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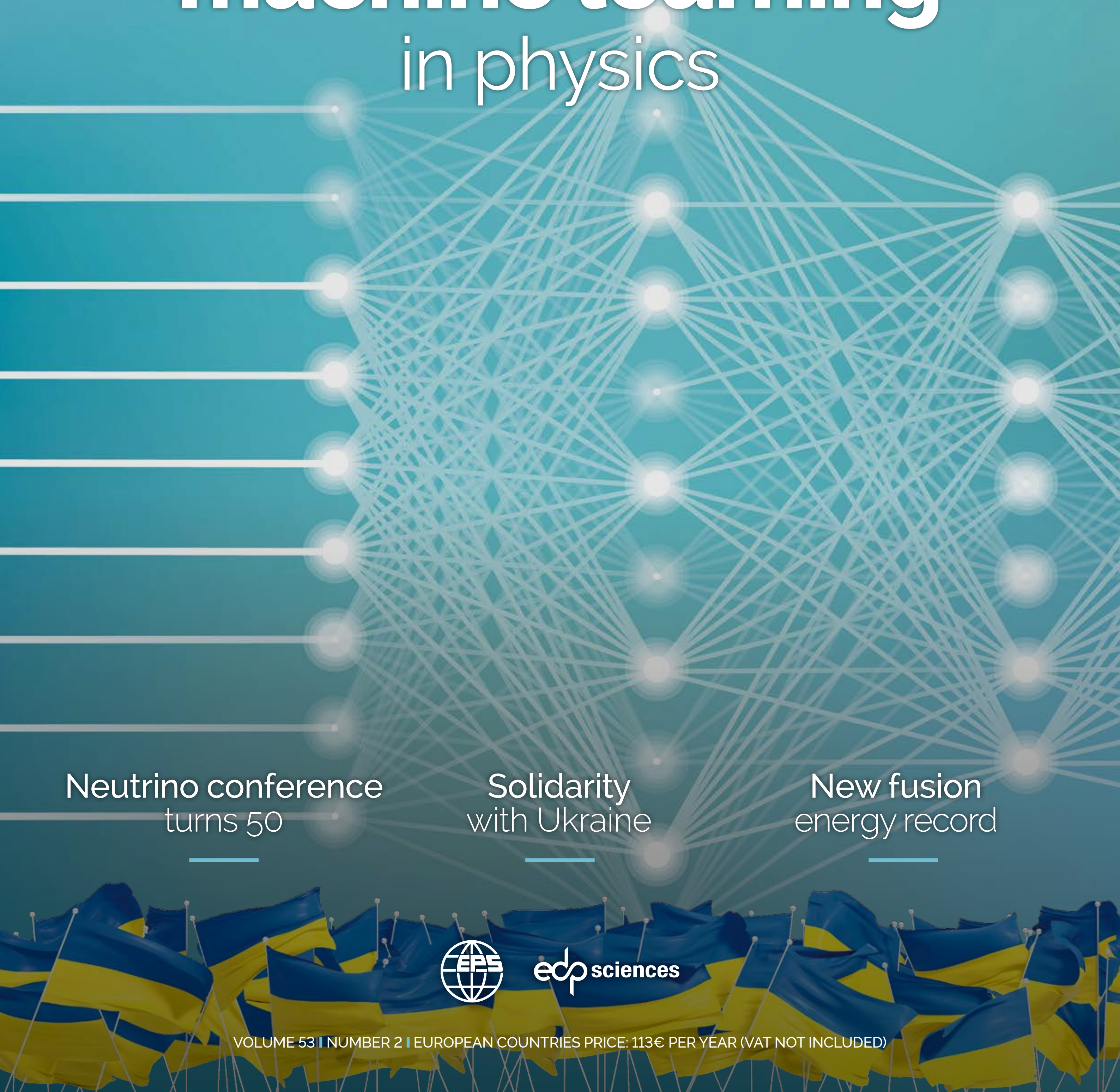
The magazine of the European Physical Society

machine learning
in physics



Neutrino conference turns 50

Solidarity with Ukraine

New fusion energy record

EPS edp sciences

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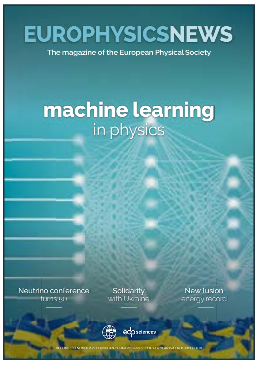

europhysicsnews

Cover picture: Deep neural network. In this issue machine learning techniques applied in physics research. ©iStockPhoto

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A taste of the future career

[EPS EDITORIAL]

The EPS stands with its Ukrainian colleagues

The covid, then Ukraine. The tragedy is back.

Despite their share of inherent disasters, these two crises demonstrate the efficiency and the need of a strong and united Europe. Massive vaccination played an essential role in controlling the epidemic. This was made possible only because Europe played the role of a powerful central purchasing body. We were able to acquire all the vaccines we needed in a short time. Thousands of lives have been saved and our hospitals have survived.

The war in Ukraine makes us rediscover how weak we are when we are unable to unite. No State in Western Europe can claim to have, on its own, what is needed to ensure the necessary protection of its inhabitants in the current geostrategic context. We need to improve the political, financial, economic and even military conditions for leading credible collective actions – and for our security.

This war is above all a tragedy for the Ukrainians. However, the expected retaliation from Russia will have an impact on our economies, our businesses and our scientific collaborations. Importantly, our young generation, who has been particularly affected by the pandemic and already suffers from the stakes of the climate crisis, will be seriously impacted. Witnessing now the violence between the nations, our students may reach a deeper level of discouragement.

The European Physical Society (EPS) is in a very peculiar situation due to this troubled context.

On the one hand, the mission of our Society is to promote physics, in Europe and in neighbouring countries, by providing a forum for discussing subjects of common interest and best practices. The EPS engages in activities to reduce the European fragmentation in physics research, funding and education. Its goal is to support physicists worldwide and to foster international collaboration everywhere.

On the other hand, the role of the EPS is also to guarantee and recall when necessary its fundamental values to which each of its 42 Member States must adhere. These values are based on the free exchange of ideas and concepts that contribute to the advance of humanity.

A nation that invades a peaceful neighbour violates these principles. A country that threatens continents - Europe in particular - to use nuclear warheads as conventional weapons dangerously perverts the fundamentals of the nuclear dissuasion and tramples on our values. A state that deliberately sets fire to nuclear power plants cannot adhere to the values of EPS.

Therefore, two days after the Russian attack in Ukraine, the executive committee of the EPS decided to condemn the war led by the Russian Federation and publish a Statement to all its members. We decided to freeze our current cooperation agreements with the Russian State, which means with all Russian institutes the EPS usually cooperated with. This initiative was carried out on March 2 and was widely welcomed in Europe (see the section 'EPS News' of this EPN issue).

As EPS President, my thoughts go first to the suffering Ukrainian people and in priority to our colleagues of the Ukrainian Physical Society, which is a member of the EPS. We stand by their side and will do all what we can to help them preserve their lives and their democracy.

We also sympathize with the Russian and Belarusian physicists who refuse the participation of their respective governments in this war. The EPS will regularly report their petitions on its media channels.

This is the same world power that, through the troops of the Warsaw Pact, invaded Czechoslovakia in 1968 – a founding event for the EPS - and that is attacking Ukraine today. The role of the EPS is to help our democratic nations to guarantee the freedoms of their peoples, including their right to free expression.

The international scientific community can count on the EPS to remain vigilant on the preservation of these freedoms and to adopt any measure against any entity who would wish to oppose them, no matter how brutal its means. ■

■ **Luc Bergé,** *EPS President*

NEUTRINO CONFERENCE TURNS 50

$$\nu + p \rightarrow p + \mu + \pi$$

András Patkós – Eötvös Lorand University, Budapest, Hungary – DOI: https://doi.org/10.1051/epn/2022201

In February 1972, in the break of a regional meeting of particle physicists held in Budapest *Herbert Pietschmann* (Vienna), *Jan Nilsson* (Göteborg) and *George Marx* (Budapest) discussed the subdued position of weak interactions at international conferences. *H. Pietschmann*: "For George Marx it was quite obvious that the neglect of neutrino physics at the big international conferences had to be neutralised by a dedicated international conference on neutrino physics. Instead of pushing some international committee, he took the idea in his own hands and organised a Europhysics neutrino conference in Hungary by himself."

The first Neutrino conference took place in Balatonfüred, Hungary June 11-17, 1972. One might just wonder how the organisers were able to invite successfully so many first class speakers and a bunch of enthusiastic young physicists on such short notice from both sides of the iron curtain. *L. M. Sehgal* (Aachen): "The Neutrino'72 Conference was the very first conference I attended and turned out to be an important event in my scientific life. There was a whole galaxy of famous people there - R. Feynman (Nobel Prize [NP] 1965), T. D. Lee (NP 1957), R. Marshak, V. Weisskopf, B. Pontecorvo, V. Telegdi, F. Reines (NP 1995), C. Cowan, R. Davis (NP 2002), J. Bahcall, B. Barish (NP 2017), D. Cline, C. Baltay and many others."

The solar neutrino problem fully recognised

Kenneth Lande (U. Pennsylvania) recalls: "The main focus at the first part of the meeting was the initial result from Ray Davis's chlorine based solar neutrino detector." Davis's initial result in 1968, based on two runs was ≤ 3 Solar Neutrino Unit (SNU). His new results based on six runs, presented at this conference, were a ^{37}Ar production rate of 0.18 ±0.10 per day. After subtraction of the estimated cosmic ray induced background, Davis gave an upper limit on the solar neutrino induced signal of 1 SNU[1].

John Bahcall then provided a clear and very detailed description of how the solar neutrino emission is determined including the dependence on the various parameters. His conclusion was that the lowest possible signal in the Davis detector was 5 – 9 SNUs. The "decrease factor" between Bahcall's predicted signal and Davis's observed signal was known as the "solar neutrino problem."

In his summary talk *Bruno Pontecorvo* took a rather conservative attitude: "the conclusion by Davis is that the Sun emits much less ^{8}B neutrinos than expected." Then he asked: "Is the discrepancy serious enough to force us to draw revolutionary conclusions about the Sun or about the neutrino properties? My opinion is: no." Since the ^{8}B neutrinos to which the reaction was dominantly sensitive represent a tiny part of the whole emission "the • • •

[1] As a reminder, a SNU is the integrated product of neutrino flux x cross section for the neutrino induced ^{37}Cl →^{37}Ar in units of 10^{-36} per second per ^{37}Cl target atom.

◂ First observation of a neutrino in a hydrogen bubble chamber, on 13 ovember 1970, at Argonne National Laboratory. Here a neutrino hits a proton in a hydrogen atom; the collision occurs at the point where three tracks emanate. The invisible neutrino comes from 'below' on the picture. In the collision a muon is created (the long track) and a pi-meson (the shorter track). The third short track is the proton.

▾ FIG. 1: Seated, from left: T.D. Lee, L. Radicati, R.P. Feynman, B. Pontecorvo, G. Marx, V.F. Weisskopf, F. Reines, C. Cowan, P. Budini

••• reactions leading to this emission are quite unimportant from the point of view of the structure of the Sun." Related to this reaction new parameters might be needed but irrespective to this "the Sun will nevertheless shine as before". His advice sounded: New detectors capable to observe pep neutrinos [generated in the reaction p + e + p → deuteron + neutrino] should be developed in the first place.

Only if these efforts would fail one could look for what Pontecorvo called "exotic" solutions. A few of them were presented in the sessions: pulsating Sun activity (Lande *et al.*), decaying neutrinos (Bahcall *et al.*), $\nu_e \leftrightarrow \nu_\mu$ oscillation (Gribov & Pontecorvo). He made two important remarks: a) with neutrino oscillations one can measure neutrino mass differences "several million times more sensitive than the ordinary ones for neutrino mass measurements"; b) "only with very sophisticated and remote experiments can the "decrease factor" become larger than 2." These remarks set out the strategic directions of neutrino physics for the last third of the 20th century. It took about 25 years until the problem of missing neutrino flux was clarified.

Constraining neutrino masses on an absolute scale was also discussed at the conference, emphasising their role in the cosmological evolution. *A. Szalay* (Johns Hopkins U.) recalls: "I was finishing my undergraduate dissertation on the cosmological effects of neutrino masses. This work was one of the first in what later became Neutrino Astrophysics. Today the best limits on the neutrino masses are still coming from astrophysics"

Neutrinos identify partons with quarks

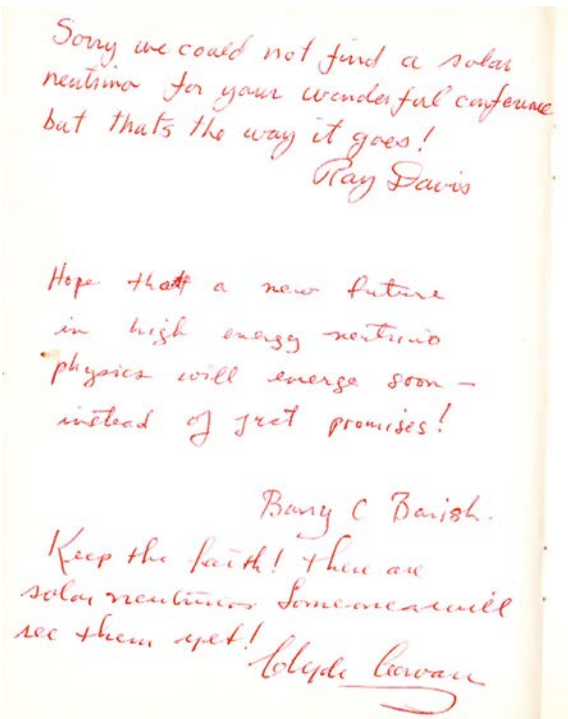
The second half of the conference dealt with weak and electromagnetic interactions as tools in exploring the subnuclear structure of the proton and neutron. The starting point was the solidly established scaling behaviour of the form factors characterising deep inelastic electron-proton scattering. The talks by *T.D. Lee* and *R.P. Feynman* in the same morning session suggested two characteristically different approaches. Lee emphasised the importance of a Lorentz invariant quantum field theoretical approach. In his bound state model the masses of the constituents combined with the constant binding coupling necessarily break scaling for large enough energies. Feynman's strategy (in the interpretation of *Victor Weisskopf*) was: "Don't bother with field theory, we know so little about it. Let us apply simple concepts. At very high energies we can consider the hadron essentially as an assembly of free partons." This picture can be valid only in a reference system where the nucleon is moving very fast, but for Feynman apparently Lorentz invariance was not an issue.

