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The Pursuit of Knowledge
Research infrastructures
Radioactive contamination of seawater
Econophysics: still fringe after 30 years?
Skating on Slippery Ice

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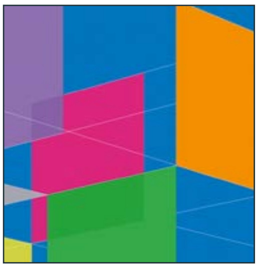
Cover picture: A man leads a woman on a winter speed skating adventure on Lake Minnewanka in Banff National Park, Alberta, Canada. © iStockPhoto. See p.28: Skating on slippery ice.



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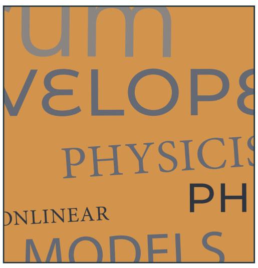

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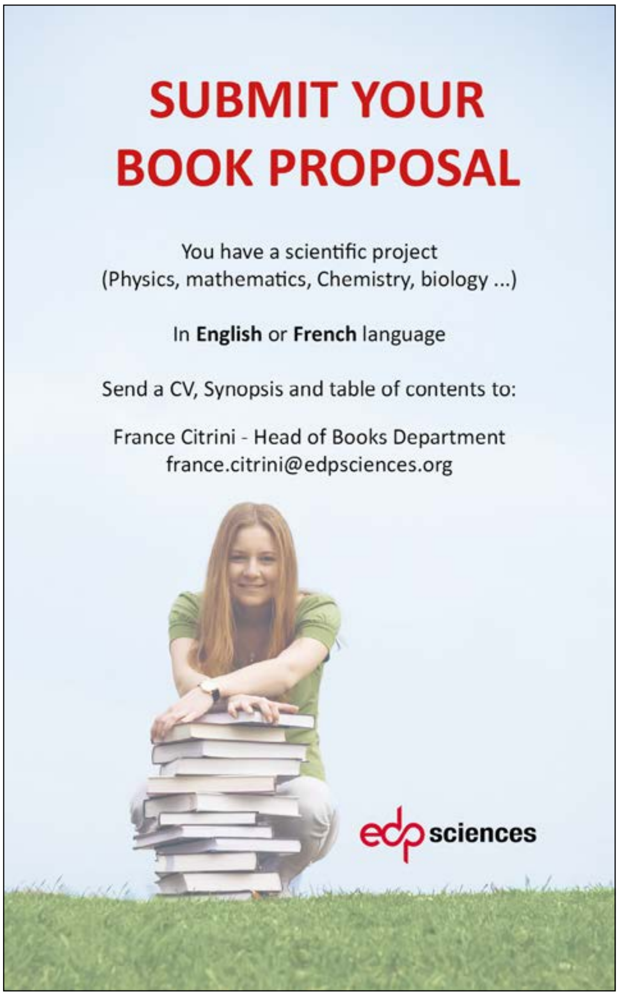
Econophysics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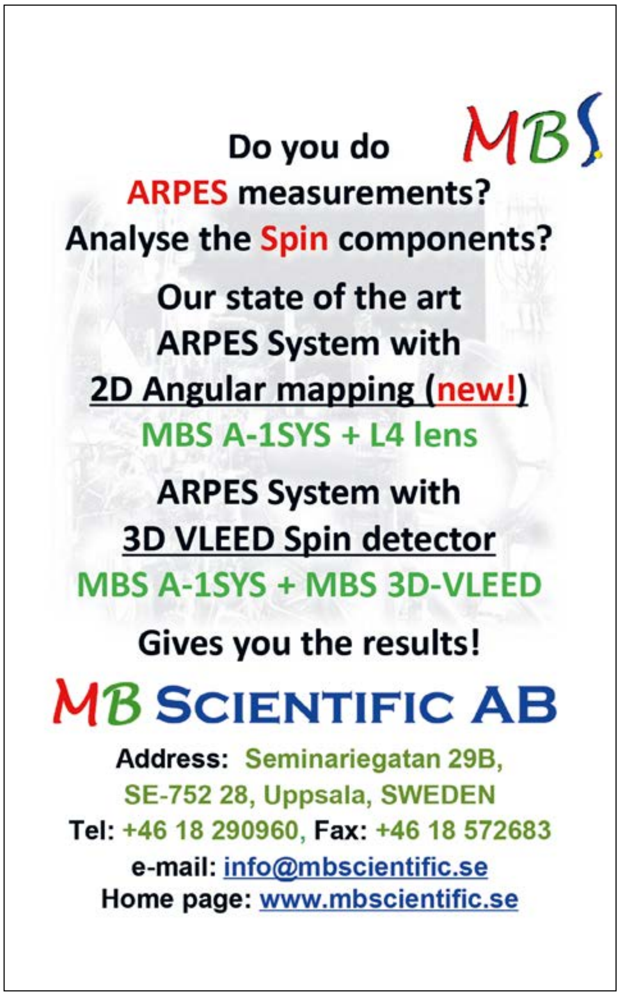
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[EDITORIAL]

S-Class publishing

cOAlition S promotes a bold plan to convert European scientific publishing to Open Access

For many years, the European Physical Society has subscribed to the principle that the results of publicly funded scientific research must be widely available to the scientific community and to the general public, with no paywalls for authors and readers, and across all scientific disciplines. In practice, however, the transition of scientific journal publishing to Open Access has advanced slower than we would like.

In this situation, "cOAlition S for the Realisation of Full and Immediate Open Access" has recently proposed "Plan S", a bold and visionary scenario for converting the publication of all results from publicly funded research to gold-standard Open Access. cOAlition S is a consortium of powerful stakeholders: principally public-sector funding agencies from major European countries, with strong backing from the European Commission and the European Research Council.

The ultimate goals of Plan S are laudable and deserve the support of the scientific community. At the same time, we need to look critically at the proposed implementation. Nobody seems to know what the "S" actually stands for, but it is tempting to translate it to "speed": in its original formulation, the plan calls for the OA transition to be completed by the end of 2019 – less than one year from now.

In the EPS, we are concerned that this and other implementation principles are at variance with a sustainable, well managed transition to OA that protects the core values of today's scientific publishing system. In the era of online publishing, the principal values added by gold-standard OA journals are professional editing, independent peer review, and reliable long-term archiving. Peer review, in particular, is universally recognized as an important – arguably the most important – element in the chain of scientific quality assurance. A forced transition to open access over a short period of time risks to undermine the financial viability of many journals, causing irrecoverable damage to established, well-functioning networks of editors and referees. Related to this, Plan S must protect competition: in a market dominated by a small number of powerful giants, small and medium-size publishers – often supported by learned societies such as the EPS, or other not-for-profit organisations – contribute significant diversity, but operate with shoestring resources and are vulnerable to economic imponderables.

Perhaps the greatest weakness of Plan S is its Euro-centric approach. Scientific publishing is today a global undertaking: non-European authors account for a significant fraction of articles published in European journals, and conversely we often like to publish in non-European journals, especially where they are perceived to be more prestigious than their European competitors. This freedom of exchange, which we take for granted today and which is an important element of competition in the publishing market, could come to an abrupt halt. Other regions and continents are lagging far behind Europe in matters of OA support: neither are their authors likely to receive dedicated funding to support OA publications, nor can major non-European journals be expected to convert to gold-standard OA in the foreseeable future.

In the EPS, we are concerned that some principles guiding the implementation of Plan S are at variance with a sustainable, well managed transition to Open Access that protects the core values of today's scientific publishing system.

Open Access can be implemented under different business models. Plan S makes no recommendation in this respect, but it is easy to predict that most publishers will choose the road of Article Processing Charges (APCs) which most non-European authors, and perhaps even many Europeans, may not be able or willing to afford. At present, most funding agencies in Central and Eastern Europe, but also other countries such as Germany, are absent from cOAlition S. One of the strongest arguments in support of OA has always been that it helps to bridge knowledge divides – not only between North and South, but even across Europe. While Plan S will facilitate access to publications for readers, it must be carefully coordinated with other stakeholders in-and outside Europe to avoid building new barriers for authors.

To be clear, the author of these lines is not an OA sceptic: more than ten years ago, I was amongst the founding fathers of the SCOAP3 consortium under which today the vast majority of papers from High Energy Physics (HEP) worldwide is published in gold standard OA or hybrid journals. SCOAP3 was designed to cater to the needs of particle physics and never had the ambition to be scalable to scientific publishing at large. Still, two important ingredients of its success are that it is a global effort, and that it operates without APCs supported by authors. And although SCOAP3 works with less than a dozen of journals, it took several years to bring it up to speed.

Perhaps there are some lessons to be learned from this example to ensure that, at the end of the day, "S" does not stand for "speed" but for "sustainable". In this spirit, the EPS stands ready to work with cOAlition S on a successful implementation. ■

■ **Rüdiger Voss,**
EPS President

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EPS HISTORIC SITES

in Budapest to Honour the Eötvös Experiment

The former physics building of the Loránd Eötvös University – the physics department was moved from the center of the city to a new campus about 20 years ago, the former building being occupied now by institutes of the Faculty of Humanities – was declared EPS Historic Site a few years ago.

The inauguration of the memorial plaque took place on 12th October 2018 in the presence of Professor Rüdiger Voss, president of EPS, David Lee, secretary general of EPS, and several other representatives of EPS, since the Editorial Advisory Board of Europhysics News held its meeting in Budapest the next day, and many of the board members arrived early enough to participate in the Historic site ceremony.

After the welcome address by Professor László Borhy, rector of the Eötvös University, Professor Voss described the Historic site program of EPS, and then Professor Jenő Sólyom, president of the Loránd Eötvös Physical Society talked about the significance of that building, the role it has played in the history of physics and about the personality of Loránd Eötvös himself.

Loránd Eötvös was professor of physics of the Budapest University from 1871 until his death in 1919. The physics building itself was built between 1883 and 1886 according to his ideas. He lived in this building during the winter season, while when the weather permitted, he came on horseback from his estate in the outskirts of the city. He conducted most of his research here, especially his groundbreaking experiments in which he demonstrated to an extraordinary degree of accuracy, to 1 in 200 million, the proportionality of inertial and gravitational mass. Inertial mass is the mass experienced when a body is forced to accelerate and gravitational mass is the mass determining roughly speaking the weight of the body. In reality the weight of a body is not simply due to the gravitational force between the body and the Earth, since there is a tiny additional component to the weight, a centrifugal force due to the rotation of the Earth, and this component is proportional to the inertial mass. The proportionality or equivalence of the two masses – this distinction is just a matter of units - has been suspected ever since Isaac Newton's experiments, but the first precise measurements were carried out by Eötvös in 1885 and later, between 1906 and 1909, by himself and his collaborators, Dezső Pekár and Jenő Fekete. It was for these measurements that they won in 1909 the prestigious Beneke Prize from the philosophical faculty

▲ Unveiling of the memorial plaque by László Borhy, Jenő Sólyom and Rüdiger Voss (Photo Tamás Selmeczi)

of the University of Göttingen. A few decades later a former student of Eötvös, János Renner could improve the accuracy by one order of magnitude, and it took many more decades until Robert H. Dicke with his coworkers could achieve a further one order of magnitude increase in the accuracy. As we heared later on in the afternoon, even nowadays people are still trying hard to improve upon these results.

The equivalence of the two masses was an important ingredient when Albert Einstein developed his general theory of relativity. This theory is based on Einstein's equivalence principle, a bold step beyond the equivalence of the two masses, namely on the complete physical equivalence of a gravitational field and a corresponding acceleration of the reference system.

Eötvös's contribution to physics and geophysics, and to science, culture and education in general was much richer than that experiment. He developed the Eötvös torsion balance or Eötvös pendulum, an extremely sensitive instrument for measuring local variations in the gravitational field. Very modestly he wrote about this device as follows: *"It is as simple as Hamlet's flute, you only have to know how to play it. Just as the musician can delight you with splendid variations from his instrument, so the physicist can measure on this balance, with no less delight, the finest variations of gravity. In this way we can peer into the Earth's crust at such depths that neither our eyes could penetrate, nor the longest drills could reach."* I wonder what he would have said if he had known that the use of his torsion balance would become instrumental in prospecting for oil fields in Texas and Venezuela.

Besides his scientific activity, he was minister for a short while responsible for public education and religious affairs, rector of the university for one period, president of the Hungarian Academy of Sciences for 16 years, and founder of the Hungarian Mathematical and Physical Society, the predecessor of the Roland Eötvös Physical Society. The international scientific community knows him, however, mostly for his achievements mentioned above. Hundred years after his death his work is still deeply appreciated and his name still comes up in almost all textbooks presenting the experiments underlying Einstein's theory. That is why UNESCO accepted the Hungarian proposal to be associated with the worldwide celebration of Loránd Eötvös in 2019 on the occasion of the 100th anniversary of his death.

After the unveiling ceremony a lecture series was organized in the main lecture hall where once Eötvös used to deliver his lectures. Professor Clifford Martin Will of the University of Florida, Gainesville gave a talk on the Eötvös experiment showing how new techniques help us to improve upon the already fantastic accuracy achieved by Eötvös and his coworkers in demonstrating the equivalence of inertial and gravitational mass. The next speaker, Professor Viktor Wesztergom, head of the Geodetic and Geophysical Institute of the Hungarian Academy of Sciences put Eötvös's contribution to the foundations of geophysics into historic perspective, pointing out that our knowledge about the Earth's interior is still unsatisfactory but expressing his belief that the intellectual heritage of Eötvös and the power of the modern geophysics may result in a breakthrough in understanding our planet.

This festive event was a good occasion for the Hungarian Physical Society to commemorate at the same time the 50th anniversary of EPS. The president of EPS, Professor Voss, talked about the fifty years of service of EPS to the European physical community, outlining its mission and actions, the challenges and opportunities, while a former president of EPS, Professor Norbert Kroó talked – illustrated with personal remembrances – about the strong connections between EPS and Hungary from the very beginning, and how physics changed our lives in the last 50 years. ■

■ **Jenő Sólyom**

▼ Celebration in front of the former physics building of the Budapest University (Photo Tamás Selmeczi)

Address for the 50th anniversary of the EPS
The Pursuit of Knowledge as European Endeavour

The EPS was formed to contribute to the development of Physics in Europe and it now plays an important role in representing the European physics community vis-à-vis European institutions. But, from the start, the idea was to do more: strengthen the European cultural identity and unity. In the worrying times we live in today, I want to talk about this wider role of Science.

In particular how the pursuit of knowledge enriches us scientists, and the society at large, in so many ways, much beyond the purely utilitarian calculations of achieving economic benefits or dealing with particular technical problems we are too often limiting it to.

It is always worth reminding ourselves of transformative contributions Science has made in the past to European society, and more widely to the whole world. What is often called the Scientific Revolution - spanning roughly the time from the publication of Copernicus's *De revolutionibus orbium coelestium* in 1543 to the publication of Newton's Principia in 1687 – was of course a time of great advancement in our understanding of natural phenomena. But these advances did far more than help us understand, for example, the movement of planets or provide us with better instruments and techniques. They revolutionised our conception of the place of Humanity in the Universe and ushered in an unprecedented change in every sphere of life. From the religious to the economic, from the personal to the political. They also gave us a firm, universal foundation on which to make progress – the scientific method.

Such a change happened thanks to great minds but also to clever inventors. Staring at the sky has probably occupied humans ever since the first one was born. And the sky is changing all the time. It was therefore natural to consider that our vantage point was at the centre of the Universe. The appearance of erratic bodies, the planets, in these constellations of stars was a challenge to the mind. Very clever but cumbersome constructions were used to provide a geometric basis for their movements, the famous epicycles.

As you all know, a radically different conception was proposed in 1543 by Nicolaus COPERNICUS, a Polish catholic cleric, in his *De Revolutionibus*: he put the Sun at the centre of the planetary system, and no longer the Earth. Soon after its publication, the Dominicans were already considering banning Copernicus' work. John CALVIN in Geneva preached a sermon in which he denounced those who *"pervert the course of Nature"* by saying that *"the Sun does not move and that it is the Earth that revolves and… turns"*.

In the second part of the 16th century, the Danish astronomer, Tycho BRAHE, although he opposed Copernicus' views, insisted on the need to rely more on observations and, for that purpose, developed more accurate instruments. He in particular concentrated his efforts on the observation of Mars, and his findings were fundamental to the major breakthrough made by Johannes KEPLER. Working in Prague with him, KEPLER proposed in 1609 and 1619 precise laws stating that planets are moving along ellipses, and not circles, of which the Sun occupies a focus. This gave a solid basis for the heliocentric system to claim victory.

Another considerable step was taken by Galileo GALILEI who, over the course of a very productive life, also developed instruments, such as the telescope, and laid the foundations for a general theory of Physics. He believed in the critical role of mathematical concepts to describe the Universe as he explained in his famous essay *Il Saggiatore* published in 1623.

