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THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

Forum Physics and Society
Which Energy Policy for France?
Surprises in cycling aerodynamics
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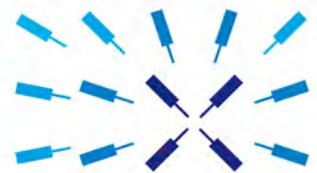
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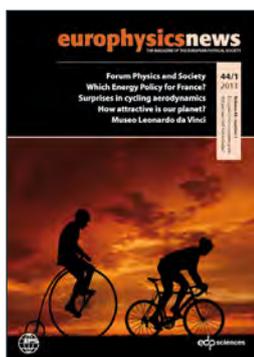
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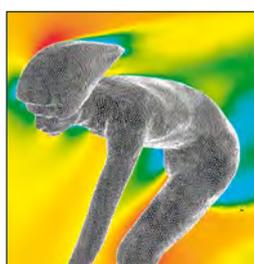
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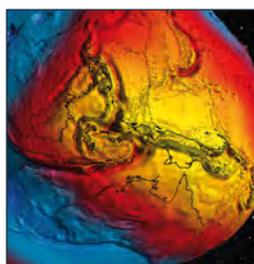
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Cover picture: Aerodynamic drag. See p.20 "Surprises in cycling aerodynamics"



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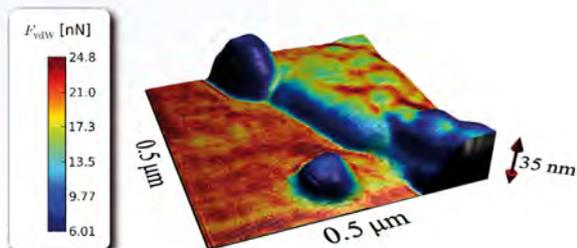
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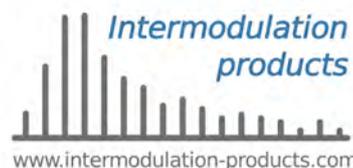
The van der Waals attractive force mapped on the surface topography. Step edge of a thin film of butylacrylate spin coated on silicon oxide.



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[EDITORIAL]

The European Physical Society is 45 years old

2013 marks the 45th anniversary of the EPS, sealing the maturity of our Society.

The EPS was founded in 1968 as "a demonstration of the determination of scientists to collaborate as closely as possible in order to further strengthen the European Cultural unity". Since then the EPS has grown, both in dimensions and objectives.

In the last two years, following the guidelines of its strategy plan, the EPS has been developing a number of activities and initiatives. You have been able to follow them in the e-EPS newsletter (www.epsnews.eu), as well as in the columns of this Europhysics News (EPN) magazine (www.europhysicsnews.org).

As for 2013, round the corner are the following:

- a report prepared for the EPS, upon its request, by an independent statistics corporation on the importance of physics in the economies of EU27 countries (plus Norway and Switzerland as two representative EFTA members);
- an EPS statement on the research and education opportunities for innovation concerning the new EU framework programme Horizon 2020 that is just about to be launched;
- the third E2C (European Energy Conference) that is foreseen in October 2013, in Budapest (HU), and jointly organized by EPS together with E-MRS and EuCheMS;
- the third ASEPS (Asia-Europe Physics Summit) that will take place in July 2013, in Japan, an EPS-AAPPS initiative focussed this time on the international strategic planning for large research facilities;

- the final declaration by the UN General Assembly of 2015 as the International Year of Light, under the continuous boost of the EPS, together with many other international/national societies and institutions;
 - the establishment of a new "EPS Women in Physics Award" that will be given in recognition of female physicists who show excellence in research and mentoring;
 - the entitlement along the year of (already!) six new EPS Historic Sites in: Warsaw (PL), Dubna (RU), Sasso Marconi (IT), Hafelekhar/Innsbruck (AT), Bern (CH), Debrecen (HU);
 - an EPS action, likely coordinated with other scientific societies like EAS, on the issue of open access for scientific publications, a question that is now boiling up worldwide.
- And this list is not exhaustive.

I would then like to invite you to take the opportunity of this 45th

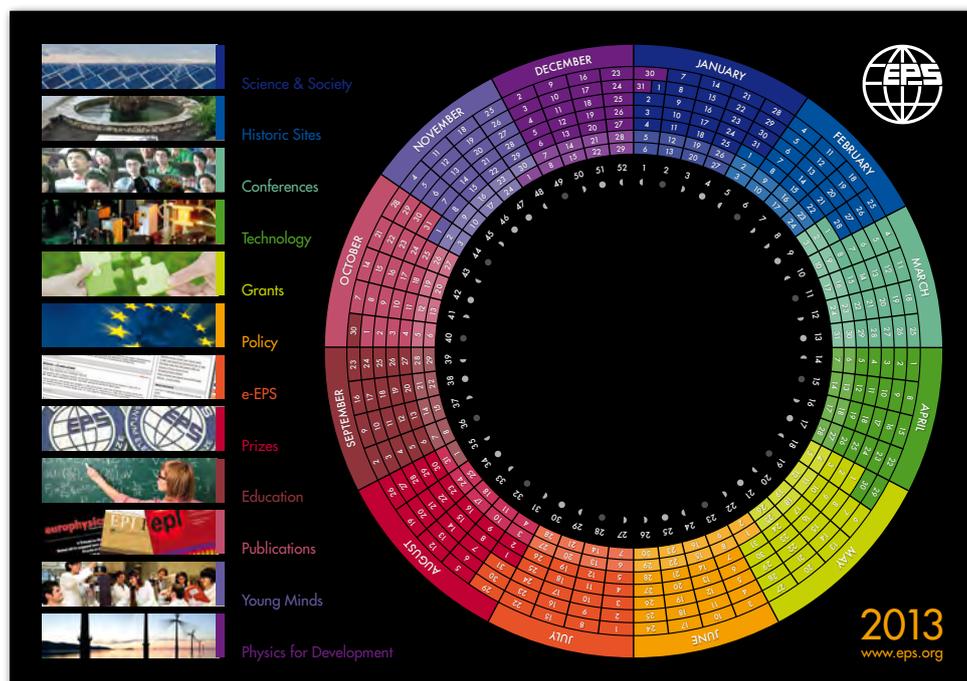
Let's enhance ideas and excellence in a coherently developing framework

anniversary celebration to promote actions, in your scientific field and in your national/local environment *etc.*, in favour of both physics and the community of physicists. There is a lot to say and a lot to be done, at all levels. Let's be proactive and demanding, let's make things happen concerning membership, prizes and awards, events and meetings, publications and opinion making, visibility and impact. Let's enhance ideas and excellence in a coherently developing framework. The political/social and scientific scenarios in Europe and worldwide are rapidly evolving. The EPS is at your service for research, education, dissemination, cooperation, outreach, spin offs *etc.* Please count on the EPS.

Happy New Year! ■

▼ The 2013
EPS calendar

■ Luisa Cifarelli
President of the EPS



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2010 to 2050: Which Energy Policy for France?

Energy is a major issue in today's political debate. However, the debate is very often dominated by preconceived ideas and irrationality, whereas policies should be based on facts and numbers. As a learned body, the French Physical Society wishes to participate in the public debate. Therefore, its Energy-Environment Committee has published a short book¹ aimed at providing factual information. Here is a summary of the book.

The committee addressed common issues of importance to most energy sources and vectors. Starting from the challenges that societies are facing, it investigated the responses technology provides for different political choices.

The book consists of two parts:

1. A brief review of energy systems and main trends of their evolution;
2. A set of 10 fact sheets devoted to different issues: resource availability, environmental impacts, hazards, cost, benefits and risks, intermittence management, grids, efficiency, mitigation of green-house gas (GHG) emissions in order to mitigate the climate change threat, long-term consequences of political choices.

Energy demand is driven first by an increasing world population that might reach 9 billion by 2050 (plateau or peak?). Other drivers are urbanization and the development of emerging economies (Brazil, China, India...). Looking at available data and forecasts, one may arrive at a three-fold conclusion:

1. By 2050, it will be difficult for the energy supply to match the energy demand anticipated from present trends. A mitigation of energy consumption is mandatory, first and

foremost in developed countries.

2. There is no such thing as a “silver bullet”, *i.e.*, a single technology whose use would solve all energy problems as they are expected to appear in the middle of this century, *i.e.*, match the needs while strongly reducing GHG emissions.
3. Unless a “degrowth²” policy is enforced, it will be mandatory to combine every available technology to match the required amounts at all relevant scales: region, country and the planet as a whole.

Most scenarios set up to describe the future as it might happen take the above statements into account. The gist can be summarized by the formula 3 × 50, translated as: 50 % more people on Earth, 50 % more energy consumption per capita worldwide, 50 % less GHG emissions. The primary energy production would be some 20 Gtoe (8.4×10^{20} J), with 75 % less carbon emission with respect to today's figures.

¹ Commission énergie-environnement de la SFP, *L'énergie en France et dans le monde. Quels choix politiques?* EDP-Sciences (2012)

² The degrowth theory is based on the hypothesis that economic growth – understood as constant increase in Gross Domestic Product (GDP) – is not sustainable for the global ecosystem. See *e.g.* www.degrowth.net

Gas and Electricity

According to the International Energy Agency (IEA) a “golden age of gas” could blossom by 2025 and last for a few decades. Natural gas is plentiful, is comparatively cheap, the more so if non conventional resources (such as shale gas) are considered, and emits significantly less carbon dioxide than other fossil fuels.

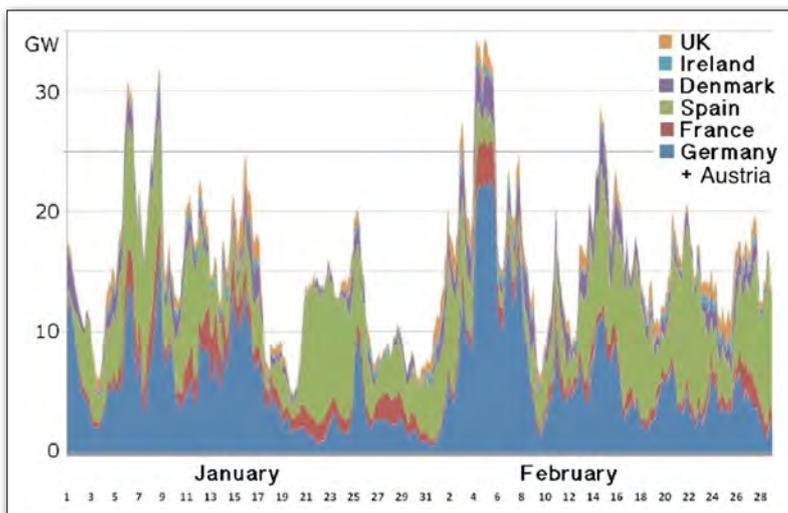
Beyond that, a “golden age of electricity” would be looming according to today’s trends. Electricity would be the dominant vector for energy transport and distribution. Contributions to such an evolution are: on the demand side, a growing number of technologies which need electric power, and on the supply side, new energy sources such as wind and solar that are mainly aimed at producing electric power.

A multi purpose energy transition is already underway: less carbon in order to mitigate GHG emissions; growing share of electricity in energy distribution; better efficiency (with a special emphasis on residential and tertiary sectors) which should eventually contribute to a lower demand ; improved energy systems safety.

Renewables

An increased share of renewables is already visible in energy production. However, some drawbacks are to be overcome. For instance, wind and to a lesser extent solar power are randomly variable which appears as a major concern. Managing intermittency in electricity production is a challenge of paramount importance. As displayed in the figure, the wind power productions from different countries of Western Europe do not complement

► Windpower in Western Europe as recorded in January-February 2011 (after H. Flocard and J.P. Pervès). Power delivered by wind farms in different countries were superimposed in order to set up this graph. Peaks and low production periods usually occur at the same time all over Europe. Spain with a more regular wind regime is a remarkable exception.



each other. Storage and/or backup will be necessary in order to match supply and demand.

The evolution of energy systems is a slow process, a point emphasized by the committee. The history of technologies shows that energy substitution takes time, *e.g.*, oil overtook coal as mankind’s main energy source in a span of about 50 years during the 20th century. Indeed, organizations dealing with energy carry inertia, the more so when the delivered or the consumed power is large. Now, demand is increasing and concentrates in large urban areas. Accordingly, dams, nuclear power plants, wind and solar farms are getting larger and larger. Transport and delivery grids grow in power and range. Many years are necessary for the implementation of such huge projects. In the future, a great deal of research and development will be required over long periods of time in order to ensure the necessary diversification of power sources and energy transport.

On the political side this leads to a recommendation and a caveat. Today’s

decisions have consequences for decades to come. Energy policies should be conceived and implemented over long periods of time. This is incompatible with both the short-sightedness of many financial institutions and the instability that would result from opposing decisions due to political changes following democratic elections.

Six scenarios

Societies are facing upcoming fuel shortages and the threat of climate change. There is little room for errors. However, proposed credible scenarios differ considerably from one another. For France, six major families can be identified whose main features are displayed in the table. They are derived from possible policy choices, from business as usual (BAU) implying undesirable environmental consequences, to enforced energy consumption reductions with potential negative effects on the economy. Some of them combine an economic growth relying on a plentiful energy supply with greenhouse gas mitigation by a factor

LETTERS TO THE EDITOR - AN INVITATION TO EPN READERS

EPN readers are invited to send letters and comments expressing their views to the Editors of EPN.

Our aim is to open a “Letters to the Editor” section, and your help is needed. Your opinions on topics related to Europhysics News, to the EPS or to Physics in Europe would make your magazine more open, controversial and lively. The editors want

to make this a regular section and need your contributions. Letters and opinions to be included in the section should be sent to Claude Sebenne, Claude.Sebenne@impmc.upmc.fr. Please include your full name and affiliation. Please note that the editors reserve the right to accept or not, and to shorten your submissions. ■

	Data for 2010	Inferred data for 2050					
		1) BAU	2) Moderate	3) with nuclear	Restrictive		6) Factor 4 négatœ*
					Nuclear free		
					4) golden age of gas	5) négawatt 2011	
Electricity TWh	450 +50 (export)	900	675	450	450	300	990
Heat (excluding electricity) Mtoe	78	110	73	49	49	35	57
Mobility (excluding electricity) Mtoe	54	75	50	33	33	22	
Total final energy Mtoe	170	271	180	120	120	85	150
Total primary energy Mtoe	266	420	261	175	153	90	279
Primary energy per capita toe	4.4	7	4	2.7	2.3	1.4	4.2
GHG emissions Mt C/yr	115	173	85	38	90	< 10	30

* in French: negatœp, see text

of 4, a target France is committed to, following the recommendations issued by the Intergovernmental Panel on Climate Change (IPCC) regarding developed countries.

In table 1, data are given in 7 columns. The first one refers to the year 2010. The 6 others display estimates by 2050. Each column corresponds to a given family of scenarios derived from policies that could be initiated in the 2010s.

1. In the business as usual (BAU) scenario, 2010 trends steadily prevail during the entire period. Energy consumption, and CO₂ emissions as well, undergo a significant increase as compared to 2010 figures.
2. A “moderate” policy aims at zero energy consumption growth except for electricity which would increase by 50%. Electrically powered transportation is boosted. Emissions decrease by roughly 30%.
3. More restrictive policies imply 30% energy savings in heat production and mobility while electric energy consumption goes back to the 2010 level after reaching a maximum.

▲ Options for an energy policy in France. The abbreviation ‘toe’ is used for ‘tons of oil equivalent’.

- Emissions are reduced by a factor of about 3, provided nuclear power plants are still running.
4. In a first option for a nuclear-free policy, electric power is still mostly provided by fossil fuels (“golden age of gas”), since renewables are unable to match the demand. CO₂ emissions decrease by 20% only, unless Carbon Capture and Storage (CCS) is implemented on a large scale.
 5. Another nuclear-free policy implies a major role of renewables combined with strongly enforced energy savings, which include significantly reduced transportation of goods and persons. GHG emissions mitigation by a factor larger than 4 is obtained thanks to a massively reduced energy consumption, including electricity (the “négawatt”³ scenario, where négawatt refers to non-consumed energy). This policy implies drastic changes in people's lifestyle, a

necessary condition to achieve such a profound energy revolution.

6. GHG emissions mitigation by a factor of 4 that does not preclude economic growth is the aim of the “négatœ” (in French “negatœp”⁴) scenario. It involves both the same increase of electrical energy consumption as BAU and the same total heat + mobility (electricity excluded) as négawatt. Nuclear plants (75% of power production) and renewables provide carbon-free electricity, whose applications extend to housing (heat pumps) and electric or hybrid vehicles.

Basically, only today's technologies are considered in the scenarios. This conservative approach suffices for a short time, typically until the middle of the century. However, although it seems unlikely, new technologies that we are unable to imagine could appear and penetrate the market within a few decades. ■

■ Jean Louis Bobin,

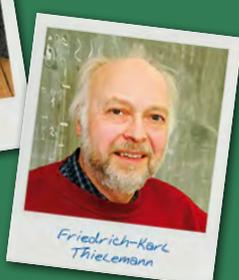
French Physical Society

Chairman, Energy Environment

Committee of the French Physical Society.

