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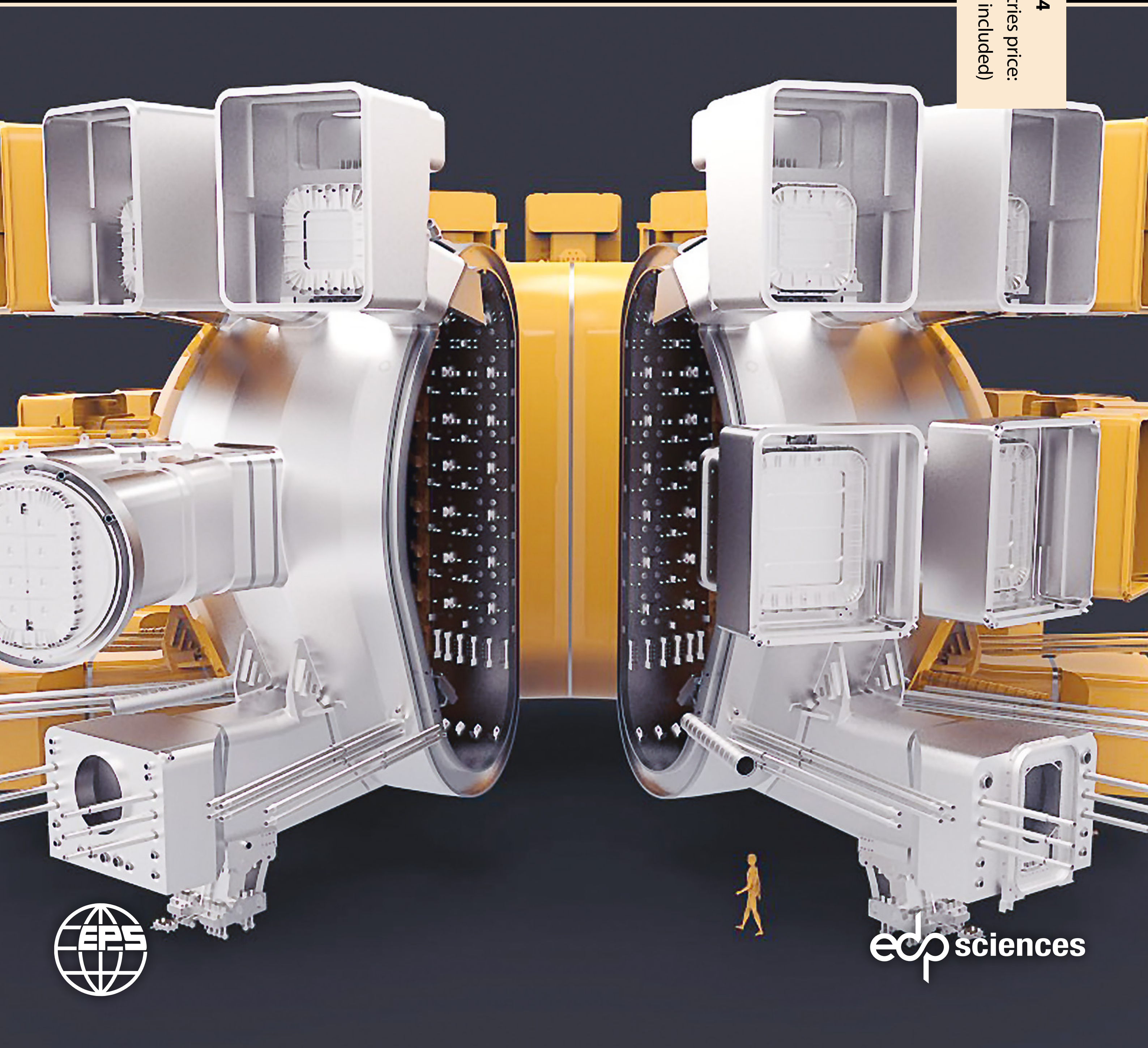
Young Minds: a career springboard

Moving teaching online



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Cover picture: Drawing of the vacuum vessel that will provide the ITER experimental fusion reactor in France a high-vacuum environment for the plasma. On 28 July 2020, the start of assembly of the ITER machine was celebrated in the presence of President Macron of France. Credits ITER Organization. Website at www.iter.org.

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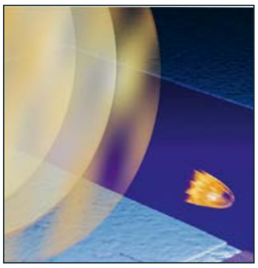

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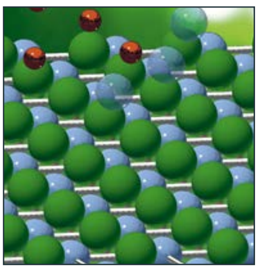

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Precise control of atoms with MBE

[EDITORIAL]

An ambitious R&I programme for Europe?

Every seven years, the European Union establishes its budget for the next seven years. There are few things as important for the EPS, as a European learned society, than the budget for the following Research and Innovation (R&I) Framework Programme.

For a European learned society, such as the EPS, one of the most exciting events every seven years is the announcement of the EU-budget for the following Research and Innovation (R&I) Framework Programme. The programme affects dramatically the national R&I policies of the Member States, their educational systems, their knowledge-based industrial policies and in general, their competitiveness.

Many Member States, if not all, wish to see every seven years an ambitious European R&I programme to dovetail with their national R&I programmes. Experience has shown that the EU is the mirror where many Member States see themselves and then adapt their national ambitions to the EU ones. An ambitious European R&I programme encourages Member States to be ambitious with their national R&I programmes; conversely, a frugal European R&I programme would discourage them in their national R&I ambitions.

It is clear that the health emergency created by the COVID-19 pandemic has produced serious economic and social effects in the EU, reflected in the budget negotiations. However, the crisis has shown beyond any doubt the importance of a strong European R&I system. While the proposal of the structure of *Horizon Europe* has reached consensus among the scientific community, we are critical of the decision of the EU Council to downsize its R&I budget for 2021-2027 from the originally proposed €94.4 billion to €75.9 billion. This represents a negligible increase over *Horizon 2020*, even after deducting the UK contribution and applying the inflation corrections.

Including the €5 billion top up from the *Next Generation EU* recovery fund, the current proposal of the EU Council for *Horizon Europe* is still far from realistic, and will not even meet the expectations set by the EU for the next seven years. Hopefully, it will maintain the current position of the European R&I system in the world - the EU invests only 2.06% of its GDP against 2.13% in China, 2.78% in the United States and 3.2% in Japan[1].

This is the moment that the European Parliament and the European Commission can still stand in favour of a larger budget for *Horizon Europe*, not only to reach the proper objectives of the framework programme, but also to reach the objectives expressed in *"Pillar 3: Learning the lessons from the crisis"* from the *Next Generation EU*'s plan.

Physics, and research in general, addresses fundamental questions and provides societies with the necessary tools to face the current and the future challenges. Hence, representing the European physics community, the EPS calls upon the European Parliament to show a greater vision for the future of Europe and boost the European R&I system with a more ambitious investment and, for that, introduce the necessary amendments in the current budget proposal to revert this downward spiral of the *Horizon Europe* R&I budget. ■

Enrique Sánchez-Bautista,
Policy Officer at EPS
and its permanent representative in Brussels

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure

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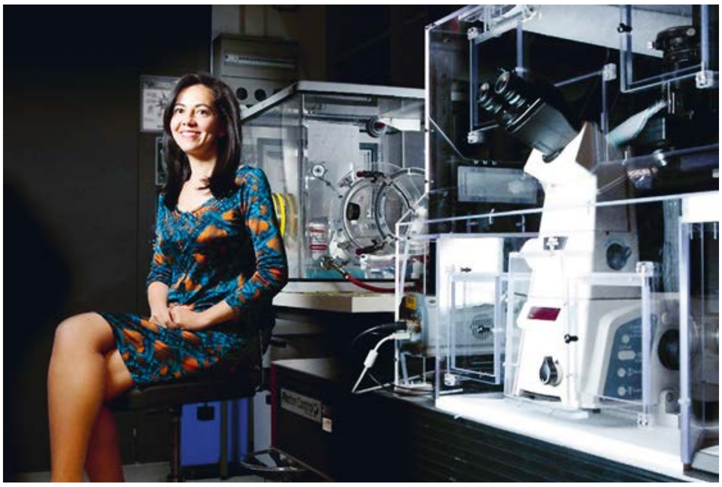
Interview with Hatice Altug

"Working with good people is the key to do great science."



Hatice Altug, full professor at the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland, was awarded the Summer 2020 edition of the EPS Emmy Noether Distinction *"for her seminal contributions to light-matter interaction at the nanoscale, manipulation of light on-chip and application of nanophotonics in biology, and her inspiring role for the next generation of researchers and women"* (quote from jury report). She is the team leader of the Bionanophotonic Systems Laboratory in EPFL's Institute of Bioengineering.

At her laboratory, work focuses on the development of the next generation nanodevices for early disease diagnostics, safety and point-of-care testing exploiting novel optical phenomena at nanoscale with nanophotonics, nanofabrication and microfluidics. "In particular, we engineer photonic metamaterials and metasurfaces by tailoring tiny nanostructures from noble metals, semiconductors and two-dimensional quantum materials. These artificial photonic systems can confine light below the diffraction limit and generate strong electromagnetic fields in nanometric volumes, which in turn enables enhanced light-matter interactions for fundamental studies and technological device applications." The expertise of her laboratory covers a broad electromagnetic spectral window ranging from visible to mid-infrared frequencies. "For instance, mid-infrared spectrum is very important for bioanalytical applications because IR absorption spectroscopy enables chemical specific and label-free detection of biomolecules by extracting absorption signals that result from molecular bonds. Despite its advantages, IR spectroscopy suffers from low sensitivity because the wavelength of Mid-IR light is much longer than the size of nanometric biosamples (*e.g.* proteins). By designing mid-IR metasurfaces, we develop ultra-sensitive surface enhanced infrared spectroscopy methods for fingerprint detection and large-area chemical imaging of biosamples as well as real-time monitoring of protein conformations in aqueous environment. In a parallel effort, we build ultra-compact and low-cost microarrays that can rapidly detect very low concentrations of disease biomarkers and pathogens from patient samples within minutes. Also, we develop powerful optofluidic bioimaging systems that can perform one-of-a-kind measurements on live cells down to the single cell level."

EPFL

After receiving her bachelor degree in Turkey, Hatice moved to Stanford University in California for her doctoral study in applied physics. "I really enjoyed my time in the US both as a graduate student at Stanford University, and as a professor at Boston University. The training I received and the research culture I have experienced in the US have been very valuable for my career. Right around my tenure time at Boston University I received several offers from other universities, and EPFL was one of them. After visiting Switzerland I got to learn more about the Swiss university system and I was impressed by the infrastructure and available sources that it offers. My research is experimental, and we heavily rely on state-of-the-art cleanroom facilities for nano/micro fabrication of optical nanostructures. EPFL has outstanding cleanroom and shared facilities. It is also a vibrant and young school with a multicultural environment, so I though it will be a step forward in my career and a great place to grow up together scientifically. Another factor is the high prestige of the university so that I could attract talented PhDs and post-docs to my lab, and working with good people is the key to do great science. Also, EPFL's location is perfect to set up collaborations with top experts all around the world and be always connected to do interdisciplinary research."

Next career steps

"In a scientific career you always have to anticipate the next important research directions, go after challenging problems and push the limits. We have been recently working with new optical nanomaterials and exploring how to marry them with smart data science tools, biology and chemistry. I am excited to exploit them in order to introduce novel sensing mechanisms and come up with revolutionary optical devices. I am also looking forward to expanding the application areas of our technologies in life sciences and getting into the translational research so that we come a step closer to the end user. Apart from research, I have been serving as the director of doctoral program in photonics. It is a rewarding task as we are working closely with teams of graduate students and colleagues from different disciplines with a goal to improve the quality of research and PhD experience for the students and the professors. I am also involved in the organisation of several networks that aim to support career building for female professors and young women in science."

How do you cope with the restrictions of the corona crisis?

"The lock-down announcements came rather suddenly in the middle of March 2020. Since we have a lot of expensive equipment and delicate experimental set-ups and samples, I remember that in the last days before the closure we were rushing to make sure that everything in our lab will stay safe during the confinement. Being in the quarantine was a bit of adjustment in the beginning. But, given that one of our research objectives is to develop low-cost and rapid point-of-care diagnostic devices, I can say that living through pandemic gave a better meaning of the research we do in the lab and what impact we could have to help save lives. We have been having Zoom calls with my lab members to brainstorm on device ideas, and discuss what we can develop for COVID-19. Apart from research I had to adapt my lectures to fit into online teaching and gave several conference talks remotely. Overall it has been difficult to manage the work from home with the family and a small kid at the same performance as before. But, when I put things in perspective and compare with great sacrifices and challenges that healthcare providers have been facing in the field, it only motivates me to progress more in our research."

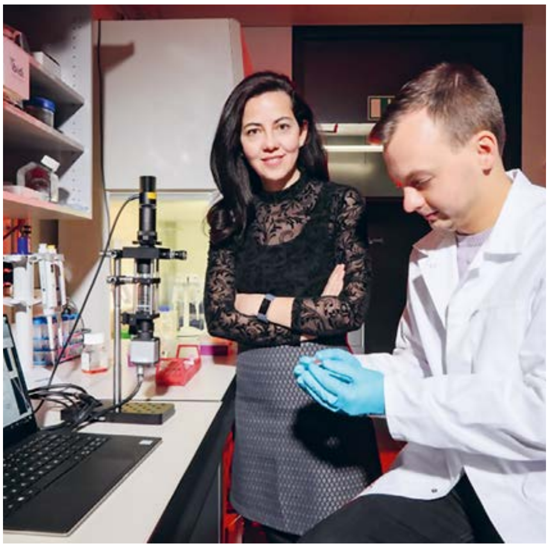
Inspiring young physicists

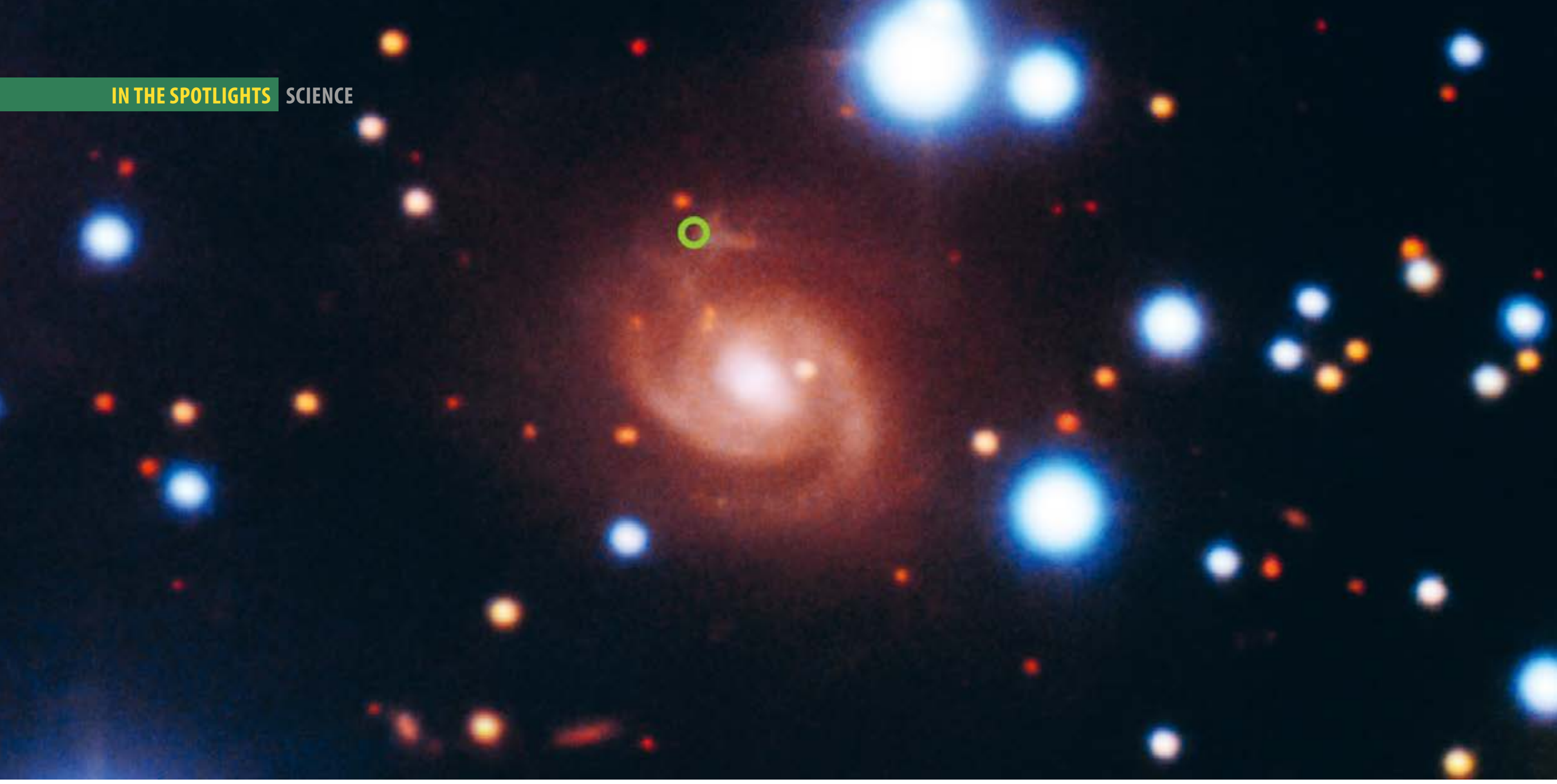
"During my lectures when I am describing a physical phenomenon, discovery or technological invention I always try to connect with the face(s) of the person(s) who made major contributions in that field and give a little bit of its history. I think it is important to expose the personal side of science as it can inspire the students that one day some of them could be among such influential scientists. As my research is in the field of photonics it is also easier for me to include the technological impact of the scientific work in our daily life. For example, in my optical biomicroscopy course while I am teaching two-photon microscopy I mention who Maria Goeppert-Mayer is, her seminal contributions in the fundamental understanding of two-photon effects, and that she was the second woman to receive Nobel prize in physics. Likewise, in 2018 I was very excited to announce that Donna Strickland, an optical physicist, became the third woman to receive the prize. Apart from teaching, I also use outreach activities with lively demonstrations to encourage even younger generation to choose physics, and always try to share my passion and motivation."