One learns the prehistory of the talk of Feynman from a recollection of *J. Kuti* (U. of California San Diego), reviewing deep inelastic lepton-nucleon scattering at the conference: "Months before the conference, the phone was ringing at my MIT office. Dick Feynman called. He introduced the notion of partons in high-energy experiments a couple of years earlier but surprisingly did not take the last step in his famous PRL publications to identify the partons with quarks. He was very concerned that he did not have any new results. Shortly before the conference he called again. He knew now what he would talk about, identifying his partons with quarks and suggesting ways of nailing down their quantum numbers in new experiments."

The information on the subnuclear structure is encoded into a number of form factors, which in the framework of the parton model depend only on the momentum fraction carried by the partonic constituents. For instance one finds for the electron-deuteron case the scaling function f_2 as sum over the form factors of the proton and the neutron $f_2^{ep}+f_2^{en}$. When partons are identified with quarks this becomes a sum over the densities of the u, d, s quarks and their antiquarks weighted by the squares of the respective electric charges. Feynman has derived for the related form factor $f_2^{\nu p}+f_2^{anti\text{-}\nu p}$ measured in (anti)neutrino-proton scattering another simple expression. Assuming the density of the strange quark (s) negligible one finds for the ratio $(f_2^{\nu p}+f_2^{anti\text{-}\nu p})/(f_2^{ep}+f_2^{en})$ the prediction 18/5.

This result generated extreme excitement as *F. Ravndal* (Oslo Univ.), a postdoc working that time with Feynman has recalled: "During that term Feynman went to Hungary to take part in a neutrino conference at Balatonfüred. He came back fired up with the first quantitative experimental confirmation of the parton model and the fractional quark charges. This was the measurement of the famous factor of 5/18."

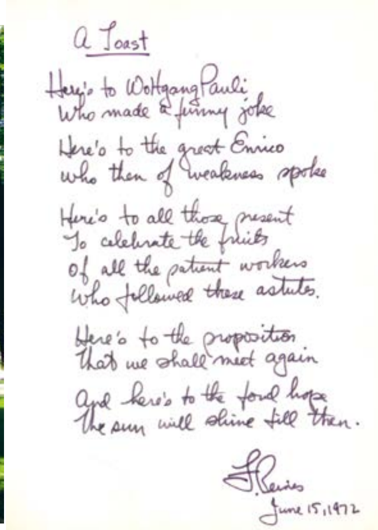
Another simple consequence of the quark-parton identification was a prediction for the ratio of the total cross section of neutrino to that of anti-neutrino nucleon scattering. The proposed value of 1/3 was close to the


Sorry we could not find a solar neutrino for your wonderful conference but that's the way it goes!
Ray Davis

Hope that a new future in high energy neutrino physics will emerge soon – instead of just promises!
Barry C Barish.

Keep the faith! There are solar neutrinos. Someone will see them yet!
Clyde Cowan

▸ **FIG. 2:** Solar neutrino puzzle as it has been told by R. Davis, B.C. Barish and C. Cowan in the guestbook of George Marx



A Toast

Here's to Wolfgang Pauli
Who made a funny joke
Here's to the great Enrico
who then of weakness spoke

Here's to all those present
To celebrate the fruits
of all the patient workers
who followed these astutes.

Here's to the proposition
That we shall meet again
And here's to the fond hope
The sun will shine till then.

F. Reines
June 15, 1972

◂ **FIG. 3:** 13th of June 1972, R. Feynman and B. Pontecorvo planting (photo by D. Rein). June 2021: the memorial trees of the first international Neutrino Conference (photo by A. Patkós)

result communicated to the conference by the Gargamelle group. For subsequent developments Kuti refers also to spin polarised deep inelastic experiments: "A few years later Vernon Hughes's experiment succeeded by measuring the deep spin-polarization distribution of quarks inside the nucleon with the experimental confirmation of an important theoretical sum rule James Bjorken established earlier."

An East-West bridge over the Balaton

For the future of the conference the local political ambiance and collegial confidence proved important. *D. Rein* (Aachen): "Apart from the somewhat depressing entrance procedures at the Hungarian border (we were amidst the cold war) I felt free and enjoyed the warm and friendly reception of the organisers and the people around. There was a smell of political tolerance and personal independence in the air, presumably mostly due to George Marx." The atmosphere has encouraged informal contacts between Soviet and US scientists. K. Lande: "George Marx offered to arrange a lunch at which our group could discuss future possibilities with our Soviet counterparts. Thus, Ray Davis, Fred Reines, John Bahcall and I met with Aleksandr Chudakov, Vadim Kuzmin, Aleksandr Pomanski and Bruno Pontecorvo. What we learned was that they were excavating, a single-ended tunnel into the side of a steep mountain of the Caucasus range. As a result of the Neutrino '72 Conference Ray Davis and I decided to try to develop the technology for a gallium solar neutrino detector. These became the basis of the SAGE (Baksan) and GALLEX (Gran Sasso) solar neutrino detectors."

A highlight happened on the Tagore Alley near the Lake Balaton. *Z. Kunszt* (ETH Zurich): "In the Alley this was Rabindranath Tagore the famous Indian poet who has planted the first tree (NP 1913). Later the Italian poet Salvatore Quasimodo also planted a tree (NP 1953). The tradition that if a Nobel-Prize laureate visits Balatonfüred he or she ought to plant a tree follows the idea of Marx. He suggested that Feynman as Nobel-prize holder should also plant a tree. But one had to have balance between East and West, so Bruno Pontecorvo has been asked to plant a tree."

The President of the International Neutrino Committee, S. Parke (Fermilab) could proudly state: "In June of 2022, the 50th anniversary of Neutrino '72, thirty such Neutrino Conferences will have been held in locations in Europe, North America and Asia/Oceania. George Marx, as founder of this series, presided over the first twenty of these meetings. The 50th anniversary meeting, Neutrino 2022 is to be held in Seoul, South Korea. Neutrino 2030 will celebrate the 100th anniversary of Wolfgang Pauli's hypothesis that there exists a light neutral lepton, the neutrino. The International Conference on Neutrino Physics and Astrophysics Series has become the premier international neutrino conference where diversity, inclusiveness and transparency are recognised as of essential importance for great discoveries." ■

About the Author

A. Patkós is professor emeritus of theoretical particle physics at the Institute of Physics of Eötvös Loránd University, Budapest. His research focusses mainly on quantum field theory of phase transitions in strong and electroweak matter. He is honorary president of the Hungarian (Roland Eötvös) Physical Society.

References

The proceedings of *Neutrino '72* have been digitized and are available at https://zenodo.org/communities/neutrino-72/?page=1&size=20

The full text of the recollections quoted in the text was published in the March special issue of Fizikai Szemle (Hungarian Physical Review), the monthly journal of the Roland Eötvös Physical Society and is also accessible at the above link.

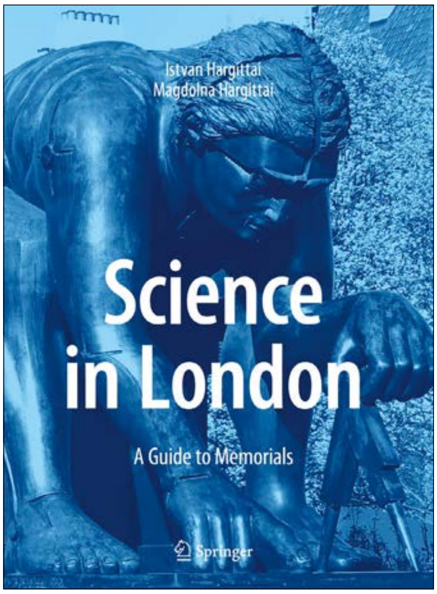
Science in London: A Guide to Memorials

By Istvan Hargittai and Magdolna Hargittai – DOI: https://doi.org/10.1051/epn/2022202

"If I have seen further, it is by standing on the shoulders of giants." A famous quote from Isaac Newton, echoed by Einstein centuries later when, asked if he stood on the shoulders of Newton, he replied "No, on the shoulders of Maxwell".

But Newton's words deeply offended his contemporary Robert Hooke, who was of small stature and took the words as a personal gibe. The book "Science in London" delves into the stories of science, such as Newton and Hooke's well-recorded shared animosity, and will appeal to anyone interested in the history of science and/or London. Its historical narrative offers us glimpses into the lives and contributions of hundreds of scientists, natural philosophers, explorers, and engineers; their stories told through their memorials in London. Although famous greats such as Einstein and Newton are well-represented, equal weighting is given to many more men and women whose contributions to the world we live in are just as profound. Who could imagine life without the electricity and telecommunications enabled by the astonishing achievements of Faraday and Maxwell? Or, particularly resonant today, the vaccines pioneered by Jenner? But "Science in London" goes deeper: showcasing other, more obscure, scientists who contributed to momentous discoveries. A great example is Benjamin Jesty, who deliberately – and successfully – inoculated his family against smallpox by exposing them to material from a cowpox-stricken cow…..20 years before Jenner's vaccine. But Jesty neither published nor publicised his discovery, whereas Jenner did (a fantastic lesson for us scientists today!).

Women are given specific mention, particularly for their contributions to medicine, highlighting the colossal barriers and prejudice they faced in both education and practice. Even Queen Victoria is mentioned: by requesting the new innovation of anaesthesia during the birth of her eighth child, she enabled the scriptural precedent that suggested women should feel pain during childbirth to be overcome. Her advocacy changed the prevailing attitude of the time and enabled obstetrical anaesthesia to be commonplace, something millions of future women would be extremely grateful for.



"Science in London" covers the full swathe of human history, from the philosophers and mathematicians of the ancient era, such as Pythagorus and Archimedes, to scientists still alive today. Nor does the book focus solely on British scientists.

"Science in London" uncovers the human side of science. Lord Kelvin may be best known for his substantial contributions to thermodynamics, but here we learn about his enthusiasm for the new long-distance telegraph technology. He both proposed to his future wife – and received her answer – via telegraph. "Science in London" describes Lavoisier becoming embroiled in the politics of the French Revolution and being executed by guillotine, only to be exonerated shortly thereafter. We discover the man responsible for the word "banana", the British botanist/spy who smuggled precious tea plants and knowledge out of China to augment the tea industry in India, and who the first person to perform true alchemy was. From a practical perspective, memorial photos are exhibited extensively throughout the book, and postcodes given for those readers seeking the memorials themselves.

"Science in London" covers the full swathe of human history, from the philosophers and mathematicians of the ancient era, such as Pythagoras and Archimedes, to scientists still alive today. Nor does the book focus solely on British scientists. Instead, it celebrates London's openness and all those contributors to its position as a city of science, both past and future. ■

Tracey Clarke,
University College London

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Print length : 297 pages

Cosmic particle accelerator

On 8 August, 2021, the recurrent Nova RS Ophiuchi exploded. The explosion was real-time followed by the H.E.S.S. gamma-ray telescopes in Namibia. The observations revealed a cosmic particle accelerator in unprecedented detail.

The Nova RS Ophiuchi comprise a white dwarf in a binary system with a large star from where it gathers continuously new material. When the gathered material goes over a critical level, thermonuclear explosions occur on the surface of the white dwarf. RS Ophiuchi repeatedly show these explosions on its surface every 15 to 20 years. The nova creates a shock wave that ploughs through the surrounding medium, pulling particles with it and accelerating them to extreme energies. The H.E.S.S. telescopes could real-time follow the course of the explosion and the accompanying shock wave in the high energy gamma-ray regime. Details of the observation and the subsequent analysis has recently been published in [1]. ■

Reference

[1] Detection of TeV gamma-ray emission from the recurrent nova RS Oph in its 2021 outburst; The H.E.S.S. collaboration; Science 2022, 10.1126/science.abn0567. Pre-print: arXiv:2202.08201v1 [astro-ph.HE]

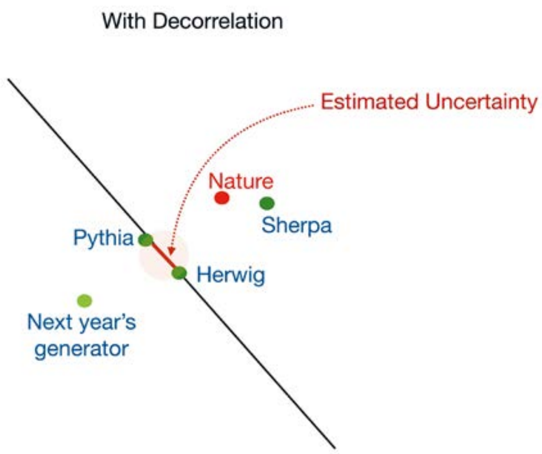
▲ FIG. 1: Artist's impression of the RS Ophiuchi Nova outburst. The fast shockwaves form an hourglass shape as they expand, in which gamma rays are produced (Image: DESY/H.E.S.S., Science Communication Lab).

A cautionary tale of machine learning uncertainty

By decorrelating the performance of machine learning algorithms with imperfections in the simulations used to train them, researchers could be estimating uncertainties that are lower than their true values – DOI: https://doi.org/10.1051/epn/2022203

The Standard Model of particle physics offers a robust theoretical picture of the fundamental particles, and most fundamental forces which compose the universe. All the same, there are several aspects of the universe: from the existence of dark matter, to the oscillating nature of neutrinos, which the model can't explain – suggesting that the mathematical descriptions it provides are incomplete. While experiments so far have been unable to identify significant deviations from the Standard Model, physicists hope that these gaps could start to appear as experimental techniques become increasingly sensitive.