³ Scénario négawatt 2011, www.negawatt.org

⁴ Cl.Acket & P.Bacher, Le scénario Négatœp, *Futuribles* n° 376, Juillet-Août 2011, p.61, download at: <http://dx.doi.org/10.1051/futur/37661>



EPS-NPD LISE MEITNER PRIZE 2012

The Nuclear Physics Division of the EPS has given its Lise Meitner Prize 2012 to **Karlheinz Langanke** and **Friedrich-Karl Thielemann**, for their work on “Supernovae, Weak Interactions, and Formation of

the Heaviest Elements”. They have kindly accepted to write a feature for Europhysics News where you will have a clear view on their beautiful work. It will come in an EPN issue of the first 2013 semester. ■

Forum Physics and Society

Physicists in the market place: strengths and weaknesses of being a physicist

The Forum Physics and Society (FPS) of the European Physical Society (EPS) aims to support a more active EPS role in the relationship of physics to society, taking seriously the challenge of maintaining a strong and critical dialogue between physicists and decision makers. Workshops and meetings organised by the FPS bring together decision makers and physicists to discuss issues related to physics and society.

GENERAL REPORT

The fifth Forum Physics and Society took place at CERN, 28 – 29 March 2012. The meeting brought together 45 physicists from universities and industry as well as economists and political scientists from 18 countries. The forum discussions focused on “physicists in the marketplace”, emphasising three themes: (i) opportunities and threats of being a physicist, (ii) the global challenge and (iii) scientific social responsibility – is physics prepared?

Invited keynote speakers from the “marketplace” supported the discussions by in depth analyses of selected issues. Invited speakers included physicists involved in policy making on the national and European levels, physicists with experience in industry, health, and finance as well as management and business experience.

After the presentations of the three topics, including lively debate and discussion, working groups drafted recommendations that contained a common core of issues to be considered by EPS. Overall, this workshop identified concerns deriving from future global trends and their impact on the physicists of tomorrow. In particular, it is worth considering how such trends can be integrated into future PhD programmes, so that students are correctly prepared for the realities of the world that they will encounter when they launch their careers after many years in the educational system.

▼ Some members of the Board (B) with two invited guests (I). Left to right: Ana Prykova (B, Bulgaria), Ove Poulsen (B, Denmark), Gerardo Delgado-Barrio (B, Spain), Moriyama Kazushige (I, Moriyama Development Inst., Izumo, Japan), Vivekanandan Paramu (I, SN College, Kerala, India) and Martial Ducloy (B, France)

Trends

The following trends were considered as deserving special attention by the Forum:

1. The growing importance of anticipating, analysing and addressing global challenges in such areas as health, energy, environmental protection, food security. Characteristically, these issues are complex and multidisciplinary, combining phenomena that are in the realms of the natural sciences (e.g., physics, biology) and the behavioural sciences (e.g., sociology, economics).
2. The ever-closer connection between basic and applied research, with industrial enterprises seeking to take advantage of cutting edge science and technology (e.g. materials, algorithms) for creating new products via accelerated processes of worldwide innovation and competition.
3. The increasing competitiveness, diversity and unpredictability of individual career paths, allowing (or forcing) individuals to take more responsibility in planning and managing their personal and professional lives.

Overall recommendations

FPS recommends that national physical societies and physics institutions focus on issues where they themselves have responsibility and thus adopt a more proactive role.

The traditional physics curricula at European and North American universities, which evolved throughout the twentieth century, are not well suited to a world that is strongly affected by the above trends. Accordingly, a well thought out process of adaptation should be undertaken, with the participation of all concerned stakeholders, including physicists’ professional societies. The Forum has identified the following elements of desirable educational and curriculum reform:

- a. More emphasis on the study of complex, open, dynamic systems – either purely physical ones, or those combined with engineering, social and behavioural sciences (e.g., “smart” electrical power grids, urban environments, climate models, ecosystems).
- b. Greater exposure to complex problems in areas other than physics (e.g., chemistry, biology, economics, sociology).



- c. More exposure to the industrial and commercial world in preparation for employment. Experience in industry should be long and intense enough to increase skills for teamwork, communication, innovation and user-oriented solutions. Better understanding of general engineering skills, including best practice in patenting, copyrighting and licensing procedures should be encouraged.
- d. More international experience, including multi-month residence in diverse cultural and linguistic settings.
- e. More attention to early career counselling, planning and management, especially on the part of faculty advisors and university administrators.

Physicist in the market place

Physicists perform comparatively well in the market place. According to data on Italian physicists (see p.09), this is due to the quality of the students in physical sciences (including their good educational and socioeconomic backgrounds, their strong intrinsic motivations) as well as to the quality and selectivity of the curricula in physical sciences. The high learning potential of physicists means that they are **flexible** and well suited to enjoy the fruits of lifelong learning. Thus, physicists' skills are effective in a wide range of job opportunities, *i.e.* jobs outside basic research and education that graduates tend to favour.

Main strengths of being a physicist:

1. strong skills in problem solving and modelling,
2. strong intrinsic technical and cultural motivations,
3. effective skills in "conventional" as well as "non-conventional" occupations *e.g.* in policy making, business, consulting, *etc.*

Main weaknesses of being a physicist:

1. "cultural barriers" in pursuing and appreciating job opportunities outside research and education. Two reasons for this were identified: (a) the educational system has biases relating to the

perceptions of what it means to be a "physicist", and the individual's aspirations for her/his career path; and (b) information on the wide spectrum of potential jobs is lacking,

2. graduates in physical sciences possess comparatively poor transferable (soft) skills (*i.e.*, team work, communication, business and entrepreneurial skills),
3. academics are not very willing to spend time and effort to interact with the outside world and to decode their research in terms of potential industrial applications (the *ivory tower syndrome*),
4. underrepresentation of women in the profession.

How can these recognised weaknesses be addressed without giving up the classical strengths of being a physicist? In other words, how can one improve job opportunities and job satisfaction and, at the same time, highlight the social value of research and physics education. The Forum agreed on the following specific recommendations.

Recommendations and a Proposal to EPS

1. Encourage universities to design appropriate curricula that take into account national, institutional, economic and social contexts; the EPS should review these different curricula and disseminate best practice in this area.
2. Encourage universities to offer students opportunities for development of transferable (soft) skills.
3. Encourage universities to improve orientation and job placement activities.
4. Knowledge transfer to society needs to be more efficient, which requires that universities, researchers and students be aware of the issue.
5. Entrepreneurial skills and opportunities for physicists need to be promoted.

Best practice is fundamental for realizing these recommendations!

The Forum Physics and Society therefore proposes that EPS – being the unique platform for this purpose – undertake a review of such best practices together with its member societies throughout Europe.

Experience in industry should be long and intense enough to increase skills for teamwork, communication, innovation and user-oriented solutions

Recommendations and proposals regarding scientific social responsibilities

Science is a powerful force catalysing major changes in society. The traditional attitude of academic scientists has been to keep society at arm's length, leaving it to reap the benefits of basic science, and distancing themselves from the discussions on consequences of scientific discoveries. If such behaviour could be defended in the past, the tremendous impact that science currently has on our daily lives requires that research scientists concern themselves with the potential benefits and risks of scientific discoveries.

This has raised the question how scientists (and physicists) can enlarge their fields of study to respond better to society on issues like:

- the general public and the societal return of investment in science,
- the science educational challenge (young students, their parents and gender issues),
- the need for innovation, which is the basis of a flourishing economy and job creation,
- general public issues, such as the scarcity of resources, environment, economic and political stability, education, aging and population growth, *etc.*

The general public hopes and expects that physicists can help in solving global challenges. Generally physicists have not been responsive enough, hiding behind the long-term contributions of basic science to the economy. Unfortunately, outreach activities practiced by professional physicists are most often not fully appreciated, either by their peers, or by their institutions.

- **The public funding agencies as well as the physics community itself must learn to value such outreach activities and recognize the importance of these activities in the public understanding of physics.**

Added to this is the low interest in studying science, particularly for physics (as the studies are long, career opportunities are not well explained, physics is viewed as a difficult discipline). Physicists need to be made aware that outreach activities are essential to attract the next generation of physicists and the way they communicate about physics needs to change.

- **Physicists should stimulate educational and outreach actions like “La main à la pâte” in France, where parents are encouraged to be more open to the wide choice of scientific studies for their children.**

Concerning the other main “payback” mechanism to society, industrial innovation plays a central role. Physicists who have traditionally focussed on basic science must engage more deeply in the innovation process and

demonstrate the specific benefits of physics. Clever physics students and graduates should be encouraged to bring their analytical abilities to the market place. Ties between academic and industrial physicists should also be strengthened.

Another element of scientific social responsibility deals with the image of physicists – still coloured by the past atomic and nuclear events (bomb, nuclear power plants accidents). Unfortunately physicists might partly be blamed for accidents like Chernobyl and Fukushima, and the public cannot fully understand these events without explanations from the scientific community. As individuals and members of the profession, physicists should take responsibility (obligation) to change this image through specific actions directed in particular towards young people. Actions of this

Physicists need to be made aware that outreach activities are essential to attract the next generation of physicists

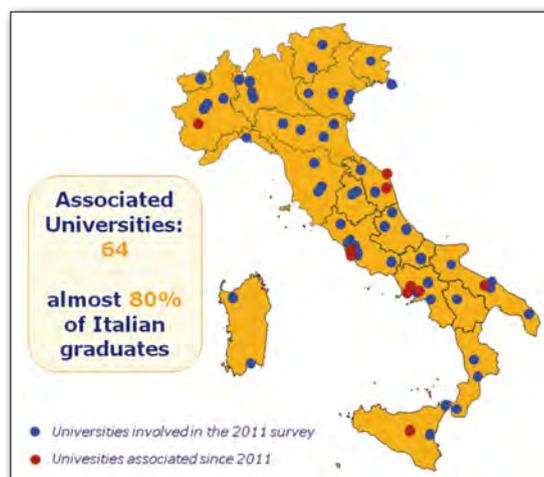
type must comprise a “physics point of view”, suitably blended with a keen understanding of societal complexity. Changing the public’s perception would also help physicists working in other fields *e.g.*, in health care, energy production and distribution, information technologies, nanotechnology, insurance and financial analysis and last but not least in education.

- **To stimulate such developments and get a better vision on scientific social responsibility, the Forum recommends establishing an Ethics commission within EPS with participants from various fields.**
- **Physicists should engage with the media and undertake Public outreach activities to enhance the image of physics and its contribution to society. ■**

■ The EPS-FPS Board

ALMALAUREA IN ITALY

The European Physical Society, on the behalf of its president, Luisa Cifarelli, organized a meeting at CERN on March 2012 to discuss the performance of *Physicists in the market place*¹. On that occasion, participants from different countries had the opportunity to compare their experiences and to envisage actions to improve physicists’ employability and job satisfaction in light of the long-term economic and technological scenarios confronting the profession. The starting point of the discussion on the *strengths and weaknesses of being a physicist* was the presentation of the unique statistical documentation provided by AlmaLaurea on the typical profile and labor-market performance of Italian physicists. AlmaLaurea is a consortium of 64 Italian Universities (it covers almost 80% of Italian university graduates, see Figure 1), founded in Bologna in 1994, which serves the demand for timely and reliable statistics on the outcomes of higher education, and which works to facilitate smooth university-to-work transitions



for Italian university graduates. AlmaLaurea conducts two-yearly surveys with response rates ranging between 75% and 90%: the survey on graduates’ profiles collects information with which to assess the *internal effectiveness of higher education institutions* (graduates’ educational and socio-economic background, academic career, satisfaction etc). The surveys carried out on graduates’ occupational status 1,3 and 5 years after graduation collect essential information with which

to assess the *external effectiveness of higher education institutions* (graduates’ wages, job satisfaction, degree efficacy etc.).

AlmaLaurea’s documentation on the typical profile of physicists and their performances in the marketplace is a good benchmark in that the latter appear to be quite representative of most European countries.

Put briefly, the features that seem to distinguish physics graduates are their strong quantitative skills and their high learning potential. This implies that physicists are very versatile and able to benefit from lifelong learning. Most importantly, the data show that physicists’ skills are effective across a wide range of applications and that there are job opportunities outside the typical employment sectors, *i.e.* basic research and education, that graduates

▲ FIG. 1: Geographical distribution of the Italian universities associated in AlmaLaurea

¹ On this theme, see also: A. Cammelli, L.F. Donà dalle Rose and G.P. Mignoli, The statistical profile of a physics graduate, in H. Ferdinande & A. Petit (a cura di), *Inquiries into european higher education in physics*. Proceedings of the second EUPEN General Forum 98, volume 2, Universiteit Gent, 1999.

	Physicists (II level, master degree)	All graduates (II level, master degrees)
Parents' educational attainment (at least one parent with tertiary education)	48%	29%
Secondary school: lyceum	87%	57%
Secondary school final grade	93/100	85/100
Motivations: cultural factors	61%	30%

▲ TAB. 1: Graduates' educational and socioeconomic backgrounds (2010 graduates)

▼ TAB. 2: Graduates' academic performance (2010 graduates)

	All graduates	Graduates in physics	Other degrees in sciences
Employment rate	88.4	93.6	89.5
Unemployment rate	9.8	4.6	7.6

in physical sciences are likely to find satisfying.

Why do physicists perform comparatively well in the marketplace and what are their comparative advantages? According to AlmaLaurea data on Italian physicists, the main reasons are the quality and selectivity of the curricula in physical sciences and the quality of the students: physics graduates have more favorable educational and socio-economic backgrounds (*i.e.* educational and socio-economic backgrounds with which are associated more favorable learning outcomes) and an intrinsic motivation to pursue their studies, which is stronger than that of other graduates (see Table 1). Hence, the quality of the human capital input (Table 2) and the quality and selectivity of the university curricula seem to explain physicists' good performance in the labor market (Table 3).

However, there are also some minor weaknesses of being a physicist. Physicists seem to be affected by *cultural and psychological* barriers in pursuing

and evaluating job opportunities outside research and education; this may be for two main reasons. First, education shapes and biases physicists' identity and aspirations; second, physics graduates often lack information about job opportunities available outside research.

The lack of knowledge about job opportunities is also the outcome of a lack of communication with the business world: in general, people involved in basic research are not particularly willing to spend time and effort on interacting with the outside world. As a consequence, they often fail to decode the output of their basic research activity in terms of potential commercial applications (the *ivory tower syndrome*).

Also to be stressed is that physics graduates seem to possess comparatively poor soft skills (team working, communication skills, entrepreneurial skills) which are highly appreciated by firms and market-oriented organizations.

▼ TAB. 3: Labour market performance. Pre-Bologna Reform (2001) graduates, 10 years after graduation

	I level (B.A. level)		II level (Master level)	
	Physical sciences and technologies	Total	Physics	Total
Share of graduates having attended at least 75% of their classes	86.8	68.3	90.3	71.8
Share of graduates completing their studies on schedule	50	38.3	52.9	47.5
Age at graduation	24.1	25.9	25.9	27.5
Graduation grade (max= 110; cum laude =113)	103.9	100.6	110.6	108.1
Share of graduates satisfied with their studies	90.7	86.4	95.1	88.1
Would you enroll again at the same university and degree course? (%)	78.2	66.3	84.6	73.9

But, how can educational institutions, governments, and EPS itself address the latter weaknesses without relinquishing the strengths of being a physicist? In other words, how can one improve the knowledge of physicists about job opportunities, and thus their job satisfaction, and the recognition of the social value of research and education in physical sciences? The EPS Meeting held at CERN put forward a set of general and specific recommendations to stakeholders and to the EPS itself in regard to these points.

- **Recommendation 1:** Design appropriate curricula in physical sciences so that student experience of the applications of physics is broadened.
- **Recommendation 2:** Improve graduate transferable (soft) skills in order to improve student employability
- **Recommendation 3:** Improve career advice and guidance and university job placement services
- **Recommendation 4:** Make knowledge transfer from university to society more effective and efficient
- **Recommendation 5:** Promote and support scientific and science policy entrepreneurship of physicists
- **Recommendation 6:** Establish appropriate reward and recognition processes in academia so as to encourage the uptake of best practices. ■

■ **Andrea Cammelli**

Università di Bologna, Founder and Director of AlmaLaurea

■ **Francesco Ferrante**

Università di Cassino e del Lazio Meridionale and AlmaLaurea Scientific Committee.



EPS HISTORIC SITES

Laboratory 'Les Cosmiques'

Col du Midi, Chamonix, France

The 23rd July 2012 was an historical day for the EPS as well as for the town of Chamonix in the Haute Savoie of France. Seven astronauts from the Endeavour Space Shuttle mission STS-134 arrived in Chamonix to be part of the 100 years celebration of the confirmation by Nobel prize-winner Viktor Hess of the extra-terrestrial origin of cosmic rays. Chamonix subsequently played a significant role at the Laboratoire des Cosmiques, among the glaciers high above the town of Chamonix.