Enriching

"I have lived in different parts of the world and got to know many smart people from all around the globe with diverse background and origin. I think this is one of the most fun and enriching aspects of my job." ■

▾ Hatice Altug with a team member of the Bionanophotonic Systems Laboratory. © Alain Herzog / EPFL 2020





A Fast Radio Burst
localised to a nearby spiral galaxy

Fast Radio Bursts (FRBs) are enigmatic astrophysical transient sources of unknown origin. Despite the fact that hundreds of FRBs have been discovered to date, only a handful of them have been successfully associated to host galaxies. The localisation of a second repeating FRB, inside a star-forming region of a spiral galaxy, has added an additional puzzle to the field, and has highlighted that FRBs can be produced in a diverse set of host galaxies and local environments.

▲ Optical image of the host galaxy of FRB 180916J.0158+65. The position of the source is highlighted by the green circle.

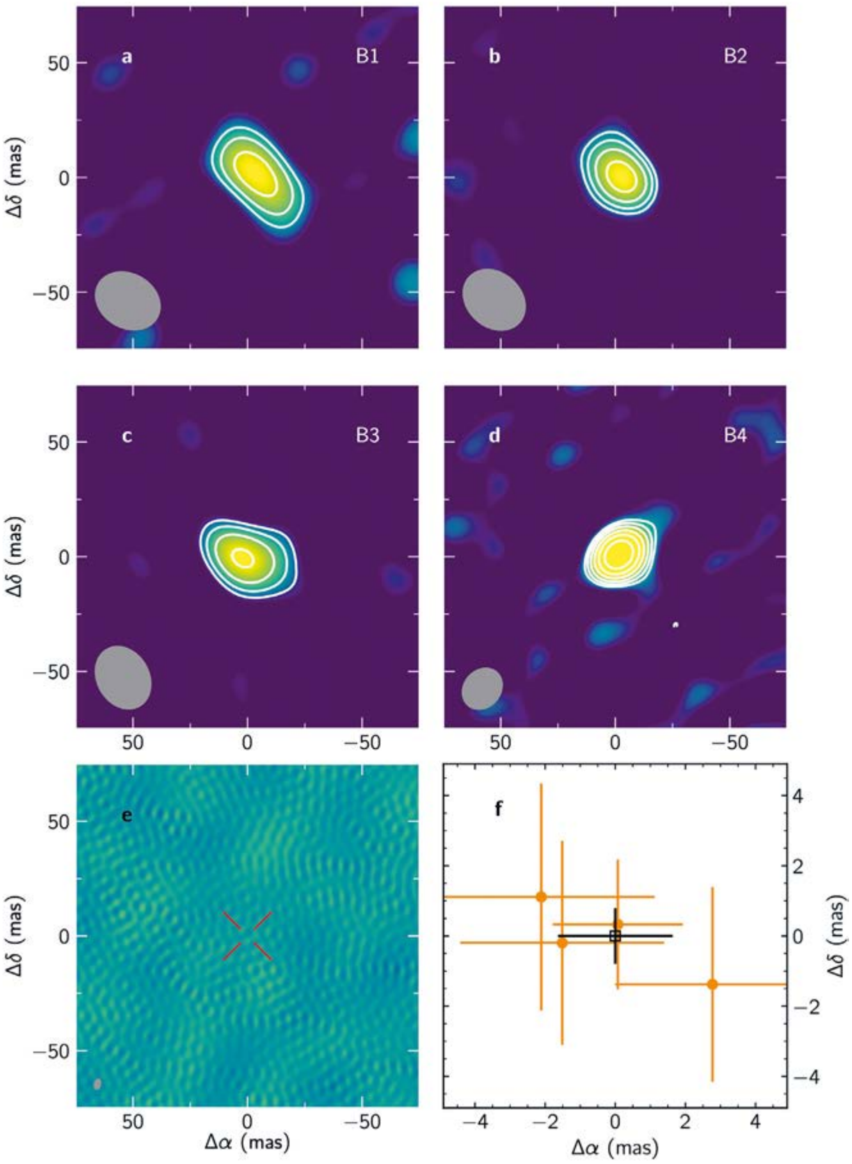
Fast Radio Bursts (FRBs), first observed in 2007 [1], are flashes of light, observed at radio wavelengths for only a few milliseconds [2]. A small fraction of the hundreds of FRBs observed to date exhibited multiple bursts - the so-called repeating FRBs. Thanks to the short timescales of the FRB emission, it is possible to directly measure the dispersion that the light suffers due to interaction with the material between the FRB source and the observer. This quantity is proportional to the column density of electrons between the source and the observer. For all discovered FRBs, the column densities significantly exceed the estimated material from the Milky Way in their line of sight, implying that they are all located at cosmological distances. In 2017, for the first time an FRB, 121102, was precisely localised to a low-metallicity star-forming region of a dwarf galaxy [3]. In 2019, three so-far non-repeating FRBs were localised [4,5,6]and found to be in different environments when compared with the repeating FRB 121102 (massive galaxies with little-to-no star formation). This discrepancy raised stronger speculations on the existence of intrinsic differences between repeating and non-repeating FRBs. However, to make strong conclusions on their possible nature, more precise localisation, particularly of the new repeating FRBs, is mandatory.

Observation of FRB 180916.J0158+65

On 19 June 2019, we followed for seven hours FRB 180916.J0158+65 with the European Very Long Baseline Interferometry Network (EVN). Discovered by the Canadian Hydrogen Intensity Mapping Experiment (CHIME) telescope, the FRB was localised somewhere between the Galactic halo and a redshift up to ~0.1 [7]. It was therefore speculated that this FRB could potentially be Galactic. The data from eight telescopes all around the world were combined in real time at the Joint Institute for VLBI ERIC (JIVE), The Netherlands. In parallel we recorded high time and frequency resolution data with the 100-m Effelsberg Telescope in Germany. We detected four new bursts from FRB 180916. J0158+65 and determined the arrival time of each burst from these Effelsberg data. Then, we combined the data from the whole array at those times to produce individual images of the bursts, reaching milliarcsecond resolution. The position of FRB 180916.J0158+65 in the sky was then determined to a precision of only 2.3 milliarcseconds [8], as can be seen in Fig. 1. Follow-up optical observations with the Gemini North telescope were conducted between July and September 2019 to obtain both photometric and spectroscopic images of the field. Spectra from both the core of the host galaxy and at the position of the FRB were obtained.

Data analysis

The bursts from FRB 180916.J0158+65 were found to arise from the apex of a prominent V-shaped star-forming region from one of the arms of a spiral galaxy located at a redshift of 0.0337 ± 0.0002. This star-forming region is unusually large (~1.5 kpc across) and exhibits a star-formation surface density of about 10^{-2} $M_{\odot}$ yr^{-1} kpc^{-2} with a metallicity consistent with the solar one. The observed shape suggests that an interaction between either multiple star-forming regions or with a presumed dwarf satellite companion could have occurred. FRB 180916.J0158+65 is the closest FRB precisely localised to date. It lacks the presence of an associated persistent radio counterpart. The obtained limits ($\nu L\nu < 7.6 \times 10^{35}$ erg s^{-1}) imply that such presumed emission must be at least 400 times fainter than the one associated with FRB 121102. While scenarios related to massive black holes are less likely for this FRB due to its environment, models considering a young and rapidly rotating magnetar could still explain this source by invoking an age about 10 times older than the one assumed for FRB 121102, thus ~300 yr. The fact that FRB 180916.J0158+65 exhibits, on average, significantly fainter bursts than FRB 121102 further supports this scenario.



◂ **FIG. 1:** Radio images of the four individual bursts detected from FRB 180916.J0158+65 during the EVN observation on 19 June 2019. Here mas stands for milliarcseconds. Each burst lasted for approximately two milliseconds. The bottom left panel shows the continuum radio image at the position of the bursts. No persistent emission is reported above the rms noise level. The bottom right panel shows the measured relative positions of the individual bursts and their 1σ uncertainties (orange circles), and the average position for the FRB (black square).

Conclusions

The obtained results reveal a wide diversity of host and local environments for repeating FRBs. The current distinction between repeating and non-repeating FRBs is no longer solid. Additionally, it may suggest that a large fraction of FRBs must be capable of repeating. While the nature of FRB 180916.J0158+65 and FRBs in general remains unclear, this new discovery provides a new context that must be taken into account by the models aimed to explain FRBs. More importantly, the proximity of FRB 180916.J0158+65 will allow a detailed multi-wavelength follow-up of an FRB for the first time. Observations from optical, X-ray, and gamma-ray wavelengths would unveil the possible existence of multiwavelength bursts and associated persistent counterparts. ■

■ **Benito Marcote,**
JIVE, The Netherlands
■ **Kenzie Nimmo,**
University of Amsterdam and ASTRON, The Netherlands
■ **Jaseon Hessels,**
University of Amsterdam, The Netherlands

References

[1] D. R. Lorimer *et al.*, *Science* **318**, 777 (2007).

[2] E. Petroff, J. W. T. Hessels, and D. R. Lorimer, *A&AR* **27**, 4 (2019).

[3] C. G. Bassa *et al.*, *ApJL* **843**, L8 (2017).

[4] K. W. Bannister *et al.*, *Science* **365**, 565 (2019).

[5] V. Ravi *et al.*, *Nature* **572**, 352 (2019).

[6] J. X. Prochaska *et al.*, *Science* **366**, 231 (2019).

[7] CHIME/FRB Collaboration *et al.*, *ApJL* **885**, L24 (2019).

[8] B. Marcote *et al.*, *Nature* **577**, 190 (2020), DOI: https://doi.org/10.1038/s41586-019-1866-z

The 2020 awards of the EPS Accelerator Group

The EPS Accelerator Group unites people interested in particle accelerators, storage rings and similar devices used in scientific research and practical applications. Every three years, the Group awards people in the community at different phases of their research career for outstanding achievements in the field. On request of EPN, three award winners describe their current work thus providing our readers with a flavour of the field modern accelerator physics.

▲ The LHC collider at CERN.

The **Rolf Wideroe Prize** celebrates the career of senior accelerator physicists. In 2020, the Prize was awarded to **Lucio Rossi of CERN, Switzerland** *"for outstanding work in the accelerator field. He is rewarded for his pioneering role in the development of superconducting magnet technology for accelerators and experiments, its application to complex projects in High Energy Physics including strongly driving industrial capability, and for his tireless effort in promoting the field of accelerator science and technology."* Until recently, during 10 years, Lucio Rossi was the project leader for the High-Luminosity LHC at CERN. In particular, he is one of the drivers of the development of superconducting magnets for the LHC.

"Particle Accelerators are engines for discovery: the discovery of the long-awaited Higgs boson, in 2012 at the CERN's LHC by the ATLAS and CMS experiments, has been the last of a long series of fundamental discoveries, indeed. The continuous particle beam energy increase, necessary for such discoveries, was made possible also thanks to new technologies, like superconductivity. All recent hadron colliders are based on powerful superconducting magnets: from the Tevatron collider at FNAL in the USA, the pioneer, passing through HERA in Hamburg, Germany and RHIC in Brookhaven, New York, to the enormous LHC in Geneva. The last one is based on nearly ten thousand superconducting magnets, and 1200 eight-tesla Nb-Ti superconducting dipoles, 15 m long, are filling more than 2/3 of the 27 km long LHC tunnel. Fields in excess of 11 tesla, based on more advanced superconductor Nb_3Sn, are being developed for the first time for the High-Luminosity LHC project (HL-LHC), the new LHC configuration that will be commissioned in 2025.

My contribution has accompanied the penetration of superconducting magnets in accelerators, from the 4-5 T range of the Tevatron and HERA to the 8-9 T field of LHC magnets, for which I was responsible from 2001 to the operation in 2011. Then my major endeavour was the design of the HL-LHC, based on the new more powerful technology of Nb_3Sn to break the 10 tesla barrier. But more is on my agenda: participation to program for 15-16 T dipole in view of the post-LHC collider, 100 km long and called FCC – Future Circular Collider – and the lead of the European research on High Temperature Superconductor (HTS) accelerator magnets that can promise us to reach the 20 T threshold, thus enhancing the physics potential of a future collider while reducing considerably (up to 50%) the energy bill associated with the collider operation.

Nowadays, superconductivity has become an invaluable asset for medicine: MRI, NMR (thousands of large superconducting magnets per year!) are part of our daily life. Hadron Therapy is using superconductivity for accelerators and more recently for gantries. The sustainable energy industry is very interested in power transmission lines of 100 kA in MgB_2 superconductor developed for the HL-LHC)." ■

The **Gersh Budker Prize** 2020 was awarded to **Hideaki Hotchi, J-PARC center of the Japan Atomic Energy Agency** *"for his achievements in the commissioning of the J-PARC Rapid Cycling Synchrotron, with sustained 1 MW operation at unprecedented low levels of beam loss made possible by his exceptional understanding of complex beam dynamics processes, thereby laying the foundations for future high power proton synchrotrons worldwide"*. He summarises the importance of the infrastructure as follows:

"The J-PARC 3-GeV Rapid Cycling Synchrotron (RCS) is a world-leading high-power pulsed proton driver, which has the design goal of achieving a 1-MW beam power. The most important issues in realising such a MW-class high-power beam operation are controlling and minimising beam loss to maintain machine activations within permissible levels. In high-power machines such as the RCS, there exist many factors causing beam loss; besides beam loss generally occurs through a complex mechanism involving several factors. In the RCS, numerical simulation was successfully utilised along with experimental approaches to isolate such a beam loss mechanism. In order to realise realistic numerical simulation, we included all the possible sources of beam loss that we have identified so far such as magnetic field errors, space charge, foil scattering during injection, beam tuning and adjustment errors, *etc.*. These efforts enable us to simulate a precise motion of beam particles propagating through the accelerator. In particular, it is a remarkable achievement that experimental beam loss was well reproduced within an error of several 10% or less. The well-established numerical simulation played a vital role in finding beam loss mechanism and its solution; various ideas for beam loss mitigation were proposed with the help of the numerical simulation, and verified by experiments. As a result of such continuous efforts iterating experiments and numerical simulations, we have recently accomplished a 1-MW beam operation with very low fractional beam loss of a few times 10^{-3}.

The beam loss amount corresponds to <1/10 the typical value in the previous high-intensity proton synchrotrons. The success of the 1-MW beam operation opened a door to further beam power ramp-up beyond 1 MW. We are now promoting further high-intensity beam tests aiming for achieving a 1.5-MW beam power, looking ahead to future upgrades at J-PARC. We could say that the J-PARC RCS sets a good example of beam commissioning, which has been developed very efficiently with the strong assist of well-established numerical simulations." ■

The **Frank Sacherer Prize** is the award for an individual in the early part of his or her career, having made a recent significant, original contribution to the accelerator field. In 2020, the Prize was awarded to **Johannes Steinmann, ANL, USA** *"for his significant contribution to the development and demonstration of ultra-fast accelerator instrumentation using THz technology, having the potential for major impact on the field of electron bunch-by-bunch diagnostics."* He presents his innovative work below.

"Accelerators are the most important building block of x-ray light sources for scientific experiments on earth. Around the world, dedicated storage rings provide extremely brilliant light beams to many users. Research is constantly striving to improve the quality of these light sources and to allow new types of experiments. A major improvement could be much shorter bunch lengths, especially shorter than the desired radiation wavelength. These bunches lead to coherent synchrotron radiation and provide a power amplification by 8 to 11 orders of magnitude, depending on the number of involved electrons. The improved features of femtosecond-scale bunches are already used by x-ray free electron laser (FEL). In a storage ring, self-interaction between electrons and emitted radiation leads to a bunch-lengthening, counter-acting compression. The resulting, low picoseconds bunch length limits the coherent emission to the THz range.

To understand and influence the instability, special diagnostic tools are needed. Since the coherence of a shortening bunch starts at low frequencies first, THz detectors are viable, non-destructive, sensitive and ultra-fast tools for bunch signals. During my PhD at the Karlsruhe Institute of Technology, Germany, I built several novel diagnostic systems for THz radiation to record each individual bunch, even at 500 MHz repetition rate, and to enable the study of the micro-bunching instability providing a pathway to its control.

