arc is maintained between two electrodes, which are sealed into the confining space of the lamp burner. In normal operation, the main gas in the lamp is mercury. Depending on lamp type, size, and application; the pressure varies from a few to several hundred bars. The former are large lamps used as street or stadium lights, the latter are tiny lamps used in video and beamer projection systems. The centre of the arc is at a temperature of about 5000 K, while the wall is maintained around 1200 K. As the lamps are in the millimeter to centimeter size range, this implies that there are strong temperature gradients. A high voltage peak starts the lamp in a noble gas, but after a few seconds the mercury begins to evaporate. Due to its lower ionization energy, the arc soon becomes a mercury discharge. Mercury discharges are very efficient, and commonly used as lamps. The main mercury emission lines, however, are in the UV region. To obtain visible light a fluorescent coating on the lamp is needed, which transforms one UV photon into one visible photon. It is the white coating on the tubular fluorescence lamps that we "see" not the UV-light generated inside the discharge. The lamp color is optimized by mixing different coatings and not by changing the discharge. Unfortunately, the energy of a visible photon is about half that of the UV photons, so the energy of mercury emission is only partly utilized. Metal halide lamps use the efficiency of a mercury discharge, while directly emitting visible photons. Thus there are no fluorescent coatings. This is achieved by adding a mixture of metal halide salts (such as DyI_3, ScI_3, CsI_2, or NaI) to a mercury arc discharge. Obviously, in the hot central arc region, the salt will dissociate and the metals will be excited and ionized. These metals are extremely efficient radiators. Even though the metal density is much less than the mercury density, most light is emitted by the metals in the visible region. As a result, metal halide lamps can be made, with power efficiencies up to 40%, significantly better than most other lamp types. A good color rendering is achieved by mixing various salts. Currently, these lamps are used for industrial lighting, street

◄ Fig. 1: A composite satellite ... discharge lamps. (© Photo: NASA)



▲ **Fig. 3** Axial segregation and color separation in a vertically operating metal halide lamp due to the combined effects of diffusion and convection. a) A picture of the arc discharge with color separation. b) An artist impression of the diffusion and convection flows.

... lighting, and city beautification. Unfortunately, the lamp also suffers from several problems, which limit its use for other applications, such as shop and home lighting. These problems include electronic control of the lamp, burning orientation, (re-)ignition problems [2] and instabilities [3]. Another problem is color separation in metal halide lamps. This means that different parts of the lamps emit different colors [4, 5].

Before going into a detailed explanation of the effect and showing the experiments, this general description of a metal halide lamp should be concluded with a remark on mercury. As is commonly known, mercury is unhealthy and thus mercury-free lamps are desirable. However, mercury lamps in general and metal halide lamps in particular are highly efficient. In assessing the ecological impact it should be noted that there are small amounts of mercury in the average fuel mix of electricity plants. During the long lifetime of these discharge lamps, generally about five to ten times more mercury is released into the atmosphere by electricity plants supplying the lamp power, than is present in the lamp. Moreover, the mercury in these lamps is easily recyclable. Since current mercury-free lamps are less efficient, there is no good alternative to the mercury-containing lamps for general lighting applications. Therefore it is important to understand how they work in order further to improve their performance.

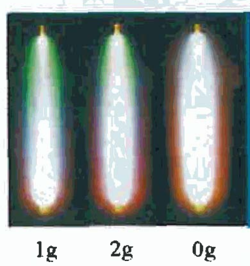
Color Separation

A metal halide lamp with color separation has different colors along its axis. As a result an object will appear differently depending on its illumination. For some applications this may not be a serious problem, but imagine if the fancy patterned shirt that you see in the mall appears to be plain white in the sunlight. Figure 3a shows an example of color separation in a lamp containing DyI_3. Whereas the bottom of the lamp is white with a reddish glow around it, the top is green.