The EPS Historic Sites committee had prepared a plaque to mark the event, with a citation which reads as follows. In 1943, during the war, here at 3613 m above sea level, the French CNRS-National Centre for Scientific Research established a high altitude laboratory under

the aegis of Louis Leprince-Ringuet to study the cosmic rays and their applications in nuclear physics. In 1946, the laboratory was inaugurated in the presence of Irène Joliot-Curie and continued to be operated until 1955. High voltage lines suspended above the glaciers supplied the

necessary electric power. "This is how up there – in the words of Leprince-Ringuet – *in really sporty conditions, with an electric cable, a local electricity power source, some electron counters, a small Wilson apparatus, we managed to study particles from cosmic radiation ...*"

▼ STS-134 astronauts (left to right) Mark Kelly, Roberto Vittori and Gregory Johnson holding the EPS commemorative plaque at the 'Refuge des Cosmiques' (Image: Mike Struik/CERN)



What linked the astronauts to Chamonix? The answer lies in the Alpha Magnetic Spectrometer (AMS-02) payload which the shuttle mission flew up to the International Space Station on 16 May 2011, on its last flight. The AMS is the latest in a long line of spectrometers to study cosmic rays, taking progressive advantage of the reduced attenuation in the upper atmosphere, from short balloon flights, through high altitude installations and finally to the multi-decade programme of the orbital AMS. The spectrometer in the Refuge des Cosmiques was one of the first terrestrial high-altitude installations. A Wilson chamber was combined with a magnet requiring a 55kW DC supply. The research post had been constructed in the most severe conditions, often requiring back-breaking transport of tons of material over the glacier. Many decades later, the AMS-02 itself had been partly constructed at CERN, thereby creating the synergy of this event between AMS, CERN and Chamonix as well as the EPS.

The day began early on an exceptionally glorious morning, gathering the astronauts, some of their family (the singular is appropriate since it was obvious that this was one big extended family) at the foot of the Téléphérique des Aiguilles du Midi to equip the astronauts for the rigours of these altitudes. The group took up the EPS commemorative plaque, shown in the photo with the citation. It was accompanied up to the summit by Jo Lister, representing the Executive Committee. Three of the astronauts braved the exposure of the Arrête des Cosmiques and descended to the Refuge des Cosmiques which is a very short distance from the abandoned hut housing the original cosmic spectrometer. The remainder of the party took a spectacular ride across the glaciers to Heilbronn and back. There had been an impressive media coverage preceding the event and a public lecture took place in Chamonix in the afternoon, to celebrate the visit by the astronauts and the inauguration of the

EPS plaque. A packed auditorium heard an inspiring scientific presentation by Prof. Maurice Bourquin of the University of Geneva, explaining the history and importance of cosmic ray research. A film of life on the International Space Station followed, underlining that it is impossible to become bored with the amazing images of and taken from the ISS. A long question and answer session, in which the astronauts had agreed to field all sorts of questions from the audience, exposed both the interest and the scientific culture of the local attendees.

The EPS warmly recognises the Commune of Chamonix, the Compagnie des Guides de Chamonix and the Compagnie du Mont-Blanc, Chamonix for their contributions to the success of this exceptional day, and above all recognises the overall organisation of the event under CERN hospitality. ■

■ Jonathan Lister

CERN, Member of EPS Executive Committee



International School on AstroParticle Physics

European Doctorate School

Neutrino Physics and Astrophysics

LSC, Canfranc-Estación - July 14 - July 23



Lectures will cover: Introductions to the Standard Model and to Cosmology, Neutrino Phenomenology, Neutrinos and Cosmology, Neutrino masses from beta and double-beta decays, Theory of Neutrino Mass, Neutrinos from the Earth, the Sun and Supernovae, Neutrino experiments at reactors and accelerators.

The lecture courses will be complemented by a few specialized seminars.

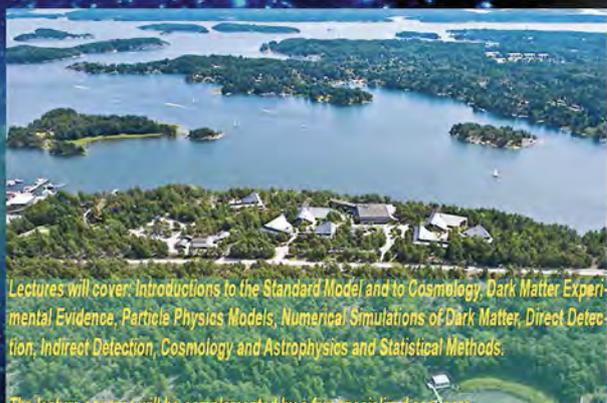
Local organizing committee: L. Baudis, G. Bellini, G. F. Bertone, A. Bettini, G. L. Fogli, A. Ianni, J. A. Villar, M. Pimenta

Local secretariat: A. Calvo, Y. Labarta, S. Fernández, A. Bayo

More information: isapp2013@lsc-canfranc.es - <http://www.lsc-canfranc.es/isapp2013/>

Dark Matter Composition and Detection

Djurönäset, Stockholm - July 29 - August 6



Lectures will cover: Introductions to the Standard Model and to Cosmology, Dark Matter Experimental Evidence, Particle Physics Models, Numerical Simulations of Dark Matter, Direct Detection, Indirect Detection, Cosmology and Astrophysics and Statistical Methods.

The lecture courses will be complemented by a few specialized seminars.

Local organizing committee: L. Bergström, C. Clement, J. Conrad, J. Edsjö, C. Fransson, A. Goobar, K. Hultqvist, A. Krislock, E. Moretti, S. Nobili, M. Pearce, J. Strandberg, S. Strandberg, K. Eitel - KIT Karlsruhe, N. Fornengo - Torino University, C. Muñoz - Universidad Madrid

More information: isapp2013stockholm@gmail.com - <http://okc.albanova.se/isapp2013stockholm.html>

Scientific Committee: G. Bellini (Milano University) - L. Bergström (Stockholm University) - A. Bettini (Laboratorio Subterráneo de Canfranc) - J. Blümer (KIT Karlsruhe) - K. Eitel (KIT Karlsruhe) - G. Fiorentini (Ferrara University) - G. Fogli (Bari University) - N. Fornengo (Torino University) - M. Gerasi (Milano Bicocca University) - J. J. Hernández (IFIC/CNIC-Valencia Univ.-RENATA) - M. Kachelriess (Trondheim University) - A. Kouchner (APC Paris 7) - H. Kraus (Oxford University) - M. Lindner (MPIK Heidelberg) - A. Maier (Padova University) - E. Meroni (Milano University) - G. Miele (Napoli University) - C. Muñoz (Universidad Autónoma de Madrid) - Y. Nir (Weizmann Institute) - L. Oberauer (TUM Munich) - M. Pallavicini (Genova University) - L. Perasso (INFN Milano) - P. Prozza (Roma Tor Vergata University) - G. Raffelt (MPI Munich) - S. Ragazzi (Laboratori Nazionali del Gran Sasso) - B. Saghai (CEA Saclay) - M. Skorkhvatov (RRK Kurchatov Laboratory) - O. Smirnov (JINR Dubna-Moscow) - S. Stancic (Nova Gorica University) - T. Suomijari (Orsay) - J.-P. Tavernier (LPNHE Paris) - S. Trottsky (INR) - J. Valle (IFIC/CNIC-Valencia University) - E. Zas (Santiago de Compostela University)

Scientific Committee Coordinator: G. Fogli - Bari Univ.

The two Schools will cover in a complementary way the above topics with regular courses and a few specialized seminars. Participation to both the Schools is suggested, but application to only one School is accepted. Details on the specific programs will be given in the web sites of each School. Support to travel and/or living expenses is available; requests have to be sent to the email address of each School, together with a short C.V.

Highlights from European journals

APPLIED PHYSICS

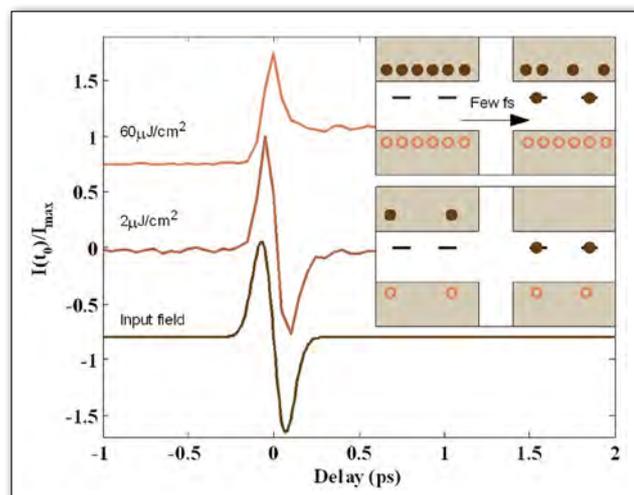
Photocurrent simulation in THz photoconductive detectors

Nowadays the most widely used spectroscopic technique in the terahertz band (0.1 to 10 THz) is called terahertz time-domain spectroscopy, which generates and detects pulses of terahertz light by triggering photoconductive antennae using infrared pulses from an ultrafast laser.

The influence of geometrical structure and semiconductor properties on the performance of photoconductive antennae has been studied extensively from the experimental point of view. However, theoretical studies on the semiconductor carrier dynamics of these devices have only emerged recently and have mostly focused on simulating the performance of emitters.

The present work develops a semi-classical Monte-Carlo model that can simulate ultrafast carrier dynamics in photoconductive detectors. The simulation tracks the motion of millions of charges under the electric field of a terahertz pulse at various times after their photo-generation taking into account the quantum mechanical scattering of each particle. By utilising a sequence of simulations the transient photocurrent was modelled precisely. In photoconductive detectors the rate at which electrons become trapped is an important parameter that determines how the measured current transient differs from the actual terahertz pulse's shape. By examining the role of carrier trapping at various illumination levels the authors demonstrated that high powers can distort the measured photocurrent. This model will

▼ The simulated signals are shown for two different gate fluences as well as the input THz field. The schematics on the right depict the reason for the difference between signals, which is caused by the saturation of the traps in the high fluence regime resulting in long lived mobile carriers which do not appear in the low fluence case.



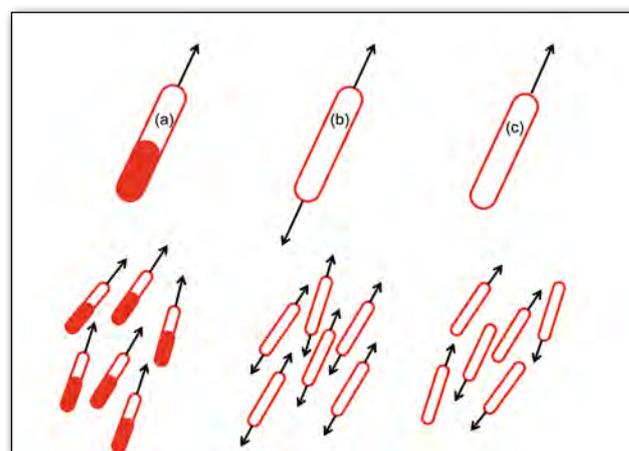
set the path for further development of detectors of pulsed terahertz radiation by providing insights into semiconductor material design for that application. ■

■ **E. Castro-Camus, M.B. Johnston and J. Lloyd-Hughes**, 'Simulation of fluence-dependent photocurrent in terahertz photoconductive receivers', *Semicond. Sci. Technol.* **27**, 115011 (2012)

BIOPHYSICS

Enigmatic Nematics

The law of hydrodynamics governing the way internally driven systems such as biological cells and bacteria behave could explain their complex structure and their inherent properties. Hydrodynamics is used here to understand the physical mechanism responsible for changes in the long-range order of groups of particles. The present work concerns ordered groups of elongated self-propelled particles, studying the breakdown of long-range order due to fluctuations that render them unstable and give rise to complex structures.



▲ Ordered macroscopic states of active particles.

The authors coined the term self-propelled nematics to refer to internally driven elongated particles that spontaneously align head to tail, like tinned sardines. These are characterised by an ordered state that is stationary on average. This means that there is a long-range order, whereas the locally preferred direction may vary throughout the medium due to local strains or disturbances.

It is found here that a uniform nematic state can be disturbed by density fluctuations associated with an upward current of active particles. Since the density in turn controls the onset of nematic order, this phenomenon is self-regulating and universal.

It is also found that instability could be triggered by a local distortion of particles' orientation. Such a distortion results in local currents that in turn amplify the distortion, leading to instability deep inside the nematic state.

Ultimately, this work may help us gain a deeper understanding of pattern formation and dynamics in a variety of internally driven systems, from epithelial cells and soil bacteria such as *Myxococcus xanthus*, to colloidal self-propelled nanorods. ■

■ **A. Baskaran and M. C. Marchetti,**

'Self-regulation in self-propelled nematic fluids', *Eur. Phys. J. E* **35**, 95 (2012)

RELATIVITY

A possible source of ultra-high-energy cosmic rays

The origin of ultra-high-energy cosmic rays, with energies around the GZK (Greisen-Zatsepin-Kuzmin) cut-off, remains an unsolved mystery. According to this cut-off, the mean free path of very energetic particles in the Universe does not exceed 50 megaparsec, due to their scattering on the cosmic microwave background radiation. However, there are no conventional sources of ultra-high-energy cosmic rays inside this radius. Hence some new sources seem to be necessary.

In the present letter a novel and intriguing explanation is suggested that links far-reaching fundamental aspects of $F(R)$ modified theories to an efficient production of highly energetic cosmic rays during the recent history of the Universe (let us recall that $F(R)$ theories present a modification of the usual General Relativity by an addition of a non-linear function $F(R)$ of the scalar curvature R . This function is chosen in such a way that it leads to accelerated cosmological expansion indicated by the recent astronomical data).

At the core of this work lies the proof that in cosmological and astrophysical systems with rising energy densities, the $F(R)$ modified theories of gravity exhibit powerful oscillations of the curvature scalar R , with an amplitude much larger than the standard value of curvature predicted by the General Relativity. These oscillations are strongly anharmonic, with frequencies that can be as large as billions of GeV. This striking and rather unexpected oscillatory behaviour of R lends support to the idea that ultra-high-energy cosmic rays can be generated by such curvature oscillations at the appropriate cosmological redshifts. ■

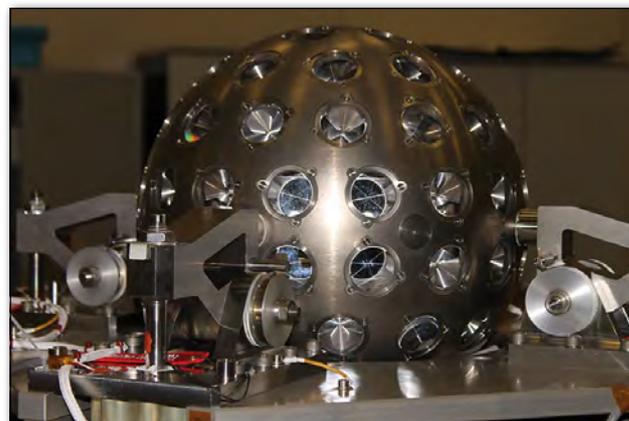
■ **E.V. Arbutova, A.D. Dolgov and L. Reverberi,**

'Curvature oscillations in modified gravity theories as possible source of ultra-high-energy cosmic rays', *Eur. Phys. J. C* **72**, 2247 (2012)

RELATIVITY

LARES: a nearly ideal satellite to test fundamental physics

The discovery of the accelerating expansion of the Universe, thought to be driven by a 'dark energy' constituting most of the Universe, has further revived the interest in testing Einstein's theory of General Relativity (GR). Frame-dragging in the gravitational field generated by a rotating body or by a current of mass-energy is one of the most fascinating phenomena predicted by GR. The recently launched LARES (LAsER Relativity Satellite) space mission is aimed at improving of about one order of magnitude the accuracy of the previous frame-dragging measurements by the LAGEOS and LAGEOS 2 satellites, using GRACE-derived Earth gravity determinations. After some years of orbital analysis of LARES, LAGEOS and LAGEOS 2 satellite laser-ranging data, frame-dragging should be tested within a few percents.



▲ The LARES satellite (courtesy of ASI)

However, at the very foundation of Einstein's theory is the geodesic motion of a small, structureless 'test-particle'. Depending on the physical context, a star, planet or satellite can behave nearly like a test-particle, so geodesic motion is used to calculate the advance of the perihelion of a planet's orbit and the dynamics of a binary pulsar system and of an Earth-orbiting satellite. Verifying geodesic motion is thus a test of paramount importance to GR and other theories of fundamental physics. On the basis of the first few months of satellite laser-ranging observations of the LARES satellite, its orbit shows the best agreement of any satellite with the test-particle motion predicted by GR. That is, after modelling its known non-gravitational perturbations, the orbit of LARES shows the smallest deviations from geodesic motion of any artificial satellite: its residual mean acceleration away from geodesic motion is less than $0.5 \times 10^{-12} \text{ m/s}^2$. LARES-type satellites and accurate satellite laser ranging measurements can thus be used for further tests of gravitational and fundamental physics. ■

■ **I. Ciufolini, A. Paolozzi, E. Pavlis, J. Ries, V. Gurzadyan, R. Koenig, R. Matzner, R. Penrose, and G. Sindoni,**

'Testing General Relativity and gravitational physics using the LARES satellite', *Eur. Phys. J. Plus* **127**, 133 (2012)

ATOMIC AND MOLECULAR PHYSICS

Charge transfer measurements in low-energy ion–atom collisions

We have used a radio frequency ion trap to study two charge transfer reactions:

- (1) Resonant charge transfer: ${}^3\text{He}^{2+} + {}^4\text{He}(1s^2) \rightarrow {}^3\text{He} + {}^4\text{He}^{2+}$,
 (2) Single electron charge transfer: ${}^3\text{He}^{2+} + {}^4\text{He}(1s^2) \rightarrow {}^3\text{He}^+ + {}^4\text{He}^+$.