An even more decisive step was taken by Isaac NEWTON in 1687 with the publication of his *Philosophiae Naturalis Principia Mathematica*. In a single book, on the model of Euclide's Elements, he made three breakthroughs: he developed the Differential Calculus leading to the notion of instantaneous speed; from this, he could derive the concept of acceleration, at the heart of the Fundamental Law of Mechanics, his second major achievement; and the third achievement was his Law of Gravitation. This allowed him to propose a coherent and comprehensive theory establishing Kepler's laws on first principles. This new framework can also be seen as the turning point in the development of industry because Newton's approach to Mechanics opened the way to more systematic quantitative engineering, a major impact of Science on Society.

All this happened within a period of 150 years with contributions from many diverse European backgrounds, at a time where Europe was a troubled territory and during which scientists did not necessarily have an easy life. They often had to struggle to find patrons, and some of them had to fight prosecutions. This was for example the case for KEPLER who dedicated much energy to defending his mother, who was accused of and at one point jailed for being a witch. Later, Kepler's tomb was destroyed by Swedish soldiers during the Thirty Years War, and his writings were lost for over a century. They were nevertheless recovered and are now kept in Saint-Petersburg. After moving from Pisa to Padova, GALILEI enjoyed a good environment for his intellectual work and also for developing technical tools. But he spent the last part of his life under house arrest, after having been forced to renounce his Copernican beliefs in order to escape torture by the Inquisition, because his claims contradicted parts of the Holy Scriptures.

So we see that Science is built on observations made possible by the development of ingenious tools and intricate interactions with sometimes counterintuitive theories. Scientists have to be open minded enough to allow observations to change their minds. And these observations can serve as the basis for others to go further by pure creative thinking.

▲Speakers of the EPS50 Festakt: Luisa Cifarelli, Serge Haroche, Ernst-Ulrich von Weizsäcker and Jean-Pierre Bourguignon.

Because, while the Scientific Revolution was at first built upon recovering ancient knowledge - in particular the foundation of ancient Greek learning as preserved and expanded by medieval Islamic science in some cases – it soon developed a method of its own, the scientific method.

The earlier Aristotelian approach of deduction, by which analysis of known facts produced further understanding, was replaced by induction - to abandon assumption and to attempt to observe with an open mind. Francis BACON played a major part in establishing and popularising this theoretical framework for Science, and many of his concepts are considered part of proper methodology today.

The late astronomer André BRAHIC, whom I miss a lot, phrased it beautifully: *"To understand the scientific method, one has to realize that progress comes from a continuous process of calling into question. A proposition is only scientific if it is falsifiable, in other words if anyone can verify it or invalidate it."* This is why *"the history of scientific ideas is an excellent school of doubt, humility, rigour, honesty and the critical spirit, which are prime virtues in the service of a passion for knowledge."*

Let me now jump ahead and bring another transformative story into focus - the coming together of electricity and magnetism, and the radical revision of our understanding of space and time that it brought, which became one of the pillars of modern Physics as you all know. The first element of this other saga was the discovery by André-Marie AMPÈRE of the need to consider electricity and magnetism as dynamically connected to one another. The proper unifying setting to develop the theory was provided by the towering figure of James Clerk MAXWELL, who published his famous equations in 1864. At the end of the 19th century, physicists around the world were struggling to determine what medium was the background supporting the motion of light, the so-called "aether".

Very careful experiments to detect relative motions vis-à-vis the aether were set up by Albert Abraham MICHELSON and Edward MORLEY and performed in 1887 in Cleveland, my first reference outside Europe. They established that the usual law of addition of velocities was violated in the case of the movement of light relative to the aether. This was discussed by Hendrik Antoon LORENTZ, who made several attempts to explain the phenomenon by a shortening of the length in the direction of the movement. This triggered Albert EINSTEIN's deep reflection on the *Electrodynamics of moving bodies*, his 1905 revolutionary paper. This led him to propose the speed of light as an absolute that cannot be surpassed in any material movement. The end of Newtonian Mechanics, which appeared only as a low velocity limit of the new Special Relativity Theory! Soon after, Henri POINCARÉ and Hermann MINKOWSKI identified the mathematical concepts underpinning Einstein's theory, a geometry which had not been given too much attention by mathematicians leading to the clarifying point of view of a four-dimensional space-time.

My interest in recalling here the way this revolution in Physics took place is two-fold: first, to show another instance where experimental facts forced theoreticians to come up with new formulations, and even finally to abandon one of the best established theory with extraordinary success, Newtonian Mechanics; second, to acknowledge the need to bring together many different points of view to come to a breakthrough and to exploit it properly. Once again, even if the initial thought-provoking experiment was conducted in the United States of America, these major achievements happened in Europe through the contributions of very diversely oriented but nevertheless interdependent scientists.

And this shows the remarkable power of Science to stand above the political fray and the constant flow of events. At the time of the Enlightenment a set of conditions arose allowing a transnational community of brilliant thinkers known as the "Republic of Letters" to freely circulate and distribute ideas and writings. And this Republic proved that it can survive even the harshest climates. We should never forget this at a time where some governments want to strictly orient the work done in the laboratories of their countries.

And these examples, many others could have been given, show that the pursuit of knowledge is a profound endeavour whose benefits go far beyond producing the next start-up or app. Frontier research increases the stock of useful knowledge, both codified (*e.g.* via publications) and tacit (know-how and experience). It trains skilled technicians, graduates and researchers in solving complex problems. It produces new scientific instruments and methodologies. It trains scientists working on panels to recognize good opportunities, spreading novel ideas. It creates international peer networks circulating the latest knowledge. As we have seen, it can even bring totally new light on questions about societal values and choices.

Intense efforts in Frontier research allow countries to be at the forefront of knowledge creation because, without access to these results, individuals, firms or countries lack the capacity to identify and assimilate potentially exploitable knowledge created elsewhere. It is a critical point as, for each country or region, the most useful knowledge most likely comes from elsewhere.

Furthermore, Research and Education, particularly postgraduate education, are intimately linked. For example, some 60% of the funding provided by the ERC for research goes to staff costs, predominantly to support PhD candidates and postdoctoral researchers working in the teams of ERC funded Principal Investigators. A number of these highly trained individuals will go on to work outside academia, using their acquired skills to impact the economy.

When Europe aims to be the top 'knowledge economy', it has no choice but to give

▲EPS presidents and guests in the EPS50 Festakt.

a high priority to funding Frontier research because it does not only produce new knowledge but also new knowledge workers. And Europe needs to create the conditions to attract the brightest students to its higher education institutions. The competition for brains has become fierce with Asia advancing at a fantastic pace, something European policy makers should never forget.

So what are these conditions? From my experience as a scientist, I see three main elements. First, we must not forget that the researchers themselves are the most essential element, as they are the human beings making things happen and work. Second, researchers need to have the time and freedom to explore new knowledge. And third, is the need to respect diversity and risk taking, as well as encouraging interdisciplinarity in Science.

Anybody entering a demanding working environment, such as ours, wants to get some assurance that she or he has a chance of a career, of advancement, of reward. In particular we need to plot out a sustainable career path for talented young researchers. We must consider employment and working conditions, open, transparent and merit-based recruitment, without forgetting of course to continue to improve the position for/of women in research, as there is still for that a long way to go. For young researchers, having the possibility of being exposed early to other research environments is critical, provided they can do that without having to rush from a one-year position to the next.

We also need to guarantee scientific freedom for researchers. The interactions between basic research, technological progress and economic growth are varied, complex and non-linear. But it is accepted that technological progress requires a combination of basic or curiosity-driven research and applied research. Policy-makers have to acknowledge that.

To understand why, we can go back to the foundation of the scientific method in Bacon's Novum Organum published in 1620. He argued that *"Nature can only be commanded by obeying her."* In other words Humanity can govern or direct the work of Nature to produce definite results but this requires understanding how Nature works. In this way, he believed, Humanity would be raised above conditions of helplessness, poverty and misery, while coming into a condition of peace, prosperity and security. And compared to his own age, he has been proven spectacularly right! Let us hope this does not get forgotten by too many people, in particular in political circles.

All technologies harness natural phenomena. These phenomena exist in the world regardless of our desires. Nobody decided one day that better means of communication were needed, and then somebody discovered electromagnetic waves. They were found by Heinrich HERTZ emphasising the beauty of Physics. He based his work on the theoretical considerations of Sir James Clark MAXWELL. The basic circuits used in computers were not found by people whose aim was to build computers. They were discovered in the 1930s by physicists counting nuclear particles. In this century Jennifer DOUDNA was one of the first to recognise the significance of CRISPR, leading to a radically new and amazingly efficient approach to genetic engineering. She began to work in this area because she thought the chemistry might be "cool". So the longer-term, higher-risk research undertaken by our universities and public research institutions needs to be supported in their own right without imposing that it should, in the first place, complement the activities of the private sector. This is why it is short-sighted, and actually counterproductive, not to allow researchers enough space to explore the latest frontiers of knowledge, rather than only what might be useful today or tomorrow morning.

Thirdly, I am convinced that a healthy science system needs diversity. Some of the research with the biggest impact lies outside firm disciplinary boundaries. As a consequence, there is need for a variety of effective programmes to support research. Their evaluation must involve people with an inside knowledge of the practices of the discipline and of the environment in which researchers operate. But the scientific community must also look at itself and behave. We, scientists, cannot ask for scientific freedom from the funders and then be too conservative in our own decisions. The quality of the selection mechanisms in the system is therefore one of the most decisive factors. Reviewers and promotion boards need a wide understanding of scientific developments and of what favours them. They have to be broad-minded and not to adhere to rigid schools of though and it is possible to find evidence of this rigidity at the highest level of science.

For example, I would like to read to you a brief excerpt from a document written on 13 June 1913 offering an ordinary membership in the Prussian Academy in Berlin to EINSTEIN, then Ordinarius at the ETH Zurich. It bears the signatures of Max PLANCK, Walther NERNST, Heinrich RUBENS and Emil WARBURG. The statement that accompanies the offer says: *"One should not take too much against him that it happened to him to go too far in his speculations, e.g. in his hypothesis of a quantum of light; without taking some risks, one cannot expect any real renovation also in the most exact natural sciences."* This text, written eight years after the *Annus mirabilis* 1905, in which EINSTEIN made three major breakthroughs, including understanding the photoelectric effect by introducing light quanta, shows that even great physicists can fail to appreciate the full significance of major discoveries. Fortunately, thanks to their acceptance of risk, they supported the idea of hiring him!

Another important aspect of this diversity is having the right institutional framework. Europe by its nature offers a diverse landscape with the existence of national and EU level as well as intergovernmental institutions to support science. Sometimes this can be a source of frustration because it forces to navigate diverse environments with different references but I think, more often than not, it is a source of strength.

Take for example the Centre Européen de Recherche Nucléaire (CERN) that was created to develop the collaboration on research on elementary particles at the European level. Establishing such an institution was indispensable to reach a critical mass to build an accelerator able to bring radically new knowledge. Initially, it was also a tool to reintroduce German scientists in the concert of science after the Second World War. It has grown into a truly international enterprise hosting scientists from many different countries, notably countries facing very tense relations, as well as developing technology at the highest level in order to achieve its scientific goals.

Let me also give another example obviously close to my heart and my responsibility - namely the creation of the European Research Council in 2007. Indeed the ERC was the result of a long struggle by the scientific community to overcome a number of obstacles over a period of more than ten years. A fundamental request by the scientific community was that the task of making key decisions for the programme be given to a group of scientists. This was finally granted but only after long and often frustrating discussions, because this would be the first time that both the European Commission and the EU Member States would give such a responsibility to an external body, the ERC Scientific Council.

The strength of the ERC is that it runs a pan-European competition and puts at the disposal of researchers with the most ambitious projects substantial and long-term funding as well as the freedom to pursue their own ideas. This allows the ERC to draw on a wider pool of talents and ideas than any national scheme and increases the visibility and prestige of European research overall. After its first decade, there is no doubt that the ERC is achieving its aims. The ERC's peer review system is widely seen as a benchmark. ERC funded researchers are producing world-class research. Some 5% of publications by researchers funded by ERC are among the 1% most highly cited, the highest proportion by far of all funding agencies worldwide. We are already seeing many concrete results from ERC funded discoveries. There is great interest in the work of ERC grantees in the mainstream media and amongst the public, and the results of each ERC call are reported widely. ERC grants boost careers and increase the reputation of the institutions hosting grantees. This means that Europe's top researchers no longer feel the need to move overseas to do their best work and increasingly that researchers from outside Europe see it as a place to do outstanding work.

This is why your active and vocal support is needed to get the new EU Research and Innovation programme for the period 2021-2027, Horizon Europe, be funded at the right level for Europe to be in a position to fulfil its ambitious goals.

The European Physical Society has been in existence for 50 years while the ERC has been around for only little over a decade. We can learn much from the exceptional work you have done and your steadfast advocacy for the ideals of Science and of Europe. It seems that the argument for these two ideals is never finally won. Instead each new generation must revalidate the reasons why we are better off together, both to advance knowledge and to advance peace, and to get society to move forward. It seems that we are at a moment in History where those of us who believe in Science and in Europe are being tested again. We must be up to the challenge! We must not let the key steps taken in the second part of the 20th century to give a basis for a brighter future for Europe after the disastrous Second World War, generated by nationalist and racist regimes, be ruined by inacceptable rhetoric and policies nurtured by fear and fake news.

We can take encouragement from the fact that, in its modern form, Science has been around for over four centuries in Europe and was the creation of minds who simply ignored borders. Such ideas are strong enough to stand the test of time but they need the right carriers. We must be some of those! So I hope that you are ready to stand up and be counted, committed to fight for Science and for Europe. Because we have seen the alternatives, and we must ensure that our continent never makes the same mistakes again. ■

About the Author

Jean-Pierre Bourguignon has been President of the European Research Council since January 2014. A mathematician by training, he is former Director of the *Institut des Hautes Études Scientifiques*. He held a Professor position at *École Polytechnique*, was President of the *Société Mathématique de France* and President of the European Mathematical Society.
He received the *Prix Paul Langevin*, the *Prix du Rayonnement Français* and is *Doctor Honoris Causa* of Keio University, Japan, and of Nankai University, China.

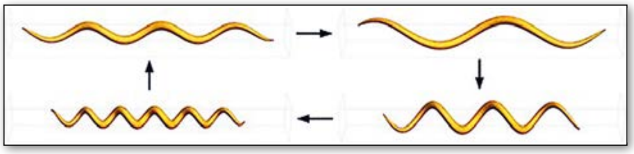
▾ Celebration of EPS 50 Anniversary.

Highlights from European journals

LIQUID PHYSICS

Bacteria-inspired motility could power a new generation of mini-robots

Physicists develop a model to explain how deforming a helix could generate additional locomotion for some microorganisms and mini-robots



▲ Diagram depicting the orientational configuration of the helix in the laboratory.