The emission in the lamp results from excited species of the metal salt. Even though the partial pressure of the mercury buffer gas is constant over the discharge, a complex interplay of diffusion and convection results in a non-homogeneous distribution of the radiating metals. Let us concentrate first on the radial direction. Going from the wall at about 1200 K to the arc core at 5000 K metal halide molecules will first dissociate and then ionize. The resultant density gradients cause strong diffusion fluxes, which are counteracted by the back-diffusion of other species: near the wall molecules diffuse inwards and atoms outwards, while near the centre atoms move inwards and the ions diffuse out. Unfortunately, the diffusion speed of the molecules is significantly smaller than that of the atoms due to their size and mass difference. Ions and atoms have similar masses, but ions diffuse faster due to ambipolar diffusion. This is a typical plasma effect: the lighter and more mobile electrons in the plasma are coupled to the charged ions by Coulomb interactions. This results in an enhanced ion transport, away from the hot plasma regions. In a stationary state with equal inward and outward fluxes, a lower speed is balanced by a higher partial pressure. The total effect is called radial segregation and results in a reduction of the partial metal pressure (in any chemical form) near the lamp center.

In addition to diffusion, there is also convection in the lamp. In a horizontally operating lamp, convection will counteract the diffusion as it effectively "mixes" the various lamp species. Unfortunately, in horizontally operating lamps, convection will also lift the hot arc into the curved shape: exactly the process from which an arc discharge derives its name. Thus upward convection brings the hot plasma region close to the cold wall, which at best lowers the lamp efficiency and in worse cases causes lamp failure. To prevent this, most high-pressure lamps are operated in a vertical orientation. In vertically operating lamps, convection causes an upward flow in the hot central arc region, which returns downwards along the cooler walls [4, 5]. The minority metal salt species follow the dominant mercury convection flow. However, due to radial segregation the metal that rises in the centre diffuses outwards to the wall and is transported down. The combined effect of convection and radial segregation is a decreased metal density in the upper part of the lamp (fig. 3b). Such axial segregation results in a non-homogeneous emission, called color separation, shown in figure 3a. The effect has a maximum if convective and diffusive flows are of equal magnitude. High convective velocities result in a good mixing of species thereby eliminating radial segregation. In the absence of convection, the lamp emission will be axially uniform but radial segregation is maximal.

This explanation, first described by Fisher [6], yields a reasonable qualitative description of the effect. However, quantitative models, needed to increase lamp efficiency, are not available. Discharge calculations of diffusion and convection in complex reactive mixtures with high temperature gradients are difficult and many thermodynamic data are not known. In addition the electrodes, the lamp geometry and wall material also affect the lamp behaviour. Experiments are necessary to provide input data and verify any model results.



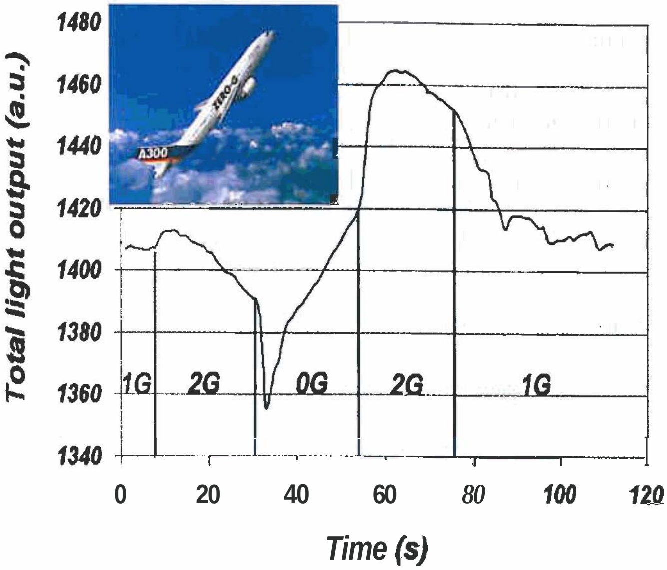
◀ **Fig. 4:** Pictures of a metal halide lamp during normal gravity, hypergravity and microgravity. The differences in the emission profiles are caused by a changing in the Dy distribution inside the lamp due to varying convection and diffusion flows.

