europhysicsnews

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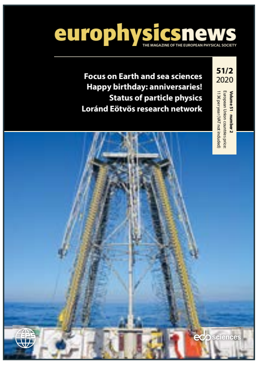
Focus on Earth and sea sciences
Happy birthday: anniversaries!
Status of particle physics
Loránd Eötvös research network

EPS
edp sciences



europhysicsnews

Cover picture: Unique structure for deep-sea oceanographic research. Lines with hundreds of high-resolution temperature sensors are attached to the arms that will spread out after over-boarding before descending to the seabed.
Picture credit: Louis Gostiaux

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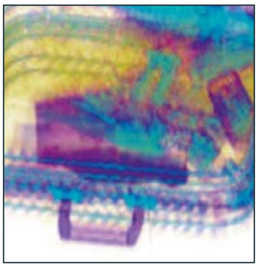
10 years of EPS Young Minds



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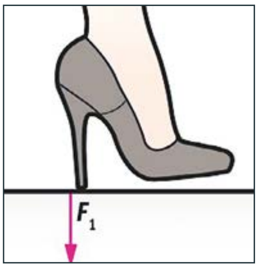
Scanning geophysical hazards



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Education: defining physical quantities

[EDITORIAL]

In times of coronavirus

Early April, the time of writing this editorial, the Covid-19 pandemic is still expanding further. It is hard to imagine how the world will be when you read this editorial.

Clearly, the impact of the crisis is significant for everyone both at the personal and professional level. Impressive reports on television, in journals, on the social media testify to the tremendous dedication of those working in vital jobs and to the tragedy of the loss of lives.

Also the physics community is affected and tries to adapt and give support to society wherever possible. The wide-spread experience of physicists with working from home, participating in larger remote physics meetings or giving remote presentations or lectures appears to be valuable. It is encouraging how many physics teachers provide on-line education at all levels. It is amazing how many young physics students help schools to set up remote teaching or contribute by giving on-line demonstrations and lectures for young students.

Although physics is not the dominant player in virology and epidemiology, there are numerous physicists working in medical organisations employing their physics background to help develop vaccines or modelling the complex multi-faceted process of the spreading of a virus among the world population. Engineers and technicians in physics labs help to solve the shortage of ventilators and protection material.

Young scientists worry about the impact the crisis will have on their careers. Many labs are closed and conferences are postponed, cancelled or turned into on-line events. It will be more difficult for them to show their talents. Surely, seniors will help them where possible by staying firmly in contact remotely. Fortunately, support plans are already being drafted by funding agencies and universities. The youngest generations of physicists deserve the full support of the physics community in the broadest sense.

Also EPS and EPN are affected by the quarantines. In particular, the EPS office in Mulhouse had to adapt to a strict lock-down and is working remotely from home as is EDP Sciences, publisher of EPN, in Paris. Together they are determined to continue their service to the EPS community. Unfortunately, the EPS Council meeting had to be postponed to October this year.

Reports on how scientists are coping with the impact of the coronavirus crisis have started to appear in various journals world-wide. With only five issues per year and a relatively long editing process, EPN is less well suited to publish such reports, but we will do our best to include some in a later issue. The present issue will be published on-line on the scheduled date at https://www.europhysicsnews.org and in the EPN archive at http://epn.eps.org. It remains, however, unknown when you will find the printed version on your doormat. The distribution channels, in particular the international ones, are largely affected by crisis-regulations.

We hope that you will find this issue an interesting and relaxing opportunity to read about the physics of Earth and Sea sciences or the personal report of a young EPS prize winner about a more cheerful corona: the Corona of the Sun.

Please, take care and stay safe!

Petra Rudolf *(EPS President)*
and **Els de Wolf** *(EPN Editor)*
for the full teams of EPS and EPN

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Early Career Researcher Prize 2019 of the EPS European Solar Physics Division

"For ground-breaking observational analysis highlighting the crucial role of small-scale photospheric magnetic fields in the structure and dynamics of the solar corona."

An old puzzle

The corona, seen as a faint glow surrounding the Sun during a total solar eclipse, is the outermost part of the solar atmosphere. In the early 1940s, it was realised that coronal gases must be millions of degrees hot, when researchers finally resolved that the mysterious green coronal emission line at 530.3 nm, first observed in 1869, is due to plasma composed of highly ionised iron (Fe xiv). However, it uncovered an even deeper mystery: how could the corona be so hot while the temperature of the photosphere, the lowest part of the solar atmosphere underlying the corona, is only about 6000 K? This is a long-standing puzzle in modern-day solar and stellar astrophysics.

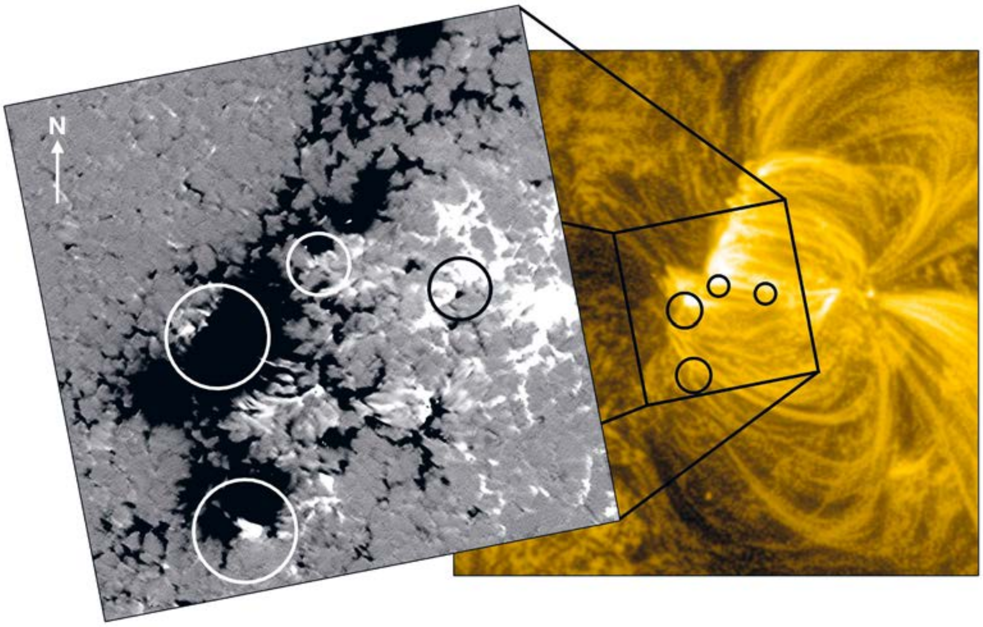
Magnetic fields at play

Space-based observations in the extreme ultraviolet (EUV) and X-ray emission reveal a dynamic corona that is spatially structured. In particular, the hot solar atmosphere overlying active regions, that host intense concentrations of magnetic fields including sunspots, appears bright in EUV and X-rays. The emission is observed to be structured in the form of giant plasma arches or so-called coronal loops, that outline the magnetic fields anchored at the photosphere. The dynamic nature of these coronal loops is then a direct consequence of the evolution of magnetic fields driven by photospheric convective (granular) motions. It provides an important clue that the nature of magnetic coupling through the solar atmosphere is closely linked to coronal heating.

But what is the role of magnetic fields in transferring the energy and heated plasma to sustain hot corona? Several theories and models have been proposed over the last eight decades to uncover the key magnetic processes that are responsible for the hot corona. However, there is no conclusive and coherent explanation for the observed high coronal temperatures.

Coronal loops and their magnetic roots

A fresh approach might help to tackle an old puzzle such as coronal heating that has been a subject of intense studies and debates over several decades. To decipher the elusive link between magnetic fields and coronal heating, I literally started to look at the roots of the problem itself. I realised that the corona cannot be treated in isolation; and my approach is that to better understand the origin of hot coronal loops, it is crucial to jointly investigate the evolution of their photospheric magnetic roots or footpoints as well.



◂ Mixed-polarity magnetic coupling of solar coronal loops. Right: Solar coronal loops at ~1 million kelvin, observed in an active region by NASA's SDO/AIA 171 Å EUV filter. Left: Photospheric line-of-sight magnetic field distribution observed with Sunrise/IMaX, covering the eastern footpoints of coronal loops. The white and black shaded regions are positive (north) and negative (south) magnetic polarities. Small-scale opposite magnetic polarity elements are detected at coronal loop footpoints (outlined by circles). Adapted from Chitta *et al.* 2017, ApJS, 229, 4.

To this aim, we first investigated the magnetic roots of coronal loops in an active region with very high spatial resolution magnetic field maps obtained with IMaX instrument on board the balloon-borne Sunrise telescope. IMaX captured solar magnetic fields at spatial resolutions as high as 100 km. This is crucial because most of the magnetic field in the photosphere is structured at such small scales. These Sunrise/IMaX data are combined with the coronal images recorded by the AIA instrument on board NASA's Solar Dynamics Observatory (SDO). We discovered that the coronal loops are often rooted in regions where the polarity of magnetic field changes, for instance from north to south or vice-versa, at spatial scales of 100 to 1000 km (see Figure). While the traditional view of a coronal loop is based on an assumption that it originates from uniform magnetic field regions, our observations suggested that this picture is likely too simplistic and that it is not universally valid.

Such adjacent opposite-polarity magnetic fields are in general interesting because they can interact and reconnect and, in the process, liberate magnetic energy to heat the plasma. Based on quantitative estimates of energetics, we proposed that magnetic reconnection at the footpoints of coronal loops could supply the required energy and heated material to the corona. In subsequent studies we found further evidence for our proposal. In particular, we observed signatures of magnetic reconnection in the form of plasma jets and bursts at coronal loop footpoints, resulting in coronal brightenings. Our recent efforts thus identified and added a new piece to the long-standing puzzle, namely, the crucial role of small-scale magnetic fields in the heating of corona. Future observations will continue to provide new details on these small-scale magnetic processes to further test our proposal.

Early Career Research Prize

I have been awarded the Early Career Research Prize by the European Solar Physics Division of the European Physical Society in recognition of my work revealing the link between small-scale magnetic fields and coronal heating. This work is only possible because of the availability of high-quality solar observations that form an important part of my research. Therefore, the award is a tribute to the scientists and engineers who build telescopes and suites of unprecedented instruments, observations which help spur new ideas and discoveries. Personally, I believe that the award has enhanced the visibility of my work to a wider community. This is always an important and helpful milestone for an early career researcher like me as the award would improve the job prospects and also motivate the next scientific steps. ■

■ **Lakshmi Pradeep Chitta**
Postdoc at Max Planck Institute for Solar System Research
Göttingen, Germany

“ Small-scale photospheric magnetic fields play an important role for the solar corona ”

175 years German Physical Society
Physics for and in Society

175 Jahre
Deutsche Physikalische Gesellschaft

Physicists need society. And society needs physics. Physics is all around, in modern communication technology as well as in advanced methods of medicine, in every piece of matter and the whole universe. The 175th birthday of the German Physical Society (*der Deutschen Physikalischen Gesellschaft* DPG) is hence an occasion to invite people to experience and share the fascination of physics and its role in society.

Physicists secure our prosperity and contribute to mastering the complex, interdisciplinary challenges of the future, such as energy supply or mobility in the context of climate change and the CO_2 discussion. The often long path from basic research to technical application can be illustrated, *e.g.*, by the quantum hypothesis presented by Max Planck at a meeting of the DPG on 14 December 1900. With this he laid the foundation for quantum mechanics, without which our modern technology would not be possible. And Albert Einstein's new concepts of space and time are proving to be indispensable for our GPS navigation today. And what began as research into the smallest components of matter led to the most diverse methods for medical diagnosis and therapy.

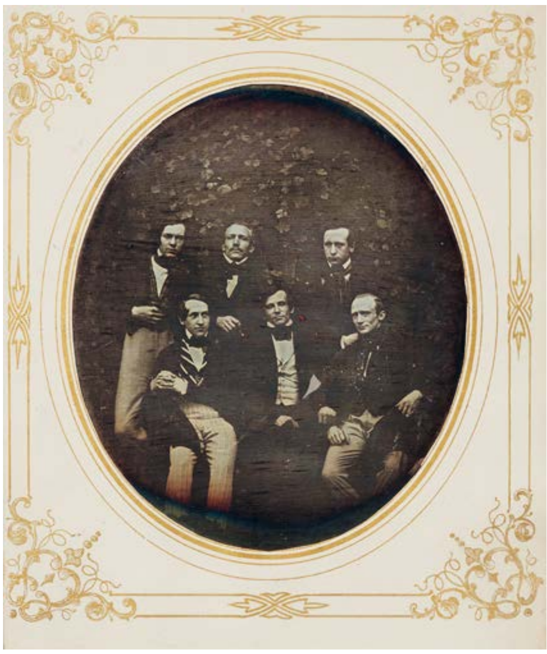
One of DPG's aims is therefore to provide understandable information and education about the opportunities as well as potential risks of physics research, a key to an informed civil society. For this reason, the anniversary year is dedicated to four special themes: physics as gaining knowledge of nature, physics and education, physics and information, and last but not least climate and energy. Many events will focus on this.

The history of DPG started with six young men of the colloquium of the German experimental scientist Gustav Magnus (2 May 1802 – 4 April 1870). On January 14, 1845, they founded the "Physikalische Gesellschaft zu Berlin" (PGzB) as an association open to all "who are interested in the physical disciplines".

"DPG invites you to celebrate its anniversary"

Thus, PGzB is the “mother” of DPG and nowadays its “daughter”. Therefore, the jubilee year was initiated on January 14th with an opening ceremony in the Magnus-Haus Berlin, DPG's representative office in the German capital. A highlight of the anniversary year will be the ceremonial event on 6 June as part of the “Long Night of Sciences” together with the Technical University of Berlin. Of course, the DPG Spring Meetings and the so called "DPG Day" in November will also focus on the importance of physics in a social context. In addition, in April, the Magnus-Haus Berlin will be inaugurated as an EPS Historic Site.

▾ Founding members of DPG



In order to widen its view, DPG will be celebrating its jubilee together with sister and partner societies: with the European Physical Society (EPS) DPG is organising the forum "Physics and Society". Furthermore, the Institute of Physics (IOP) and the DPG are jointly organising an event in Great Britain. In addition, a workshop for Eastern European societies is planned in Berlin.