Many microorganisms rely on helices to move. For example, some bacteria rotate a helical tail, called a flagellar filament, for thrust and deform these tails during rotation. In addition, some types of bacteria, named *Spirochaetes*, rely on the deformation of a helical body for their motion. To better understand such locomotion mechanisms, scientists have created mathematical models of mini-robots with helical structures, referred to as swimmers. In a study published recently, the authors identify the factors enhancing the agility of deforming helix swimmers. They examine what happens when these swimmers placed in a fluid uniformly change the radius, the helical pitch and the wavelength of the helix across their body. They identify swimming strokes that allow rotation and motion in a given direction and thus explain how the helix's deformation influences the direction in which the swimmers move. ■

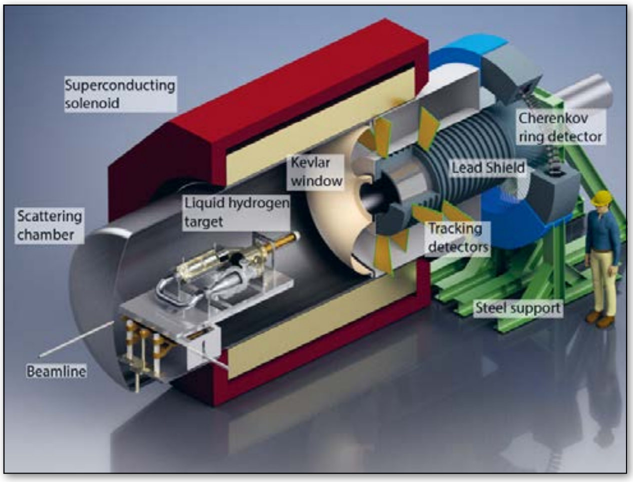
■ **L. Koens**, **H. Zhang**, **M. Moeller**, **A. Mourran**, and **E. Lauga**, 'The swimming of a deforming helix', *Eur. Phys. J. E* **41**, 119 (2018)

NUCLEAR PHYSICS

P2 – The weak charge of the proton

The P2-experiment at the new electron accelerator MESA in Mainz aims at a high-precision determination of the weak mixing angle at the permille level at low momentum transfer. This accuracy is comparable to existing measurements at the Z-pole but allows for sensitive tests of the Standard Model up to a mass scale of 50 TeV. The weak mixing angle will be extracted from a measurement of the parity violating asymmetry in elastic electron-proton scattering. The asymmetry measured at P2 is smaller than any asymmetry measured so far in electron scattering, with an unprecedented accuracy. This review describes the underlying physics and the innovative experimental techniques, such as the Cherenkov detector, beam control, polarimetry, and the construction of a novel liquid hydrogen high-power target. The physics program of the MESA facility comprises indirect, high-precision search for physics beyond the Standard Model, measurement of the neutron distribution in nuclei, transverse single-spin asymmetries, and a possible future extension to the measurement of hadronic parity violation. ■

■ **D. Becker** and **45 co-authors**, 'The P2-Experiment - A future high-precision measurement of the weak mixing angle at low momentum transfer', *Eur. Phys. J. A* **54**, 208 (2018)

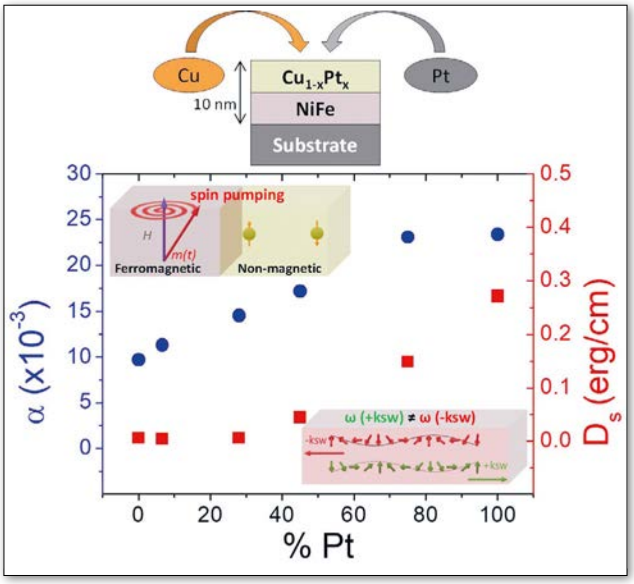


▲ The experimental setup of the P2-experiment to measure the weak mixing angle at the new electron accelerator MESA in Mainz.

APPLIED PHYSICS

How to optimise an interface in spin-orbitronics?

Spintronics is a rapidly developing field of applied physics seeking to exploit electron spins as a further degree of freedom, which is extremely appealing to numerous applications related to magnetic information processing and data storage. Creation of energy saving spintronic devices based on spin currents operated without magnetic fields is currently a key challenge in this domain. This fundamental problem can be resolved by making use of the effects related to Spin-Orbit Coupling



▲ Tuning α and Ds through % Pt.

(SOC), the approach adopted in a novel direction referred to as spin-orbitronics.

Such effects are typically of interfacial nature that take place in ferromagnetic metal/heavy metal bilayers, Pt being the most promising heavy metal candidate. In this paper the authors have investigated major tendencies in the behaviour of three of them, the Gilbert damping *α*, the magnetic anisotropy and the interfacial Dzyaloshinskii–Moriya interaction D_s, as a function of Pt concentration in Py (5 nm)/$Cu_{1-x}Pt_x$ bilayers. Although they demonstrate correlated general features as Pt is replaced by Cu, confirming their common physical nature, their behaviour is not identical. This opens up the possibility of creation of optimised interfaces with SOC-related parameters tuned independently for a specific application. ■

■ **H. Bouloussa**, **R. Ramaswamy**, **Y. Roussigné**, **A. Stashkevich**, **H. Yang**, **M. Belmeguenai** and **S. M. Chérif**, 'Pt concentration dependence of the interfacial Dzyaloshinskii–Moriya interaction, the Gilbert damping parameter and the magnetic anisotropy in Py/$Cu_{1-x}Pt_x$ systems', *J. Phys. D: Appl. Phys.* **52**, 055001 (2019)

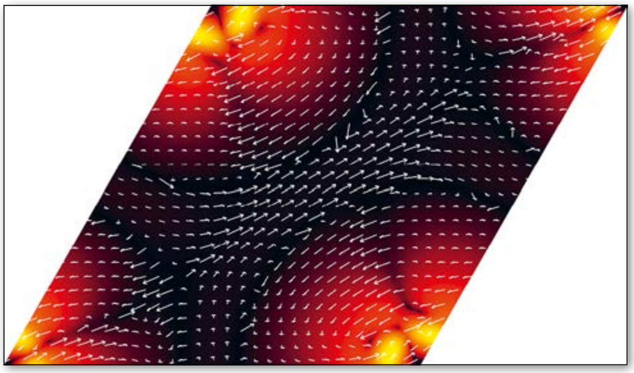
CONDENSED MATTER

Precise electron spin control yields faster memory storage

New ultra-fast laser method aims to improve control over the electron's degree of freedom, called spins, could enhance memory storage devices

Data storage devices are not improving as fast as scientists would like. Faster and more compact memory storage devices will become a reality when physicists gain precise control of the spins of electrons. They typically rely on ultra-short lasers to control spins. However, improvement of storage devices via spin control requires first to develop ways of controlling the forces acting on these electronic spins. In a recent study published recently, the authors have developed a new theory to predict the complex dynamics of spin precession once a material is subjected to ultra-short laser pulses. The advantage of this approach, which takes into account the effect of internal spin rotation forces, is that it is predictive. The authors find that internal spin rotation forces only contribute significantly to spin dynamics when the variation in different directions of the magnetic energy—or magnetic anisotropy energy—is small. This is the case with materials which are highly symmetric such as bulk metals with a cubic structure. When such magnetic anisotropy energy is large, the spin rotation effect is too small to cause any significant precession of spins below 100 femtoseconds. ■

▼ Panel shows a 2D view of spin dynamics for bulk nickel.



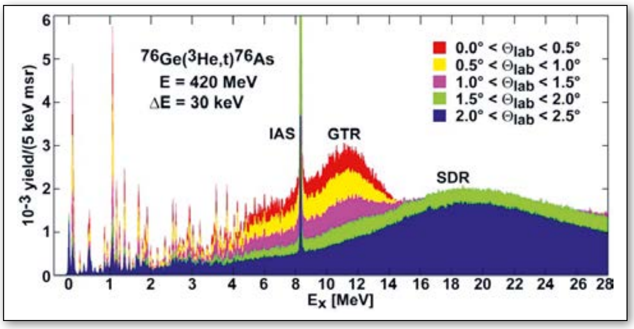
■ **J. K. Dewhurst**, **A. Sanna**, and **S. Sharma**, 'Effect of exchange-correlation spin-torque on spin dynamics', *Eur. Phys. J. B* **91**, 218 (2018)

NUCLEAR PHYSICS

The power of resolution **in charge-exchange reactions**

This review highlights the extraordinary power of the hadronic charge-exchange reactions at intermediate energies and at highest spectral resolution, as exemplified by the (n,p)-type (d,^{2}He) and the (p,n)-type (^{3}He,t) reactions. The review shows how areas of nuclear physics, astrophysics and particle physics alike benefit from such enhanced resolution. A major part of this review focuses on weak interaction processes in nuclei, especially on those, where neutrinos play a pivotal role like in solar neutrino induced reactions or in ββ decay. Unexpected and even surprising new features of nuclear structure are being unveiled as a result of high resolution. (See figure).

High resolution proves to be of equally high importance in areas where this would not immediately be expected. This is



▴ Spectra of the ^{76}Ge(^{3}He,t)^{76} As reaction unveiling an enormous number of resolved states at low excitation energies. Five colour-coded spectra are stacked on top of each other showing the angular dependences. The isobaric analog state (IAS), GT resonance (GTR) and spin-dipole resonance (SDR) are indicated.

outlined in the chapters dealing with the neutron-neutron scattering length, with the properties of halo-nuclei or with the explosion dynamics of supernovae. Finally, the review portrays how high-resolution charge-exchange reactions connect to the symmetry energy and the nuclear equation-of-state or to processes involving ordinary capture of muons by nuclei. Clearly, the insight into the physics, which is made possible with high-resolution charge-exchange reactions, could not possibly be more diverse. ■

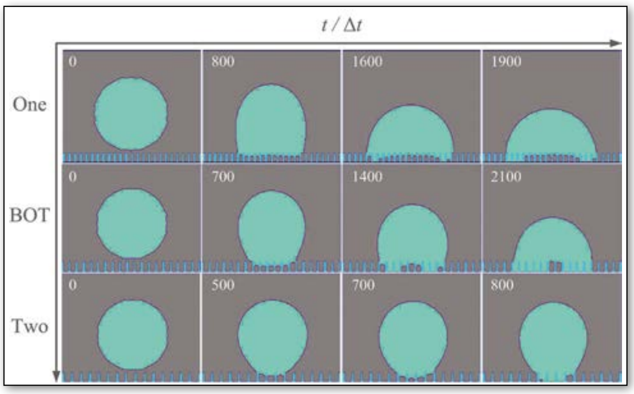
D. Frekers and **M. Alanssari**, 'Charge-exchange reactions and the quest for resolution', *Eur. Phys. J. A* **54**, 177 (2018)

LIQUID PHYSICS

Wetting routes of droplet upon **patterned hydrophilic surface**

The wetting transition of a droplet on the patterned hydrophilic surface can occur spontaneously and may further lead to superwetting that has the potential to develop novel technologies in the field of anti-fogging, printing and heat transfer. However, it is still unknown how the wetting transition occurs on such a patterned surface. In contrast to the conventional view that wetting occurs immediately in the vertical direction upon the contact of the droplet with the solid surface due to the capillary force, we find that the droplet spreads first in the horizontal direction if the patterned surface has a large enough roughness. Then, the wetting transition occurs at the periphery rather than at the middle part of droplet, which is termed as "one-dimensional wetting". We ascribe such an interesting phenomenon to the competition between the horizontal force arising from the non-equilibrium surface tension and the vertical capillary force as well as to the different pressure under the droplet, which lead to three different wetting routes (one-dimension wetting (One), two dimension wetting (Two), Between one and two dimension wetting (BOT)). ■

▾ Different wetting routes of droplet upon patterned hydrophilic surface.

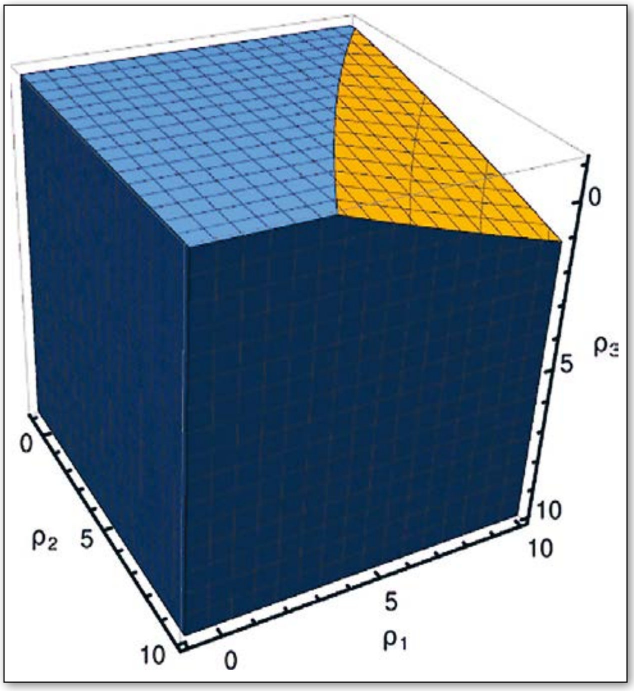


T. Li, **X. Liu**, **H. Zhao**, **B. Zhang** and **L. Wang**, 'Counterintuitive wetting route of droplet on patterned hydrophilic surface', *EPL* **123**, 36003 (2018)

COMPLEX SYSTEMS

Factors affecting **turbulence scaling**

Study focuses on hydrodynamic effects of external disturbances on fluids at critical points, including inconsistent turbulence in all directions, or anisotropy, and varying degrees of compressibility



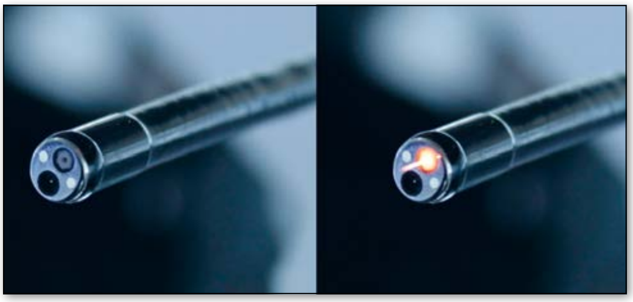
▴ Stability regions calculated by a model for a given compressibility.

Fluids exhibiting scaling behaviour can be found in diverse physical phenomena occurring both in the laboratory and in real-world conditions. For instance, they occur at the critical point when a liquid becomes a vapour, at the phase transition of superfluids, and at the phase separation of binary liquids whose components exhibit two different types of behaviour. Until now, models have not fully taken the effect of external turbulences into account. In a recent study published recently, the authors investigate the influence of ambient turbulent speed fluctuations in physical systems when they reach a critical point. These fluctuations are found to be the result of a lack of spatial regularity in these systems, or anisotropy, and of the compressibility of fluids. What is unique about this study is that the turbulence introduced in the model is novel and helps to elucidate the extent to which the speed of these fluctuations affects their scaling behaviour. ■

■ **M. Hnatič**, **G. Kalagov**, and **T. Lučivjanský**,
'Scaling behavior in interacting systems: joint effect of anisotropy and compressibility', *Eur. Phys. J. B* **91**, 269 (2018)

PLASMA PHYSICS

Making plasma medicine available for in-body applications



▲ Endoscope tip without and with Neon plasma.

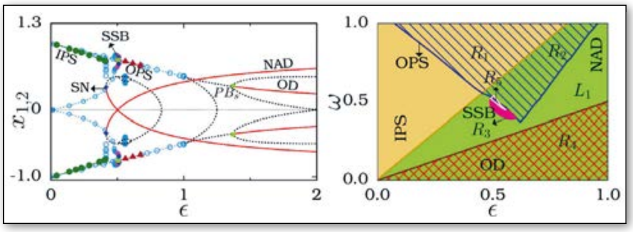
Ever since non-thermal plasmas showed efficacy in decontamination and wound healing, the idea of deploying plasma medical therapy within the human body emerges. Besides the need for flexibility, small dimensions and biological effectiveness, also a minimal plasma-caused applicator erosion as well as an electrically safe operation mode are necessary. Of course, the endoscopic plasma source must also operate inside hollow cavities independent of the environmental conditions present. Since all requirements need to be fulfilled at the same time, the development task is quite complex.

The present paper tackles those requirements and sets special focus on new approaches for reducing leakage current, increasing the bactericidal efficacy and avoiding material erosion simultaneously. The jet-like plasma at the tube tip is maintained by a capacitively coupled discharge configuration. An additional shielding gas surrounds the jet in order to assure reproducible environmental conditions inside the body. Finally, it is found that a combination of Neon feed gas, CO_2 shielding gas and a current-limited high voltage supply gives the best bactericidal results and, at the same time, reduces material erosion as well as patient leakage current. ■

■ **J. Winter**, **Th. M. C. Nishime**, **R. Bansemer** , **M. Balazinski**, **K. Wende** and **K.-D. Weltmann**,
'Enhanced atmospheric pressure plasma jet setup for endoscopic applications', *J. Phys. D: Appl. Phys.* **52**, 024005 (2019)

COMPLEX SYSTEMS

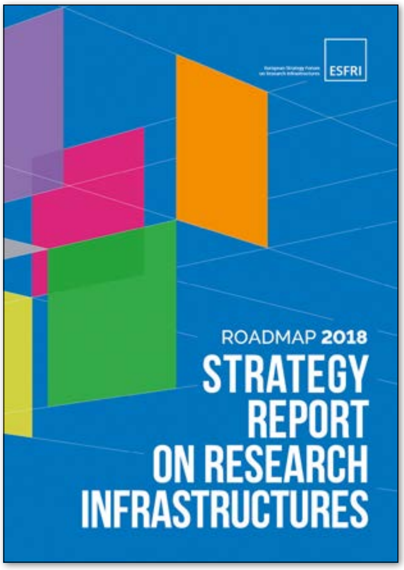
Wetting routes of droplet upon **patterned hydrophilic surface**



▲ Analytical and numerical representations of dynamical regimes in the system.