Microgravity Experiments

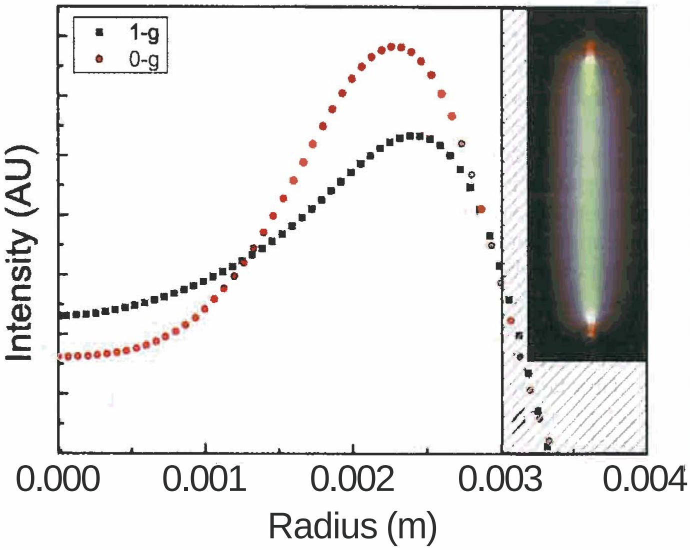
The previous discussion shows that diffusion and convection play a key role in understanding the lamp behaviour. To be able to unravel the complex interaction between convection and diffusion, extended experiments under zero gravity have been performed. In the absenc of gravity, convection is eliminated, so the effect of diffusion can be studied undisturbed and compared with the model results. Parabolic free falls in an airplane have been performed in an airbus of the European Space Agency (ESA) and extended microgravity experiments were done in the International Space Station (ISS). During a parabolic flight, a level-flying airplane pulls up strongly before closing the engines and going into a parabolic free fall for about 20 s. At the end of the parabola, a second strong acceleration is used to prevent the plane from crashing. The result is that the plane is subjected to a series of 1.0–1.8–0–1.8–1.0 g gravity conditions. During the hyper-gravity (1.8 g) phases, there is an increased convection, whereas there is no convection during the microgravity phase.

Figure 4 shows pictures of a test lamp during various phases of the parabolic flight. At normal gravity conditions the color separation is clearly visible, as the lower part of the lamp emits bright white light, whereas in the top part only weak mercury emission is seen. The lamp efficiency is measured by placing the lamp in an integrating sphere [7]. Such a sphere collects all lamp emission and determines the lamp efficiency by using an optical filter that imitates the human eye. The photographs in figure 4 show that segregation in the hyper-gravity phase is significantly less than under normal gravity conditions. This indicates that for this particular lamp increased convection results in a better mixing of the radiating metal species. The integrated sphere measurements (fig 5) confirm this as the total lamp emission increases during this phase. In the microgravity phase light emission is homogeneous in the axial direction. In this phase convection is absent so there is no axial segregation. Radial segregation dominates and depletes the central region of light emitting metal. This is visible in figure 5 as a decrease in the emission at the start of the microgravity phase. The subsequent increase is caused by an increase of the lamp temperature in the absence of convective cooling. A temperature increase results in a higher metal vapor pressure inside the lamp and thus a higher emission. It also shows that the 20 s of microgravity, available in an airplane, are insufficient to obtain a stable lamp. In order to study a fully stabilized lamp under microgravity conditions, measurements in the ISS are the only option. Under these conditions, there is no axial segregation and the lamp is completely homogeneous. Comparing spatially resolved spectral measurements from the ISS with those at normal gravity show a significant increase of radial segregation under microgravity conditions (fig 6). There is less metal in the center of the lamp as it diffuses outwards, resulting in a strong gradient of the partial pressure of the light emitting species. Obviously, these variations have a strong impact on the lamp emission and its efficiency. More details on the various measurements both under normal and microgravity conditions can be found in the references [8, 9].