In the anniversary year, emphasis will also be placed on internal exchanges, which should open opportunities for members to enter into a personal dialogue. Participatory activities are intended to strengthen the identification with the DPG. Furthermore, the social media project "175 Impulses" shows that physical fun facts are hiding in everyday life. And the project "175 Inspiring" presents inspiring physicists – from highly dedicated pupils or students to Nobel Prize winners or TV-Stars to reflect the wide variety of DPG members. ■

All information on the anniversary, including a calendar of events, is available on the DPG anniversary page: http://175.dpg-physik.de?set_language=en

Translation and adjustment of an article from Physik Journal 1/2020 of Alexander Pawlak: https://www.pro-physik.de/restricted-files/141051

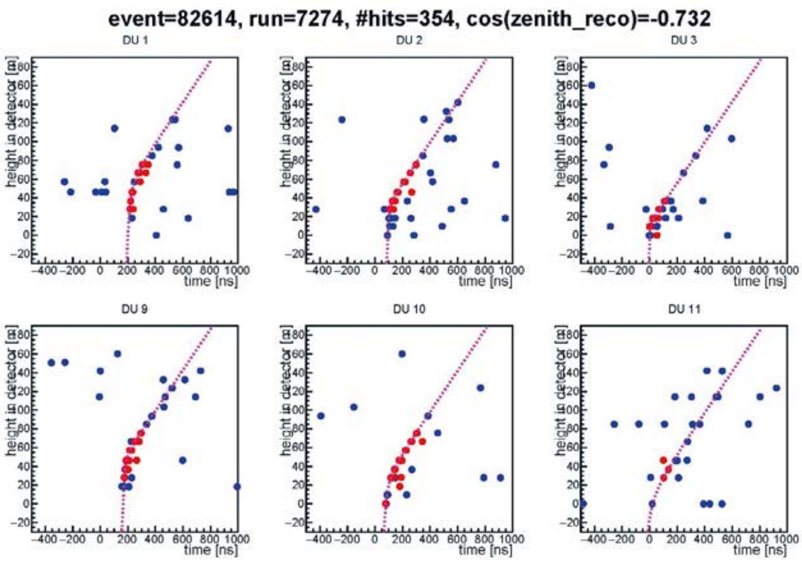
Building a neutrino telescope in Europe

With the installation of two more detection units at the French site of KM3NeT, the first phase of building the ORCA detector of the KM3NeT neutrino telescope is completed. Since 27 January 2020, the detector is taking data with six detection units.

KM3NeT is a research infrastructure under construction in the deep Mediterranean Sea. It will house the ARCA and ORCA neutrino telescopes located off-shore Sicily and Southern France, respectively. Once completed, the telescopes will consist of hundreds of detection units, long vertical lines equipped with 18 optical sensor modules to record the faint Cherenkov light generated by charged particles in the sea water. During a sea campaign in January 2020, Phase 1 of ORCA was completed with the connection of two new detection units to the seafloor network at the KM3NeT/ORCA deep sea site, 40 km offshore from Toulon, France (Fig. 1). The detection units were successfully positioned twenty metres apart to within a metre of their target position 2,500 m below the sea surface. In the next phase of ORCA, the detector will be extended to 115 detection units. With the full ORCA detector, researchers of the KM3NeT Collaboration aim to determine the neutrino mass ordering using atmospheric neutrinos.

▸ **FIG 1:** Detection unit with optical sensor modules coiled on a spherical frame and placed on its (yellow) anchor. After deployment, with the anchor firmly fixed to the seabed, the deployment frame floats back to the sea surface while unfurling the detection unit to its full length. The empty frame is recollected for re-use. Copyright KM3NeT Collaboration.

"Important milestone for KM3NeT"



▴ **FIG 2:** A so-called z-t plot of a reconstructed candidate neutrino event measured in ORCA. The six plots correspond to the six detection units. On the y-axis the height in the detector and on the x-axis the time of arrival of the light. Each point represents a detected photon. The red points are the hits that triggered the event and the red line is the projection of the fitted Cherenkov light cone. Copyright KM3NeT Collaboration.

Searching for neutrino events

Each optical sensor module of ORCA comprises 31 3-inch diameter photo-multiplier tubes (PMTs) recording the intensity of light flashes, *i.e.* the number of photons, and – with a nanosecond precision – when it arrives. A compass, tilt meter and acoustic receiver enable the position and orientation of the module in the sea water to be determined within a few centimetres. From the recorded light flashes the path of charged particles through the ORCA detector is reconstructed. Most of them are muon particles generated in the Earth's atmosphere and travel downwards through the detector. A few others travel upwards (Fig. 2); this is an indication that they are generated by neutrinos that have passed through the Earth and interacted in the vicinity of the detector. ■

REFERENCES

[1] Website: www.km3net.org

[2] YouTube channel: www.youtube.com/user/KM3NeTneutrino

[3] Twitter: @km3net

JENAS - Astroparticle, nuclear and particle physicists meet

The first JENAS Seminar attracted 230 participants resulting in a full auditorium at the Laboratoire de l'Accélérateur Linéaire (LAL) in Orsay. For three days senior and junior members of the astroparticle, nuclear and particle physics communities presented their overlapping challenges.

JENAS, Joint ECFA (European Committee for Future Accelerators)-NuPECC (Nuclear Physics European Collaboration Committee)-APPEC (AstroParticle Physics European Consortium) Seminar, marks the recognition of the three European committees of the importance of reinforcing their interdisciplinary links beyond the regular information exchange. The three scientific communities share a strong aspiration to explore nature with a view to understand both the smallest and the largest structures.

Synergy, Innovation and Outreach

On the technology front they seek to make visible the invisible at these extremes, and these successes are transformed into opportunities at the human scale for, amongst others, health, energy and safety. Readout electronics, Silicon Photomultipliers, Big Data computing and Artificial Intelligence for analysis are only some examples of developments essential for our research. Related to the quest of unravelling new insights in fundamental physics, coverage is required from all three fields in order to address the dark matter problem, the neutrino sector and the physics with gravitational waves. In presentations on organisational matters related to education, outreach, open science and software as well as careers, synergies are clearly identifiable.

Diversity

At the occasion of this meeting a Diversity Charter has been launched by APPEC, ECFA and NuPECC. From a survey among the seminar participants the diversity aspects will be analysed together with those from other conferences and events organised by the three communities.

Expressions of Interests

The JENAS2019 event, which was jointly organised by LAL-Orsay, IPN-Orsay, CSNSM-Orsay, IRFU-Saclay and LPNHE-Paris, allowed astroparticle, nuclear and particle physics researchers to sniffle into each other's activities. The identified challenges can transform via joint programs into opportunities to deepen our understanding of physics. Being informed by the presentations and discussions and with a view to further explore topical synergies between the disciplines, in the closing remarks a call has been issued for novel Expressions-of-Interest. Bottom-up and community thoughts can be submitted to the chairs of the three committees/consortia for further discussion within APPEC, ECFA and NuPECC. Thoughts revolving around potential synergies in technology, physics, organization and/or applications are welcome. The letters should elaborate on the synergy topic, the objectives, the initial thoughts and the potential communities involved. These letters are not the end of the process, but potentially the start of further communications on the expressed interest. APPEC, ECFA and NuPECC will discuss and propose actions to pursue your thoughts with a view to the next JENAS event in two years. ■

Website: https://jenas-2019.lal.in2p3.fr

> **"I believe that the ambitious goal of JENAS has been reached by this first edition. JENAS has proved to be a successful forum for stimulating researchers belonging to different research fields to look beyond the headlines and for helping them to bridge the various physics topics."**
>
> ■ **Eugenio Nappi (INFN Bari), participant**

■ **Jorgen D'Hondt**, *Chair ECFA*
■ **Marek Lewitowicz**, *Chair NuPPEC*
■ **Teresa Montaruli**, *Chair APPEC*

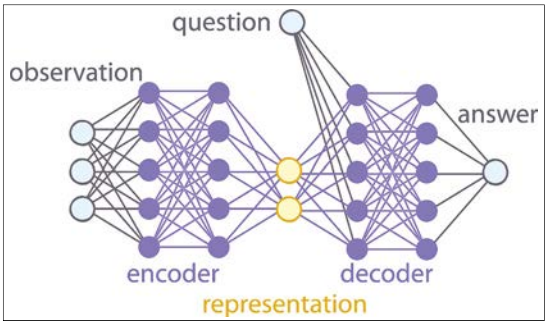
Artificial Intelligence finds a heliocentric representation of the solar system

Researchers from ETH Zürich used a neural network, which they call SciNet, to "re-discover" from simulated experimental data that the planets in our solar system orbit around the Sun rather than the Earth.

A neural network structure based on the physical reasoning process can be used to extract physical concepts from experimental data. When asked to make predictions about future positions of the Sun and Mars on the night sky based on current positions, SciNet internally switches to heliocentric angles to achieve its task. These heliocentric angles are stored in the neural network and can be read out directly by humans [1].

SciNet

The network structure is based on an idealised version of physicists' reasoning processes and was designed to find natural representations of experimental data. It is similar to the structure of a so-called auto-encoder, a well-known tool for machine learning. For example, auto-encoders can find features in images, such as the height of a chair from a picture of the chair. In the case of SciNet, first a network, called encoder, compresses the experimental data from physical experiments into a simple representation. A second network, called decoder, is then used to answer questions about the physical system based on this representation (Fig. 1). The compression forces the network to identify features in the experimental data that are relevant for making future predictions. Because the compressed representation is small, it can be analysed by hand and allows researchers to gain insight into how the network solves its task. This is typically impossible for large "black-box" neural networks, where any information about how the network solves its task is distributed across thousands of parameters inside the network, which cannot be interpreted by humans.



▲ **FIG 1:** The neural network structure for SciNet. Observations are encoded as real parameters fed to an encoder (a feed-forward neural network), which compresses the data into a representation (latent representation). The question is also encoded in a number of real parameters, which, together with the representation, are fed to the decoder network to produce an answer. Note that the number of layers and neurons depicted is not representative.

Demonstrations

The study demonstrates how such a neural network can be used to gain conceptual information about simple physical toy models in quantum and classical mechanics. For example, it shows how to gain information about a quantum state from tomographic data, or that the neural network exploits angular momentum conservation to make predictions given time series data of colliding objects. Interestingly, SciNet recovers the same quantities as those in standard physics textbooks, without being provided with any physical prior knowledge apart from the experimental data.

Long-term goal

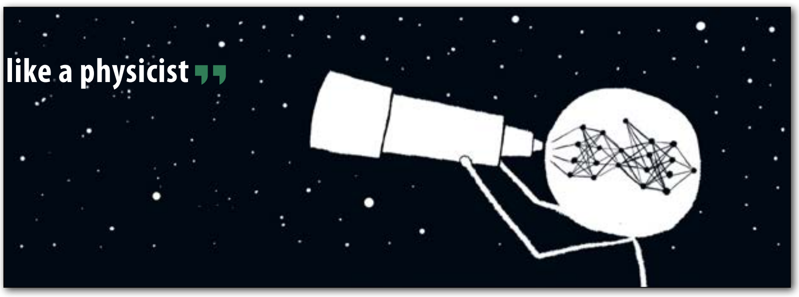
The application of machine learning to physics is a thriving area of research, but most work so far has focused on specific physics problems. This means that researchers make use of prior knowledge about the physical system under consideration and machine learning serves as an optimization tool within these constraints. SciNet is a first step towards the long-term goal of using machine learning to gain novel insight beyond the scope of existing physical models. However, the human eye is still necessary to interpret the representation found by the network, and so far, only small toy examples well within the scope of existing physical theories have been demonstrated. In the long term, such methods might help shed light on the foundations of quantum mechanics, where major conceptual problems, such as the "measurement problem", are still unsolved. The researchers from ETH hope that using machines that are not biased by knowledge about classical physics may eventually serve as a useful guide for coming up with an alternative description of quantum mechanics. ■

Raban Iten, Tony Metger, Henrik Wilming, Lídia del Rio and Renato Renner

Reference

[1] R. Iten, T. Metger, H. Wilming, L. del Rio, and R. Renner, *Phys. Rev. Lett.* **124**, 010508 (8 January 2020) (preprint version arXiv:1807.10300 [quant-ph]).

" AI reasoning like a physicist "



▸ **FIG 2:** Cartoon of the SciNet neural network.

Celebrating 10 years of EPS Young Minds

The Young Minds (YM) program has seen an impressive growth since its birth in 2010. We are proud of being part of what is now an established pan-European network of young scientists, and we wish to witness to many more successes in the years to come. Happy birthday YM!

A little bit of history

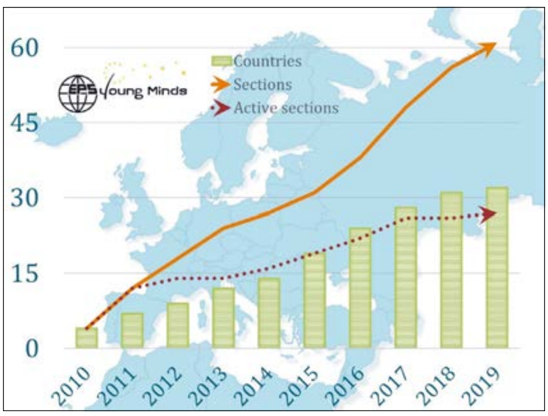
Back in 2010 Maciej Kolwas, former president of the European Physical Society, conceived the idea of building up an initiative dedicated to the young scientists within EPS. One year later, YM had already 12 active sections in seven countries – showing how much the initiative was appreciated all over Europe.

Two major objectives are at the core of the project: encouraging leadership and proactiveness in the new generations of European physicists and establishing a connected European-wide community of young researchers to network and foster cultural exchange and mutual understanding.

Annually, at the Leadership Meeting, representatives of each section meet for a 2-day workshop hosted by local sections, and providing a valuable opportunity to learn how to set up an international conference. Central to the Leadership Meeting is sharing and comparing experiences and ideas – especially when participants have different backgrounds. Besides getting to know peers from all parts of Europe, sections are provided with the opportunity to present their activities, organise visits to local industries, organise events aimed at sharing the fascination for physics with the public, organise large international conferences for young scientists or physics escape rooms. Further, there is always a designated time slot for talks by distinguished lecturers, and of course, time for social events to stimulate fruitful discussions on a more informal level.

Ten years after YM have been brought to life, it can look back on an impressive growth. The number of active sections and countries that are represented with at least one section is shown in Fig. 1, revealing that the project is set on the way of reaching its vision of creating a pan-European network. Each student or post graduate with a membership of a national physical society can join the YM program, without needing an EPS membership. Moreover, YM is not limited to countries that are geographically included in Europe and includes sections from Morocco, Egypt, Israel and the Palestinian territories. This wide distribution reflects the international spirit of YM and provides a great opportunity for YM members to learn about other cultures and scientific communities.

A key commitment of YM sections is fostering of physics in their local communities. Activities include professional development seminars and workshops, scientific outreach at schools or public events, and programs to support physic students during their degree studies. In 2019 YM has supported these and other activities with a total number of 89 grants.



▼FIG. 1: Evolution of the YM program. Active sections are sections that applied for grants or attended the annual Leadership Meeting.

The YM Action Committee

The Action Committee (AC) is the governing body of YM. It comprises young researchers and professionals, with experience with YM such as section management, representation of the project and the review of grant submissions from the sections. In addition, the Action Committee includes EPS president and Secretary General and the designated Project Manager. Currently, the YM representatives in the AC are Roberta Caruso (Italy), Giorgio Nocerino (Italy), Imran Khan (Germany), Hripsime Mkrtchyan (Armenia), Daryna Pesina (Ukraine), Tanausú Hernández (Spain), Araceli Venegas (UK) and Richard Zeltner (Germany).

