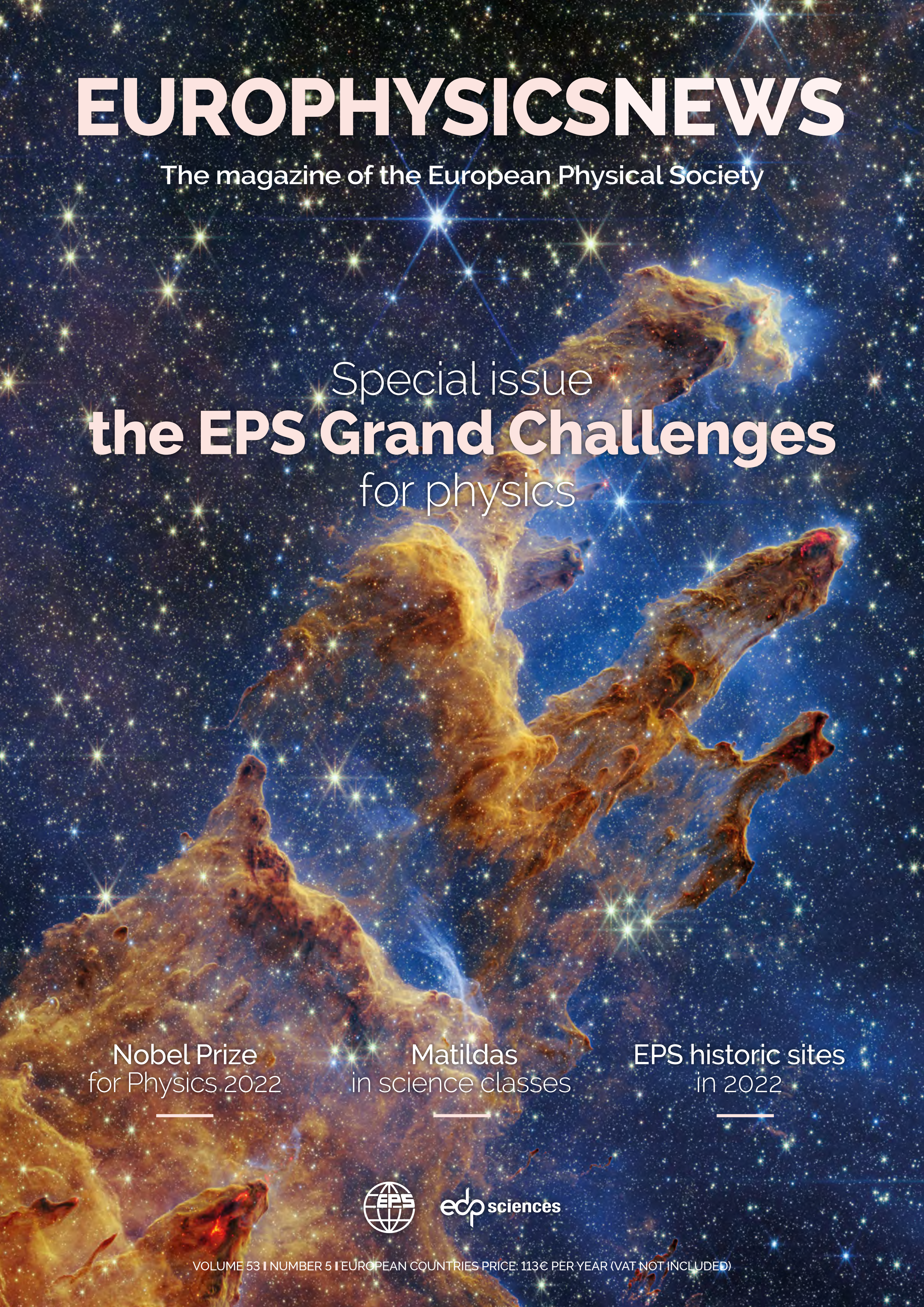

EUROPHYSICSNEWS

The magazine of the European Physical Society

Special issue
the EPS Grand Challenges
for physics

Nobel Prize
for Physics 2022

Matildas
in science classes

EPS historic sites
in 2022

EPS edp sciences

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EUROPHYSICSNEWS

Cover picture: Near-infrared image of the Pillars of Creation from the James Webb Space Telescope. Credit: NASA, ESA, CSA, STScI, STCI; Joseph DePasquale (STScI), Anton M. Koekemoer (STScI), Alyssa Pagan (STScI).

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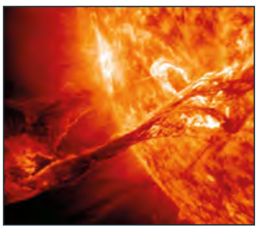
Physics for understanding life



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Physics for environment

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[EPS EDITORIAL]

About the EPS Historic Sites and our cooperation with Eastern Europe

One of most dynamic projects of the European Physical Society (EPS) is the Historic Site programme launched in 2011 by a highly visionary EPS president, Luisa Cifarelli. Under the leadership of Karl Grandin, this vivid programme has enjoyed an ever-increasing success for more than 10 years. Sites that are significant to physics and its history can be considered for the Historic Site distinction from the EPS. These are generally laboratories, buildings, universities, *etc.* associated with an event, discovery or research by individuals who made long lasting contributions to physics. So far almost 70 sites have been awarded, not only in Europe, but also in the United States, and the EPS continuously attracts the interest of many cities, universities or research institutions in obtaining this distinction.

In September 2022 only, three new sites - the Aldo Pontremoli Department of Physics at Milan University, the old building of the Zagreb-Grič Observatory (first Croatian historic site), and the Victor Franz Hess Messstation in Innsbruck, Austria - received the coveted title. These inaugurations are all opportunities for fruitful exchanges between local and national officials, representatives of research organisations and physicists. For the recipient institute, the light given by the EPS through this event brings more notoriety. For the EPS, awarding this title increases the weight of our Society in the physics community. Therefore, ultimately, a historic site celebration is a win-win partnership.

The month of September 2022 was particularly intense for me, as I had the chance to travel twice in Eastern Europe. First, the 11th Conference of the Balkan Physical Union (BPU) was held in Belgrade, Serbia (28 August - 1 September 2022). BPU Members are the National Physical Societies of Albania, Bulgaria, Cyprus, Greece, Montenegro, Moldova, North Macedonia, Romania, Serbia and Turkey. Postponed in 2021 because of the pandemic, this 2022 edition met a great success, with the participation of several hundreds of attendees. The EPS contributed with the organisation of two round tables by the Young Minds Action Committee on "Career in Physics" and "Quantum and New Technologies". A particularly moving moment was the closing of this event with the transfer of responsibilities between the former president of BPU, Goran Djordjevic, and his successor, Radu Constantinescu - both of them are well known to the EPS for their unfailing commitment to the European Integration Committee. The BPU11 congress was also the opportunity to co-sign a memorandum of agreement between the EPS and BPU, making the latter a cooperating society of the EPS.

Two weeks later, the EPS was again present in Belgrade to actively participate in the World Conference on Basic Sciences and Sustainable Development (19-22 September 2022) organised as part of the International Year of Basic Sciences for Sustainable Development (IYBSSD 2022). The main aim of IYBSSD 2022 is to mobilise national, regional, and global scientific institutions to demonstrate to the public and especially to political and business leaders worldwide how basic sciences can help us to establish an inclusive, balanced, and sustainable development of the planet. I had the honor of conducting a session dedicated to advanced basic research in mathematics and physics, where were addressed the societal impacts of these basic sciences and how scientific research may help achieve the sustained development goals of the United Nations' 2030 Agenda. Many interesting exchanges took place, both on science and society. A special session was previously devoted to the latest report of The Club of Rome – "Limits and Beyond" – 50 years after the Meadows report.

To end with, let us again recall that less than 1500 kilometers away from Belgrade to the East, the war continues in Ukraine. In these troubled times, the EPS becomes more and more involved in helping our Ukrainian colleagues. The EPS has recently published an exhaustive list of initiatives that, to the best of our knowledge, are currently supporting the Ukrainian scientific community. We are also in regular contact with the representatives of the Ukrainian Physical Society and have together worked out some priorities to support them. One of the envisaged actions is to unite with our member societies to seek sponsors capable of financing long stays in Western Europe for Ukrainian master students. We hope that our first exchanges on these actions will turn to concrete proposals as soon as possible.

Today more than ever, it is urgent to pay attention to Eastern Europe. ■

■ **Luc Bergé,** *EPS President*

Survey about the First EPS Forum in Paris

On June 2 and 3, the EPS held its first Forum at the International Conference Center of Sorbonne University (SU) in Paris, France. Prepared for more than a year with our Member Societies and our Divisions and Groups, the EPS Forum welcomed 487 participants among whom 184 students coming from 30 different countries.

The EPS Forum (www.epsforum.org) proposed a series of conferences, round tables and workshops on the following topics: Energy and sustainability, accelerators, high-energy particle physics, nuclear physics, quantum technologies and photonics, machine learning and artificial intelligence, biophysics, technological sequencing of biomolecules and human health, condensed matter physics: from quantum materials to additive manufacturing. The first day of the Forum fostered direct exchanges between physicists - with a majority of master, PhD students, postdocs - and stakeholders of physics-based industrial companies. The second day hosted a scientific colloquium highlighting the latest achievements on the previous topics. In parallel to these two days, three hands-on sessions and one masterclass trained students on quantum computing and scientific writing, while the patio of the Conference Center housed 25 stands that allowed exchanges with young graduates looking for job opportunities.

A few days after this meeting, the EPS Secretariat together with the members of the Executive Committee prepared a survey to get a feedback from the Forum's participants. The EPS secretariat received 75 responses that are summarized below.

1/ 63% of the respondents considered the EPS Forum to be a good use of their time to attend this event. Between 56% and 60% agreed that the first three objectives of the Forum – i/ to showcase applied and industrial research in physics, ii/ to help young researchers and postdocs to learn about careers outside of academic research, and iii/ to highlight the latest achievements in physics research across a wide range of fields - were met.

2/ 62% of the respondents visited the exhibitors' stands. However, only 36% found the offers of the booth useful and/or informative.

▼ A few photos extracted from the Forum, including Serge Haroche's plenary talk in the auditorium, the lunch break at the patio of the Conference Center, the Young Minds Leadership Meeting and a hands-on session.

3/ The overall organisation of the Forum was well rated, with 45% attributing the mark 4/5 and 44% the mark 5/5.
4/ A majority of 49% of the respondents opted for having a regular meeting every two years (36% every year, 11% every three years).
5/ 40 respondents then mostly confirmed that their initial expectations about the Forum had been satisfied. Some concerns were raised, however, about the lack of potential candidates for some exhibitors or the too busy schedule of the sessions.
6/ Most of 44 respondents positively answered the question about the professional contacts and collaboration among the EPS Members fostered by the EPS Forum.
7/ The last item was open to free suggestions: 36 responses were received; they proposed, among others, to improve some logistical points, reduce the parallel sessions, present awards to young researchers during the poster session, and decrease the overall costs.

The programme committee and the organisation committee of the First EPS Forum thank all the participants to this meeting and those who sent us their feedback to the present survey. Their responses and proposals will be carefully taken into account when considering the opportunity to prepare a second edition of this event. An EPS Forum Committee has already been set up during the last Executive Committee meeting of the EPS in order to address this issue. ■

The I Northwest Meeting of Young Researchers in Optics - Young Minds Santiago

Bastián Carnero, Alejandro Doval, Andrea Iglesias-Ramas, Alicia Muñoz-Ramos, Carlos Damián Rodríguez-Fernández, Damián Insua-Costa, Irene Romo-Díez, Javier Varela-Carballo, José Paz-Martín, Sabela Fernández-Rodicio, Verónica Villa-Ortega and María Teresa Flores-Arias

EPS Young Minds Santiago Section, Universidade de Santiago de Compostela.

Organising a scientific conference for early-career researchers in photonics: a learning and networking experience

The I Northwest Meeting of Young Researchers in Optics (I NW MYRO) has its origin in the persistent idea of the Santiago Young Minds (YM) Section of holding its own scientific conferences. In addition to the local YM Section, the I NW MYRO was collaboratively organised by two entities from the University of Santiago the Compostela (USC) - the Students Association LUZADA and the Optica Student Chapter USCOPTICA- as well as the Optica Student Chapter OSAL from the University of Salamanca (USAL). The event took place in Santiago de Compostela, from 5th to 7th of May 2022, and was sponsored by the European Physical Society (EPS) YM Programme, and other societies such as Optica (Formerly OSA) and the Spanish Royal Physics Society (RSEF). The two-day meeting was tailored to the interests and needs of early-career researchers and aimed to strengthen the scientific network within the northwest region of Spain.

Talks and roundtables

The first day of the congress focussed on two objectives: providing an overview of the current research in optics and photonics in the northwest region of Spain and highlighting the industrial opportunities within those fields. The first objective was addressed by organising a session of plenary talks that brought together experts from the following regional research institutions: Laser Laboratory for Acceleration and Applications (L2A2), Iberian Nanotechnology Laboratory (INL), University of Vigo (UVIGO), University of A Coruña (UDC), USC and USAL. The spokespeople introduced various interesting topics related to their work, such as quantum biology, optical materials manufacturing, or different laser applications. Regarding industry, two local Galician companies (BFlow SL and AIMEN) and an international one (Menlo Systems) participated with a talk followed by a roundtable, where the company representatives had the opportunity to present the main R&D lines, highlighting the decisive role played by optics and photonics in their business model.

Roundtable format was also exploited to deal with a completely different, yet important, topic: the situation of women in science. For this panel, female colleagues from different career levels were invited to debate about the academic and professional difficulties they face day-to-day for the mere reason that they are women.

During the final session of the first day, early-career attendees presented their work with a short talk. This was not only an excellent way to actively involve them and to give them an opportunity to practice their public speaking and communication skills, but also fostered networking and the creation of new connections.

To increase the impact and reach of the sessions, they were live streamed on LUZADA Twitch profile (@luzada_usc), fostering the acquaintance with digital outreach tools that came with the Covid-19 pandemic.

Outreach sessions

The second day was devoted to outreach. Two events were celebrated to commemorate the International Day of Light 2022 and to bring science closer to the general public. In collaboration with both the Natural History Museum (NHM) of the USC and the House of Sciences of A Coruña, a series of experiments related to different light phenomena was carried out. For the NHM session, specially devoted to children, the focus was on visual and funny light experiments such as polarisation glasses or long-exposure photography. The activities were hold in parallel and reached a large audience, around 1000 people, of all ages. They allowed us to share our passion for optics and physics, and to bring those fields a little closer to the general public, which we consider key for spreading awareness about scientific practices and concepts, and inspiring new generations of scientists.

Conclusion

The Santiago YM Section successfully organized - with the priceless collaboration of its partners - and hosted the I NW MYRO, celebrated in Santiago de Compostela, Spain. The meeting featured plenary talks and roundtables given by a large and egalitarian list of excellent researchers in optics and photonics and offered outreach activities organised in cooperation with two science museums. The topical content of the meeting was strongly aligned with the goals of the YM Programme, which allows the emergence of initiatives capable of strengthening scientific bonds, promoting dissemination opportunities, and helping the professional growth of new generations of physicists throughout Europe.

We thank OSAL Student Chapter for their collaboration in the organisation of the event. We also thank the European Physics Society, Optica, the Spanish Royal Physics Society and the University of Santiago de Compostela for their economical support, and SEDOPTICA, BFlow SL, AIMEN and Menlo Systems GmbH for their collaboration. ■

Nobel Prize in Physics 2022

This year's Nobel Prize in Physics was awarded to Alain Aspect of the University of Paris-Saclay, John F. Clauser of J. F. Clauser & Associates, and Anton Zeilinger of the University of Vienna and the Institute for Quantum Optics and Quantum Information "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science". The story of their individual research paths is not only a fascinating narrative of how experimental physics confirmed the most counterintuitive prediction of quantum mechanics, but also that of a struggle for the right to conduct research out of pure curiosity, regardless of the potential for its application. Ironically, quantum entanglement is today at the heart of rapidly developing quantum information technology.

Quantum mechanics does not predict what outcome will occur in a single run of an experiment, only the probability that it will occur. But are the measurement outcomes fundamentally probabilistic, or do they only appear so, like in the lottery or classical statistical physics, because our information about them is limited and insufficient to discern an underlying deterministic reality? At the heart of the answer to this question is the work of this year's Nobel laureates Aspect, Clauser and Zeilinger. But first let's go back in history to the time when the phenomenon of quantum entanglement was discovered.