It is currently beyond our capabilities to fully understand and model a commercial metal halide lamp with a complex shape and chemistry. Therefore, the measurements have been performed on a reference lamp with a simple geometry and chemistry. The absence of convection under microgravity conditions greatly simplifies the problem. The measurements reveal a great deal about lamp behaviour, which needs to be reproduced by any valid lamp model. Qualitatively the lamp behaviour is well understood and the measurements supply ample data for the quantitative validation of a model. In addition, the measurements clearly show that there is still room •••



A **Fig. 5:** Light output of a 10 mg mercury lamp with DyI_3 during a single parabola of an airplane. The light emission, measured using an integrating sphere, increases in the hyper-gravity phase. In the microgravity phase the emission decreases initially due to radial segregation but then starts to increase as more metal enters the lamp [7]. The inset shows the ESA plane during a parabolic flight (photo: ESA)



A **Fig. 6:** Light emission from excited atoms as a function of radial position in the lamp at normal (black squares) and micro-gravity (red dots) conditions. Due to dominant radial segregation there is less emission from the central lamp region under micro-gravity conditions. The microgravity measurements are performed in the international space station where the lamp shows no axial segregation as seen in the picture. The normal gravity data are taken with the same lamp just before launching. The data are reconstructed from spectrally resolved side-on measurements, which is reliable until the shaded area. [8]

... for efficiency gain. Obviously, changing gravity is not a practical solution, but it may help to identify how to optimize discharge parameters,so that we can light our world using less energy.

About the author

Winfred Stoffels did his PhD on experimental plasma physics at the Eindhoven University in The Netherlands.After a two year period at the University of Kyoto, Japan,he returned to Eidhoven studying dusty, electronegative and molecular plasmas. Currently his focus is on the physics of gas discharge lamps in order to obtain more efficient light sources.

Acknowledgments

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Surviving the sauna

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Human beings are not made for living in a 90°C environment. And yet this is the temperature in the average sauna. How do we cope with such harsh conditions?

First, we use a towel to sit on, or we touch wood. Touching metal at that temperature is no fun at all. Even the glass door feels hot, although its thermal conductivity is far below that of metals, and its temperature is only about 60°C, halfway between in and outside temperature. Second, the *air* is dry, which enhances cooling by perspiration. Incidentally, the dry air comes for free: Due to the steepness of the water vapour pressure curve, even if the outside *air* at, say, 20 degrees is 100 % humid, the humidity drops to 3 % once the *air* is heated to 90°C. If it freezes outside, that would even drop to 1 %, provided that no water is added.

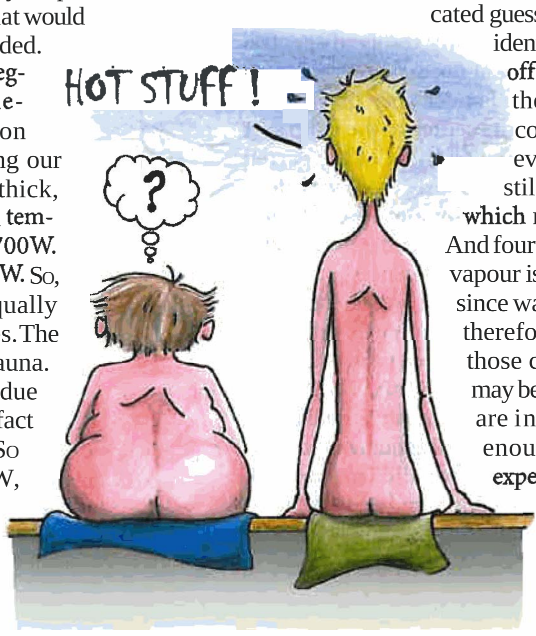
How fast would our body heat up, if we neglect perspiration? Let's do a back-of-the-envelope calculation. First the conduction term. Since the effective air layer surrounding our body can be assumed to be around 3 mm thick, assuming a body surface area of 1.7 m^2 and a temperature difference of 50K, we find some 700W. Likewise, the radiation term yields about 800W. So, conduction and radiation are roughly equally important, just like in normal circumstances. The difference is that they are reversed in the sauna. And they are an order of magnitude larger, due to the larger temperature difference and the fact that we have ..eh... adapted our clothing. So the total heat load on our body is 1,5 kW, which corresponds to the power of an electric heater! Tall people suffer extra, in view of the vertical temperature gradient.