The activities that made the difference

YM has established the annual Best Activity Award (BBA) for sections that organised a very impactful or creative event. The prize is sponsored by EPL - Europhysics Letters. The winning event must have original traits and have impact on the non-scientific community or on the international scientific community. It has to involve the largest possible number of section members or volunteers, to ensure the networking that is one of the pillars of YM. The first recipient was the BMSTU section in Moscow for optics demonstrations and laser games for school children during the local Festival of Science. In following years, the Debrecen section won the award for a series of experiments for 7^{th} grade pupils; the YM Section of the University of Valladolid in Spain for an amazing outreach show on physics and superpowers;

▲ FIG. 2: Authors of this article and currently member of the Action Committee. From left to right: Roberta Caruso (post-doctoral researcher at in the field of low temperature physics, University of Naples), Imran Khan (MPL Erlangen, his research focus is on quantum key distribution), Daryna Pesina (Biological physicist with the research focus on magnetic nanoparticles), Araceli Vengas (PhD student at University of Strathclyde) and Richard Zetner (Development and custom projects department of Menlo Systems GmbH).

the PONYS Naples Section for the realisation of a physics-based comic book, printed and distributed during the Naples city comic-con; Vilnius YM Section for the Open Readings, an international conference for students of physics and natural sciences; Kharkiv YM Section from Ukraine for the IEEE Young Scientists Forum on Applied Physics and Engineering. Finally, last year the first prize was granted to two sections in Armenia: the Yerevan Section received it for the handmade scientific tool-kits for school pupils and the Artsakh Section was acknowledged for the Brain-Ring Physics Game. In 2019 an additional award, honoring the best scientific outreach video, was announced. Ten sections responded to the call and submitted a short video explaining a physical effect in a comprehensible manner. The videos were presented at the 2019 Leadership Meeting at MPL Erlangen, and the award went to the Warsaw section – for a creative and informative video demonstrating how to guide light with a jelly waveguide.

Our brick in the wall

To reflect the international spirit of YM and to ensure that different regions are represented, care is taken that the AC members are coming from different locations all over Europe. Besides managing the project as a whole, each member of the AC is the direct contact person for a number of sections and provides support and advice on various topics regarding the section management, if needed.

Special concern of the AC is to strengthen the exchange between the sections and to establish the mindset that YM is more than "just" the work in the local section, and that every section is part of a bigger idea. To this end the AC has established a new grant to specifically support sections that are aiming at organising national and international conferences. Further, the AC has started to optimise its representation on social media, with the objective of providing interesting content for existing sections, informing sections about the activities of other sections on a more regular basis, and reaching out to people that are not yet part of YM. Further to facilitate the involvement of students in YM, the AC has worked towards waiving of the EPS member fees for Bachelor and Master students joining the YM program. This goal was achieved in November 2019.

The next 10 years

While Young Minds started as a project 10 years ago with just a few sections and a lot of personal interaction, it has now grown to a full program. Its mission and vision have grown into something that connects European young scientists, helps bridge cultural gaps and furthers understanding with our neighbouring countries. At the same time, networking is performed, connections are made, and soft skills are trained. With all of this in mind, Young Minds is looking at a bright future that we envision to be driven by its members rather than a centralised organisation. As the AC is still receiving a large number of applications and requests to form new sections, continuous growth of the project can be expected. Further, the AC works towards developing new ways to connect with one another, and to serve as a catalyst and therefore boost the individual impact of each of the sections.

▶ FIG. 3: Group picture of the participants to the last Leadership Meeting in Erlangen, May 2019. Courtesy of MPL.

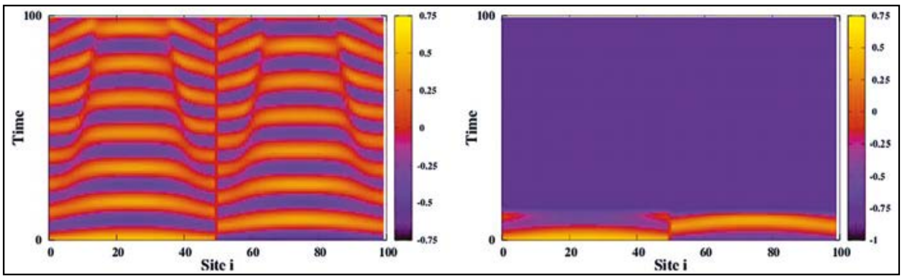
YM website: www.epsyoungminds.org
YM Twitter: @epsyoungminds
YM email: ac@epsyoungminds.org

Highlights from European journals

DYNAMIC SYSTEMS

Chimera states are fragile under random links

In a chimera state of large interactive systems the underlying symmetry of the dynamical system is spontaneously broken and the spatial profile splits into synchronised and desynchronised groups.



▲ Example of a chimera state in a ring of coupled oscillators (left) destroyed by the presence of a single random link (right).

In this work the surprising fragility of chimeras in the presence of very few time-varying random links is demonstrated in wide-ranging examples. Spatial randomness restores the symmetry of the emergent spatial patterns, with chimeras giving way to uniform steady states or spatiotemporal chaos. The size of the basin of attraction of chimeras rapidly shrinks under increasing randomness, indicating its strong impact on the global stability of chimeras. These results impact the search for chimeras in real-world systems. ■

▮ **Sudeshna Sinha**,
'Chimera states are fragile under random links', *EPL* **128**, 40004 (2019)

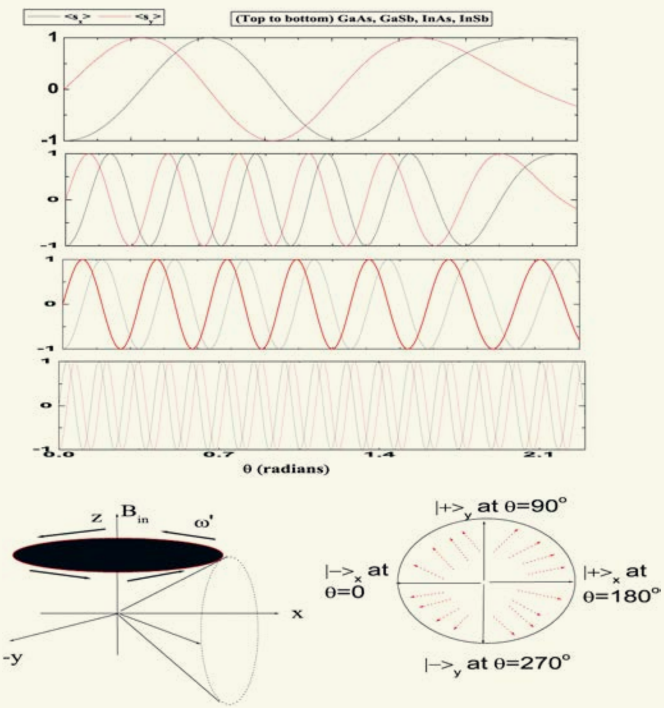
THEORY

Spinning quantum dots

A theoretical analysis of electron spins in slowly moving quantum dots suggests these can be controlled by electric fields.

'Quantum dots' are particles of semiconducting materials that are so tiny – a few nanometres in diameter – that they no longer behave quite like ordinary, macroscopic matter. Thanks to their quantum-like optical and electronic properties, they are showing promise as components of quantum computing devices, but these properties are not yet fully understood. In this work the theory behind some of these novel properties is described in detail. ■

▮ **S. Prabhakar** and **R. Melnik**
'Berry phase and spin precession without magnetic fields in semiconductor quantum dots',
Eur. Phys. J. B (2019), https://doi.org/10.1140/epjb/e2019-100268-3



▲ Graph showing the expectation value of the electron spin for different rotation angles in four different semiconductor materials, showing a strong pattern of beats in each case.

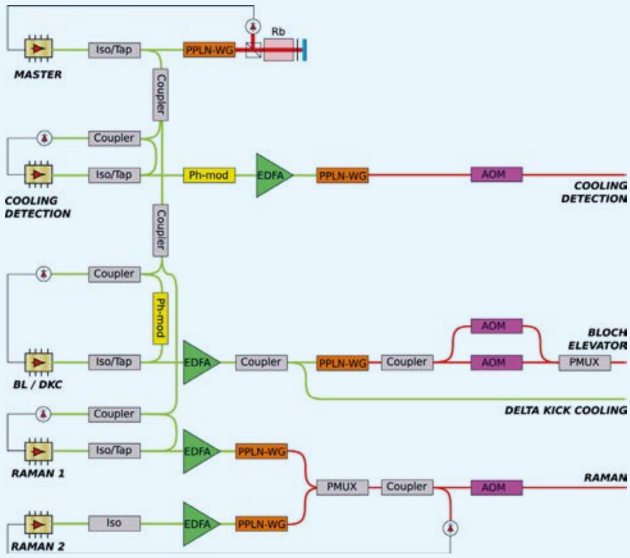
INSTRUMENTATION

Laser-based prototype probes **cold atom dynamics**

A new prototype design doubles the frequencies of widely used telecommunications lasers to study the dynamics of cold atoms while in space.

By tracking the motions of cold atom clouds, astronomers can learn much about the physical processes which play out in the depths of space. In this work, an innovative prototype for a new industrial laser system is presented that paves the way for development of cold atom inertial sensors in space. ■

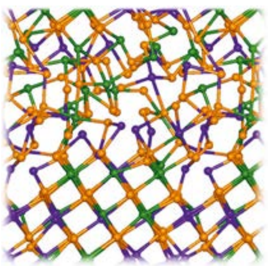
R. Caldani, S. Merlet, F.P. Dos Santos, G. Stern, A. Martin, B. Desruelle and **V. Ménoret**
'A prototype industrial laser system for cold atom inertial sensing in space', *European Physical Journal D* **73**, 248 (2019), https://doi.org/10.1140/epjd/e2019-100360-2



▲ Apparatus for cold atom inertial sensing.

APPLIED PHYSICS

Nano amorphous Interfaces in phase-change memory materials



▲ Model of nano interface between amorphous and crystalline phases in a PCM material.

Phase-change memory (PCM) is an emerging non-volatile memory technology. It encodes data through the rapid and reversible transition between amorphous and crystalline states of PCM materials.

In this work the effects of three kinds of nano amorphous interfaces in PCM materials are summarised, *i.e.* interfaces could either enhance phase stability (the amorphous Si/amorphous Sb_2Te_3 interface and the amorphous GeTe/cubic Sb_2Te_3 interface) or promote crystallisation (the amorphous/crystalline GeSbTe interface). Therefore, these nano interfaces can be used to enhance data-retention ability or accelerate data-encoding speed. ■

X.-P. Wang, **Y.-T. Liu**, **Y.-J. Chen**, **N.-K. Chen** and **X.-B. Li**,
'Nanoscale amorphous interfaces in phase-change memory materials: structure, properties and design',
J. Phys. D: Appl. Phys. **53**, 114002 (2020).

ASTRONOMY

mm Universe @ NIKA2 Conference Proceedings

▲ The NIKA2 camera opens a new area for millimeter observations of the Universe.

NIKA2 is a millimetre camera recently installed at the 30-m telescope of IRAM. It can survey large areas of the sky at a high-angular resolution, with a high sensitivity and a large field of view. It allows observers to address questions, such as the environment impact on dust properties, the star formation processes at low and high redshifts, the evolution of the large-scale structures and the use of galaxy clusters for precision cosmology. In June 2019, the mm Universe conference in Grenoble brought together the scientific community working with the NIKA2 camera. It was the first edition in a series of conferences that will accompany the scientific exploitation of NIKA2. ■

F. Mayet, **A. Catalano**, **J.F. Macías-Pérez** and **L. Perotto (Eds.)**
'mm Universe @ NIKA2 - Observing the mm Universe with the NIKA2 Camera, Grenoble, France, June 3-7, 2019', *EPJ Web of Conferences* **228** (2020), ISBN: 978-2-7598-9097-2

SCANNING GEOPHYSICAL HAZARDS

James Baker – School of Civil Engineering, The University of Sydney, Australia – https://doi.org/10.1051/epn/2020201

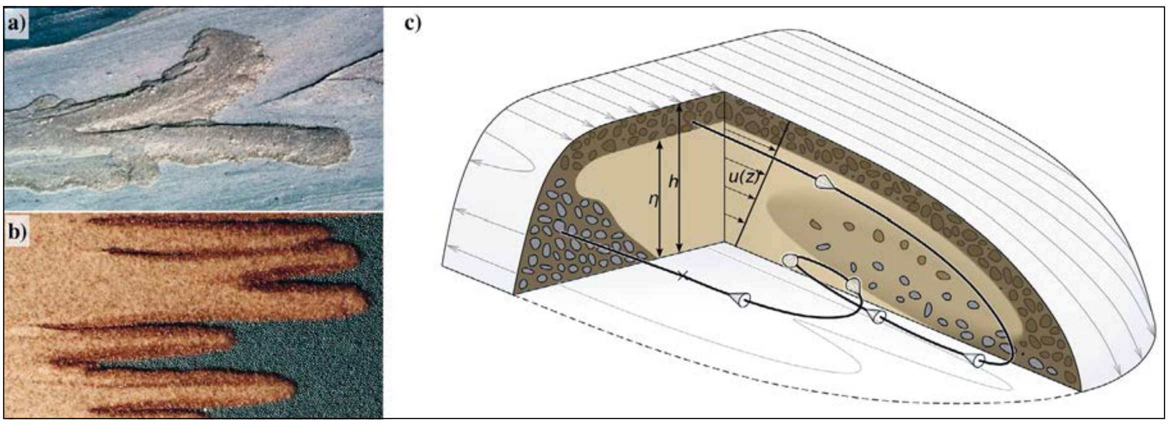
Granular physics, the study of how collections of macroscopic particles behave *en masse*, helps us to model geophysical hazards like snow avalanches and landslides. Before placing trust in any predictions, we need a complete picture of how opaque grains flow. X-ray technologies provide an unobtrusive means to see beyond the surface. Whereas classical tomography does not work for moving samples, new dynamic X-ray approaches can handle genuinely flowing regimes, offering fresh insight.

Geophysical granular flows

Geophysical hazards such as snow avalanches, debris flow landslides or volcano pyroclastic currents - fast-moving flow of hot gas and volcanic matter - can exhibit gas-like behaviour, with large powder clouds forming above the slope as well as solid-like behaviour, with grains maintaining fixed shapes in the undisturbed fringes. However, it is actually the dense flow-like regime (fig. 1a) in between the stationary and gaseous regions that causes the most damage. This has also proven to be the most difficult to decipher, and it is especially difficult to understand what goes on at the interfaces between the different zones. So, from a geophysical hazards point of view, improving our understanding of dense granular flows is an important undertaking.

Granular materials can behave like water…

Granular flows can be modelled using Newtonian fluid dynamics. This is especially true for the modelling of geophysical hazards, which are "shallow" in that the ratio of the flow thickness to downslope extent is typically small. As a result, they are amenable to depth-averaged approaches, allowing the problem complexity to be reduced by removing one spatial coordinate. Researchers have adapted the classical shallow water equations to account for the differing effective friction of granular materials to produce simple, easy-to-implement models that are still the most widely used in hazard modelling. What is more, granular flows also



▸ **FIG. 1:** Dense granular flows. a) Pyroclastic flow deposits from the 1980 volcanic eruption of Mt. St. Helens, Washington, showing two finger-like channels (source: USGS). b) Similar features observed in laboratory experiments (adapted from [2]). c) Conceptual image of the formation of such channels (source: Chris Johnson).

exhibit hydrodynamic instabilities related to those observed in water. An example is the Kapitza, or roll-wave, instability, where a fluid flow develops capillary surface waves. Similar waves have also been detected during geophysical events, as well as reproduced in small-scale granular experiments [1]. They have modelling implications because the individual pulses are more destructive than the base flow from which they develop. Another striking hydrodynamic instability in dense granular flows is finger formation (fig. 1b), where a uniformly propagating front breaks into a series of distinct channels, each travelling significantly faster and further than the uniform front. This again bears a strong resemblance to the fingering instability of viscous fluids, something we see as water runs down the outside of a window on a rainy day.