Spontaneous symmetry breaking (SSB) is a phenomenon that can facilitate the onset of a rich variety of complex patterns observed in several natural systems. In SSB, asymmetric states arise from symmetric systems spontaneously as a control parameter is varied. This study reveals the existence of spontaneous symmetry breaking state induced by conjugate coupling which corresponds to coupling in paradigmatic Stuart-Landau oscillators. The system exhibits distinct dynamical states, namely in-phase synchronized (IPS), out-of-phase synchronized (OPS), nontrivial amplitude death (NAD) and oscillation death (OD) states. We have deduced the explicit analytical solutions of these states and have studied their stability. The system also exhibits multistabilities among the dynamical states including IPS-OPS (R_1), OPS-NAD (R_2), SSB-NAD (R_3), NAD-OD (R_4) and SSB-NAD-OPS (R_5). It is known that feedback is a useful control mechanism in many biological systems. While introducing the feedback factor in a conjugately coupled system it completely suppresses the SSB and OD states but does not influence the NAD state. These results will shed light on the dynamics of SSB and the control of such dynamical states. ■

■ **K. Ponrasu**, **K. Sathiyadevi**, **V. K. Chandrasekar** and **M. Lakshmanan**,
'Conjugate coupling-induced symmetry breaking and quenched oscillations', *EPL* **124**, 20007 (2018)



RESEARCH INFRASTRUCTURES AS A KEY OPTIMIZER OF EUROPEAN RESEARCH

Giorgio Rossi – ESFRI Chair 2016-2018 – DOI: https://doi.org/10.1051/epn/2019101
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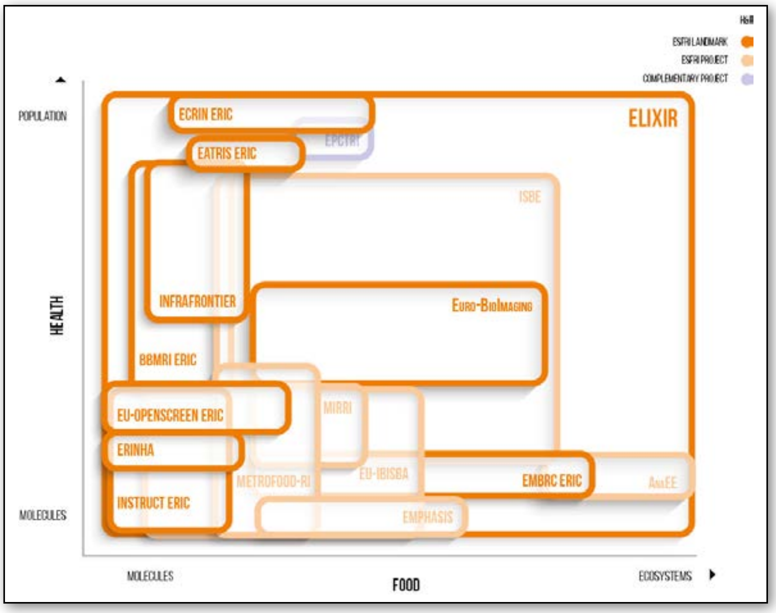
The European Strategy Forum on Research Infrastructures (ESFRI) has been created to advise the Competitiveness Council of the European Union on the needs and opportunities to build a strong Research Infrastructure (RI) system, covering all domains of research, providing the most advanced tools that cannot be realized at national level, and that must be accessible to all strongly motivated researchers in order to increase the European science competitiveness.

The ESFRI Forum

Scientific and ministerial delegations from the 28 Member States and the 12 Associated Countries form the Forum, that has structured its activities with six Strategy Working Groups on the research areas of Energy, Environment, Health & Food, Physical Sciences & Engineering, Social & Cultural Innovation, Data & Computing & Digital Research Infrastructures, and one Implementation Group, all made of experts proposed by the Forum. *Ad hoc* Working Groups of Experts are created by ESFRI, with a focussed short-term mandate, when they are needed.

▾ **FIG. 1:** The ESFRI RIs of different level of organization covering specific areas in the Health & Food domain.

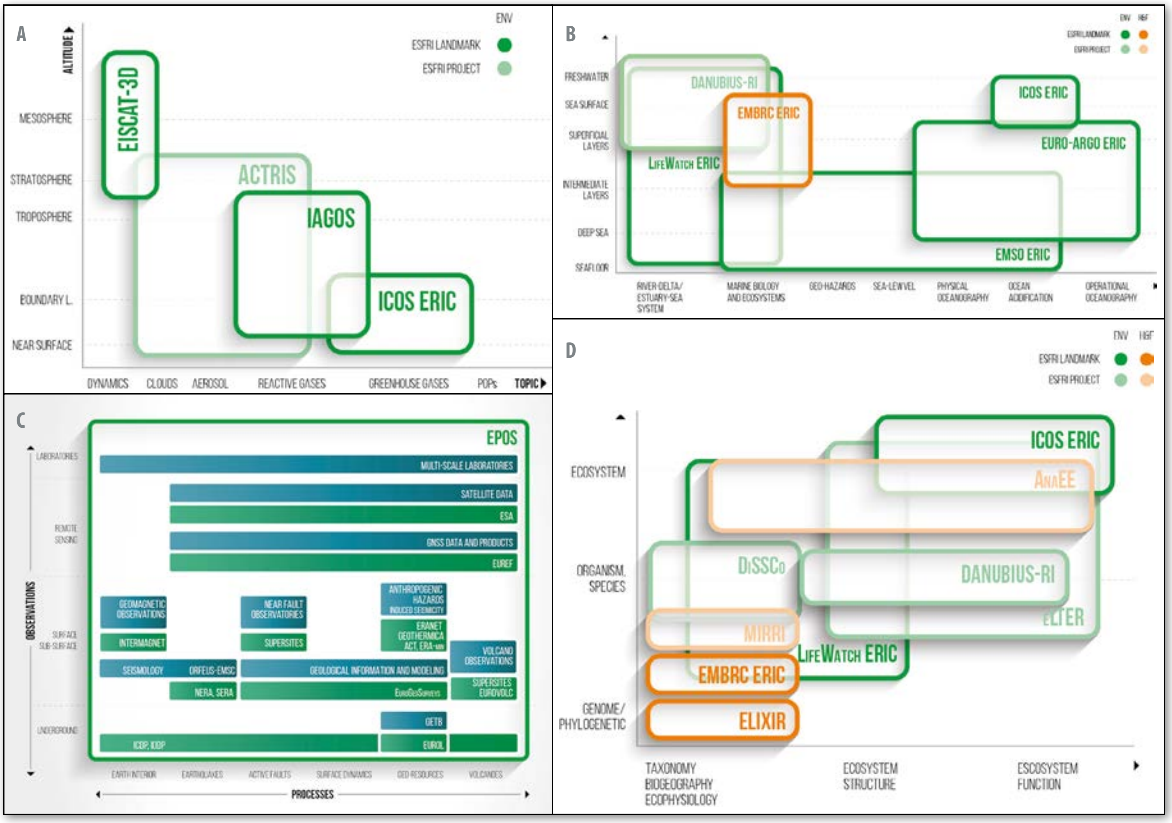


The ESFRI Roadmaps

ESFRI has produced three roadmaps in the years 2006-2010 that identified a set of about 50 RIs representing the state-of-the-art in the respective fields, as well as global undertakings in some cases, these were the "orange-cover" roadmaps. Then the Competitiveness Council mandated ESFRI to adapt its action to the goals of the Innovation Europe programme, and to help the implementation of at least 60% of the roadmap infrastructures by 2016. This was done through assessments (the European Commission organized the High-Level Assessment Expert Group) and by monitoring the state of play of the RIs, and optimizing a special support programme under H2020.

The blue-period started with the blue-cover Roadmap 2016 that introduced important new rules and methodology including firstly a political support threshold for eligibility, and secondly clear implementation targets, like the ten-year rule for new Projects to achieve full maturity. The status of Landmark was introduced to identify those successfully implemented RIs that are engaged for a long-term operation at the forefront of their research domain, and to emphasize the need of continuous support for producing the maximum return on investment.

New projects are adopted in the roadmap after a selection process that addresses both the scientific merit of the RI proposal, its uniqueness and pan-European dimension, and its organizational structure (governance, legal status, solidity of multi-national consortium, financial



◂ **FIG. 2:** The ESFRI RIs covering specific areas in the environmental research domains: A) atmosphere, B) hydrosphere, C) geosphere D) biosphere

commitments, human resource capital and access rules for the users community). Once enlisted by ESFRI the RI Projects have a maximum of ten years to reach the condition of fully mature implementation-ready infrastructure.

The ESFRI Landmarks

The Landmarks are RIs that offer openly accessible science services or support direct access to the resources for advanced research by all European and international researchers, with priorities set by peer-review of the scientific proposals. The lifecycle description of RIs, from conceptual outline to full operation and eventually termination, has been adopted by ESFRI to rationalize the objectives and performances expected by the RIs at any given stage of their life.

The Roadmap 2016 listed 21 Projects and 29 Landmarks, including two EIROforum upgrade projects that had already been approved from their Councils: the High Luminosity Large Hadron Collider of CERN (HL-LHC) and the Extreme Brilliant Source of the European Synchrotron radiation facility (EBS-ESRF).

The Landscape Analysis

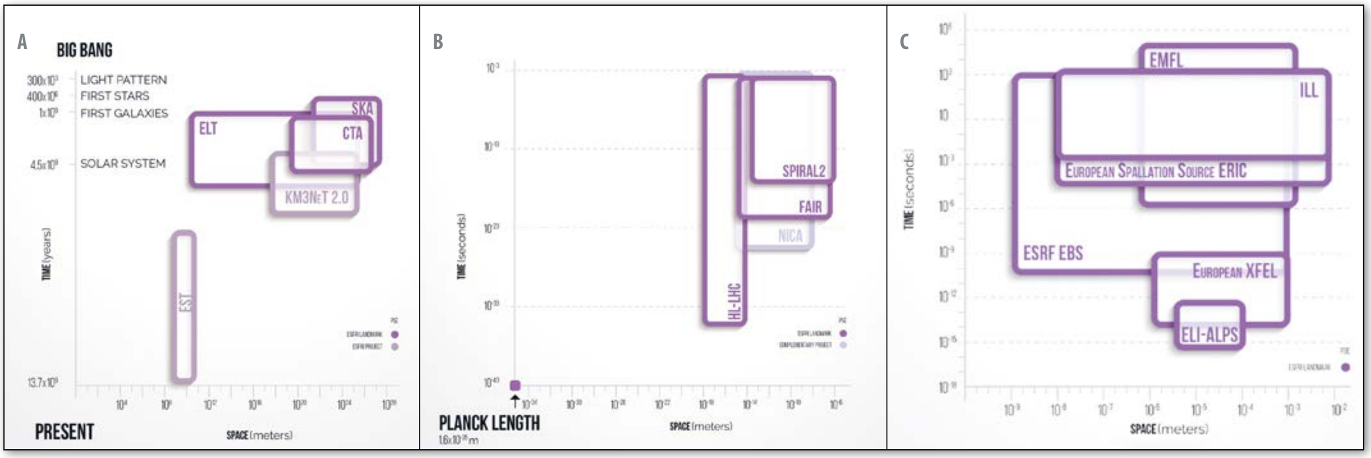
The Roadmap 2016 was complemented by an extensive Landscape Analysis (LA) carried out as a comprehensive recognition of the national RIs that operate in Europe with international open access in each of the scientific areas identified by ESFRI, as well as an analysis of the trends of their development, of the outlook elaborated by the scientific societies, and a gap-analysis pointing to the weaknesses of the overall landscape. The LA and the individual descriptive cards of each Project and Landmarks were published in the new www.ESFRI.eu web-site, whilst only the introduction, concept and list of Research Infrastructures were published in hard copy and presented in a dedicated event on 10th March 2016 in Amsterdam.

The new ESFRI Roadmap 2018 was presented in Vienna last September 11th , before the International Conference on Research Infrastructures (ICRI-2018), representing the European analysis and contribution to the realization of open access Research Infrastructures for the benefit of European and global science, including all its parts, endorsed by the Forum, in a hard-copy volume.

The new Project list counts 18 initiatives, including 6 new entries in the Energy (ENE), Environment (ENV), Health & Food (H&F) and Social & Cultural Innovation (SCI) domains; the Landmark list counts 37 operational Research Infrastructures showing that most, albeit not all, ESFRI projects complete successfully their incubation towards implementation within the ten years on the Roadmap. The science domains populate the ESFRI list with a number of initiatives that reflect the development of global science.

The strategic domains

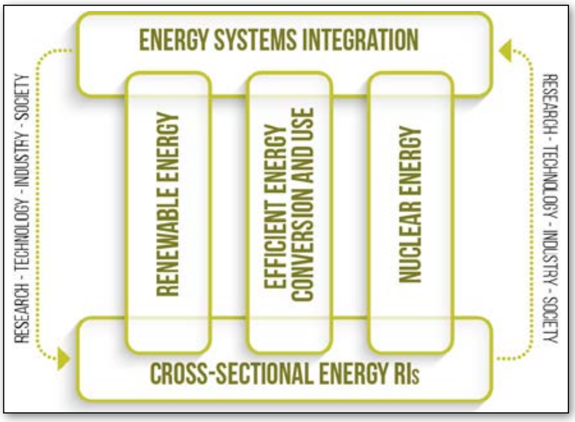
The Health & Food domain counts ten Landmarks and six Projects, all distributed infrastructures that in fact integrate a large number of national nodes in a strategically driven federation coordinated by a unique, jointly participated, hub that becomes both the science policy maker and the single access point for the users proposals that are then performed



▲ **FIG. 3:** The ESFRI RIs covering specific areas in the Physical & Engineering domain: A) Astronomy and Astroparticle Physics, B) Particle and Nuclear Physics, C) Analytical Physics.

at the most suitable national nodes, with a variety of access modes. The ensemble of the H&F Landmarks addresses the health challenge, covering from molecule to ecosystem and to population dimensions, as well as the food challenge again from molecular scale to ecosystem and to economy. The ensemble of targeted Landmarks cover specific research needs and addresses, with state-of the-art methods and resources, the big societal challenges. Much of the elaboration by ESFRI on the optimization of the distributed infrastructure model has benefited from this domain and has fed back to it as well as to the whole roadmap more generally. A general bioinformatics infrastructure is providing operational interfaces to all the Landmarks of the domain and is acting as a reference to accelerate the optimal data flow among them, and contributes to set standards for an effective open-science/open-data paradigm (See Figure 1).

The seven Landmarks and four Projects in the Environment domain are also all distributed infrastructures as their research is performed in dedicated observatories as well as on integrated observational data from a very broad array of national and international observatories that are present in the European and world territory with scopes merging science and environment control, including RIs and civil protection national services. The fine structure of the Landmarks in this broad and strategic domain can be described as research on the atmosphere, from near ground to near space, on the hydrosphere from freshwater to marine, on the biosphere covering biodiversity and



▸ **FIG. 4:** The ESFRI RIs interplay in the Energy domain.

ecosystems, and on the geosphere from the earth surface to the interior of the planet covering geo-hazards and geo-resources. Large data management and advanced data services are developed by the RIs, coping with all the dimensions of the research and the data flow among them in ENV and across disciplines (See Figure 2).

The Social & Cultural Innovation sector has five Landmarks and two Projects, again all distributed, addressing the integration of big social data from research through longitudinal and horizontal surveys on the ageing of the European population and on the social behaviours of the population and evolution of their institutions; enabling access by all researchers to advanced social data archives; addressing the language commons across all the idioms of European culture and their meanings; addressing the digitalization of the cultural heritage of arts and humanities, the research, elaboration and memory of the holocaust, and the novel concept of heritage science that exploits the most advanced scientific analytical approach to understand the make and materials of the richest cultural heritage on earth, and to develop science-based preservation strategies.

The Physical Sciences & Engineering domain counts twelve Landmarks and two Projects that are mostly unique and central research facilities, installed in a single site or in a few interconnected sites, addressing fundamental research in astronomy, astrophysics, and on the nature of matter from high energy particle and nuclear physics to the fine analysis of materials. These RIs include major ground based observatories of the universe and large installations to probe the intimate structure of matter, as well as the broadly interdisciplinary research based on advanced analytical probes like X-ray sources (synchrotron radiation, free electron laser, extreme performance laser) and neutron radiation (nuclear reactor and spallation source) as well as installations allowing to reproduce extreme conditions for probing matter in very high magnetic fields. The research needs for observatories of the universe require to build and combine installations from different observation points on the earth, *e.g.* in both hemispheres, as well as the extreme specialization of laboratories built in different sites for sustainability and development of regional scientific communities. The *multi-messenger* research method has been prompted by the observation of the gravitational waves (GW) and the correlated observations by all electromagnetic-field (EM) observatories at all wavelengths and astroparticle observatories. The real-time response to GW observation events by all other astronomy and astrophysics observatories has major implications on the technology for synchronous operation and on the data transfer and analysis methodologies. Similarly probing complex materials by broad energy range photon, electron, neutron, muon, ion beams and advanced computational simulations converge into a *multi-messenger* approach to the understanding of aggregated matter (See Figure 3).