How fast will our body start to heat up? Taking a fair estimate for the heat capacity of our body of 200 kJ/K, we find a heating rate of 0.5K per minute – as long as perspiration is negligible.

This is a sure way to disaster. So after a few minutes the sweating should begin. And it does, fortunately, even before we notice that our skin gets wet. Keeping up with the 1,5 kW heat load by sheer sweating would require 2.2 liter per hour. Our body will not be able to evaporate that much without forced *air* circulation.

Being physicists, we surely want to do a small experiment. Why not put some water on the stove, and see what happens? This makes us feel even hotter, and the question is why. Here is an educated guess. At least four contributions can be identified. First, the 100°C steam coming off the stove is somewhat hotter than the sauna air. Second, it causes forced convection, which will heat our body even more, particularly if our skin is still dry. Third, the humidity goes up, which makes perspiration more difficult. And fourth. the thermal conductivity of water vapour is slightly higher than that of dry air, since water molecules are a bit lighter (and therefore faster) than N_2 or O_2. Which of those contributions is the dominant one may be something to sort out next time we are in the sauna. After all, there is time enough to do some calculations and experiments.

But don't forget to keep an eye on the hourglass..



'Exploring matter with neutrons'

The role of large facilities in modern research is increasing both in quantity and quality. Despite their intrinsic negative aspects (organisation of the requests, filtering of the proposals submitted to scientific committees, slow evolution of the instrumentation), the possibilities opened by recent synchrotron sources, neutron sources or accelerators attract an increasing number of users from very different disciplines. A large part of the most important experimental results come today from these installations.

Very early on, about 60 years ago, E. Fermi and other pioneers realised that the properties of the neutron offered the prospect of a fantastic new tool to study the structure and the dynamics of condensed matter. The evolution of such studies confirmed their view and many neutron sources, some entirely dedicated to neutron scattering, have been built around the world, particularly in most of the main European countries. With the emergence of high flux reactors, substantial progress in instrumentation has been achieved, particularly at the European "Institut Laue-Langevin" at Grenoble. In the last few years the possibilities for neutron research have been extended with new sources either under construction or existing sources upgraded.

However, probably because their situation is often external to the academic sphere, the opportunity to utilise such large facilities is still ignored by a portion of potential users. Moreover, the teaching of most university courses on experimental physics reserves only a small place to them. In this context, any action in favour of a better knowledge of the possibilities existing in different European large facilities would be welcome and should be supported by national scientific authorities as well as at the European level.

The CD "Exploring matter with neutrons" produced by Nanopolis (issued from the Romanian company iMediasoft) with the collaboration of seven of the major neutron centres is intended to address all aspects of neutron research. It is one of a series of 3 CDs, the other two being dedicated to synchrotron sources and to nanotechnologies.

The CD content is divided into five sections: Science, Sources, Tools of Neutron Physics, Applications and a short presentation of the facilities which participated to the preparation of the CD. It is organised like an interactive encyclopaedia with many links that allow the clarification of a concept, the development of a theme or simply another direction in the consultation to be taken. Each page is illustrated either with a photograph or a short animation illustrating or exemplifying a short text explaining some notion or describing some technical aspect in a remarkably concise way. For example, the principle and operation of the spin-echo spectrometer is nicely presented with a short movie showing the Larmor precession of the neutron spin and the way the measurements are actually performed.