My work benefited from the great collaboration within the accelerator community around the world as well as the Accelerator Technology Platform at KIT, bringing together engineers and physicists. Currently, I am on leave to the Advanced Photon Source at the Argonne National Lab, USA. ■

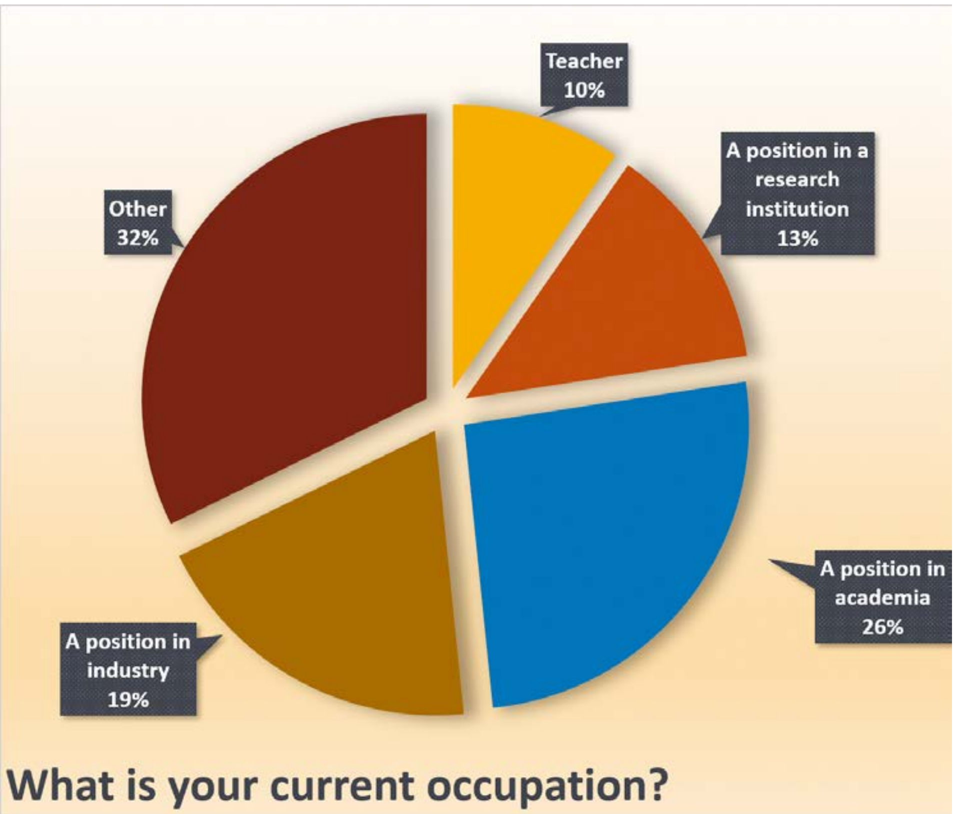
Young Minds,
a career springboard for young physicists

R. Caruso, R. Zeltner, A. Marino

Ten years ago, the Young Minds (YM) program of the European Physical Society (EPS) was born to create a network of young physicists throughout Europe, and to foster their professional development [1]. What started as an ambitious initiative of a small team, has developed into an established program: today YM comprises over 60 sections operating in 30 countries. We asked YM alumni on the impact of the YM program on their professional career.

The 10th anniversary of YM [2] marks an important milestone in the development of the program and is a good time to evaluate its impact on the students engaged in it. Naturally, the benefits of such engagement can be of very different nature and time perspective, ranging from short-term, *e.g.* getting in touch with local peers more easily, to long-term, *e.g.* acquiring skills and a professional network for the student's later professional life. Here we focused on the latter. We reached out to YM alumni and asked them to evaluate the impact of the program on their career. The survey was initially conducted for the Italian Physical Society [3], and now its results are presented to the international community.

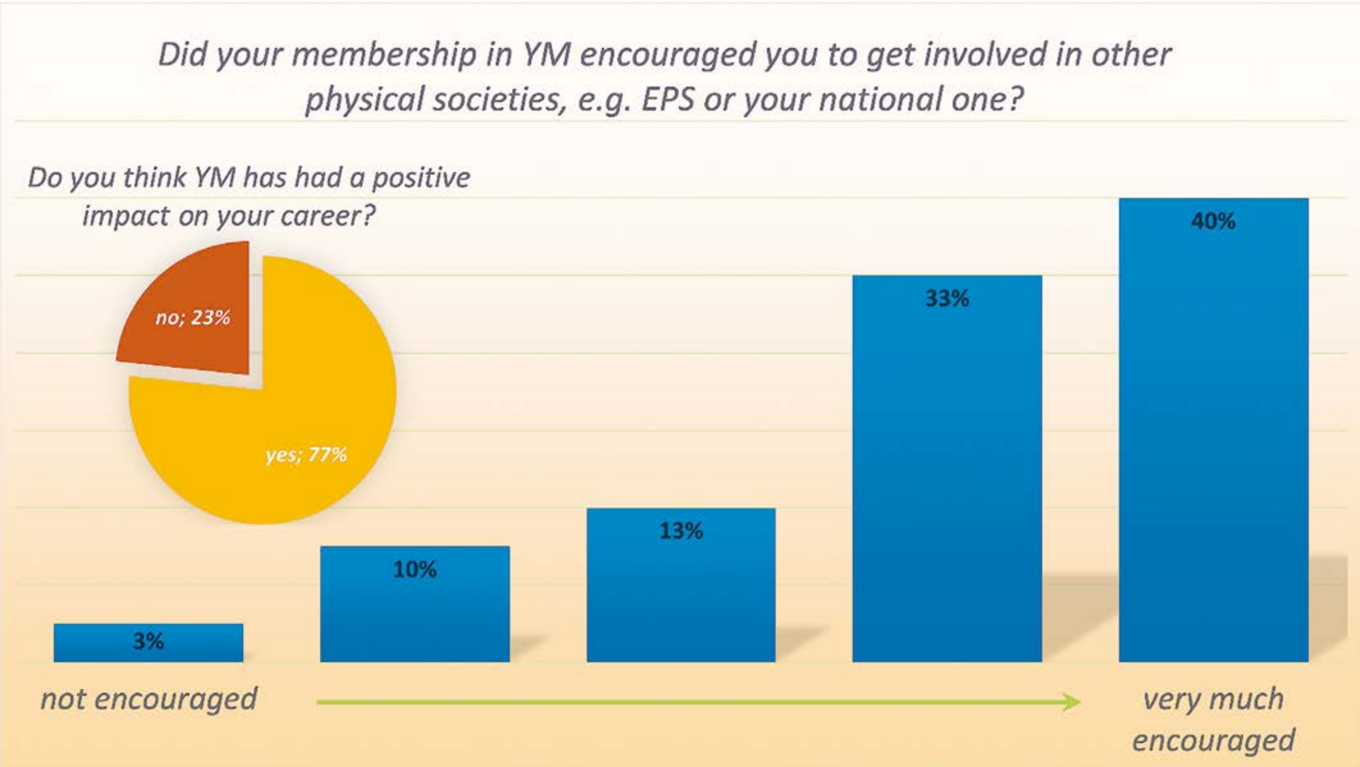
▾ Current occupation of YM alumini.



76 % of the Alumni joined YM when they were BSc or MSc students, and the remaining 24 % started out as PhD students. This composition indicates that, at least in its early days, YM had been a strong catalyst for younger students. This may well be due to the fact, that engagement in YM offered a range of possibilities, *e.g.* the organisation of conferences and the creation of an international network, which are otherwise hardly accessible to such young students. As reported in Fig. 1 the careers paths taken by the alumni are very diverse, but a strong fraction remained engaged in research at either a university or a research institution.

With the EPS being the umbrella organisation for many national physical societies, YM can play an important role in increasing the awareness about local physics communities among students that have not yet established a connection to said communities. This is particularly true for countries in which the national societies are weakly represented in *e.g.* digital media or suffer from lack of resources. As can seen from Fig. 2 more than 73% reported that YM increased their engagement in EPS and in their national physical society, while only 13% did not report a positive effect.

From the survey it also becomes apparent that YM played a key role in the individual growth of its members,



▲ Role of the YM program in favoring the engagement within EPS and national societies. Inset: Impact of YM on the careers of survey participants.

fostering the acquisition of specific skills, such as leadership and networking skills, or the ability to speak in public. Strongly aligned with the vision of creating a pan-European network, 40 % of alumni reported that cultural exchange has been a fundamental experience. This underlines that, besides contributing to the professional development of its members, YM supports the awareness of other cultures and the knowledge of what is not one's own immediate neighbour. In the era of international connection and interaction such mutual understanding is a key requirement for working together as individuals and societies. This insight strongly validates the commitment of the EPS and the national physical societies, which supported the project from the very beginning to set the trails for successful European collaborations in the future. In this sense, the exposition to an international environment within the framework of YM helps to gain experiences at an early career stage, which is an advantage when seeking an international career.

When being asked which kind of activities they consider most useful and interesting, many alumni responded with outreach activities and the Leadership Meetings. Being engaged in YM ourselves for quite some years both answers are not surprising to us. First, besides the fact that experiencing the keen interest of the broad public can be very fulfilling, outreach is a great way to improve one's own communication skills. While in principle effective communication can be broken down into textbook knowledge, mastering it requires practicing of different aspects. First, one's knowledge must be adapted such that it is accessible to the audience. Second, depending on the activity format, the audience and the goal one learns to modulate the approach and the language. Obviously, once developed these skills are extremely valuable in other contexts as well, *e.g.* during conferences or, to give an example from industry, when trying to convince a customer that your technology is superior to that of the competitors. The second pivotal activity emerging from the survey, the annual meeting, is naturally a great opportunity to network and to get in touch with other cultures.

We conclude with the most decisive numbers: 77 % of the alumni are convinced that YM had a positive impact on their career, and 97 % would recommend getting engaged in it. These numbers demonstrate that the program had a strongly beneficial impact on many early members and will certainly benefit many more in the future. Moreover, driven and supported by digitalisation, YM has grown into an established international network, very much as envisioned by its founders. Our birthday wish for YM is to keep faithful to itself and its spirit of growth and collaboration, keeping up with current [4] and future challenges. ■

"Impact of YM on professional career is considerable"

References

[1] A. Marino, G. Volpe, A. Niederberger, O. Fornari, D. Lee, M. Kolwas, *Europhysics News* **41**, 4 (2010).

[2] R. Caruso, *Europhysics News* **51/2**, 10 (2020)

[3] R. Caruso, A. Marino, *Il Nuovo Saggiatore* **36/3-4**, 84 (2020)

[4] R. Caruso, Tanausú Hernández Yanes, *Europhysics News* **51/3**, 10 (2020)

Highlights from European journals

MODELLING

What protects minority languages **from extinction?**

Mathematical modelling of competing languages in a geographical area suggests two scenarios in which one or more minority languages will be more likely to survive.

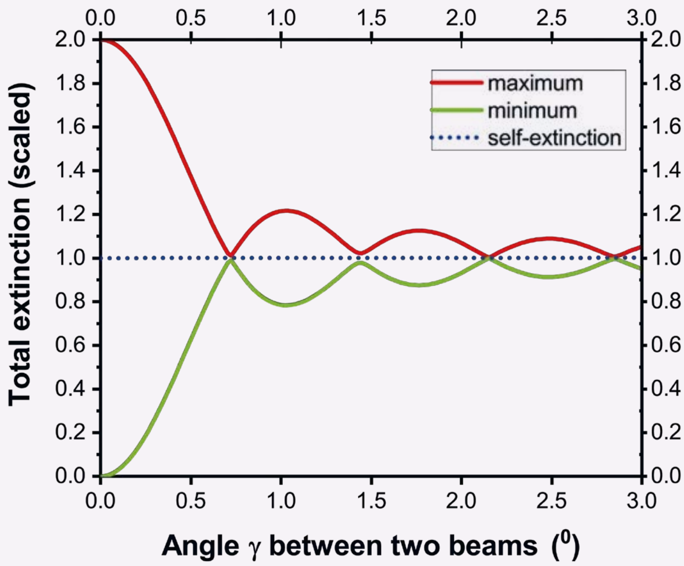
Over 6,000 languages are currently spoken worldwide, but a substantial minority - well over 5% - are in danger of dying out. It is perhaps surprising that this fraction is not higher, as most models have so far predicted that a minority language will be doomed to extinction once contacts with speakers of the majority language reach a certain level. This work describes, using mathematical modelling, two mechanisms through which this doomsday scenario does not occur, *i.e.* several languages come to coexist in the same area. ■

▲ Greetings in some of the world's 6,000+ languages. (CC BY-SA 2.0, by Flickr user quinn.anya).

■ **J.-M. Luck** and **A. Mehta**,
'On the coexistence of competing languages', *European Physical Journal B* **93**, 73 (2020), DOI: 10.1140/epjb/e2020-10038-1

PHYSICS OF LIGHT

Mutual extinction of light



▲ Calculated total extinction in a setup with two beams incident on a rectangular box containing many scatterers, plotted versus the angle between the two beams.

In many branches of the natural sciences Nature is interrogated by performing wave scattering experiments. An incident wave impinges on a sample, and characteristics of the scattered and transmitted waves are analysed to find detailed information about the target.

When a single light wave is incident on a complex scattering medium, the transmitted intensity differs from the incident one due to extinction. We introduce the new concept of mutual extinction, which occurs when more than one light wave is incident and propose new experiments to observe mutual extinction and transparency in two-beam experiments with either elastic and absorbing scatterers. ■

■ **A.Lagendijk** ***et al.***,
Mutual extinction and transparency of multiple incident light waves, *EPL* **130**, 34002 (2020)

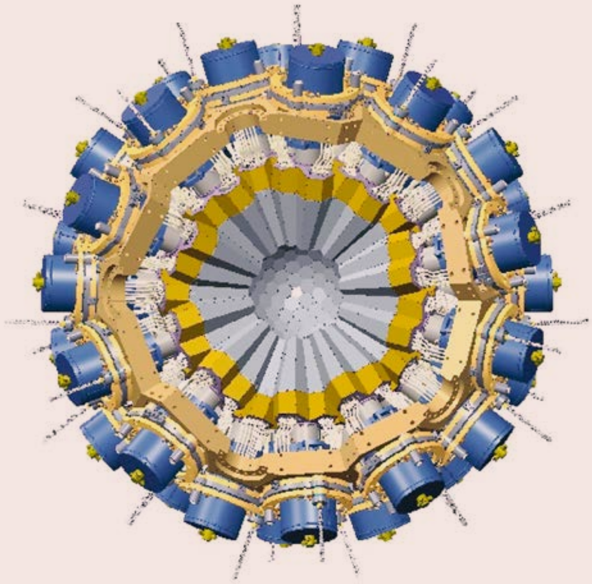
NUCLEAR PHYSICS

Advancing AGATA – Future Science with The Advanced Gamma Tracking Array

The Advanced Gamma Tracking Array is a multi-national European project realising a high-resolution gamma-ray spectrometer for nuclear physics.

As a travelling detector AGATA will be employed at the major European research facilities delivering stable and radioactive ion beams. It will have a large impact on nuclear structure studies at the extremes of isospin, mass, angular momentum, excitation energy and temperature. AGATA is capable of measuring γ rays from a few tens of keV to beyond 10 MeV, with high angular resolution and high count-rate capabilities. This review describes the exciting science program to be performed with AGATA enabling us to uncover and understand hitherto hidden secrets of the atomic nucleus. ■

▮ The AGATA Collaboration, W. Korten *et al.*,
Eur. Phys. J. A **56**,137 (2020)
https://doi.org/10.1140/epja/s10050-020-00132-w



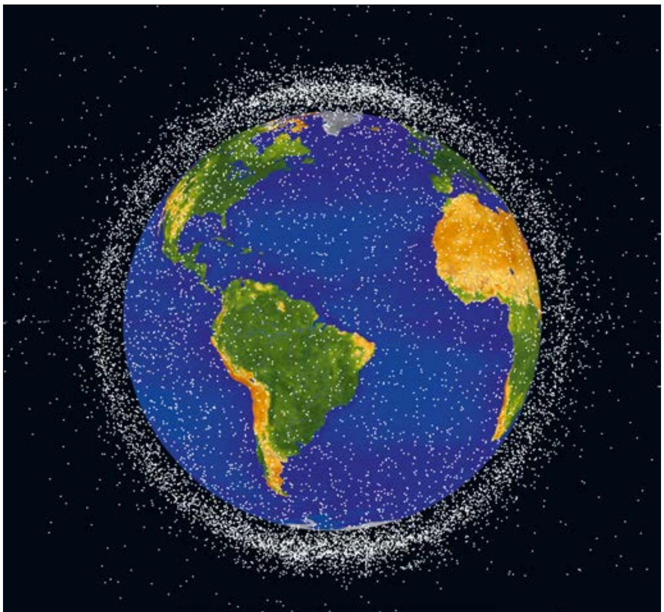
▲ View into the Advanced Gamma Tracking Array - AGATA for high-resolution gamma spectroscopy

SPACE SCIENCE

SPACE SCIENCE

Space exploration is moving into a new era, with the focus of science and research move from one-of achievements and firsts, to the establishment of frameworks that will encourage sustainability.

At the same time, the more we learn about space, the more we realise that plans must be put in place to mitigate threats from beyond our own atmosphere. In an EPJ-ST Special Topics issue on 'Celestial Mechanics in the XXIst Century' in particular studies related to the risk of collisions of space vehicles with space debris and strategies to avoid a collision of an asteroid with the Earth are presented.