A key element of these improvements is the use of machine learning algorithms, which can automatically improve upon classical techniques by using higher-dimensional inputs, and extracting patterns from many training examples. Yet in new analysis published in *EPJ C*, Aishik Ghosh at the University of California, Irvine, and Benjamin Nachman at the Lawrence Berkeley National Laboratory, USA, show that researchers using machine learning methods could risk underestimating uncertainties in their final results. In this context, machine learning algorithms can be trained to identify particles and forces within the data collected by experiments such as high-energy collisions within particle accelerators – and to identify new particles, which don't match up with the theoretical predictions of the Standard Model. To train machine learning algorithms, physicists typically use simulations of experimental data, which are based on advanced theoretical calculations. Afterwards, the algorithms can then classify particles in real experimental data.These training simulations may be incredibly accurate, but even so, they can only provide an approximation of what would really be observed in a real experiment. As a result, researchers need to estimate the possible differences between their simulations and true nature – giving rise to theoretical uncertainties. In turn, these differences can weaken or even bias a classifier algorithm's ability to identify fundamental particles.



▲ FIG. 1: Potential impact of training a decorrelated classifier: the small estimated uncertainty between the predictions of the Pythia and Herwig LHC-event generators excludes not only the predictions of other generators but also does not cover nature.

Recently, physicists have increasingly begun to consider how machine learning approaches could be developed which are insensitive to these estimated theoretical uncertainties. The idea here is to decorrelate the performance of these algorithms from imperfections in the simulations. If this could be done effectively, it would allow for algorithms whose uncertainties are far lower than traditional classifiers trained on the same simulations.

But as Ghosh and Nachman argue, the estimation of theoretical uncertainties essentially involves well-motivated guesswork – making it crucial for researchers to be cautious about this insensitivity. In particular, the duo argues there is a real danger that these techniques will simply deceive the unsuspecting researcher by reducing only the estimate of the uncertainty, rather than the true uncertainty. A machine learning procedure that is insensitive to the estimated theory uncertainty may not be insensitive to the actual difference between nature, and the approximations used to simulate the training data. This in turn could lead physicists to artificially underestimate their theory uncertainties if they aren't careful. In high-energy particle collisions, for example, it may cause a classifier to incorrectly confirm the presence of certain fundamental particles.

In presenting this 'cautionary tale', Ghosh and Nachman hope that future assessments of the Standard Model which use machine learning will not be caught out by incorrectly shrinking uncertainty estimates. This could enable physicists to better ensure reliability in their results, even as experimental techniques become ever more sensitive. In turn, it could pave the way for experiments which finally reveal long-awaited gaps in the Standard Model's predictions. ■

Reference

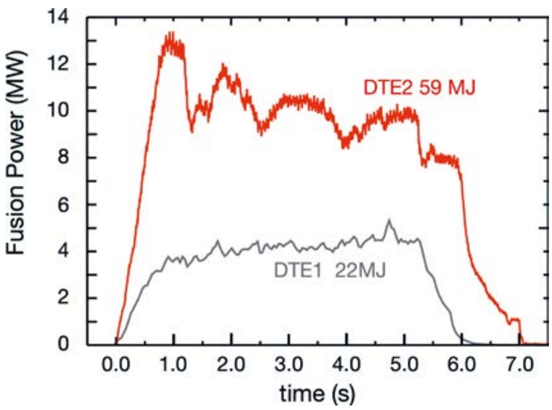
[1] Ghosh, A., Nachman, *B. A cautionary tale of decorrelating theory uncertainties. Eur. Phys. J. C* **82**, 46 (2022). https://doi.org/10.1140/epjc/s10052-022-10012-w

JET achieves a fusion energy record

Scientists at the Joint European Torus near Oxford, UK, announced on 9 February that the tokamak, using a 50-50 mix of deuterium and tritium as production fuel, had produced for five seconds a record of 59 megajoules of sustained fusion energy.

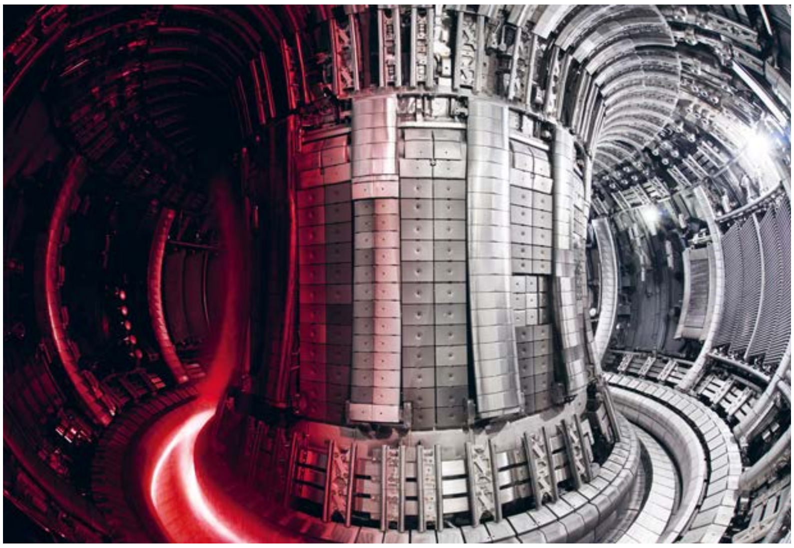
JET – the Joint European Torus – is the largest and most powerful operational tokamak in the world at the UK Atomic Energy Authority (UKAEA) site in Oxford[1]. The 59-megajoules record more than doubled the previous fusion energy record of 21.7 megajoules set there in 1997. The new record had a power ratio of Q=0.33. The record is good news for the international ITER fusion research project[2] currently building an tokamak fusion reactor in southern France.

The success of JET was the result of a decade-long refurbishment of the tokamak that turned it into a testbed for ITER. One of the key research issues is the understanding of material migration, erosion, transport and deposition in the tokamak. The process is related to the lifetime of the material components facing the plasma. Using remote-controlled robotic arms, the entire first wall of the JET vacuum chamber made of graphite – around 10,000 tiles – was replaced by one made of alternative materials, such as beryllium and tungsten. Beryllium is an element that is less susceptible to chemical erosion and has a low atomic number. The lower chemical sputtering of beryllium leads to lower fuel retention in remote areas and an easier release of fuel gas via cleaning methods, while its low atomic number results in a tolerable impurity concentration in the fusion plasma. Tungsten has the highest melting point of all metals (3,422 oC). In particular, this material is chosen to armour the divertor at the bottom of the vacuum vessel. The divertor extracts heat and ash produced in the fusion reaction, minimises plasma contamination and protects the surrounding walls from thermal load.



▲ Fusion output comparison: records in 1997 (grey) and in December 2021 (red); Credit UKAEA

Tony Donné, CEO of the EUROfusion Programme[3], states that "The record, and what we have learned about fusion under these conditions shows that we are on the right path to a future world of fusion energy. If we can maintain fusion for five seconds, we can do it for five minutes and then five hours as we scale up our operations in future machines." ■



▲ JET interior with superimposed plasma; Credit UKAEA

[1] JET website at https://ccfe.ukaea.uk/research/joint-european-torus/

[2] ITER website at https://www.iter.org/

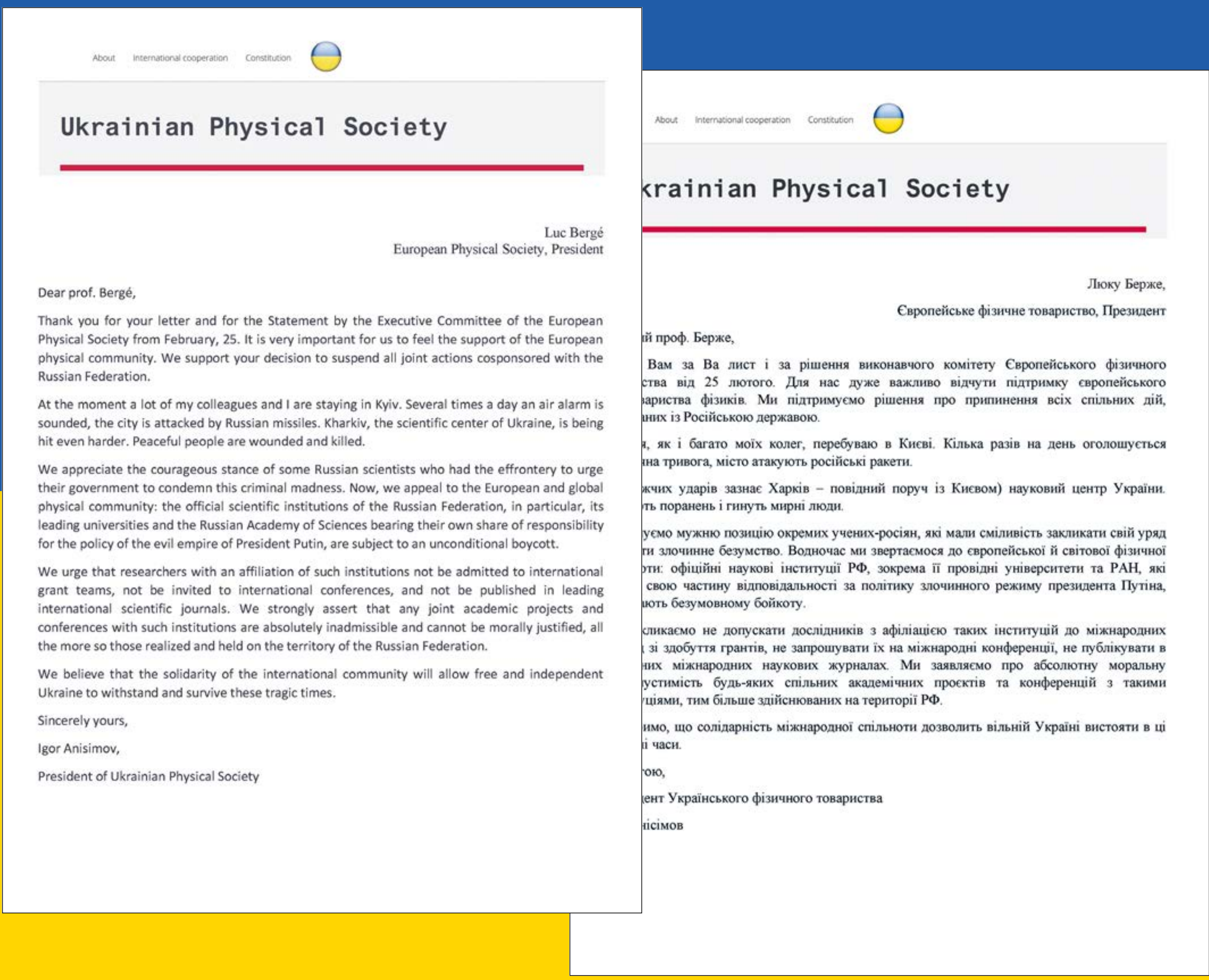
[3] https://www.euro-fusion.org/

EPS Statement

The EPS condemns the continuing attacks by the Russian Federation against Ukraine and expresses its full solidarity with the Ukrainian Physical Society.

The European Physical Society (EPS) firmly condemns the aggression of Ukraine by the Russian armies. Today more than ever, the EPS stands alongside the Ukrainian people and the Ukrainian Physical Society, a Member Society of the EPS. We call on the entire scientific community to be uncompromising in their protest against the war. In solidarity with our Ukrainian and Russian colleagues who refuse this war, the EPS has suspended all joint actions co-sponsored with the Russian State for the time being, until further measures be considered at the next EPS Council planned in Paris in June 2022. Freezing the EPS collaborations with Russian institutes currently applies to the United Physical Society of the Russian Federation, the IOFFE Institute, The Joint Institute of Nuclear Research at Dubna, the University of St-Petersburg, and the Troitsk Spectroscopy Institute of the Russian Academy of Science.

The EPS Statement, published here, was approved or relayed by a number of Member Societies of the EPS, including the Institute of Physics, the Spanish Royal Physics Society, the Austrian Physical Society, the Ukrainian Physical Society and the Belarus Physical Society. As can be read from the thankful letter reproduced below, the Ukrainian Physical Society appreciates the support of the EPS and the decision to freeze its cooperation with the Russian Federation. ■



About International cooperation Constitution

Ukrainian Physical Society

Luc Bergé
European Physical Society, President

Dear prof. Bergé,

Thank you for your letter and for the Statement by the Executive Committee of the European Physical Society from February, 25. It is very important for us to feel the support of the European physical community. We support your decision to suspend all joint actions cosponsored with the Russian Federation.

At the moment a lot of my colleagues and I are staying in Kyiv. Several times a day an air alarm is sounded, the city is attacked by Russian missiles. Kharkiv, the scientific center of Ukraine, is being hit even harder. Peaceful people are wounded and killed.

We appreciate the courageous stance of some Russian scientists who had the effrontery to urge their government to condemn this criminal madness. Now, we appeal to the European and global physical community: the official scientific institutions of the Russian Federation, in particular, its leading universities and the Russian Academy of Sciences bearing their own share of responsibility for the policy of the evil empire of President Putin, are subject to an unconditional boycott.

We urge that researchers with an affiliation of such institutions not be admitted to international grant teams, not be invited to international conferences, and not be published in leading international scientific journals. We strongly assert that any joint academic projects and conferences with such institutions are absolutely inadmissible and cannot be morally justified, all the more so those realized and held on the territory of the Russian Federation.

We believe that the solidarity of the international community will allow free and independent Ukraine to withstand and survive these tragic times.

Sincerely yours,

Igor Anisimov,

President of Ukrainian Physical Society

About International cooperation Constitution

krainian Physical Society

Люку Берже,

Європейське фізичне товариство, Президент

й проф. Берже,

Вам за Ва лист і за рішення виконавчого комітету Європейського фізичного
ства від 25 лютого. Для нас дуже важливо відчути підтримку європейського
вариства фізиків. Ми підтримуємо рішення про припинення всіх спільних дій,
них із Російською державою.

я, як і багато моїх колег, перебуваю в Києві. Кілька разів на день оголошується
на тривога, місто атакують російські ракети.

жчих ударів зазнає Харків – повідний поруч із Києвом) науковий центр України.
ть поранень і гинуть мирні люди.

уємо мужню позицію окремих учених-росіян, які мали сміливість закликати свій уряд
ти злочинне безумство. Водночас ми звертаємося до європейської й світової фізичної
ти: офіційні наукові інституції РФ, зокрема її провідні університети та РАН, які
свою частину відповідальності за політику злочинного режиму президента Путіна,
ють безумовному бойкоту.