Alain Filhol, with 154 contributors
(Nanopolis, 2006, orders: http://www.nanopolis.net)

Each technical or scientific term appears in a different colour allowing one to see immediately its definition and the eventual developments related to it. Consequently, the organisation of the presentation is like a strongly connected network. The scientific level is not too high and remains always accessible to undergraduate students. Obviously, the purpose is to introduce neutron scattering in all its scientific and technical domains to potential users. Nevertheless, frequent users of neutron scattering facilities may benefit from the beautiful and concise presentation, even discovering some new aspects.

The CD goes a little beyond its announced scope and presents some short notices about historical features (including photographs of the main scientists) as well as side aspects of neutron sources, such as nuclear power plants and even a reference to the accident at Chernobyl.

There is also an English-French version of the CD. It is possible to jump at any time from one version to the other, keeping the same page, which may be useful for users interested in the respective spelling of technical concepts. Unfortunately, there are many mistakes and spelling errors in the French version. New editions need a careful revision of the translations.

Jose Teixeira,
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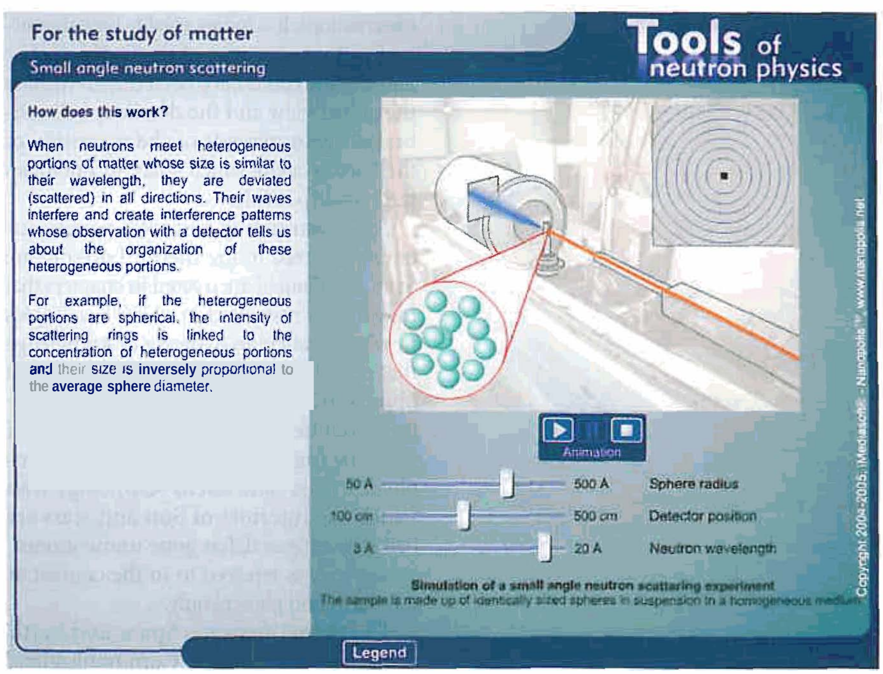
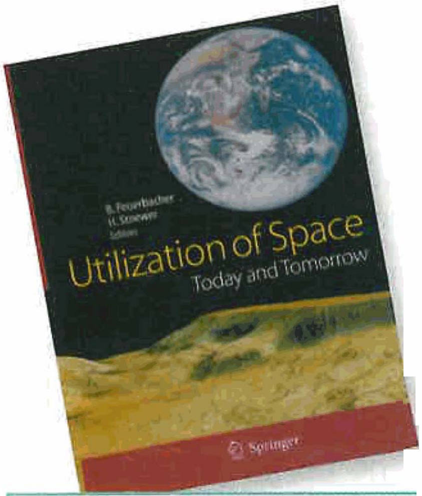


'Utilization of Space: Today and Tomorrow'