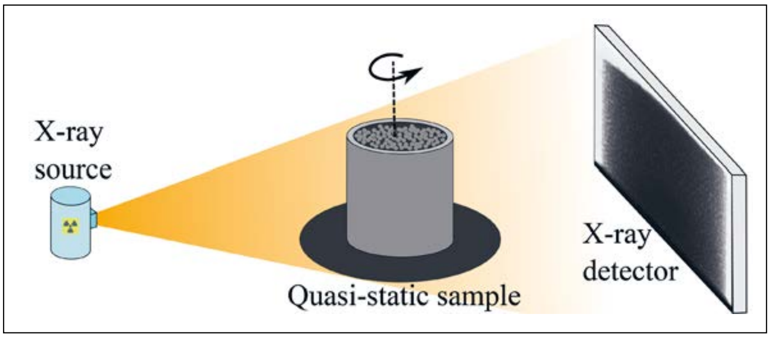
For the measurement of the velocity of a flow of granular materials the method of Particle Image Velocimetry (PIV) is used. The method was already developed in the 1980s to measure the velocity of transparent fluids. It involves the use of high-speed cameras to record successive images of tracer particles in the flow. These images are divided into 'interrogation windows', and cross-correlation analysis is employed in each window to deduce the most probable particle velocity. The tool is used to test model predictions against experimental velocity measurements and form conceptual pictures of flow mechanisms (fig. 1c).

…but things aren't always so simple

However, unlike water, granular media are highly heterogeneous with a wide range of particle shapes, sizes and material properties, that have a tendency to segregate, especially by size, which can lead to complex behaviour not present in classical fluids. The fingering instability is one such example. Whereas in classical fluids this is driven by viscosity and surface tension, in granular flows the fingers form due to particle size-segregation and increased basal friction. We therefore are forced to develop entirely new mathematical models to capture the important physical mechanisms [2]. Moreover, experimentally with granular flows optical cameras can only capture what is going on at the surface and walls and the measurements are not necessarily representative of what is really going on inside.

So how do we see inside?

A promising technique is the method of 3D computed tomography of the granular flow using X-rays as an unobtrusive method that does not require any special sample preparation. Since our ultimate aim is to measure macroscopic velocity fields, the idea is to bypass the microscopic description and directly reconstruct continuum fields. This is essentially how regular PIV works – rather than tracking each individual grain, it employs a statistical method to extract the macroscopic velocity field in each interrogation window. One can apply the principles of PIV to high-speed X-ray radiographs recorded from a single direction [5]. Combined with multiple sources and detectors a fully 3D velocity fields can be reconstructed. Such an approach was first employed in classical fluids [6], before recently being adapted to granular flows [7]. The latter method involves collecting high-speed images from three mutually perpendicular directions, and splitting each into macroscopic interrogation windows (fig. 2) For three-dimensional flows each window does not represent a single velocity - there is actually a complete distribution arising from grains at different positions in the beam path.



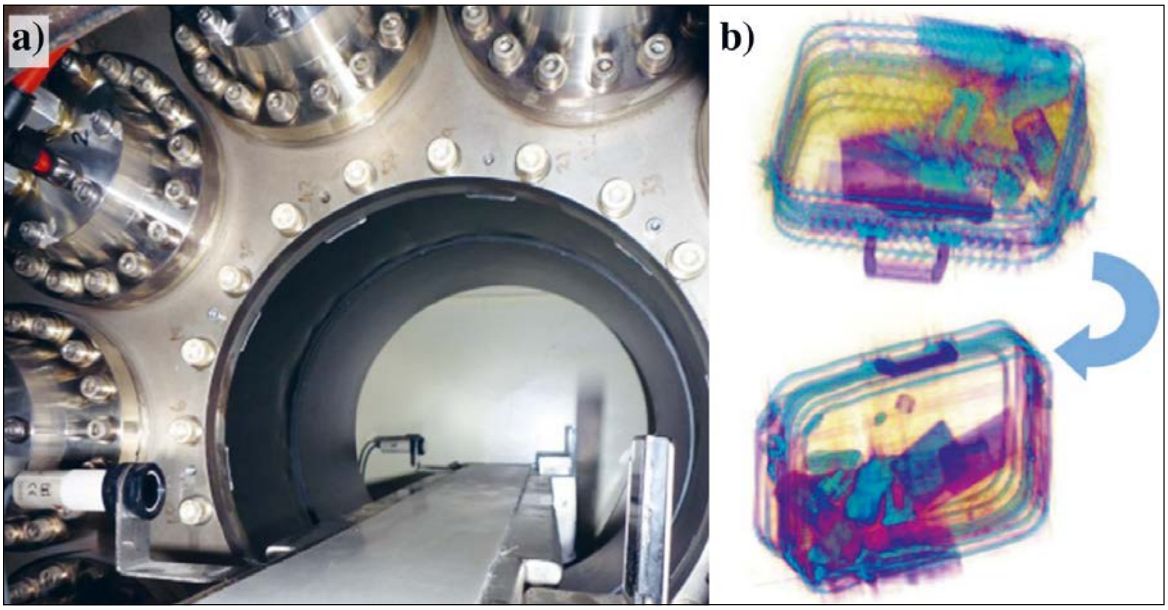
▲ **FIG. 2:** In X-ray CT the sample is typically rotated to allow radiographs to be collected from different angles.

Back to geophysical modelling

The new X-ray insights will allow us to validate continuum models with internal measurements, not just at the boundaries, and hence use small-scale experiments to make better predictions. Besides velocity fields, there are other macroscopic quantities that would be beneficial to know in 3D. The distribution of different sized particles is one such field, since particle size segregation has important implications for hazard mitigation through

INSPIRATION FROM THE AIRPORT

Some of the next generation baggage scanners currently being rolled out across the world make use of 3D tomography with multiple sources and detectors. If you've been wondering why some airport securities have suddenly decided that liquids and laptops can stay in your bag after all, it's because their new machines are now computing full 3D tomograms, as opposed to 2D radiography (fig. 3). This allows staff to easily find all items, especially when combined with automatic detection algorithms for specific objects [3]. Whilst some of these scanners resemble regular medical CT, some use a ring of sources and detectors that fire in quick succession around your bag [4], building up a 3D image one slice at a time as the conveyor continuously moves the luggage along. Could we one day see a similar approach taken in the lab to reconstruct experimental slices as grains flow through an array of sources and detectors?



▸ **FIG. 3:** a) Prototype baggage scanner that uses multiple X-ray sources and detectors (from [4]), allowing b) reconstruction of 3D images in real time (from [3]), meaning we can now leave liquids and laptops in bags at airport security.

spontaneous finger formation (fig. 1). It is certainly possible that similar reconstruction principles could be used to achieve this, allowing us to investigate segregation-mobility feedback effects from a new perspective. Currently, this is all still at the laboratory scale, and a common challenge with geophysical hazards is understanding how the granular behaviour scales up to the field. To address this researchers have conducted large-scale experiments, for example at the USGS debris flow flume [8], or installed monitoring stations to measure forces and flow heights of real events [9]. Perhaps we could also scale-up these new dynamic X-ray technologies to give the first pictures of what really goes on inside these hazards, and confirm how far our conceptual image is from the mark.

About the author

James Baker is a Postdoctoral Research Associate at the University of Sydney, Australia. He has a PhD from the University of Manchester, UK, in Applied Mathematics and an MMath degree from the University of Oxford.

Acknowledgements:

The author wishes to thank colleagues at Manchester and Sydney for providing figures and suggestions for this article.

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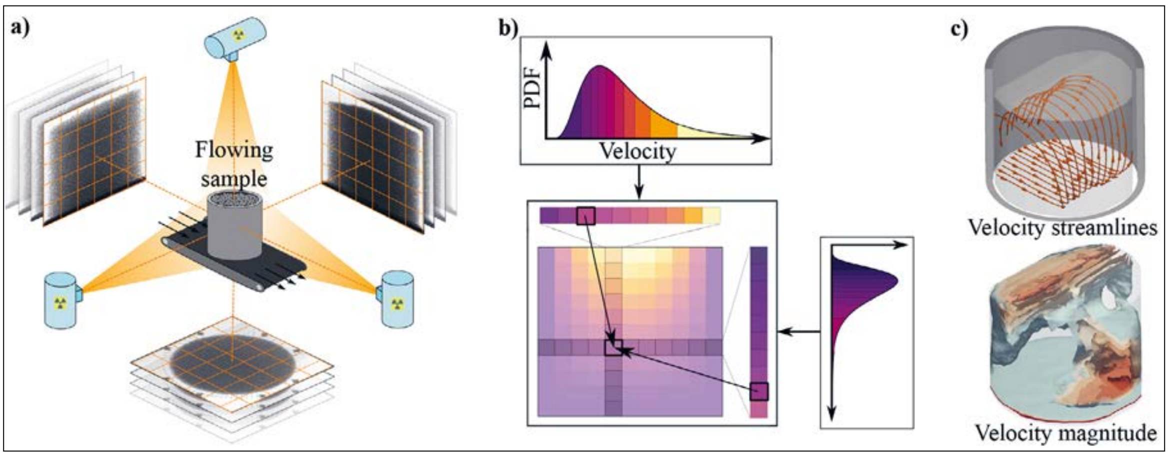

▸ **FIG. 4:** X-ray rheography. a) Flowing sample is interrogated with high-speed X-rays from three perpendicular directions. b) The velocity PDF is extracted in each window from all directions, and internal picture is reconstructed by combining different directions in process resembling a Sudoku puzzle. c) Resulting 3D reconstructions (adapted from [8]).

DEEP MEDITERRANEAN TURBULENT CONVECTION

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Life in the deep sea requires turbulent mixing and advective transporting water flows for the supply of nutrients. However, because of the harsh environmental constraints in the deep sea, detailed quantitative measurements are scarce. Recent high-resolution measurements demonstrate that the deep Mediterranean Sea waters are far from stagnant, even though temperature variations over a day and 100 m in depth are of the order of 0.0001°C. An innovative 3D-mooring structure was used supporting 550 highly sensitive temperature sensors.

Research in the Mediterranean Sea

The Mediterranean Sea can be considered a large laboratory. In its (deep) waters, astrophysicists build a cubic kilometer large neutrino telescope to study fundamental particles of physics and far-away stellar systems [1]. Hydrodynamicists study geophysical flows at high Reynolds numbers between 10^4 and 10^7 that are difficult to generate elsewhere. Oceanographers see the Mediterranean as a test-basin for the larger oceans, in which nearly all relevant fluid dynamical and biogeochemical processes occur. While tides are virtually negligible in most of the Mediterranean, this sea is an example for studies on atmosphere-ocean exchange because of its evaporation surplus [2].

Hydrodynamics in the Mediterranean Sea

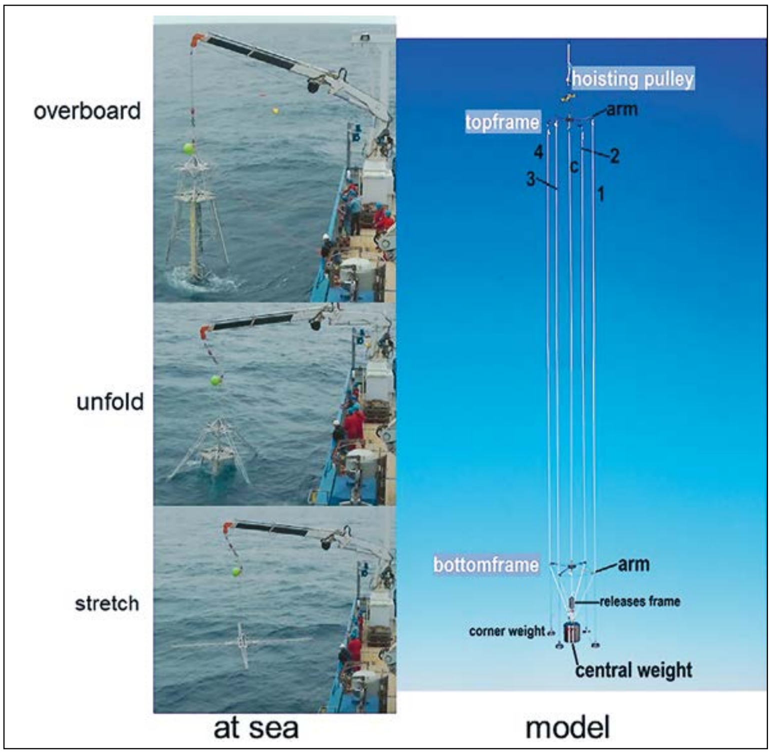
In comparison with the open ocean, Mediterranean water depths are of the same order of magnitude with averages of 3700 and 1500 m, respectively, but effects of distant atmospheric disturbances are less in the latter so that shipborne activities are slightly easier. In the Mediterranean deep sea the coast is relatively close. This proximity generates a fast response of current-flow generation by, *e.g.*, wind, if it blows (or not) from mountain regions: Meltemi (Greece), Tramontane (Pyrenees), Mistral (Alps), Sirocco (Sahara) are 'on' or 'off'. The response in the sea is a generation of inertial waves, with mostly circular horizontal motions, via the Coriolis force. The 'on' or 'off' winds result in the generation of groups of inertial waves that, in the absence of

▲ Mid-winter afternoon above the KM3NeT site near Toulon. About 2500 m deeper at the seabed the described data are recorded. Courtesy Ernst-Jan Buijs.

“Detailed observations in the deep Mediterranean provide unprecedented opportunities as a hydrodynamic laboratory. Processes like natural (free) convection, internally forced convection, and current-shear play a role in this turbulent environment.”

tides, are the most important source of internal waves that can propagate into the interior of the sea at large depths. Internal waves are supported by the stable stratification in density, gravity waves, and variations in angular momentum of the rotating Earth, inertial waves in a stricter sense [3]. The latter occur as gyroscopic waves in near-homogeneous layers and have virtually only been observed in the Mediterranean [4]. Due to solar insolation at the surface of a water basin, relatively less dense warm water remains stably over deeper colder water. As molecular diffusion of heat is a relatively slow exchange process, the high Reynolds number environment causes turbulent vertical exchange to be dominant nearly everywhere in the sea. Two processes are distinguished [5]. First, shear-induced turbulence of vertical current-flow gradients destabilises a stable stratification. Second, turbulent 'natural' convection under gravity induced by cooling (generates relatively cold water) and evaporation (generates salty water) at the sea surface occur in many areas with vertical exchange down to typically 10 m, especially during nighttime. At few sites convection occurs to greater depths: Near the poles (cold) and in the Mediterranean (salty). Coastal proximity and especially

▼ FIG. 1: Five-line three-dimensional temperature sensor mooring. The model is to scale. Sensors on the central line 'c' reach to within 5 m from the seafloor, as in a standard 1D-mooring, and on the corner lines '1',…,'4' to within 0.5 m from the seafloor.



steep continental slopes show current-flows similar to the Gulf Stream and Kuroshio: Wind- and density-driven flows that become reinforced by natural convection [6] and which are important for transporting suspended materials. Studies on the (in)stability of these boundary flows, on associated meanderings and detached eddies, provide information on relatively rapid eddy-dynamic vertical transport of fresh biological materials from the sea surface to great depths and even the deep seafloor within a day [7]. All aforementioned hydrodynamic processes occur near Toulon (France).