Two Landmarks and four Projects in the Energy domain cover the needs of research on materials for energy applications and the methodologies for renewable energy production with large central installations as well as the study of global challenges as the carbon dioxide capture and storage based on a distributed set of experiments (See Figure 4).

FIG. 5: The ESFRI RIs Interconnections with different scientific domains

Finally the Data & Computing & Digital Research Infrastructures domain identified one Landmark for the interdisciplinary use of advanced computation organized as one large distributed infrastructure representing the European federated effort in supercomputing with a hierarchical structure of powerful, world standard, computing resources.

The interconnections, beyond the disciplinary paradigm to address global issues

Knowledge develops across and beyond the disciplinary paradigm that still dominates European culture and high education institutions. The ESFRI Roadmap 2018 gives evidence on the actual impact of the Research Infrastructures on other domains that enlarge their significance well beyond the scientific community that has originally prompted their need. A *multi-messenger* approach is becoming ubiquitous in science, and a well interconnected RI system is the tool for developing it.

The analysis of the interconnections between the ESFRI RIs and all scientific domains helps in capturing the general significance of a well structured European RI system for pursuing novel scientific knowledge as well as to enable multidisciplinary research efforts. This is in fact one of the challenges for the development of the European Research Area: to become a powerful research system capable to address the urgent needs of new knowledge for coping with the criticalities in the evolution of the planet and of humanity, as well as to effectively pursue solid understanding of life and the universe.

The interconnections represent also the clear need for effective information exchange through high quality data and data services that could also scale up to a general system for accessing scientific knowledge and to a system capable of pursuing the knowledge needs when these are formulated in a non-disciplinary way, as it is the case for the so-called major challenges that humanity faces that are intrinsically complex with tangled implications on energy needs, environment effects and resources, social development and understanding, quality food supply and better health for all people, yielding a more advanced understanding of the concept of global sustainability.

The general issues to which the RIs can, and do, contribute are also reflected in the LA: education and training are within the scope of all ESFRI RIs and it is high time to address the complementarity with the higher education system, *e.g.* by introducing formal credits; innovation in economic and social activities has a motor in the RIs, but it also depends on improving the knowledge transfer process to the social and economic actors; the socio-economic impact of RIs is to be understood at all relevant levels starting from the optimization of the science production, *e.g.* of the overall research budget, to the local economy when single site large infrastructures and large hubs contribute to, or even shape, the regional development. Scope of the RIs is the global competitiveness of European research, through shaping international collaborations on major research undertakings as well as playing a prime role in science diplomacy and in the diffusion of scientific knowledge and trustable data.

ESFRI receives additional specific mandates from the Council about RIs, with requests ranging from developing methods for monitoring performance of all Research Infrastructures, to the analysis and strategies of their sustainability, to the overall alignment of scope and methodology with national roadmaps, to contributing towards the making of the European Open Science Cloud as a key instrument for Open Science. ESFRI addresses these mandates, also in good collaboration with the European Commission, and the results of the work by the Forum and by the *ad hoc* expert groups can lead to publications, the ESFRI Scripta, that diffuse the results of strategy analysis on specific issues.

The results achieved by ESFRI and represented in the ESFRI Roadmap 2018 are broadly acknowledged. This implies that it is now urgent to refine a strategy for the future shaping its broad mission and continuously adapting its procedures to cope with the new mandates and goals. The reflection on the new challenges has started in the Forum and will have a first dedicated plenary workshop in January 2019, under the leadership of the new Chair and Executive Board.

ESFRI has proven to be a truly pan-European effort involving both scientific communities and ministerial authorities of all Member States and Associated Countries and its results demonstrate the high merit and great potential of European collaboration in developing visions and sustainable perspectives for progress, in the spirit of freedom and of the common aim for reaching advanced synthesis and ambitious goals for science and society. ■

About the Author

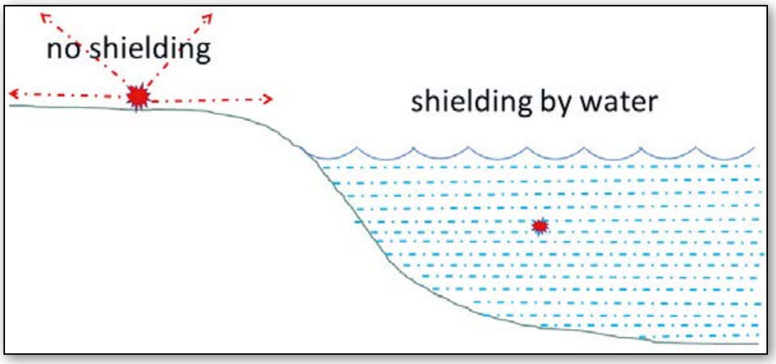
Giorgio Rossi is Professor of Physics at the Università degli Studi di Milano. Italy. He leads the APE (Advanced Photoelectric Effect Experiments) and NFFA (Nano Foundries and Fine Analysis) groups at CNR-IOM and Elettra in Trieste, performing research on the electronic and magnetic properties of surfaces and nanostructures, also operating synchrotron radiation spectroscopy and *in situ* materials growth facilities open to academic and industrial users. He is author or co-author of over 220 research papers in ISI journals.

He coordinates the NFFA-Europe (Nano Foundries and Fine Analysis) integrated infrastructure since 2008. He has chaired the Physical Sciences & Engineering Strategy Working group of ESFRI in 2013-2016, and served as ESFRI Chair since 1st July 2016 to 31st December 2018.

TOO MUCH FEAR FOR RADIOACTIVE CONTAMINATION OF SEAWATER

J. Goudriaan – Emeritus professor WUR, Wageningen, The Netherlands – DOI: https://doi.org/10.1051/epn/2019102

Radioactive contamination of seawater has often caused concern, for example about releases from Sellafield and Le Havre and later about the Fukushima disaster. Repeated reporting has contributed to the general feeling that the sea is particularly sensitive to radioactive contamination (Greenpeace,1998). This is not the case, it is rather the opposite. Marine life is much better protected against radioactive contamination than life on land. This protection is due to three natural factors: shielding, dilution and isotope competition.



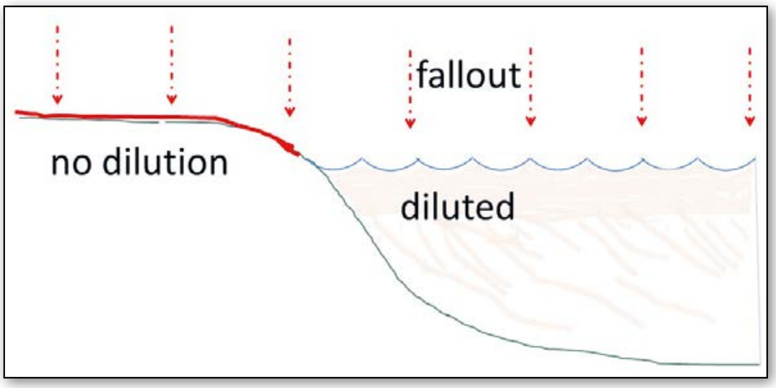
▲FIG. 1: Radioactivity in water is almost perfectly shielded, as opposed to radioactivity on land. The red arrows represent the range of the radioactivity.

Shielding

Water itself shields radiation. It does so much better than air, simply because its density is about 1000 times larger. Not all radioactive radiation is the same. For simplicity here only the three major types are considered: alpha-, beta- and gamma radiation. Alpha radiation (which is identical to the nucleus of helium consisting of 2 protons and 2 neutrons) is emitted in the decay chain of unstable heavy elements such as uranium and plutonium. It is emitted with such high energy (around 5 MeV) that serious damage in biological and human tissue may occur, notably in the DNA of cell nuclei. If such damaged cells survive, multiple undesirable mutations may occur in subsequent mitosis. The interaction of alpha radiation with matter is so strong that it loses its energy very quickly and so it does not penetrate deeper than one tenth of a millimetre, whether in water or in even a dead upper epidermis. However, inside living tissue such as a mucous membrane or a vein, alpha radiation is 20 times as harmful as beta or gamma radiation for the same amount of absorbed energy. Therefore it is assigned a radiation weight factor of 20. Beta radiation (in fact electrons) and gamma radiation (photons) usually carry less energy and their interaction with matter is much smaller, so that they can penetrate much deeper. Yet 10 meters of water is usually enough to block them. This means that any radioactive source under water loses danger if it is shielded by more than 10 meters of water. This fact is one of the reasons why large pools of water are being used to store containers with high level radioactive waste. No radiation can reach us from sea emitted by sources at a depth greater than 10 m. Possible dissemination from sea to man , by fishery for example, will be dealt with below.

Of course, fresh water and seawater are alike in this shielding property, but the amount of fresh water is minute in comparison to the amount of seawater.

▼FIG. 2: Fallout in sea is much more diluted than on land as indicated by the colour dilution in sea.



Dilution

This difference in size brings us to the second mechanism which is that the mass of the ocean is enormous in comparison to the mass of the atmosphere or to the mass of the land biota. Any radioactive material will therefore be much more effectively diluted in the sea than a similar amount on land. Radioactivity in sea will much faster drop below the natural background radiation than on land. Even the huge radioactive contamination by the thermonuclear explosions in the sixties that have released about one hundred times more radioactivity than Chernobyl, is nowadays diluted to a radioactivity of plutonium that does not exceed 0.1 Bq m^{-3} (Hirose, 2009) (Box 1). This level is negligible in comparison to the natural radioactivity of seawater of 12000 Bq m^{-3} (mainly from radioactive potassium ^{40}K). ^{40}K is a natural component of potassium (at 0.012%), also in seawater which contains about 400 g of K per m^3. Even if the effective radiation dose of an ingested alpha emitter such as plutonium is much larger than that of beta radiation, the radiation dose due to plutonium at the mentioned level is ten thousand times smaller than the background level. The beta radiation of ^{40}K penetrates deeper than alpha radiation: some tens of centimetres. Therefore, it can penetrate the human body from outside, although much less than the gamma radiation from the same radionuclide. Interestingly, the potassium concentration in our body is eight times as high as that in seawater, and so in a crowd we irradiate each other eight times stronger than while swimming in the sea!

Another illustration of the effectiveness of dilution in the ocean is the course of events in Fukushima. The total emission there has been about one tenth of that in Chernobyl. A considerable part of this release ended up in the sea, largely by outflow of cooling water. Because of this, the radioactivity of the seawater near Fukushima peaked at 25 Bq/litre during the first weeks after the disaster, mainly from caesium, both ^{137}Cs and ^{134}Cs (Grossman, 2012). This looks like being serious, but in fact it amounts to only twice the natural radioactivity of seawater and a quarter of that of the human body! "Alarming" reporting about radioactive caesium near the Californian coast does exist, but the levels were so low that these findings are a good reason for admiration of the detection potential rather than for any worry.

Isotope competition

Radioactive iodine, caesium and strontium are among the most feared and most dangerous radioactive substances released during a nuclear accident. It is precisely these elements that encounter their non-radioactive counterparts abundantly present in seawater (Table 1). By sheer number these harmless isotopes largely outcompete the radioactive contaminants in the process of biotic uptake.

	CONCENTRATION	QUANTITY PER KM^3
Iodine	50 10^{-9} g/g	50 10^3 kg
Caesium	2 10^{-9} g/g	2 10^3 kg
Strontium	13 10^{-6} g/g	13 10^6 kg
Calcium	450 10^{-6} g/g	450 10^6 kg
Potassium	400 10^{-6} g/g	400 10^6 kg
Radioactivity	12 Bq/litre	12 TBq

▲ Table 1.: Contents in seawater

The mechanism of the protective action of seawater is identical to that of medical pills of iodine which are recommended in case of a nuclear accident. The rationale of this protective measure is to saturate the thyroid with Iodine so that it will no more take up any radioactive iodine.

Iodine shortage is much more frequent in inland regions far from the sea, where seafood is hard to obtain, than in coastal regions. Consequently, the human population in such regions is more vulnerable to radioactive ^{131}I.

In the unfortunate case that radioactive iodine finds its way to the sea, it can hardly cause any damage because its quantity is minute in comparison to the stable Iodine already present in seawater. As little as 8000 m^3 of seawater (equivalent to a large swimming pool) already contains 400 g of iodine, the total quantity released by Chernobyl.

In the case of caesium and strontium a similar argument applies. In Chernobyl 26 kg of ^{134}Cs and ^{137}Cs was released with a radioactivity of 85 PBq and ^{90}Sr with a radioactivity of 10 PBq. Both isotopes have a half value time of about 30 years, which makes them dangerous for many decades. Chemically, caesium is like potassium that is mainly present in muscles and nerves and strontium is more like calcium, the major constituent of bones. Caesium and strontium will therefore be transported to these tissues. Upon decay, ^{137}Cs emits both beta- and gamma radiation (with an energy between 0.5 and 0.7 Mev), upon conversion to stable barium. ^{40}K releases radiation with practically twice the energy (1.3 MeV beta with 89% occurrence and 1.46 MeV gamma with 11% occurrence) . This means that the specific radiation danger per Bq of ^{137}Cs is half of that of ^{40}K, the main natural source of radiation in seawater. Using the data in Table 1, it is easily shown that the total radioactivity of ^{137}Cs released by Chernobyl is equal to the amount that is naturally present in 7000 km^3 of seawater. This volume of water occupies a surface area of 150 × 150 km for a well-mixed surface layer of 300 m above the thermocline, a much smaller area than what has been contaminated after Chernobyl.

In this scenario, radioactive caesium would make up a fraction of 1.8 ppm (part per million) of the stable caesium already present in seawater. In addition, the potassium concentration in seawater is two hundred thousand times higher than that of the stable caesium. This all means that radio-active caesium has almost no chance to be taken up, which is why the radioactive contamination of sea fish in the waters near Fukushima remained very small (UNSCEAR, 2013).

The concentration of strontium in seawater (Table 1) is still a lot higher than that of caesium so that ^{90}Sr gets even less opportunity to be taken up. In addition, it has also to compete with calcium that is present in seawater in high concentration as well.

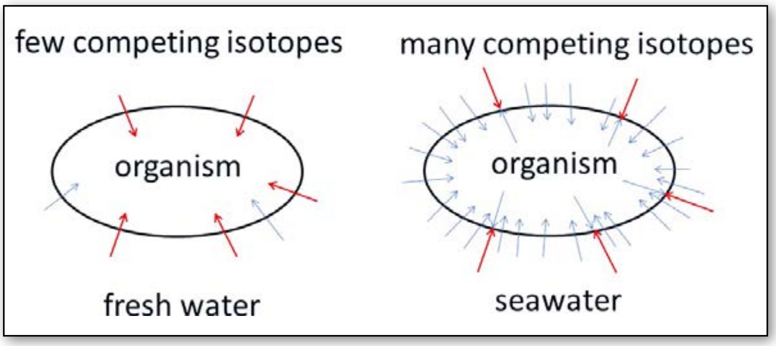
On land, especially in acidic, oligotrophic (nutrient-poor) regions, the situation is exactly the opposite. In case of shortage of calcium and potassium, their substitutes strontium and caesium are eagerly taken up, whether radioactive or not. In many regions of northern Europe where much of the Chernobyl fallout precipitated, precisely such poor soil conditions are prevalent.

Upon consumption of radioactively contaminated seafood, the protecting competition mechanism does not work, because we do not drink seawater. Fortunately, in practice the risks appear to be small. According to Chen (2013) even a copious consumption of the most contaminated fish in the Fukushima region would have caused a negligible radiation dose. Table C18 in the UNSCEAR report of 2013 about Fukushima shows that the consumption of fish in the region was responsible for less than one thousandth of the total radiation dose of the population. Considering that more than half of the total quantity of escaped radioactive caesium found its way to the sea, the ensuing exposure of man has been exceedingly small. From the sea it is not radioactive caesium or strontium that contributes most, but polonium of natural origin.