B. Feuerbacher and H. Stoewer, Eds.
Springer-Verlag Berlin Heidelberg
2006,410 pp., ISBN-10 3-540-25200-2

Today, we use robotic satellites as a matter of course. But fifty years ago, Sputnik, the first orbiting satellite, was a sensation. Under the then prevailing political circumstances it triggered a technological and scientific competition between the two major world powers. There was, to be sure, also a military motivation: building powerful and precise rockets. Nevertheless, early space endeavours led to well-publicised collaborative efforts between the two dominant powers, such as the Apollo-Soyuz mission, where American and Russian astronauts linked their space capsules in orbit. Less well noticed, numerous scientific collaborations across the Iron Curtain took place at the same time. The general topic 'Space' thus is attractive not only from a technical and scientific perspective; it has a political fascination as well.

The editor of the present book, Berndt Feuerbacher, is a physicist, Heinz Stoewer, his associate editor, is an engineer. They present their subject in about 400 pages with the help of a suite of eighteen, mostly German and Dutch, specialist authors. Bracketed between an introduction and a conclusion, both written by the editors, the main part of the book is organised into four main themes, namely 'Looking down: our Earth', 'Looking up: Stars and Planets', 'Between Space and Earth' and 'Space as a Laboratory'. The specialist authors cover each of these themes in a varying number of chapters. In reading the chapters belonging to the theme 'Looking down: our Earth' one realises how much Earth science has benefited from space observations. It is inconceivable how the current picture of change of the Earth's surface and climate could have been drawn without the global view and the detailed, well-calibrated measurements of characteristics of the Earth system, which space technologies have made possible.

Space astronomy and solar system sciences, covered in the theme 'Looking up: Stars and Planets: are treated in chapters that may be too restricted in size. These topics now cover such an expanse of knowledge that one of the more obvious astronomical objects, namely our Sun, has been nearly forgotten here. As a consequence, one of the more important modern tools of astrophysics, helio- and astero-seismology, with which the interiors of Sun and stars are being investigated, has gone unmentioned: seismology is referred to in the context of the Earth and planets only.

The theme 'Between Space and Earth' comprises two chapters: 'Communications' and 'Satellite Navigation'. They cover concisely, yet with adequate explanations the scientific and technical foundations as well as the applications.

What may be of special interest to the natural scientist is the theme 'Space as a Laboratory: In material and life sciences, use is made of an additional test parameter namely the reduction of gravity to insignificant levels — usually referred to as 'microgravity'. More specifically for physicists: today's space technology has reached a refinement, which offers 'picogravity' (i.e., residual gravitational perturbations of the order of 10^{-12} g only). This enables us to test fundamental principles and predictions of gravitational theory at a hitherto inaccessible level of accuracy. Hints could thus be found — for example, through proving the breakdown of current assumptions — that eventually might lead to unification of the three quantised forces with the still metric gravitational force. Such advanced space technology will also enable us to search for low-frequency gravitational waves.

The editors conclude the book with an outlook focusing on the human needs. Over the past fifty years, space exploitation has changed from a government- supported scientific (and prestige-driven) endeavour to a wide range of demand-oriented schemes with mostly dominant ground-based infrastructures. Requirements of commercial markets, military use and society needs dominate today, and begin to seriously squeeze funding for science. Science in space, however, continues to open new vistas and brings inspiration to humanity. It remains a true frontier.

This book, edited and written by thoughtful space experts, provides handy references for the professional. Yet it also offers well-presented information to the interested layman. Students in the many disciplines that make use of space infrastructures will also greatly benefit from consulting this compendium. The book is generously illustrated in colour. The introduction is presented in a tone that is agreeably free of the hype that usually marks publications on space. A list of abbreviations and space acronyms, presented in two columns over six pages, gives access to the space jargon, and an extensive keyword index helps to quickly find a specific topic of interest.