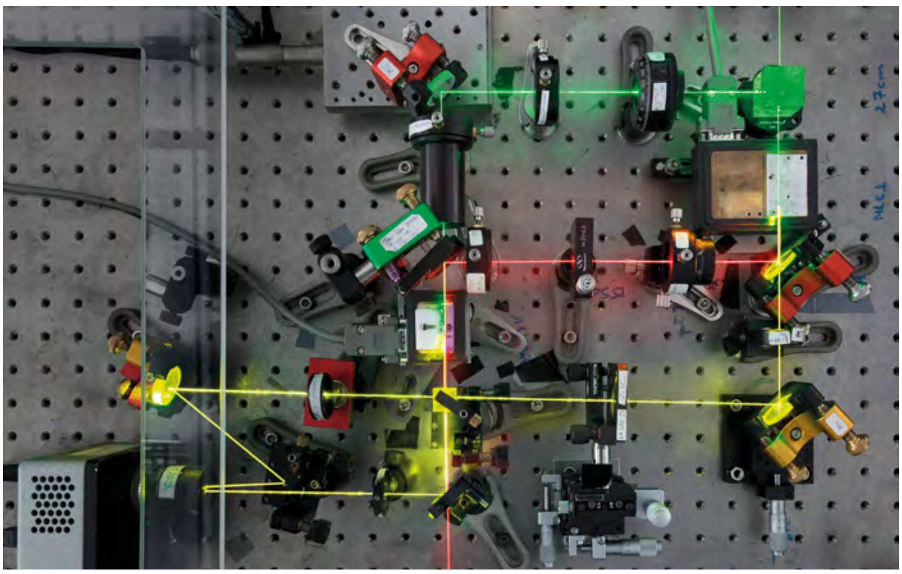
In 1935, Albert Einstein, Boris Podolsky and Nathan Rosen (EPR) presented a scenario in which a pair of entangled particles are separated by an arbitrarily large distance before being measured. They argued that quantum mechanical description of the situation is not complete and that it must be supplemented by so-called "local hidden variables". These variables then predetermine the results of all possible measurements, and they are local, so that no action at spacelike separated locations can influence a local hidden variable (ruling out faster-than-light influences).

In the same year in which EPR published their paper, Niels Bohr and Erwin Schrödinger famously disputed their argument, but the debate continued until the beginning of the Second World War, largely on the basis of purely interpretative and philosophical preferences, without any agreement being reached. After the war, most quantum physicists continued their work in other, more practical fields taking the view that the question of whether or not there was a more complete description in terms of EPR was not testable, and hence is as irrelevant "as the ancient question of how many angels are able to sit on the point of a needle", as Wolfgang Pauli put it in a 1954 letter to Max Born.

All this led to a specific scientific dogmatism and to social pressure, so physicists who wanted to work on foundational questions in quantum mechanics often had difficulty to find employment in their profession and were sternly advised that they could ruin their careers by doing so. As reported by Clauser, most members of the physics faculty at the University of California at Berkeley, where he was working on the foundations of quantum mechanics at the time, thought "it was all a pointless waste of time." He never became a professor.

Fortunately, there are always physicists who are prepared to challenge conventional wisdom. John Stewart Bell, a theorist at CERN, was one of them. In 1964, Bell proved that the EPR argument actually led to the opposite result to what it was originally supposed to show. He derived what is today known as Bell's inequalities, which must be satisfied by correlations in any theory based on local hidden variables, and showed that quantum mechanical correlations violate them. This opened up the possibility for experimental physics to answer a philosophical question about the nature of physical reality.

▾ A typical quantum optical experimental setup with entangled photons. A single photon from the pump laser generates a pair of entangled photons in an optically nonlinear crystal through the process of spontaneous parametric downconversion. The photons are directed towards the interferometer.



In 1972, Clauser along with then-PhD-student Stuart Freedman conducted the first test of Bell's inequalities. They built a setup in which two entangled photons were sent in opposite directions toward a fixed set of polarization filters and detectors. While the measured data violated Bell's inequality, the experiment had a limitation known as the "locality loophole": the orientation of each polariser was fixed in advance, so that information about which measurement will be made was in principle available at the time the photons were generated. The measurement statistics could thus be simulated by local hidden variables generated in the photonic source.

In 1982 Aspect and his colleagues improved the set-up and addressed the locality loophole by rapidly switching between one or the other filter with different angles for each photon after the photons had left their source but before they arrived at a detector. The switching was too fast for information about which filter was selected on one side to reach the other side and influence the measurement result. The last major loophole, the detection loophole, for the Bell test, was only closed in 2015 through the work of four different research groups, including Zeilinger's. If the detection efficiency is too low (*i.e.* the detection loophole is open), a local hidden variable can determine which pairs of photons will be detected, so that it looks like they violate Bell's inequalities, even though the results would be explainable by local hidden variables if all photons were detected.

The question of how the correlations between entangled particles can ultimately be explained is still the subject of debate among scientists. Some of them believe that they are established dynamically through some non-local interaction between the particles during measurement (an example of such an account is Bohm's theory). Others believe that the concept of "reality" itself is at stake: although, individually, the measurement results of the two particles are completely random and occur with no cause, not even a hidden one, the correlations between them are nevertheless well-defined. Roughly speaking, two entangled particles are better understood as a "single entity", even if they are separated by arbitrary distances.

▲ In 2012, Zeilinger's team set a new distance world record in quantum teleportation by reproducing the state of a photon over a 143 km free-space link between the transmitting station on La Palma and the European Space Agency's Optical Ground Station on Tenerife.

What is the use of it? What is that all good for? Zeilinger was confronted with precisely these questions during the time of his first experiments. He proudly answered: "It's not good for anything. I'm only doing this out of curiosity, because quantum physics has totally fascinated me from the very beginning," as he said in a recent interview. Although it has proven problematic in the past to judge curiosity-driven research by its potential applicability, ironically, it often led to discoveries of economic and practical importance whose returns exceed by far the initial investment. Early experiments in quantum foundations have led theorists to think about how to use genuine features of quantum systems, particularly quantum entanglement, to solve classically impossible communication and computational tasks. They came up with a plethora of ideas, including quantum key distribution, quantum teleportation and quantum computation. (This year's Breakthrough Prize in Fundamental Physics honors the pioneers of quantum information science, Charles H. Bennett, Gilles Brassard, David Deutsch and Peter W. Shor).

Zeilinger and his colleagues have greatly expanded the implementation and exploration of entangled quantum states in quantum information. Among other things, they demonstrated quantum teleportation (together with Francesco De Martini's team), entanglement swapping and quantum key distribution, and in 2017 collaborated on setting up the first quantum communication link via the Chinese satellite Micius.

The tenacity with which Clauser, Aspect and Zeilinger continued their investigations despite the prevailing critical opinion in the physics community shows how important it is for scientists to question the work of others and how counterproductive it is for scientific progress to cling to the belief that all problems in any field of science have been solved. It is quite possible that such a belief in the field of quantum mechanics in the 1960s led to significant delay in development of quantum information science. More than sixty years on, the end of quantum physics doesn't look any closer. In contrast, it seems, more than ever before, that a full understanding of the relation between quantum and space-time physics is still missing. Thanks to the work of Aspect, Clauser and Zeilinger, we know that quantum entanglement must be part of it. ■

Časlav Brukner

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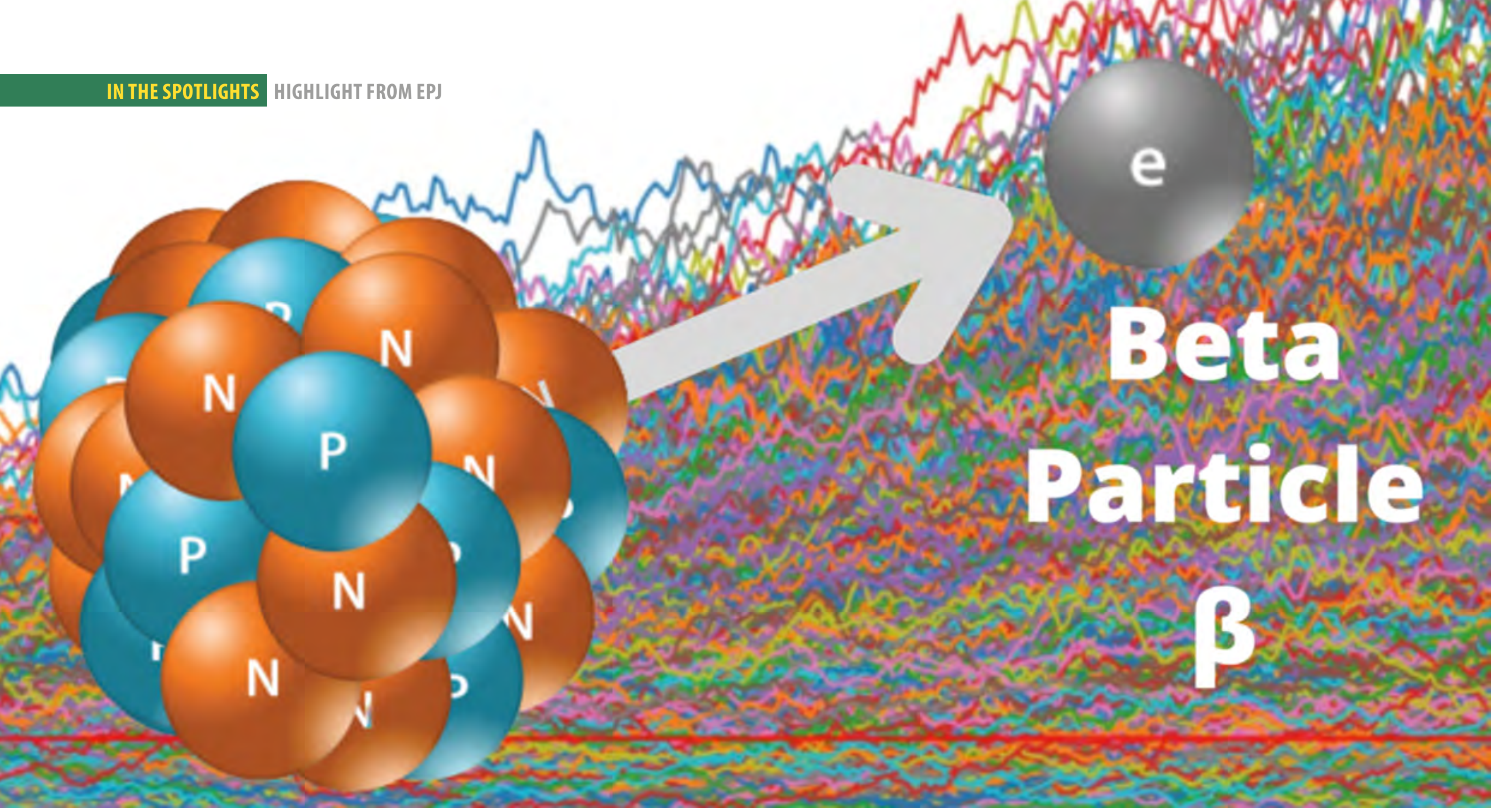
The author did his PhD under supervision of and worked with A. Zeilinger.



Modelling the use of Beta Radiation in cancer treatment

New research pits the simulation of beta radiation doses in tumour treatment against an analytical method.

Treating superficial skin tumours especially when they are located above cartilage or bone with beta radiation can help protect sensitive structures during the delivery of treatment.

The use of short-range beta radiation in cancer treatment is not without its disadvantages, however, especially when it comes to the measurement of radiation exposure—dosimetry. When experimental dosimetry is not feasible, researchers use simulations and calculations to study the interaction of the ionizing radiation with matter and estimate the radiation dose delivered to a target organ.

A new paper published in EPJ Plus and authored by Eduardo De Paiva, from the Division of Medical Physics at the Institute of Radiation Protection and Dosimetry, Rio de Janeiro, Brazil, and his colleagues, pits the gold standard of simulation techniques—Monte Carlo (MC) simulation—against an alternative analytic method, the Loevinger formula.

"We measured the dose of a treatment applicator using mathematical techniques—a simple technique, no experiment needed and no practical challenges," De Paiva says. "The comparison of MC simulation and Loevinger formula on the setup of our research was the novelty of our study."

Non-experimental dosimetry techniques like MC simulation are advantageous for their ability to handle different geometries and materials, but MC simulations require heavy computation and this can impede their implementation.

Analytic methods are another set of techniques for dosimetry of beta radiation that can produce results faster than MC methods. Thus far, these methods have been less favoured because they are associated with lower accuracy.

▲ An illustration of beta decay proceeding against the backdrop of a Monte Carlo simulation. Credit: Robert Lea

The team used MC simulation and analytical calculation—the Loevinger formula—for dosimetry of radiation dose from a multi-well skin brachytherapy applicator with two beta sources. The results of the two approaches were compared to see how accurate the analytical method is.

"The Loevinger formula, which is a quick method for dosimetry showed a good agreement with gold standard Monte Carlo methods," Paiva concluded. "Thus, the Loevinger formula can be used, as the basis of a dosimetry software, for straightforward dosimetry of beta sources in simple geometries." ■

Reference

[1] E. De Paiva, M. Robatjazi, A. Pashazadeh, *Eur. Phys. J. Plus* **137**, 916 (2022). https://doi.org/10.1140/epjp/s13360-022-03116-5

by Lorena Ballesteros Ferraz[1], Sébastien R. Mouchet[1,2] and Riccardo Muolo[1,3]
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Let "Matildas" get the place in science classes that they deserve

The world population is almost equally split between men and women[1] and the same statistics stands for Europe. Yet, when a girl enters a European Physics class, the teacher or the lecturer is most likely a man, probably white and in his middle age or older.

As she learns about the developments of Physics throughout the years, it is almost certain that she is going to hear only about men (not necessarily aged, but most of them white) who made discoveries and contributions to the advancements of the field. This reality unfortunately also occurs for other disciplines of science. Where are the women scientists? Is it possible that the pillars, on which Physics stands, were built almost only by men? Well, it is true that men have kept women subordinated for a long time, not allowing them to study, nor to hold positions of power. Science is no exception, so that women scientists have been less numerous than men. Nonetheless, they have been present and their contributions in the advancement of the field have been determining, despite often unrecognized. So, again, where are they in the history of science?

This question can be partly answered by the Matilda effect, as defined by historian Margaret W. Rossiter [1]: women's contributions have indeed been neglected by society, as well as by their own close collaborators, mentors and relatives, who sometimes took the whole credit for joint works or even stole tout court ideas, findings and discoveries. We urge for a reformulation of science classes, lectures and books, from primary school to university, in order to give all "Matildas" the spot that they deserve. Teachers and Professors need to acknowledge all contributors of science, and not only those who officially received credit for it. Different topics commonly taught in physics classes arise from the research carried out by women. Examples abound: Chien-Shiung Wu, who experimentally demonstrated that parity is not conserved, for which her men colleagues Chen-Ning Yang and Tsung-Dao Lee were awarded the Nobel prize. Mileva Marić, who partly described the photoelectric effect, for which her husband Albert Einstein was later awarded the Nobel prize. Jocelyn Bell, discoverer of pulsars, who earned the Nobel to her supervisor Antony Hewish. And this is not even the tip of the iceberg.

We understand that it is not easy to change the way that one tells a story that they were told, and then they repeated many times in a certain way, and we recognize that sources on the subject are scarce. For this reason, we encourage Physics lecturers, teachers, and educators to include and highlight, in their narratives, and course materials, these hidden figures who, as much as those who were acknowledged, shaped modern science. The lack of recognition towards these women is firstly unfair to them, but also spoils the enthusiasm of today's women scientists, feeding the vicious circle against them in the scientific community. Promoting the role of women scientists and researchers from minorities in STEM to our youngsters will help bringing more diversity to academia and benefit the whole society. ■

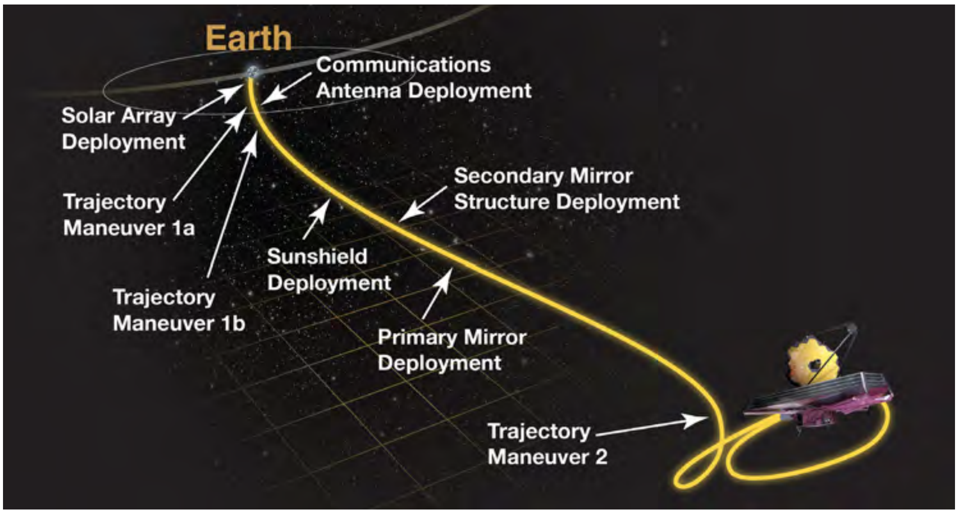
References

[1] Margaret W. Rossiter, *"The Matthew Matilda effect in science". In: Social studies of science* **23.2**, 325 (1993).