кликаємо не допускати дослідників з афіліацією таких інституцій до міжнародних
зі здобуття грантів, не запрошувати їх на міжнародні конференції, не публікувати в
них міжнародних наукових журналах. Ми заявляємо про абсолютну моральну
устимість будь-яких спільних академічних проєктів та конференцій з такими
ціями, тим більше здійснюваних на території РФ.

имо, що солідарність міжнародної спільноти дозволить вільній Україні вистояти в ці
і часи.

ою,

ент Українського фізичного товариства

ісімов

EUROPEAN PHYSICAL SOCIETY

Statement by the Executive Committee of the European Physical Society

26 February 2022

The European Physical Society (EPS) strongly condemns the continuing attacks by the Russian Federation against Ukraine, an independent and sovereign country.

In clear violation of international law, the Russian government's decision will have drastic and negative consequences that are difficult to foresee, including on the development of the scientific cooperation between Eastern and Western European nations.

The values of the EPS are based on the free exchange and free expression of ideas and concepts in physics that nourish the development of our civilisation, and thereby contribute to the advance of humanity.

A country that invades its peaceful neighbor and threatens the other nations clearly violates these fundamental principles.

Therefore, the EPS calls on the entire scientific community and all citizens working in physics and beyond, to be uncompromising in their protest and to take active measures against the ongoing violence of the Russian army in Ukraine.

Today, the EPS expresses its deepest solidarity with the suffering Ukrainian people who find themselves in an unwanted and tragic situation in which not only their basic freedoms but also their very lives are threatened by the armed intervention of a foreign army. The Ukrainian Physical Society is a Member Society of the EPS and, as such, the EPS will do everything in its power to help to ensure the continuity of its cooperation with Ukrainian physicists.

Today, the EPS also sympathizes with the Russian physicists who refute the aggression of their government and suffer similarly from not being able to freely express their disagreement in their own homeland.

Today, in solidarity with our Ukrainian and Russian colleagues, the EPS suspends all joint actions co-sponsored with the Russian State for the time being. Further measures to be undertaken will be considered and acted by the next EPS Council in June 2022 in Paris, as the situation dictates.

Today, despite the dreadful and extremely dangerous crisis that the European continent is going through, the EPS firmly believes in a better future for tomorrow.

On behalf of the Executive Committee of the European Physical Society, Luc Bergé, President.

EPS Young Minds - an outlook in 2022

Mažena Mackoit Sinkevičiene, Anna Grigoryan, Richard Zeltner, Daryna Pesina, Carmen Martin, Hripsime Mkrtchyan, Tanausú Hernández and Mattia Ostinato

The Young Minds (YM) programme of the European Physical Society (EPS) was initiated 12 years ago, with the goal to connect young students and researchers all over Europe, to strengthen their collaboration and the exchange among them, and to support their professional and personal growth. The programme now comprises more than 60 active sections operating in over 35 countries within Europe and the neighboring Mediterranean countries. This article provides a summary of the latest developments within the Young Minds Action Committee and gives an outlook to planned and ongoing activities within 2022.

The EPS YM Leadership Meeting

During the annual Leadership Meeting (LM) section delegates from the whole network are coming together to engage in various professional development and networking activities. While the LM in 2022 had to be cancelled due to the Corona pandemic, a virtual LM meeting brought the community back together online in May 2021. Now, with the pandemic situation being seemingly under control, the YM community is looking very much forward to the first physical LM since 2019, which will take place in co-location with the EPS Forum 2022 at Sorbonne University in Paris. In addition to a seminar on "Science Outreach and Mass Media" by Dr. Giuliana Galati, and talks from Dr. Antigone Marino, former EPS YM Action Committee Chair, and Dr. Jean-François Morizur, Co-Founder and CEO of Cailabs, the participants will have the possibility to roam the

▾ Mažena Mackoit Sinkevičiene, former president of the Vilnius Section, and Anna Grigoryan, former president of the YM Artsakh, joined the Action Committee. Damián Rodríguez Fernández, current president of the YM section at the University of Santiago de Compostela, will join the committee after the summer break.

forum programme. Most notably, the participants will be able to attend the talks of three Nobel Laureates, Barry Barish (2017), J. Michael Kosterlitz (2016) and Serge Haroche (2012). Thus, 2022`s LM will be a unique meeting, providing opportunities for personal development of the Young Minds` well beyond that of previous meetings. It will further help to strengthening the ties within the network after more than three years of limited connection, in particular for the sections that were founded during the pandemic and that never had the chance to physically engage with the network before.

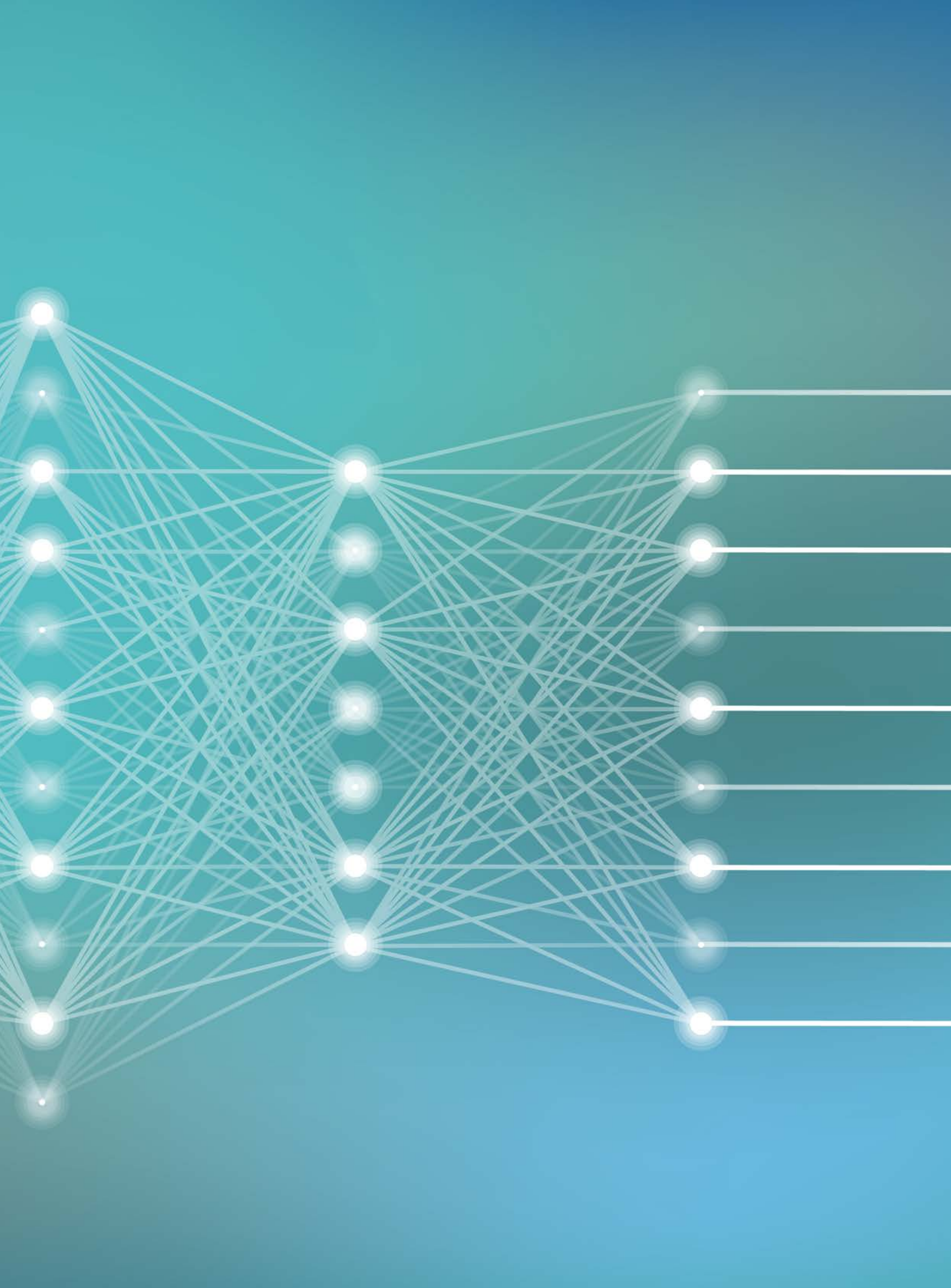
▾ The YM LM 2022 will be co-located with the EPS Forum 2022, providing unique opportunities to all section delegates attending.

New members in the Action Committee

Reacting to the continuous growth of the programme and the increasing number of tasks and projects that accompanies this growth the Action Committee called for applications to join its ranks in December 2022. A large number of YMs responded to this call and submitted their applications, showcasing how vivid and active the network is and how motivated its members are to contribute to the development of the programme. Among the many impressive applications Mažena Mackoit Sinkevičienė, former president of the Vilnius Section, and Anna Grigoryan, former president of the YM Artsakh, were selected and invited to join the committee, in recognition of their leadership and commitment in the development of their local communities. Damián Rodríguez Fernández, current president of the YM section at the University of Santiago de Compostela will join the committee after the summer break.

Activities planned in 2022

In consideration of the success of the first edition of "From PhD to CEO", a webinar series jointly organised by EPS YM, EPS and Optica in which researchers share their stories of starting up a company it has been decided to launch a second edition. Among the speakers in this second series is Piotr Węgrzyn, former president of the YM section at the university of Warsaw and CEO and co-founder of the Candela Foundation, a NGO that supports the growth and development of the optics and photonics community in Poland, and the young people it comprises. Additionally, the Action Committee is currently organising special sessions together with local YM sections at the 14th European Conference on Atoms Molecules and Photons, taking place in July in Vilnius, and the 11th Conference of the Balkan Physical Union, taking place end of August in Belgrade. Among the invited speakers are Christian Oswald from the European Research Council, who will present the ERC funding opportunities, and Gediminas Račiukaitis, President of the Lithuanian Laser Association, will talk about Career Opportunities in the Industry. ■



Data intensive approach in modern sciences

DOI: https://doi.org/10.1051/epn/2022203

The purpose and methodology of science is based on the functioning of human intelligence and overlaps to a large extent with the specificities of everyday thinking. This was true in historical times and in the scientific big data era, aided by modern artificial intelligence.

When we describe thinking, we usually distinguish between the observed reality and the thinker. Information flows from the world through the senses into our minds, where an internal, simplified version of reality, a "model", is dynamically formed based on our innate "hardware" and "pre-installed software". This internal model represents the objects, creatures and phenomena of the outside world. The representation is not passive, like a photograph or a film, but dynamic, capable of dealing with phenomena and events, and also capable of rehearsing situations that have not happened and also to make predictions. Science has taken this process of perception and modelling to extremes and has extended it beyond the limits that evolution has readily provided.

Our organisms as a whole have evolved to specialise in performing the functions necessary for survival, and are therefore not universal. With our eyes we can see the phenomena around us with high temporal and spatial resolution, but we cannot see the trajectory of a bullet, we cannot resolve the scale of cells, and we cannot see the faint galaxies. In fact, we can only detect the narrow band of the entire electromagnetic spectrum, visible light, not radio waves and gamma rays.

The invention of the telescope, followed by a number of other instruments capable of detecting the broader range of the electromagnetic spectrum, played a major role in the development of astronomy and, through it, modern science. Telescopes can be seen as a prosthesis that gives our eyes capabilities we did not have before.

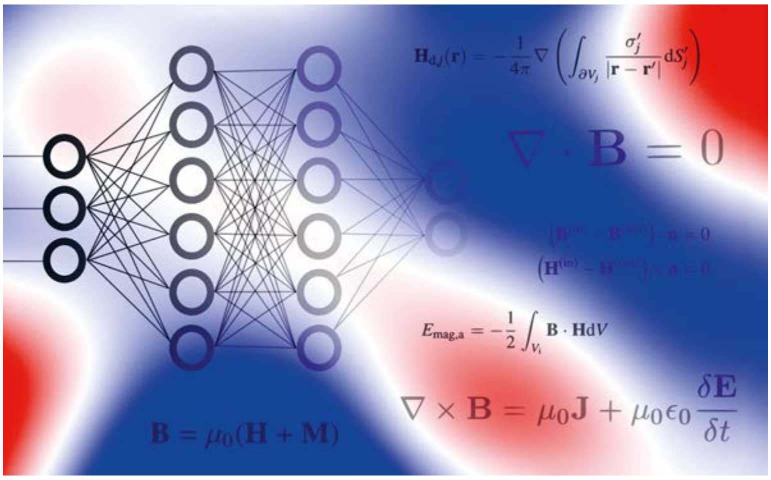
We may be less aware of it, but like our senses, our brain is a purpose-built device, too, rather a universal intelligence. On the one hand, we are amazed at how sophisticated is the human intelligence already at birth. An infant can imitate a face which process involves complex image recognition and coordinated control of many muscles: all feats that modern computers with their enormous capacity cannot match. However, it takes six to eight years on average to learn to perform elementary operations on numbers below 20. In the same way that there was no evolutionary pressure to develop a gamma detector eye, it is likely that the talent for courting took precedence over the ability to divide a fraction by a fraction in the allocation of mental capacity, although the latter could be achieved with surprisingly few neurons.

It is not only our senses that need prostheses, even the minds of most talented scientists are not universal and limited in capacity. Our short-term memory buffer can only hold 7±2 items, and while we know the multiplication table of 10 by reflex, not many people can multiply ten-digit numbers in their heads. The simplest mental prosthesis is paper and pencil: with a little patience, writing can be used to perform very complex operations

These sensory and brain prostheses, hardware and software additions, have enabled us to perceive modalities, develop theories and understand phenomena that would have been impossible with instinctive human reasoning. The science and the technology that has been built on it has transformed and is transforming the world.