We have determined the resonant charge transfer (RCT) rate coefficient of ${}^3\text{He}^{2+}$ with para- ${}^4\text{He}(1s^2)$ at energies below 1 eV (reaction (1)). The rate coefficient is measured to be $5.9 \pm 0.6 \times 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ at an equivalent temperature of 1200 K and is in reasonable agreement with recent calculations. This measurement extends our knowledge to a lower energy region thus adding to our understanding of the charge transfer process of ${}^3\text{He}^{2+}$, α -particles, with He encountered in astrophysics and fusion research.

While this measurement extends the experimental results below eV energies for the first time, it however provides an interesting observation. The rate coefficient for resonant two electrons transfer (reaction (1)) is orders of magnitude larger than the rate coefficient for single electron transfer (reaction (2)) at comparable temperature reported in the literature. This may lead to the following fundamental questions. The electron spin in para-He is anti-parallel. The spatial wave function that represents the two electrons is symmetric. The probability density for the two electrons close together is finite. Can the proximity of the two electrons account for this relatively large two electrons resonant charge transfer rate coefficient? Is it possible that the two anti-parallel electrons couple to form a loosely bound electron pair that is responsible for this relatively fast two-electron transfer? Can we gain some physical insight by measuring the rate coefficient of the resonant charge transfer of ${}^3\text{He}^{2+}$ with ortho- ${}^4\text{He}(1s2s)$ (metastable helium (2^3S_1)) where the two electron spins are parallel? ■

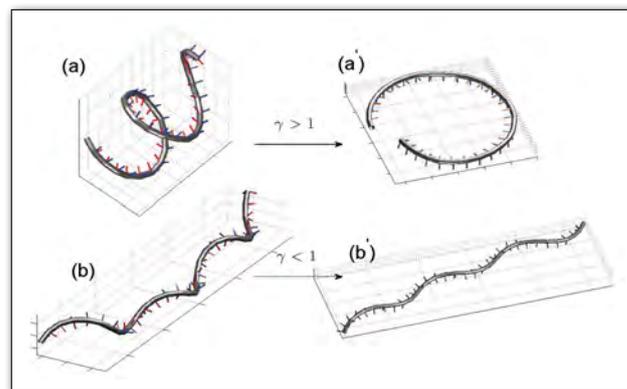
■ **C. Kyriakides, B.S. Clarke, W.M. O'Donnell, B. Zygelman and V.H.S. Kwong,**

'Resonant charge transfer of ${}^3\text{He}^{2+}$ with ${}^4\text{He}(1s^2)$ at energies below 1 eV', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 235701 (2012)

BIOPHYSICS

Physics of Squeezed Helices

Helically coiled filaments are everywhere in living nature. In experimental situations, filaments are often squeezed flat (or nearly flat) onto two-dimensional surfaces. Under such 2D confinement filament-helices form what we call "squeelices" - peculiar squeezed conformations often resembling looped waves, spirals or circles. Many such shapes have been observed and reported for a variety of biological and man-made filaments. With filament-helices being such a ubiquitous structure, we asked the question: what happens when filament helices



▲ When confined to a surface helical filaments form "squeelices". Two categories of squeelices exist, depending on the sign of the twist-kink self-energy (positive and negative for $g > 1$ and $g < 1$ respectively). (a,b) Typical filament-helices in 3-D before confinement. (a',b') When confined, (a) transforms into untwisted circularized shapes ($g > 1$) while (b) assumes twisted and wavy shapes ($g < 1$).

become confined? We found that the confinement produces some dramatic changes in filaments shape, giving rise to several notable and surprising effects. In particular "squeelices" can display an enhanced cyclisation probability, unusually strong end-to-end fluctuations and a conformational multistability. The conformational dynamics of confined helices is most naturally described in terms of discrete particle-like entities - which we call the "twist-kinks". These "twist-kinks" turn out to be analogous and are physically related to crystal dislocations in solids and Sine-Gordon-kinks from soliton physics. Twist-kinks move thermally along the confined helix and interact much like quasi-particles. Confined helices can further thermally switch between discrete twist-quantized states comprising different numbers of twist-kinks.

Doing simple things (confining) to simple objects (helical filaments) can give rise to complex physics. ■

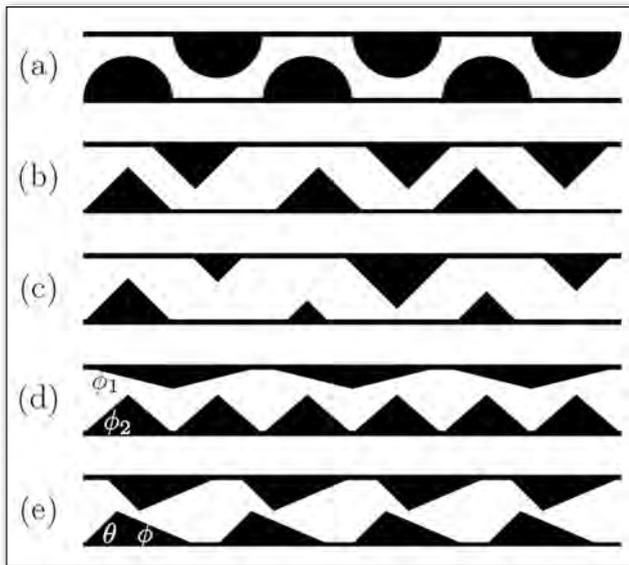
■ **G-M. Nam, N-K. Lee, H. Mohrbach, A. Johner and I.M. Kulic,** 'Helices at interfaces', *EPL* **100**, 28001 (2012)

MATERIAL SCIENCE

Heat flux anomaly at nanoscale

Nanomaterials are promising platforms for testing fundamental heat transport theories. The present review article outlines anomalous heat transport in nanometric scale materials from the latest developments in experimental, theoretical and numerical studies of heat conduction. It shows that the standard laws governing conduction at macroscopic scale no longer apply in nanostructures, which has implications in electronic, optoelectronic, and thermal devices.

Nanostructures are low-dimensional materials such as single carbon atom layers of graphene, nanowires or nanotubes. Laws governing heat transport through what are known as phonons, representing the vibrational modes of lattices, are different in such materials compared to the macroscopic scale. This is



▲ Geometrical configuration of billiard gas channels

because the phonon characteristic lengths are comparable to the characteristic lengths of these nanostructures. Particularly, heat carriers diffuse faster than in a random walk but slower than in a straight trajectory motion.

This paper outlines the recent experiments on quasi-one-dimensional nanostructures and two-dimensional graphene that display a thermal conductivity with this anomalous behaviour, linked to heat diffusion's size dependency. Such studies present a dual challenge in that the technique associated with measuring heat flux in nanosystems is combined with the complexity of accurately controlling object at nanoscale.

Due to these measurement challenges, experimental results need to be complemented by theoretical studies. Hence, this paper also accounts for numerical studies on heat conduction of nanotubes, nanowires and graphene, concentrating particularly on atomic-level simulations.

In addition, the latest theories explaining the mechanisms of such anomalous heat conduction are presented. But these are by no means complete. Further systematic investigations are needed for better thermal energy management and control in nanoscale devices. ■

■ **S. Liu, X.F. Xu, R.G. Xie, G. Zhang and B.W. Li,**

'Anomalous heat conduction and anomalous diffusion in low dimensional nanoscale systems', *Eur. Phys. J. B* **85**, 337 (2012)

CONDENSED MATTER

Graphene Mini-Lab

A mini-laboratory is proposed to study fast moving electrons in the carbon-based material called graphene as a model for massless particles moving in a noisy environment with velocities close to the speed of light, in analogy to relativistic Brownian particles such as cosmic rays.

In graphene (one atom-thick carbon layer forming a honeycomb lattice) the interaction of electrons with atoms changes the effective mass of the electrons. As a result, the energy of these electrons becomes similar to the photon energy. Therefore, electrons in graphene can be regarded as ultra-relativistic particles even though their actual velocity is 100 times lower than the speed of light.

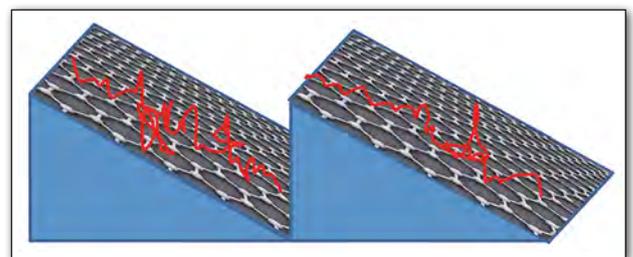
The authors used the classical Brownian motion formalism to study the dynamics of electrons within the confines of the graphene mini-laboratory. They considered different chip geometries and subjected them to changing conditions affecting the way these electrons diffuse through the material such as temperature and electric field strength.

Going one step further, the authors were able to rectify electron fluctuations and to control the electron motion itself from an unusual chaotic to a periodic motion by varying the electric field. Future work would experimentally demonstrate how variation of the temperature could be used positively to enhance the performance of graphene chips by gaining a greater control over electron transport. Such graphene mini-labs could also ultimately help understand the dynamics of matter and anti-matter in cosmic rays. ■

■ **A. Pototsky, F. Marchesoni, F. V. Kusmartsev, P. Hanggi and S. E. Savel'ev,**

'Relativistic Brownian motion on a graphene chip', *Eur. Phys. J. B* **85**, 356 (2012)

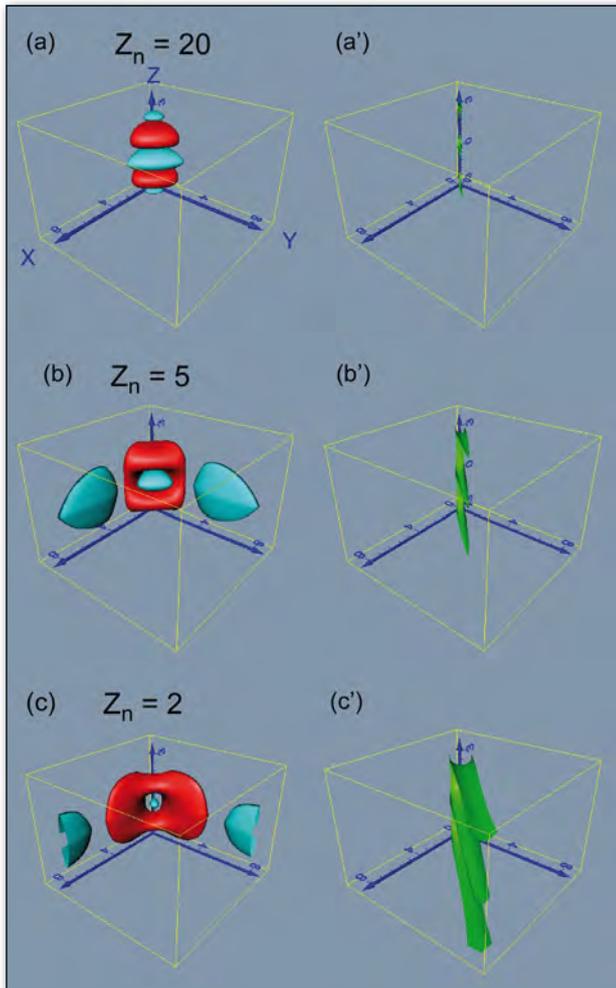
▼ Dirac electron diffusion (represented by a red semi classical trajectory) on a ratchet asymmetric potential represented by blue triangles can be rectified by ac drives.



ATOMIC AND MOLECULAR PHYSICS

Conjugate Fermi hole and the first Hund rule

Empirically derived Hund's rules of the pre-quantum-mechanics era predict the ordering of the energy levels possessing different spin and orbital angular momentum quantum numbers. They have proved to be almost universally valid for atoms, molecules, and quantum dots. Yet, despite of a long-standing debate, the search for their origin persists primarily due to the lack of the precise knowledge of the electronic structure in different spin states. We explore the origin of the first Hund rule for a two-dimensional model of He-like systems and that



▲ Structure of the genuine and conjugate Fermi holes in the internal space for the $(1s)(2p)$ singlet-triplet pair of states of He-like systems: (a) – (c) correspond to the nuclear charge Z_n of 20, 5, and 2, respectively. (a') – (c') represent the electron repulsion potential for the corresponding Z_n .

of two-electron quantum dots. They represent ideal systems providing a direct fundamental insight into the structure of the internal part of the fully correlated wave functions, allowing an unambiguous argument.

An examination of their probability density distributions reveals indeed the existence of a region in the internal space, which we refer to as a *conjugate Fermi hole*. In this region the singlet wave function has a smaller probability density than the corresponding triplet one, in contrast to the genuine Fermi hole where the triplet has a smaller density than the singlet. Due to the presence of this conjugate Fermi hole the singlet probability density has to migrate far away from the centre of the one-electron potential. This rationalizes the well-known broader electron density distribution of the singlet state relative to the corresponding triplet. This key observation explains the singlet-triplet energy gap. ■

■ **T. Sako, J. Paldus, A. Ichimura and G. H.F. Diercksen**, 'Origin of the first Hund rule and the structure of Fermi holes in two-dimensional He-like atoms and two-electron quantum dots', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 235001 (2012)

STATISTICAL PHYSICS

Replica techniques can predict learning curves

We show that statistical physics approaches, in particular the replica method, can be used to accurately predict the learning curve of a Gaussian process (GP) inferring a function from noisy data, for a wide range of discrete input spaces. The learning curve quantifies performance as average mean square error versus number of training examples.

GPs are a popular Bayesian inference technique. A GP prior is placed over a function space, and combined with the likelihood of the observed data given a function. Bayes' theorem then gives a posterior distribution over functions. For a likelihood describing Gaussian noise corrupting the observed function values, this is again a GP, which can be used to make predictions about the function.

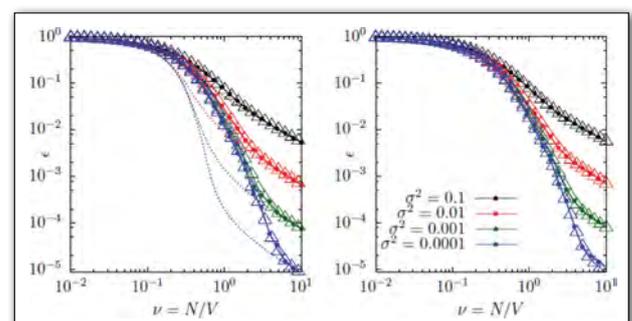
GPs are "non-parametric": they effectively represent functions with infinitely many parameters. This makes analysis of their learning curves non-trivial, and much has been achieved for GPs learning functions whose inputs are real-valued. However, predictions are generally only qualitatively correct, with exact solutions only for special cases. We show for the case where inputs are discrete, specifically vertices on a random graph, that replica techniques can be used to predict learning curves exactly in the limit of large graphs.

The starting point is to represent the average error as the derivative of a partition function. We rewrite this so that only neighbouring vertices are directly coupled. From here one can apply the replica method to find the required quenched average over the randomness in the data set. The results apply to random graph ensembles constrained by any fixed degree distribution, and can be generalised to more complicated ensembles. ■

■ **M.J. Urry and P. Sollich**,

'Replica theory for learning curves for Gaussian processes on random graphs', *J. Phys. A: Math. Theor.* **45**, 425005 (2012)

▼ Predicted mean square errors vs number of examples per vertex, for different noise levels σ^2 (triangles), agree very well with numerical simulations (circles, graphs with 500 vertices) and improve significantly on existing approximations (dashed line).