[1] With this, we refer to the sex assigned at birth, which does not account for non-binaries and other gender categories.

Tribute to JWST in pictures

At the end of 2022, we look back at the amazing introduction of the James Webb Space Telescope (JWST) in the research community. Design and construction were a global effort of the space agencies of the US, Europe and Canada.



▲ Artist's impression of the 'path' from Earth to the Lagrange point. Credit: NASA and M. Clampin, GSFC.

The new generation telescope conducts infrared astronomy with a resolution and sensitivity that allow it to view objects at unprecedented distance and of faint appearance. It will enable a broad research field of astronomy ranging from the observation of formation of the first galaxies to detailed atmospheric studies of exoplanets. Its expected operational life time is 20 years. The mirror of JWST consists of 18 hexagonal segments of gold-plated beryllium which give the telescope a light-collection area of about 25 m^2. Its instruments are optimised for the observation of light in the near-infrared or mid-to-long infrared frequency range. The telescope is kept at a temperature below 50 K to avoid that the infrared light emitted by the telescope itself does not interfere with the collected light. It is deployed in a solar orbit near the Sun–Earth L2 Lagrange point, where its five-layer sunshield provide protection from warming by the Sun, Earth, and Moon.

JWST was launched about a year ago, on 25 December 2021. A month later it arrived at its final orbit around the second Sun-Earth Lagrange point, about 1.51 million kilometers from Earth. After a commissioning period, scientific observations started in July 2022 and the first full-colour images and spectroscopic data were publicly released. An exciting future with stunning pictures and data began.

Here we present a selection of the many stories that can be read on the NASA and ESA websites. ■

Webb's First Deep Field

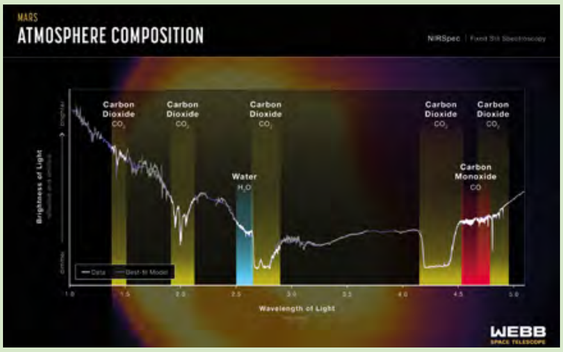
In July two different views of JWST's first deep field with Galaxy cluster SMACS 0723 were published side by side for comparison. Left a colour coded view of the cluster in mid-infrared light and at the right a view in near-infrared image. The near-infrared highlights the areas with dust, which is a major ingredient for star formation. The mid-infrared data will allow for the improvements of star and galaxy formation models with more precise calculations of dust quantities.

▲ Credit: NASA, ESA, CSA, STScI, Webb ERO Production Team

Interpretation

Stars are brighter at shorter wavelengths, which is why they appear with prominent diffraction spikes in the image at the right. If an object is blue in the left image and lacks spikes in the image at the right, it is a galaxy. The galaxies contain stars, but very little dust. This means that their stars are older – there is less gas and dust left to condense to form new stars. The red objects in the left image are still enshrouded in thick layers of dust, and may be distant galaxies. Some may be stars, but more research is needed for this to be determined. Green indicates that the dust of a galaxy includes a mix of hydrocarbons and other chemical compounds. The orange arcs at the center of the galaxy cluster in the image at the right are galaxies that are stretched and magnified by gravitational lensing. They appear blue in the mid-infra-red image at left. These galaxies are older and have much less dust. The size of the Galaxies in both images offer information about their distance to Earth – the smaller the object, the more distant it is. In mid-infrared light, galaxies that are closer appear whiter. ■

Spectrum of Mars

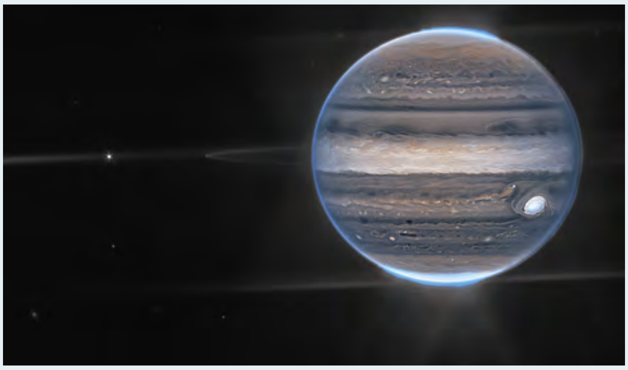


▲ Credits: NASA, ESA, CSA, STScI, Mars JWST/GTO team

In September the Webb's first near-infrared spectrum of Mars was published. The spectrum shows a combination of sunlight reflected from the surface and atmosphere of Mars, and light emitted by the planet as it gives off heat. Preliminary analysis reveals the spectral dips at wavelengths where light is absorbed by molecules in the atmosphere of Mars, specifically carbon dioxide, carbon monoxide, and water. The broad shape of the spectrum and the slope of the curve reveal information about dust, clouds, and surface features. By constructing a best-fit model of the spectrum, abundances of given molecules in the atmosphere can be derived. ■

Webb's image of Jupiter

In August a wide-field view in near-infrared light of Jupiter was published. The faint rings of the planet, which are a million times fainter than the planet, and two tiny moons called Amalthea and Adrastea are visible. The fuzzy spots hardly visible in the lower background are likely galaxies. The image of Jupiter is a composite of two colour filter systems in the near-infrared camera of the Webb telescope. Above the northern and southern poles of Jupiter the auroras are visible. The bright white regions in the image have a higher altitude. They are likely cloud tops of condensed convective storms, while the dark regions have little cloud cover. ■



▲ Credit: NASA, ESA, CSA, Jupiter ERS Team; image processing by Ricardo Hueso (UPV/EHU) and citizen scientist Judy Schmidt.

The Pillars of Creation

Several Webb images of the iconic 'Pillars of Creation' were published. It was the Hubble telescope that made the Pillars famous. EPN published in 2020 the image on the occasion of 30 years of the Hubble telescope. The 'Pillars of Creation' is a small region within the vast Eagle Nebula, which lies 6500 light-years away. It is filled with semi-transparent gas and dust, the ingredients for star 'creation'. When knots of gas and dust with sufficient mass form, they collapse under their own gravitational attraction, slowly heat up and eventually form new stars. The red flecks at the end of the pillars are examples of areas where this process is going on. The Webb image of the Pillars was selected as the frontpage of this special EPN issue as one of the Grand Challenges for astronomy and physics. ■

◂ Left: Visible light image of the Pillars of Creation made by the Hubble Space Telescope in 2014. Right: Near-infrared-light image from the JWST peering through more of the dust. Credits: NASA, ESA, CSA, STScI; Joseph DePasquale (STScI), Anton M. Koekemoer (STScI), Alyssa Pagan (STScI)

Summary of
The world beyond physics: how big is it?

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Modern science is increasingly confronted with problems of paramount societal impact: Energy, Environment, Health, are just three major keywords underlying scientific problems of utmost complexity, hardly within grasp of any single scientific discipline.

Speaking of complexity, it is widely accepted that the frontier between physics, chemistry and biology provides one of its most compelling and fascinating playgrounds [1]. Progress in handling complexity is guaranteed to secure societal impact: for instance, a thorough theoretical understanding of the protein folding process would advance our ability to combat neurological diseases. Likewise, the ability to describe the motion of complex biological molecules from first-principles would bring major benefits to industrial drug design.

Thanks to the astounding advances of computer modeling and simulation, including the recent vigorous assist from modern AI, such as machine learning, it is tempting to speculate that bridging the gap of complexity between physics and biology is just matter of time [1].

Nevertheless, a few noted scholars, Stuart Kauffman in the first place, maintain that the gap is here to stay, in fact it can only widen up because the inventive power of the biosphere is virtually unbounded, meaning that it cannot be captured by any pre-stated formalism, no matter how accurate and sophisticated [2]. In particular, these scholars invoke the intriguing TAP (Theory of Adjacent Possible) whereby the space of opportunities offered to a biological system displays combinatorial growth, just because these opportunities may be realized by a myriad of so-called affordances, namely lucky strikes offered by the environment to its co-evolving biological guests.

The TAP picture is replenished with intellectual charm; yet, with all due respect to John Keats, charm does not necessarily equate with truth. In the Perspective "The world beyond physics: how big is it?", I endeavored to argue that modern developments of non-equilibrium statistical physics have made re- markable strides in accounting for the complexity of the biological world, with no need to to advocate radical views such as TAP [3].

1This has no bearing on religious considerations: the fact that physics might one day account for the evolutionary properties of matter, does not, in my view, rule out the existence of a Supreme Being

This is not to detract from the fascination of such theories, but just a sober invitation to explore the full potential of non-equilibrium statphys before declaring the demise of physics and math in the face of biological complexity.

In hindsight, the Perspective should have mentioned the potential impact of AI, and most notably Machine Learning, in boosting the power of theory and modeling to tackle biological complexity. This is not to be confused with the shallow hype whereby "theory is obsolete" and "correlation replaces causation", which is easily dismantled by rather elementary considerations from the theory of complex systems [4, 5, 6, 7].

Yet, there is now mounting evidence that machine learning permits complex tasks, such as the efficient exploration of hyper-dimensional spaces, which would otherwise be intractable by modeling and simulation alone [8].

The combination of modeling, simulation and machine learning is starting to provide a major boost in science, and computational medicine, just to come back to Grand Challenges, is a likely candidate for drawing major benefits from such developments [9].

Maybe they will always fall short of capturing the full-blown complexity of the biosphere, but certainly this cannot be argued on the basis that "physics describes machines" and since "the world is not a machine", physics cannot describe the world [2]. This syllogism is outdated: statistical physics and computational science have gone great lengths in describing complexity beyond the Newtonian paradigm and, to some extent, beyond quantum field and string theories as well [10].

As also witnessed by the 2021 Physics Nobel, physics is embracing complexity in earnest and nobody really knows how far it can reach down this fascinating and paramount route. ■

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[INTRODUCTION]

Grand Challenges for physics

Our developed society is based on science and technology but only a minority of the general public has an understanding of how they work. Equally unknown are the opportunities opened by fundamental research and their impact in our daily lives.

The history of science offers a wide range of examples of discoveries with unforeseen social value. The discovery of the delicate mechanism by which ozone is naturally produced and destroyed in the stratosphere is a good example. It illustrates how vulnerable the Earth actually is under human stewardship, while at the same time illustrates the human capability to address challenges making use of basic science with a mixture of scientific curiosity and a touch of environmental awareness. Scientific endeavour means very often exploring unknown territories. Here its strength lies in its capability for developing self-correcting strategies based on available evidence to explore the limits of science and the science of limits.

Historically scientific breakthroughs have been steady but slow, occurring over a span of centuries. Leonardo da Vinci [1452-1519] was a true Renaissance person. His artistic talent is comparable to his genius to dream the future. Leonardo da Vinci's greatest ambition was to fly. Centuries later, flying like a bird was still a dream in Goya´s time [1746 – 1828]. Fly has been a driver of creativity and fantasy - to go where no one has gone before, to overcome human limits, to fulfil high and demanding goals. It took more than 500 years to build a flying machine that would allow humans to get a unique view of our planet. A photograph, snapped from the Voyager 1 in 1990 at a distance of about 6 thousand million kilometres, showed our planet as a lonely pale blue dot in the great enveloping cosmic dark. A unique image taken by scientists that exceeded Leonardo's and Goya dreams a few centuries latter.

Today the pace of innovation has accelerated drastically. Over the last decades, the European Physical Society community has been promoting and examining some of the biggest problems humankind faces right now and the role physics to address them. But what about the big challenges in physics that are brewing for the future?. In the Horizon 2050, what challenges might be on the world's physics agenda to solve? Predictions are difficult to be made but we can get clues from how current trends in science and technology may play

▾ **Leonardo Da Vinci's first attempt to fly was in the late 15th century. He never succeeded to make his dream reality.**

▲ In one of Goya´s most striking prints, a series of people are flying through an endless night (Goya, El Prado Museum). They are like new Icaruses, assisted by broad wings. The story of Icarus is one of the most famous tales from Greek myth that is often interpreted as a metaphor for human's overreaching their limits.

out, and where physics has a key role to play. This is the purpose of the *EPS Grand Challenges: Physics for Society at the Horizon 2050 project*, exploring our ability to imagine and shape the future using modern day scientific tools and methods. The project is designed to address the social dimension of science and the grand challenges in physics with two pillars: (i) *physics as global human enterprise for understanding nature*; and (ii) *physics developments to tackling major issues affecting the lives of citizens*. A fascinating journey, from the smallest scale that we have ever explored – quarks particles that are of the scale of 10^{-18} m – to the largest things we have ever mesured – the greater breadth of the universe at the scale of 10^{27} m. A project highlighting the key role of interdisciplinarity to address some of the grand scientific and social challenges that lay ahead us, such as the climate change or understanding life.

An editiorial board and chapter coordinators from different European institutions played a key role in the development of the project and the preparation of a book. More than ten Editorial Board meetings were held during 2019 – 2021 to approve terms of reference and topics to be covered in seven chapters of the book: (i) Physics bridging the infinities; (ii) Matter and waves; (iii) Physics for understanding life; (iv) Physics for health; (v) Physics for environment and sustainable development; (vi) Physics for secure and efficient societies; (vii) Science for society.

All these topics are widely recognised today as the most important global challenges in physics. Interdisciplinarity allows interconnections between many areas of knowledge, involving physics, mathematics, biology and chemistry, in such a way that the whole body of connected ideas might suddenly expand due to small advances within the islands of specialised knowledge. In the project, we have looked at all these aspects to explore what makes us, human beings, really unique in nature: our ability to shape the future by making use of science and technology.