Measuring turbulence in the deep Mediterranean

During the last decade, high-resolution sensors have been developed at NIOZ, the Royal Netherlands Institute for Sea Research, to record water temperature with a precision better than 0.0005°C and noise levels below 0.0001°C. The sensors can withstand static pressure up to 1100 bar. The corrosive seawater is kept away from the micro-electronics via capillary glass-tubes, titanium housings and rubber O-rings. The salty seawater is used for closure of the electric circuit on clock-synchronisation of multiple stand-alone sensors. As a result, a vertical temperature profile can be measured over hundreds of metres within less than 0.02 s. Recently, NIOZ developed a simple 3D-mooring structure consisting of five parallel lines 105 m long, 4 (and 5.6) m apart horizontally, that can hold 550 T-sensors. The lines are held under tension between two sets of arms that can be compacted into a 6 m tall structure on board. After being stretched overboard, it is lowered to the seafloor in free fall (Fig. 1). Between November 2017 and September 2018 this NIOZ 3D-mooring was deployed near one of the neutrino telescope sites of KM3NeT, 30 km offshore or Toulon, at 2480 m water depth.

Sudden heating from above

Generally, the deep Mediterranean water flow is weak with velocities less than 0.1 m s^{-1}. Late winter, the flow-velocity increased up to 0.38 m s^{-1} and varied with 15 to 20 day periodicities due to boundary layer eddy-meandering. Only after August in summer, this late-winter intensification disappeared. In late winter, the boundary current along the continent intensifies, and with it turbulence processes intensify over the entire water column. Varying turbulence intensities have a vertical extent of 100 m and more. The sudden 0.002°C warming at day 430 passes the instrumentation in 1.5 h (Fig. 2). The warmer water structure has a length of about 700 m, computed from observed mean flow-speed of 0.16 m s^{-1}. The warming from above consists of multiple 'tubes' of alternating slightly warmer and colder water. This suggests typical convection, but it is not gravitationally driven by temperature instabilities, as the temperature stratification is stable. Possibly, the relatively warm waters are also relatively salty, to such extent that the density is statically unstable which generates natural convection. Alternatively, non-linear internal waves break and generate instability via (internally) forced convection from the waves' acceleration. The warm water passage is associated with an average of 0.03 m s^{-1} strong downward flow (Fig. 2a) and associates with 10 dB increase in acoustic reflectance off suspended particles (Fig. 2c).

Sudden heating from below

A few days later, a large column passes of near-homogeneous waters, having less than 0.1 mK temperature variation over vertically 100 m and to within 0.5 m from the seafloor on day 439.05 (Fig. 3). This water is warmer than the environment and seems to (have) spread over the seafloor around the column. If salt does not contribute to density variations in this case, the observations can be one of natural convection, following large-scale homogenisation. Like in the previous example, small finger-like convective tubes are observed as if the seafloor is on fire. The large column has a diameter of 700 m, given the 0.13 m s^{-1} average horizontal flow speed, it associates with an increase in acoustic reflection, and shows -0.007 m s^{-1} mean vertical particle velocity.

Continuation

The observations demonstrate various hydrodynamic processes at great depths in the Mediterranean that have hardly been observed hitherto. Strong natural and (internally) forced convection besides shear-induced turbulence can only be observed using sensitive specialised instrumentation. The measurements demonstrate the feasibility of the new 3D-mooring. Presently at NIOZ, a larger unique 3D-mooring is under construction with 45 lines and 3000 temperature sensors that will approximately fill a cubic hectometer to provide more insights in the development of deep-sea turbulence.

About the author

Hans van Haren is senior scientist in physical oceanography at the NIOZ, Royal Netherlands Institute for Sea Research Texel. His major research topics are tidal motions, internal waves and turbulent exchange in seas and oceans, which he studies via in-situ observations using custom-made instrumentation.

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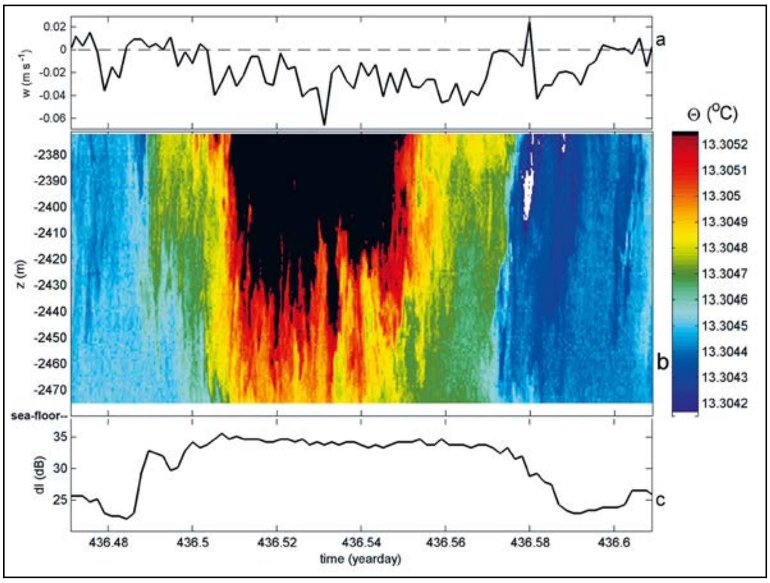

▲ **FIG. 2:** 3.5 hours of temperature and flow observations during an eddy-passage of warm water in late-winter. (a) Time series of vertical velocity measured at z = -2310 m. (b) Time-depth image of corrected temperature from the 104 T-sensors at the central line of the 3D-mooring. The lowest sensor is 5 m from the seafloor that is at the horizontal axis. (c). Time series of relative acoustic reflectance at -2310 m.

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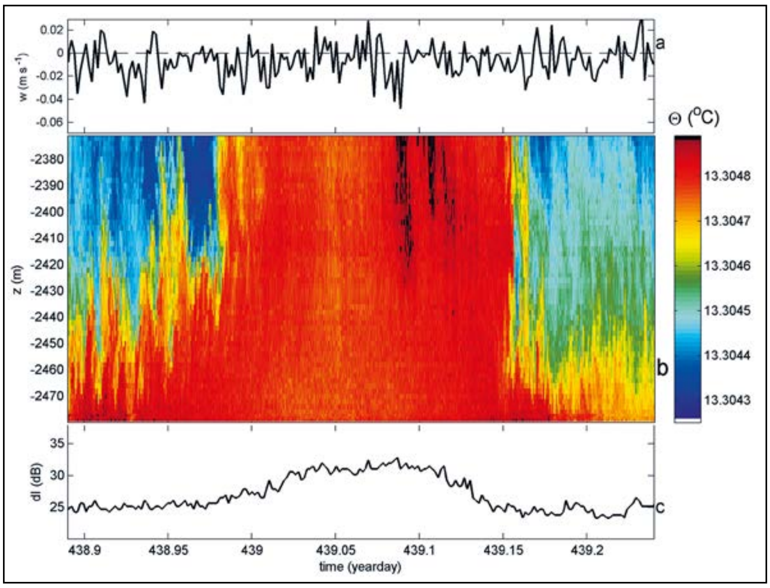
▼ **FIG. 3:** As Fig. 2, but for 8.5 h observations made two days later. In b. T-sensor observations are given from cornerline-1 that reached to within 0.5 m from the seafloor.



CARBON CAPTURE AND STORAGE:

MAKING FOSSIL FUELS GREAT AGAIN?

Berend Smit[1] and Susana Garcia[2] – DOI: https://doi.org/10.1051/epn/2020203

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At present, Carbon Capture and Storage, in which CO_2 is captured from flue gasses and stored in geological formations, is one of the technologies to reduce CO_2 emissions associated with the use of fossil fuels. Are there some good arguments to continue to invest in fossil fuels, a technology of yesterday?

▲ The world's ever-expanding CO_2 emissions (credit: Luke Robus and Emmet Norris)

The best way to sequester carbon is to leave all fossil fuels in the ground. A simple solution, and as the price of renewables has dropped significantly, a solution that seems to be almost within reach. However, globally, last year more CO_2 was emitted in the atmosphere than ever before (Fig. 1), which suggests that we have many years to go before our energy production is completely renewable. In the meantime, storage of CO_2 in geological formations seems attractive. The technology of Carbon Capture and Storage (CCS) involves three steps: the capture of CO_2 from flue gasses, the compression and transport of CO_2, and the injection in geological formations [1][2]. The different technologies that are used in each of those steps are not new, as in a different context they are routinely used in our current economy.

Carbon Capture

Carbon capture technology is based on the natural gas sweetening process and uses amine solutions to capture the CO_2 [3]. This technology can be easily adopted to separate CO_2 from flue gasses. However, the amine-based capture technology is not cheap. Given the volumes of flue gasses, capture plants must be enormous and require a capital investment of about the same amount as the one for the original power plant. In addition, once the CO_2 is captured in the amine solution, the solution must be regenerated by removing the CO_2, which requires the redirecting of steam from the power plant. This steam loss together with the work required for the subsequent CO_2 compression can give a loss of efficiency of a power plant of about 30%. Therefore, reducing the costs of the capture process is the main driver for the research in that field. Hence, research has been mainly focused on finding better amine solutions and improvements in the process. However, because of the oxygen content in the flue gas by which amines tend to oxidise and thermal degradation, the amines must be replaced over time and clean-up of the waste stream is necessary. Therefore, there are considerable research efforts to develop alternative technologies to amine-based ones [4]. These include different separation technologies such as membranes, solid adsorbents, or chemical looping.

CO_2 transport and injection in geological formations

Transport and injection of CO_2 in geological formations is routinely carried out for enhanced oil recovery. The fact that the major oil companies know how to transport and inject CO_2 in geological formations makes CCS ready to be employed on a very short timescale. The idea to use geologically sequestered CO_2 to even produce more fossil fuels does not sound like a sensible solution to reduce CO_2 emissions. At present there are some projects that use the more expensive, anthropogenic CO_2 in which CO_2 is injected in such a way that a maximum amount of CO_2 remains in the oil production field. In such projects the CO_2 emissions per unit oil is (slightly) less than oil production without enhanced oil recovery [5]. But more importantly, this is one of the few CCS-related technologies that are economically viable without a carbon tax or other regulation to limit CO_2 emissions. Therefore, the fact that the use of CO_2 in enhanced oil recovery offsets the costs makes the process one of the few large-scale demonstration projects to further develop the technology. Alternatively, research is also being carried out into the feasibility to sequester CO_2 in the oceans [6].

Pilot projects for CO_2 injection

In addition to enhanced oil recovery, there are a few pilot and demonstration projects in which CO_2 is injected in geological formations for the sole purpose of permanently sequester the CO_2. The projects have been successful from a technical perspective, yet the public perception of CO_2 storage in geologic formations is focused on the perceived risks. Therefore, most of the research related to geological storage focusses on obtaining such a high level of understanding of the behaviour of CO_2 injected in these geological formations that we can guarantee that the CO_2 is permanently sequestered. Elementary thermodynamics tells us that CO_2 is not the most stable form of carbon; over time the carbon in CO_2 ends up in carbonate minerals such as limestone ($CaCO_3$). Therefore, eventually the injected CO_2 will be converted to different carbonate forms, but this takes place over time scales of more than tens of thousands of years [7]. These pilot and demonstration projects provide essential data to validate the predictions of the long-term behaviour of the injected CO_2. Unfortunately, most of the large-scale injection field projects, which were so essential to further build the confidence of the public in the long-term CO_2 storage, have been put on hold or delayed.

CO_2 utilisation

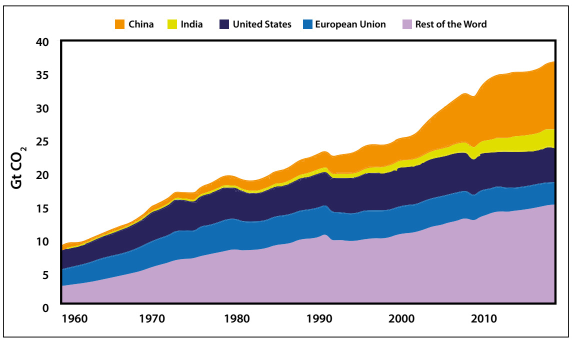
One can often hear the argument, why do we sequester the CO_2 in geological formations? Would it not make much more sense to recycle the CO_2? Here, we have a problem of scale. The amount of CO_2 we produce by power generation is gigantic. If we would compare it with the top 50 of all chemicals produced by the chemical industry, CO_2 would be number one, with a production 10 times larger than this top 50 combined! [8]. We simply produce too much CO_2 that if we would convert it into the most beautiful and used product one could imagine, it would simply saturate any conceivable market. One can envision to convert the CO_2 back into a fuel. Indeed, there are days in which there is an excess of solar energy and converting CO_2 into a fuel is one of the many ways to store energy. However, if the source of the CO_2 is the burning of fossil fuels one has to be careful. One can recycle CO_2 as many times as one likes, but eventually this CO_2 molecule needs to be sequestered; for every fossil fuel carbon atom we take out of the ground we need to put one CO_2 molecule back, otherwise it will eventually end up in the atmosphere.

Direct Air Capture of CO_2

As 40% of the emitted CO_2 will stay 500-1000 years in the atmosphere, CO_2 emissions have much more in common with nuclear waste than we might think; once generated we have to live with the consequences for a very long time. This long lifetime of CO_2 in the atmosphere combined with our inaction to address CO_2 emissions makes it most likely that we will overshoot the CO_2 levels associated with the 1.5 and 2 °C increase in global temperatures. If this happens, the only option we have is to reduce CO_2 levels by capturing CO_2 directly from the air [9]. Basic thermodynamics tells us that the lower the CO_2 concentration the more energy is required for the capture process. Hence, if CCS already looks expensive, allowing CO_2 molecules to escape in the atmosphere and worrying about it later, can be an even more expensive solution.