Reducing the risk of space debris collision

A plausible method of clearing space debris could be achieving through the use of a tug vehicle that requires a successful connection procedure. ■

▮ A.D.C. de Jesus, **G.L.F. Santos**,
'Reducing the risk of space debris collisions using conditions or performance simultaneous operation in minimum time',
Eur. Phys. J. Spec. Top. **229**, 1419 (2020). DOI 10.1140/epjst/e2020-900194-x

Protecting Earth from asteroid impact with a tethered diversion

The use of a tether assisted system could prevent an asteroid impacting Earth without the risk of fragmentation. ■

▮ F. C. F. Venditti, **L. O. Marchi.** , **A. K. Misra**, **D. M. Sanchez**, **A. F. B. A. Prado**,
'Dynamics of tethered asteroid systems to support planetary defence', *Eur. Phys. J. Spec. Top.* **229**, 1463 (2020). DOI 10.1140/epjst/e2020-900183-y

Spacecrafts get a boost in 'Aerogravity Assisted' interactions

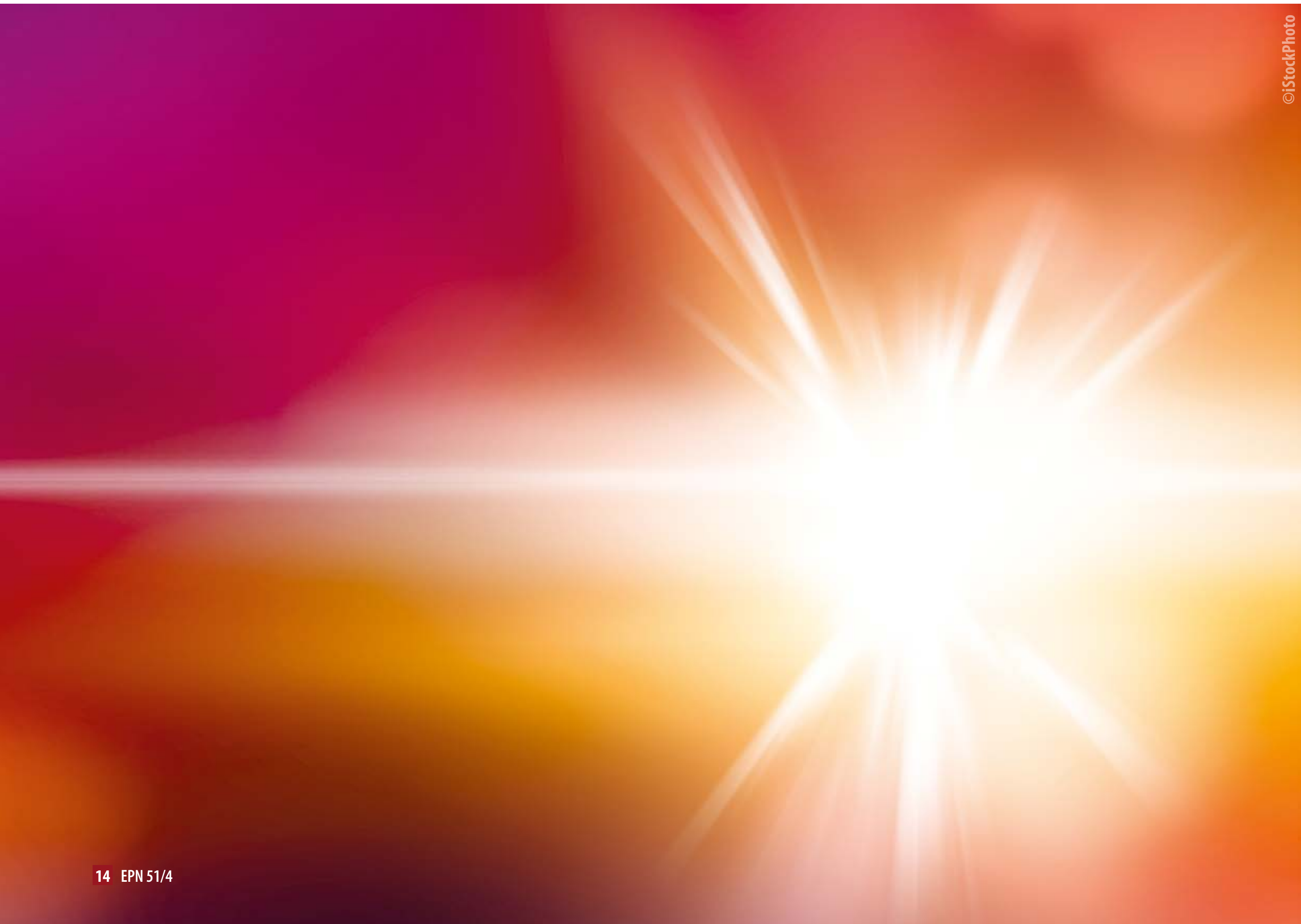
New research examines the effect of rotation and other variables in the applications of 'aerogravity assisted' manoeuvres to obtain an energy boost for space crafts. ■

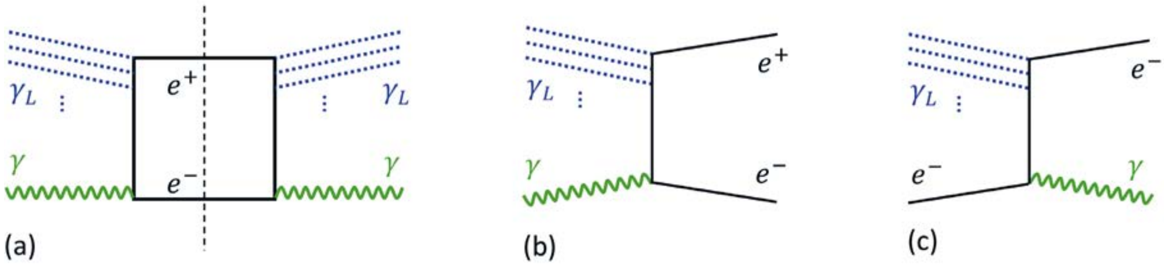
▮ J. O. M. Piñeros, **V. M. Gomes**, **W. A. dos Santos**, **J. Golebiewska**,
'Effects of the rotation of a spacecraft in an atmospheric close approach with the Earth', *Eur. Phys. J. Spec. Top.* **229**, 1517 (2020). DOI 10.1140/epjst/e2020-900144-9

LUXE:
COMBINING HIGH ENERGY AND INTENSITY TO SPARK THE VACUUM

Beate Heinemann[1], Tom Heinzl[2] and Andreas Ringwald[3] – https://doi.org/10.1051/epn/2020401
[1] DESY and Albert-Ludwigs-Universität Freiburg – [2] University of Plymouth, UK – [3] DESY

The vacuum of quantum electrodynamics (QED) can be viewed as a medium akin to a dielectric which can be polarised by external fields. If these are sufficiently strong, the response of the vacuum becomes nonlinear and involves phenomena such as light-by-light scattering ('nonlinear optics') and, *in extremis*, 'dielectric breakdown', *i.e.* real pair production, if a critical field strength is exceeded. The LUXE experiment aims to realise near-critical fields through collisions of photons stemming from an ultra-intense optical laser with high energy electrons or photons provided by the European XFEL linear accelerator. This set-up provides a golden opportunity to enter the uncharted territory of strong-field quantum electrodynamics in the non-perturbative regime.





◂ **FIG. 1:** Diagrams representing basic processes of strong-field QED. (a) Light-by-light scattering of laser photons (γ_L) and probe photons (γ). (b) Nonlinear Breit-Wheeler pair production. (c) Nonlinear Compton scattering.

The quantum vacuum and its breakdown

Faraday, Maxwell and Hertz have told us that the vacuum is filled with electromagnetic fields, but it took an Einstein to realise that this does not require a luminiferous aether: Fields and their wave excitations do not need a medium in which to propagate. Ironically, with the advent of quantum field theory, the idea of the vacuum as a medium was resurrected. It is the quantum fields themselves, through their virtual fluctuations, which lend the vacuum properties akin to a dielectric [1]. The basic phenomenon in this context is vacuum polarisation: Applying a weak external field (*e.g.* due to an electron), the vacuum dipoles formed by virtual electron positron pairs align and screen the electron charge. A probe particle 'diving' into the polarisation cloud surrounding the electron will thus 'see' the elementary charge, *e*, increasing with probe energy (charge renormalisation). As a result, 'perturbative QED', based on the coupling being small ($e^2/4\pi \ll 1$) becomes invalid at ultra-high energies.

Alternatively, one may ask what happens if one applies stronger and stronger external fields. The first issue to address is the notion of a 'strong' field in QED. As a relativistic quantum field theory, QED contains two fundamental constants of nature, Planck's constant, $\hbar$, and the speed of light, *c*. Combining these with the QED parameters, *e* and *m*, the electron mass, one can form the QED electric field strength, $E_S = m^2c^3/e\hbar = 1.3 \times 10^{18}$ V/m. This enormous field magnitude is typical for elementary processes in QED. The associated energy balance, $eE_S(\hbar/mc)=mc^2$, corresponds to an energy transfer of mc^2 (the electron rest energy) over the distance of a Compton wavelength, $\hbar/mc$. The challenge, though, is to realise the QED field strength E_S over macroscopic distances, say 1μm or larger. Sauter noted in 1931 that even in this *classical* field scenario the anti-particles of the electrons, the positrons, become relevant [2]. This was further elaborated by Schwinger (1951) who interpreted the appearance of the positrons as an instability of the QED vacuum which starts to 'spark' with electron positron pairs [3]. The vacuum thus becomes 'conducting' similarly to an insulator suffering dielectric breakdown.

Pictorially, the situation is described in Fig. 1(a) which displays a vacuum polarisation loop forming a virtual electron positron dipole. This dipole is exposed to the superimposed fields of laser and probe photons, γ_L and γ, respectively. This diagram describes the nonlinear interaction of light with light, a subtle quantum effect first analysed in [1]. Schwinger calculated its imaginary part, which physically amounts to pair production via the nonlinear Breit-Wheeler process, $\gamma + n\gamma_L \rightarrow e^+e^-$, see Fig. 1(b), and corresponds to the creation of matter from light.

The regime of electromagnetic field strengths reaching or even exceeding E_S is referred to as strong-field QED. It may be realised by approaching highly localised charge distributions, for instance at a distance of 30 fm from an electron. Alternatively, one may probe *bound* Coulomb systems by colliding heavy ions or by analysing the spectroscopy of heavy atoms, hence studying the physics at large atomic number *Z* [4]. High field strengths are also relevant for the early Universe and several astrophysical phenomena such as the gravitational collapse of Black Holes [5], the propagation of cosmic rays [6], or the surface of strongly magnetised neutron stars [7], and for future linear high energy e^+e^--colliders [8]. Unfortunately, most suggestions above suffer either from nuclear effects (at large Z) or experimental inaccessibility (astrophysics).

The LUXE experiment

To overcome these problems, the LUXE collaboration proposes [9] to approach the critical field, E_S, by exploiting recent advances in high-power laser technology and the 'magic' of Lorentz invariance. The increase in laser intensity due to chirped pulse amplification (Nobel prize 2018 [10]), allows production of optical-laser fields with a lab-measured strength just a few orders of magnitude below the Schwinger field. Employing relativistic electrons (E_e>5 GeV) a gamma factor $\gamma_e > 10^4$ is reached, so that even at lower laser intensities the electron sees the critical field in its rest frame.

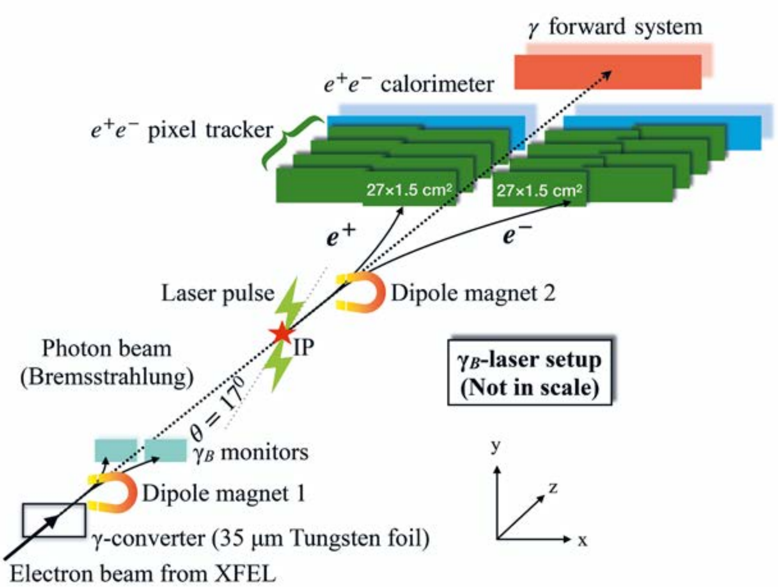
The basic experimental ideas are the following: one can send the electrons through a tungsten converter foil, in order to generate photons (γ) by bremsstrahlung and then collide these with the photons (γ_L) of the laser beam, $\gamma + n\gamma_L \rightarrow e^+e^-$, see Fig. 1 (b). Alternatively, one may collide the electrons directly with the laser beam, $e^- + n\gamma_L \rightarrow e^- + \gamma$, see Fig. 1 (c).

A previous experiment (SLAC E144) has employed 50 GeV electrons and a 1 TW laser to explore what is now called *two-step trident pair production*. This is a *succession* of the two nonlinear processes introduced above,

◂ Illustration of a collision of two photon beams using the photons produced in nonlinear Compton scattering by colliding them with the laser photons to produce pairs, recall Fig.1. The observed production rates were proportional to higher-than-linear powers of the laser intensity thus clearly detecting nonlinearity. The goal of LUXE is to enter far deeper into the strong-field region by using the much more powerful lasers available today, together with the high energy electrons from the European XFEL (EuXFEL) accelerator. This will enable probing the transition from the nonlinear to the *non-perturbative* regime, which may be characterised by a key parameter, the *dimensionless laser amplitude*, ξ. It is defined as the ratio of the work done by the laser field E_L when 'pushing' an electron across a reduced laser wavelength and the electron rest energy. When this is of order unity, an electron probing the laser becomes relativistic. There is more to this parameter, though: A process involving $n > 1$ laser photons (see again Fig. 1) contributes with a probability amplitude proportional to ξ^n. When ξ approaches unity, all these n-photon amplitudes become equally important, and one has to sum over all of them. As higher order effects thus cease to be 'small perturbations' of lower order ones, the overall process becomes *non-perturbative*. The SLAC E144 experiment had $\xi \sim 0.5$, still in the perturbative regime. For LUXE we expect $\xi > 2$, which takes us well into the uncharted non-perturbative regime.

The second key parameter is the *quantum parameter*, $\chi_e \equiv 2\gamma_e\, E_L / E_S\, (1+\cos\theta)$, where θ is the angle between the laser and particle beams. For LUXE, with $\gamma_e = 3\times10^4$ from the EuXFEL beam, the genuine quantum regime, $\chi_e > 1$, is reached for $\xi > 5$.

LUXE is also in the unique position to test the structure of the vacuum near the Schwinger limit via light-by-light scattering. High-energy probe photons, γ_B, created through bremsstrahlung will be brought into collision with the ultra-intense laser-beam. This will allow to study the nonlinear Breit-Wheeler process in isolation for the first time. The relevant parameter in this case is $\chi_\gamma = \xi \times \omega_L\, \omega_B\, (\hbar / mc^2)^2$, ω_L and ω_B denoting the photon frequencies. At low ξ and χ_γ, the rate follows the power-law ($\sim\xi^{2n}$) based on counting the number of photons contributing in perturbation theory. In contrast, when $\xi \gg 1$ and $\chi_\gamma \approx 1$, a non-perturbative QED calculation shows that the rate of e^+e^- production is proportional to $\chi_\gamma \exp(-8/3\chi_\gamma)$. Measuring this rate will be a direct experimental test of non-perturbative QED.



▼ **FIG. 2:** Sketch of the experimental setup for the γ_B–laser collisions. A dipole magnet and a set of detectors (pixel tracker, calorimeters) for the $e^\pm$ and γ detection are shown behind the IP. A γ_B–monitoring system after the tungsten foil is also shown.

Experimental setup

The EuXFEL is designed to run with energies up to E_e=17.5 GeV and trains of 2700 electron bunches, each typically containing 1.5×10^9 electrons that pass at a rate of 10 Hz. For the beam-laser interaction, one electron bunch per bunch train is extracted using a fast kicker magnet and guided to the interaction region hosted in a currently unused annex of the shaft at the end of the linear accelerator.

The laser envisaged has a power of 40 TW at an initial stage and about 400 TW in a later stage. Its light will be focused to achieve intensities of about 10^{20} W/cm² initially (and 10^{21} W/cm² later). An elaborate laser diagnostics system will be designed to measure the absolute laser intensity to better than 5%. The angle between the beam and the laser will be about 20°.

A schematic layout of the experiment is shown in Fig. 2 for the $\gamma_B + n\gamma_L$ interactions. For this layout, photons are produced through Bremsstrahlung of the beam electrons on a tungsten foil. For $e + n\gamma_L$ interactions (Fig. 1(c)), the layout is similar, except that there is no converter foil, and the particle detection systems are adapted accordingly.

Expected Scientific Results

Compared to previous, current or planned facilities [12], LUXE will achieve higher values of χ_e for the electron-laser collisions and will be the first to directly study photon-laser collisions. The calculated rate [13] of e^+e^- pairs per laser shot for the $\gamma_B + n\gamma_L$ process is expected to initially rise like a power-law, however, at $\xi \sim 2$, the rate increase slows down. The goal of LUXE is to measure these rates to better than 10%.

Conclusions

LUXE will shed new light on the vacuum and reveal new insights into our Universe. It presents a unique opportunity to pioneer a novel regime of quantum physics, the strong-field regime of QED, employing one of the premier European research infrastructures, the European XFEL. The goals are to observe for the first time directly the $\gamma\gamma \rightarrow e^+e^-$ process, and to perform the first studies of the transition from the perturbative to the strong-field (non-perturbative) regime. ■

About the Authors

Beate Heinemann is an experimental physicist. She is a leading scientist at DESY and a full professor at the Albert-Ludwigs-Universität Freiburg. Her research interest is the understanding of fundamental laws of Nature that governed the constituents of the Universe in its early phase before stars were formed. She has worked on several large particle physics experiments, most recently the ATLAS experiment at the Large Hadron Collider. She is also leading the LUXE experiment, proposed by Andreas Ringwald, at DESY and the European XFEL to study strong-field QED.

Tom Heinzl is an Associate Professor (Senior Lecturer) in Theoretical Physics at the University of Plymouth, UK. His research interests are strong interactions in various guises, with a current focus on quantum electrodynamics in the presence of ultra-intense laser fields. As a theorist, he is developing (mostly) analytic methods to understand the nonperturbative dynamics involved.

Andreas Ringwald is a theoretical particle physicist at DESY. He is working on a broad class of theoretical, phenomenological and cosmological questions. One focus of this work is on non-perturbative processes in the Standard Model of particle physics. More than a decade ago, he brought up the idea to collide the EU.XFEL beam with an intense laser beam to study non-perturbative pair production in QED.

References

[1] W. Heisenberg and H. Euler, *Z. Phys.* **98**, 714 (1936).

[2] F. Sauter, *Z. Phys.* **69**, 742 (1931).

[3] J. Schwinger, *Phys. Rev.* **82**, 664 (1951).

[4] I. Pomeranchuk and Y. Smorodinsky, *J. Phys. USSR* **9**, 97 (1945).

[5] R. Ruffini, G. Vereshchagin, and S.-S. Xue, *Phys. Rept.* **487**, 1 (2010).

[6] A. I. Nikishov, *Sov. Phys. JETP* **14**, 393 (1962).