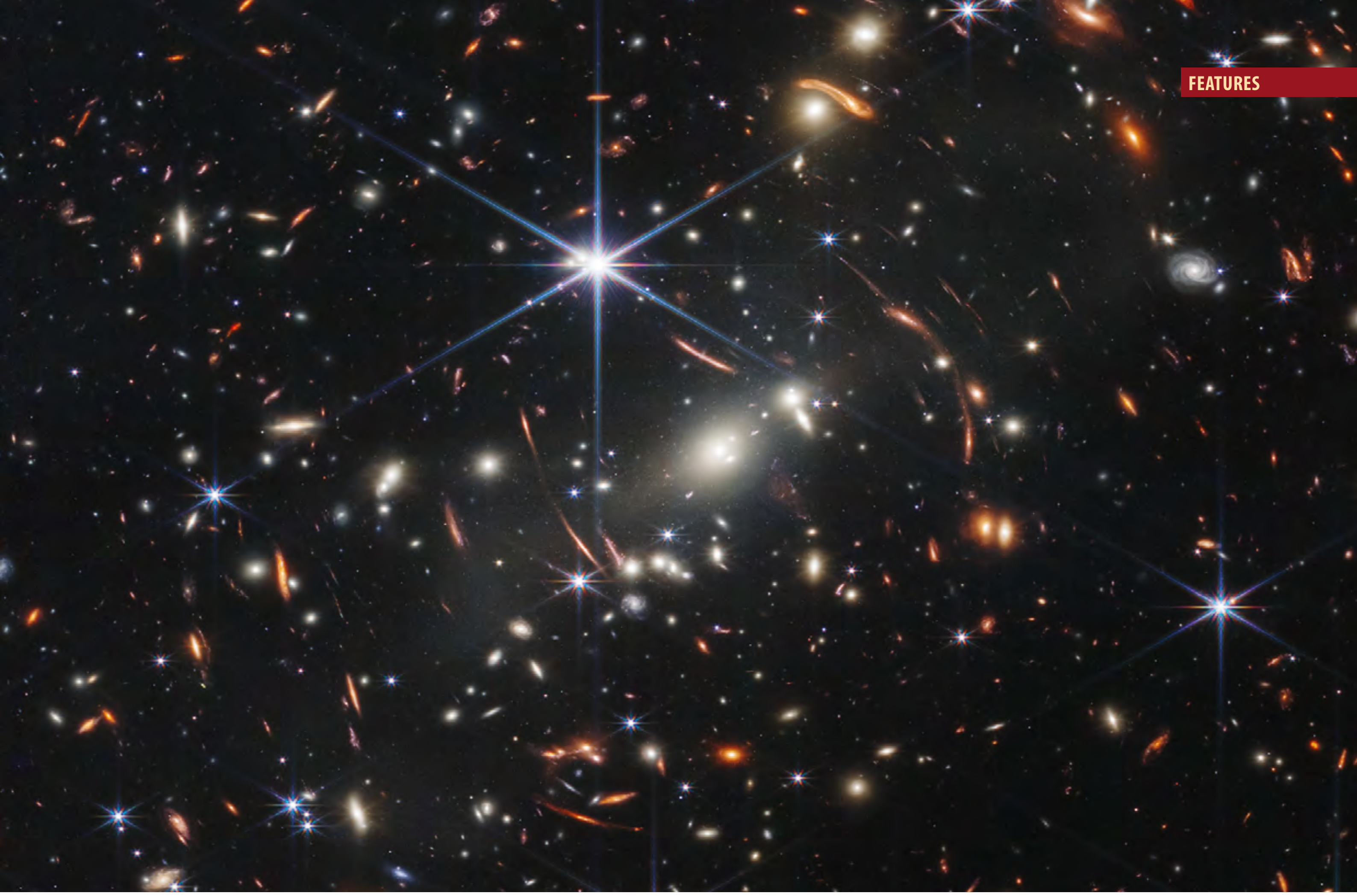
This EPN special issue provides a glimpse of the *EPS Grand Challenges in the Horizon 2050 project* addressing world's physics agenda to solve in science and technology. The resulting book will be published by IOPP under the umbrella of the EPS in early 2023. The most up to date information will be published here: https://www.eps.org/page/GrandChallengesInPhysics.

The essays, prepared by a panel of more than 70 leading scientists, are based on detailed and in-depth analyses to illustrate the strong links between basic research and its social impact. Reports are expected to reach a broad audience that is willing to explore a future shaped by science. ■

■ **Carlos Hidalgo**
Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain
■ **David Lee,**
EPS General Secretary

THANK YOU!

The EPN Editors are very grateful to Carlos Hidalgo, who as Guest Editor introduced us to the 'EPS Grand Challenges for Physics' project. Together with the many coordinators of the project and with an excellent introduction together with David Lee, an attractive overview is given of the many chapters in the project, that will be published as a book by IoP. We highly appreciate your work and endeavour for EPN. Thanks a lot to all of you!



PHYSICS
BRIDGING THE INFINITIES

Mairi Sakellariadou[1] and Claudia-Elisabeth Wulz[2] – DOI: https://doi.org/10.1051/epn/2021502
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At the horizon 2050, our physics textbooks will have to be rewritten. The contributions in the first chapter of the EPS Grand Challenges explain why. Will all or many of the open questions be answered at the horizon 2050? There is justified hope, supported by a plethora of theoretical developments and experimental facilities on Earth and in space. Will new questions arise? You bet.

The contributions in the first chapter of the EPS Grand Challenges reflect the main research directions that are undertaken to find an answer to the many open questions.

The Higgs boson - When the Higgs boson was found in 2012 at CERN's Large Hadron Collider (LHC) in Geneva, history was made. The Higgs particle, and its associated field, are the reasons why atoms, stars, galaxies, and people are tangible entities. In addition, a tiny asymmetry between matter and antimatter that developed soon after the Big Bang, made it possible that we can exist at all. Without the Higgs boson and this asymmetry, only radiation would permeate the Universe. Fig. 1 shows collision

▲ Thousands of galaxies flood this near-infrared image of galaxy cluster SMACS 0723. High-resolution imaging from NASA's James Webb Space Telescope combined with a natural effect known as gravitational lensing made this finely detailed image possible. @NASA, ESA, CSA, STScI events with a Higgs boson decaying into a Z boson and two particle jets from charm-anticharm quarks, recorded by the ATLAS and CMS experiments at CERN. These events represent just a few of the possibilities how the Higgs boson can decay.

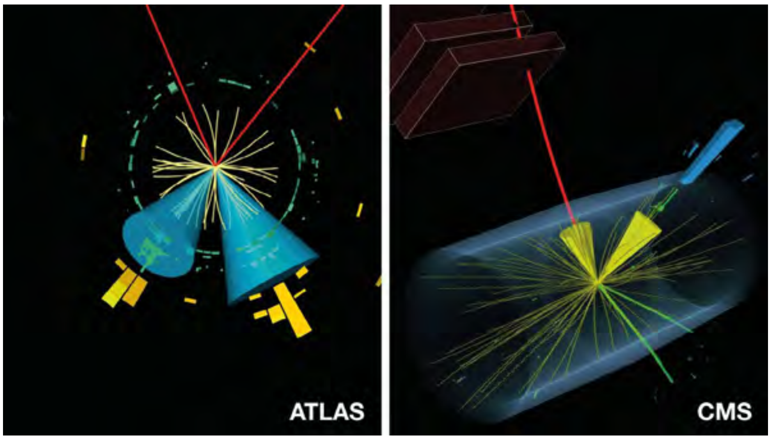
Detailed studies of the Higgs boson at current or future colliders, as well as precision measurements of the properties of matter and antimatter at a multitude of different experiments will reveal how the standard model of particle physics has to be amended.

Read more: Particle physics: physics beyond the standard model, Freya Blekman.

Dark matter and dark energy - That it needs to be extended is evident. It does not contain dark matter, whose existence was already manifest decades ago. Another phenomenon, only discovered in 1998 through the study of the brightness of supernovae as a function of their distance, is dark energy, which makes our Universe expand in an accelerated fashion. Known or "visible" matter, the so-called baryonic matter, only accounts for 5% of the Universe, and is well described by the standard model of particle physics. The rest are dark matter (27%), and dark energy (68%). We have hardly any clues, but many ideas of what they could be (Fig. 2).

Read more: What is the Universe made of? Searching for dark energy and dark matter, Emmanuel N. Saridakis and Jochen Schieck.

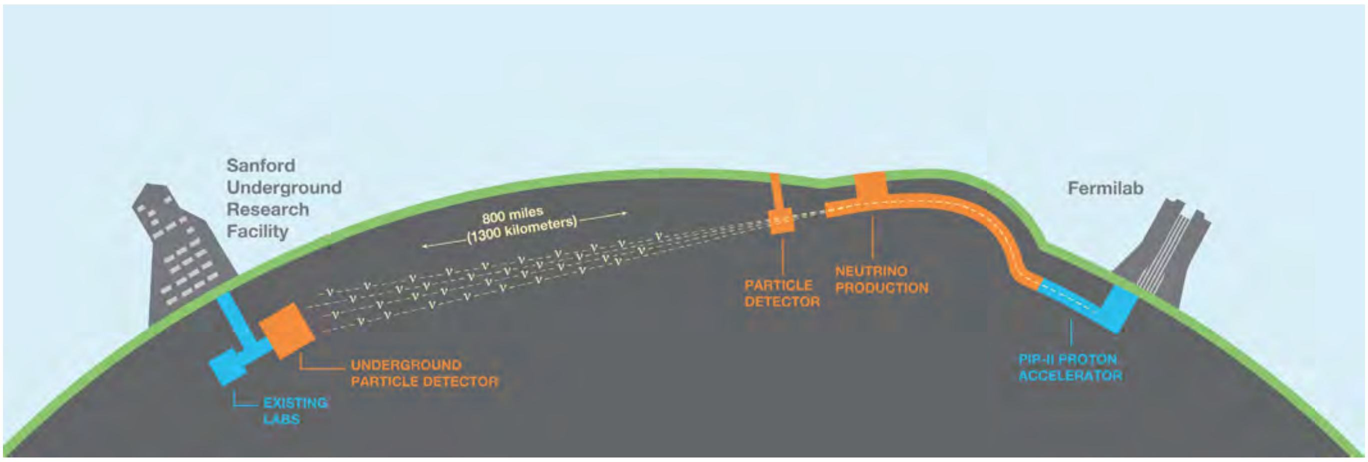
Neutrinos - Although postulated already in 1930, neutrinos are another category of particles that are still mysterious. It was only ascertained in the 1990's that they have mass, in contrast to the assumption in the standard model of particle physics, and that they come in different



▲ **FIG. 1:** Decays of a Higgs boson into a Z boson and a charm-anticharm quark pair, seen by the ATLAS and CMS Collaborations. In the ATLAS event, the Z boson decays into two muons depicted by the red tracks, whereas the charm-anticharm quark pair is not directly visible, since free quarks cannot exist. They hadronise, thus producing collimated sprays of particles around the original flight directions of the charm or anticharm quarks. In the CMS event, the Z boson decays to an electron and a positron, depicted by the green tracks. In both ATLAS and CMS the two charm-anticharm quark jets are depicted by blue or yellow cones. © CERN, for the ATLAS and CMS Collaborations

▲ **FIG. 2:** The heart of the XENON1T project, the Time Projection Chamber TPC after assembly in a clean room. @XENON1T team.

▼ **FIG. 3:** Cutaway illustration showing the path of neutrinos in the Deep Underground Neutrino Experiment. A proton beam is produced in Fermilab's accelerator complex. The beam hits a target, producing a neutrino beam that travels through a particle detector at Fermilab, then through 1,300 km of earth, and finally reaches the far detectors at the Sanford Underground Research Facility. @FNAL.



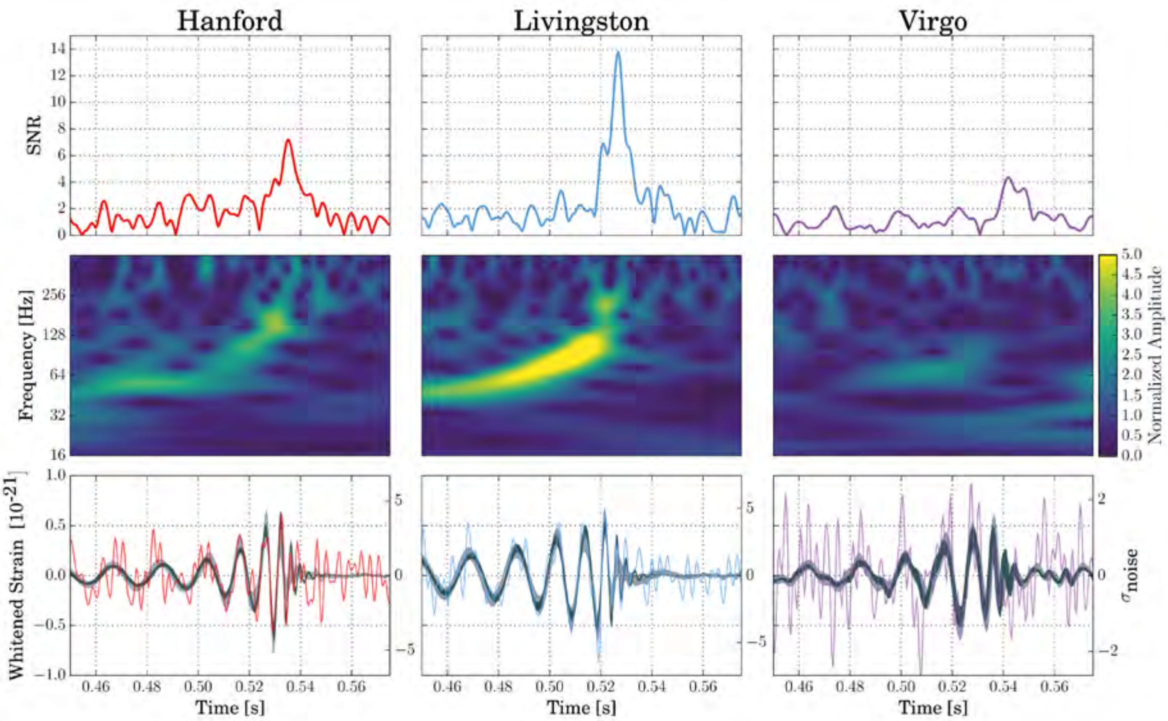
Read more in Chapter 1 of the EPS Grand Challenges.

flavours that can transform into each other. There might even be more varieties – sterile neutrinos, which do not interact through the forces described by the standard model, but only through gravity (Fig. 3).

Gravitational waves - Gravity is so present in our everyday life and the movements of objects in the cosmos, it is the least understood force, and is not part of the standard model of particle physics. We do not even have a quantum-mechanical formulation of the theory of gravity yet, which would allow us to describe this force down to the smallest scales of the Universe. Our current understanding is based on Einstein's theory of general relativity, which however breaks down at the Big Bang and the centre of black holes. Everywhere else, it has so far been proven to be perfectly descriptive and accurate. The spectacular direct discovery of gravitational waves in 2015 – ripples in space-time predicted to arise from violent events in the cosmos, such as mergers of black holes or neutron stars – confirmed it once more. The first observation of a gravitational-wave event on 14 August 2017 in the VIRGO interferometer in Italy, hosted by the European Gravitational Observatory, together with the corresponding signals measured in the two LIGO detectors in the United States, at Hanford (Washington) and Livingston (Louisiana), respectively, is depicted in Fig. 2.
Read more: Quantum gravity – an unfinished revolution, Claus Kiefer

Multi-messengers astronomy - The discovery of gravitational waves has further opened up a new field called multi-messenger astronomy. We are no longer limited to observing the sky with our eyes or with telescopes detecting light or other electromagnetic waves, but we now also have gravitational waves, and neutrinos, at our disposal as messengers from cosmic sources. We can study all kinds of signals in a coordinated fashion, in experimental facilities around the globe and even in space.
Read more: A gravitational universe : black holes and gravitational waves, Nelson Christensen.

Nuclear physics - There are many bridges between the smallest and the largest scales. Nuclear physics, with its quest to understand the origins of known matter, from the primordial soup made of quarks and gluons, the protons and neutrons, the atomic nuclei, to the formation of the heavy chemical elements in explosions of stars, connects these infinities. It also has a large potential for technological spin-offs, such as nuclear fusion to ensure the supply • • •

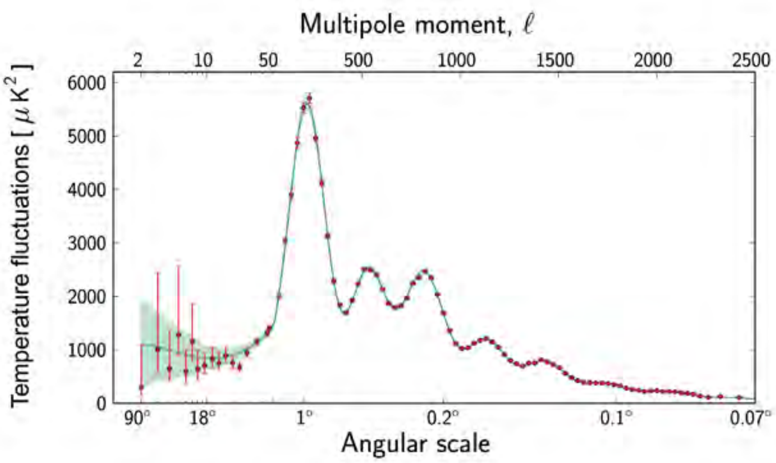


▸ **FIG. 4:** First gravitational-wave event (GW170814) detected by VIRGO, and seen in LIGO. © LIGO and VIRGO Collaborations

of electric power, and medical applications such as cancer therapy, as well as efficient and affordable isotope production for diagnostic purposes. For the latter, imaging techniques using artificial intelligence and other means are drivers for improving diagnostic accuracy, rapidity, and the comfort of patients. Astrophysics and high-energy particle physics are also connecting the scales, and have given rise to the new field of astro-particle physics. *Read more: Nuclear physics: the origin of visible matter in the Universe, Angela Bracco*

Cosmology - with its quest to understand the largest scales and nothing less than the fate of our Universe, cosmology needs information about its smallest components. Amongst others, measurements by space observatories such as Planck operated by the European Space Agency have helped establish the now widely accepted standard model of cosmology, as can be seen from Fig. 5. For the time being, we are at a turning point in the knowledge about the future of our Universe. Soon we should know more about its evolution, and in particular, whether it will be confirmed to expand continuously forever, or to rip apart, or even contract again.