APPLIED PHYSICS

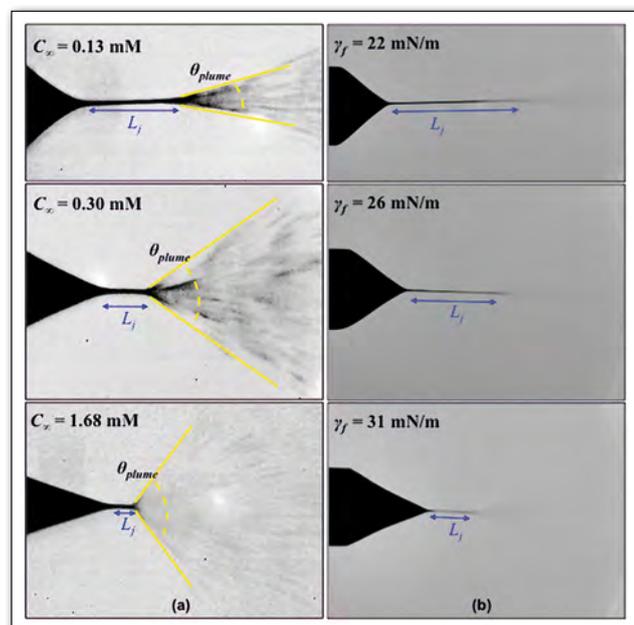
Droplet production for electrolyte solutions

Proteomic mass spectrometry and chemical imaging require the generation of nanometer-sized charged water drops that are emitted in a precise direction. This is done with the remarkable ability of an electric field to sharpen a mm-sized spherical drop into a sharp cone with a universal half angle of 49 degrees, to emit a micro-jet at the cone tip and to breakup the charged micro-jet explosively into a plume of nanodrops, whose plume angle and charge per drop sensitively affect the measurement accuracy of the instrument. This paper captures the underlying nanoscale physics of DC electro spray with a combination of strong electrolyte theory, electrostatics, interfacial phenomena and potential spectral theory for geometric singularities. The electric field of the most singular harmonic near a cone that sharpens the drop is also shown to charge a nanoscale capacitor at the interface of the micro-jet, with a dimension of the Debye length. The interfacial charging increases downstream of the cone tip until the space charge separation is below the Bjerrum length, when the repulsive Coulombic energy between two charges exceeds the thermal energy. The resulting Coulombic fission accounts for the explosive breakup of the micro-jet into the nanodrop plume. The micro-jet length, the charge per nanodrop and the nanodrop plume angle as functions of ion strength are accurately captured by the theory as functions of the ionic strength and surface tension. Strong ionic strength and low surface tension produce the longest micro-jet, the smallest plume and the most precisely directed nanodrops. ■

■ **Y. Wang, M. K. Tan, D. B. Go and H-C. Chang,**

'Electrospray cone-jet breakup and droplet production for electrolyte solutions', *EPL* **99**, 64003 (2012)

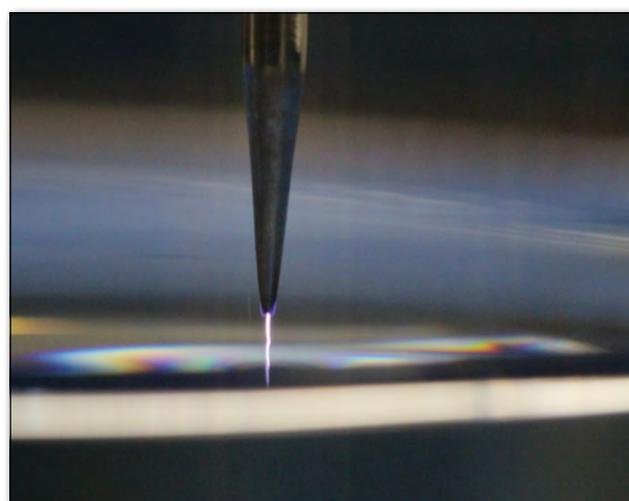
▼ The micro-jet length L_j and nanoaerosol θ_{plume} angle are observed to be strong functions of the ionic strength C_∞ and interfacial tension γ_f .



PLASMA PHYSICS

Plasmas as gaseous electrodes for aqueous electrochemistry

Plasmas are ionized gases made up of electrons and gaseous ions. In theory, plasmas are a source of charge that can be coupled with liquids to initiate electrochemical reactions in solution. This has been known for some time, at least since 1887 when Gubkin first reported the use of plasmas for electroplating silver from silver nitrate. Unfortunately, plasmas are inherently difficult to stabilize at atmospheric pressure, and vacuum operation has limited prior experiments to solvents with low vapour pressures such as ionic liquids.



▲ Atmospheric-pressure microplasma stably formed in a flow of argon gas at the surface of acidic water

The present work shows how to get stable atmospheric-pressure plasmas allowing aqueous electrochemical reactions. The approach is based on pd scaling (gas pressure p and dimension d of the plasma) which imposes to reduce the dimension of the plasma to go to higher pressure. Atmospheric operation is achieved by forming a μm -scale plasma, or microplasma.

Upon operating the microplasma as the cathode at the surface of an aqueous solution, the electrons from the plasma reduce the protons to produce hydrogen gas. At the platinum counter-electrode, oxidation reactions lead to the formation of oxygen gas. The electrolysis of water is well known in electrochemistry, but this is the first time it has been demonstrated with a plasma electrode.

As plasmas are increasingly in use with wet electrodes for medical and materials applications, it is crucial to understand the high complexity of plasma-liquid interactions. The role of electrons has thus far been largely overlooked, and this work brings a crucial piece of the puzzle. ■

■ **M. Witzke, P. Rumbach, D.B. Go and R.M. Sankaran,**

'Evidence for the electrolysis of water by atmospheric-pressure plasmas formed at the surface of aqueous solutions', *J. Phys. D* **45**, 442001 (2012)

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Heavy ice

Water is a vital substance for life on planet Earth. This is obvious for liquid water with its crucial role for any species living on the globe. But also solid water plays a more important role than one might expect. For one thing, in the old days before people managed to build bridges across rivers, the formation of ice in winter time increased the mobility of mankind substantially. And – for the sporty among us – ice is great fun to skate on. This pleasant aspect of ice was touched upon in an earlier column (EPN 41/6; *Physics in Daily Life* p.29). The freezing process itself has some remarkable aspects. For example, in most of Europe, the ice layer on lakes and ponds never reaches the bottom, which is good news for fish and other creatures living in the water. As physicists, we realise that the basic reason behind this is that the ice layer grows more slowly as it gets thicker. Remember that the ice layer grows at its bottom, where the temperature is constant at 0 °C by definition, and that the heat of solidification must be transported through the ice layer to the cold air above.

Let us assume for simplicity that the temperature at the top of the ice layer is constant, so that the heat flow through the ice layer of thickness h is proportional to $1/h$. Since the growth rate dh/dt is proportional to the heat flow, we have $dh/dt \sim 1/h$, yielding $h \sim \sqrt{t}$.

In other words, if air temperature and wind speed are constant, the ice layer thickness is proportional to the square root of time.

All this relies on a rather unique property of water: the fact that it expands when it goes solid. For most substances this is not the case. For example, if we look at the elements, only gallium, germanium, silicon and bismuth have that property.

It is interesting to speculate on what would happen if water would behave like most substances, *i.e.*, if it would shrink upon freezing. The freezing process would be entirely different. To begin with, the very first pieces of ice that are formed at the surface would sink to the bottom, exposing a fresh layer of water ready to be frozen at the top. The freezing top layer would now remain directly in contact with the cold air above, and the slowing down of the freezing process described above would not occur. Instead, the pond would freeze rapidly from the bottom up. The poor fish would have no choice but to swim higher and higher until the whole pond had frozen solid.

Poor fish!

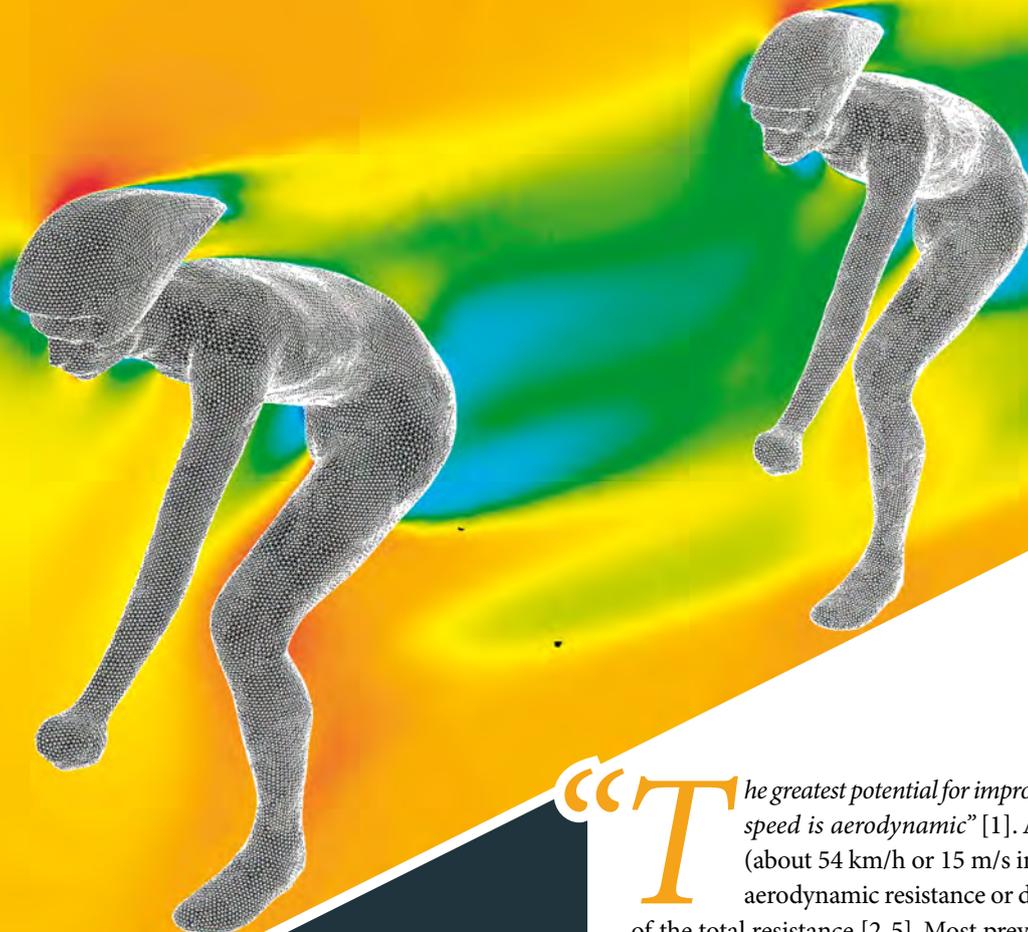
It's even worse. In cold winters, many lakes outside the tropics would behave precisely the same, and most of the marine life would be ruined. And that's not even the end of the story. Just think of the glaciers in Greenland or Antarctica, sliding into the ocean. Instead of forming floating icebergs as they do today, they would sink to the bottom, out of reach of the sunrays that would melt them. Sooner or



later the deep sea would be filled with ice, instead of with water at 4 °C as it is today. That would completely upset life in the deep ocean.

Fortunately there is a bright side to the story, and things might not be as bad as sketched above. The density of sea water is about 1.027 kg/l, and it would go up even higher if the above scenario were to materialize. So, if freezing water would shrink only a little bit, the oceans would remain safe: only our ponds and lakes would freeze solid. And our favourite fish restaurant would no longer serve pike-perch with champagne sauce, but just herring, salmon and cod. ■

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Surprises in cycling aerodynamics

■ Bert Blocken¹, Thijs Defraeye², Erwin Koninckx³,
Jan Carmeliet⁴ and Peter Hespel⁵ - DOI: 10.1051/eppn/2013102

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■ ⁵ Bakala Academy - Athletic Performance Center - Univ. of Leuven - Heverlee, Belgium

Drafting is riding close behind each other to reduce aerodynamic drag. New simulations and measurements for drafting cyclists show that also the leading cyclist experiences a drag reduction, up to 3.1%. For six or more similarly-sized drafting cyclists, the position enjoying the largest drag reduction is the one-but-last position.

“**T**he greatest potential for improvement in cycling speed is aerodynamic” [1]. At racing speeds (about 54 km/h or 15 m/s in time trials), the aerodynamic resistance or drag is about 90% of the total resistance [2-5]. Most previously published studies on cycling aerodynamics aimed at reducing the aerodynamic drag of a single cyclist. Fewer publications have addressed the drag reduction due to drafting. In drafting, two or more cyclists ride close behind each other to reduce aerodynamic drag. The few published studies on drafting all confirm the large drag reduction for the trailing riders (up to 30-40%), whereas there seems to be a lack of consensus about the effect of drafting on the leading rider. In this respect, Olds [6] stated:

“It has been suggested that riding close behind a leading cyclist will also assist the leading rider in that the low pressure area behind the cyclist will be “filled up” by the trailing rider. However, both Kyle (1979) and McCole et al. (1990) failed to find any measurable effect either in rolldown experiments or in field VO₂ measurements.”

On the other hand, Computational Fluid Dynamics (CFD) studies on human body models with simplified geometries (such as elliptical cylinders) found drag reductions for the leading cylinder up to 5% [9]. However, to the best of our knowledge, no studies have yet been published on detailed 3D CFD simulations of drafting cyclists based on realistic human body geometries. Such 3D CFD simulations were the focus of this new study, which included also wind-tunnel measurements. First, the wind-tunnel measurements were used for CFD validation for single cyclists and two drafting cyclists. Next, supported by the validation study, CFD simulations were performed for groups up to eight drafting cyclists, allowing assessment of aerodynamic drag at every position in the group.

Wind-tunnel measurements

Three sets of wind-tunnel measurements were done. The first set included overall drag force measurements as well as point measurements with 30 pressure plates on the body of a real cyclist (Cyclist A: height 1.83 m, weight 72 kg) in different positions, including the upright position (UP), the dropped position (DP) with straight arms and the time-trial position (TTP) (Figs. 1, 2a). The second set comprised overall drag force measurements and point measurements with 115 pressure taps on two reduced-scale (1/2) models of cyclist A, obtained by rapid prototyping (Fig. 2c,d). The third set consisted of overall drag force measurements on two drafting cyclists (Cyclists B and C) behind each other at a wheel-to-wheel separation distance $d = 0.15$ m. In all measurements, the wheels and legs were static (*i.e.*, no pedalling). For brevity, only the results of the overall drag force measurements on the real cyclists are presented in this article. A conservative estimate of the measurement error of the drag force is 0.3% at approach-flow air speed $U_\infty = 15$ m/s. The measurement results are reported together with the CFD results in the next sections. More detailed information about the wind-tunnel measurements can be found in [4,5].

Computational models

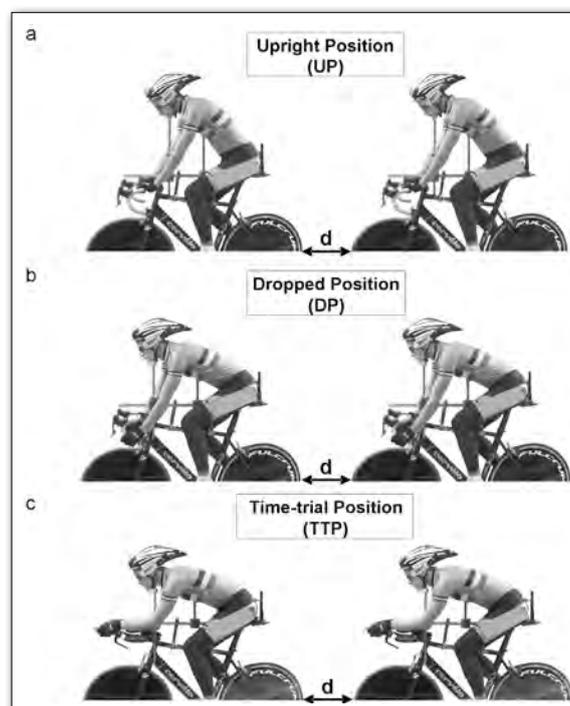
Digital models of the cyclist (Cyclist A) were obtained with high-resolution 3D laser scanning, capturing the specific body characteristics in UP, DP and TTP (Fig. 2b). To generate groups of up to eight riders, the cyclist geometry (only cyclist body, not bicycle) was copied and the cyclists were placed behind each other with a wheel-to-wheel separation distance $d = 0.01$ m. The cyclists were placed in a computational domain with dimensions and spatial discretisation according to best practice guidelines in CFD and based on grid-sensitivity analysis [10–13] (Fig. 3). Very small control volumes of $30 \mu\text{m}$ were applied at the cyclist body surface to resolve the boundary layer down to the thin viscous sub-layer (Fig. 3b) This is important because boundary layer separation determines to a large extent the aerodynamic drag. Further away from the surface, tetrahedral cells were used with an average size of about 0.03 m. The grids for the single cyclist contained about 7.7×10^6 cells versus 35.6×10^6 cells for the eight drafting cyclists. The simulations were made with a uniform inlet velocity of 15 m/s and a turbulence intensity of 0.02% as in the wind tunnel, representing the relative air movement when cycling at this velocity in still air (zero wind speed). The 3D steady Reynolds-averaged Navier-Stokes (RANS) equations were solved with the standard $k-\epsilon$ turbulence model [14], near-wall modelling with the one-equation Wolfshtein model [15], pressure-velocity coupling with the SIMPLE algorithm, second-order pressure interpolation and second-order discretisation schemes using the commercial CFD code ANSYS/Fluent 12. Convergence was monitored carefully and the iterations were terminated when all residuals showed no further reduction with increasing number of iterations.