[7] C. Kouveliotou *et al.*, *Nature* **393**, 235 (1998).

[8] M. Bell and J. S. Bell, *Part. Accel.* **24**, 1 (1988).

[9] H. Abramowicz *et al.*, arXiv:1909.00860 (2019).

[10] https://www.nobelprize.org/prizes/physics/2018/summary/

[12] C. N. Danson et al, *High Power Laser Science and Engineering* **7**, e54 (2019).

[13] A. Hartin, A. Ringwald and N. Tapia, *Phys. Rev. D* **99**, **no. 3**, 036008 (2019), arXiv:1807.10670.

LISTENING TO THE QUANTUM VACUUM: A PERSPECTIVE ON THE DYNAMICAL CASIMIR EFFECT

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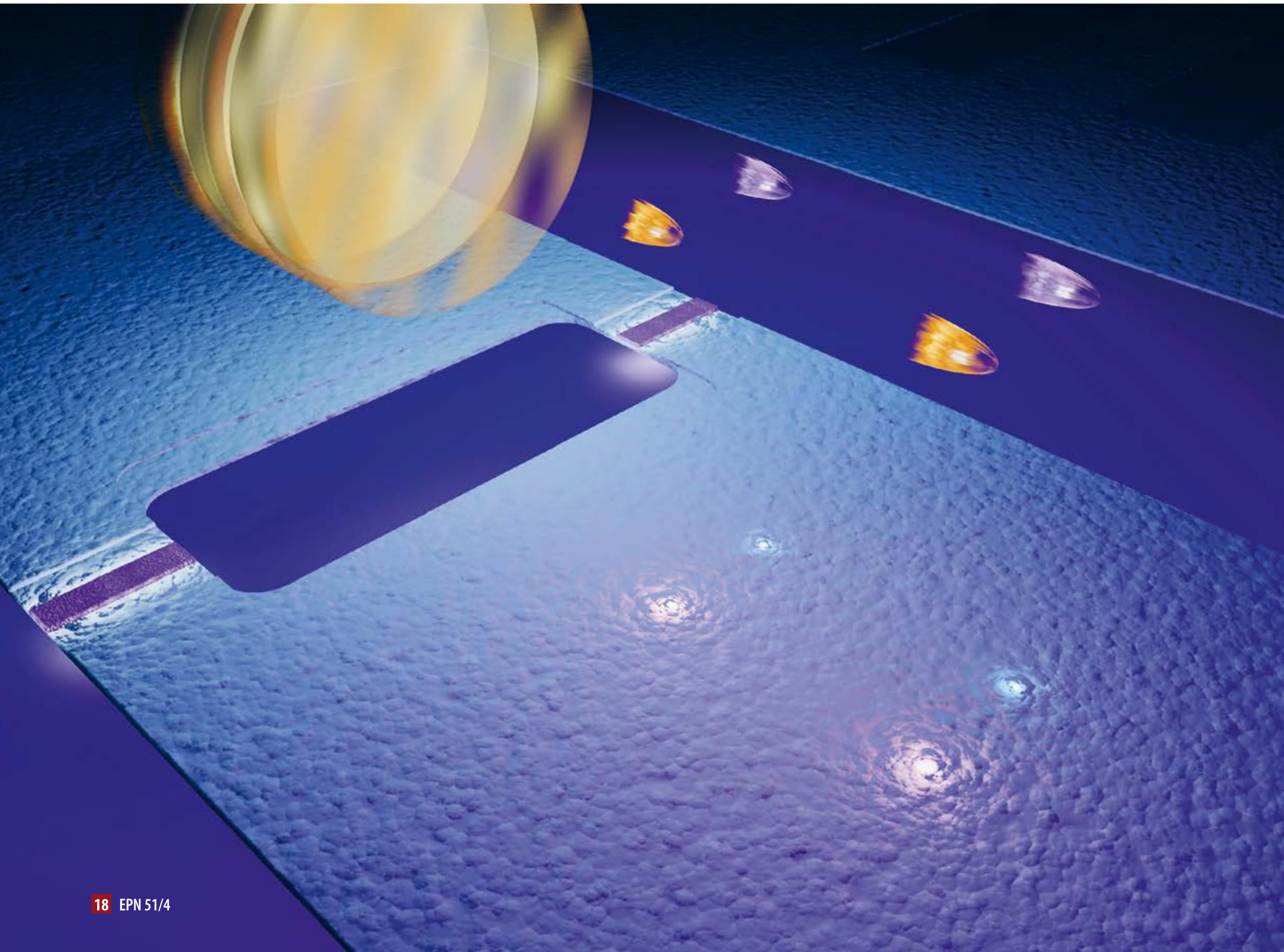
Modern quantum field theory has offered us a very intriguing picture of empty space. The vacuum state is no longer an inert, motionless state. We are instead dealing with an entity teeming with fluctuations that continuously produce virtual particles popping in and out of existence. The dynamical Casimir effect is a paradigmatic phenomenon, whereby these particles are converted into real particles (photons) by changing the boundary conditions of the field. It was predicted 50 years ago by Gerald T. Moore and it took more than 40 years until the first experimental verification..



This year, we celebrate 50 years since the publication of the seminal paper of Gerald T. Moore [1]. This work offered a first glimpse into a puzzling quantum-field phenomenon - predicting what happens as we change the boundary conditions of an empty electromagnetic cavity, *e.g.* by moving one of its mirrors. Classically, nothing should happen - we act, in some sense, on a non-existing object.

In quantum physics, there is a time-energy uncertainty relation $\Delta E \Delta t \geq \hbar/2$ suggesting that if we consider small time-intervals Δt, we also need to consider an uncertainty of the energy of at least $\Delta E \geq \hbar/2\Delta t$. Thus, even though the vacuum has zero energy, we need to take into account the possibility of a particle with energy $\Delta E/2$ spontaneously appearing, together with its own antiparticle, and then annihilating each other again within a time Δt. There is no way we can extract this so-called zero-point energy from the vacuum, so how can we verify this very nontrivial description of nothing?

In 1970, Moore told us that if we move a mirror fast enough, we can prevent the annihilation and the particles are forced into existence. This process is called the dynamical Casimir effect (DCE). The energy is taken from the motion of the mirror and the particles should typically be created in pairs. Could this effect be observed experimentally?

Radio signals from the vacuum

To figure this out, we need a quantitative description of this phenomenon. One interesting way to derive the result starts from a 1D gas of photons in thermal equilibrium at temperature T. Physically, this could be a single mode optical fiber or a microwave transmission line terminated by a black body at temperature T. This temperature determines the power associated with the creation of particles via the Stefan-Boltzmann law in one dimension,

$$P = \frac{\pi k_B^2 T^2}{12\hbar}.$$

But how can we connect temperature to motion? First, we should recall that the vacuum is Lorentz invariant, and so we do not expect any photon emission from a mirror moving uniformly in free space. However, for an accelerating mirror such a connection exists. In the mid-1970 Paul Davies [2] and Bill Unruh [3] showed that an observer moving through vacuum with a constant acceleration a experiences a field at thermal equilibrium with the temperature

$$T = \frac{\hbar}{2\pi k_B}\left(\frac{a}{c}\right),$$

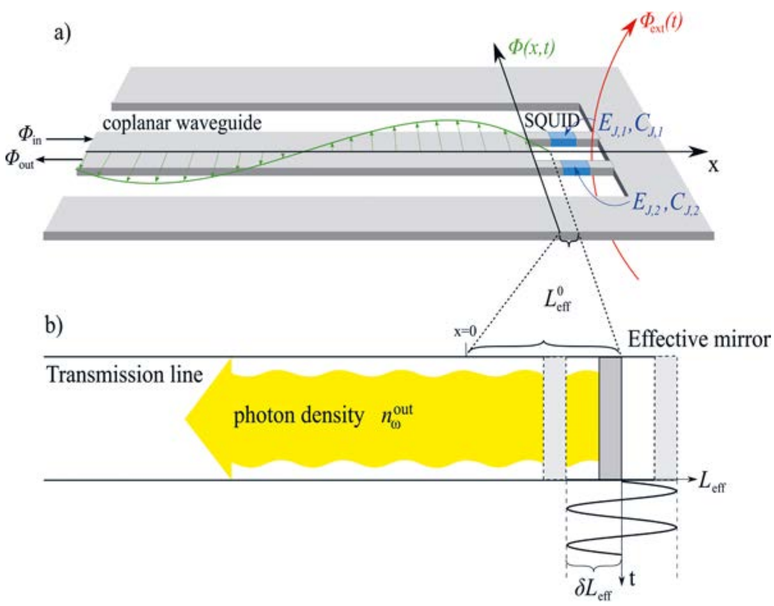
where *c* is the speed of light. To get a measurable temperature in a laboratory, we would need to accelerate objects. Some of the highest accelerations can be obtained in the lab by using a coilgun (Gauss rifle), producing $a \approx 10^9$ m/s^2 with mg-mass objects. We can attach a small mirror to the bullet and ... let it shine! Unfortunately, using the equations above, we get a dismal $T = 5 \times 10^{-12}$ K. The emitted power corresponds to a single quanta of frequency 0.5 Hz, emitted every minute. Needless to say, this is well below any realistic experimental detection sensitivity.

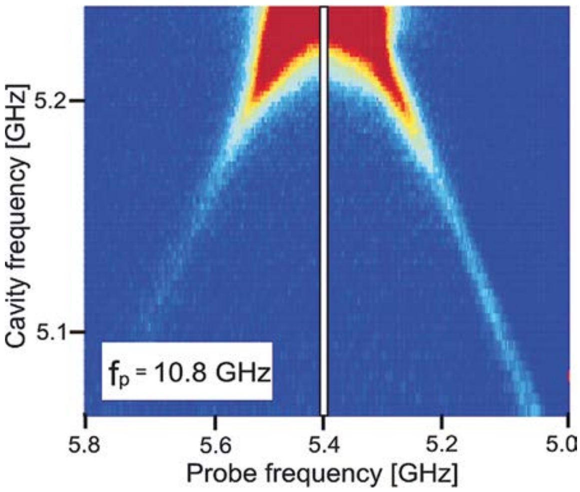
But there is another way. We note that what really matters is that the electromagnetic modes get squashed by the motion of the mirror. This we can achieve, for example if the mirror does not physically move, but instead quickly changes its index of refraction.

Consider a microwave transmission line terminated to ground through a single Superconducting Quantum Interference Device (SQUID) or an array of SQUIDs, see Fig. 1. The SQUID forms a tunable inductance, and by changing the magnetic flux threading it, it can be tuned from almost a short to a highly inductive state. This will change the standing wave pattern of the electromagnetic field in front of the mirror, from a voltage node at the mirror to an anti-node. This corresponds to moving the mirror a fraction of a wavelength, which is around a centimeter at microwave frequencies. The SQUID can be operated at 10 GHz, giving effective accelerations of around 10^{17} m/s^2, yielding a temperature of 12 mK and a power level of about -130 dBm, perfectly measurable with cryogenic microwave techniques. Just by this simple observation we get 9 more orders of magnitude compared to the coil gun, pushing the power and temperature into the experimentally observable region. Indeed, the existence of this radiation has been successfully confirmed by two experiments, one using a single SQUID [4] and the other an array of SQUIDs [5] in experiments performed at Chalmers University, Sweden and Aalto University, Finland.

In the introduction we mentioned that the particles are created in pairs together with their antiparticles and that

▾ **FIG. 1:** (a) An on-chip microwave transmission line (TL), terminated by a Superconducting Quantum Interference Device (SQUID), implementing a tunable inductance connecting the center conductor to the surrounding ground plane. (b) By modulating the magnetic field through the SQUID, the electromagnetic field in the TL sees a similar boundary condition as from a moving mirror. Adapted from Ref. [6].





▸ **FIG. 2:** Spectral power of the emitted photons recorded at various frequencies (horizontal axis). The vertical white line marks the position of half of the pump frequency. Generation of photons with an array of 250 SQUIDs, forming a cavity with relatively low quality factor of ~100. The vertical axis shows the cavity resonant frequency, which can be tuned by applying a magnetic field. The resulting sparrow-tail feature is a hallmark of the dynamical Casimir effect for this system. Adapted from Ref. [5].

the motion of the mirror prevents their annihilation. Also, we noted that the energy needed to create the particles is taken from the motion of the mirror. In both experiments mentioned above, the mirror was modulated harmonically with a pump frequency f_p in the GHz range. The dominant process creates a pair of DCE photons, whose energies add up to one pump photon. Hence the DCE spectrum should be symmetric around the pump frequency [6,7]. The exact shape of the spectrum depends on the density of states in the transmission line. In the Aalto experiment [5], there is a well-defined resonance resulting from the fact that the SQUID array forms a low-Q cavity, and the symmetry of the DCE spectrum is clearly visible in Fig. 2.

Further developments

The pair of photons created by the dynamical Casimir effect demonstrate quantum correlations called entanglement [8]. Entanglement has been observed in both situations - in the cavity case [5] and recently in the broadband case [9]. Entanglement is a resource for quantum information processing and the dynamical Casimir effect can be used to generate this resource [10]. The entangled microwave photons could also be used as a source for a quantum radar. Photons can be generated from vacuum by using not only one, but several pumps [11], aiming at using multimode correlations as a resource [12]. And there is more to it. Vacuum can be regarded as the working fluid in quantum engines - therefore it can serve as a tool to probe the principles of thermodynamics in the quantum regime. Analog gravitational phenomena - such as the emission of Hawking radiation - have also been proposed [13].

All these show that vacuum is not inert, but instead it bursts with activity [14] that can be harnessed for quantum information processing, as well as for foundational experiments in quantum thermodynamics and analog gravity. We are willing to bet that next time you take a flight and play with those light-dimming windows, you will try to estimate how many photons you have created. ■

About the authors

Gheorghe Sorin Paraoanu leads an experimental group focusing on superconducting circuits at Aalto University in Finland. His main research interests at present are quantum metrology and quantum simulation.

Göran Johansson is professor in Applied Quantum Physics at Chalmers University in Sweden, leading a theory group investigating microwave quantum optics and acoustics as well as quantum algorithms.

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GSP acknowledges the Academy of Finland (projects 312296,328193), EU project QUARTET (grant agreement no. 862644), and the Scientific Advisory Board for Defence of Finland.

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References

[1] G. T. Moore, *Journal of Mathematical Physics* **11**, 2679 (1970).

[2] P. C. W. Davies, *Journal of Physics A* **8**, 609 (1975).

[3] W.G. Unruh, *Physical Review D* **14**, 870 (1976).

[4] C. M. Wilson, G. J. Johansson, A. Pourkabirian, M. Simoen, J. R. Johansson, T. Duty, F. Nori, and P. Delsing, *Nature* **479**, 376 (2011).

[5] P. Lähteenmäki, G. S. Paraoanu, J. Hassel, and P. J. Hakonen, *Proceedings of the National Academy of Sciences* **110**, 4234 (2013).

[6] J. R. Johansson, G. Johansson, C. M. Wilson, and F. Nori, *Phys. Rev. Lett.* **103**, 147003 (2009).

[7] J. R. Johansson, G. Johansson, C. M. Wilson, and F. Nori, *Phys. Rev. A* **82**, 052509 (2010).

[8] J. R. Johansson, G. Johansson, C. M. Wilson, P. Delsing, F. Nori, *Phys. Rev. A* **87**, 043804 (2013).

[9] B. H. Schneider, A. Bengtsson, I. M. Svensson, T. Aref, G. Johansson, J. Bylander, and P. Delsing, *Phys. Rev. Lett.* **124**, 140503 (2020).

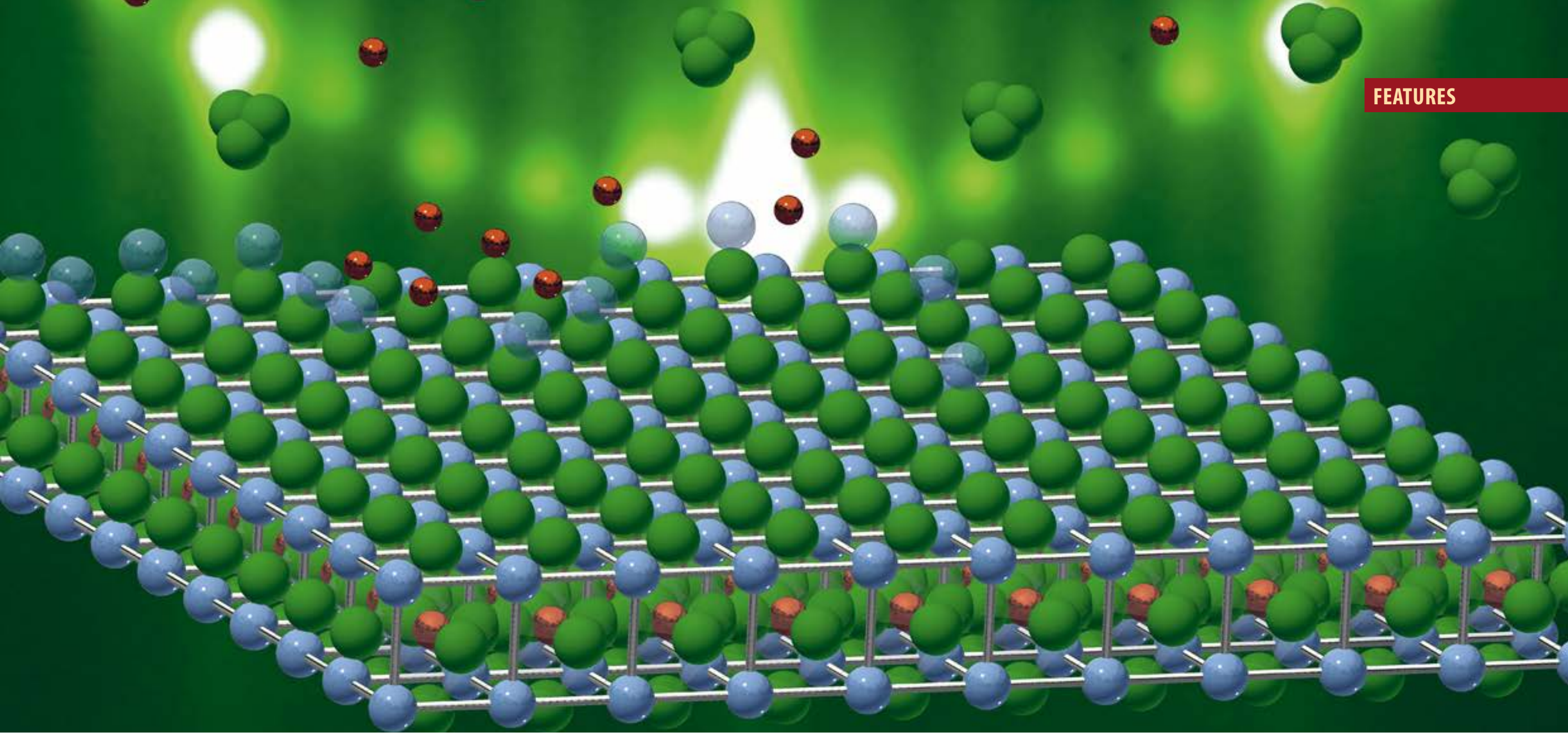
[10] S. Felicetti, M. Sanz, L. Lamata, G. Romero, G. Johansson, P. Delsing, and E. Solano, *Phys. Rev. Lett.* **113**, 093602 (2014).