▾ **FIG. 5 :** The power spectrum as measured by Planck. The green curve represents the best fit of the standard model of cosmology, currently the most widely accepted scenario for the origin and evolution of the Universe to the Planck data. © Planck Collaboration and ESA



Other research areas - The stars, the sun and the planets, including our own, still have secrets themselves. Their formation and evolution are vibrant research areas, tackled through computations and observations, and exploiting a multi-disciplinary approach. The study of exoplanets has also become a central subject in astrophysics. More down-to-earth, geophysics addresses topics that can affect us all, such as volcanic eruptions, earthquakes, or even changes in the Earth's magnetic field. The understanding of these phenomena can help predict their occurrence, for the benefit of mankind.
Read more: Stars, the Sun, and planetary systems as physics laboratories, Patrick Eggenberger and Physics of the Earth's interior, Emanuel Dormy

Acknowledgement

The authors would like to thank Freya Blekman, Angela Bracco, Nelson Christensen, Emmanuel Dormy, Patrick Eggenberger, Claus Kiefer, Emmanuel Saridakis and Jochen Schieck for their valuable contributions to the EPS Grand Challenges project.

PHYSICS OF MATTER AND WAVES

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The scales of length, time, and energy that are intermediate between the infinitely small and the infinitely large define the world we live in and that we experience. The relevant fundamental forces that act on these scales are, for nearly all phenomena, the gravitational and the electromagnetic forces. This is the subject of Chapter 2 of the EPS Grand Challenges

At the energy scales that characterise our world, the relevant physical approaches take atoms, ions, and electrons as fundamental building blocks of matter, and photons as those of light. The constituents, in the unimaginable vastness of their numbers and the fantastic variety of their possible arrangements, lead to the astounding complexity of our world and the dazzling phenomena it harbours. The world we experience is also the world on which we may intervene. When done in a controlled manner, this intervention – or experiment – belongs to the realm of science and technology. But even when we do not strive to control, our actions are still determined by the physical workings of the world's constituent building blocks and their interactions. When one comes to think of it, an atom itself is a hugely complex system. Mathematics abdicates when faced with the problem of providing an exact description of more than three interacting objects, and all atoms are in this situation: quarks make up hadrons, hadrons make up the atomic nuclei, and nuclei and electrons make up the atom. The internal organisation of the atom is the result of, for most elements, numerous "correlations". The simultaneous presence of several and often many interacting particles lead to the organisation of matter. This is even more true when one assembles atoms into molecules, atoms and molecules into liquids and solids, and liquid and solid components into complex systems. We witness that the forces • • •

▲ **FIG.1:** Interactions and emergence, illustrated by a water drop falling on a water surface. Because of the interaction between water molecules, the small drop has a visible effect over a large range, leading to the emergence of the ripple and the central rebound.

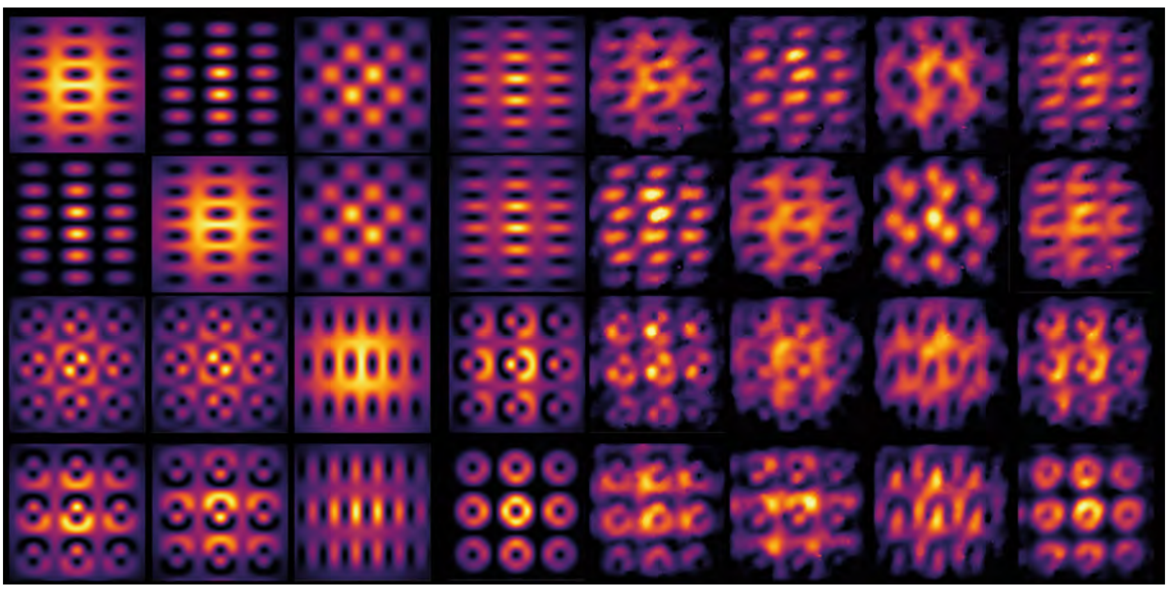
▲ **FIG. 2:** Manipulation of light. This example illustrates the numerical design of a microscale optical system separating different spectral waves and funnelling them into different waveguides. Adapted from [1] with permission from APS.

which objects around us exert on each other, and the phenomena that emerge, are the net result of their internal, physical organisation. The myriad particles involved and the manner in which they can interact and can be made to interact vouch for complexity. In chapter 2 of the EPS Grand Challenges work done in the various research fields are presented.

Quantum many-body systems - The study of "Quantum many-body systems and emerging phenomena" is concerned with the organisation of matter and the excitations its constituents can undergo when stimulated by light or other, impinging, particles. It describes how "emergent" behaviour can emerge from the interaction of many constituent particles (see Figure 1 for a parabolic illustration), and how the quantum mechanical nature of our world determines the nature of the objects that constitute it, even though we may not at all be aware of such. It also describes when a quantum description is needed, that is, when the conditions of observation are such that coherent interactions and propagation of light and particles are guaranteed. When the quantum mechanical coherence of light and matter is disturbed in the process at hand, we may resort to what has become known as the "classical description".
Read more: Lucia Reining, Quantum many-body systems and emerging phenomena.

New materials - In searching for new materials the – even limited - understanding of the organisation of matter helps mankind fashion the materials and tools need to tackle the world's challenges and problems. Here, in principle, there is nothing new. Did not the smithies and rock-hewers of prehistoric and early historic times draw on their experience to fashion stone and metal tools? Now, the formidable scientific progress accumulated over the last two centuries allows for mankind to imagine and make materials according to need, in a sustainable and controlled manner, at all scales down to that of the very constituent atoms. New and urgent challenges are to take into account the availability of material and energetic resources and to design those material assemblies and those processes that are most appropriate for a given application, choosing from the many millions of materials that nature would allow.
Read more: Claudia Draxl and José Maria de Teresa Nogueras, The search for New Materials.

Manipulating atoms and photons - Nowhere does the force of science have an impact as great as when matter and light are manipulated on the smallest of scales – the nanometer (*i.e.* 10^{-9} m) or below. "Manipulating Atoms and photons, photonics and nanophysics" shape today's and tomorrow's technologies and allow us to dive into



▸ **FIG. 3:** Twisting Light Beams on Demand: Beams of light with phase-structured wave fronts provide a robust, high-dimensional medium for metrology and communication applications (from A.R. Cameron *et al.*, Phys. Rev. A 104, L051701 (2021) © APS

the smallest length scales defining materials and the systems they can constitute and, indeed, back into the quantum realm. The understanding of how interactions between particles manifest themselves differently depending on the length scale we are working on and how the quantum mechanical nature of these interactions can be brought out, allows one to put both to work to define entirely new tools, systems, and paradigms (see *e.g.*, Figure 2).
Read more: Jean-Jacques Greffet, Antoine Browaeys, Frédéric Druon, and Pierre Sénéor, Manipulating photons and atoms: photonics and nanophysics.

Extreme light - What goes for matter also goes for light, and what goes for space also goes for time. Recent and astounding advances now allow one to fashion extremely bright light beams, extremely short light pulses, or a combination of both, giving rise to the realm that has become known as "Extreme Light". Extreme brightness allows us to examine the structure of matter, its organisation, and its response to excitations in the very finest details – for it is those details that most often give away the fundamentals at stake in determining the nature of the studied object in the first place. Ultra-short and bright pulses allow one to make "movies of matter". Much as stroboscopic illumination of moving beings can reveal the gestures in motion, pico- and femto-second illumination of matter unveils the dance of electrons in matter: how matter is excited, how matter reacts, how matter transforms. Extremely spectacular results with high-stake implications in many fields (chemistry, biology, medicine…) are to be expected here. Moreover, being able to intervene at the rhythm of matter itself allows us to reorganise it, yielding yet another tool for the creation of new (quantum) states of matter designed as tools to face the challenges of humankind.
Read more: Franck Lépine, Jan Lüning, Pascal Salières, Luis Oliveira e Silva, Thomas Tschentscher, Antje Vollmer, Extreme Light.

Extended classical systems – In the EPS Grand Challenges, the summary of the Physics of Matter and Waves in the world as we know it and discover it is completed by the description of classical systems with numerous degrees of freedom and the multiplicity of interactions in systems that are not necessarily characterised atomic length and time scales and quantum coherence. This opens the way for the most complex of organisations of matter as we know it: life itself.

Acknowledgement
The authors would like to thank Marco Baldovin, Antoine Browaeys, Claudia Draxl, Frédéric Druon, Giacomo Gradenigo, Jean-Jacques Greffet, Franck Lépine, Jan Lüning, Lucia Reining, Pascal Salières, Pierre Seneor, Luis Silva, José Maria de Teresa, Thomas Tschentscher, Antje Vollmer and Angelo Vulpiani for their valuable contributions to the EPS Grand Challenges project.

PHYSICS FOR UNDERSTANDING LIFE

Felix Ritort[1] and Bart van Tiggelen[2] DOI: https://doi.org/10.1051/epn/2022508
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"Living" matter distinguishes itself from "ordinary" matter by its capacity to grow, to reproduce or to multiply, and most of all by its autonomous functional activity, baptised "intelligence", to sense its environment to adapt or to survive. This last feature truly is one of the miracles of life. Find out more in Chapter 3 of the EPS Grand Challenges.

Our current knowledge of life is relatively recent. The "molecule of life", Deoxyribose Nucleic Acid or DNA, was first discovered by Miescher in 1860. The discovery of the double helix structure by Watson and Crick in 1951, and the determination of its sequence of nucleic acids by Sanger and Coulson in 1975 have been major breakthroughs of the last century. Can science discover what conditions have facilitated the origin of life on Earth? Does some kind of "life" exist on extra-terrestrial planets? Can we create "artificial life" that self-replicates or has intelligence? Can we design and implement "artificial intelligence"? These challenges are hopefully within reach on the Horizon 2050. Is life nothing but "vital dust", *i.e.* a natural consequence of non-equilibrium physics and chemistry, or was it rather a "magnificent accident"? Famous physicists like Erwin Schrödinger and Freeman Dyson struggled with the role of physics in the origin of life. Schrödinger wondered how life manages to stay out of equilibrium while respecting the Second Law. Dyson argued that metabolism and replication could have originated separately and that "life actually began twice". Physics is not enough for understanding life, but life may reveal new physics. To understand life, we need interdisciplinary collaborations between biologists, computer-scientists, chemists, physicists, astrophysicists and engineers. Chapter 3 of the EPS Grand Challenges is devoted to the field of physics for understanding life.

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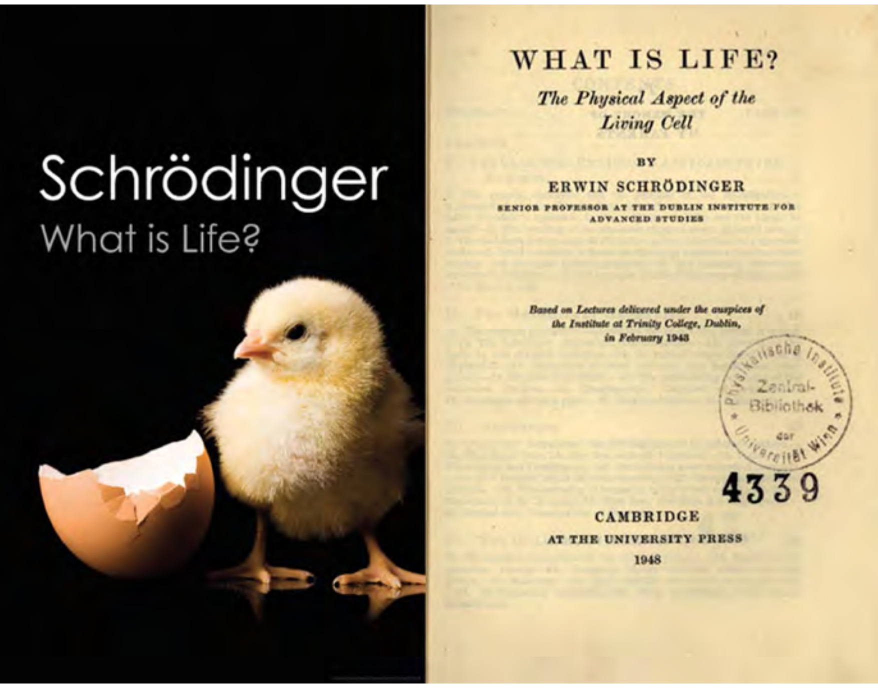
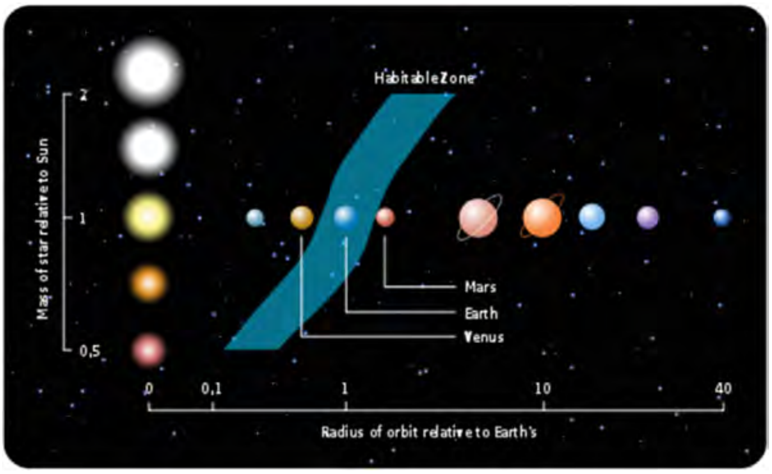


▼FIG. 1: What is life? by Erwin Schrödinger (source: Wikipedia)

Where do we come from? How life on Earth began remains an unsolved, complex scientific problem. After the brilliant experiments by Pasteur and Tyndall in the nineteenth century, the concept of "spontaneous generation" of life from non-living matter was rejected for once and for all. Life may have emerged only 400 million years after the "Hadean" Earth was created (Hades was the king of the ancient Greek underworld), only 200 million years after liquid water had first appeared. The absence of a well-preserved crust older than 3.3 billion years makes it difficult to get a precise information about the chemical composition of the Hadean Earth. The time variations on all scales of the Earth-Sun connection must



▲ **FIG. 2:** The habitable zone predicted on the basis of liquid water present at the surface of the planet. (source: Wikipedia)

have played a major role in the chemistry that created life. Stellar evolution models tell us that the young Sun was 70 % fainter than today. The "faint young Sun paradox" states that this low flux implies water on Earth to be frozen until well beyond the Hadean age, which we know is not true. Greenhouse gases such as CO_2 must have been present, heating up the atmosphere much like they do today. The rapid rotation of the young Sun in only a few days led to strong magnetic activity and intensive space weather, so that energetic X-ray fluxes must have been up to 100 times larger than today.