Outlook

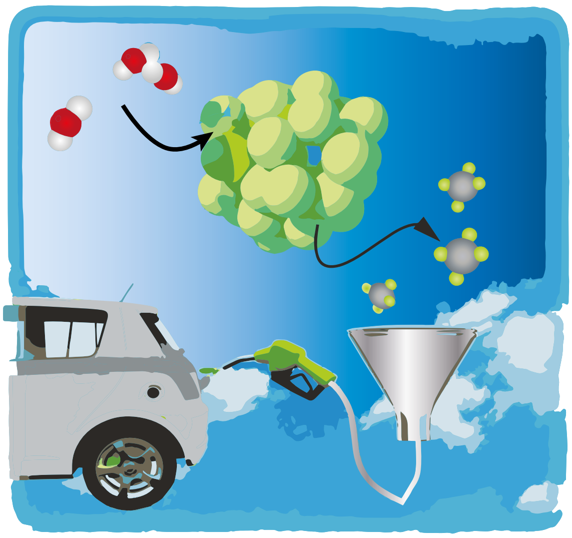
We will have to accept the fact that there will be a price on carbon which will be so high that we need to find solutions for any source of carbon. Even if power generation



◂ **FIG 1:** Global CO_2 emissions per country (Source: IEA World Energy Balances 2019, https://www.iea.org/data-and-statistics) is completely decarbonised, there are still many sources of CO_2. This implies that we will have to replace fossil fuels as the source of carbon by CO_2 for the chemical industry [10]. This can be done by capturing CO_2 from, for example, waste incineration or the production of biogas. We also need to capture the CO_2 from many industrial sources, including the production of cement and steel. We need to ensure that fossil fuels are replaced by synthetic fuels by capturing CO_2 from the air or any other source [11] (Fig. 2), and converting it to fuels. All these require a complete rethinking of the chemical industry. In such a world, there are many small and large local sources of CO_2 and many routes to convert CO_2. The research we are carrying out in this vision towards achieving zero anthropogenic CO_2 emissions, is to find novel materials that are tailor-made for all possible different types of CO_2 emitting processes. Our research [12] combines state of the art computational methods in which we screen millions of possible materials for which we predict the performance before a material is even synthesized [13]. The ranking of these materials will depend on a performance metric, which is related to an optimal process design for a given source and target of CO_2.

Conclusions

We can all agree that the best way to permanently sequester carbon is to leave all fossil fuels in the ground, but we also have to face the fact that there are large uncertainties when or even if this will happen. The urgency to reduce CO_2 emissions now cannot not be stressed enough. One may need to be pragmatic, energy is a too important factor in our economy to be ignored. The fossil fuel industry is still the major player. Large-scale carbon capture combined with geological storage is a viable technology that allows us to significantly reduce CO_2 levels. From a scientific point of view, providing a solution that does not remove the root cause of the problem is not great. That will be difficult to accept for those who feel one should not invest in technologies we should be moving away from. One does need to keep in mind that reducing CO_2 levels is the most important challenge of our generation, and making the fossil fuel industry part of the solution goes against all logic. However, the argument is not about logic but about the urgent need to do something now, and for that we need all the help we can get.



▸ **FIG 2:** A sustainable way to replace fossil fuels is to capture CO_2 from the air and by using renewable energy to convert it into synthetic fuels using an efficient catalyst (figure adopted from Tan and Maroto-Valer).

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Acknowledgements

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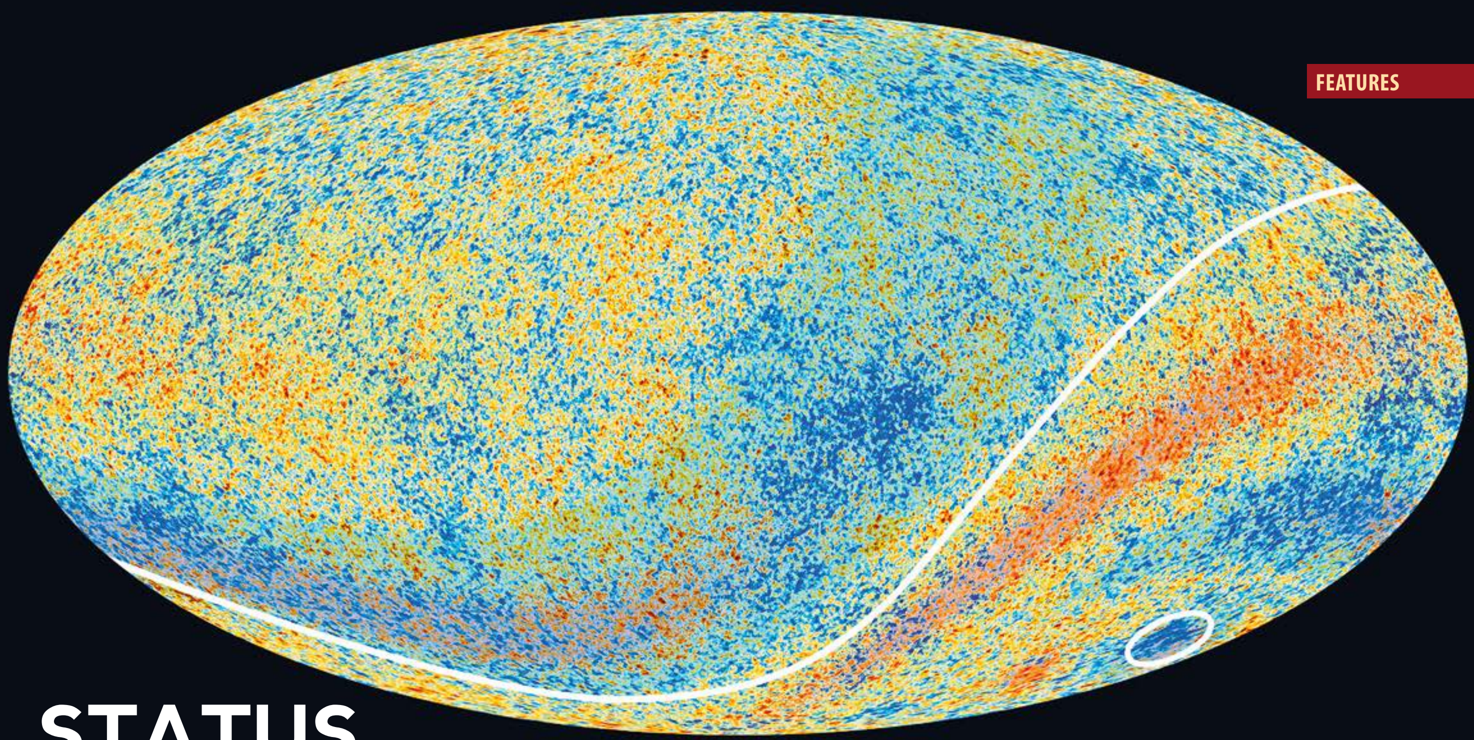


STATUS OF PARTICLE PHYSICS

Zoltán Trócsányi – ELTE Eötvös Loránd University, Budapest, Hungary – https://doi.org/10.1051/epn/2020204

While at CERN the upgrade of the Large Hadron Collider and the detectors is in full swing and the European strategy for particle physics research is being shaped we summarise the current status of particle physics, focusing on the established experimental observations at the energy, the intensity and the cosmological frontiers.

Standard model of particle interactions

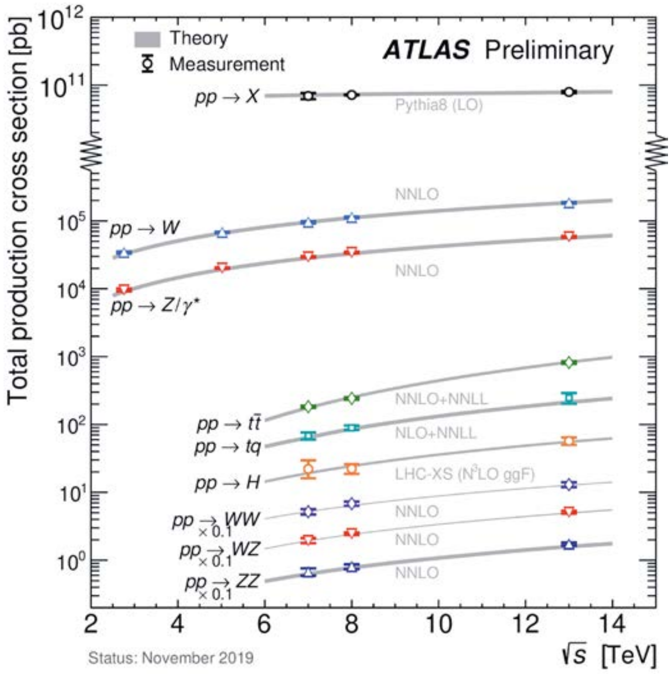
The standard model (SM) of particle physics describes the decays and collisions of elementary particles with extraordinary precision. It builds on three fermion families, each containing two electrically charged quarks, a charged and a neutral lepton. The neutral leptons are the neutrinos that are distinguished only by their *flavours*. The flavour of a neutrino means which charged lepton (electron, muon or tau) appears with it in the decay of a charged $W^{\pm}$ boson – the massive, electrically charged akin of the photon. Apart from particle flavour, the only difference between the families is the mass of the particles. The three forces (the strong, electromagnetic and weak interactions) are mediated by bosons, whose existence follows automatically from symmetry principles. We require that the Lagrangian of the model, is invariant under local $SU(3)\otimes SU(2)\otimes U(1)$ gauge transformations.

The standard model became complete in 2012 when the Higgs particle was discovered by the ATLAS and CMS experiments at the Large Hadron Collider (LHC) [1,2]. To date this is the only known scalar elementary particle in the standard model. The correct design of the accelerator and detectors needed for the discovery would not have been possible without the detailed and precise predictions of the SM theory.

Experimental status of the standard model

The standard model has 19 free parameters (considering the neutrinos exactly massless). These parameters were determined from fitting a plethora of measurements with SM predictions. Most of the parameters were also measured directly at the Large Electron-Positron collider. The fitted and the measured values were found in excellent agreement, suggesting a consistent and precise experimental support for the validity of the model. Such a support has also been confirmed by the measurements performed at the TEVATRON and LHC hadron colliders. Fig. 1 shows the results of ATLAS measurements of eight benchmark processes for which the theoretical predictions are the most precise [3]. It is a great triumph for the

> Invariance under local gauge transformations means that the equations do not change if we transform the ψ fermion fields by multiplying it with a matrix $U = \exp(i\,\boldsymbol{\alpha}(x)\cdot \boldsymbol{T}) \in SU(N)$. The vector $\boldsymbol{\alpha}$ has N elements that are space-time dependent arbitrary real numbers. The vector $\boldsymbol{T}$ has also N elements, each being a matrix, and are called generators of the $SU(N)$ group.



▲ **FIG. 1:** Total cross sections of benchmark processes at the LHC as a function of the centre-of-mass energy of the colliding particles [3]. Experimental uncertainties are shown by error bars, and the theoretical ones are presented as very narrow bands. The largest theoretical uncertainty stems from the neglected higher-order radiative corrections in Quantum Chromodynamics in the perturbation series of the cross sections. The label 'NNLO' represents the first three terms in the expansion. The 'NNLL' label means that the three largest powers of logarithmic contributions are summed up.

standard model that the predictions and measurements agree very well. Fig. 2 shows the comparisons of standard model predictions and data measured by the CMS experiment [4]. In total there are 37 final states, out of which only in two instances the deviation between theory and experiment exceeds 1-σ uncertainty, meaning a confidence of 62%. These are the s-channel single t-quark and W+H productions. In both cases the measured value is larger than the predicted one. However, the probabilities of these final states are very small, so the excesses may be simple statistical fluctuations.

Search for physics beyond the standard model

In the high-energy literature, a lot of models have been proposed that predict new particles. Apart from the stringent tests of the SM, the ATLAS and CMS experiments focus mainly on searches for new particles. The most important message of such searches is presented in exclusion limits for the masses of the predicted particles. Many hypothetical particles have been excluded below 1 TeV/c^2 mass, which corresponds to about a thousand proton masses. We can draw similar conclusions from the searches for weakly interacting massive particles (WIMPs) that may constitute the dark matter in the Universe. These results are often called "negative", although one may also consider them "positive" in the sense that the high-energy experiments do not seem to favour rich physics beyond the SM. Thus, we can state that high-energy particle collisions provide firm basis for the validity of the standard model and show no sign of new physics. Nevertheless, there are several discoveries that cannot be explained by the SM, and call for its extension. We turn to their descriptions.

Observations that do not fit into the standard model

Neutrinos have masses

An important discovery was the observation of *neutrino oscillations* [5]. It is a quantum mechanical interference effect, which can be interpreted by the existence of neutrino masses. If the flavour and mass eigenstates of the neutrinos differ, then the flavour-eigenstate neutrinos produced in a decay (say of a pion) are mixtures of mass eigenstates that will have an increasing phase difference as they propagate. As a result, an interference in the flavour space of neutrinos occurs [6].

Dark matter fills the Universe

Another key observation is that the measured energy density of matter in the Universe is about five times more than that of baryonic matter that we are made of (mostly hydrogen and helium, but includes radiation and neutrinos as well). The difference of matter and baryonic matter is called *dark matter* that we do not know. Dark matter feels gravity like ordinary matter, but otherwise it has very weak interaction with matter. The most precise measurements that support this observation is provided by the Planck satellite [7] that measures the intensity of the cosmic microwave background radiation (CMBR). This intensity can be transformed into temperature by Planck's formula of blackbody radiation. The temperature of CMBR is found to be (2.7260±0.0013)K almost independently of direction of observation, but there are fluctuations at the 100μK scale. Those temperature fluctuations can be explained by the cosmological standard model containing six parameters that can be fitted to the measured data. These fits show that the energy density of matter (in units of critical density belonging to eternal expansion) is 0.306±0.007, while that of baryonic matter is 0.0484±0.0005. The difference clearly does not vanish, signalling that some unknown material has a significant contribution to the energy content of the Universe. In the absence of any credible astrophysical explanation it is natural to assume that dark matter consists of particles. Particle physicists exert immense effort to find those.

Baryon-antibaryon asymmetry

The third firm observation is our *existence*. According to the cosmological standard model, at some time in the past the Universe was filled with a hot and dense plasma, in which matter and antimatter particles were present in equal amounts. Our existence proves that this symmetry was broken because today we find only matter in the Universe, but no antimatter. We can create antimatter in the laboratory in small amounts. The CP-violation phase (implying that the equations *change* if we perform simultaneous charge conjugation and space reflection) is present in the Lagrangian of the SM, but it is not sufficiently large to explain the cosmological observations. Among about $4{\cdot}10^{10}$ protons and antiprotons there was one more proton than antiproton after the Big Bang. At present we do not have a proven model of particle interactions that could explain the matter-antimatter asymmetry. The neutrino oscillations may also imply a CP-violation phase that can be large enough to explain sufficiently large lepton-antilepton asymmetry. If so, there is a mechanism proposed theoretically, called sphaleron process, that could lead to baryon-antibaryon asymmetry.

Accelerated expansions of the Universe

The fourth observation is the *accelerated expansion* of the Universe at *present* [8], observed by studying the recession speed of type Ia supernovae [9]. This accelerated expansion is attributed to dark energy, which refers to the existence of energy density ε. Dark energy is characterised by an equation of state $p = w\,\varepsilon$, with $w < -1/3$, implying negative pressure. According to the measurements of the Planck satellite, about 70% of the energy density in the Universe comes with $w = -1.028 \pm 0.032$. We do not have experimental proof for the rapid expansion in the early universe, called inflation. Nevertheless, it is generally accepted that several firm observations can be explained by this assumption. As the early Universe was hot and dense, particle interactions were dominant over gravity. Hence it is natural to search for particle physics origin of inflation.

An exciting future

In summary, we can say that the standard model is firmly established experimentally, yet there are several observations that predict the existence of physics beyond the SM. The SM – in addition to explaining the results of measurements – is highly economical. The underlying symmetry principle – *the Lagrangian has to be invariant under local transformations of the symmetry group, which can be broken only spontaneously by the vacuum* – is simple, suggesting that its extension should also be economical. Any extension is tightly constrained by data. The new model has to respect the precision measurements and at the same time provide explanation for the few observations not fitting into the SM. The status is similar to that 120 years ago at the dawn of the quantum revolution when "almost everything was known about physics, only the spectrum of blackbody radiation required understanding".