[11] P. Lähteenmäki, G.S.Paraoanu, J.Hassel and P.J. Hakonen, *Nature Communications* **7**, 12548 (2016).

[12] D. E. Bruschi, C. Sabín, and G. S. Paraoanu, *Phys. Rev. A* **95**, 062324 (2017).

[13] P. D. Nation, J. R. Johansson, M. P. Blencowe, and F. Nori, *Rev. Mod. Phys.* **84**, 1 (2012).

[14] G. Paraoanu, Boston Stud. Philos. Sci. (I. Parvu, G. Sandu, and I. D. Toader, *eds.)* **313**, 181 (2015).



PRECISE CONTROL OF ATOMS WITH MBE: FROM SEMICONDUCTORS TO COMPLEX OXIDES

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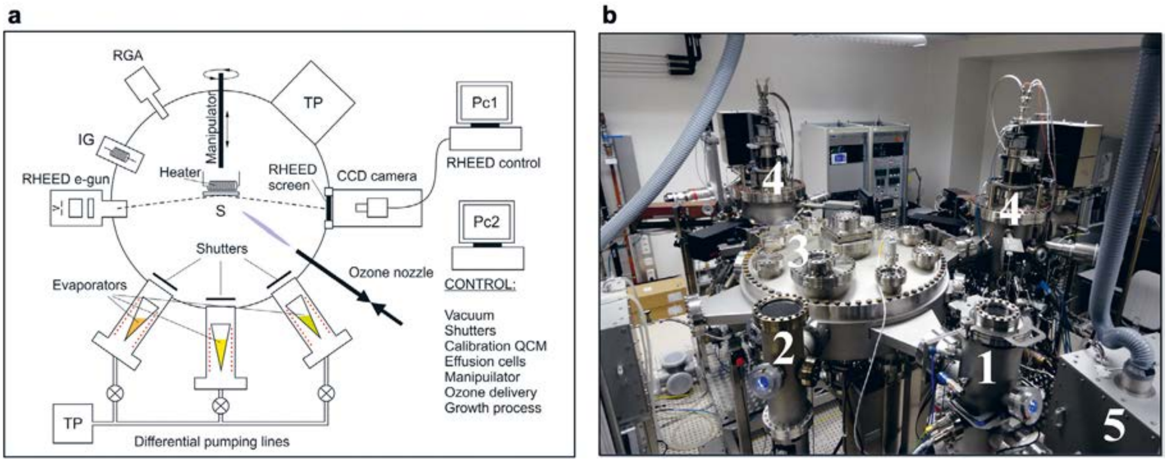
Molecular Beam Epitaxy (MBE) is a high-vacuum technique with atomic-layer control and precision. It is based on the chemical reaction of the atoms, molecules, or atomic clusters vaporized from the specific evaporation sources on the substrates. The _molecular beam_ defines a unidirectional ballistic flow of atoms and/or molecules without any collisions amongst. In the late 1960s, MBE was initially developed for the growth of GaAs and (Al, Ga)As systems[1,2] due to the unprecedented capabilities and then was applied to study other material systems. MBE growth is conventionally performed in vacuum and ultra-high vacuum (UHV) (10^{-8}–10^{-12} mbar) conditions.

Nevertheless, additional gases can be assisted in the growth chamber and this MBE is known as *reactive* MBE and is mainly used for nitrides or oxides [3,4]. Reactive oxide MBE benefits the advantages of both UHV MBE and highly oxidation conditions, while it requires precise gas load control and suitable pumping. Due to the essential requirement of preserving the ballistic path of evaporated atoms, the upper pressure is limited by ~10^{-4} mbar This background pressure determines the choice of the oxidizing gas, for instance, pure ozone injection, which is exceptionally reactive but provides the variety. Similar variety and atomic-layer (AL) precise synthesis can be obtained also with atomic layer deposition (ALD) based on the sequential absorption and desorption of the precursors from the surface[5].

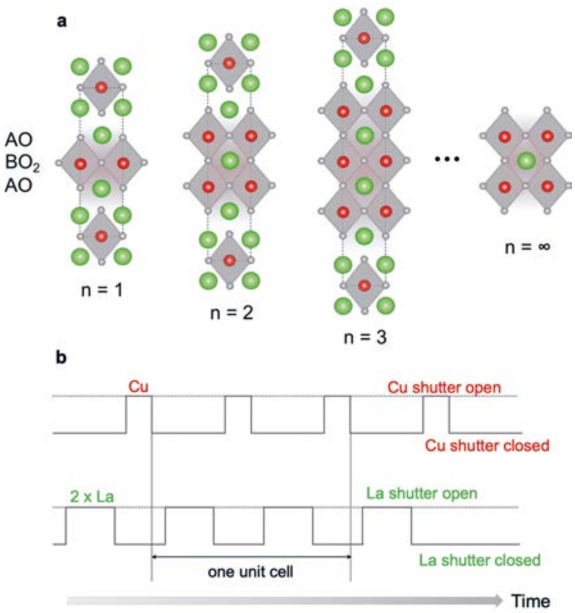


▸ **FIG 1:** (a) Sketch of an ozone-assisted MBE growth chamber. The abbreviations stand for TP–turbo-molecular pump, S–oxide crystal substrate, RGA–residual gas analyzer, Pc1– computer for controlling the RHEED system, Pc2– computer that controls growth itself. (b) Photo of dual chamber MBE (DCA Instruments Oy) in Max Planck Institute for Solid State Research [8] (1) load lock, (2) storage chamber, (3) central distribution chamber, (4) two growth chambers, and (5) the ozone delivery system.

MBE delivers (i) **great versatility and flexibility in the target compound selection:** An MBE system can be equipped with evaporation sources that could be reloaded with different elements offering variety in synthesizing new compounds; (ii) **reliable growth control:** MBE systems are equipped with reflection high energy diffraction (RHEED) tools using surface-diffracted electrons to monitor the surface quality in real-time. Together with additional in-situ tools such as low energy electron diffraction (LEED) or angular resolved photoelectron spectroscopy (ARPES) RHEED allows the precise deposition control with low deposition rates (typically one monolayer/min); (iii) **atomic layer by atomic layer (AL-by-AL) deposition.** The selective AL deposition (with one AL at a time) and the precise control of the concentration of the impurities paves the way for designing functional heterostructures to engineer novel metastable compounds; (iv) **the lowest energy of impinging atoms:** Different than other physical deposition methods MBE has the lowest energy of impinging atoms (<0.1eV) providing the lowest undesirable cation intermixing at the interfaces. These superiorities allow versatile heterostructural design with a controlled thickness down to a single sheet of atoms resulting in abrupt heterointerfaces[6]. These heterostructures are the building blocks of different kinds of diodes, transistors, including solar cells as well as microprocessors and memory devices. While scaling down the electronics has been the roadmap for semiconductor technology during last more than 50 years[2], the progress in the MBE was stimulated after the discovery of high-temperature superconductivity (HTSC) in 1986 in La-Ba-Cu-O compound[7], which spiked up the interest to complex oxides family.

Complex oxide materials have ionic crystal structures containing a transition metal (TM) ion centering the unit cell. The layered crystal structure of TM oxide compounds are generally represented by Ruddlesden-Popper (RP) phases with $A_{n+1}B_nO_{3n+1}$ formula, where A represents alkali, alkaline earth, or rare earth metal, B is the TM, and n - integer number. These RP phases consist of two-dimensional perovskite-like slabs (Figure 2a) that can be precisely designed by MBE[6]. The AL-by-AL method is best suited for the fabrication layered oxides, where the precise counting of the constituent atoms is realized via *shuttering*. Shuttering times are individually determined according to the flux emanating from each elemental source. For instance, in the case of synthesis of La_2CuO_4, which has RP crystal structure with n = 1 (represented in Figure 2a: A=La and B=Cu) the sequence of operation of La and Cu shutters are represented in Figure 2b. The time between the shutter open and close is computer controlled and the whole process is monitored by *in-situ* RHEED with real-time feedback.

The adaptable perovskite structure of TM oxides offers constructing them in different forms, such as ultrathin films or heterostructures[9], but also leads to diverse physical properties ranging from HTSC[10–12] to thermoelectricity[13]. In other words, engineering of epitaxial oxides grants unlimited combinations of multilayers delivering a fundamental playground for device fabrication and possible applications. A multilayer, *e.g.* a superlattice, composed of the same material with same crystal structure (even with modulation doping)



▸ **FIG 2:** (a) Sketch of crystal structures of Ruddlesden-Popper (RP) $A_{n+1}B_nO_{3n+1}$ phases with different n (n=∞ corresponds to cubic perovskite crystal structure). (b) Sequence of the operation of La and Cu shutters during single AL-by-AL growth of La_2CuO_4 (RP with n=1) epitaxial film.

is an example of *homo-epitaxial* growth, while a multilayer built by stacking of materials with different chemical formula and crystal structure, this is an example of *hetero-epitaxial growth*.

The strong electron correlations at the designed hetero-interfaces emerge novel interfacial properties when different materials are attached adjacently. Thus, interface engineering is an intriguing yet challenging task and the atomically precise design of complex oxide heterostructures requires atomic-resolution identification of individual layers and interfaces (Figure 3). The prominent role is played by aberration-corrected scanning transition electron microscopy (STEM) with high-resolution imaging and spectroscopy capabilities[14,15]. STEM high-angle annular dark field (HAADF) images of three different La_2CuO_4-based heterostructures are presented in Figure 3a-c[6] displaying the ideally arranged crystal structure without any extended defects.

In conclusion, besides of high-quality semiconductor fabrication MBE can also be effectively used for synthesis of difficult compounds, *e.g.* complex oxides with a crystal quality analogous to the semiconductor multilayers while the interfaces even more abrupt. Complex oxides have been widely studied recently and even though it requires time to put the new substances to practical use, a substantial progress has been already established. ■

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References

[1] A. Y. Cho, *Journal of Applied Physics* **41**, 2780 (1970).

[2] M. A. Herman, H. Sitter, Molecular Beam Epitaxy: Fundamentals and Current Status, Springer-Verlag, Berlin Heidelberg (1989).

[3] S. Yoshida, S. Misawa, Y. Fujii, S. Takada, H. Hayakawa, S. Gonda, A. Itoh, *Journal of Vacuum Science and Technology* **16**, 990 (1979).

[4] D. G. Schlom, L.-Q. Chen, X. Pan, A. Schmehl, M. A. Zurbuchen, *Journal of the American Ceramic Society* **91**, 2429 (2008).

[5] S. M. George, *Chem. Rev.* 2010, 110, 111.

[6] Y. E. Suyolcu, G. Christiani, P. A. van Aken, G. Logvenov, *J Supercond Nov Magn* **33**, 107 (2020).

[7] J. G. Bednorz, K. A. Müller, *Z. Physik B - Condensed Matter* **64**, 189 (1986).

[8] F. Baiutti, F. Wrobel, G. Christiani, G. Logvenov, *in Metal Oxide-Based Thin Film Structures* (Eds.: N. Pryds, V. Esposito), Elsevier, 53 (2018).

[9] R. Ramesh, D. G. Schlom, *Nature Reviews Materials*, 1 (2019).

[10] A. Gozar, G. Logvenov, L. F. Kourkoutis, A. T. Bollinger, L. A. Giannuzzi, D. A. Muller, I. Bozovic, *Nature* 2008, 455, 782.

[11] Y. E. Suyolcu, Y. Wang, F. Baiutti, A. Al-Temimy, G. Gregori, G. Cristiani, W. Sigle, J. Maier, P. A. van Aken, G. Logvenov, *Scientific Reports* **7**, 453 (2017).

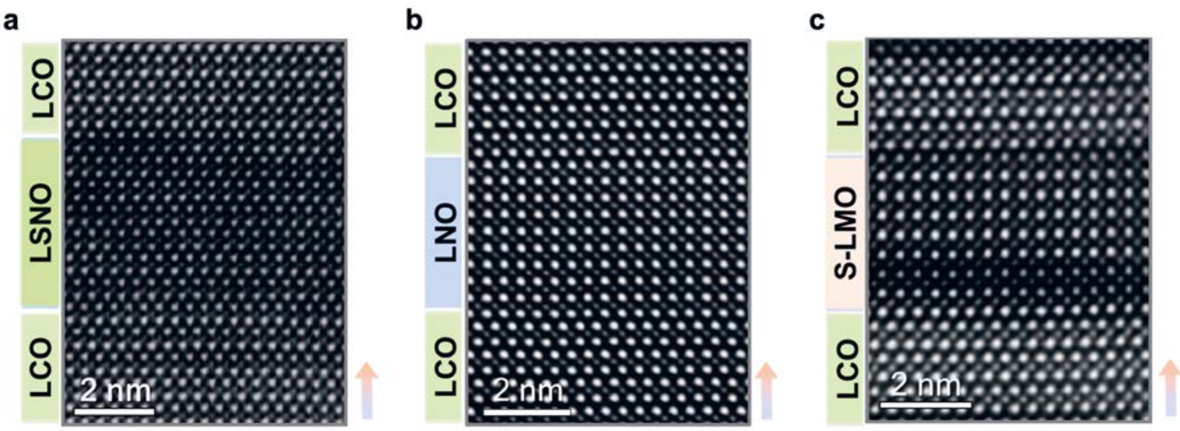
[12] F. Baiutti, G. Gregori, Y. E. Suyolcu, Y. Wang, G. Cristiani, W. Sigle, P. A. van Aken, G. Logvenov, J. Maier, *Nanoscale* **10**, 8712 (2018).

[13] P. Kaya, G. Gregori, F. Baiutti, P. Yordanov, Y. E. Suyolcu, G. Cristiani, F. Wrobel, E. Benckiser, B. Keimer, P. A. van Aken, H.-U. Habermeier, G. Logvenov, J. Maier, *ACS Appl. Mater. Interfaces* **10**, 22786 (2018).

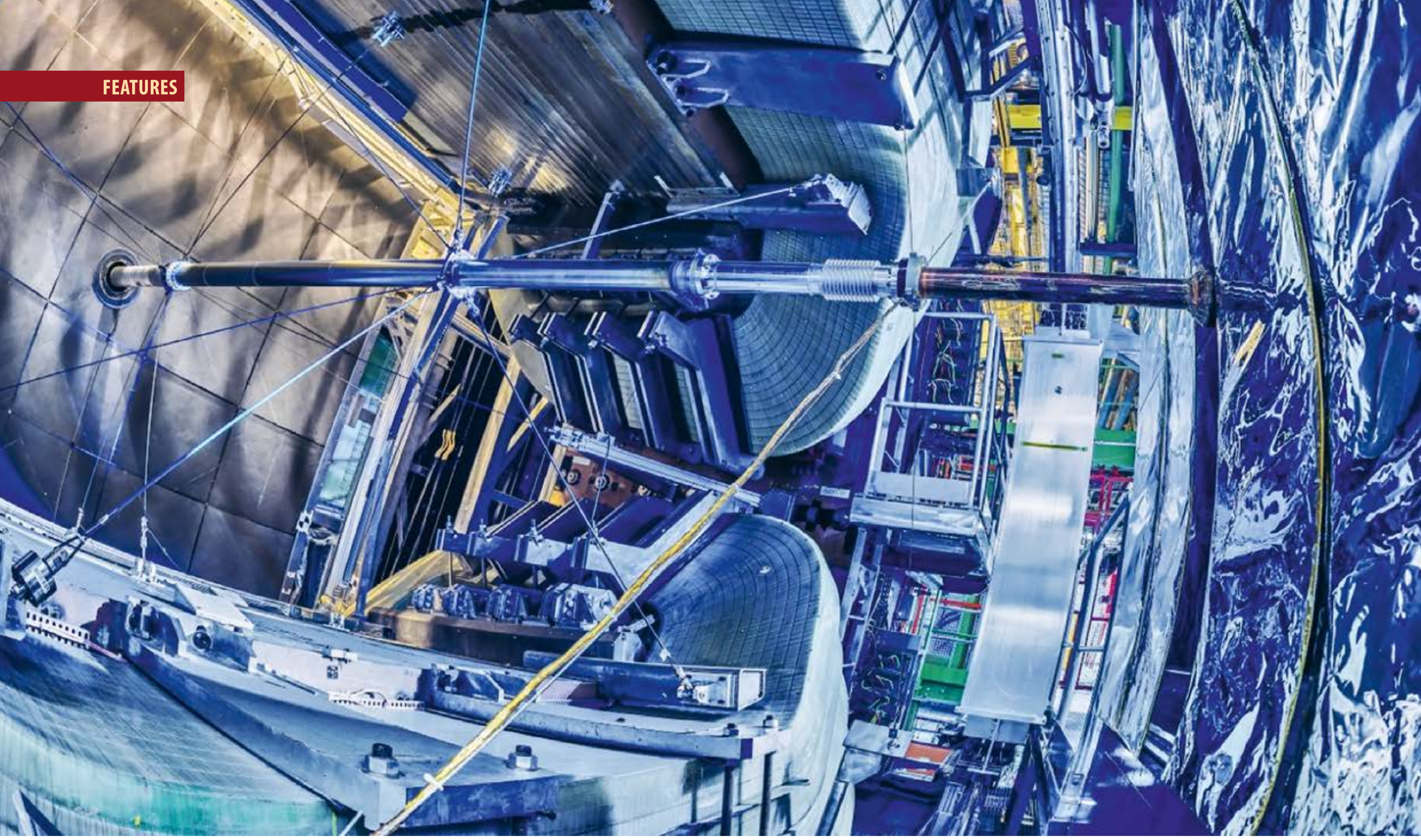
[14] Y. E. Suyolcu, Y. Wang, W. Sigle, F. Baiutti, G. Cristiani, G. Logvenov, J. Maier, P. A. van Aken, *Adv. Mater. Interfaces* **4**, 1700737 (2017).