CFD simulations versus wind-tunnel measurements

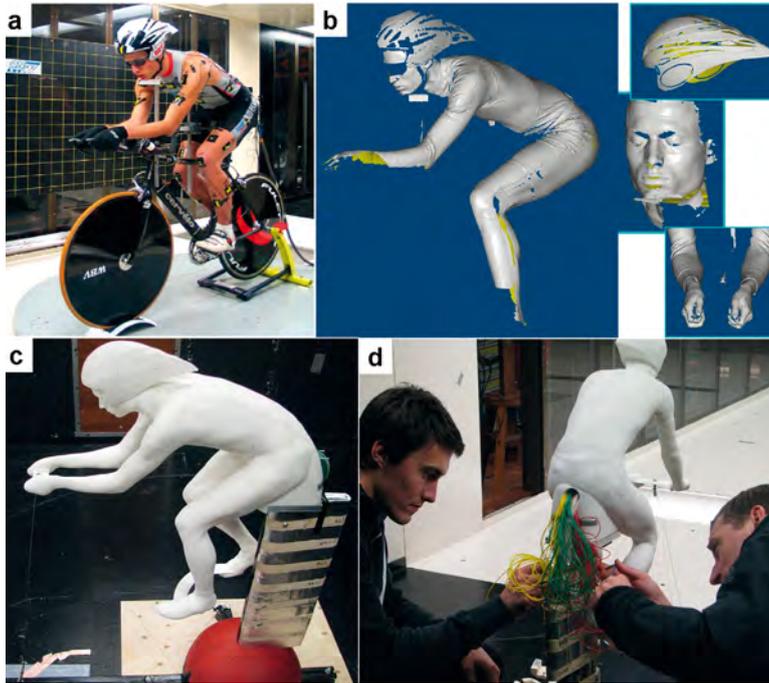
The CFD simulations only consider the body of the cyclist. Therefore, the corresponding experimental drag area of the cyclist body is obtained by subtracting the experimental drag area of the bicycle configuration plus force platform, which was measured separately, from the total experimental drag area of the cyclist body, bicycle and platform. The deviations between CFD simulations and measurements are 10.5%, 3.5% and 0.7% for the UP, DP and TTP, respectively. Given the very low percentage deviation for TTP, it is likely that some errors have cancelled each other. Similar simulations were made for the two drafting cyclists in DP at $d = 0.15$ m, yielding a drag reduction for the leading cyclist of 1.3% versus 1.6% from the wind-tunnel measurements. Both the CFD simulations and the wind-tunnel measurements confirm the drag reduction of the leading rider due to the presence of a trailing rider in his wake. The agreement between the CFD simulations and the wind-tunnel measurements is considered to be very good, which justifies using these simulations for further analysis of the flow field and also using the same computational models (grid, turbulence model, *etc.*) for the CFD simulations of groups of up to eight drafting cyclists.

Flow-field analysis for two drafting cyclists

Compared to the single cyclist in TTP, the drag reductions for two drafting cyclists (TTP, $d = 0.01$ m) are 2.6% for the leading and 13.9% for the trailing cyclist. The validated CFD simulations are used to explain these drafting effects. Figure 4 displays the pressure coefficient C_p in the vertical centre plane and in a horizontal plane at waist height of the cyclist(s). C_p is defined as $(P - P_0)/(0.5\rho U_\infty^2)$ with P the static pressure, P_0 the reference static pressure, ρ the air density and U_∞ the approach-flow air speed. The figure legend is limited



◀ FIG. 1: Three cycling positions with indication of bicycle separation distance d (wheel-to-wheel): (a) Upright position (UP); (b) Dropped position (DP) with straight arms; (c) Time-trial position (TTP).



▲ FIG. 2: (a) Cyclist A in the DNW LST wind tunnel in Marknesse. The cyclist and bicycle are positioned on the force balance and equipped with 30 pressure plates. (b) 3D laser scanning of body geometry of cyclist A. (c) Half-scale model of cyclist A in time-trial position with 115 pressure taps. (d) Half-scale model of cyclist A in upright position with 115 pressure taps. Photo shows pressure tubes exiting from the hollow model.

to the interval $[-0.05; 0.1]$ in order to highlight the changes in the pressure field due to drafting; the actual maximum and minimum (absolute) values of C_p are much larger. The figures clearly show the area of overpressure in front of the cyclists and the area of negative pressure behind them. In case of two drafting cyclists, the wake behind the leading cyclist interacts with the overpressure area in front of the trailing cyclist, which not only results in a drag reduction for the trailing cyclist, but also for the leading cyclist. Note that also the size of the negative pressure area behind the leading rider decreases due to a trailing rider in his wake. This effect shows a striking correspondence with the statement by Olds [6] about the low-pressure area behind the leading cyclist being “filled up” by the trailing cyclist.

Drag reductions for larger groups

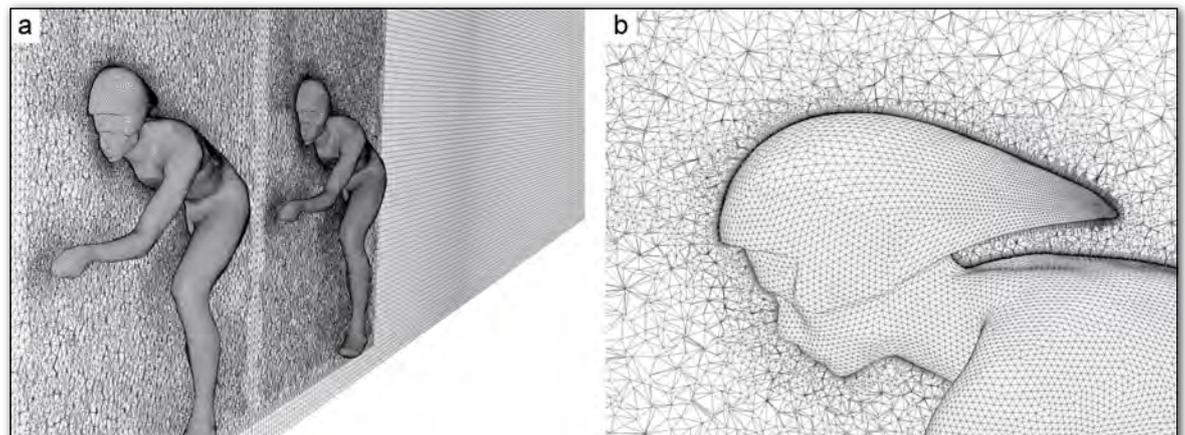
Because the aerodynamic drag of a leading cyclist is significantly reduced by a trailing cyclist in his wake, it can be expected that in larger groups of cyclists, the largest drag reduction is not experienced by the last cyclist – as is generally

assumed – but by the one-but-last cyclist. Indeed, while the last cyclist benefits from the leading riders in front of him, the one-but-last cyclist benefits from both the riders in front of him and from the rider behind him. This is confirmed by the CFD simulations: Figure 5 shows the drag reduction for every cyclist in a group of 2, 4, 6 and 8 riders. For groups of 6 or more similarly-sized riders, the one-but-last rider experiences the largest drag reduction. For smaller groups, it is the last rider that has the largest drag reduction. The reason is that the wake behind the riders widens with downstream position. Therefore, as an example, the last rider in a group of 3 benefits more than the last one in a group of 2. The widening of the wake becomes less pronounced from about the 5th position, and the beneficial effect of having a trailing rider in your wake then becomes comparatively more important. In addition, note that the leading cyclist in a team of three or more experiences a larger benefit (3.1%) than in a team of two (2.6%), due to the upstream disturbance of the flow (overpressure area) by the 3rd rider that extends up to the position of the 1st rider.

Strategy in team time trials

Many factors determine the outcome of a race. In regular races, the above-mentioned drag reductions for the leading cyclist are probably too low for this knowledge to lead to different racing behaviour. This is certainly the case for a chaotic peloton sprint. However, team time trials are much more organised than peloton sprints. In these races, a group of cyclists of the same team try to apply drafting in the best possible way to achieve the best possible team performance. During the race, the members of the team alternate to take the lead role. Apart from the alternating order, of course also body size and shape and position on the bike are important. A larger trailing rider will provide a larger drag reduction for a smaller rider in front of him, while the trailing rider himself will benefit less because of the smaller wake from the smaller leading rider. In addition, different cyclists also have different power curves. The best strategy and alternating sequence in team time trials can be determined based on the combination of aerodynamic drag simulations and power performance curves.

► FIG. 3: (a) Computational grid for two drafting cyclists (body of cyclist A) in time-trial position and with bicycle separation distance $d = 0.01\text{m}$. The grid on the cyclist body and in the vertical centre plane is illustrated. (b) Detailed view of computational grid near upper body, head and helmet. Note the very high grid resolution at the body surface.



Limitations

The two main limitations of the study are, first, that all cyclists had identical body geometry and position on the bicycle, and second, that only static positions (*i.e.*, no pedalling) were evaluated. The simulations were also performed for cyclists directly behind each other at a separation distance of only 0.01 m. While this distance is unrealistically low when riding precisely behind each other, it should be noted that cyclists often ride much closer to each other, be it in a slightly staggered arrangement, with the front wheel of the trailing rider next to the back wheel of the leading rider. In such cases, the drag reductions might be even larger. Future work will include analysis of drag effects in such arrangements.

Conclusions

CFD simulations validated by wind-tunnel measurements show that drafting also benefits the leading rider, due to the presence of trailing riders in his wake. The drag reduction for the leading rider is up to 2.6% with one trailing rider and up to 3.1% with two or more trailing riders. The same effects imply that in a group of 6 or more similarly-sized riders, the position with the largest drag reduction is not the last, but the one-but-last. The difference in drag reduction between both positions is about 1%. In top competitions, where winning or losing is often a matter of seconds, these drag reductions due to trailing riders are significant and can be decisive. ■

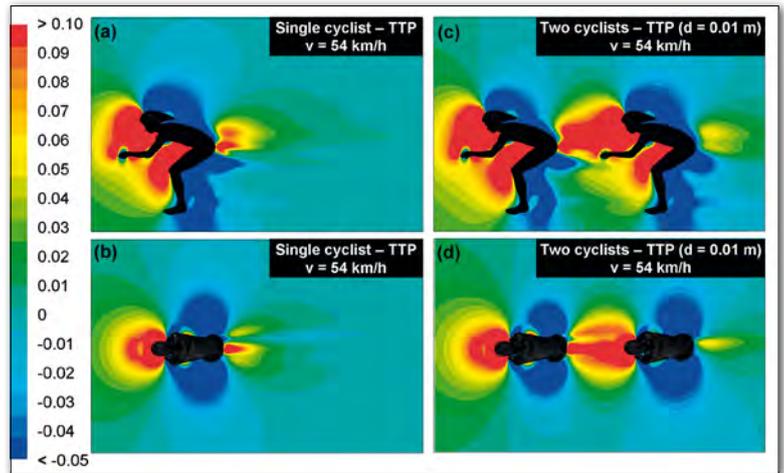
About the Authors



(1) **Bert Blocken** is full professor and chair of building physics at Eindhoven University of Technology, with specific expertise in (urban) aerodynamics. (2) **Thijs Defraeye** is a postdoctoral fellow of the FWO-Flanders in biosystems engineering at Leuven University in Belgium. (3) **Erwin Koninckx** is a postdoctoral researcher with a background in both engineering and biomedical kinesiology working at the Flemish Cycling Federation. (4) **Jan Carmeliet** is full professor and chair of building physics at ETH Zurich. (5) **Peter Hespel** is full professor in biomedical kinesiology at the Bakala Academy at Leuven University.

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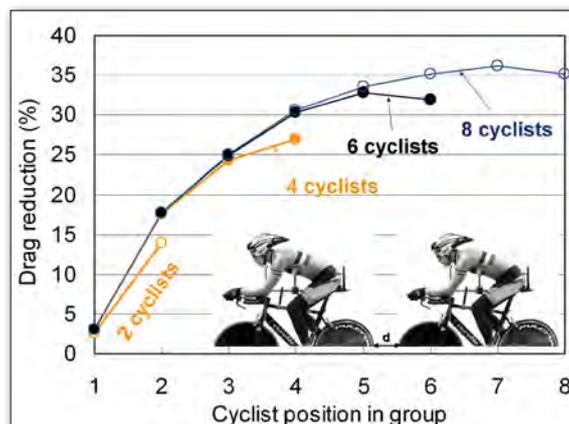


▲ FIG. 4:

Pressure coefficients C_p in the vertical centre plane (a,c) and in a horizontal plane (b,d) at waist height for (a,b) isolated (single) cyclist and (c,d) two drafting cyclists in time-trial position (TTP) with bicycle separation distance $d=0.01$ m. The cycling speed is 54 km/h.

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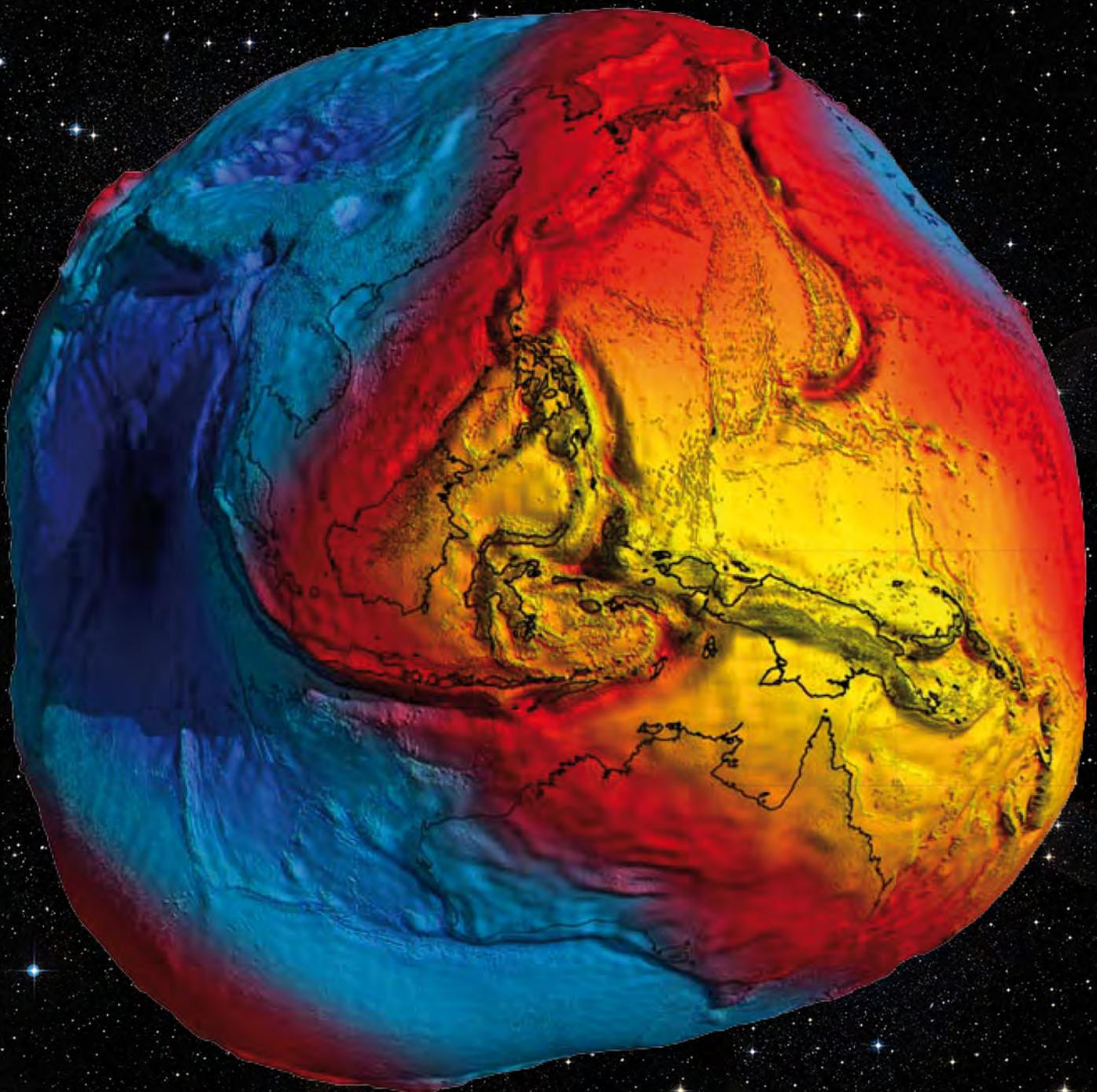


◀ FIG. 5: Numerically simulated drag reduction in groups of 2, 4, 6 and 8 cyclists, in time-trial position with bicycle separation distance $d=0.01$ m.

Earth gravity from space or how attractive is our planet?

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In March 2011 the European Space Agency (ESA) released an impressive new picture of the figure of the earth. It was based on the first science data from the satellite GOCE. It shows the geoid with its undulations highly exaggerated, which makes the Earth look almost like a potato, but very attractive. The picture received great attention from the media and even made it to the front page of many leading international newspapers.