The presence of liquid water is a major condition for life to form, but other habitability conditions exist, such as the presence of organic molecules and energy sources – providing at least 150 kJ/mol - to initiate prebiotic chemistry. Energetic solar photons must have provided a lot of this energy. Organic molecules such as HCN and CH_2O could also have been created by the lightning-triggered dissociation of carbon-dioxide and abiotic methane. A mostly reducing (oxygen-poor) early atmosphere with energetic sparks could have been a play-ground for prebiotic chemistry and a world-famous "Miller-Urey" experiment supporting this vision was done in 1952. Carbonaceous meteorites impacted the Earth and brought also many organic compounds, including amino acids. Where exactly prebiotic chemistry took place is still subject to a large debate. Energetic radiation does not penetrate more than 1 cm in water.

H.J. Cleaves, Prebiotic Chemistry: What We Know, What We Don't, Evolution: Education and Outreach ***5****, 342 (2012).*
C. Sagan and G. Mullen, Earth and Mars: Evolution of Atmospheres and Surface Temperatures,Science. ***177*** *(4043): 52 (1972).*
H.C. Urey, On the early chemical history of the Earth and the origin of life, P.N.A.S. ***38****, 351 (1952).*
S.L. Miller, Production of Amino Acids Under Possible Primitive Earth Conditions, Science ***117****, 528 (1953).*

Life for understanding new physics. In his 1944' beautiful essay Erwin Schrödinger wrote: *"The large and important and very much discussed question is: how can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?"*. The marvellous complexity of living matter raises the question of whether biology hides new, emerging physical laws awaiting discovery. From the Brownian motion of pollen grains to cell motility, animal motion, the many behaviours of active matter, and the evolution of bacterial populations, the interface between biology and physics offers an unprecedented wealth of new phenomena that can be investigated at an exquisite level of detail. For example, single-molecule techniques permit us to monitor how a protein folds and measurements of energies with 1 kT ($\approx 10^{-21}$J) accuracy reveal how a molecular motor moves one step at a time. By increasing the bar of spatial, temporal, and energy measurement accuracy, we hope to uncover vital discrepancies between our current theoretical knowledge and experiments on biological systems. Teleonomy is the continuous "purposefulness" of living beings to sleep, feed, trade, play, laugh, *etc.* They are not found in non-living matter where just the laws of physics and chemistry prevail. Does it escape our comprehension? What is the role of physical information in biology? Does information set a new paradigm for emerging complexity that connects biology to quantum physics? All these are relevant questions waiting for an answer.

F. Ritort, The Noisy and Marvellous Molecular World of Biology, Inventions ***4.2****, 24 (2019).*

What is the nature of the human mind? Artificial intelligence (AI) covers all techniques that enable machines to solve tasks like humans do. AI applications are immense, from medicine to robotics and basic science. AI has seen fast growth since the fifties when cybernetics and feedback, the branch of science introduced by Wiener in 1948, took off as an effort to understand information processes in machines and living beings. The Greek term "cybernetics" (*kybernetiké*), the art of guiding, was introduced by Ampère in his classification of sciences published in 1834, subsequently taken up by Maxwell. Subsequent work by Bertalanffy on the general theory of biological systems, Maturana and Varela on *autopoiesis* (the idea of self-sustaining cycles), Von Neumann, Shannon, and Gabor on automatic systems have set the basis of modern AI. Good old-fashioned AI (GOFAI), as it is called nowadays, embraces the power of using basic symbols (words, pictures, actions, *etc.*.) to represent physical patterns to build up high-order symbolic structures to be manipulated with programs and algorithms. A key limitation of GOFAI is that programs can neither adapt themselves nor acquire new knowledge on their own, which led to the "AI winter" in the eighties without significant progress. The subsequent development of connectionism in artificial neural networks and statistics-based inference methods (machine learning) that allow data internal structure to evolve, has led to new functionalities. In the current view, intelligence stands for the ability to avert the ever-present threat of the exponential explosion of search options. What about consciousness? If brains can be considered as probabilistic prediction machines they must somehow deal with uncertainty. Is this related to consciousness? Are we going to understand consciousness one day?

N. Wiener, Cybernetics or Control and Communication in the Animal and the Machine, MIT press (2019)

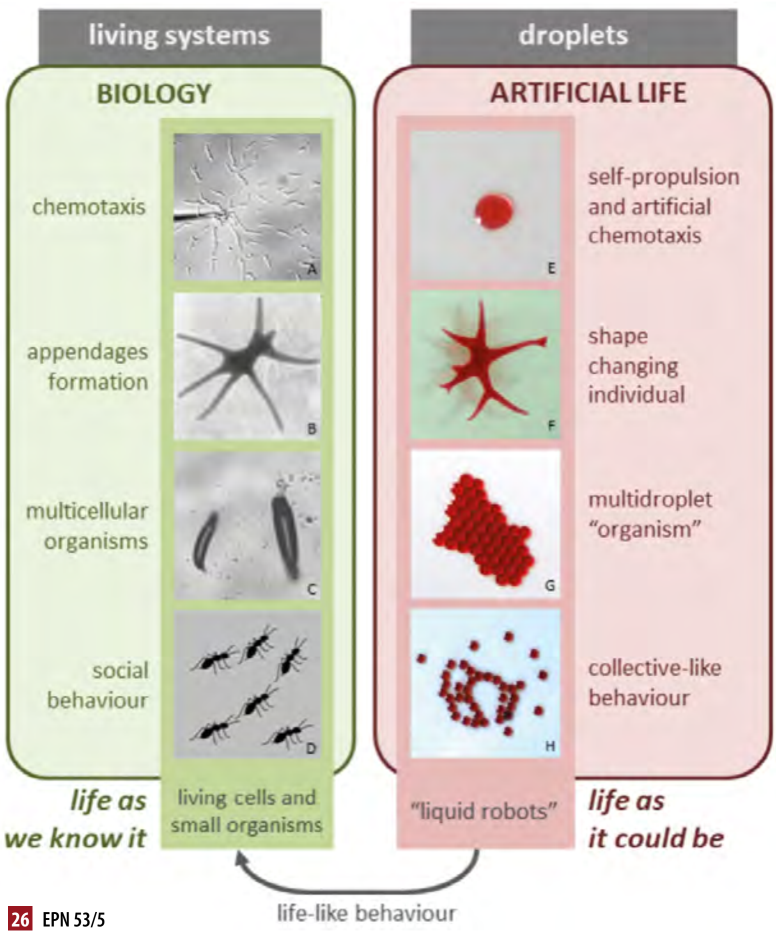
*J.C. Maxwell, On Governors. Proceedings of the Royal Society of London **16**, 270 (1868)*

O.A. Newell and A.S. Herbert, Computer science as empirical inquiry: Symbols and search, ACM Turing award lectures, 2007 (1975).

Can we build artificial life? Artificial life (ALIFE) aims at building sustainable self-replicating systems resembling living beings. ALIFE comes in three forms: computer-designed AI programs and algorithms (soft ALIFE), hardware-based robots (hard ALIFE), and chemical and biochemical systems with life-like behaviour (wet ALIFE). The basic tenet of ALIFE is that if Nature has found one way of organizing living matter, other (unknown) ways should exist. Can we build synthetic cells endowed with homeostasis, self-reproduction, and evolution? Man-designed cell-like droplets exhibit limited properties and functionalities, such as self-propulsion, artificial chemotaxis, organism-like multi-droplets, collective-like behaviours, *etc.* Building synthetic ALIFE systems represents a daunting task ahead. Besides possessing basic properties such as robustness, autonomy, efficiency, recycling, intelligence, self-repair, adaptation, self-replication, *etc.*, they must show open-ended evolution and teleonomy. Are we ever going to leap this gap?

A. Pross, What is life?: How chemistry becomes biology. Oxford University Press, 2016.

▾ **FIG. 3:** Life-like behaviour, comparison between living systems in biology and droplets in artificial life.



Is there anybody out there? The question whether extra-terrestrial life exists is as old as mankind. No matter how small the probability is for life to emerge, its existence "somewhere, sometime" in the huge Universe is largely accepted by scientists. The Drake equation, actually proposed as an agenda item for a meeting on alien communications in 1961 but today argued to be one of the most important equations in science, gives estimates of up to many millions of detectable alien civilisations in our own Galaxy. The famous paradox raised by Enrico Fermi during an after-dinner talk in 1950 states that if there are really so many, then "where are they?". One possible answer is that intelligent civilisations tend to self-destruct.

With the recent observation of exoplanets, the first proof of extra-terrestrial life may be within reach. Will it have the same biochemistry that created life on Earth? The establishment of a list of "biosignatures" - molecules whose origin we believe requires a biological agent - has top-priority. Molecular oxygen is a clear biosignature, and is hardly found elsewhere in our solar system. A molecular biosignature must be stable with respect to the local planetary environment, though its detection may be false alarm due to abiotic reactions. Within our solar system several bodies such as Mars, Jupiter's moon Europe and Saturn's moon Titan have been identified as possible candidates to host or to have hosted life. Sample-return missions and in-situ search for "biosignatures" started with the Viking lander missions to Mars in 1976 and continue today with the rover Perseverance. Indications exist that Mars might host methane-producing micro-organisms at its subsurface. The complication on Mars is that many identified biosignatures were possibly destroyed by (per)chlolates.

Our knowledge about exoplanets outside the solar system entirely depends on remote sensing. Today, more than 4000 exoplanets have been identified. The recently launched James Webb telescope will facilitate the study of infrared absorption lines in the spectra of exoplanet atmospheres, observed while transiting in front of the star, and possibly due to biosignatures. The perfect exoplanet to observe "Earthian" life would be an Earth-sized planet in an Earth-like orbit around a Sun-like star. Unfortunately, due to observational selections effects, few such perfect exoplanets are currently known. A recently observed candidate is one of the

◂ **FIG. 4:** Dragonfly mission concept of entry, descent, landing, surface operations, and flight at Titan. @NASA

three exoplanets of our nearest star Proxima Centauri. It is Earth-like and estimated to be in the habitable zone of liquid water. Several next-generation proposals exist to overcome the problem detecting exoplanets of fainter, more distant stars, such as the "Seventy Billion Mile Space Telescope" FOCAL that uses the Sun as a gravitational lens. We might even launch relativistic "spacechips" to Proxima Centauri. Despite huge technological progress in the decennia to come, no watertight proof of life on exoplanets may ever come. A fundamental question is whether we can live with that.

F. Drake and D. Sobel, The Origin of the Drake Equation, Astronomy Beat ***46****, 1 (2010)*

J.P. Faria et al., A candidate short-period sub-Earth orbiting Proxima Centauri, Astronomy & Astrophysics ***658****, A115 (2022)*

V.R. Eshleman, Gravitational Lens of the Sun: Its Potential for Observations and Communications over Interstellar Distances, Science, ***205*** *(4411), 1133 (1979)*

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The authors would like to thank Patricia Bassereau, Angelo Cangelosi, Jitka Cejkova, Carlos Gershenson, Raymond Goldstein, Zita Martin, Sarah Matthews, Sara Seager, David Vernon and Francis Westall for their valuable contributions to the EPS Grand Challenges project.

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Last but not least, articles dealing with Environmental questions such as the Management of Radioactive Waste, or studies of Technico-economics for nuclear systems belong to *EPJ N*. ■

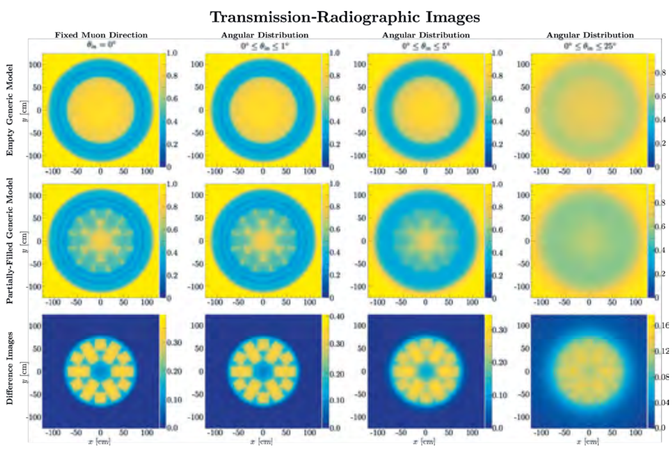

Figure 7, EPJ N authors

PHYSICS FOR HEALTH

Ralph W. Assmann[1], Giulio Cerullo[2] and Felix Ritort[3] – DOI: https://doi.org/10.1051/epn/2022504
[1] DESY, Hamburg, Germany
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[3] Small Biosystems Laboratory, Condensed Matter Physics Department – Facultat de Física – Universitat de Barcelona, Spain

The fundamental research on the physics of elementary particles and nature's fundamental forces led to numerous spin-offs and has tremendously helped human well-being and health. This is the subject of Chapter 4 of the EPS Challenges for Physics.

▲ MRI scanning equipment ©iStockPhoto

Prime examples include the electron-based generation of X rays for medical imaging, the use of electrical shocks for treatment of heart arrhythmia, the exploitation of particle`s spin momenta for spin tomography (NMR) of patients and the application of particle beams for cancer treatment. Ten-thousands of lives are saved every year from use of those and other physical principles. A strong industry has developed in many countries, employing hundreds of thousands of physicists, engineers and technicians. Industry is designing, producing and deploying the technology that is based on advances in fundamental physics.

Major research centers have established and provide cutting-edge beams of particles and photons for medical and biological research, enabling major advances in the understanding of structural biology, medical processes, viruses, bacteria and possible therapies. Those research infrastructures serve tens of thousands of users every year and help them in their research. Modern hospitals are equipped with a large range of high technology machines that employ physics principles for performing high resolution medical imaging and powerful patient treatment. Professors and students at universities use even more powerful machines for conducting basic research in increasingly interdisciplinary fields like biophysics and robotics. New professions have developed involving physicists and reaching out to other domains. We mention the rapidly growing professions of radiologists, health physicists and biophysicists.

▲ **FIG. 1:** Virtual Reality (VR), advanced user interfaces and telecommunications and robot technology combine to create an enhanced surgical experience.

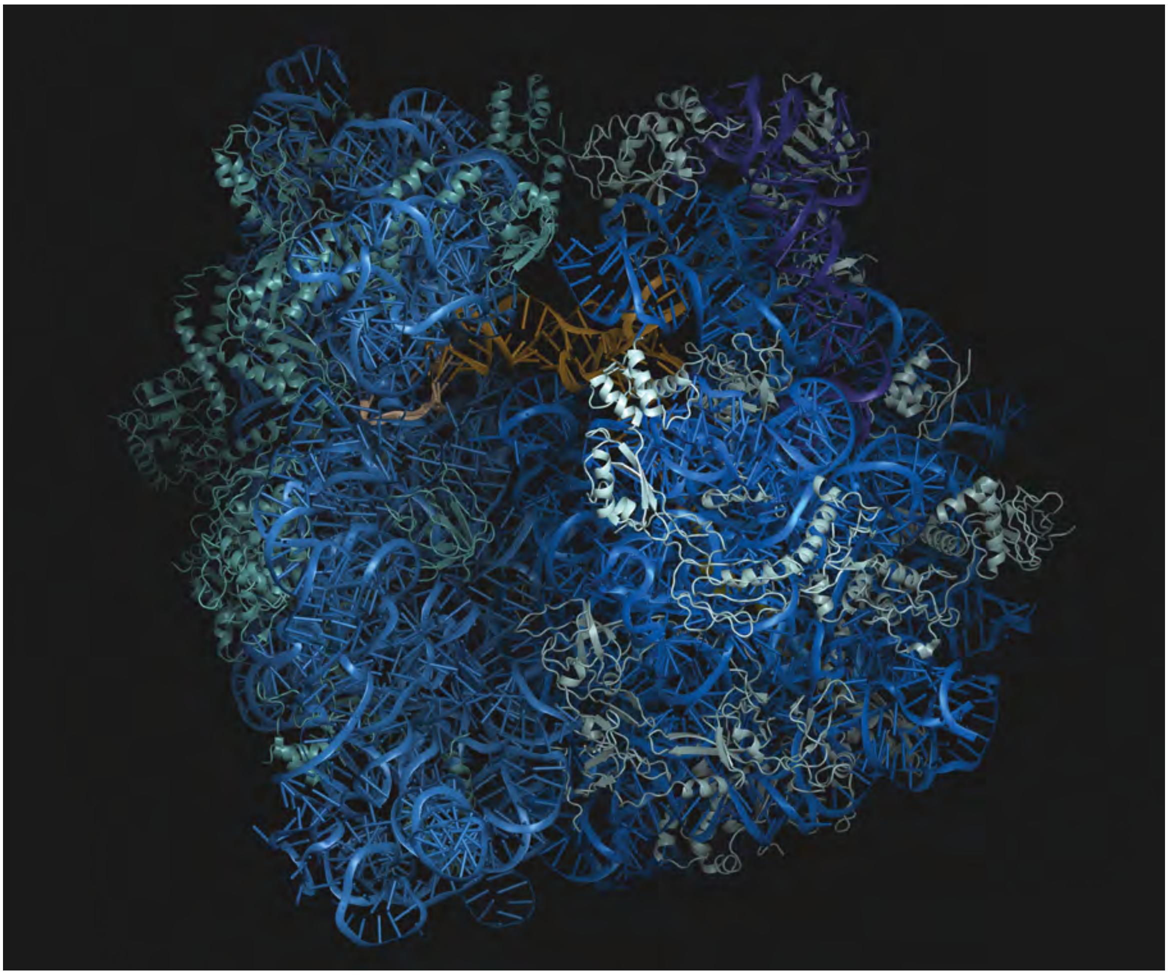
While physics spin-offs for health are being heavily exploited, physicists in fundamental research keep advancing their knowledge and insights on the biochemical mechanisms at the origin of diseases. New possibilities and ideas keep emerging, creating unique added value for society from fundamental physics research. Chapter 4 of the EPS Grand Challenges on physics for health does not aim to provide a full overview of the benefits of physics for health. Instead, the authors are concentrating on some of the hot topics in physics and health related research. The focus is put on new developments, possible new opportunities and the path to new applications in health.