About the author

Zoltán Trócsányi is a professor at Eötvös Loránd University in Budapest, an expert of the theory of strong interactions. He was awarded many prizes for his contributions to the advancement of particle physics in Hungary.

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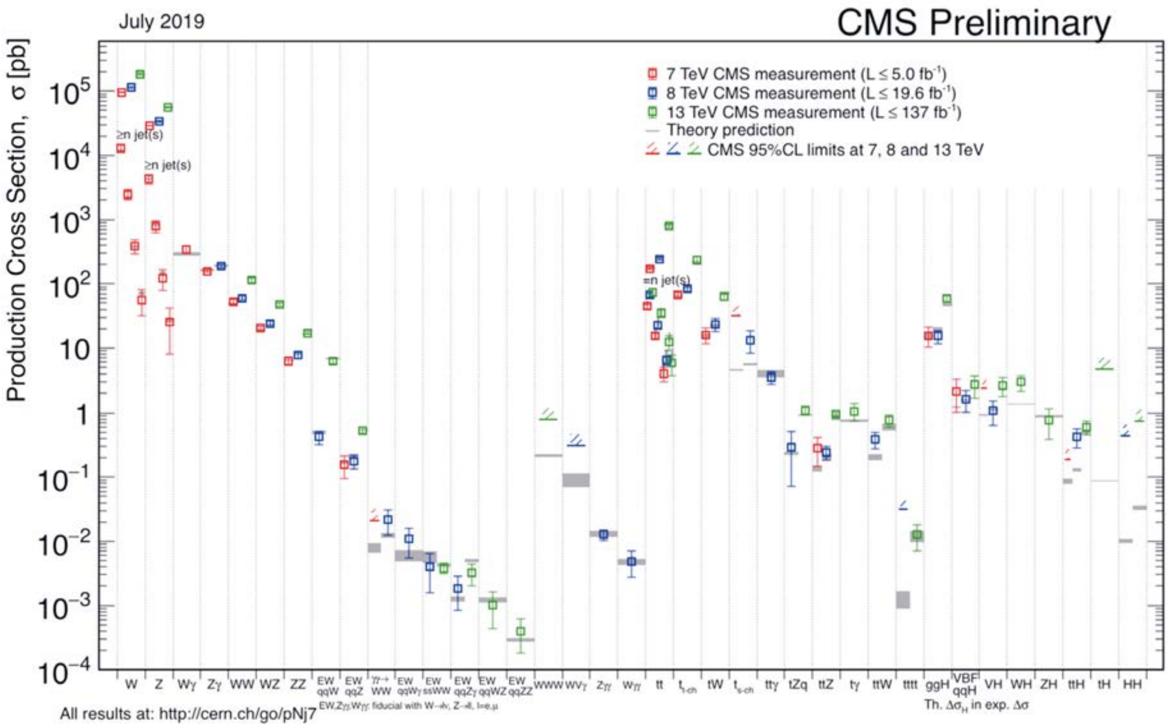
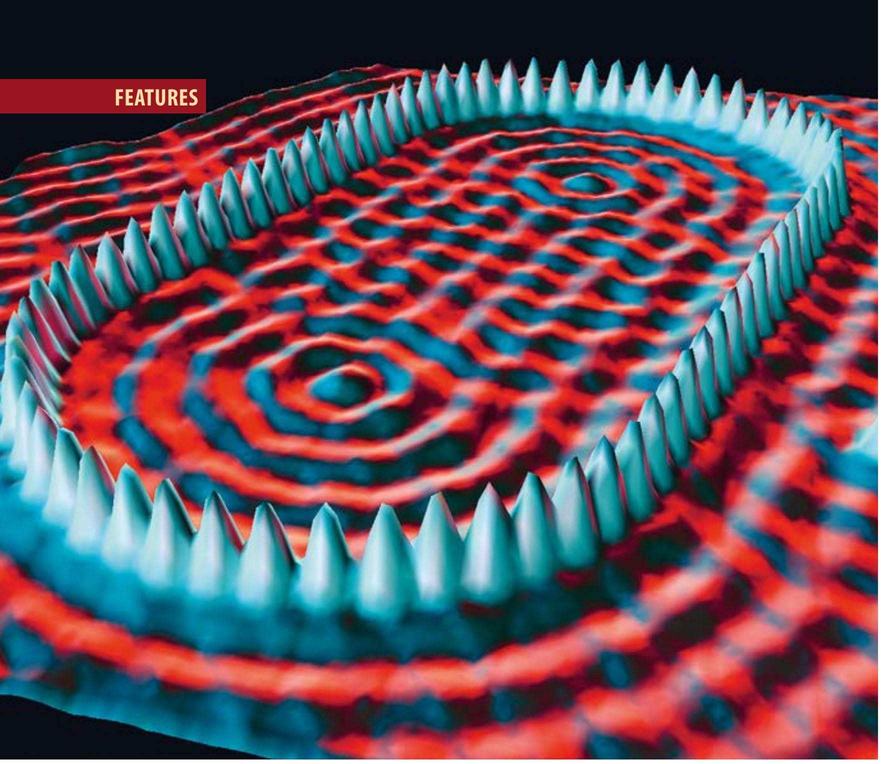


◂ **FIG. 2:** Total production cross sections of the final states [on x-axis] observed by the CMS detector and predictions (grey bands, whose thickness represents the theoretical uncertainty) [4].



30 YEARS OF MOVING INDIVIDUAL ATOMS

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DOI: https://doi.org/10.1051/epn/2020205
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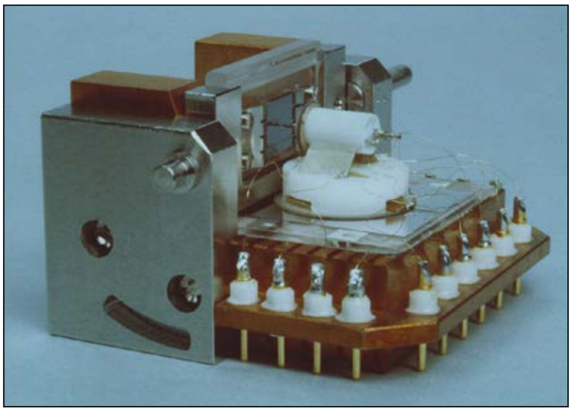
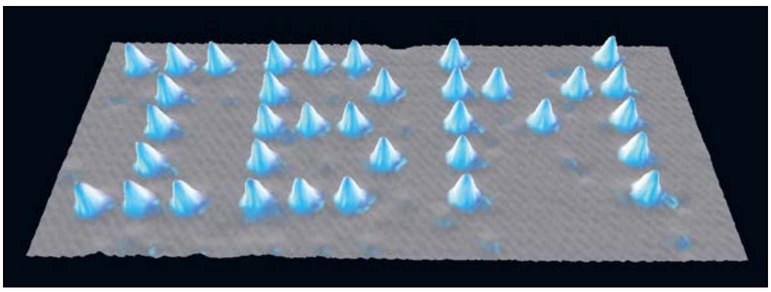
In the thirty years since atoms were first positioned individually, the atom-moving capability of scanning probe microscopes has grown to employ a wide variety of atoms and small molecules, yielding custom nanostructures that show unique electronic, magnetic and chemical properties.

This year marks the thirtieth anniversary of the publication by IBM researchers Don Eigler and Erhard Schweizer showing that individual atoms can be positioned precisely into chosen patterns [1]. Tapping the keyboard of a personal computer for 22 continuous hours, they controlled the movement of a sharp tungsten needle to pull 35 individual xenon atoms into place on a surface to spell the letters "IBM" (Figure 1). Eigler and Schweitzer's demonstration set in motion the use of a newly invented tool, called the scanning tunneling microscope (STM), as the workhorse for nanoscience research. But this achievement did even more than that: it changed the way we think of atoms. It led us to view them as building blocks that can be arranged the way we choose, no longer being limited by the feeling that atoms are inaccessibly small.

It is difficult to believe that only a hundred years ago, when quantum physics and relativity came into focus, the idea that atoms are real individual objects was still viewed with suspicion [2]. As late as 1952, Erwin Schrödinger wrote that "…we never experiment with just one electron or atom or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences…" [3]. These consequences are not ridiculous, but are profoundly intriguing since many of the early speculations have become experimentally accessible in recent decades. For example, the atoms seen by Erwin Müller's field ion microscope in the 1950s [4], inspired many scientists, who marveled at the nested rings of individual atoms at the apex of the sharp metal tips. The atoms at the most exposed corners could be dislodged by voltage pulses, but could not yet be placed in predetermined arrangements. To achieve this, an invention that could sense and guide the atoms in a much gentler environment was required. This invention was the STM.



▲ **FIG. 2:** The STM that Don Eigler and coworkers used to position atoms. The tip is seen touching its reflection in the sample's surface. (Credit: IBM)



▼ **FIG. 1:** Thirty-five xenon atoms arranged on a nickel surface to spell IBM in letters 5 nm tall. (Credit: IBM)

A tool for imaging and moving atoms

In 1981, Gerd Binnig and Heinrich Rohrer, working at IBM's research laboratory in Zurich, created the first STM by raster scanning a sharp metal tip held just a few atomic diameters away from the surface [5]. They succeeded for the first time to image the atoms of a surface of silicon, an achievement that earned them the Nobel Prize in Physics in 1986. The principle of the STM is to control the narrow gap width between the tip and the surface by measuring the flow of electrons that quantum tunnel across this gap. Holding the current constant, the tip traces out contours that display the pattern of atoms. The key property that allows atomic resolution to be achieved is the exponential dependence of the tunnel current on the gap size. Indeed, if the tip is moved by one atomic diameter towards the surface, the current will increase by a factor 100. This extreme resolution opened the door to the nanoworld.

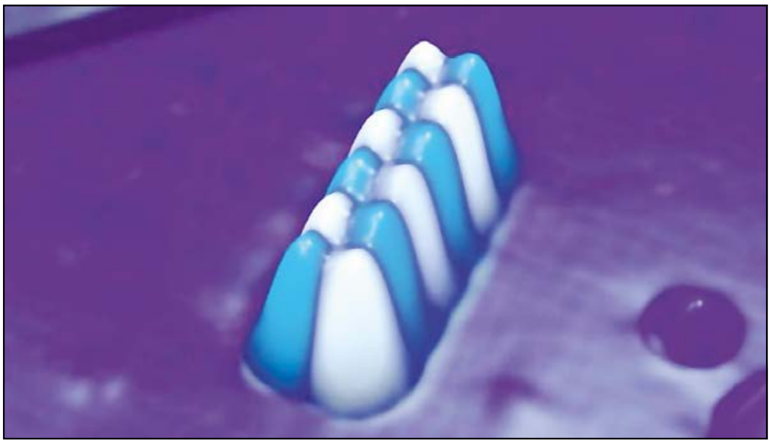
In the late 1980's Don Eigler constructed the first STM operating at liquid helium temperature (4 Kelvin) and under ultrahigh vacuum to keep the surface atomically clean. It was vibrationally isolated so that it had uncontrolled tip-sample motion of only 2 picometers (or 1/100th of a typical atomic diameter). The result was an instrument capable of positioning individual atoms. The whole table-sized STM apparatus is a vacuum chamber bristling with connectors. But the core of the STM – the scanner and sample holder – is small enough to hold in the palm (Figure 2). A sharpened tungsten wire serves as a tip, which is moved in three dimensions by piezoelectric actuators.

Eigler's STM can image individual atoms attached to a surface, even weakly bound elements like the xenon atoms used to write the IBM logo. The controlled motion of atoms depends on the right balance of forces: the atom must not desorb or move spontaneously on the surface while the tip must be able to pull it to a new location with large enough lateral forces. Due to the weak Van der Waals force to the surface, xenon atoms are moved easily by the tip. Other atomic elements require greater pulling forces, reached by bringing the tip in closer contact with the atom on the surface.

The atomic force microscope (AFM) is a sibling of the STM that relies on the force between sample and tip, rather than on the tunneling current. It was demonstrated in 1986 by researchers at IBM and Stanford [6]. The AFM has the advantage of being able to probe insulating surfaces and it provides complementary information to the STM. Nowadays many low-temperature tools measure force and current simultaneously, so they incorporate both AFM and STM capabilities, collectively called scanning probes.

Arranging atoms to control electrons

Controlled positioning of metal atoms has made it possible to construct large atomic arrangements such as the stadium-shaped "quantum corral" of introduction figure, which produces a standing wave pattern of electrons confined inside the corral [7]. Subsequently, various chemical elements were used to assemble a rich variety of structures having well-designed quantum states and band structures [8].



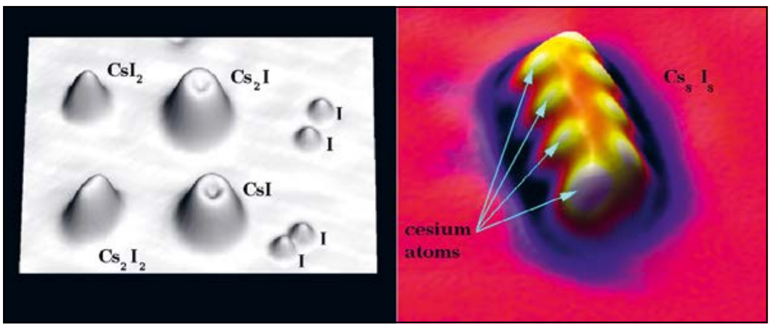
▲ **FIG. 3:** Bistable antiferromagnet made of 12 Fe atoms on an MgO film. Blue/white color shows the measured spin direction. (Credit: IBM)

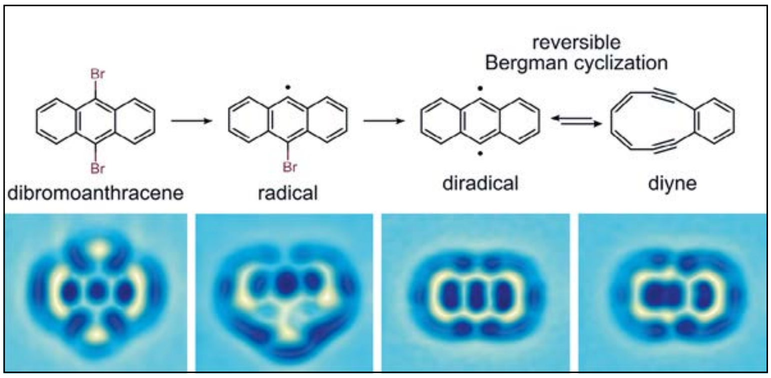
The STM has proven adept at constructing and imaging magnetic nanostructures. Atoms bound directly on the metal surface show many intriguing magnetic properties [8]. Placing them instead on a thin layer of insulating material, such as copper nitride or magnesium oxide (MgO), has yielded long-lived quantum magnetic states. Structures were assembled by transferring each magnetic atom onto the STM tip and back to the insulator, using voltage pulses for each transfer. An example is the antiferromagnet made of 12 iron atoms shown in Figure 3. This tiny magnet can be switched by flipping all the spins at once using a current pulse from the tip, making it a writable magnetic memory bit [9].