Science has entered a new era, from understanding the simple to understanding increasingly complex phenomena. To describe complex reality, complex models are needed, which often cannot be derived from fundamental laws. This approach has received a new impetus in recent years with the framework of artificial intelligence. Beyond the applications in everyday life, this approach is gaining ground in sciences, including physics. This transformation is demonstrated by the articles in this issue and by the fact that the 2022 EPS Forum will also dedicate a special section to machine learning and artificial intelligence. ■

■ **István Csabai,**
Eötvös University, Budapest



DEEP LEARNING FOR MAGNETISM

Stefan Pollok and Rasmus Bjørk –
DOI: https://doi.org/10.1051/epn/2022204
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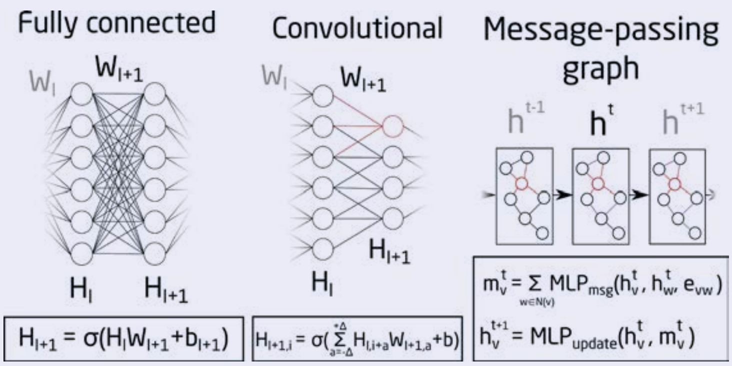
In deep learning, neural networks consisting of trainable parameters are designed to model unknown functions based on available data. When the underlying physics of the system at hand are known, *e.g.*, Maxwell's equation in electromagnetism, then these can be embedded into the deep learning architecture to obtain better function approximations.

Magnetic fields are used in a multitude of applications, from MRI scanners to electric motors. These applications must have the magnetic field that ensures the highest application performance. Realising this field can involve everything from analytical or finite element modeling [1] to magnetic field measurements and device prototyping. To ease this process, whether it is reducing the computational load, assisting in characterising field measurements or suggesting new designs, machine learning is being increasingly used in the field of magnetism. This is what we explore in this work, with a special focus on deep learning (DL).

Deep learning - Function approximation with neural networks

Like other machine learning algorithms, DL is data-driven. The data can originate from measurements or simulations. Characteristic of DL is the mapping of input data to the output domain with a biology-inspired neural network (NN) structure. NNs consists of multiple layers of trainable parameters with the idea to extract progressively higher-level features. During training, NN parameters are updated to minimise the difference between the given outputs and the corresponding predictions based on a set of input data.

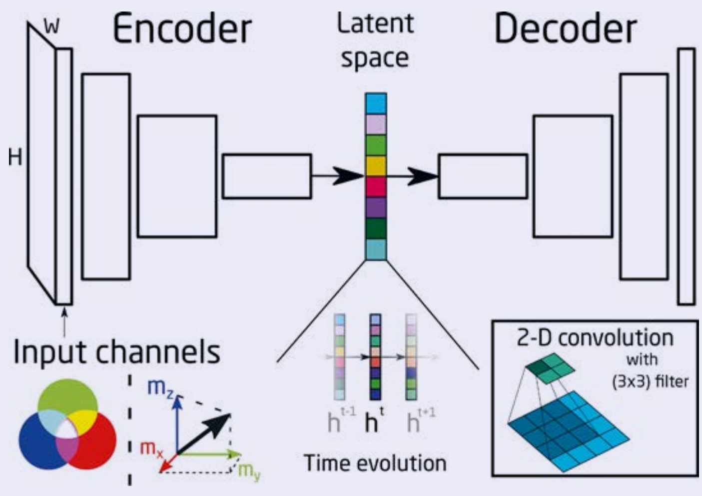


Layer setup of three different neural network architectures: Fully connected, convolutional, and message-passing graph. In the fully connected setup, each node of layer $\mathbf{H}_l$ is connected to the nodes of the next layer $\mathbf{H}_{l+1}$ by an individual weight. The values of these weights are updated during training to approximate a target function. After having multiplied the resulting weight matrix $\mathbf{W}_{l+1}$ with H_l and having added a bias term $\mathbf{b}_{l+1}$, a nonlinear activation function σ completes the mapping. In convolutional neural networks, the weight matrix between successive layers is sparse. As Δ is 1 in the presented case and the weights for all receiving nodes in the layer $\mathbf{H}_{l+1}$ are shared, the weight matrix contains only 3 parameters. In message-passing graph neural networks, the input data is embedded into nodes and edges. For each time step, a message $\mathbf{m}_v^t$ is calculated as the sum of incoming information from neighboring nodes $\mathbf{h}_v^t$ with edges $\mathbf{e}_{vw}$. The state of node v is then updated from $\mathbf{h}_v^t$ to $\mathbf{h}_v^{t+1}$ with $\mathbf{m}_v^t$. MLP stands for multilayer perceptron, which can be any feedforward neural network.

We consider three types of NN, which are visualised in Box 1:

- In the fully connected setup, each incoming node is connected by individual weights with all outgoing nodes. By stacking multiple layers followed by a nonlinear activation function, complex nonlinear mappings can be approximated.
- In convolutional neural networks (CNNs), there is a sparse connection between successive layers and the weights of a small filter matrix are shared, which makes it more data-efficient. The filter convolutes the neighbouring, incoming nodes to create local receptive fields in the next layer. By stacking multiple of these layers, high-level features can be learned.
- In graph neural networks (GNN), the NN nodes can be arbitrarily connected with other nodes. The next layer is created by updating each node with the sum of incoming messages from connected nodes. This can lead to powerful representations.

Although DL was established in the machine learning community some decades ago, it was not before residual connections [2] were introduced that DL was used in magnetism. Instead of modeling the unknown, underlying mapping between input-output pairs directly, DL architectures were built to model the residual between input and output. These reformulated mapping functions exhibit properties that are more easily learned during training.



Encoder-decoder structure realised with multiple 2-D convolutional layers. The input data has shape C×H×W, where C is the number of channels, H is the number of pixels in the height, and W is specifying the width of the input. The number of channels increases in the encoder part from layer to layer while the window size becomes smaller. By doing this, higher-level features can be extracted progressively while preserving information. A rich, low-dimensional representation of the input is obtained in the latent space. Optionally, time evolution or other operations can be performed computationally efficient in the latent space. In the decoder, the convolutional layers are translated to increase the window size back to a desired resolution $C_{out} \times H_{out} \times W_{out}$. In Kovacs *et al.* [5], the output of this structure shall resemble the magnetisation vectors of the input. This special case of an encoder-decoder setup is called an autoencoder. Here, the main learning objective of the neural network weights of the 2-D convolution filter matrices is to find the rich latent space representation. In Khan *et al.* [4], the output of the decoder shall represent the magnetic field strength as target domain while feeding material information into the encoder. Originally, this DL architecture was used in computer vision to extract information of RGB images.

Motivation for deep learning for magnetism

We study the application of DL in magnetism because this is an ideal subset of physics for which to study if DL can extend our modeling capabilities, expand our physical understanding, and help realise more efficient technologies. The reason for this is that the physical laws governing magnetism has been understood since Maxwell, and the equations give rise to a predictable physical behaviour. Said in other words, magnetism does not contain complexities such as turbulence or chaotic behavior. This means that magnetism is an ideal proving ground for testing DL before moving on to more complex physical domains.

In physics, DL has been employed as a surrogate model for computationally expensive models, as a PDE solver without meshing, or in analysing tasks where data is available but the underlying physics is unknown. Within magnetism, DL has been employed in magnetostatics, micromagnetism, and electromagnetic (EM) setups. In magnetostatics, the calculation of magnetic fields is performed on the macroscale, *e.g.*, from low-frequency EM devices [3] or from permanent magnets [4]. In micromagnetism, the magnetisation inside a material is found and how this responds dynamically to, *e.g.*, the application of an external field [5]. EM setups include design optimisation of electric machines [6], controller design for electric drives [7], and finding the solution of EM field scattering [8].

Convolutional neural networks in magnetism

In 2019, DL in micromagnetism was first used by Kovacs *et al.* [5] to approximate the time evolution of the magnetisation in a thin film, as governed by the Landau-Lifshitz-Gilbert equation [9]:

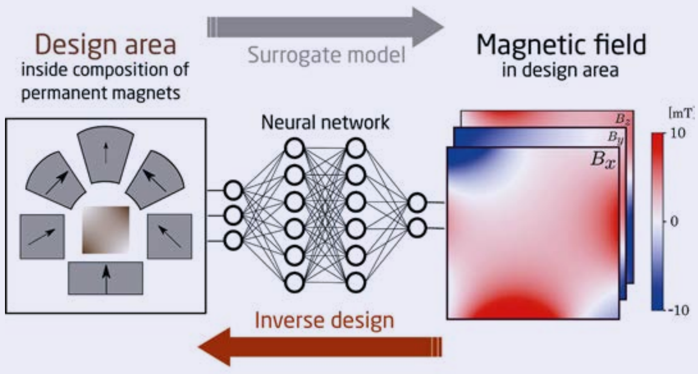
$$\frac{\partial m}{\partial t} = -\gamma \mathbf{m} \times H_{eff} + \alpha \mathbf{m} \times \frac{\partial m}{\partial t},$$

where **m** is the local magnetisation, γ is the gyromagnetic factor, α the dampening constant, and H_{eff} the effective field, usually composed of four terms representing the exchange, demagnetisation, anisotropy and •••

• • • applied field. The authors employed a CNN in an encoder-decoder structure as depicted in Box 2. The idea behind the encoding pathway is to progressively extract higher-level features and to obtain a rich, low-dimensional representation of the data in a latent space without loss of information. In the autoencoder setup, the original data is reconstructed from latent space with a decoder. In this low-dimensional space, the time integration of the local magnetisation was learned with a second, fully connected NN based on previous states and the applied field. The method showed good agreement with a finite difference model.

Around the same time, Khan *et al.* [3] demonstrated that Maxwell's equations for low-frequency EM devices can be modeled by CNNs. In a similar encoder-decoder as shown in Box 2, the magnetic field is approximated given only design geometry, excitation, and material properties. The input material data was formulated similar to multichannel images with a resolution of H × W. This was done because DL was mainly developed within computer vision, where it extracts information from RGB images. Therefore, the magnetic problem was represented similarly, *i.e.*, by meshing the 2-D area around the EM device into a uniform grid. The material information *mat* at the center of each pixel was assigned to the channels previously used for the color components, resulting in a *mat* × H × W representation. The preprocessed input data was then convoluted with multiple stacked CNN layers with decreasing resolution but increasing number of channels. Thereafter, the compressed state was upsampled to the original resolution with stacked transposed convolutional layers. Instead of using it as an autoencoder, the norm of the magnetic field in each pixel center was learned directly. During training, the CNN parameters were updated to minimise the difference between predictions and the solution of a finite element model. For unseen EM configurations, this resulted in a normalised root mean square error of ~1%.

This early work in DL for magnetism inspired other researchers to switch the mapping direction between input and output of the DL network [4] as shown in Box 3. Now, based on a given magnetic field, the properties of a permanent magnet to generate that specific field can be inferred, allowing for inverse design of permanent magnet configurations.



Possible pathways for the use of deep learning in magnetostatics. In many modern applications like magnetic resonance imaging or electric motors, permanent magnets of different shapes and magnetic properties are assembled to produce a magnetic field, whose field strength and homogeneity match the requirements for the given application in a design area. When finite element modeling becomes computationally expensive, a trained neural network can approximate Maxwell's equations and serve as a surrogate model during topology optimisation. As the mapping direction between input and output can easily be interchanged in a deep learning setup, a neural network can also be trained to take the desired magnetic field as input and to predict the structural properties of the composition of permanent magnets necessary to produce such a field.

Application of more sophisticated deep learning architectures

So far, we have only described CNNs in an encoder-decoder fashion. Since the work of He *et al.* [2], more sophisticated DL architectures have emerged, which have been recently applied to magnetism.

For instance, generative adversarial networks are used for magnetic field prediction [10]. Given only a few points measurements in a 2-D area of interest, a trained generator network, consisting of multiple layers of CNNs, can predict missing magnetic field values with an error below 6 %. This is achieved by updating the generator parameters in such a way that a second NN, a so-called critic, cannot differentiate between real magnetic fields and generated magnetic fields. Additionally, reconstruction and physical constraints are included during training.

Such an embedding of the underlying physical laws into a DL architecture has been pursued further with so-called physics-informed neural networks [11]. Here, the underlying physical laws, *i.e.*, Maxwell's equations, along with surface and boundary conditions are directly integrated into the loss function of the DL architecture. Recently, this setup was extended to parametric magnetostatic problems by using a 10-dimensional parameter vector to allow for more flexibility [12].

Another interesting direction is the use of deep reinforcement learning in magnetism to perform controller design for magnetic technologies. Degrave *et al.* [7] recently showed that a trained NN can autonomously control the magnetic actuator coils to shape and maintain plasma inside tokamak vessel.

Conclusion and Outlook

We have described the use of DL within magnetism and documented how DL has been used to calculate magnetic fields, to predict inverse magnet properties and to time evolve a micromagnetic model. Future directions of DL with magnetism can be to represent, *e.g.*, compositions of multiple permanent magnets as graphs. As graph structures do not rely on uniform grids in contrast to CNNs, magnetic fields can be predicted more efficiently. An instance of message-passing GNNs for predicting molecular properties was developed by Schütt *et al.* [13]. Recently, a general framework for modeling dynamics of physical systems with Transformers, a fully connected version of GNNs, was proposed by Geneva *et al.* [14]. This shows how exciting this area is and that it is likely to expand and evolve in the coming years. ■

About the Authors

Both authors are from the Technical University of Denmark, Department of Energy Conversion and Storage.
Stefan Pollok has been a PhD-student at the department since 2019 and is an expert on machine learning.

Rasmus Bjørk is professor and has worked with magnetism since 2007, both within modeling and experimental devices. They both develop the open-source modeling framework MagTense.