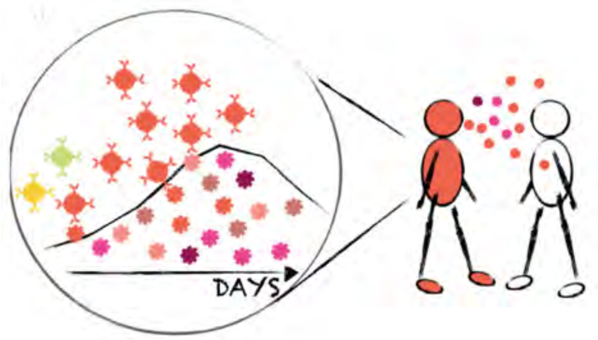
Using particle accelerators - Angeles Faus-Golfe and Andreas Peters describe the role of particle accelerators and the use of their beams for irradiating and destroying cancer cells. State of the art machines and possibilities for new irradiation principles, *i.e.* the FLASH effect, are introduced. As physics knowledge and technology advance, tumors can be irradiated more and more precisely, damage to neighboring tissue can be reduced and irradiation times can be shortened.

Using robotic systems - Darwin Caldwell looks at the promise and physics-based development of robotic systems in the macroscopic world, where they are complementing human activities in a number of tasks from diagnosis to therapy. Friedrich Simmel looks at the molecular and cell-scale world and explains how nanorobotics, biomolecular robotics and synthetic biology are emerging as additional tools for human health, for example as nano-carriers of medication that is delivered precisely [Fig. 1].

Using light - Henry Chapman and Jürgen Popp describe the benefits of light for health [Fig. 2]. Jürgen Popp is considering the use of lasers that have advanced tremendously in recent years in terms of power stability and wavelength tunability. Modern lasers are used in several crucial roles in cell imaging, disease diagnosis

▸ **FIG. 2:** The molecular structure of the ribosome, as determined by X-ray crystallography at DESY in Hamburg, showed researchers how this complicated nano-machine synthesises new proteins by reading genetic information encoded in messenger RNA molecules.





▲ **FIG. 3:** Within an infected host the cells of the immune system target existing viruses (and pathogens in general) by binding and neutralizing them. Each host has a vast repertoire of immune cells (denoted by different colors) from which those that best target the infection are chosen (same color as the viral strains). In some cases, these cells can further somatically evolve to increase their recognition power.

and precision surgery. Henry Chapman considers the use of free-electron lasers for understanding features and processes in structural biology. He shows that the advance of those electron accelerator-based machines has allowed a tremendous progress in the determination of the structures of biomolecules and the understanding of their function.

Pandemics - Aleksandra Walczak, Chiara Poletto, Thierry Mora and Marta Sales describe Physics research against pandemics, a multidisciplinary problem at the crossing of immunology, evolutionary biology and networks science. Pandemics is also a multi scales problem at the spatial and temporal levels: from the small pathogen to the large organism; and from the infective process at cellular scale (hours) to its propagation community-wide (months) [Fig. 3]. Simple mathematical models such as SIR (Susceptible-Infected-Recovered) have been a source of inspiration for physicists who model key quantities at an epidemic outbreak, such as the effective reproductive number R, in situations where a disease has already spread. A prominent example is the recent COVID-19 pandemics that has been more than a health and economic crisis. It illustrates our vulnerability where interdisciplinary & multilateral science play a crucial role to address a global challenge that is affecting societies at their core.

Outlook - Promise and progress in further diagnostics and therapies is also considered. Lucio Rossi explains the progress in magnetic field strength as it can be achieved with super-conducting magnets, while Marco Durante discusses the progress in charged particle therapy for medical physics.

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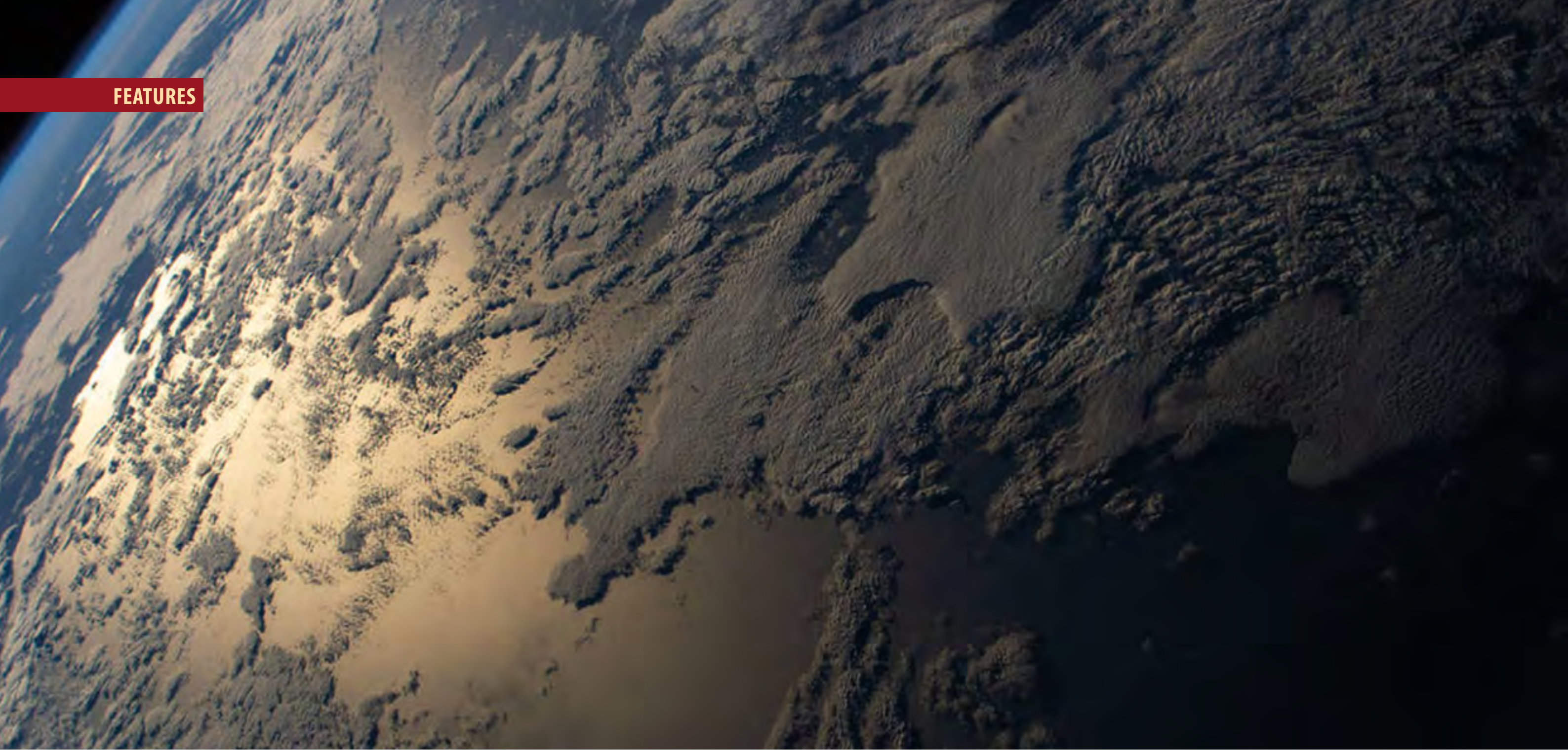

PHYSICS FOR ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

Luisa Cifarelli[1] and Carlos Hidalgo[2] – DOI: https://doi.org/10.1051/epn/2021505
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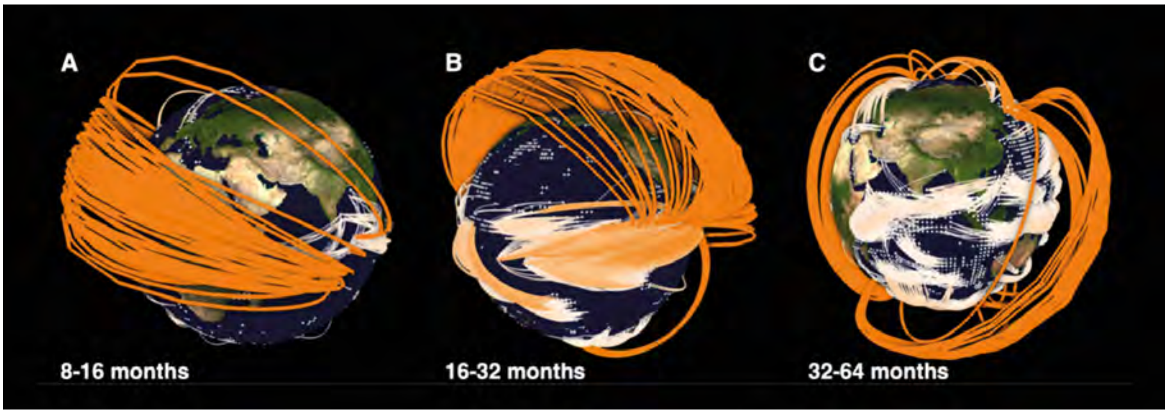
One of the most crucial and challenging development of the last decades has been the discovery that environment is fragile. Read about it in Chapter 5 of the EPS Challenges for Physics.

▲ Sunlight glints above the Indian Ocean as the ISS orbited about 270 miles above the Earth near western Australia. Credit: NASA.

A discovery that shows that we cannot afford to delay the implementation of actions to tackle climate change if the long-term objective is to try limiting the increase in the global temperature of the planet at an affordable cost. Although the environment problem is too complex to admit simple solutions, recent developments illustrate how basic science, together with social awareness and political actions, can be successfully pulled together to avert an environmental tragedy. The contributions in chapter 5 of the EDP Grand Challenges present work done in a wide range of research areas illustrating how humanity not only has the responsibility to preserve our delicate planet but also the power to affect its environment. Together, they highlight the strength of fully interdisciplinary effort among physicists, mathematicians and chemists as well as multilateral science to address global challenges that affect societies at their core.

Nonlinear physics - Key concepts from nonlinear physics enable us to treat challenging problems of Earth sciences and climate projections. A reliable understanding of the Earth system is essential for the quality of life in a modern society. Natural hazards are the cause of most life and resource losses. The ability to define the conditions for a sustainable development of humankind to keep the Earth system within the boundaries of habitable states or to predict critical transitions and events in the dynamics of the Earth system are crucial to mitigate and adapt to Earth system related events and changes and to avert the disastrous consequences of natural hazards. Modelling climate requires the development of methods to simulate the interactions of the important drivers of climate, including atmosphere, oceans and land surface (Fig.1). *Read more: Earth system analysis from a nonlinear physics perspective, Juergen Kurths, Ankit Agarwal, Ugur Ozturk, Shubham Sharma, Norbert Marwan and Deniz Eroglu.*

Energy - Energy is the blood that moves today's society and is one of the factors that has decisively contributed to improving humanity's quality of life. The debate about the connection between energy sources and climate change has profound political and ethical consequences. It addresses the further development of energy storing

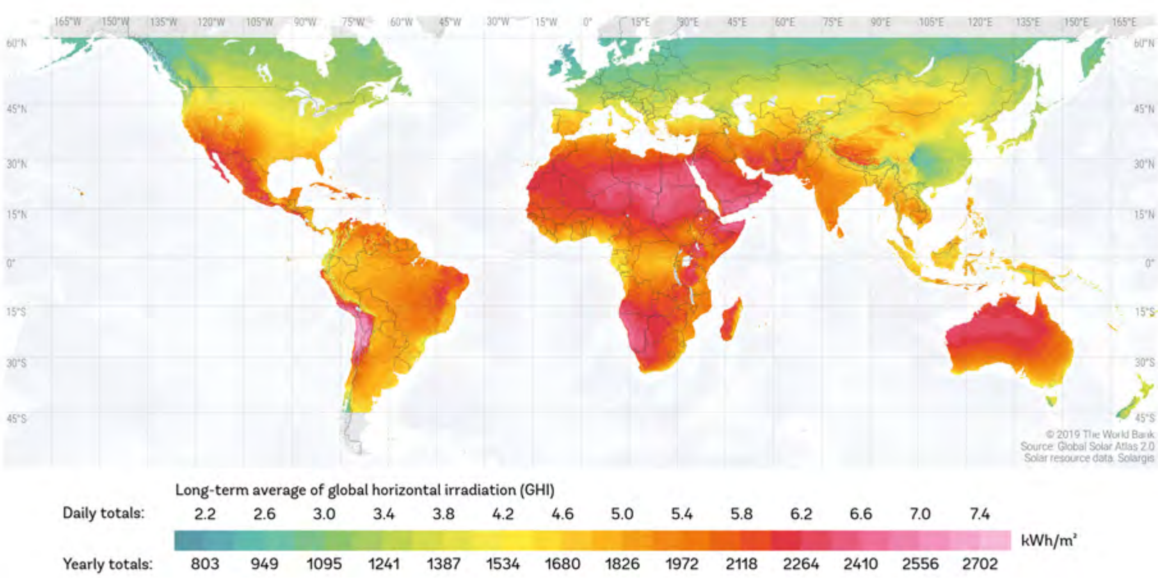


▸ **FIG. 1:** Spherical three-dimensional globe representation of the long-range teleconnections at different timescales in sea surface temperature network.

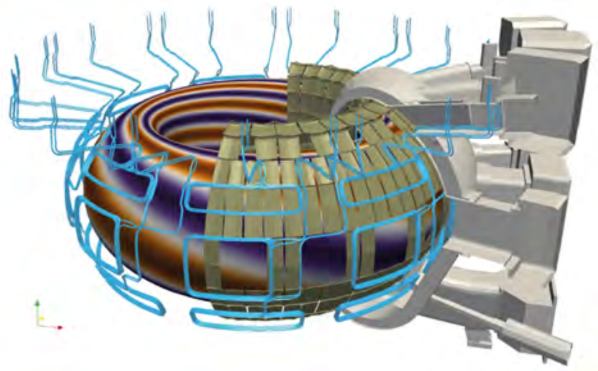
systems and of energy sources, like solar, wind, nuclear fission as well as the quest for nuclear fusion since the dominance of fossil fuels must decline (Fig. 2). It highlights the potential challenges and opportunities in the development of global energy systems, emphasising how deeply interconnected the energy and climate debates are. Now the physics and technology strands need further convergence and integration for the development of massive and sustainable energy sources. From this perspective the next few decades will be crucial to demonstrate the scientific and technical viability of fusion as an energy source by integrating the acquired knowledge in physics such as confinement and engineering optimisation, *e.g.* tritium technologies (Fig. 3).
Read more: Solar Energy, Robert Pitz-Paal and Bernd Rech.
Wind Energy. H. - J. Wagner.
Energy Storage, Søren Linderoth.
Fission Energy, Marco Ripani.
Fusion energy Development, Alberto Loarte.