Polonium

^{210}Po is continually formed in the decay chain of uranium (^{238}U), after radon and before lead. It is therefore of natural origin. Radon gas is a notorious source of alpha radiation as it is released by most soil types and non-organic building materials. Several isotopes of radon exist, but the

▼ FIG. 3: In seawater competing non-radioactive isotopes hamper uptake of radioactive I, Cs, and Sr. This mechanism is lacking in fresh water and on land.



only important one is ^{222}Rn of the decay chain of ^{238}U. It has a half value time of 3.8 days, which is long enough to accumulate in poorly ventilated rooms. Being a gas, it can be inhaled and exhaled without causing radiation damage in the lungs but the real problem is that it decays (via short lived descendants) to lead (^{210}Pb). This element adheres easily to aerosols and fine dust particles that may stay in the lungs, the more so because ^{210}Pb has a relatively long half value time of 22 years. On its turn it decays to ^{210}Po which is the dangerous one. It is an alpha emitter with a short half value time of 138 days, decaying to the stable lead isotope ^{206}Pb. One could have thought that because of this short half value time, polonium should be present in very small quantities and therefore not be dangerous. The first is true, but the second is not. If one thinks of the decay chain of uranium as a series of cascades, it is easily understood that in the long run the flow through each pool should be the same, whatever the size of the pool. Thus, the total global decay rate of each element in the chain is the same in terms of Bq: they are in secular equilibrium. Radon, being a gas, is widely spread and so is its successor polonium. Both in air and in water, ^{210}Pb and ^{210}Po attach to fine particles and readily precipitate to the soil or to the bottom of the water. A considerable amount of polonium in seawater is taken up by bacteria and microplankton, thus entering the marine food chain (Carvalho *et al.*, 2017). It is also omnipresent on the seafloor where it quickly finds its way into the marine food chain, helped by the high chemical affinity of proteins for polonium (Hosseini *et al.*, 2008; Carvalho, 2018). Seafood has an important share in the Japanese diet and it contributes 0.80 mSv per year to the average human radiation dose in Japan, largely due to polonium. The average radiation dose from food is only 0.12 mSv per year worldwide (Ota *et al.*,2009). An instructive visual representation of the contribution of various sources of radioactivity to the annual radiation dose for humans is given by the Radiation Dose Chart https://xkcd.com/radiation/. Bio-accumulation of polonium also explains the large internal radiation dose in dolphins which was found to be even three orders of magnitude higher than the average radiation dose in man (Malta and Carvalho, 2011). In dolphins 97% of their radiation dose came from polonium against only 3 % from ^{40}K and ^{14}C.

Above I used the background radiation of ^{40}K to find out how much ocean volume would be needed if one were to dilute the total Chernobyl fallout to the same level. In view of the much larger effect of polonium, this calculation was on the safe side.

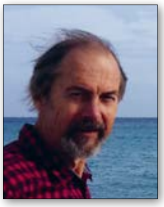
BOX

One Becquerel (Bq) means one radioactive decay event per second, irrespective of the type of nucleus or type of radiation or particle released. The dose absorbed by an organism is expressed in the unit Gray (Gy) in J/kg. To allow for the health effects on humans of different types of radiation in different organs, the unit Sievert (Sv) is used. One Sv carries with it a 5.5% chance of eventually developing cancer, assuming a linear effect with zero threshold. The natural background radiation causes an annual dose of 2.4 mSv. In the conversion from Bq to Sv many factors are involved (ICRP, 2006).

Conclusion

The marine biosphere is much less sensitive to radioactive contamination than the terrestrial biosphere. This is due to: (1) shielding by water, (2) the huge mass and volume available for dilution, and (3) suppression by non-radioactive isotopes that are omnipresent in seawater in high concentrations. Natural radioactivity, notably from polonium, is a much larger contributor to the radiation dose of sea life and indirectly also to that of humans than man-made radioactivity. ■

About the Author



Jan Goudriaan, born 1946, MSc degree in 1970 in Physics at the Technical University of Delft, The Netherlands. PhD degree in 1977 at WUR, Wageningen. Research on the global carbon cycle as affected by terrestrial vegetation and the ocean. Akzo-Nobel prize in 1992.

References

[1] Y. Chen, *Evaluation of radioactivity concentrations from the Fukushima nuclear accident in fish products and associated risk to fish consumers. Radiation Protection Dosimetry*. 2013 Nov; 157(1): 1–5.

[2] K. Hirose, *Journal of nuclear and radiochemical sciences* **10-1**, 7 (2009).

[3] Greenpeace, 1998. *Report on the world's oceans*.

[4] ICRP, 2006. *Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public*. ICRP Publication 101a. Ann. ICRP 36 (3).

[5] UNSCEAR, 2013. *Sources, effects and risks of ionizing radiation. Annex A. Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami.*

[6] A. Hosseini, H. Thorring, J.E. Brown, R. Saxen and E. Ilus, *Journal of environmental radioactivity* **99**, 1408 (2008).

[7] F. Carvalho, S. Fernandes, S. Fesenko, E. Holm, B. Howard, P. Martin, M. Phaneuf, D. Porcelli, *G. Pröhl and J. Twining. The environmental behaviour of polonium. IAEA Technical Report Series* 484, IAEA, Vienna (2017).

[8] F.P. Carvalho, *Journal of environmental radioactivity* **186**, 124 (2018).

[9] M. Malta and F.P. Carvalho, *Journal of environmental radioactivity* **102**, 473 (2011).

[10] T. Ota, T. Sanada, Y. Kashiwara, T. Morimoto and K. Sato, *Japanese Journal for Health Physics* **44-1**, 80 (2009).

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ECONOPHYSICS: STILL FRINGE AFTER 30 YEARS?

JP Bouchaud – CFM – DOI: https://doi.org/10.1051/epn/2019103

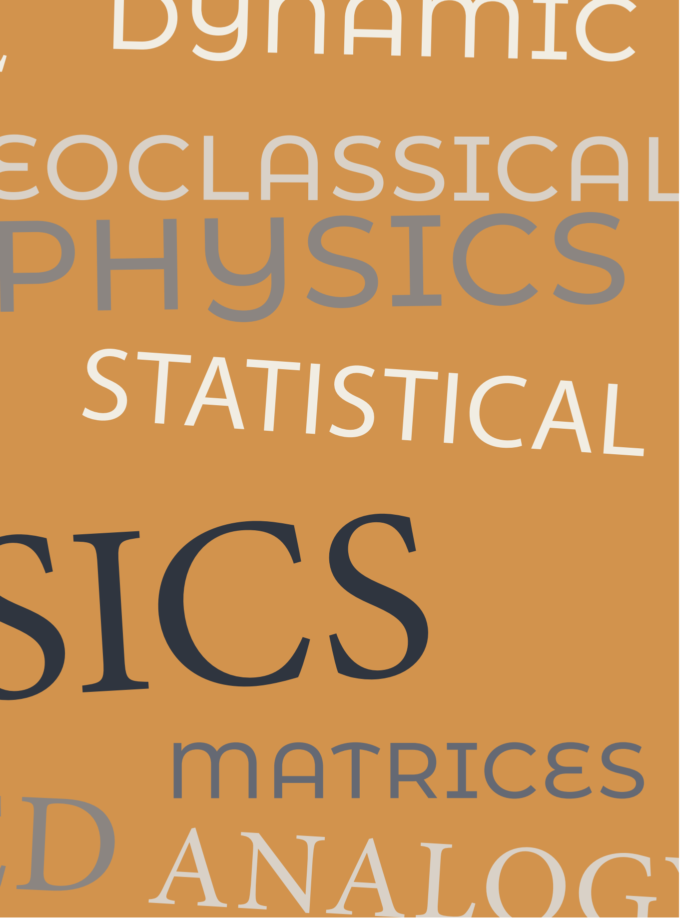
It is customary to date the initial foray of physicists into economics to the September 1987 Santa Fe conference on "Economics as a complex evolving system", organised by two famous physicists (Phil Anderson & David Pines) and one famous economist (Ken Arrow)[1]. When confronted with the theories of Rational Expectations and Efficient Markets, then at the peak of their glory, Phil Anderson famously quipped: *Do you guys really believe that?*[2] Many inspiring and insightful ideas were discussed during that conference [1], suggesting a potentially productive cross-fertilisation between economics and the (back then) nascent theory of complex systems.

After all, economics is primarily about inferring the coordination properties of large assemblies of heterogeneous, interacting individuals – a difficult endeavour that statistical physics has been grappling with for more than a century.

Unfortunately, this cross-fertilisation did not really follow through, at least not on a large scale, in spite of the involvement of larger and larger cohorts of physicists in the development of what is now called "econophysics" [2] and "sociophysics" [3]. Until recently, mainstream economists have essentially muddled through along the same well-trodden path, developing monetary policy tools based on the idea that agents are rational calculators with infinite foresight, who optimize their "utility function" assuming others will do the same. In 2003, Robert Lucas – one of the dons of Rational Expectations and Nobel Prize recipient in 1995 – declared that *the central problem of depression prevention ha[d] been solved*. We know all too well what happened in 2008. Jean-Claude Trichet, then Chairman of the European Central Bank, declared: *Models failed to predict the crisis and seemed incapable of explaining what was happening [...] in the*

[1] There were of course several forerunners (for example W. Weidlich).

[2] Ironically, the US stock market crashed ~22% in a single day a month later, on October 19th, 1987.



face of the crisis, we felt abandoned by conventional tools. Queen Elisabeth II candidly asked why nobody had seen it coming[3]. Robert Lucas doubled down in 2009 when he declared that *the 2008 crisis was not predicted because economic theory predicts that such events cannot be predicted.*

Let's face it: we humans are lost in the dark, using acceptable – but not optimal – rules of thumb to cope with complex problems. We strongly interact with one another, either directly or indirectly through market prices or other aggregate indicators while subject to an impressive list of behavioural biases [4] that lead to systematic errors. Analogously to many complex systems they have learnt to deal with [5, 6], physicists believe that all these ingredients should lead to collective effects, instabilities and crises, which may be relevant to economics and finance. It is, I believe, a fair description of the agenda that early econophysicists had in mind, which, owing to the failings of established dogma, seemed like a worthwhile endeavourindeed. This belief is bolstered by a set of empirical results that do not fit well in the framework of classical economics while sounding rather familiar to statistical physicists.

Classical economics is fraught with so-called "anomalies" and" puzzles". One of the most famous is the *excess volatility puzzle*: the fluctuations of financial markets and of large economies are far too big to be explained by fundamentals alone. In theory, large economic systems should average-out idiosyncratic shocks (say as $N^{-1/2}$ where N is the size of the economy), however, aggregate "volatility" – defined as the standard deviation – is in fact very high. (For example the month-on-month volatility of the US industrial production index since 1950 is as high as 0.75% around the average growth trend of 0.25%). This of course reflects the propensity of the economy to cycle through booms and busts. But what shocks are responsible for such economic fluctuations? *Despite at least two hundred years in which economists have observed fluctuations in economic activity, we still are not sure,* wrote economist John Cochrane in 1994. In fact, the basic mechanism that triggered the 2008 crisis is still hotly debated.

The standard macroeconomic model (the so-called Dynamic Stochastic General Equilibrium – DSGE – model) describes mild fluctuations around a stable equilibrium, and is therefore not well-equipped to deal with endogenous crises (this explains the dismay of J.-C. Trichet, quoted above).

In financial markets, stock prices move by ~2% a day or more, which is much too high to be justified by objective changes of the firms' fundamental value. In fact, only a small fraction of the volatility can be attributed to news; most of the price jumps seem to come out of nowhere.

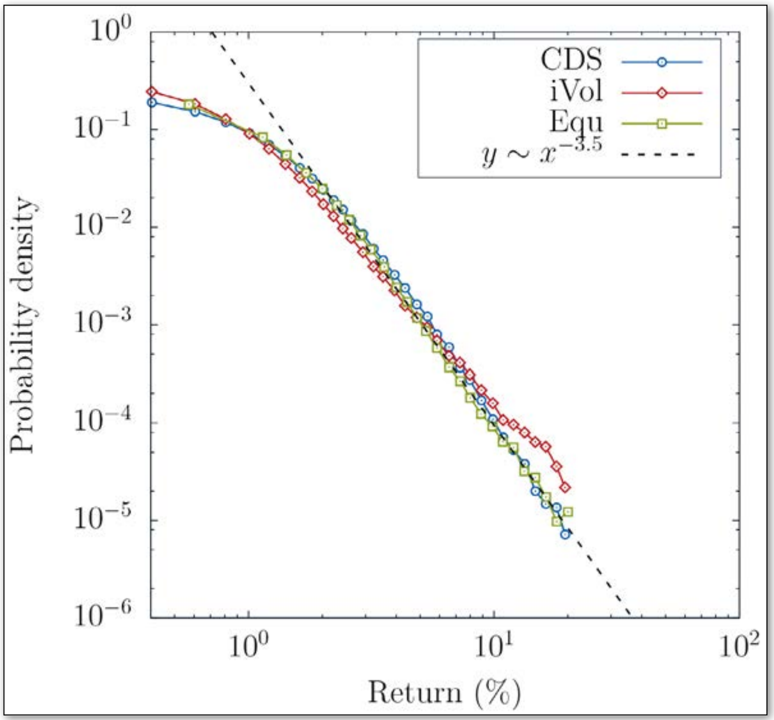
What is even more interesting is that the statistics of price changes appears to be universal across many different asset classes (stocks, commodities, currencies, but also derivatives such as options and CDSs, see Fig. 1). The distribution of price changes falls off as a power law, as in many physical systems close to their critical point. The dynamics of markets is strongly intermittent and resembles multifractal turbulent flows. This was first pointed out by Benoit Mandelbrot in the 60s and 70s, and was the starting point of the spree of econophysics papers in the mid-90s (with some overlap with contemporaneous work in financial econometrics [7]).

The strongly non-Gaussian and universal nature of the fluctuations are further hints that financial markets are mostly driven by self-referential, endogenous effects, and very little by exogenous shocks affecting the fundamental value of firms.

Many other fat-tailed distributions have been identified in economics, such as the famous Pareto distribution of wealth and income, or the distribution of firm sizes [8]. For example, a beautiful study by Rob Axtell in 2001 [9] shows that the frequency of firms with a certain number of employees S decays as S^{-2} over 4 decades. This is highly relevant from a modelling point of view, since the assumption of a "representative agent/firm" that replaces a whole population by a single average agent or firm might be totally unjustified if the said population is so strongly heterogeneous.

We know in physics that strong disorder can completely change the nature of the problem (think of Anderson's localisation, or of the fragility of materials when micro-cracks are present). Furthermore, these observations lead to more puzzles for classical

[3] See the answer of UK economists to the Queen: www.feed-charity.org/user/image/besley-hennessy2009a.pdf



▸ **FIG. 1: Empirical distribution of normalised daily returns of (squares) a family of US stocks, (circle) the spread of the \credit default swaps" (CDS) on the same stocks, and (diamonds) the so-called \implied volatilities" (iVol, related to option markets), again on the same stocks; all during the period 2011-2013. Returns have been normalised by their own volatility before aggregation. The tails of these distributions follow a power-law, with an exponent approximately equal to 3.5.**

economic theories: how can wealth be so unequally distributed when competition is supposed to lead to efficient markets and fair transactions? How can firms be so broadly distributed around a putative equilibrium optimal size?

All these anomalies made for a perfect cocktail in piquing the interest of physicists. Perhaps these reflect interesting (and often universal) underlying collective effects, which are the fundamental mechanism leading to crises and crashes? Quite amazingly, Keynes himself had anticipated such a change of paradigm when he wrote that *we are faced at every turn with the problems of Organic Unity, of Discreteness, of Discontinuity the whole is not equal to the sum of the parts, [...], small changes produce large effects, the assumptions of a uniform and homogeneous continuum are not satisfied.*

My own favourite definition of a complex system is precisely that small changes may, with some probability, produce disproportionally large effects, *i.e.* a system that responds to perturbations in a highly intermittent, non-linear way. The holy grail of econophysics research is to find models that are simple enough to be understood in detail, yet rich enough to generate such a non-trivial phenomenology, with truly unexpected collective phenomena emerging at the macro level.

This may in the end be the most relevant contribution of physics to economics: crises and discontinuities must be understood as interaction-induced, aggregate phenomena that cannot take place in a world of non-interacting, perfectly rational agents.

This agenda is ambitious enough. But what did econophysics actually *achieve* in the last 30 years? In terms of total number of papers, quite a lot. In terms of number of very good papers, maybe not that much. In terms of number of very bad papers, certainly too much. In terms of impact on mainstream economics, very little. I don't have the luxury here of reviewing all the work that I particularly value, but, instead, will offer a possible broad classification.

Econophysics has engaged in three types of research projects: i.) empirical studies (for example, as mentioned above, identifying distributions of economic/financial variables); ii.) technical papers (for example, Random Matrix Theory applied to covariance matrices or Network Theory applied to default contagion) and; iii.) modelling. The final item can be further decomposed into three categories: phenomenological models, metaphorical models, and realistic (Agent Based) models[4].

A phenomenological model is mostly descriptive: it attempts to capture in concise mathematical terms the essence of an observation, without necessarily understanding its deeper origin. The Brownian motion as a description of the dynamics of stock markets is the prime example of such models[5].