GOCE (acronym for Gravity and steady-state Ocean Circulation Explorer) was launched in March 2009. It is still in orbit. The end of the mission is projected for the second half of 2013, when the spacecraft will have used up most of the Xenon of its ion propulsion system, which is needed to keep it in an extremely low orbit. Its primary goal is the global determination of the geoid and of gravity with an accuracy of one part per million (1 ppm). To achieve these objectives the principle of gravitational gradiometry is applied, the first time ever in a spacecraft. The gradiometer instrument consists of three pairs of ultra-precise accelerometers, and the satellite is essentially a laboratory built around the gradiometer. In order to enhance the gravitational signal the orbit altitude is chosen very low, only 255 km. Despite the high accuracy of the gradiometer instrument, data analysis can still be based on Newton's universal law of gravitation.

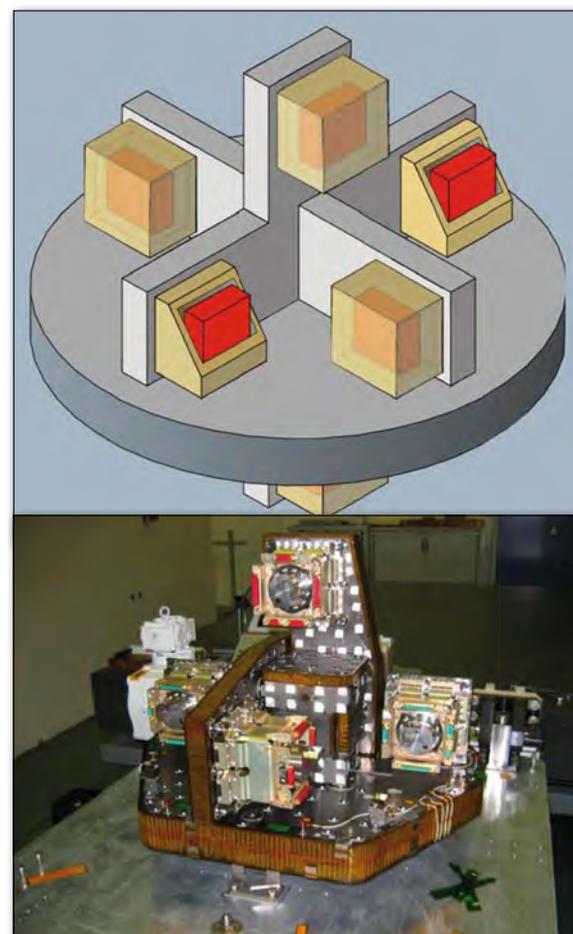
Gravity is the combined effect of 'true' gravitation and the centrifugal acceleration due to earth rotation. In first approximation, for a spherical earth it is a constant, the well-known 9.8 m/s^2 . The deviations from this value are small. The largest, of the order of $1/300$, is due to the combined effect of centrifugal acceleration and of the Earth's oblateness which is essentially a result of Earth rotation. Newton was the first to use gravity measurements as a confirmation of his theory about equilibrium figures and the earth's flattening. For this purpose he considered 'seconds pendulums' employed for astronomical measurements, and analysed the adjustments applied to their length at stations at various latitudes.

Density variations

Gravity differences due to topography and density variations in the earth's interior are even smaller; they are less than 10^{-4} . They are caused by phenomena ranging from large-scale density variations due to tectonic processes and mantle convection, to small-scale effects such as cavities in the underground or density jumps in soil or rock material. For this latter reason, terrestrial gravimetry belongs to the standard methods of exploration geophysics. Temporal variations of gravity are less than 1 ppm. The largest contribution is due to the tidal effect of sun, moon and planets on the oceans and the deformable earth. Smaller contributions are caused, e.g., by changing groundwater levels and

variations of atmospheric pressure. Some contributions and their size are listed in Table 1.

The traditional measurement techniques are absolute gravimetry, employing rather sophisticated free-fall apparatus [1], and relative gravimetry with spring gravimeters. Temporal variations are measured most accurately by superconducting gravimeters, stationary and under laboratory conditions. They are also relative gravimeters. Their relative sensitivity is as high as about 10^{-12} . This approach employs a superconducting sphere which is kept levitated by a magnetic field of superconducting, persistent current coils [2]. However, even more than fifty years of terrestrial measurement activity worldwide resulted only in a rather incomplete and incoherent situation. Only in some highly developed countries dense and accurate gravity networks exist. In a much larger part of our world gravimetric measurements are either missing or they are sparse, inhomogeneous and inaccurate.



◀ FIG. 1: The GOCE geoid "potato". The geoid undulations are highly exaggerated. Their maximum values, expressed relative to a best fitting global ellipsoid, are -100 meters South of India and +80 meters around New Guinea (courtesy: ESA)

◀ FIG. 2: The GOCE gravitational gradiometer consists of three perpendicular one-axis gradiometers. Each of them comprises a rigid bar with two accelerometers at its ends. The accelerometers are the gravity signal sensors. In each of them a test mass ($4 \text{ cm} \times 4 \text{ cm} \times 1 \text{ cm}$) is kept levitated by an electrostatic feedback system. The applied current is proportional to the gravitational acceleration signal.

Upper panel: principle of the gradiometer with its six cubic test masses (in red).

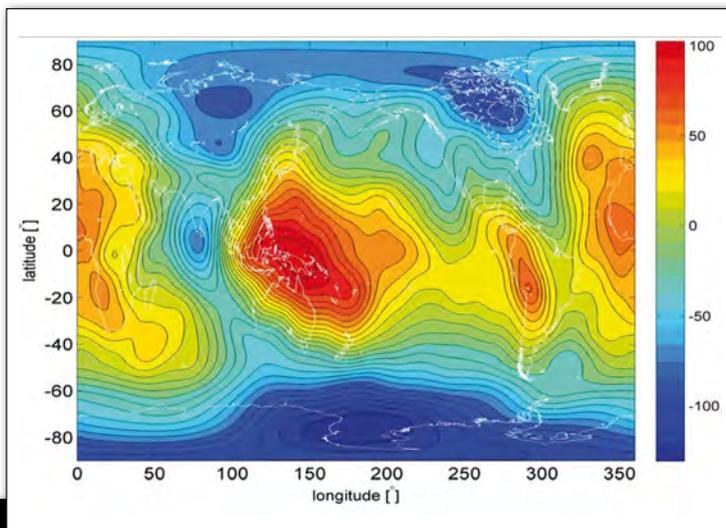
Lower panel: the actual GOCE gradiometer instrument (courtesy: ESA).

BOX 1

The complete gravitational tensor consists of the nine second derivatives $V_{ij} = \partial^2 V / \partial x^i \partial x^j$ of the gravitational potential at the location of the satellite. Due to its symmetry only six elements remain. GOCE measures four of them with high precision, namely V_{xx} , V_{yy} , V_{zz} and V_{xz} while V_{xy} and V_{yz} are measured much less accurately. Geometrically, the tensor elements represent the local curvature structure of the field, i.e., the curvature of the equipotential surfaces and plumb lines. Equivalently, the accelerations may be interpreted as measurement of the tidal field generated by the attraction of the Earth inside the GOCE satellite, cf. [4]. ■



In order to recover the small variations of the earth's field, the relative precision has to be 1 ppm



Satellites

With satellites the earth's gravitational field can be measured globally, homogeneously, fast and much more conveniently. The tracking of any earth-orbiting satellite from observatories on ground may be regarded as measurement of the free fall of a test mass, the satellite itself, in the gravitational field of the earth. The orbit trajectory is a Keplerian ellipse; it is precessing in space due to the earth's flattening, and modulated by the gravitational signal caused by field variations originating from the earth, and – to a much lesser extent – from the sun, moon and planets. The gravitational signal is like a successive series of tiny accelerations and decelerations along the orbit. Already in 1958, with data from Sputnik-1 and Sputnik-2, the Earth's flattening could be determined from orbit analysis much more accurately than from the preceding 150 years of classical triangulations all around the world. With the advent of the Global Positioning System (GPS) a further break-through happened. Now the orbit of any satellite in a low orbit can be followed from the constellation of GPS-satellites in much higher orbit uninterruptedly, in three dimensions and with cm-precision. However, while this approach proved rather successful, being global, uniform and fast, an intrinsic problem remained. It is the limitation of spatial resolution due to the large distance of satellites from the Earth. The strength of the field is quickly decreasing with increasing distance from the earth as expressed by Newton's "inverse squared distance law".

▼ FIG. 3: GOCE sensor system with the gradiometer instrument in its center, a geodetic GPS-receiver, three star trackers, two ion thrusters at its rear end, magnetic torquers and cold gas thrusters for calibration (courtesy: ESA)

◀ FIG. 4: Global map of geoid heights (in meters) relative to an ellipsoidal figure in hydrostatic equilibrium



EARTH GRAVITY AND ITS CONTRIBUTIONS

Size of effect relative to g [in m/s^2]	The various contributions
10^0	Earth as a homogeneous sphere
10^{-3}	Oblateness and centrifugal acceleration
10^{-4}	Mountains, valleys, ocean ridges, subduction zones
10^{-5}	Density variations in lithosphere and upper mantle
10^{-6}	Sediments, salt domes, ores
10^{-7}	Temporal variations due to solid earth and ocean tides
10^{-8}	Loading effects, atmospheric pressure, groundwater variations
10^{-9}	Pole tide, sea level

◀ TABLE 1:
Earth gravity and
its contributions

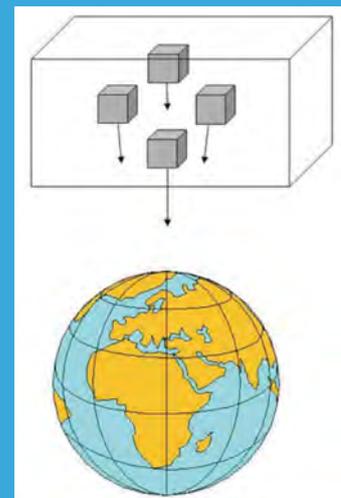
Gravitational gradiometry

For this reason GOCE is applying the principle of gravitational gradiometry. Gravitational gradiometry is designed to counteract the signal attenuation at orbit altitude. Instead of measuring the “free fall” of a single satellite, gravitational gradiometry is the measurement of the relative motion between several test masses. In the case of GOCE six test masses are used. The gradiometer consists of three orthogonal single-axis gradiometers, each 50 cm long, with their common midpoint at the satellite’s centre of mass. The x-axis is parallel to the satellite body of GOCE, roughly in flight direction, the z-axis is pointing towards the Earth and the y-axis is perpendicular to the former two, approximately orthogonal to the plane of the orbit. Each single-axis gradiometer has two very precise accelerometers at its end points. These contain a $4\text{ cm} \times 4\text{ cm} \times 1\text{ cm}$ cubic test mass, made of Rhodium-Platinum. Their weight is 320 gram. Each test mass is kept levitated inside its housing without touching its walls, suspended by an electrostatic feed-back system [3]. If one of these accelerometers would be placed exactly at the satellite’s centre of mass, it would sense zero- g : The gravitational attraction of the Earth on the accelerometer’s test mass would be identical to that on the satellite. At 25 cm distance from the satellite’s centre the accelerometers are operating in a “micro- g ”-environment. They sense the tiny gravitational acceleration difference of the Earth’s field between the location of the test mass and that of the satellite’s centre of mass, just 25 cm above, below, in front, behind, to the left or to the right of it. The signal size is less than 10^{-6} of g . In order to recover the small variations of the earth’s field, caused by mountains and valleys, ocean ridges, subduction zones or mantle convection, the *relative* precision has to be 1 ppm. See also Box 2. This implies that the required sensitivity of the accelerometers is of the order of 10^{-12} m/s^2 . The gravitational gradients are then the differences of the measured accelerations in x, y and z direction along each of the three gradiometer arms. The gradiometer instrument is shown in Figure 2. Since the gradiometer instrument is rigidly mounted in the spacecraft and the satellite is Earth-pointing it performs one full rotation with each orbit revolution. Essentially this

is a rotation about the out-of-orbit-plane y-axis in inertial space. Consequently, the gravitational signal is superimposed by centrifugal and angular accelerations. They have to be reconstructed and eliminated. While the gravitational and centrifugal part of the 3×3 matrix formed by the nine

BOX 2

We see a “satellite” with four freely floating test masses in its interior, in orbit around the earth. If one of these test masses would be placed exactly at the centre of mass of the satellite it would remain there. Seen relative from the satellite, it feels “zero- g ”. Seen from the outside, the gravitational force of the earth on the satellite is identical in magnitude and direction to that on the test mass. There is no acceleration difference. If the test masses are placed slightly “higher” or “lower” or in front or behind the satellite’s centre of mass, as shown in the figure, they are attracted by the earth slightly more or less or in a different direction compared to the satellite, as indicated by the arrows in the figure. So the test masses are in a “micro- g ”-environment. There is a tiny difference between earth gravitation on the satellite and on each of the four test cubes. At a distance of one meter from the satellite centre this difference is of the order of one millionth of g . In the case of the GOCE gradiometer, the test masses are kept at a fixed position using an electrostatic feedback system. The gradients are derived from the measured acceleration differences. ■



acceleration differences is symmetric, the angular accelerations part is skew-symmetric. It can therefore be identified. The angular accelerations are then combined with the observations of a set of three highly sensitive star trackers in order to reconstruct the angular rates [5]. In parallel to the gradiometric method, the gravity field is deduced (with much less spatial details) from the GOCE-orbits in a classical manner, as mentioned above. The orbits are reconstructed purely geometrically from the ranging of GOCE relative to the GPS constellation, *i.e.*, without employing orbit mechanics. Regular comparisons with laser distance measurements from several ground stations confirm their centimetre accuracy.

Atmospheric drag compensation

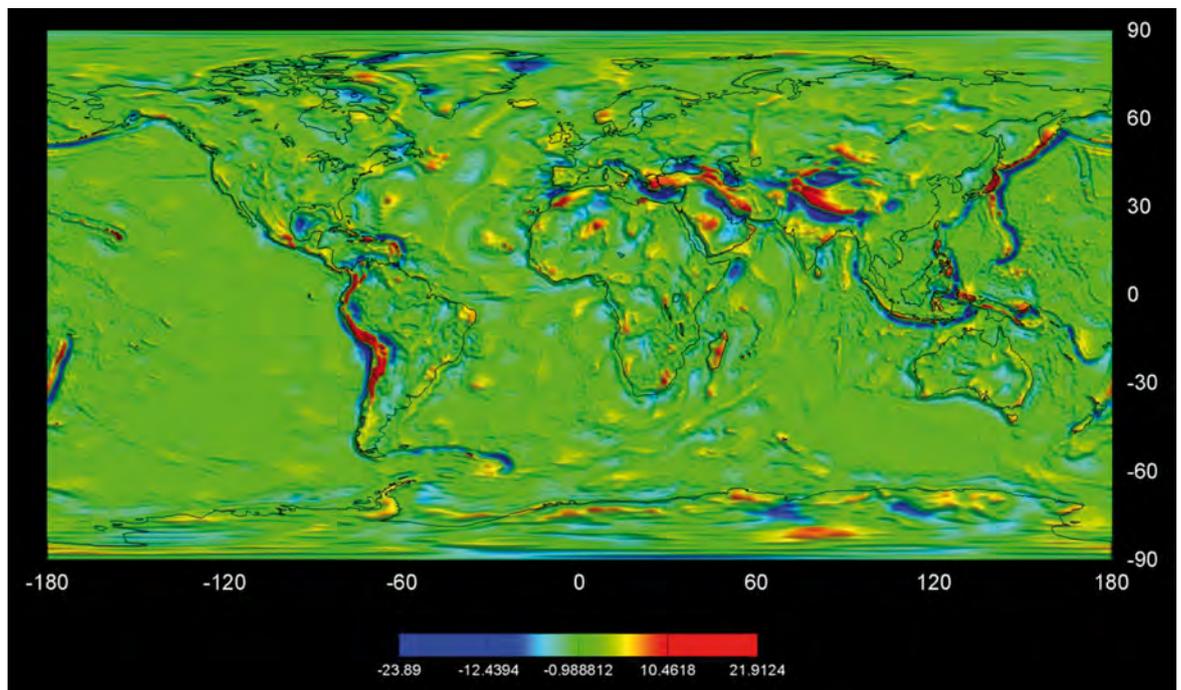
A further novelty of GOCE is its extremely low orbit altitude of only 255 km. Such low orbit requires continuous compensation of atmospheric drag. The drag effect on the spacecraft is measured by the complete set of accelerometers as common-mode signal and counteracted by a set of two proportional ion-thrusters. The orbit is sun-synchronous with an inclination of the orbit plane of 96.7 degrees relative to the equator plane. In 61 days GOCE covers the Earth with a dense net of ground tracks. After each of these orbit cycles the gradiometer is re-calibrated. This is done by randomly shaking the satellite with a set of cold-gas thrusters. Time varying gravitational effects coming from the satellite itself are minimized. For this reason the solar panels are rigidly mounted to the satellite body; the satellite structure is stiffened using carbon sandwich structures and the gradiometer instrument is operating under almost perfect thermal stability. The complete sensor system is shown in Figure 3. In summary, the gradiometer is operating in a laboratory environment, perfectly