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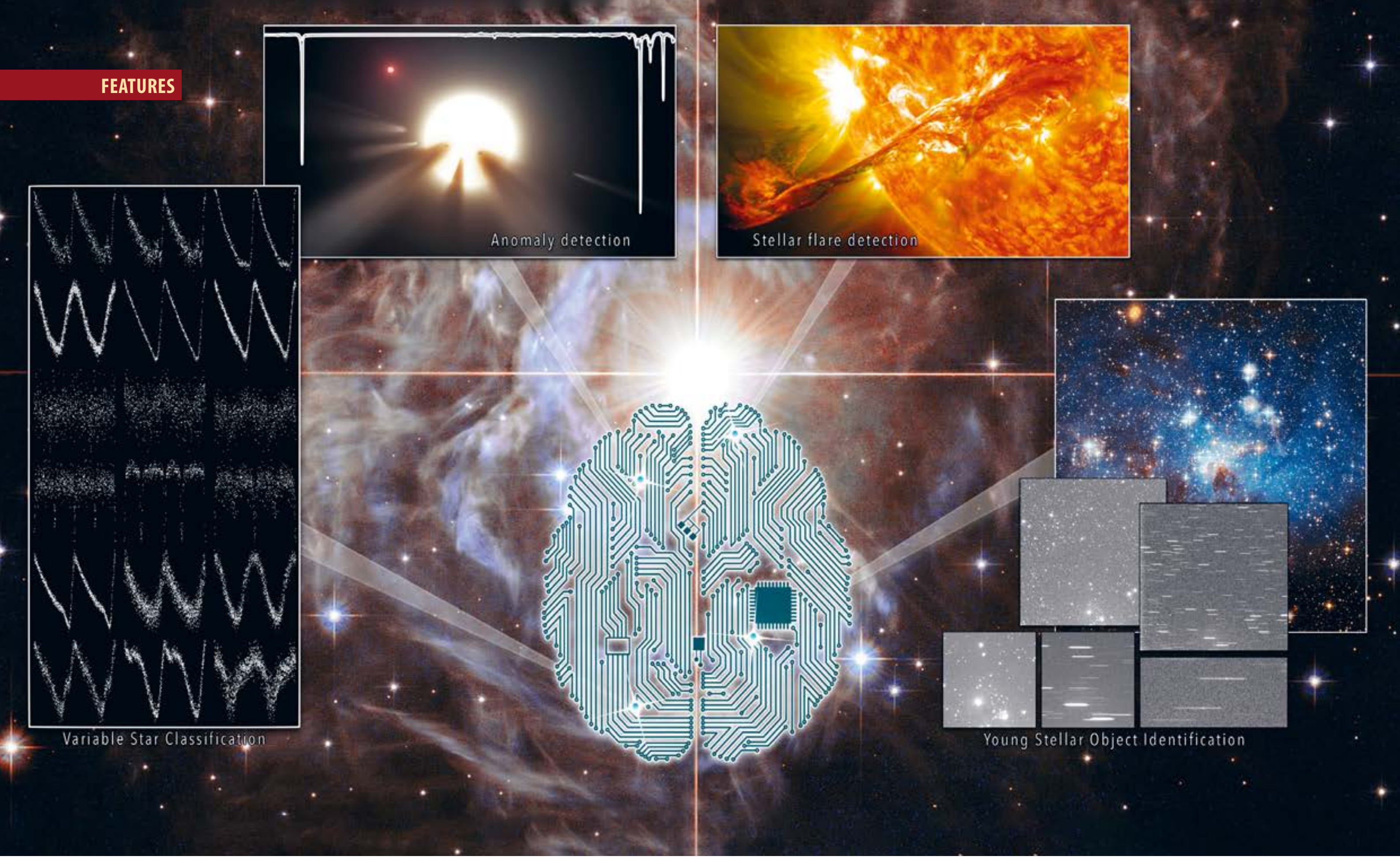

MACHINE LEARNING IN PRESENT DAY ASTROPHYSICS

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Machine learning is everywhere in our daily life. From the social media and bank sector to transportation and telecommunication, we cannot avoid using it, sometimes even without noticing that we are relying on it. Astronomy and astrophysics are no exception. From telescope time and survey telescope scheduling through object detection and classification, to cleaning images and making large simulations smarter and quicker to it is ubiquitous to use machine learning algorithms. To illustrate this silent revolution, we checked the NASA Astronomical Data System website[1] and searched for the keyword 'machine learning' in abstracts of astronomical and astrophysical papers. In 2000 we found 56, in 2010 889, and by 2020 no less than 35,659 abstracts contained the magic two words.

[1] https://ui.adsabs.harvard.edu/

▲ Typical applications of machine learning techniques in astronomy from object detection and classification to finding anomalies.

No wonder, since existing and upcoming astronomical databases are truly 'astronomical': Vera C. Rubin Observatory's Legacy Survey of Space and Time[2] will deliver 150 Petabytes of photometric data and images in the optical and near-infrared wavelength range, while the upcoming Square Kilometer Array[3] will produce 5 Zettabytes of data in the radio domain by 2030, just to mention two soon-to-be-online large surveys. To keep up with, exploit, and understand this tsunami of data, applying machine learning is a must. In this paper we highlight a few interesting cases in astronomy admitting that because of the breadth of this topic only a subjective selection is possible.

Anomaly detection, let's find the 'unknown unknowns'

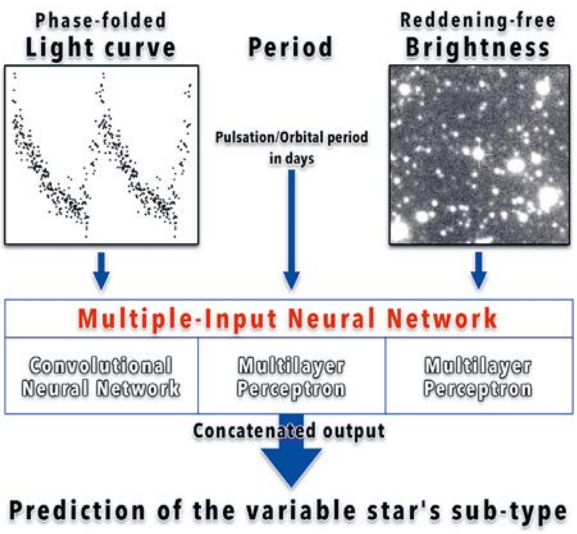
The discovery of new astrophysical phenomena has long been the major goal of astronomical research. In astronomy a new physical phenomenon can manifest itself in many forms, from strange-looking shapes in images to exotic behaviours in time-series observations. With the advent of large-scale sky surveys such as Gaia, Pan-STARRS, ZTF, LSST, not only the well-known stars are being regularly observed, but everything that is bright enough to be detected with few-meter-class telescopes. Thanks to these observations, it has become possible to discover such intriguing bodies as 'Oumuamua, the first known interstellar object that passed through the Solar System, or the Boyajian star, the 'most mysterious star in the Universe', whose brightness variation is so unusual that at one point even alien megastructures were invoked to explain the observations. However, due to the exponentially growing amount of data, the traditional, human supervised way of data processing is less and less feasible, indicating the necessity of development of automatic novelty detection methods. The increasing pressure to enter the era of big data has led the astronomical community to utilise machine learning techniques to look for out-of-distribution anomalous astronomical objects.

A few recent examples for novelty or anomaly detection in astrophysics: [1] processed the raw data of the Open Supernova Catalog and identified non-supernova events and representatives of the rare supernova classes. [2] proposed and demonstrated a new anomaly detection technique to discover anomalous X-ray sources via high-resolution spectroscopy. [3] proposed a method to find a second Earth, *i.e.*, to detect potentially habitable exoplanets as anomalies. Finally, [4] used the light curve of periodic variable stars and identified stars with irregular variability. The one-million-dollar question is of course how to find the needle in the haystack, *i.e.*, how to find and follow-up(!) the rarest and/or most interesting (maybe Nobel-prize winning) objects among the million(s) of transients detected by LSST on a given night when the 8-meter large field-of-view Simonyi telescope starts surveying the Chilean sky in 2023.

> **"Our research team has developed high-precision algorithms to classify the light curves of periodic variable stars into a few main classes."**

Classification – let's teach the computer to 'see' like a human

Classification is the guinea pig of machine learning applications in astronomy. Large sky surveys conveyed millions or billions of images, spectra, positions, and proper motions of stars and galaxies and other celestial bodies. To make sense of these data one needs help from the 'silicon brains.' A subfield of astrophysics – but nonetheless a very important topic – is studying variable stars. These stars allow an unprecedented view into stellar interiors, help to establish the cosmic distance scale, and can be used as tracers of Galactic formation and evolution. Astronomers traditionally have classified objects that vary their brightness based on their light curves, that is graphical representation of light variation as a function of time. If additional information (*e.g.*, a spectrum) is available, then certain degeneracies can be broken. Classification can be performed based on several mathematical parameters of light curve data (range, scatter, number of zero crossings, skewness, *etc.*), but what if we want to mimic the human brain and feed images of light curves into the computer? Well, our group did exactly that [5].

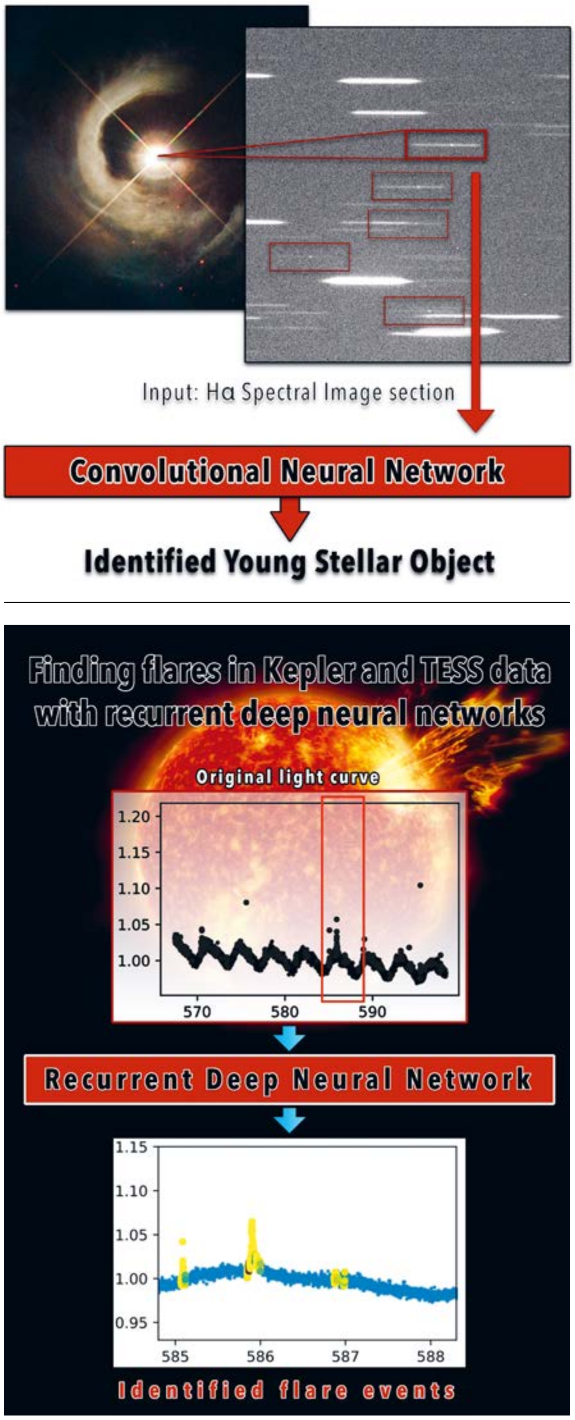


▲ **FIG. 1:** Schematics of the image-based classification of periodic variable stars [5].

[2] https://www.lsst.org/

[3] https://www.skatelescope.org/

Our research team has developed high-precision algorithms to classify the light curves of periodic variable stars into a few main classes. If humans (professional astronomers) see a light curve of adequate quality, they can assign a variable type to the light curve. If the period is also known, then the classification can be close to perfect. However, human beings can classify only a few dozens of light curves (at maximum) every minute, and they cannot sustain this rate for long. Our supervised image-based machine learning method supplemented with numerical parameters (*e.g.*, period, luminosity, *etc.*) can reach or exceed the accuracy of human classification. Not to mention its speed that can be orders of magnitude faster than that of the human classifiers. Our neural network is a 'Multiple-Input Neural Network', which is made up of a Convolutional Neural Network and Multilayer Perceptrons and it can handle both image and numerical data. Recently we extended this method to incorporate sub-classes of variable stars, as well, with similar performance. Now we can not only tell cats and dogs apart but can classify millions of variable stars in a few minutes. And we don't need an army of graduate students to do the boring job. Although the job had had to be done manually at least once – our method needs labeled data, and labeled data are almost never available in astronomy for obvious reasons.



▸ **FIG. 2:** Upper panel: Identification of young stellar objects with a Convolutional Neural Network via detection of Hα emission lines (small point-like blobs) in low-resolution spectra. Lower panel: identification of stellar flares with a Recurrent Deep Neural Network.

Object detection – how to separate the wheat from the chaff?

Like many other disciplines, astronomy relies heavily on the possibilities offered by imaging tools. The large sky survey programs produce vast amounts of data – many terabytes per night – which cannot be processed manually on human time scales. With the use of machine learning tools, we are able to identify and categorise the distant galaxies of the Universe, stellar streams (remnants of dwarf galaxies) in the halo of our Galaxy or even the comets and asteroids of our own Solar System. Another application is the detection of young stellar objects (YSO) in astronomical recordings. These types of celestial bodies are stars in an early evolution stage, for example protostars or pre-main-sequence stars. Although these objects appear as "normal" stars in a CCD image, if we take low-resolution spectra, the YSOs' spectra will show strong emission in the Hα line. Based on this idea we created a Convolutional Neural Network. After proper training, the neural network can distinguish ordinary stars from YSOs with high precision.

How to turbo-boost your simulations with machine learning?

Large cosmological simulations are extremely resource intensive, since they take into account the action of gravity of billions of particles that trace the cosmic matter distribution including dark matter. This can easily be a bottleneck despite the ever-increasing computational capacity of the largest supercomputers. Well, who said that it is easy to simulate the whole universe? However, generative adversial networks (GANs) may come to the rescue [6]. This machine learning tool can generate cosmic web simulations that are quantitatively and qualitatively practically indistinguishable from real simulations, especially on large scales. The difference in computational time is huge: a fraction of a second for

[2] https://exoplanets.nasa.gov/

the GANs corresponds to many hours using traditional full-scale simulations.