A metaphorical model does not attempt to precisely describe reality, nor does it necessarily rely on very plausible assumptions. Rather, it aims to illustrate a non-trivial mechanism, the scope of which goes much beyond the specifics of the model itself [10]. Well known examples are the Ising model in physics, where the phenomenon of phase transition and collective effects appears in a bare bone model of magnetism, or the Schelling segregation model, that explains how populations can end up living in completely segregated neighbourhoods even though each person individually would not mind living in a mixed neighbourhood.

Finally, realistic (or Agent-Based) models attempt to build a faithful representation of the world from the bottom up [11] – like when we derive the laws of thermodynamics and the Navier-Stokes equation from an atomistic description of gases.

Some metaphorical models have, I believe, performed extremely well and are quite influential. One particular example is the Minority Game [12], which

[4] Of course, the line between these three types of models is blurred, and sometimes phenomenological/metaphorical models are just the first stone needed to build more realistic models.

[5] This idea dates back to Bachelier in 1900 and is the most widely used model for prices in financial mathematics. Unfortunately, such a model fails completely at describing the intermittent, fat-tailed nature of stock prices that we described above, see Fig. 1.

is one of the most comprehensive and compelling efforts to show how heterogeneous, competing agents who learn to play a complex game, can generate an extremely rich aggregate behaviour and some of the phenomenology of financial markets. The Schelling metaphorical model can help understand how Adam Smith's invisible hand (another time-worn metaphor) can badly fail when individual agents only follow their self-interest. Simple metaphorical network models for trust evaporation have been devised to help understand how the 2008 crisis unfolded so suddenly, and so violently [13].

Nevertheless, it is a safe bet to think that Agent-Based Models (ABM) will make for the natural common ground for economists and physicists to meet and make progress[6]. Starting from realistic models of agents' and firms' behaviour, one is able to generate plausible economies at the macro-scale, with for example spontaneous business cycles and crises without news [14, 15]. These models are also particularly well-suited for conducting monetary policy experiments. For these reasons, ABMs are becoming increasingly popular in both some economics departments and in public institutions (such as the Bank of England [16] and the OECD).

As models become more realistic and hone in on details, analytics often has to give way to numerical simulations. This is now common practice in physics, where numerical experimentation has gained a respectable status, bestowing on us a telescope of the mind, (as beautifully coined by Mark Buchanan) *multiplying human powers of analysis and insight just as a telescope does our powers of vision*. However, the uptake and acceptance of computer simulations as a proper way to do science has been much slower in economics.

Although the economic cost has been dire, the 2008 crisis may have been a blessing for getting theoretical economics out of the rut it had dug for itself. Dissenting voices and alternative, fringe ideas are becoming noticed, even by mainstream economists.

Calls for "rebuilding macroeconomics" [17] and rethinking economics undergraduate curricula are now plentiful. For many years, economists' inflexible insistence on Rational Expectations and Efficient Markets made it difficult for physicists to engage in a constructive conversation. This is no longer the case and a window of opportunity is opening up [7], which should not be missed nor botched.

Real cross-disciplinary efforts have actually started and will hopefully proliferate in years to come – which means that universities should actively foster "double curricula" that mix (statistical) physics and economics at an early stage. This is the only way econophysics will not remain on the fringe for the next thirty years. ■

About the Author

Jean-Philippe Bouchaud graduated from École Normale Supérieure (Paris) in 1985. His work includes the physics of disordered and glassy systems, granular materials, the statistics of price formation, stock market fluctuations, and agent based models for financial markets and for macroeconomics. He co-founded the company Science & Finance in 1994, which merged with Capital Fund Management(CFM) in 2000. He was awarded the CNRS Silver Medal in 1995, the Risk Quant of the Year Award in 2017,and is a member of the French Académie des Sciences since 2018.

References

[1] See the conference proceedings: P. W. Anderson, K. Arrow, D. Pines, *The Economy as an Evolving Complex System*, Addison-Wesley (1988)

[2] R. N. Mantegna, & H. E. Stanley, (1999). *Introduction to econophysics: correlations and complexity in finance*. Cambridge University Press.

[3] see *e.g.* C. Castellano, S. Fortunato & V. Loreto, *Reviews of modern physics* **81(2)**, 591 (2009).

[4] see: https://en.wikipedia.org/wiki/List-of-cognitive-biases

[5] P. Bak, *How Nature Works: The Science of Self-Organized Criticality*, New York: Copernicus (1996)

[6] J. Sethna, K. Dahmen, C. Myers, *Nature* **410**, 242 (2001)

[7] on this point, see the very interesting discussion in F. Jovanovic & C. Schinckus (2017). *Econophysics and Financial Economics: An Emerging Dialogue*. OUP.

[8] for a review: X. Gabaix, *Annu. Rev. Econ.* **1(1)**, 255 (2009).

[9] R. Axtell, *Science* **293(5536)**, 1818 (2001)

[10] for a partial review of such models, see: J. P. Bouchaud, *J. Statistical Physics* **151(3-4)**, 567 (2013).

[11] for very insightful introductions to ABMs, see J. M. Epstein, *Complexity* **4(5)**, 41 (1999); R. L. Goldstone & M. A. Janssen, *Trends in cognitive sciences* **9(9)**, 424 (2005).

[12] D. Challet, M. Marsili, Y.C. Zhang, *Minority Games*, Oxford University Press (2005)

[13] see *e.g.* K. Anand, P. Gai & M. Marsili, *J. Economic Dynamics and Control* **36(8)**, 1088 (2012); J. da Gama Batista, J. P. Bouchaud & D. Challet, *European Physical Journal B* **88(3)**, 55.

[14] D. Delli Gatti, A. Palestrini, E. Gaffeo, G. Giulioni & M. Gallegati (2008). *Emergent macroeconomics: an agent-based approach to business fluctuations*. Springer.

[15] S. Gualdi, M. Tarzia, F. Zamponi & J. P. Bouchaud, *J. Economic Dynamics and Control* **50**, 29 (2015).

[16] A. G. Haldane & A. E. Turrell, *Oxford Review of Economic Policy* **34(1-2)**, 219 (2018).

[17] *Oxford Review of Economic Policy* **34(1-2)**.

[6] There is already a well-connected community of economists, computer scientists and physicists working on ABMs.

SKATING ON SLIPPERY ICE

T.H. Oosterkamp, T. Boudewijn and J.M.J. van Leeuwen – DOI: https://doi.org/10.1051/epn/2019104
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Skating has been popular for centuries but is still poorly understood. Is it sufficient that the surface of ice is wet in order to explain why skating is possible for a wide range of temperatures, velocities and types of skates? Or do we need a layer of water formed between skate and ice by the frictional heat? Here we discuss the physics of the water layer and its implications at large velocities as occurring in speed skating.

The friction of a skate on ice is orders of magnitude smaller than the friction between steel and another solid. So one wonders what exceptional property of ice leads to this low friction. Ice has the rare property that the solid phase is less dense than the liquid phase: ice floats on water. This property has a profound impact on our habitat. Would life be possible if the polar ice would sink and accumulate at the bottom of the ocean? Skating is a minor beneficiary of this property, as canals freeze on top and not at the bottom. So, after a few nights of frost, an ice layer develops sufficiently thick to carry a human body. The fact that the

volume change from ice to water is negative has another implication through the Clausius-Clapeyron relation

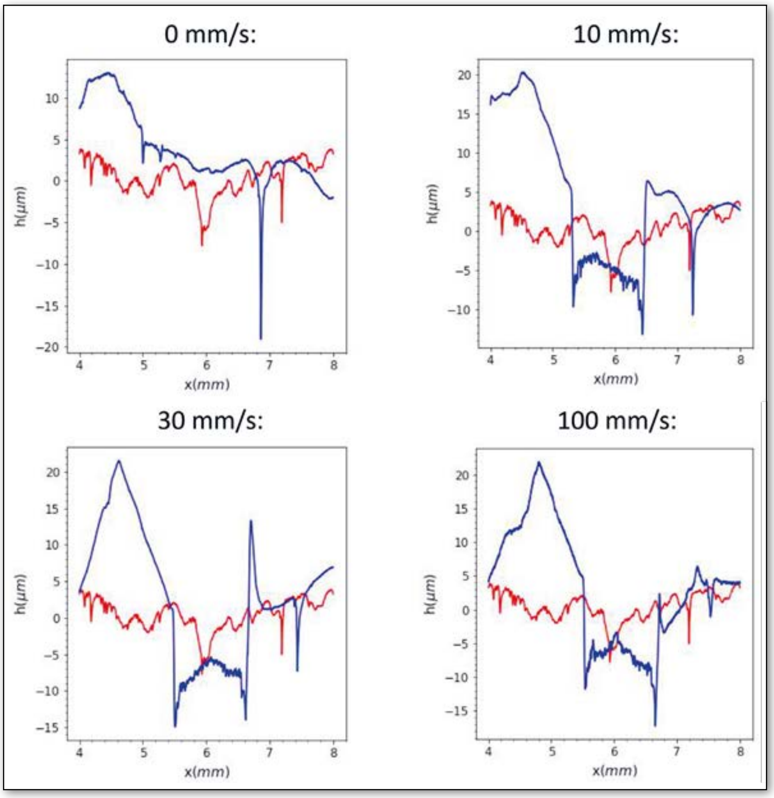
$$\frac{dP}{dT} = \frac{L_h}{T\Delta v}. \qquad (1)$$

Here Δv is the (negative) volume change from ice to water, T the absolute temperature and $L_h = 0.33 \cdot 10^6$ J/kg the latent heat of melting. dP / dT is the derivative of the melting line and, as $\Delta v < 0$, the melting temperature *decreases* with increasing pressure. This feature has led to the still popular, though wrong, explanation of skating: due to the pressure exerted by the weight of the skater, the ice underneath the skate melts and the skate glides on this layer of water. The lowering of the melting temperature under pressure was once demonstrated in high schools with a steel cable, melting itself through a block of ice under the pressure of a load. The spectacular aspect is that above the steel cable the water regelates, such that after the steel cable has melted itself through the block of ice, the two parts still form one solid block of ice!

The simplest objection against this explanation is that skaters, leading to a pressure of some 15 MPa, give only a lowering of 1 degree centigrade, while skating is perfectly possible at 10 degrees below freezing. Apart from this argument one would have to explain the origin of the heat necessary to melt a sufficient layer of water. The steel cable gives a clue. The regelation of the ice above the cable, provides the heat needed to melt ice underneath the cable. It works due to the high heat conductivity of steel. A nylon cable with equal pressure does not melt the ice.

Faraday [1] already suggested that the surface of ice is wet. This leads to another explanation of skating, based on the motto: *slippery when wet*. Careful experiments combined with molecular dynamics calculations [2,3,4] have demonstrated the existence of a surface with a layer of very mobile molecules for temperatures above -30°C. The strong similarity in the behaviour of the surface mobility and the friction as function of the temperature, prompted the authors to see this layer as the key to the slipperiness of ice. Such a surface certainly contributes to lowering the friction, but the question is whether it is sufficient for skaters of a weight of 75 kg with a speed of 15 m/s. Then the ice is touched for about a millisecond and one has to show that surface mobility can keep up with this fast process.

The more standard approach links the heat of friction to the formation of a thin layer of water between the skate and the ice. Such a layer has never been demonstrated experimentally. Efforts to detect the layer are underway [5], but are difficult since the water layer is calculated to be only 1 μm thick. So up till now, the water layer features only through its implications, following from the hydrodynamics and the heat balance of the water layer. In this article we focus on the quantitative analysis of the pressure and temperature distribution [6] in the layer of water, which is created by and which controls in part the friction of the skate with the ice.



▲ **FIG. 1:** Indentations for static and dynamic deformations.

Not only the thickness of the water layer is important, but also the depth of the indentation that the skate causes in the ice. Indentation is essential for skating, since skating is not only a matter of gliding, but also of pushing oneself forward. This requires sharp edges on the skates. Figure-, hockey- and speed skaters know that sharp edges are extremely important for a good performance. As we are most interested in skating at high velocity, we restrict ourselves to speed skates, having a rectangular shape in the transverse direction with a width $w = 1.1$ mm and a radius of curvature $R = 22$ m in the longitudinal direction.

Sharp edges always lead to a plastic deformation of the ice and therefore the hardness of ice plays a central role. The hardness is the pressure above which deformations are plastic and no longer elastic. Before we embark on the physics of skating we discuss briefly the hydrodynamics of a sheared thin layer of water.

The hydrodynamic properties of a layer of water under shear

Consider (box 1) a layer of water of thickness h, which on top moves with the speed V of the skate and which is at the bottom at rest, such that in the vertical direction a velocity gradient V/h exists. As the layer is thin, the lubrication approximation applies and the gradient causes at the top a friction force $F_w = \eta V/h$ per area, with $\eta = 1.7 \cdot 10^{-3}$ Pas. So the friction of the skate is $F_w wl$, where w is the width of the skate and l the contact length. An estimate, to be articulated later, gives the contact length from the

BOX 1: FRICTION AND PRESSURE IN THE WATER LAYER

Fig. 3 shows the velocity profile in a thin layer of water of thickness h moving at the top with velocity V and at rest on the bottom. The velocity in the longitudinal x-direction is given by

$$v_x = Vz/h, \quad (11)$$

with z the perpendicular direction. In order to keep the water moving at the top one has to apply a shear force

$$F_{fr} = \eta\left(\frac{V}{h}\right) wl, \quad (12)$$

with V/h the velocity gradient, w the width in the transverse y-direction and l the contact length.
There is also a velocity profile v_y in the transverse direction

$$v_y \sim yz(h - z), \quad (13)$$

since the water is squeezed out sideways. v_y vanishes at the top and the bottom of the layer. The pressure needed for this transverse flow is of the form

$$p - p_h \sim \eta(w^2/4 - y^2). \quad (14)$$

It is a parabola with the top in the middle $y = 0$. Eqns. (13) and (14) satisfy the hydrodynamic equation $\nabla p = \eta \Delta v$.

force balance: the weight of the skater must be balanced by the product of the pressure times the contact area

$$Mg = pwl. \quad (2)$$

Here M is the mass of the skater and p the pressure. We will argue that the deformations of ice due to skating are mostly plastic. Evidence for plastic deformation is the visible trail that a skater leaves behind on virgin ice and the fact that a skating rink has to be regularly mopped up from the ice debris. So the hardness p_h is a reasonable figure to get an order of magnitude estimate. Pourier *et al.* [7] give for the hardness the formula

$$p_h = 14.7 - 0.6(T - T_m), \quad (3)$$

with p_h in MPa and the temperature difference $T - T_m$ in centigrade. This expression is open for critique [8,9], since other measurements give substantial lower values and the method of measuring the hardness by dropping steel balls is somewhat disputable. We take for the calculations $p_h = 10$ MPa and a skater of 72 kg. Then the contact length $l = 6.4$ cm. That in turn gives for a layer of 10 nm, a friction force of 122 N. This is an order of magnitude higher than the measured value by de Koning *et al.* [10], who find for a skater of 72 kg frictions in the range of 3.8 N for the straights and 4.9 N for the curves. That a straight stroke has less friction than a curved stroke, indicates that an upright skate has less friction than a skate in a slant position. The analysis of an upright skate is easier than that of a slant skate and therefore we restrict ourselves to the former case.

As the friction is an order of magnitude too large for a layer of water of 10 nm, it is a problem to understand that shrinking the layer to 1 nm would bring the friction in the right ball park.

A stable layer of water

Friction produces heat at the interface between skate and ice. But is the heat sufficient to melt a layer of ice into water, forming the interface between skate and ice? The answer is positive, since the layer is self-establishing. If the layer gets thinner by a fluctuation, the heat generation increases making the layer thicker. In the same way a fluctuation enlarging the layer is damped out by lowering the friction and the heat generation. This stability makes skating robust against irregularities in the ice surface. One has to show however that the generated heat is indeed available for melting and does not leak away *e.g.* to the skate instead of to the ice. In box 2 we make up the heat balance between the generation of heat and the thickness of the water layer. It results in the layer equation, describing the thickness $h(x)$ as function of the position x along the skate.

$$-\frac{dh(x)}{dx} = \frac{k}{h(x)}. \quad (4)$$

Here k is a parameter of the dimension of a length

$$k = \frac{\eta V}{2\rho L_h}, \quad (5)$$

with ρ the density of ice $\rho = 962$ kg/m^3 and L_h the latent heat of melting $L_h = 0.33$ MJ/kg. k is quite small: $k = 2.8 \cdot 10^{-11}$ m, for $V = 10$ m/s. The solution of Eq. (4) reads

$$h(x) = \sqrt{2k(l - x)}, \quad (6)$$

with l again the contact length as integration constant. So the layer vanishes at the tip of the skate $x = l$ and has it largest thickness in the middle at $x = 0$. With $l = 6.4$ cm we find the small value $h(0) = \sqrt{2kl} = 1.9\mu$m This makes the experimental demonstration of the water layer difficult. In the derivation we have assumed that the generated heat streams in equal proportions towards the ice and the skate, which is the case when the skate has the temperature of the ice. This is accounted for by the 2 in the denominator of Eq. (5) for k. As it is unlikely that the skate gets colder than the ice, 1/2 is a lower limit.