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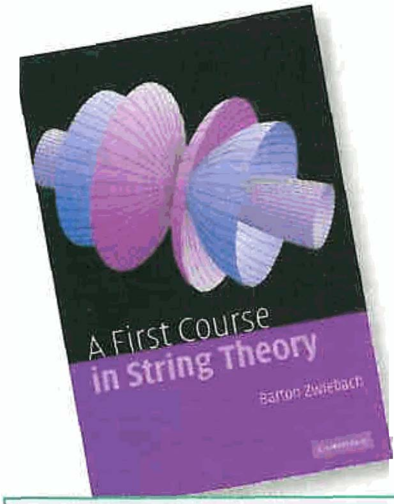
'A First Course in String Theory'



B. Zwiebach,
Cambridge University Press
2004, 578 pp., ISBN-13: 9780521831437

My point in the present review is that this book should be in every University library. I am aware that this statement may provoke the raise of some eyebrows but I do know that I am quite right in this recommendation.

Allow me first to point the merits of B. Zwiebach's book. It constitutes the most (i) pedagogical and (ii) self-contained presentation of String Theory, to both novices and seasoned experts. There are of course other books, like the three-volume by M. Green, J. Schwarz, E. Witten as well as the more recent two volumes of J. Polchinski or the books by M. Kaku and J. Johnson, thoroughly focusing on the fundamental principles and providing additional details and applications. However, only *'A First Course in String* Theory'brings together the benefits of (i)-(ii) above. It also distinctively conveys enthusiasm, clarity, and adequate care in introducing the area for non-experts. The book proves indeed that one can teach the basics and some (advanced) essentials of String Theory to undergraduates: From suitable analogies and invoking plenty of examples from other areas, B. Zwiebach explains the formalism with physical intuition, with plenty of helpful exercises (solutions, yet incomplete, can be found in a companion web site).

X *First Course in String Theory'* begins by bringing special relativity and electromagnetism within the domain of extra dimensions. This is a great idea: One can present that to students in their first years of any science course. The classical dynamics of relativistic strings follow. The quantization of open and closed bosonic strings is discussed, avoiding to stagnate the presentation with too much detail, unnecessary at this stage. Subsequently, the reader is prepared most adequately to other areas, where the full description can only be found, e.g., in the other books above cited: D-branes, string thermodynamics, T-duality of open and closed strings, Born/Infeld electrodynamics, covariant string quantization and string interactions.

A more sceptical reader may argue that String Theory suffers from a (rather relevant) weakness: There is (currently!) no observational register to support its results or principles. So, why buy or even read such a book? The point is that this may change in the next years at LHC or with satellite experiments/observations, *if* some glimpses of supersymmetry and/or extra spatial dimensions are identified. Moreover, String Theory provides solutions to so many intricate problems in theoretical physics (in particular, regarding the unification of interactions without divergences) that, even if it is not the 'final word' about it, surely it will be a most (if not a decisive) pertinent one.

Therefore, the reader of this review is strongly recommended to purchase (or suggest to his/her university library) the book *'A First Course in String Theory'*. Any updated and attentive physicist will not want to be left behind, without the awareness that String Theory would provide. For an economical (an e-book version is now available) self-contained and pedagogical introduction, *'A First Course in String Theory'* is the book for you, your library and your university.

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Book available for review

Concepts in spin electronics
S. Maekawa, Oxford Science Publications, 2006, 398 pages

Coherent X-ray optics
D. M. Paganin, Oxford Series on Synchrotron Radiation 6, 2006, 411 pages

Intense terahertz excitation of semiconductors
S.D. Ganichev, W. Prettl, Oxford Science Publications, 2006, 418 pages

Ludwig Boltzmann, the man who trusted atoms
C. Cercignani, Oxford University Press, 2006, 329 pages

Modern supersymetry, dynamics and duality
P. Weingartner, Springer 2004, 367 pages

An introduction to galaxies and cosmolology
J. Terning, Oxford Science Publications, 2006, 324 pages