Cosmology is not the only subfield where complex simulations are required. Much less demanding computations – at least in terms of mass particles involved –, but still very long integration times arise in celestial mechanics, for example when one has to decide whether a planetary system is stable or not on a timescale of billions of years. The discovery of close to 5000 exoplanets[4] during the last 28 years makes this problem even more acute. Direct integration of the motion of multiplanetary systems in large numbers is still prohibitive. However, machine learning can speed up the process by 5(!) orders of magnitude [7] by learning relevant, physically motivated features (chaos indicators, strengths of mean motion resonances, variance in eccentricity difference, *etc.*) from the beginning of the simulation period. That way the method can make accurate predictions about the stability properties of the system. ■

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Tamás Szklenár is a software developer working with R. Szabó's group. His main interest is machine learning methods and their applications. He is also interested in binary stars.

Acknowledgements

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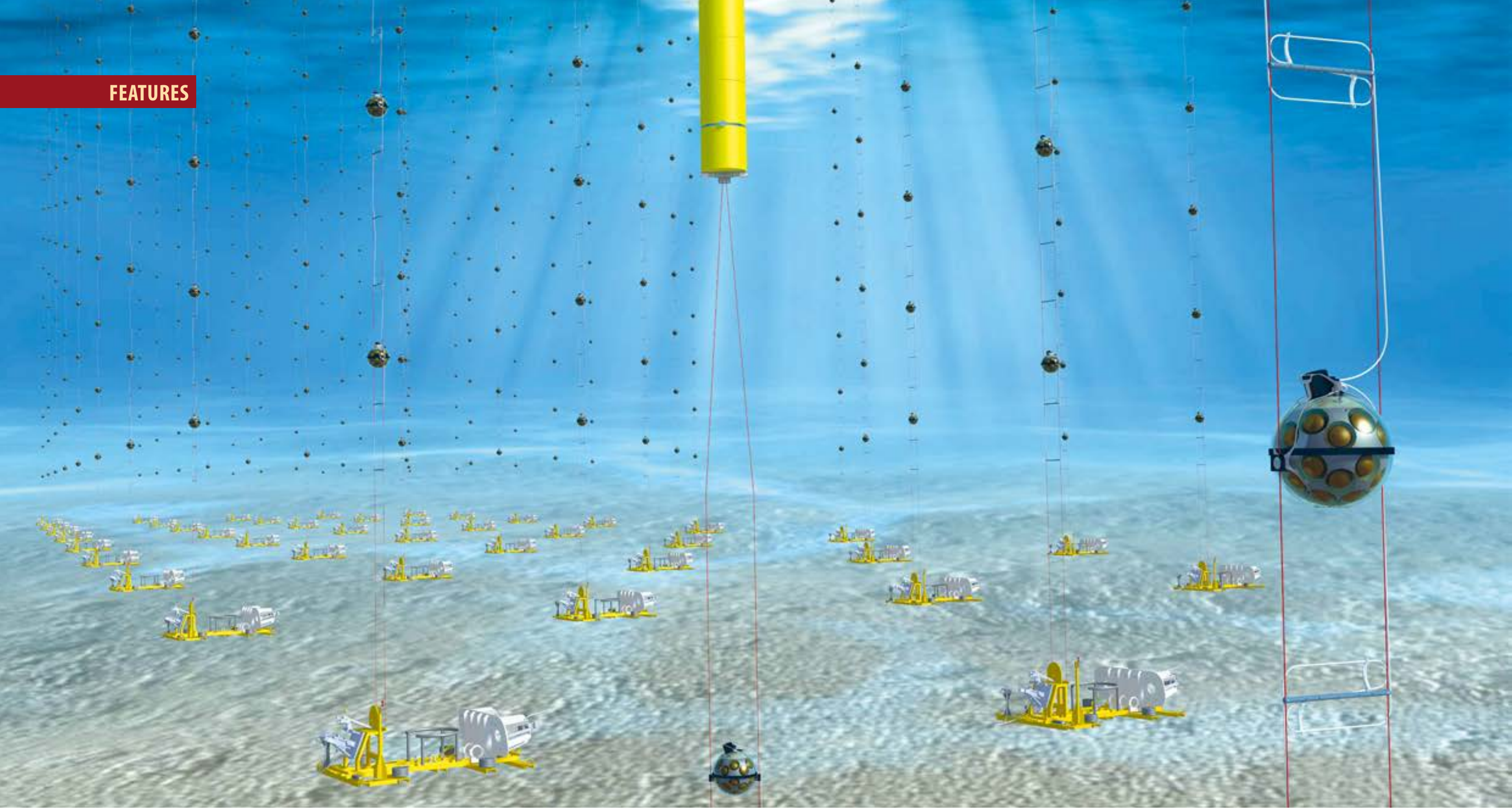

MACHINE LEARNING TECHNIQUES DEEP UNDERWATER IN KM3NET

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On behalf of the KM3NeT Collaboration

Deep in the water of the Mediterranean Sea, the KM3NeT detectors aim at the exploration of the cosmos through the detection of neutrinos and to determine the neutrino mass ordering. Machine learning techniques are widely used to push the performance of the detectors to the limit.

▲ **FIG. 1:** Rendition of a KM3NeT detector anchored to the seabed. In reality daylight does not reach the depths at which the detectors are installed. Credit KM3NeT Collaboration

The deepest abysses of the seas do not simply represent the last frontier of exploration of our planet. They also give an opportunity to look at the farthest reaches of the cosmos. With the two detectors ARCA and ORCA[1] well under construction in the Mediterranean Sea, KM3NeT has the ambitious goal to detect neutrinos coming from astrophysical sources such as supernovae, gamma ray bursters or colliding stars; and to study neutrino properties exploiting neutrinos generated in interactions of cosmic rays in the Earth's atmosphere [1].

The detectors of KM3NeT

ARCA and ORCA, respectively tailored to the two main scientific aims of KM3NeT, are built as grids of optical sensors which can detect the faint light signals induced by the Cherenkov effect when the secondary particles produced in neutrino interactions propagate in the water of the deep sea. A rendition of the detector grid is shown in Fig. 1. The ARCA detector is located at about 90 km from the coast of Capo Passero, at the southern tip of Sicily, at a depth of almost 3500 m. ORCA is located about 40 km offshore Toulon, not far from the installation site of the predecessor experiment ANTARES[2] [2], at a depth of about 2500 m.

The technology of KM3NeT has been developed building to a large extent on the experience achieved with ANTARES. The basic detection node of KM3NeT

[1] ARCA/ORCA: Astroparticle / Oscillation Research with Cosmics in the Abyss
[2] ANTARES: Astronomy with a Neutrino Telescope and Abyss environmental RESearch

is represented by the optical module (Fig. 2), a pressure-resistant glass sphere equipped with 31 photomultipliers with a three-inch photocathode diameter. The module also includes timing and positioning calibration devices and the electronics for data acquisition and long-range communication [3]. Eighteen modules are arranged on a vertical detection unit which stands on the sea bottom to a height of almost 700 m in ARCA and 200 m in ORCA. The detection units have a slender design (see Fig. 1): the optical modules are attached to two ropes stretching from an anchor resting on the sea floor to a top submersed buoy meant to keep the structure taut. An electro-optical backbone cable runs the full length of the unit and connects all optical modules to an interface module located on the anchor, which is in turn connected through a network of submarine cables and junction boxes to a control station located onshore. For installation purposes, the detection unit is mounted on a launcher vehicle [4] which is temporarily attached to the anchor (Fig. 3); once this compact stack has been deployed to the predefined position on the sea floor, and the connection to the submarine network has been made, a release mechanism is opened by a remotely operated vehicle, leaving the buoyant launcher vehicle free to rise and float to the sea surface, while the detection unit unfurls from it. In their full configurations, ARCA will comprise a forest of 200 such detection units, ORCA more than 100. At the current stage of construction, data taking is already taking place using a total of 18 detection units which have been installed in the two sites.

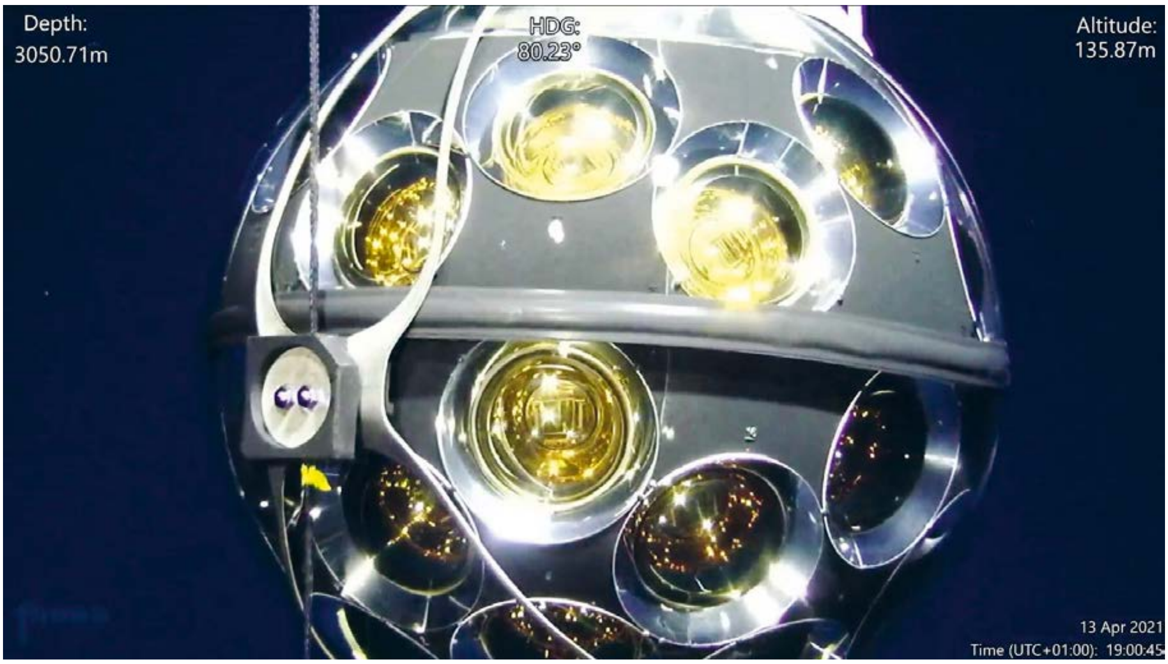
Machine learning techniques

The photomultiplier signals - 'hits' - are used to reconstruct the properties of the incoming particles, such as their energy and direction. For this purpose, the nanosecond-precision arrival time of the light at the sensors, the position of the sensors, their orientation, and the amount of light registered by each photosensor are recorded in a time window defined around the decision of one or more trigger algorithms. The hits recorded in such an 'event' then serve as input for offline reconstruction and classification algorithms.

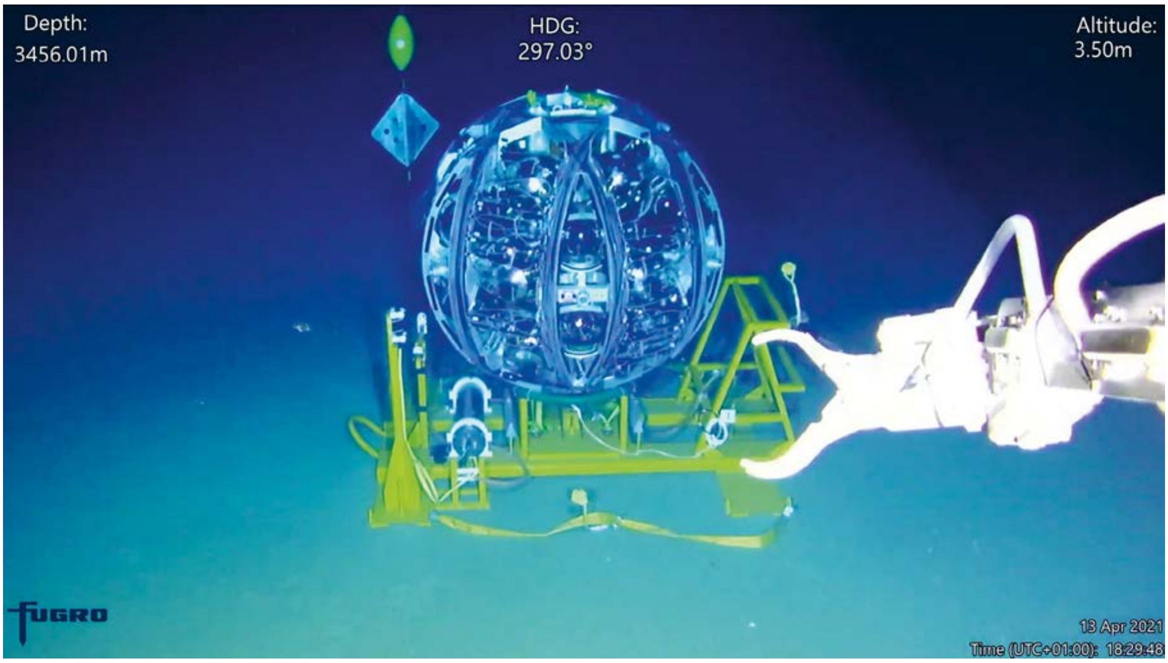
KM3NeT can detect all possible configurations of neutrino-induced events, including long tracks due to high-energy muons, multi-muon events, and the more complex signals due to electromagnetic showers and the hadronic cascades of secondary particles induced in neutrino-nucleus interactions. Classical machine learning techniques for the offline analysis of KM3NeT data have been in use since the start of the project. KM3NeT mainly employs algorithms based on sets of decision trees for event-type classification that are trained on extensive sets of Monte-Carlo simulations. Random decision forests, an ensemble learning method for classification, has been applied successfully to the identification of atmospheric muon events, which may provide million times more abundant detectable events than neutrinos and represent the main background to neutrino event identification in a neutrino telescope. With this technique, it could be shown that an efficient background suppression is possible. The method is also applied for the identification of different neutrino flavours and interaction types. For this purpose, the spatial and temporal distribution of the hits is used to calculate discriminating observables that encode information about flavour and interaction type.