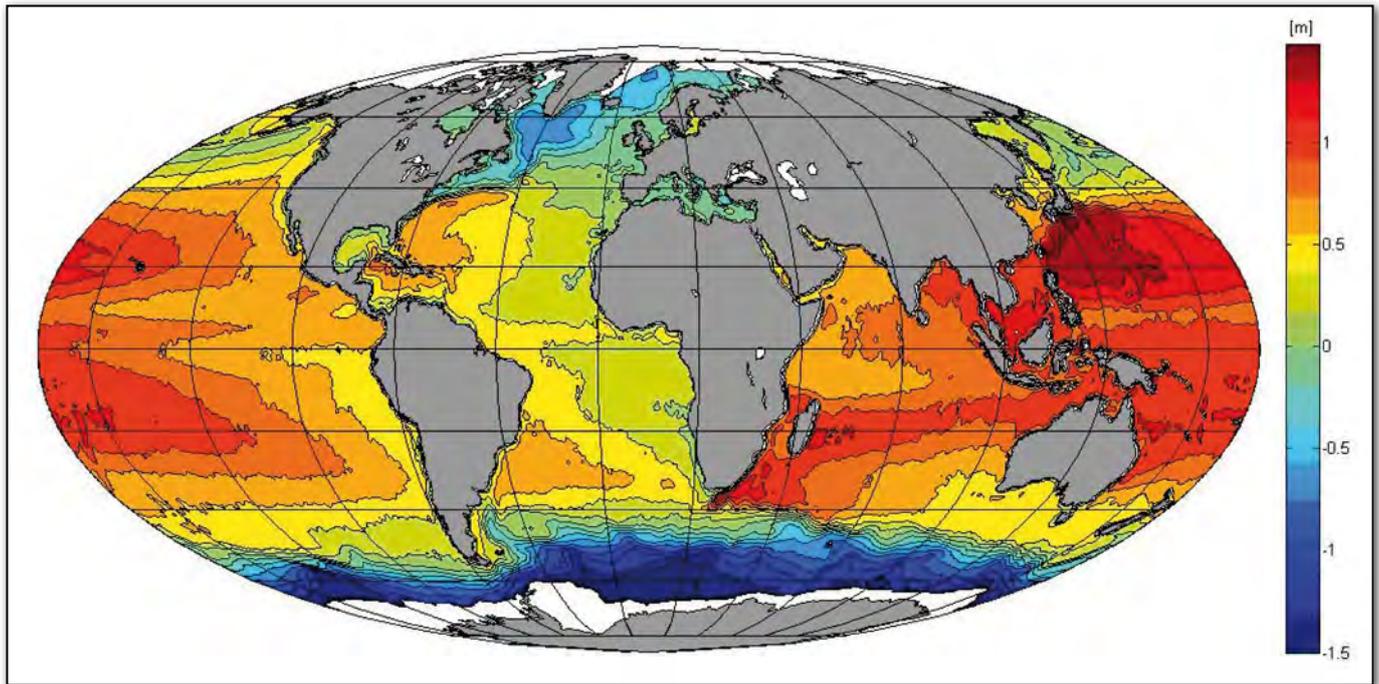
tailored to the needs of a gravitational experiment of this high standard. Since November 2009 GOCE is delivering science data [6], see also [7].

Figure 1 shows the global geoid as derived from the first six months of data. The bumps and dips shown there represent the deviations of the geoid from a best fitting ellipsoid; they range from -100 m south of India to +80 m around New Guinea and they are caused by large density contrasts deep in the Earth's mantle. The geoid is one of the level surfaces of the Earth's gravity field. It is the equipotential surface at mean sea level. Probably more revealing than figure 1 is a comparison of the geoid to an ellipsoidal figure in *hydrostatic equilibrium*, see Figure 4. It nicely emphasizes the imbalance between the major zones of upwelling hot mantle material, the so-called ring of fire, and those with colder material descending from the surface into the mantle. If one removes the long wavelength structure of this map, say scales longer than 1000 km, the high correlation of the remaining geoid looks almost like an introduction into geodynamics. This is done in Figure 5. It emphasises all tectonic features of the lithosphere and upper mantle, such as subduction zones, ocean ridges, transform faults and zones of postglacial uplift.

This immediately suggests employing the GOCE geoid and gravity maps together with seismic tomography for a joint inversion, with the goal of improving global and regional Earth models. Several groups are currently working in this direction. First tests show that GOCE is producing much more consistent and accurate gravity and geoid maps of South America, Africa, Himalaya, South-East Asia and, very importantly, Antarctica [8]. It may also shed light on the open question of a suspected large meteorite impact in Wilkes Land, probably hidden under Antarctica's thick ice shield.

► FIG. 5: Global map of the short-scale structure of the geoid (spherical harmonics up to degree and order 20 subtracted). The geoid anomalies exhibit a strong correlation with geodynamic processes such as subduction zones, ocean ridges, transform faults and areas of glacial isostatic adjustment





Oceanography

While in solid-earth physics the geoid serves as a measure of mass imbalance, its role in oceanography is that of the hypothetical ocean surface at rest. Without tides, winds and the effect of atmospheric pressure differences the ocean surface would coincide with the geoid. The deviation of the actual ocean surface from the geoid is therefore a measure of the strength of ocean circulation. Several very accurate models of the actual mean sea surface exist. They are derived from a 20-year long sequence of satellite radar altimetry missions. The difference of the two surfaces, the altimetric mean sea surface and the GOCE geoid, gives the mean dynamic ocean topography, representing the deviation of the actual sea surface from its hypothetical state-of-rest. The height variations are only of the order of 20 to 30 cm, with maximum values up to 1 to 2 metres in the major ocean circulation systems such as the Gulf Stream, the Kuroshio Stream or the Antarctic Circumpolar Current, as shown in Figure 6. Ocean topography is maintained by the balance of the pressure differences induced by the dynamic topography and the Coriolis force on the water masses moving relative to the rotating earth. From the slopes of the mean dynamic ocean topography follows directly the strength of the ocean flow [9]. It is now for the first time, that the variations of the mean dynamic ocean topography are available, globally consistent, accurately and with such high spatial detail. They are derived from space without the aid of any oceanic in-situ data or models. It is important new input for improved numerical models of the ocean and for improved estimates of heat and mass transport in the oceans.

The GOCE geoid model is also needed for a unification of the national and regional height systems around the world. First trials with height data from North America,

Europe and Australia have revealed off-sets of close to one metre. A globally consistent height reference is needed for sea level studies, geo-information systems and the conversion of GPS-heights to physically meaningful heights above the geoid. GPS-heights alone are simply heights above a conventionally adopted reference ellipsoid.

All sensor systems of GOCE are functioning well. The expectation is that after re-processing and analysis of the full data set from November 2009 to summer 2012 all mission objectives will be met. Currently plans are discussed to use the last year of the mission (from autumn 2012 to autumn 2013), to descend the satellite to an even lower orbit, ultimately by 20 km. This will further enhance the sensitivity and lead to a further improved spatial resolution and accuracy of the GOCE geoid and gravity field world map. ■

▲ FIG. 6: Mean dynamic ocean topography (MDT) deduced from the difference of the mean sea surface and the GOCE geoid. The mean sea surface is derived from twenty years of satellite radar altimetry. Typical variations of MDT are of the order of 30 centimeters, MDT of the major ocean currents such as Gulf stream, Agulhas, Kuroshio or Antarctic Circumpolar Current reaches one to two meters

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Museo Leonardo da Vinci

■ Paola Cueno National Museum of Science and Technology, Milan, IT DOI: 10.1051/eptn/2013104

Even a short visit to the National Museum of Science and Technology Leonardo da Vinci in Milan can give an idea of the two worlds that this institution tries to bind together. Past and present coexist in its buildings: the Main building, hosted in an early sixteenth century Olivetan monastery in the heart of Milan, stands next to the Air and Water building from the 1960s and the Rail building with a façade that mirrors that of a late 1800s train station.

The Museum is named after Leonardo da Vinci, an emblematic character that still embodies the merging of scientific and humanistic knowledge. It houses the world's largest collection of models interpreting Leonardo's drawings. Created in the 1950s, it is the first to have dealt systematically with Leonardo da Vinci's scientific-technical studies. Today a selection of models is permanently exhibited in the Leonardo Gallery and still represents a central attraction in the Museum.

With its 40,000 m² surface it is the largest science and technology museum in Italy. Since its opening in 1953 - by its founder Guido Ucelli, engineer and Milanese industrialist - the Museum developed following the idea that a modern museum of

science and technology could fill the conventional gap between scientific and humanistic knowledge.

Its collections include technical and scientific instruments and equipment, machines and small and large-sized plants mainly related to transport (road, water, rail and air transport), production of energy, iron and steel, history of telecommunication, development of polymeric materials, astronomy. It represents a record of the history of science, technology and industry in the 19th and 20th century, particularly in Italy.

The largest object in the Museum, that has attracted many visitors since its arrival, is the Toti submarine (1967) the first to be built by Italian shipbuilders since WWII.

Other large objects on display are the Regina Margherita thermo-electric

▲ Il Museo under LED illumination during the international Light Festival of Milan

plant (1895) at the entrance of the Museum, the Gr 552 036 steam engine known as "Indian suitcase" (1900) and the Gr 691 022 steam engine (1895) in the Rail building, the schooner "Ebe" (1921) and the bridge of the Conte Biancamano liner (1925) in the Air and Water building, the Siziano-Pavia radio transmitting station (1932) in the Telecommunication area. At the Museum visitors also find experimental and industrial devices belonging to the Nobel Prize laureate Guglielmo Marconi. Other objects related to Nobel Prizes are Giulio Natta's work table and his model of isotactic polypropylene, together with the Central Section of the UA1 (Underground Area, Experiment One) Detector used at CERN, Geneva, by Carlo Rubbia and Simon van der Meer.

Unique or very rare items on display

per tuo disturbam
I nanotecnologi sono al Museo per studiare le proprietà dei materiali nanostrutturati e per confrontarsi con te. Hai qualche curiosità sulle nanotecnologie? Chiedi ai ricercatori.

please disturb.
Nanotechnologists are here to study the properties of nanostructured materials and to talk with you. Interested in nanotechnologies? Ask the researchers.



are the reconstruction of Giovanni Dondi's 14th century Astrarium (built by Luigi Pippa in 1963); the celestial and terrestrial globes by Vincenzo Coronelli and Silvestro Amanzio Moroncelli (end of 17th century); Jeremiah Sisson's Equatorial Sector (1774); Nipkow-Baird's mechanical television (1930-32); Macchi's MC.205 Veltro military aircraft (1943).

Exhibitions include authentic historical workspaces created in the 1950s and in the 1960s. Many of these include original objects with a great historical value. Among these are a cast-iron foundry; a bells foundry; a trip hammer hall; the Falck rolling mill; a monastery pharmacy; clock-maker Bertolla's workshop; lutist Bisacchi's workshop.

The Museum also invites visitors to experience phenomena directly and to

meet contemporary science through numerous interactive workshops (13 interactive laboratories – i.lab - being constantly renewed and expanded). Explainers invite school groups and families during weekends and holidays to take part in activities regarding Energy, Biotechnology and Genetics, Food, Robotics and many other areas of scientific interest. Children aged 3 to 6 can always take part in specifically designed activities while in the Leonardo i.lab adults and children can operate some reproductions of the master's machines or get messy with his artistic techniques. At the Museum there is also a real research laboratory, created within the European project NanoToTouch, where nanotechnologists of the University of Milan conduct their research behind a glass window, always available to answer

▲ (upper) Please disturb the scientists in the nanotechnology lab!

◀ (left) Having fun at the robotics interactive workshop

▲ (centre) Mechanism for wing flapping by Leonardo da Vinci

▶ (right) Visitors to the largest piece on display: the Toti submarine

questions from visitors passing by. Connected to Leonardo's models collection, the Museum has recently developed a free Italian and English iPhone App "Leonardo Around" dedicated to the exploration of Leonardo's work and legacy in Milan. Furthermore, it has recently inaugurated at the *Cité des Sciences et de l'Industrie* in Paris, the exhibition "Léonard de Vinci, projets, dessins, machines" (open until 18th August 2013), which is based on 40 historic models from the Museum's Leonardo collection.

Museum website:

www.museoscienza.org (in Italian and English).

Contacts:

info@museoscienza.it

Tel.: + 39 02 48 555 1



Opinion: Rethinking our relation with society and industry

Wim van Saarloos, *Theoretical Physicist and director of the Foundation for Fundamental Research on Matter (FOM) in the Netherlands*

There is ample reason for us physicists to reflect on the relation of academic physics research with society and industry. Europe is struggling with an economic crisis and will face an increased competition from Asia. New initiatives to make Europe a true 'Innovation Union' will no-doubt call upon the innovative power of our field. The 'grand challenges' that Horizon2020 focuses on will have similar impact. These include industrial leadership directly, but touch on the relation between science and industry in less obvious ways as well.

Let me take the energy challenge as an example. There is no doubt that, in order to reduce global CO₂ emissions drastically, we have to come up with radically new ways to generate energy in a sustainable way. Fundamental research on how to harvest sunlight, not only in the form of electricity but preferably also in the form of 'solar fuels', is therefore crucial. Through my own involvement in taking initiatives in this direction, I have come to appreciate that such 'use-inspired basic research' does not fit the traditional dichotomy into basic and applied research. In order to get radical new ideas and concepts, we do need to explore various avenues and leave room for the unexpected possibilities and the creativity of our best minds. In short, we need basic research. Yet, at the same time, the transition to a sustainable society is so gigantic and complex, and involves massive infrastructure from both private and public companies – just think of the oil and electricity companies – that we better focus our research on avenues

In order to get radical new ideas and concepts, we do need to explore various avenues and leave room for the unexpected possibilities and the creativity of our best minds.

which, at least in principle, can be scaled up. Thus there is little reason to explore effects that rely on scarce materials, or compounds and methods which will most likely be expensive to produce on a massive scale. We may also want to keep in mind the willingness of society to accept certain solutions more than others. This is new for most of us, but many are willing to take up this challenge, in view of the enormity of the energy problem. Indeed, a recent workshop we held in the Netherlands on CO₂-neutral fuels had scientists from industry and academia address precisely the question which path fundamental research should explore, given these unusual boundary conditions.

Returning to the goal of making Europe more competitive through enhancing innovation: increasing investment in R&D to meet the Lisbon target is an important first step. Furthermore, the new initiatives taken under the flag of Horizon2020 are crucial top-down initiatives aimed at reaching this. However, top-down approaches and consortia tend to stimulate mostly incremental innovation, and we should also pay attention to the bottom-up innovative power of physics generated by radically new ideas, concepts and gadgets. According to recent studies, there is still a lot to be gained by harvesting bottom-up innovation, and the need to do so will even increase. Indeed, the companies dominating the USA economy are on average quite a bit younger than those dominating the European economy. Moreover, world-wide we see companies become more volatile:

the portfolio of companies that dominate the economy is changing more and more rapidly since radical innovation often comes from the newcomers. Unlike accepted myths of governments in countries like the UK or the Netherlands, the American government does play an active role in stimulating bottom-up innovation. It does so through its investments and programmes, as it realizes the power of creative minds in a research environment which fosters openness towards the possible spin-off of basic research. I believe we owe Europe in these difficult times that we take steps to enhance the contribution of our field along these lines as well. ■

COMING EPS EVENTS

- **ACSTAC**,
Anatolia College Science and Technology Annual Conference
9-10 March,
Thessaloniki, Greece
www.acstac.gr
- **CLEO 2013**,
European Conference on Lasers and Electro-Optics and XIIth International Quantum Electronics Conference
12-16 May 2013,
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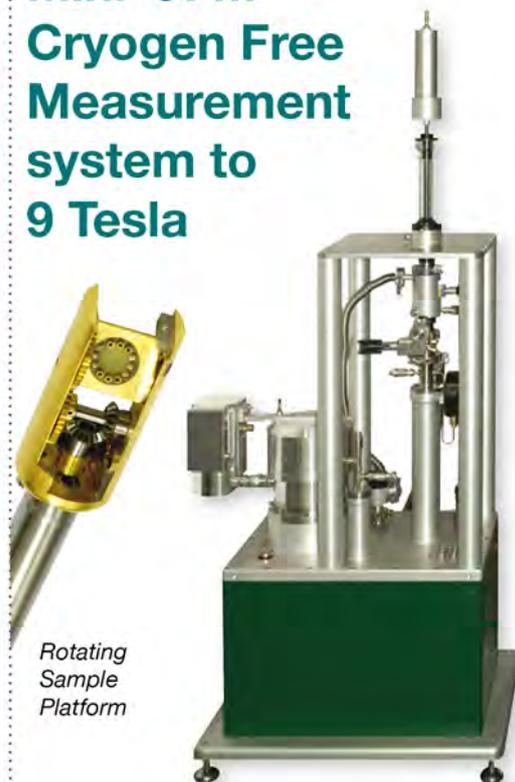
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Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Uuq	Uup	Uuh	Uus	Uuo

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