[15] Y. E. Suyolcu, Y. Wang, F. Baiutti, W. Sigle, G. Cristiani, G. Gregori, G. Logvenov, J. Maier, P. A. van Aken, *JEOL News* **53**, 8 (2018).

[16] G. Kim, Y. Khaydukov, M. Bluschke, Y. E. Suyolcu, G. Christiani, K. Son, C. Dietl, T. Keller, E. Weschke, P. A. van Aken, G. Logvenov, B. Keimer, *Phys. Rev. Materials* **3**, 084420 (2019).



◂ **FIG 3:** Example STEM-HAADF images showing the structural coherency between the layers of (a) LCO-LSNO-LCO [12], (b) LCO-LNO-LGO [13], (c) LCO-SMO/LMO-LCO [16] grown on (001) LSAO crystal substrates [6]. The abbreviations stand for LCO – La_2CuO_4, LSNO – $La_{2-x}Sr_xNiO_4$, SMO – $SrMnO_3$ and LMO – $LaMnO_3$ [6].



VACUUM SCIENCE AND TECHNOLOGY AT CERN

José Miguel Jiménez and Paolo Chiggiato, CERN, Geneva, Switzerland – https://doi.org/10.1051/epn/2020404

Vacuum is essential in particle accelerators. Low gas density allows charged particles beams to circulate without excessive losses. Indeed, beam losses are detrimental for instrumentation; they increase induced radioactivity, background noise in particle detectors, and beam-induced heat loads to cryogenic equipment.

▲ View of the central beam pipe of the LHCb, one of the four gigantic LHC's experiments.

Moreover, the interaction of beams with gas provokes beam instability and beam-size growth leading to a reduced probability of collisions in detectors. Finally, vacuum is necessary to avoid electrical breakdown in high-voltage devices and serves as an excellent commonly used thermal insulator in cryogenics. CERN has one of the world largest vacuum systems in operation [1]. Along 127 km of vacuum vessels, the pressure requirements cover a large range, from 10^{-6} mbar in the first stage of linear accelerators down to 10^{-15} mbar in the antimatter experiments. The Large Hadron Collider (LHC) is the best example of CERN's prowess in vacuum technology [2]. Building its vacuum system required more than 250,000 welded joints and 18,000 vacuum seals, thousands of pumps, valves, pressure gauges, PLC and controllers that need continuous monitoring with highest standards of reliability.

The beams as the main cause of gas release

Materials in vacuum release gas spontaneously. In particle accelerators, the beams stimulate additional desorption that can be the dominant gas source. Beam-stimulated desorption occurs directly due to beam losses or indirectly by emitting synchrotron light and accelerating electrons and ions created by residual-gas ionization. Bombardment of surfaces by such particles results in gas desorption. In the LHC, 7-TeV proton beams emit synchrotron radiation with a critical energy around 40 eV, largely enough to extract photoelectrons and induce desorption. All these phenomena contribute to the degradation of the static vacuum, generating the so-called dynamic vacuum. For cost reasons, accelerator vacuum systems are never designed to cope with full beam performance on day one but rely on performance ramping-up scenarios. The impingement of photons, electrons and ions cleans the surface and provokes surface modifications that cause the reduction of desorption yields. As an example, a dose of 10^{-2} C.mm^{-2} of 300-eV electrons reduces the desorption yield of H_2 by roughly one orders of magnitude. Accelerators affected by stimulated desorption are initially run at progressively increasing beam current so that the dose of impinging particles increases without unduly rising beam losses. In the jargon, we call this process 'scrubbing run' leading to 'surface conditioning'. Typical surface transformations are reduction of hydroxides and graphitization of hydrocarbon contamination [3]. Such transformations have also a beneficial effect on the secondary electron yield of the exposed surfaces and, consequently, mitigate electron multipacting phenomena!

Distributed pumping

Spontaneous and beam-induced gas release are distributed along the ring of the accelerators, while vacuum pumps are installed in precise positions and act locally. The difference in the distribution of gas source and pumping action generates parabolic pressure profiles with a maximum in between two consecutive pumps. The pressure bump is amplified when the beam-pipe conductance is small, *i.e.* for small diameters and long length. Such an issue has been removed with the development of distributed pumping. An innovative solution based on non-evaporable getter (NEG) film coatings was developed in the late nineties at CERN [4]. The vacuum chamber is coated with a µm-thick Ti-Zr-V thin film. The film is activated in the accelerator by heating the chamber to temperatures of at least 180° for 24 h. The activation process dissolves the native oxide layer into the bulk of the film. When back at room temperature, the surface is very clean and pumps most of the residual gas species. Activated NEG coatings provide also lower stimulated desorption and secondary electron yields, therefore significantly reducing the conditioning time and electron multipacting. About 1400 vacuum chambers, around 6 km of beam pipes, were NEG coated for the LHC and are since 2008 operating with beams [5]. Those located in the centre of the four gigantic LHC's experiments, made of beryllium, are the most demanding in terms of vacuum performance and mechanical properties. The implementation of NEG thin-film coatings has allowed innovative design for the new generation of synchrotron light sources. Thanks to such materials, it is possible to pump inside long vacuum chambers having a few-mm diameter. Conductance limitation is no longer a showstopper! This solution is considered for new low-emittance synchrotron radiation sources. Among them, MAX IV (Lund, SE) is the archetype [6].

Beam screen, heat load and carbon thin film

NEG coating can be applied only in bakeable sections of accelerators operating at room temperature. In the case of the LHC, about 40 km of beam pipes are inserted in superconducting magnets operating at 1.9 K with superfluid helium. During operation, gas pumping relies only on adsorption on the cold surfaces. The cryogenic temperature compromises the 'surface conditioning' as the desorbed gasses are immediately re-adsorbed on the nearby surfaces. The problem is circumvented separating the surface where photons and electrons strike from the one where the most critical gas, *i.e.* hydrogen, is condensed. This is obtained by inserting in the cold bore of the magnets, which is at 1.9 K, an additional pipe, called beam screen (Fig. 2), kept at a slightly higher temperature between 10 and 20 K. Gas molecules can reach the coldest surface through mm-wide pumping slots where they are screened from beam-induce effects. Among several other functions, the beam screen has also the role of intercepting at higher temperatures than 1.9 K the heat load transferred from the beam to the cryogenic system, therefore reducing the electric energy consumption of the cryogenic system.

Since 2014, the LHC cryogenic plants have experienced an unexpected high thermal load in the beam-screen circuits. The excessive heat is not uniformly distributed along the ring; only four octants are affected. Today, there is enough evidence that the issue is due to secondary electrons accelerated by the proton beams and multiplied by the beam-screen surfaces, the so-called electron cloud phenomenon. CERN has developed a solution that has a mitigation effect on electron multipacting [7]. Since

▾ **FIG. 1:** The beam screen prototype for the Q2 quadrupole magnets of the final focusing system for High-Luminosity LHC.

2008, sputtered graphitic-like amorphous carbon coatings have been studied and recently retrofitted in the accelerator beam pipes [8]. Fifty nanometres of this material are enough to decrease the maximum secondary electron emission yield below one and, consequently, cancel the electron multipacting. A similar reduction of the secondary electron emission can be achieved increasing the surface roughness by laser. Emitted secondary electrons are intercepted by the corrugated surface preventing them from being accelerated by the proton beams. This process was proposed by two British institutes [9] and it is under development for implementation in accelerators at CERN.

Future challenges

The present trend shows that surface modification and monitoring are key challenges for improving vacuum systems of high energy and intensity particle accelerators. In the future, four additional breakthroughs need to be addressed.

Cost containment. With the increasing size large scientific instruments such as the gravitational waves detectors or future colliders, there is strong demand for cost-optimised solutions that challenge present materials, surface treatments, pumps and operation procedures.

Miniaturisation, primarily for electron accelerators. The search for ultimate emittance (*i.e.* smaller transverse beam sizes) requires magnets with very small apertures, putting the beam-pipe walls as close as technically possible to the beams. Development of vacuum technology at the mm-size diameter requires inventiveness for alternative manufacturing processes, pumping and pressure measurement.

To cope with high energy and intensity beams. Both high energy and high intensity may become a show-stopper in accelerators like the High-Luminosity LHC, which will run in 2027, and the Future Circular Collider (FCC-hh), which is at the study level. The higher induced radioactivity, in particular nearby the experimental areas, would require that vacuum systems become compatible with robotic interventions. Preliminary works have been launched to design systems that can be installed, dismounted, and leak tested remotely. Innovative joints based on shape memory alloys [10] have been recently developed for a complete remote handling of junctions between vacuum chambers.

Finally, the quest for "absolute" vacuum. Experimental physics requires unprecedented low residual gas densities to address new types of experiments. Recently, the request for gas density of the order of one H_2 molecule per cm^3 has been formulated by the PUMA experiment, which aims to interact radioactive ions with stored antiprotons [11]. Gas density simulations, choice of materials, mechanical vibrations, transport constraints, and pressure measurement must be analysed in detail and all together to validate the feasibility of such experiments.

Undoubtedly, and through decades, the use of vacuum in large-scale scientific instruments has generated an impressive progress in Vacuum Science and Technology. The recently approved European Strategy for Particle Physics opens the path for new developments to respond to the needs of high energy and nuclear particle physics, and potential technology spin-off that may serve astrophysics and gravitational wave experiments. ■

About the authors

José Miguel Jiménez and **Paolo Chiggiato** are CERN's Technology department head and Vacuum Surfaces and Coating group leader, respectively. They have an extensive experience in vacuum technology with focus on accelerators' operation and surface modifications. They gave an important contribution to the understanding of surface related phenomena in particle accelerators, *e.g.* beam-induced dynamic effects such as electron cloud and chemical pumping. Both contributed to the design, installation, commissioning and operation of the Large Hadron Collider (LHC) vacuum systems, and are actively involved in technology transfer programmes and international collaborations.

References

[1] J. M. Jiménez, *Vacuum* **84**, 2 (2009).

[2] P. Chiggiato, "CERN's prowess in nothingness," CERN COURIER, 1 June 2018. https://cerncourier.com/a/cerns-prowess-in-nothingness/

[3] R. Cimino, M. Commisso, D. R. Grosso, T. Demma, V. Baglin, R. Flammini and R. Larciprete, *Phys. Rev. Lett.* **109**, 064801 (2012).

[4] C. Benvenuti, P. Chiggiato, P. Costa Pinto, A. Escudeiro Santana, T. Hedley, A. Mongelluzzo, V. Ruzinov and I. Wevers, *Vacuum* **60 1-2**, 57 (2001).

[5] P. Chiggiato and P. Costa Pinto, *Thin Solid Films* **515**, 382 (2006).

[6] CERN Bulletin, 25 June 2016, "Vacuum chambers full of ideas for the Swedish synchrotron" https://home.cern/news/news/engineering/vacuum-chambers-full-ideas-swedish-synchrotron

[7] CERN Bulletin, 29 February 2016, "A new type of coating to chase the clouds away", https://cds.cern.ch/journal/CERNBulletin/2016/09/News%20Articles/2133913?ln=en

[8] CERN Bulletin, 1 October 2019, "LS2 Report: Dissipating the electron clouds", https://home.cern/news/news/accelerators/ls2-report-dissipating-electron-clouds

[9] R. Valizadeh, O. B. Malyshev, S. Wang, S. A. Zolotocskaya, W. A. Gillespie and A. Abdolvand, *Appl. Phys. Lett.* **105**, 231605 (2014).

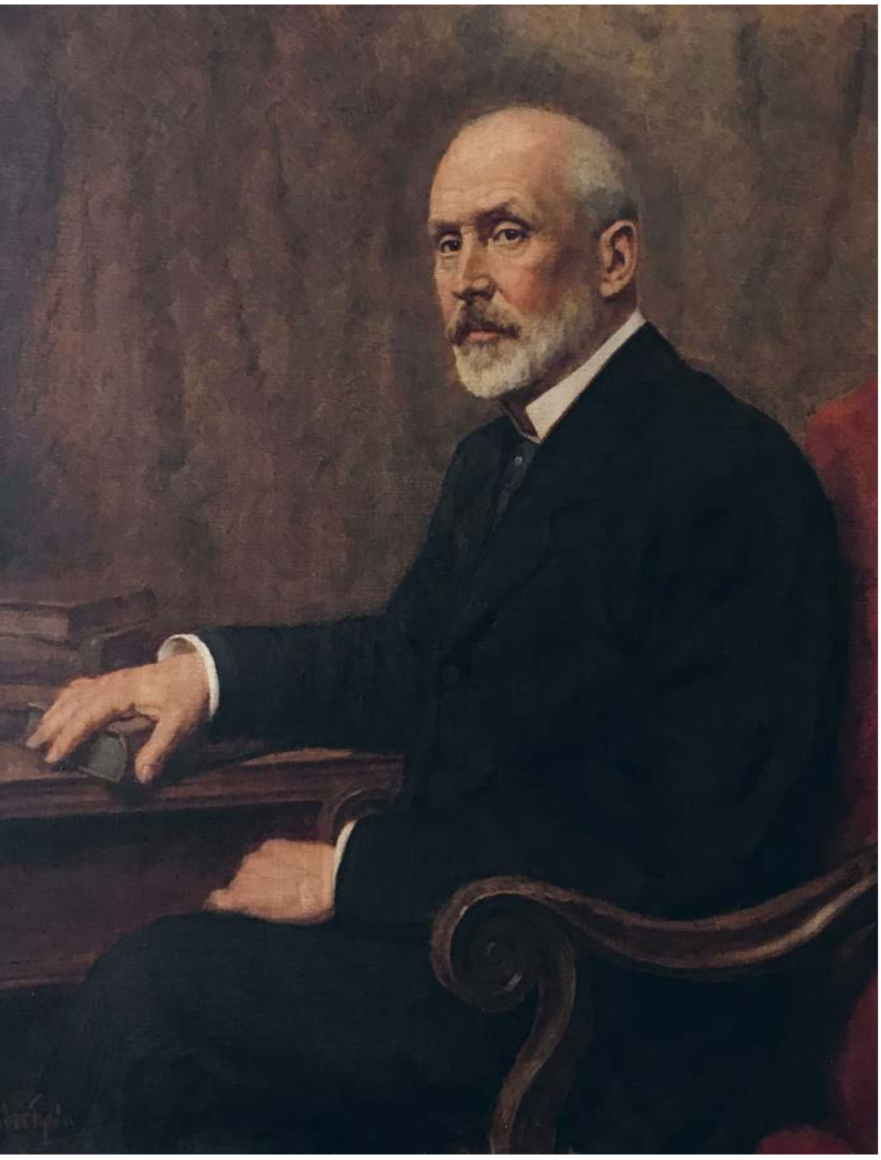
[10] CERN Bulletin, 11 April 2016, "Shape memory" material provides a solution for the HL-LHC", http://cds.cern.ch/journal/CERNBulletin/2016/16/News%20Articles/2144535?ln=en

[11] A. Obertelli, "Experiment Proposal for PUMA: antiprotons and radioactive nuclei", 2019, http://cds.cern.ch/record/2691045/files/SPSC-P-361.pdf

A TRIBUTE TO LORÁND EÖTVÖS

Henk Kubbinga – University of Groningen (The Netherlands) – DOI: https://doi.org/10.1051/epn/2020405

The last decades of the 19th century Hungary came to flourish as an independent part of the Austrian-Hungarian Monarchy; 1867 was a crucial year, a year of 'Ausgleich', 'Compromise'. József Eötvös, Hungary's leading intellectual and Cabinet Minister, reorganized science. He sent his son to Heidelberg, where junior learned physics from i.a. Bunsen, Helmholtz and Kirchhoff. What more could a youngster wish for? Roland Eötvös returned home with a predilection for fundamental matters, most of all for the nature of gravity and its relation to inertia. Geophysics, Hungary's pride, finally took centre stage.



▲ FIG. 1: Loránd Eötvös by Gyula Éder (oil on canvas; 89×73 cm; 1941), after a photograph made by Aladár Székely (1913). Courtesy: Eötvös University, Budapest.

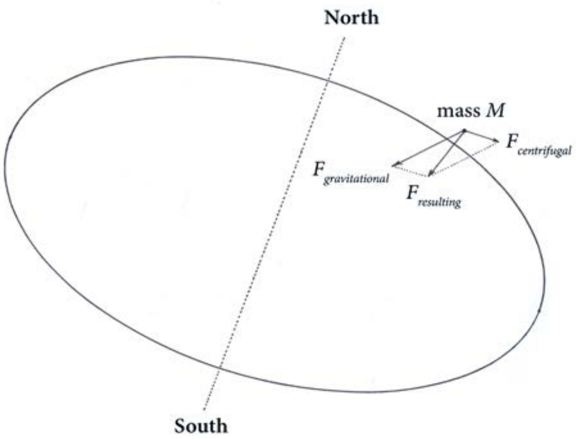
Politics, science, fundamental science

In order to be prepared for an eventual political career, like that of his father, Loránd Eötvös studied law at Budapest's University (1865-1867), before definitely switching to physics, mathematics and chemistry. On 7 July 1870, he passed the PhD under supervision of Gustav Kirchhoff in Heidelberg without a formal dissertation. In 1872 he was nominated Professor of Physics at the University of Budapest, the university which, since 1950, carries his name.