From atoms to molecules

A step toward building molecules using STM is to assemble ionic clusters made of alkali halides. Figure 4 shows how cesium (Cs) and iodine (I) atoms were manipulated to form precise molecule-like clusters [10]. The Cs atoms, stable only when attached to an I atom, were moved from one I atom to another by using an I-terminated tip in order to form clusters such as Cs_2I and Cs_2I_2. The Cs_2I_2 clusters were then pulled along the surface as a unit and attached together into polymer chains. Sodium iodide clusters were also obtained, suggesting that it will likely be possible to build a variety of alkali halide structures in the future.

▼ **FIG. 4:** Assembling planar ionic molecules from cesium and iodine atoms. Left: Small Cs- and I-based structures on a Cu(111) surface. Right: A Cs_8I_8 chain achieved by sliding four pre-assembled Cs_2I_2 units together. (Credit: IBM)





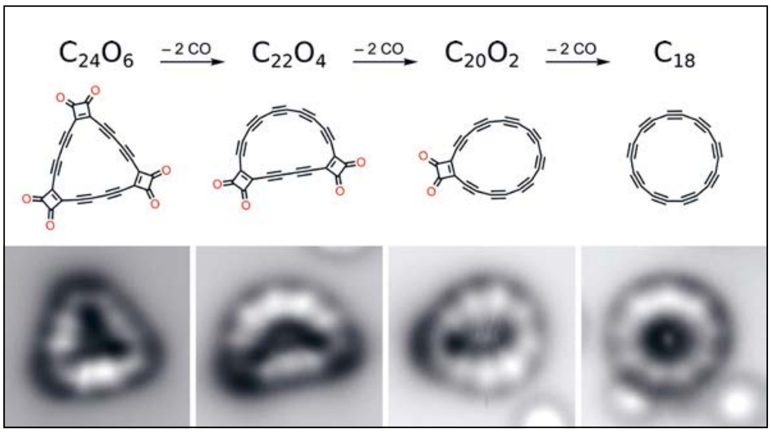
▲ **FIG. 5:** Breaking and forming covalent bonds by atom manipulation. Applying voltage pulses from the tip, two Br atoms are successively dissociated from a precursor molecule to generate a diradical. This diradical can be reversibly and repeatedly transformed into a diyne, breaking and forming covalent carbon-carbon bonds within the molecule. The AFM images are taken using a CO-functionalized tip. Adapted from ref [14], Springer Nature.

Atom manipulation can be used not only to move and place atoms and molecules on a surface, but also to break or form covalent bonds in molecules [11]. The synthesis of a molecule by atom manipulation was demonstrated by Saw-Wai Hla and coworkers in a landmark experiment in 2000, performing all steps of an Ullmann coupling reaction [12].

Recently, molecule and atom manipulation made great progress thanks to high-resolution AFM that uses CO terminated tips, revealing the internal structure and chemical bonds of molecules [13]. This approach permits chemical reactions to be followed step by step and to identify intermediate and final products with atomic resolution. On chemically inert surfaces such as NaCl or Xe monolayers, highly reactive molecules such as radicals and reaction intermediates can be generated, remaining stable enough to be studied. Figure 5 shows bromine (Br) dissociation followed by reversible carbon-carbon bond cleavage and bond formation in an individual molecule [14].

Exploiting the inert surface and the controlled influence of the scanning probe tip, elusive molecules can be generated that cannot be studied otherwise. For example, the cyclo[18]carbon C_{18}, a highly reactive allotrope of carbon, whose structure had been debated for years, was recently synthesized by atom manipulation [15].

▼ **FIG. 6:** Elusive molecules created by atom manipulation. The cyclic carbon C_{18} was formed by atom manipulation on a bilayer NaCl film on Cu(111). Here CO masking groups from the precursor $C_{24}O_6$ were dissociated by voltage pulses. In the AFM images (bottom row) the triple bonds appear with a characteristic bright contrast. Adapted from ref [15], AAAS.



The AFM images (Figure 6) settled a long-running debate by showing that the final structure is not cumulenic with only double bonds but polyynic, consisting of alternating single and triple bonds.

Prospering in the room at the bottom

Richard Feynman's 1959 essay "There's plenty of room at the bottom" looked into a future time when objects will be assembled atom-by-atom. As we strive to approach this ultimate level of miniaturization, we will benefit by making intentional use of every atom. In the last 30 years, scanning probes have led the way forward, and their versatility will surely keep them at the forefront of this exciting exploration. ■

About the Author

Christopher Lutz is a Senior Scientist at IBM Research – Almaden in San Jose, California. He joined the group of Don Eigler in 1990 and has led the group, now the atom manipulation and nano-magnetism project, since 2016.

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by David Sands and Daniel Heanes
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Defining physical quantities for upper secondary school students

Familiarity breeds contempt, or so the old English saying goes. Complacency rather than contempt might be a better word for what we have in mind, but ironically semantic accuracy would not in this case convey nearly so well our intended meaning. We are concerned with the definitions of physical quantities, such as weight and electric field, for which accuracy is crucial. Physics education research has shown how easy it is for students to develop incorrect conceptions. Take Newton's third law of motion for example. Although it is not a physical quantity, students' difficulties with this law are well known and illustrate just how easy it is for students to misunderstand a basic idea through loose terminology. The classical form of the law, to every action there is an equal and opposite reaction, can easily be transformed into, for every force there is an equal and opposite force. Far from enlightening students, this can very easily, and often does, lead to the misconception that in simple mechanical systems dissipative forces, such as friction or air resistance, will inevitably increase until there is no nett force acting. The choice of words and phrasing is crucial in shaping our thoughts and complacency is the enemy of precision.

Many professional physicists will use ideas like weight or electric field without ever stopping to think about their precise definitions. Imagine, though, that you are a teacher looking to find the correct definition to convey to your students. It might be that you are familiar with the ideas but want to brush up on your basic knowledge or, as is occurring increasingly across much of Europe, if physics is not your specialty but you are still tasked with teaching it, you might be looking for either insight or knowledge you don't currently possess. You have access to untold quantities of information and it is very unlikely you will find a single definition. How do you know which to choose?

You could always look for an authoritative source and instinctively you might turn to a text book. After all, psychologists tell us that an essential component of reasoning is access to usable knowledge, so surely it must follow that if school students are to learn to think and reason correctly about physics at school then surely what they are told must be correct? This might indeed be the ideal, but at least in the UK, if not elsewhere in Europe, things are a little more complicated. In the UK there are five awarding organisations (AO) that administer A-level examinations and the qualifications derived from them. Each publishes its own resources, complete with its own set of definitions. A teacher might naturally stick to the resources from the particular AO administering the exams his or her students will be taking and whilst that might suit an individual teacher, it means that school students up and down the country are being taught different things according to where they live and whose examination they are taking.

This wouldn't be so bad if all the different definitions of a given quantity were equivalent, but, whether a definition is actively misleading or simply open to mis-interpretation, there is no mechanism of oversight and nothing to guarantee that intended and actual meanings converge. This is the situation that an interested group of people at the Institute of Physics, led by the then Director of Education, Prof. Peter Main, and working with the National Physical Laboratory, set out to address by constructing a glossary of physical quantities for use with 16-19 year-olds. The glossary currently consists of 34 definitions, both in print and on the web[1], with a similar number to be added to the website in the near future.

For consistency and clarity, the definitions all have the same structure. They start with a description and a discussion followed by the units, first the SI units, then their expression in terms of SI base units and, if relevant, other frequently used units. The common mathematical expressions then follow, though if necessary mathematical definitions are given earlier. Related entries in the glossary are then listed and finally the definition is put into some kind of context. For magnetic field, for example, the relative strengths of several different fields, including the Earth's magnetic field and the field in a MRI scanner, are described.

Many of the descriptions and discussions are augmented by simple diagrams that convey the essential concept.

[1] https://spark.iop.org/collections/glossary#gref

The figure below shows the diagram associated with stress and illustrates the importance of ratio of applied force to area rather than total force. The mass of a person wearing a stiletto high-heeled shoe is likely to be around 50kg, give or take, whereas a for full-grown elephant the mass could be anything between 3500kg and 6500kg, depending on its sex and whether Indian or African. However, the cross-sectional area through which the weight is transmitted is likely to differ by a factor of many thousands, meaning that the stress beneath the foot of an elephant is less than the stress beneath a stiletto heel. This is depicted by the lighter shading associated with the former compared with the latter.

Having a set of authoritative definitions such as these in a single accessible place has obvious advantages, not least for supporting teachers who are not specialists in physics and the Physics Education Division of the EPS is working with the IOP to promote the use of the glossary across Europe. The glossary is free to use as it is by anyone, not just teachers in the UK. For those wanting to edit or amend it, for example by translating it into a European language, the IOP is in the process of developing a franchise model which we anticipate will be available in the spring of 2020. Whilst we will be happy to accommodate individual teachers, we are particularly keen to make contact with those responsible for school curricula and assessments in different countries across Europe. Any readers around Europe who are interested in either using a franchised version of the glossary or are able to put us in contact with appropriate organisations within their own countries are asked to contact David Sands on d.sands@hull.ac.uk. ■

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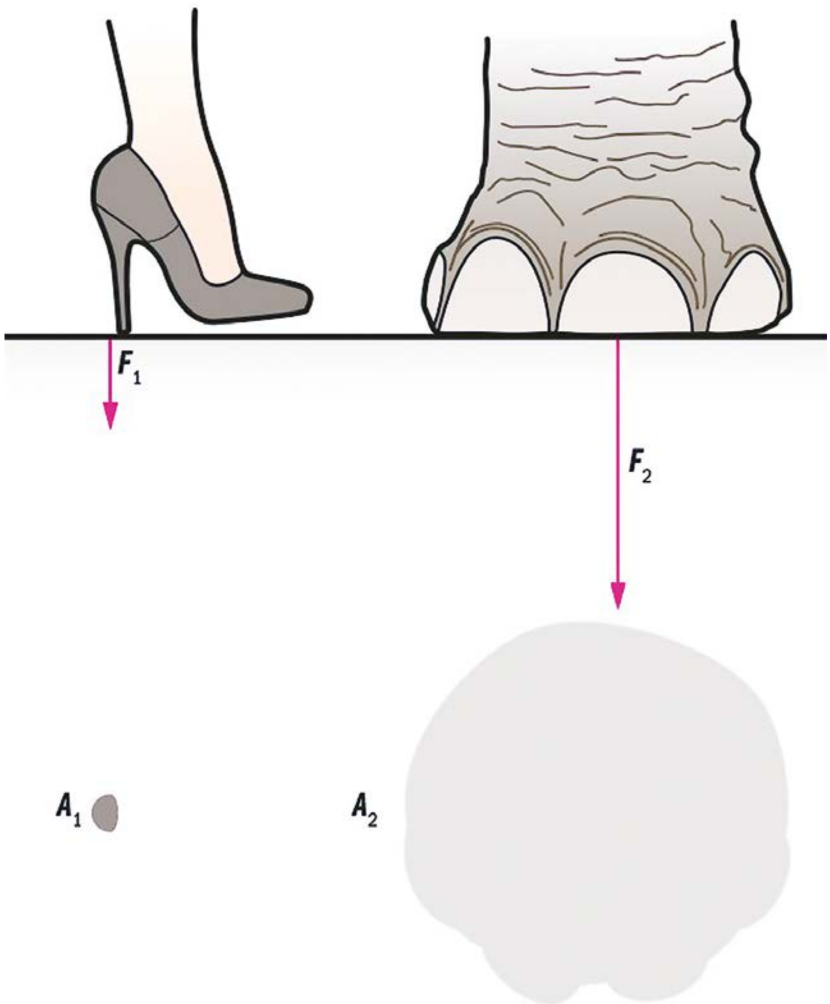

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Loránd Eötvös and Hungary's restructured research network

Loránd Eötvös is one of the best-known Hungarian physicists (his first name is Loránd in Hungarian, but he used the German version, Roland, in his publications written in German). The new research network ELKH in Hungary is named after him.

Eugene Wigner is probably the best-known physicist of Hungarian origin world-wide, followed by John von Neumann, Edward Teller, Leo Szilárd and Theodore von Kármán. Eötvös fits very well into this series, and it is a matter of taste which position you would assign him in this list. Something they have in common is that after having finished high school in Budapest they all went abroad to study science. While Wigner, Neumann, Teller, Szilárd and Kármán remained there, and eventually went to the US, Eötvös, after getting his PhD in Heidelberg, returned to Hungary and made his whole scientific career there. Their different decisions can be explained by the completely different political climate in the seventies of the 19th century and in the post-World War I period of the 20th century.

"Loránd Eötvös valued fundamental research"

In the year 2019 we commemorated, together with UNESCO, the 100th anniversary of his death. The celebrations started with the inauguration of the memorial plaque attesting that the ancient physics building of the Budapest University, which now carries the name of Eötvös, was declared EPS Historic Site. It was in that building that he started his most famous experiments to demonstrate to an extreme accuracy the proportionality of inertial and gravitational mass. Nowadays we see a revival of interest in these experiments. That is why the English transcript of Eötvös's original autograph describing their work in detail is now available in the book entitled *The Eötvös Experiment in its Historical Context*.

Throughout his life Eötvös's main interest was in fundamental research. In his inaugural address as president of the Hungarian Academy of Sciences (HAS) he expressed his conviction that the so-called useful discoveries were not made by those who wanted to find such things, but by scientists searching selflessly the abstract truth, and the useful discoveries were simply consequences of their scientific results.

Hence it is ironic that when the Hungarian government decided to reorganise the research network supervised earlier by HAS – with the declared aim to improve efficiency and promote innovation, thus bringing science closer to applications – the new structure has been named Loránd Eötvös Research Network (ELKH in Hungarian).

Until August 2019, most research institutes in Hungary worked under the umbrella of HAS. Their basic allocation came from the state budget via the Academy, the directors were nominated by the president of HAS, and the body to which the secretary general of HAS had to report on the research activity and scientific achievements of the institutes was the General Assembly of HAS.

Since September 2019 the basic allocation comes via ELKH; the institute directors, who all remained in office until now, will later be nominated by the head of ELKH, and the scientific committees of ELKH will supervise the scientific activities carried out in the institutes.

When the structural reform was announced, there was quite an uproar, not only in Hungary. The argument of the opponents of the reform was that by this move the government would gain control over the research establishment. Politicians and not scientists would decide what kind of scientific activity should be financed, and therefore scientific freedom was in danger, the step was a „crackdown on academic freedom".

After almost half a year we may say that until now these fears do not seem to be justified. The governing body of ELKH consists of 13 people including the Chair. The Chair is a former vice president of HAS, 9 out of the 12 regular members are members of HAS. Two other members are also highly respected scientists (one is member of Academia Europeae, the other is the rector of the Veterinary University), and only a single member of the board is a civil servant, a deputy secretary of state of the Ministry of Innovation and Technology. As far as the money is concerned, all research institutes have got the same allocation as the year before.

Of course we do not know precisely how science policy of the government will develop in the next years. We can only hope that academic freedom as a core value will be respected in the future as well. ■

Jenő Sólyom, *President of the Roland Eötvös Physical Society*