Performance

Recently, the use of random decision forests in KM3NeT has been superseded by another predictive model that also uses ensembles of weak learners to build a ●●●



◂ **FIG. 2:** A photo of an optical module in the deep sea at a depth of 3050 m. Credits KM3NeT Collaboration.

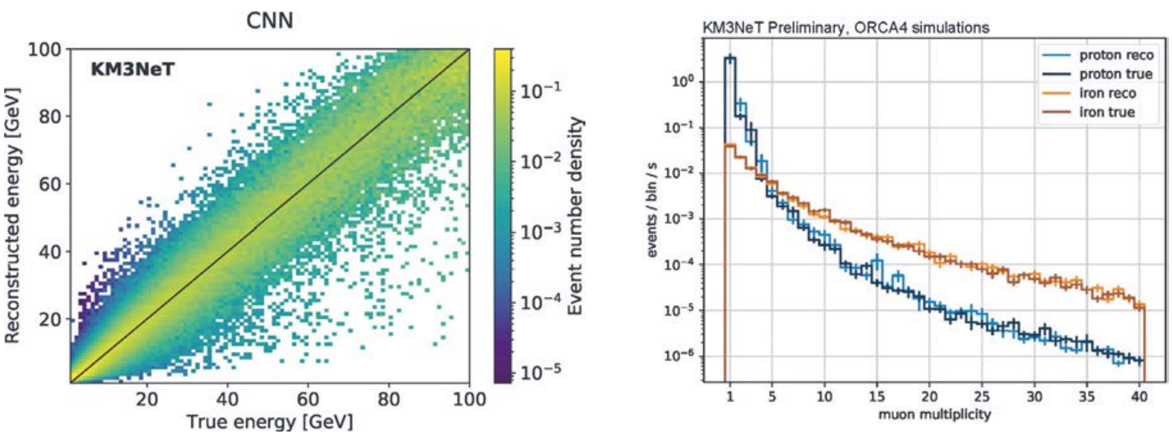


▶ **FIG. 3:** Detection unit in its launcher vehicle, anchored to the seabed at 3456 m. in the foreground the arm of the submarine which will activate the release mechanism for unfurling. Credits KM3NeT Collaboration.

••• strong classifier, XGBoost [5], an open-source software library well known for winning various awards, notably the HiggsML challenge. It has been found to outperform random decision forests while integrating more easily, in particular for machine learning applications, into the KM3NeT software eco system, which is largely based on python.

Deep learning algorithms have been adopted in KM3NeT since the middle of the last decade. Convolutional Neural Networks (CNNs), based on their TensorFlow[3] implementation, were explored first and successfully for event classification and neutrino property regression tasks in ORCA [6]. For training and validation of the CNNs, simulated events were transformed into multi-dimensional images binned in space and time. Different CNN architectures have then been tested and trained to achieve the same classification tasks as with the classical machine learning methods, and in addition were used to reconstruct the neutrino direction and energy (see Figure 4 left for an illustration) including a prediction for the respective uncertainty, allowing for resolution binning in data analysis. Based on extensive and detailed Monte-Carlo simulations of the neutrino interactions, the secondary particle propagation and detector response, it has been found that CNNs can outperform the classical decision tree methods for KM3NeT. In order to facilitate the time-consuming training and evaluation process of neural networks for KM3NeT and other neutrino telescopes a publicly available training organiser framework has been implemented [7].

In order to avoid the need for spatial and temporal binning that in general results in a loss of information, and since the data recorded by KM3NeT closely resembles point clouds, Graph Neural Networks (GNNs) have recently been found to be a natural choice for the network architecture. In the input to the GNN, the information of each single hit becomes a network node feature. The architecture of the GNNs used now for KM3NeT closely resembles the ParticleNet model [8]. It comprises three



▶ **FIG. 4:** Left: Energy as reconstructed by a convolutional neural network versus true Monte-Carlo neutrino energy for electron neutrino charged-current events in KM3NeT/ORCA (taken from [6]). Right: GNN reconstructed and true Monte-Carlo muon multiplicity rates in KM3NeT/ORCA with 4 detection units for protons and iron nuclei as cosmic ray primaries.

[1] http://tensorflow.org

edge convolutional blocks, followed by a global pooling layer and two fully connected layers, implemented as an open-source python package based on TensorFlow [8].

The GNN implementation is currently employed for a variety of different networks and tasks. It shows for the same tasks similar or better performance than the previously used CNNs. Consequently, the GNNs are now evaluated and used for neutrino flavour oscillation analyses with ORCA data. Another GNN with a different architecture even allows for the reconstruction of the properties of atmospheric muon bundles. These are created in collisions of cosmic-ray particles with atomic nuclei in the atmosphere. Reconstructing the bundle multiplicity and extension is challenging, and the application opens up the possibility, as illustrated in Fig. 4 right, to study the mass composition of primary cosmic rays exploiting the large data sets of atmospheric muon events collected routinely by very large neutrino telescopes operating in natural media. ■

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A TASTE OF THE FUTURE CAREER DISCOVERING PROFESSIONAL ROLES THROUGH ONLINE TESTS

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Scientists and engineers end up in a wide variety of professional positions. Research emphasises the need for supporting students to explore the broader work field and to enhance professional role awareness. Within the European PREFER project a professional roles model for engineers has been developed and implemented in education thanks to associated ready-to-implement tools. But what about scientists?

'Employers, education providers and youth live in parallel universes' states the European Report 'Education to employment: designing a system that works' [1]. Employers and education providers should communicate and collaborate more to increase mutual understanding and youth should be better informed to understand professions. Higher education institutions increasingly acknowledge their responsibility to guide students, both in their academic growth and in their career development. However, research indicates that, even close to graduation, many students remain uncertain about what they could do in the future [2-3]. This leads to a gap between the graduates' expectations and their actual experiences with significant negative correlations to job satisfaction. Employers also refer to this mismatch, indicating that there is still a skills gap and that they experience difficulties in finding graduates with the right set of competencies or the required competency level.

Several theories for career choice underline the importance of awareness of both personality (*e.g.*, interests, strengths and weaknesses) and future career opportunities as more congruency between personality and career leads to increased employability, greater job satisfaction and success [4]. This reasoning implies the premise that students have enough information about (a) their own competencies, preferences and personality and (b) the educational, training or job requirements.

Raising awareness and triggering reflection

In the Professional Roles Framework developed by the PREFER project (Professional Roles and Employability for Future EngineeRs), three distinct possible engineering roles are defined, each with a very specific focus: Operational Excellence (process or product optimisation and increasing efficiency), Product Leadership (radical innovation and research & development) and Customer Intimacy (tailored solutions for individual clients) [5]. The PREFER model represents three roles in a flexible way since engineers can combine two or even three of these professional roles at the same time.

Through the nominal group technique, a mixed method design closely linked to the Delphi design, 19 professional competencies were assigned to the professional roles in collaboration with industry. For example, innovation, vision and creativity were deemed more important in a Product Leadership role whereas client focus, capacity for empathy and clear communication were considered indispensable in a Customer Intimacy role [6]. Some competencies are labelled as essential in more roles. However, the meaning can be slightly different. For example, client focus in a Product Leadership role means knowledge of the market needs in order to discover gaps which can be filled with new products and processes, whereas in a Customer Intimacy role the focus is on partnership with the client in order to develop custom-made products and processes. When interpreting the overview of the professional competencies required to be successful in a professional role (Figure 1) one should be aware that in fact all engineers need all 19 competencies but the importance of the included competencies is perceived higher in the particular role. As such, the PREFER model must be interpreted as a reflective instrument and not as a matching instrument aiming a one-on-one fit.

Exploring preferences and strengths

In order to make students aware of their personal preferences, two tests have been developed. The PREFER EXPLORE is a short personal preference test that measures to what extent engineering students prefer certain professional roles . Students get 10 cases related to engineering practice and are asked to rank three options given the case from most to least preferred. An automated detailed feedback report allows them to reflect on these choices. The tool is intentionally developed in such a way that no substantive engineering knowledge is needed to take the test and it can be used with first year students. The PREFER MATCH is a more elaborate situational judgement test. A set of professionally relevant cases is presented to the respondents who are asked to rate different possible reactions to these cases on a scale of appropriateness. In collaboration with industry leaders, academics and HR experts, several situations were identified for each role based upon the competency profiles. An example can be found in the box. The test does not provide an in-depth measurement of each individual competency. Instead, each competency serves as a steppingstone to build the case and as such, the combination of these cases represents a cross section of typical situations in a particular role. The feedback report gives insight in role alignment and triggers reflection on one's strengths or weaknesses.

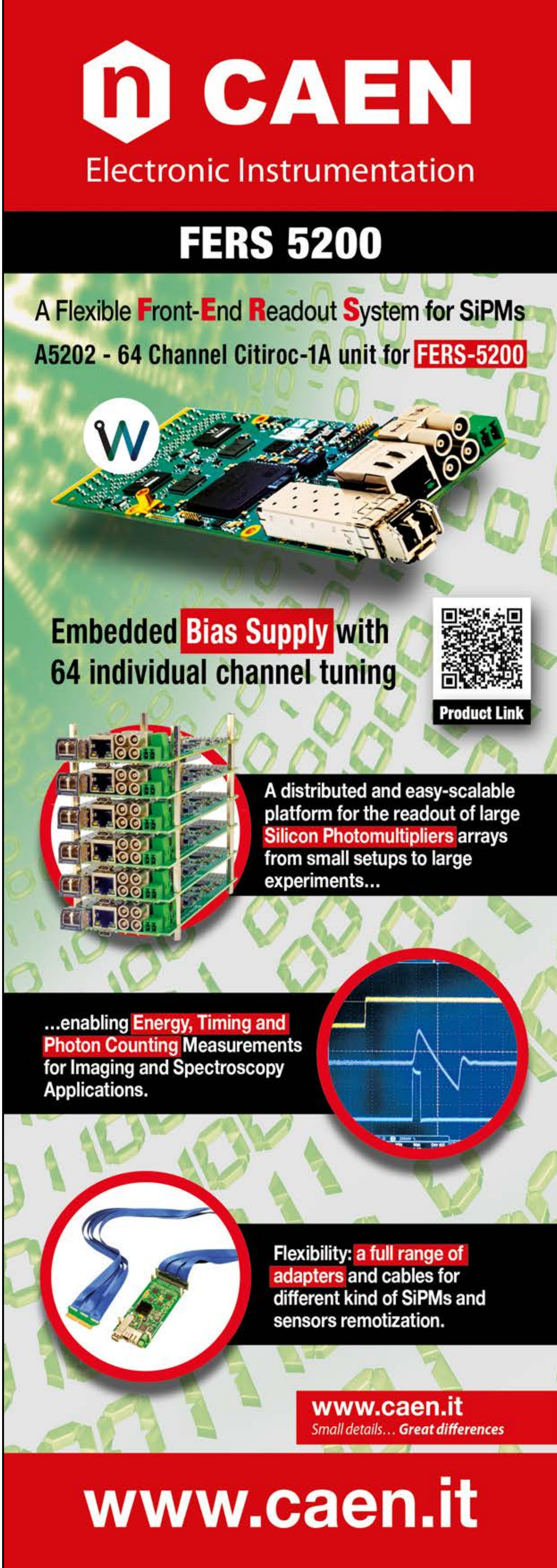
Preparing future engineers through university-industry interaction

The PREFER model and tools are designed and validated in strong interaction with industry, guaranteeing an engineering discipline-independent, future-proof framework that is ready to implement in the engineering curriculum. Universities can provide their students with these online instruments to highlight the career opportunities and requirements, since the importance of specific professional competencies might vary across jobs or work contexts.

What about future scientists?

One can wonder whether and how this framework should be adapted when focusing on scientists instead of engineers. Indeed, also scientists end up in a wide variety of professional positions, both inside and outside academia. However, in contrast to the engineering technology students for which the PREFER model and tools were developed originally, science students typically have a very strong "taste for science" [7]. On average 20 % of the recently graduated Science students start a PhD at the University of Leuven, compared to 3% of the Engineering Technology students (University of Leuven, Data Management Centre). Although PhD holders in science are highly employable mainly outside academia, also for them industrial positions vary greatly depending on their scientific research orientation. These jobs in industry seem, however, much less familiar for graduating science students and initiatives to make them aware of their personal preference would be very welcome.

In addition, for basic science graduates, becoming a science teacher is also a typical role in Belgium. The PREFER research indicated that in the case of engineers, teachers were recognized in a customer intimacy role. Pupils or students could be perceived as clients and it seemed that similar • • •



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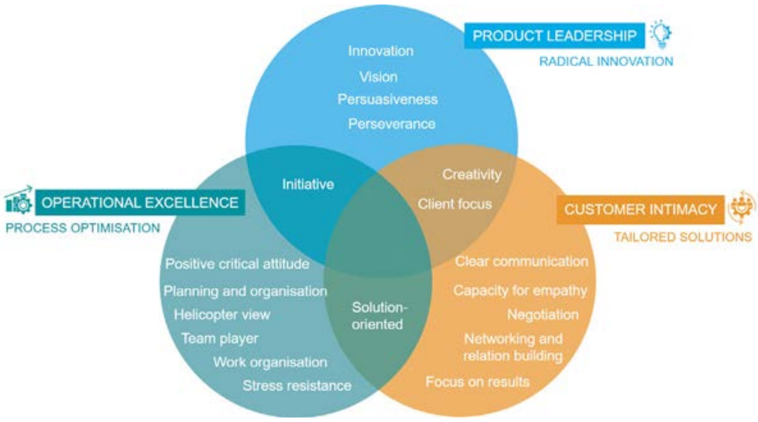

▲ **FIG. 1:** Professional competencies required to be successful in a professional role.

• • • competencies were deemed essential: clear communication, capacity for empathy, aiming for learning results, building relations with students *etc.* Given the societal relevance of high-quality science education, further research is required to investigate whether scientists also perceive the customer intimacy role as such or whether the role should be included more explicitly as a fourth role.

Overall, the PREFER model seems to have potential beyond engineering. We suggest further research to (1) finetune and validate the model for early career scientists and (2) translate the EXPLORE and MATCH tests to more scientist tailored contexts. The instruments could support future scientists in their career choices by giving them a taste of their future career. ■

About the Authors

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