In the mid 1880s an interest in gravitation became apparent, in all probability initiated by the first results of the triangulation campaign of the territory of Austria-Hungary (1860-1913) with the European degree measurement in the background. Gravitation—or gravity, if you please—had been part of the physicist's subconsciousness since Newton, and every now and then it resurfaced, mostly in the context of a debate on conservation laws.

Instruments and their accuracy

Eötvös started by considering the instruments that would allow for an exact measurement of the gravitational constant (his γ, our g), or perhaps better: its 3D-variation. Among his new instruments featured the torsion balance of 1891. It consisted of two equal weights of about 30 g fixed at the ends of a horizontal beam of 25 cm, the beam being attached in the middle to a platinum wire carrying the whole. That wire also carried a small mirror such that the reflection of a ray of light, produced *e.g.* by a storm lantern, could be observed from a distance. It was affected by heavy masses like lead balls, so it worked indeed. With a brass sphere at the one end, the material at the other end could be varied (glass, cork, an empty glass sphere, ...). When the beam was put orthogonal to the local meridian, its behaviour was observed, first, when the brass



▸ **FIG. 2:** The earth as a rotating ellipsoid; for clarity's sake the ratios are exaggerated. A resting mass M at heigth h experiences two forces, $F_{gravitational}$ and $F_{centrifugal}$, whose resultant produces a net effect to the South.

sphere pointed to the East and, next, when it pointed to the West. Since the effect on both weights is the result of the centrifugal force combined with gravity, both experience a net force to the South (Fig.2). Any difference in gravitational mass, then, brings about a difference in that net force, producing a torque on the beam and hence a torsion. And it worked correspondingly, the answer being: "No, there is no difference."

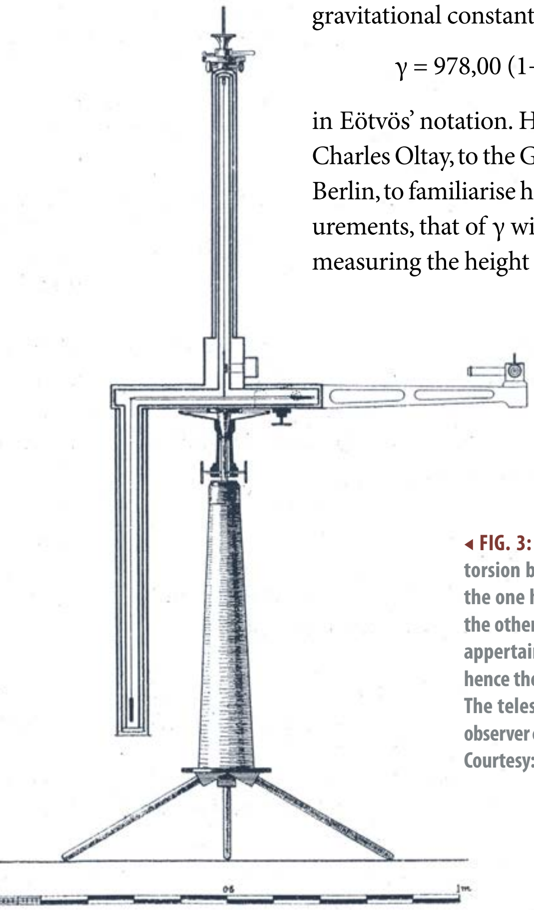
Chartering the earth; geophysics on the move

The state of the art in geophysics was defined by data from Friedrich Bessel (Kaliningrad; 1841) and Friedrich Helmert (Aachen; 1884). Bessel had calculated the dimensions of an idealized earth as an ellipsoid with half axes of 635.607.895 cm and 637.739.716 cm, Helmert contributed a formula for the interdependence of the gravitational constant, γ, and latitude, φ:

$$\gamma = 978{,}00\,(1+0{,}00531\sin^2\varphi)\ \mathrm{cm}\cdot\mathrm{sec}^{-2},$$

in Eötvös' notation. He, then, sent one of his assistants, Charles Oltay, to the Geodetic Institute in Potsdam, near Berlin, to familiarise himself with the two relevant measurements, that of γ with the pendulum and that of φ by measuring the height of Polaris. The idea was to charter interesting terrains using the data obtained for Potsdam and Budapest as gaugepoints. With pendulums borrowed from Potsdam, the local value of the gravitational constant, γ, could be measured and, subsequently, its spatial variation with the torsion balance. Imagine, then, such a torsion balance, equipped with equal brass spheres, above the surface of a perfectly horizontal, homogeneous underground, or above a homogeneous sphere of infinite radius: nothing will happen, since the common equipotential surface is (almost) perfectly flat. However, as soon as there are deviations, *e.g.* in case of an earth-like sphere featuring a mountain ridge, a torsion balance put on top of the ridge starts turning: the beam with its counterweights experiences a torque tending to turn it in line with the ridge, the torsion effect dictating the outcome.

This may be checked in advance. By turning subsequently the balance as a whole in the direction of the ridge the deflection angle tends to vanish. On moving the torsion balance along the ridge the deflection remains nill, γ being virtually constant; on moving the balance sidewards, however, down along the slope, the beam will remain in place though γ will change. Hence the possibility of charting a landscape in terms of lines of equal γ, *isogammic* lines in Eötvös' terminology: from each observation point, then, a gradient can be constructed, a kind of vector indicating the intensity of the γ-variation and its direction. Importantly, the same effect will show up in case of *invisible* mountain ridges on the bottom of a deep lake—think of Lake Balaton—or on mainland, *e.g.* under the pastures of the Great Hungarian Plain, roughly the South-Eastern part of the country. However, when the subsurface is of a less outspoken relief, no regularities show up. In such cases the sensitivity of the balance could be increased by exchanging one of the counterweights by a platinum thread carrying a similar counter-weight: the new version was called a 'horizontal variometer', later known as the one and only 'Eötvös torsion balance' (Fig.3). With respect to the earth the two weights now occupy different equipotential surfaces, so that any difference in the form of those surfaces will bring about a torque on the beam causing it to turn. Given the possibility to charter the subsurface in terms of density variations, that is: by systematically scanning the area, the interest of Eötvös' ideas for geology and mineralogy was obvious. Indeed, within a decade geophysics—the term was introduced by Julius Fröbel (1834)—became booming science.



◂ **FIG. 3:** The 'horizontal variometer' or 'Eötvös torsion balance'. The beam carries two weights, the one hanging down fixed to a platinum wire, the other directly fixed to the beam. Each weight appertains to an equipotential plane of its own, hence the appearance of a horizontal component. The telescope on the right carries the scale; the observer carries *e.g.* a storm lamp as light source [4]. Courtesy: Hungarian Academy of Sciences.

Gravitation and inertia

In 1896 Eötvös summarized his research on gravitation and earth magnetism in a widely read paper in the *Annalen der Physik* [2]. In due course he became keynote speaker at various trendsetting conferences. So it happened also that in 1906 a prize-contest was launched by the University of Göttingen, inviting the community to address Eötvös' work. The question asked was: the medium between *charges*—the dielectricum—does it, or does it not, play the same role as the medium between *masses* like two molecules, the one in the Sun, the other in the Earth? The question was an acute one, since it had recently been demonstrated that charge carriers—the new 'electrons'—indeed behaved like tiny masses. Maxwell, moreover, had shown that electromagnetic phenomena propagate with the speed of light and the question now was: did gravitation propagate instantaneously—that is: with an infinite speed—or with a finite speed? One Albert Einstein (Bern), as yet unaware of Eötvös' activities, even pondered on the *varying* mass of objects in motion… Eötvös and his collaborators Dezsö Pekár and Jenö Fekete interpreted the Göttingen challenge as an instigation to reconsider the relation between gravity and inertia. Slightly adapted their argument runs as follows [3].

According to Newton's first law two masses M_1 and M_2 at a distance r attract each other with a force

$$F_{gravity} = f\frac{M_1 M_2}{r^2},$$

f being a constant, such that mass M_2—let's say, one of the spheres of a torsion balance—experiences a gravitational acceleration γ with respect to the Earth, M_1, of

$$\gamma = f\frac{M_1}{r^2},$$

If equal masses of different materials indeed feature different gravities this reduces to saying that their constant f varies, which may be expressed as follows:

$$f' = f(1+x)$$

In their paper, Eötvös *et al.* claim that Newton's experiments with pendulums had shown that $x < 10^{-3}$ and those of Bessel that $x < 5 \cdot 10^{-4}$; in both cases the estimate had been based on the presumed accuracy of the weighing procedures of Newton and Bessel. The new experiments, then, further narrowed down x to $< 2 \cdot 10^{-7}$. In a way typical for the problem at stake Eötvös *et al.* reason backwards: given the presumed equivalence or identity of gravitational and inertial mass, as demonstrated by Newton and Bessel, the task is to increase the numerical accuracy of that proposition. So they started from the smallest possible observable deviation on the screen and argued backwards: what is the smallest possible observable change in the ratio $F_{gravitational}/F_{centrifugal}$? The experiments proper were conducted with the aforementioned torsion balance (Fig.3) and a doubled version, featuring two parallel balances in opposite directions (Fig.4); the latter balance allowed for two measurements at the same time. Broadly speaking the equivalence or identity of gravitational and inertial mass was confirmed once and for all with a new record-accuracy. Though, properly speaking, slightly at odds with the intentions of the contest, the essay submitted by Eötvös, Pekár and Fekete was nonetheless awarded the 1909 prize because of the fundamental physics involved. ■

◂ **FIG. 4:** Double torsion balance in brass. The two telescopes are mounted with prisms to facilitate the observations. Courtesy: Eötvös Museum, Mining and Geological Survey of Hungary, Budapest.

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About the author

Henk Kubbinga (University of Groningen) is a member of the EPS-History of Physics Group. Actually he is finishing the fifth and last volume of *The collected papers of Frits Zernike (1888-1966)*.

References

[1] R. Eötvös, *Ann.d.Phys.* **27**, 448 (1886).

[2] R. Eötvös, *Ann.d.Phys.* **59**, 354 (1896).

[3] R. Eötvös, D. Pekár and J. Fekete, *Ann.d.Phys.* **68**, 11 (1922).

Written and compiled by David Sands from original contributions from Laura Kormos and Jaroslaw Nowak, University of Lancaster, Helen Vaughan, University of Liverpool, Alison Voice, University of Leeds, and Stan Zochowski, University College London.

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Moving teaching online during the COVID-19 pandemic

The outbreak of COVID-19 and the subsequent pandemic has caused, and continues to cause, a substantial upheaval across much of society, including higher education. The imposition of social distancing measures and eventually lockdown in early 2020 led to a rapid switch to remote and online learning. Academics had to support students to learn physics in a new environment with very little notice and minimal preparation. For the next academic year, though, there is at least some time to prepare, but the resurgence of the disease in areas where previously it appeared to be under control means that there is no realistic prospect of universities opening as normal in the immediate future. Universities across Europe have been planning for some kind of blended learning with a substantial proportion of teaching to be delivered on-line and there is little prospect of any on-campus, face-to-face delivery until some time in 2021. How will universities, and physics departments in particular, cope? In this short article, I present some of the experiences of academics from the UK. My own teaching had essentially finished by the start of lockdown and what follows is culled from the experiences of the contributing authors named above who were identified through a network established with the support of the Institute of Physics in London to help academics share practices and ideas, and support each other during this difficult and demanding time.

Currently hosted by Dr Helen Vaughan (Central Teaching Laboratories, University of Liverpool), the network runs a series of regular on-line community meetings which consist of two or three presentations on a single theme followed by the opportunity to join a breakout room to talk about the topic. For those unable to attend, the presentations are recorded and reports of the break-out room discussions are made to create a lasting resource (hosted here (https://www.liverpool.ac.uk/central-teaching-hub/physicslthe/)). Attendance at the meetings is typically in excess of 100 from across the UK and Ireland and topics and contributors are sought from across the community. We have been able to discuss experiences and plans for teaching online; virtual and remote laboratories and ensuring students feel included with many more topics being suggested all the time. Accompanied by an email listserve, it is intended that this network will support the UK community through the current challenges and be a place to continue to collaborate in the future.

Stan Zochowski, from University College London (UCL) has been teaching a course in mathematics for physics on line to approximately 240 first year undergraduates per year for the last three years and shared his experiences with the network. The course runs over 11 weeks and is divided into eight portions, with each portion containing content, quizzes and a plenary session to summarise the content and address students' questions.

The biggest challenge that Stan reports facing was around technology: which technology to use and then how to master it. Stan chose to deliver the content by video and students reported liking the self-paced study that this affords. Once students have achieved a minimum level of mastery over the content in a particular portion, as evidenced by their score on the associated quiz, the next portion is made available to them. Learning is thus tailored to the individual, but the plenary sessions provide an opportunity to ask questions directly.

Delivering content in this way requires a lot of time to prepare the content. It is sometimes necessary to continue with a video simply because there isn't time to remake it, but, adjustments to video content notwithstanding, Stan is confident that he has a format that is effective. The level of engagement by the students is higher than with conventionally delivered material and students also appreciate the different way that this material is delivered compared with their other courses. This raises the prospect in the coming year that the on-line delivery of much of the other content that students will face will reduce the impact of Stan's teaching.

Jaroslaw (Jarek) Nowak, from Lancaster University, taught a complete course in quantum physics for about 200 first year students following lockdown. Delivered conventionally, this would comprise sixteen 50-minute long lectures over a period of five weeks with weekly tutorials, a designated office hour and weekly coursework. The electronic version comprised recorded lectures which students could access in their own time, "office" hours and two "live" interactive tutorial sessions delivered synchronously using Microsoft Teams. Four teaching assistants supported the live sessions and also assisted with marking.

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At the end of each week students had to complete a worksheet on the recorded lectures, each of which was dedicated to a single topic. In consequence, topics that would ordinarily take a small fraction of a live lecture, and therefore could be easily overlooked by students, could be given more prominence. Lengthy mathematical derivations were written in LaTeX and also recorded separately in a video. Links to external resources, such as YouTube videos or simulations, practice problems and supplementary videos on background knowledge, such as the wave equation or complex numbers were provided to support students. Preparing all this material proved a real challenge, especially working at home, but there were also advantages to this approach. Each recorded lecture contained three questions aimed at providing feedback and the comments and questions provided by students were discussed during the synchronous sessions. As with Stan's course, students were in control of their own learning in as much as they could work at their own pace, accessing the recorded lectures and supplementary videos as needed, provided that they completed the work within the week. The main challenge is to get more students involved in the discussions, as these are not very effective with the numbers currently participating.

Laura Kormos, also at Lancaster University, delivered two different activities online. The first was a course in vector calculus delivered to 162 first year students in two 1-hour sessions per week live-streamed through Microsoft Teams. The lectures were supported by five 1-hour workshops per week for smaller groups of 35 students. These were organised by Laura, but run through Microsoft Teams by her and four teaching assistants. Students had to complete a Moodle quiz and three other worksheets by way of course work. The second course was in place of a laboratory class for second year students. Delivered to 54 students in one 7-hour session per week, students were expected to work with a partner to analyse the data from an experiment on the Zeeman effect. Supporting materials included a lab script and photographs of equipment, including fringes at different stages of the experiment. The students produced a logbook using LaTeX and recorded a presentation in conjunction with their lab partner.

On the face of it, Laura's predominantly synchronous approach appears to require less preparation than either Stan's or Jarek's predominantly asynchronous approach, but in fact it is no less demanding. In Laura's own words, "The biggest challenge was time and energy. The sheer amount of organization, of typing ideas, plans and changes, answers to students' queries, sharing with the Director of Teaching what the plans were as they were evolving." Students could ask questions during both the live-streamed lectures and the lab sessions using the chat window. More students asked questions than would normally do so in a face-to-face lecture and other students could indicate their support for a question by liking it. Some even answered the question before Laura could. Although this is a positive benefit, it nonetheless caused difficulties: "I can type 90 words/minute but couldn't type fast enough to answer everyone's questions". Mastering the technology, including learning to use MS Teams and MS Whiteboard, was "tough" and took "a lot more time than my usual teaching."

Alison Voice, from Leeds University, identified seven key elements to successful online delivery that neatly summarise the issues raised above.

1) WORKLOAD: The pandemic arrived suddenly. Staff have a short timescale to adapt and students have to cope with more than normal. The solution should be simple and effective whilst allowing students to interact with staff.
2) LEARNING OUTCOMES: Focusing on the educational aims and important deliverables at the outset allows extraneous content or activities to be released.
3) SYNCHRONICITY puts learners at the heart of teaching, but ASYNCHRONICITY allows students to work at their own pace and places fewer demands on staff during teaching.
4) CONTENT DELIVERY: Technology affords creativity, freeing both staff and students from the constraints of 50-minute lectures.
5) UNDERSTANDING can be developed with self-testing and feedback. Delivery should thus be punctuated with regular short conceptual quizzes and/or practice problems with feedback.
6) ENGAGEMENT: For effective learning students need to be active, both individually and with other learners. Content liberally spaced with questions, videos or simulations will motivate, and group work will provide both social and academic stimulation.
7) BELONGING: With so much remote study we should take special care to ensure all students feel part of the class, and follow up individually those who are less engaged.

Teaching online is time-intensive in a way that lecturing face-to-face is not and it is open to question whether many universities are properly equipped for the transition. There is a strong community desire within the UK to share and seek solutions and colleagues across Europe are invited to join in the online meeting and discussions.

◂ **Left to right: Laura Kormos, Jaroslaw Nowak, David Sands, Stan Zochowski, Helen Vaughan, Alison Voice**

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