An important consequence of the solution (6) is that it leads to the friction

$$F_w = \eta w \int_0^l dx \frac{V}{h(x)} = 2\eta w V\left(\frac{l}{2k}\right)^{1/2} = 2w\sqrt{\eta\rho L_h V l}. \quad (7)$$

That the friction depends on the skate velocity as $\sqrt{V}$ is surprising. Approaching $V \to 0$ the layer vanishes but the friction also vanishes! For $V = 10$ m/s the friction force $F_w = 1.3$ N. This value is substantially lower than the measured 4 N by de Koning et al. [10]. Clearly we must have missed a few loss mechanisms. We list a number of the possibilities.

- The water does not stay underneath the ice, but is squeezed out sideways. One can account for this effect by computing the pressure distribution in the water layer. The pressure varies as a parabola with the top in the centre and the lowest points at the edges, where the water escapes from the layer.
- In box 2 we have assumed that the upper surface of the layer is flat, while it is curved by the curvature of the skate.
- By the melting, the temperature of the surface of the ice is suddenly raised to the melting temperature (to be precise to the melting temperature at the pressure in the layer). This heat shock causes a gradient inside the ice by which heat also leaks away inside the ice.
- We calculated the friction for an upright skate, while skating happens mostly at an angle, even for the straight strokes. The measurements of de Koning *et al.* [10] indicate indeed that the upright position has the least friction.
- Ice and skates are not perfectly smooth *etc.*

The combined effect on F_w of the first two items is a substantial increase of the friction, as it shrinks the water layer. However, if we consider the pressure distribution, we have to include also the influence of the pressure on contact length and the indentation of a skate in ice. Most importantly of all omissions is that we have ignored the friction due to motion of this indentation: the skate does not only glide over the water, but also has to plough its way through the ice.

Ploughing

The indentation $d(x)$is a sphere segment, approximately given by

$$d(x) \approx d - \frac{x^2}{2R}, \;\rightarrow\; d \approx \frac{l^2}{2R}. \tag{8}$$

It is maximal in the middle of the skate $d = d(0)$ and for $l = 6.4$ cm it equals 94 μm. A simple expression for the ploughing friction is [11]

$$F_{pl} = p_h w d. \tag{9}$$

wd is the cross-section of the furrow that the skate ploughs against the hardness as counter pressure. For the skating parameters we find $F_{pl} = 1.0$ N. Addition of F_w from Eq. (7) to F_{pl} then leads to the total friction force.

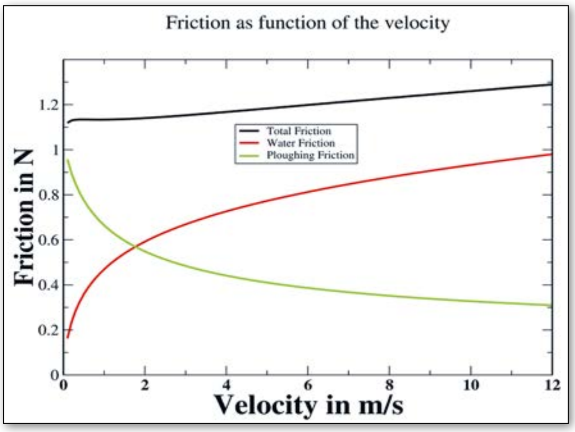
That the skate really ploughs through the ice is demonstrated by the laboratory experiment [13], in which a skate is pushed over a strip of ice. A sensitive roughness tester scans the height of the ice surface. In Fig. 1 we show the results. The red curves give, as reference, the surface in a run of the tester perpendicular to the skate, before the skate has touched the ice. Pushing the skate into the ice with a force of 500 N and removing it, leaves the ice in a state which is tested again. The blue curve in the upper left corner shows a minor difference between the surface before and after the move. This indicates that the deformation is mostly elastic. In contrast when the skate is moved with a velocity, the skate leaves a clear indentation behind, showing that the deformation is plastic and that the skate leaves a furrow behind. The difference between static and dynamic behaviour is simply explained by the fact that a static deformation has twice the contact length of a dynamic deformation. So the counter pressure of the ice in the dynamic case, needs to be twice that of the static case. Using the values of the hardness for $T = -10$°C, one finds indeed that in the dynamic case the pressure exceeds the hardness for 500 N. This makes the indentation plastic.

However, we should realize that in the dynamic case the skate does not directly touch the ice. It is not the skate, but the pressure in the water layer that pushes the ice down. Moreover the pressure in the water layer exceeds the hardness, amongst others in order to squeeze out the water sideways. And for speed skating the pressure must be such that the ice is pushed down with a certain velocity. For a velocity of 10 m/s the ice at the tip of the skate has to give way downwards at a rate of 1 cm/s. Therefore we need a sort of dynamic hardness that gives the rate v_{ind} at which the ice indents. We propose for this rate the following relation, inspired by the Bingham solid, [6]

$$v_{ind} = \gamma(p - p_h). \tag{10}$$

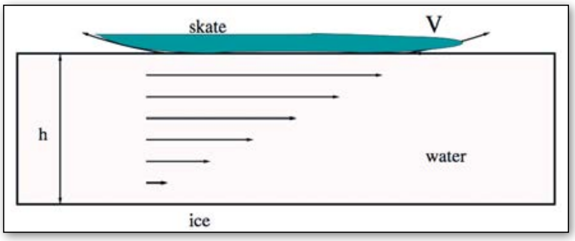
Below p_h the deformation is elastic, above p_h the ice starts to flow with the velocity v_{ind}. We have no measurement of γ, only an estimate, coming from shear flow of ice. We use $\gamma p_h = 1$ mm/s for the computation.

The above formula is an interpolation between two recent theories on skating. Lozowski and Szilder [11] implicitly assume that the pressure in the water later always equals the (static) hardness. This comes down to a value $\gamma = \infty$. On the other hand Le Berre and Pomeau [12] ignore the rate of indentation, which boils down to a value $\gamma = 0$. Now the indentation rate is dictated by the shape of the skate. It behaves as $v_{ind} = Vx/R$, with x/R the slope of $d(x)$. v_{ind} is maximal at the tip of the skate (1 cm/s at $V = 10$ m/s) and zero in the middle. So Eq. (10) gives the pressure inside the water layer needed to realize this velocity. That would imply that the pressure at the tip, is 11 times the static hardness for $V = 10$ m/s! Such a pressure increase shortens the contact length,



◂ **FIG. 2:** Total friction as function of the velocity *V*

which has a twofold consequence.



▲ **FIG. 3:** A thin layer of water between the skate and the ice.

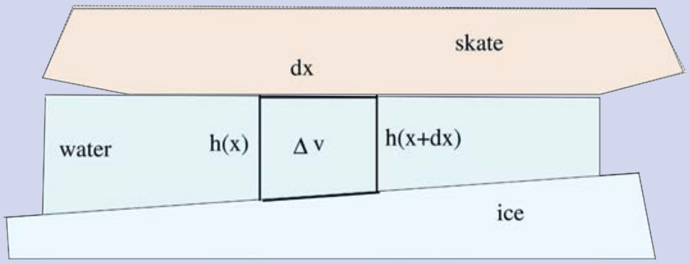
- A shorter contact length l yields a smaller indentation depth $d = l^2/2R$. If the average pressure is twice the static hardness, the contact length is reduced by a factor 2 and the depth d by a factor 4. So the ploughing product pwd is reduced by a factor 2. The counterintuitive result, that ploughing faster meets less resistance, is a form of *aquaplaning*: the skate is lifted and ploughs less deep through the ice.
- A shorter contact length reduces also the friction F_w as ice and water get a smaller surface of contact. This effect is substantial and undoes for the greater part the rise in friction due to the thinner water layer.

If we take all facets into account, we get the following picture for the total friction as function of the velocity V (see Fig. 2).

The rise of the resistance due to the friction in the water layer is largely compensated by the reduction of the ploughing resistance. As result we get a weakly rising friction as function of the velocity, which makes skating at high speeds possible: the world record is 93 km/hr. The computed values have a large margin of uncertainty, mainly due to the uncertainty in p_h and γ. Fortunately the total friction varies only mildly with the value of γ. An increase of a factor 100 in γ gives about a factor 2 increase in the total friction. Nevertheless a test of Eq. (10) is more than welcome! ■

BOX 2: THE HEAT BALANCE

▼ **FIG. 4:** Heat generation and melting in a volume v



The rate of heat generation in a volume $\Delta v = h(x)wdx$ reads

$$\frac{dH(x)}{dx} = \eta \frac{V^2}{h^2(x)} \Delta v = \frac{V^2}{h(x)} wdx. \quad (15)$$

This leads to an increase of the water volume

$$\frac{d\Delta v}{dx} = \frac{dH(x)}{dt} \frac{1}{2\rho L_h}, \quad (16)$$

assuming that only half of the heat flows towards the ice and the other half flows towards the skate. On the other hand the volume increases via $dx = -Vdt$ as

$$\frac{d\Delta v}{dx} = w \frac{dH(x)}{dt} dx = -w \frac{dh}{dx} Vdx. \quad (17)$$

Equating these two expressions gives the layer equation (5) in the text.

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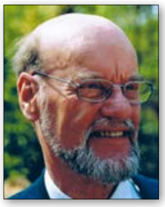
Tjerk Oosterkamp is professor at the Physics Department of the University of Leiden. His main research interest is MRI at the nanoscale using force microscopy and the development of experiments that may shed light on wavefunction collapse.

Thom Boudewijn is Master Student in experimental phyics at the University of Leiden. His Masters Project is a laboratory experiment of a skate gliding over a thin layer of ice, with the aim of measuring the friction and indentation of the skate in ice.



J.M.J. van Leeuwen is emeritus professor in theoretical physics at the Lorentz-Institute of the University of Leiden. Apart from his interest in skating he is concerned with problems in Statistical Physics.

References

[1] M. Faraday, Experimental Researches in Chemistry and Physics, Taylor and Francis, London (1859) p. 372.

[2] B. Weber, Y. Nagata, S. Ketzetzi, F. Tang, W. J. Smit, H. J. Bakker, E. H. G. Backus, M. Bonn and D. Bonn, *J. Phys. Chem. Lett.* **9** **11**, 2838 (2018).

[3] W. J. Smit and H. J. Bakker, *Angew. Chem.* **129**, 15746 (2017)

[4] W. J. Smit, F. Tang, M. A. Sánchez, E. H. G. Backus, L. Xu, T. Hasegawa, M. Bonn, H. J. Bakker, Y. Nagata, *Phys. Rev. Lett.* **119**, 133003 (2017).

[5] T. H. A. van der Reep, *Masters Thesis* (2014) Univ. Leiden.

[6] J. M. J. van Leeuwen, *SciPost Phys.* **3**, 042 (2017).

[7] L. Pourier, R. I. Thompson, E. P. Lozowski, S. Maw and D. J. Stefanyshyn, *21st Int. Offshore and Polar Eng. Conf.* (2011) Maui, ISOPE, 3 1071.

[8] B. Weber, *PhD. thesis* (2017) Univ. Amsterdam.

[9] A. Penny, E. P. Lozowski, T. Forest, C. Fong, C. Maw, P. Montgomery and N. Sinha, *Physics and Chemistry of Ice* (2007) 495, W. F. Kuhn, editor, Roy. Soc. Chem.

[10] J. J. de Koning, G. de Groot and G. J. van Ingen Schenau, *J. Biomechanics* **25**, 565 (1992).

[11] E. P. Lozowski and K. Szilder, *Int. Journ. of Offshore and Polar Engineering* **23**, 04 (2013).

[12] M. Le Berre and Y. Pomeau, *Int. Journ. of Non-linear Mech.* **75**, 77 (2015).

[13] T. Boudewijn, *Masters Thesis*, (2019) Leiden University.

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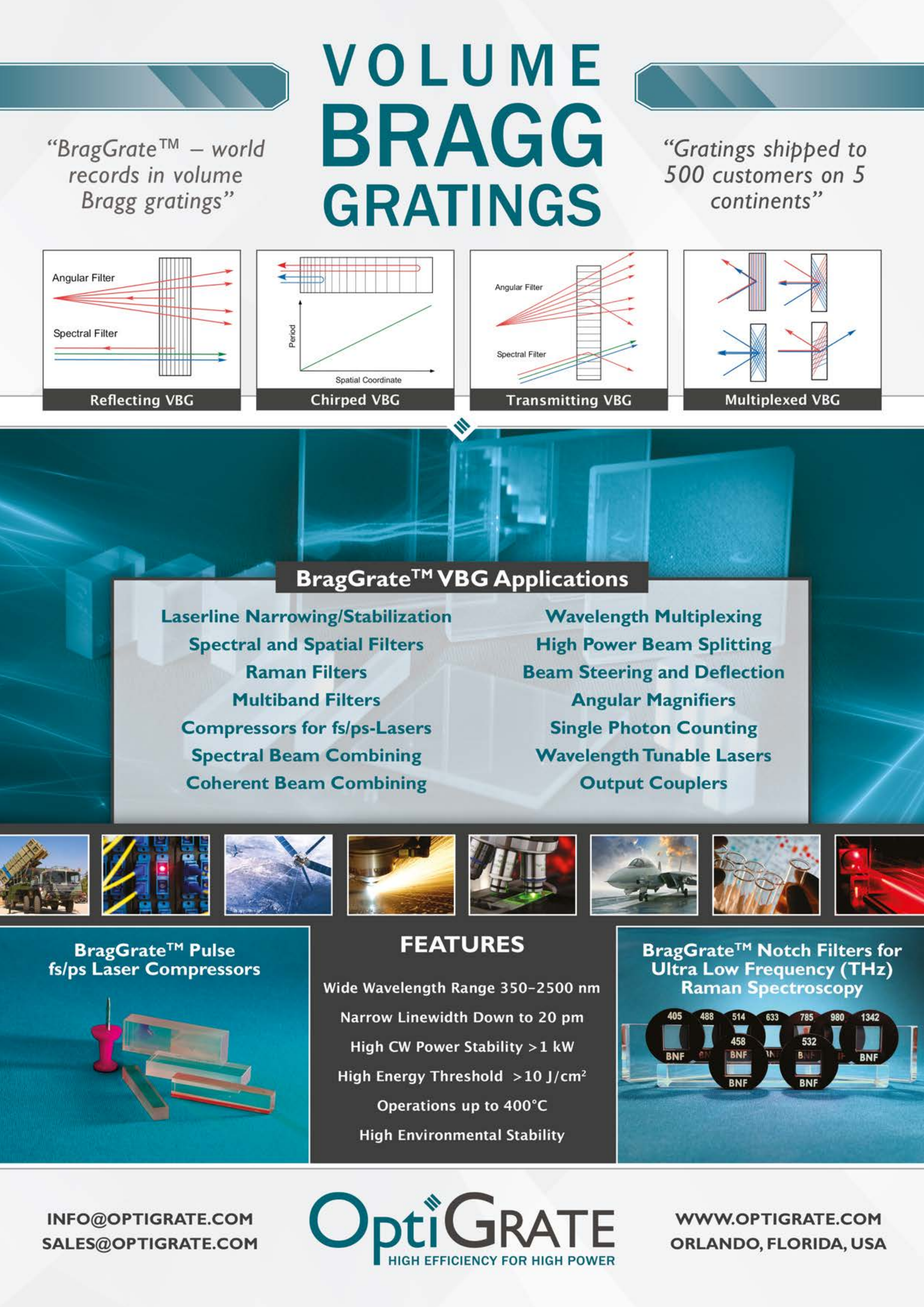
VOLUME
BRAGG
GRATINGS
"BragGrate™ – world records in volume Bragg gratings"
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Angular Filter
Spectral Filter
Reflecting VBG
Period
Spatial Coordinate
Chirped VBG
Angular Filter
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Transmitting VBG
Multiplexed VBG
BragGrate™ VBG Applications
Laserline Narrowing/Stabilization
Spectral and Spatial Filters
Raman Filters
Multiband Filters
Compressors for fs/ps-Lasers
Spectral Beam Combining
Coherent Beam Combining
Wavelength Multiplexing
High Power Beam Splitting
Beam Steering and Deflection
Angular Magnifiers
Single Photon Counting
Wavelength Tunable Lasers
Output Couplers
BragGrate™ Pulse fs/ps Laser Compressors
FEATURES
Wide Wavelength Range 350-2500 nm
Narrow Linewidth Down to 20 pm
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High Energy Threshold >10 J/cm²
Operations up to 400°C
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BragGrate™ Notch Filters for Ultra Low Frequency (THz) Raman Spectroscopy
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980
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