Green cities and transport - The invention of the combustion engine radically transformed industrial and personal transport and, consequently, our social organisation system. Improving the performances of batteries and fuel cells cannot be based exclusively on an empirical approach; it requires a deeper understanding of the complex multi-scale phenomena occurring in batteries and fuel cells. This challenge can be achieved by making use of computational simulation in combination with advanced characterisation techniques. Therefore, significant effort must be devoted to model validation against experiments.
Read more: Green cities and transport, Natalio Mingo; Gérard Gebel; Philippe Azais; Thierry Priem; Tuan Quoc Tran; Didier Jamet; Florence Lefebvre-Joud; Simon Perraud.

Environmental safety - Hazardous wastes and materials are diverse, with compositions and properties that vary significantly between industries and related energy sources. Challenges include air quality avoiding and reducing pollutant emissions, access to safe drinking water and food, economics and scale of waste management as well as public acceptability. From a chemical perspective environmental emissions and waste disposal can be managed to meet sustainable development criteria. Technical innovation is required to handle the foreseen burst of chemicals on environmental safety and health.
Read more: Environmental Safety, Jacob de Boer



▸ **FIG. 2:** The solar energy distribution is quite inhomogeneous on the earth surface. As the output of solar energy converters is almost proportional to its input, the cost of solar energy for both PV and CSP is strongly related to the selected site.



▲ **FIG. 3:** Magnetic confinement fusion plasmas maintain equilibrium by the magnetic fields creating a force that opposes the expansion of the hot plasma and this equilibrium may become unstable. These instabilities (so-called magneto-hydrodynamic instabilities) impact directly the achievable fusion power production and therefore their control is crucial. The figure shows the set of 27 coils (in blue) to control edge instabilities in ITER.

Space weather - Space weather describes the way in which the Sun, through emergence of magnetic field into its atmosphere, flares, coronal mass emissions, high-energy particles and subsequently induced space conditions, impacts human activity and technology both in space and on the ground (Fig. 4). It causes substantial socio-economic impact on human infrastructures in space and at Earth; therefore it is a great challenge developing robust methods that allow prediction of space weather events with sufficient accuracy. With the rapid increase in computational power, new opportunities are arising to address non-linear processes where numerical experiments can guide us to the frontiers of solar and space weather physics.

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The authors would like to thank Ankit Agarwal, Philippe Azais, Jacob de Boer, Deniz Eroglu, Gérard Gebel, Didier Jamet, Juergen Kurths, Florence Lefebvre-Joud, Søren Linderoth, Alberto Loarte, Norbert Marwan, Natalio Mingo, Ugur Ozturk, Simon Perraud, Robert Pitz-Paal, Stefaan Poedts, Thierry Priem, Bernd Rech, Tuan Quoc Tran, Marco Ripani, Shubham Sharma, Hermann-Josef Wagner for their valuable contributions to the EPS Grand Challenges project.

▼ **FIG. 4:** One of the key drivers of space weather are solar eruptions. These include both solar flares and Coronal Mass Ejection

PHYSICS FOR SECURE AND EFFICIENT SOCIETIES

Christian Beck[1] and Felicia Barbato[2] – DOI: https://doi.org/10.1051/epn/2022506
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Physics research contains two very different aspects–there is the fundamental research driven by curiosity, with the ultimate aim of understanding very small interacting systems, very large interacting systems, and the complex behaviour on intermediate scales, but there is also the applied side, where physics is applied to develop new technologies, new analysis methods and new concepts and insights that are useful for society. Read about it in Chapter 6 of the EPS Grand Challenges for Physics.

▲FIG. 1: Augmented reality and smart sensors will allow greater control of production processes

Ultimately, much of what physics for interacting systems encounters with is nonlinear, high-dimensional, and complex, and the final goal is to apply novel physical insights to real-world systems, providing useful applications that are helpful for society in general. The topic of this chapter, physics for secure and efficient societies, is very broad and general, and has many different aspects, and our chapter in no way makes an attempt to treat it in full generality. Rather, we have selected a few topics that we find particularly interesting, with the emphasis of looking into the future—perhaps looking towards the year 2050 or towards a similar time scale.

Read more in Chapter 6 of the EPS Grand Challenges for Physics.

Quantum computing. One important aspect for the future of society is the further development of information technologies—proper communication and information processing and enhanced computer development is absolutely essential. Our world today is dominated by computers in their various shapes and sizes, from small to big, from personal to institutional, from local to world-wide. Science has made immense progress by implementing modern machine learning technologies and artificial intelligence, so a natural question is where is computing going to, what is the next generation of computers made of, and what is the next generation of algorithms? Still in its infancy today, quantum computing may hold the key for outstanding novel computational developments of the future—some problems are so complex that they can't be solved with present conventional computers, but require something that is orders of magnitudes faster, or need algorithms and novel approaches that are very different from what is currently used in mainstream simulations.

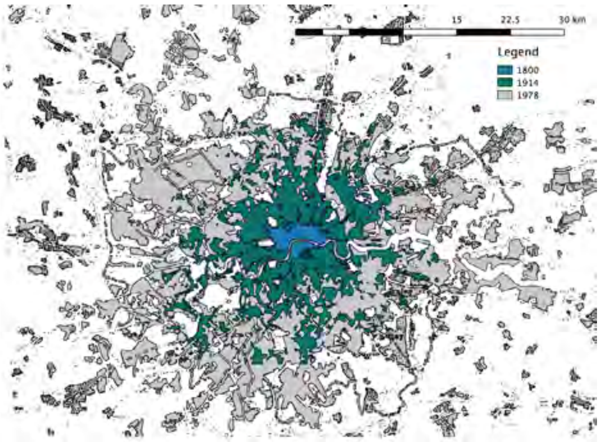
The article by Daniel Malz and J. Ignacio Cirac in our chapter summarises the most important principles of quantum computing, exploiting quantum superpositions and entanglement for the purpose of future quantum computers. The aim is to solve certain problems much faster than with conventional computers. In addition to this, the article by Zeki Can Seskir and Jacob Biamonte looks at the historical development of quantum computing research and in particular quantum algorithms and new types of machine learning models, which are expected to be very relevant in the future.

▾ **FIG. 2:** The Galileo System constellation.

Sensor development. How do we actually get the data that we feed into our physical models, to make accurate predictions for the future, using the best computers and analytical techniques available? The problem is non-trivial, as bad data yield biased and unprecise predictions. Sensor technology has made immense progress recently. The convergence of multiple technologies, real-time analytics, machine learning, ubiquitous computing, embedded systems gave birth to the Internet of Things (IoT) and the automation and control of industrial processes can be seen as the fourth industrial revolution, also known as the Industrial Internet of Things (IIoT) [Figure 1]. In her article, Antigone Marino walks in the historical basic steps of sensor developments arriving then at the future challenges set by Europe climate change strategy for 2050. In this framework, smart sensors are fundamental for monitoring all services related to the automation of processes as regards to the sphere of waste reduction, clean water, environmental control and finally to expand the quality of life in the workplace.

Space exploration. The use of smart sensors is also open to the space sector which is gaining more and more importance and is going to enter in its golden age driven by the longstanding dream of mankind, the space exploration, with many interesting new perspectives and applications for the benefit of humans on the horizon. In his article on the space sector, Javier Ventura-Traveset reviews the current status of next future missions and explores the prospects of the space sector beyond 2030/2035. Many intriguing topics are covered, starting from more gnoseological problems like space science, going through futuristic scenarios about human and robotic exploration of space, and finally touching more practical issues like understanding the climate change trend, its sources, its dynamics and the major anthropogenic impacts. In this article, Javier Ventura-Traveset makes it very clear how space exploration has, and will have even more in the future, huge impact on our society both from the economical and the social point of view, and how future society can benefit from this emerging sector [Fig. 2].

Complex systems. Finally, another problem of utmost relevance for future societies is the understanding of the complexity that is underlying the real-world systems that surround us and the daily life aspects of our living. Here statistical physics, in its modern form, has a lot to say.



▲ **FIG. 3:** A city.

One particular example is the science of cities [Fig. 3]. A very large part of the world population these days live in cities, but how do cities actually function, how do they evolve, how can we improve the day-to-day structures and life quality in a sustainable and environmentally friendly way? Cities are spatially extended complex systems, and statistical physics, in its modern formulation, can be applied. In the historical Boltzmann formulation particles are replaced by agents (companies, vehicles, people, sustainable energy sources, …), interactions are replaced by communications (mobile phones, e-mail, Twitter, …) , phase transitions correspond to an abrupt change of relevant observables (opinions, prices, behavioural patterns, …) , and so on. In his article Marc Barthelemy provides a state-of-the-art overview on city modelling, city growth aspects, traffic congestion, and much more, using the tools of statistical physics and complex network theory.

Overall, the example topics treated in this chapter show that often there is initially fundamental basic physical science, which then feeds into more advanced applied models relevant for the future development. For example, starting from quantum physics we proceed to modern methods and algorithms of quantum computing, starting from classical equilibrium and nonequilbrium statistical physics we proceed to a modern science of cities, and so on. Better predictions and better models can be made if we have access to better data, obtained with more powerful sensors, by better satellite navigation methods, and so on. Let's hope that in 2050, most of the world's population will be living in a clean, peaceful and sustainable environment, where physics helped a lot to attain this stable state. ■

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SCIENCE FOR SOCIETY

During the second part of the 20th century, the social contract between science and society was merely a tacit agreement foreseeing that public money would finance the research that would sustain technology development and innovation and enhance the socio-economic well-being of our society. The spheres of science, politics, and society were largely separate. Today this model has changed. Chapter 7 of the EPS Challenges for Physics deals with this issue.

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▲ Talking birds as a symbol for open communication and education. ©iStockPhoto.

In the last 25 years, this model has been broadly questioned. Blurred ethical standards and catastrophes in addition to the dissemination of "fake news" have repeatedly undermined the faith in science. Innovation has not always been driven by the Common Good or the needs and expectations of the citizens. Most importantly, there has been an increasing awareness that the world is facing new drastic challenges, from climate change and food security to migrations and energy supplies, which will determine its future.

Against this background, a new normal is arising. It is about the interplay of all sciences, including natural, social, and human sciences, without which societal challenges cannot be solved: education and training must be rethought to foster inter- and trans-disciplinarity. It is about a democratic governance of science and innovation which, while protecting the inspiration and creativity that drives research, facilitates the participation of all stakeholders in developing choices and processes. It is about greater expectations from citizens regarding communication and accountability from scientists at a time when the internet revolution and social media make it possible for all to access, understand and share the knowledge and scientific data. At the dawn of the open science era, it is also about reaping the benefits of Information Technology and Artificial Intelligence to consolidate and speed up the research and innovation process. Finally, it is about trust between citizens and science, which is conditioned by aspects of research such as ethics, integrity and transparency.

A global goal is to generate the new knowledge that will help to better understand and address the major challenges of our time and facilitate the transfer and integration of scientific findings into politics and society. But science has its own limits, being either theoretical, experimental, ethical or philosophical.

Since all these issues will determine the future of scientific research – and ipso facto of mankind – they are addressed and discussed in in a separate chapter of the EPS Grand Challenges. Chapter 7 of the EPS Grand Challenges is divided into five main sections: Education and research in an interdisciplinary environment, Science with and for the citizens, Open communication and responsible citizens, Science and ethics and finally the Limits of science. ■

> **“We need a new social contract between science and society”**

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Outlook to 2023

Every year in September the Editors of EPN together with the External Advisory Board select the focus topics for the year to come. This is our choice for 2023.

EPN 54/1

Traditionally, the first EPN issue in the year is dedicated to 'Nobel prize physics', notably the physics field that was awarded the prize in the preceding fall. Consequently, the focus of EPN 54/1 will be on 'Quantum entanglement'. Already we have invited a few experts in the field for their contribution.

EPN 54/2

For the second EPN issue to be published in April 2023, we have chosen to highlight a few projects in the field of 'Citizen science in physics'. Citizen science is research conducted with participation from the public. If you are involved in a citizen science's project and interested to submit a contribution, please contact the EPN science editor (see colophon).

EPN 54/3

The third EPN issue will be published in June/July 2023. For this summer issue we selected the focus on 'Green urban science'. What is the role of physics in this interdisciplinary field? If you are interested to submit a contribution, please contact EPN's science editor.

EPN 54/4

In the September issue, we focus on 'Magnetism'. Are you the person who would like to share your knowledge and research in this attractive 'hard-core-physics' field? Please, contact us.

EPN 54/5

Since a few years it is tradition to make the last issue of the year a 'special issue' together with one or more guest editors. The subject for 2023: 'Big European research infrastructures'. Early next year, we will meet with established physicists to discuss the contents of the issue.

We wish you all a happy, healthy and safe 2023!
The EPN Editors

EUROPHYSICS NEWS
The magazine of the European Physical Society

The editors wish you all a healthy, safe and
HAPPY 2023

New EPS Historic Sites

In 2022, the following EPS Historic Sites have been inaugurated:
10 May 2022 – Physics Department of Lund University, Sweden
25th May 2022 – Zeemanlaboratorium, Amsterdam, The Netherlands
2nd July 2022 - Theodor von Grotthuss laboratory, Žeimelis, Lithuania
16th September 2022 - The Department of Physics “Aldo Pontremoli” of the University of Milan, Italy
23rd September 2022 – The Zagreb-Grič Observatory, Croatia
7th October 2022 – The Cargèse Institute of Scientific Studies, France
29th September 2022 – The Victor Franz Hess measuring station on the Hafelekar, France

Physics department of Lund University, Sweden

The building at Biskopsgatan in Lund, served the Lund physicists during the years 1885 to 1950. This is the place where Johannes Rydberg worked. He formulated a general formula to describe the spectral lines of hydrogen, which was published in 1890 in Zeitschrift für Physikalische Chemie. In the formula occurred a constant, that was the same for all elements and all spectral series - the well-known Rydberg constant. Other physicist active in the building were Manne Siegbahn (1886-1978) with high-precision X-ray spectroscopy studies and Bengt Edlén (1906-1993), who in 1941 solved the problem of the origin of the corona lines from the sun.

Zeeman laboratory, Amsterdam, The Netherlands

In 1923, Pieter Zeeman became directory of the laboratory in Amsterdam named after him. He is known from the ‘Zeeman effect’: under influence of a magnetic field, a spectral lines split up into several separate lines. The phenomenon could be theoretically explained by the electron theory by Zeeman’s mentor, Hendrik Lorentz. They were rewarded the Nobel prize for physics in 1902. Today the building has been converted to apartments.

The Victor Franz Hess measuring station on the Hafelekar in Austria

In 1912, Victor Franz Hess discovered the cosmic rays during daring balloon flights. In the workshop of the Nordkettenbahn on the Hafelerkar, he found a suitable location for his cosmic rays measurements. He received the Nobel prize in physics in 1936. In 1937 Marietta Blau and Hertha Wambacher observed for the first time on photographic plates exposed here how a particle of the cosmic rays shattered an atomic nucleus. A neutron monitor and muon detectors were installed in the 1960s and 1970s. This enabled the researchers to individually measure two types of particles contained in the cosmic rays and gain important insights.

EPS awards and distinctions during the year 2022

The EPS congratulates the 2022 laureates for EPS prizes and distinctions for their outstanding achievements in physics across Europe and around the world. The EPS is grateful to the physics community for submitting the truly excellent nominations received. The EPS highly appreciates the work by the EPS Divisions and Groups in identifying individuals and their research that contribute to the development of physics and our understanding of our world.

Biannual Physics Estoire Prize

The Biannual Physics Estoire Prize was awarded to **Olivier Darrigol** (Research Director at Centre National de la Recherche Scientifique, Paris), for *'His rich, original, and profound work in history, philosophy, and epistemology of physics.'*

EPS Europhysics Prize

The EPS Europhysics Prize was awarded to **Agnès Barthélémy** (CNRS/Thales laboratory of University Paris-Saclay, **Manuel Bibes** (CNRS/Thales laboratory of University Paris-Saclay) **Ramamoorthy Ramesh** (UC Berkeley and **Nicola Spaldin** (ETH Zurich), for *'seminal contributions to the physics and applications of multiferroic and magnetoelectric materials.'*

EPS Hannes Alfvén Prizes

The EPS Hannes Alfvén Prizes have been awarded to **Annick Pouquetl** (Laboratory for Atmospheric and Space Physics, University of Colorado, and National Center for Atmospheric Research, Boulder, Colorado), for *'fundamental contributions to quantifying energy transfer in magneto-fluid turbulence. Annick Pouquet's contributions, together with her colleagues, include predicting the inverse cascade of magnetic helicity, extending the accessible frontier of nonlinear numerical computations, and key steps forward in the analytical theory of turbulence. Her work has facilitated remarkable advances in the understanding of turbulence in astrophysical and space plasmas',* to **Sergei Krasheninnikov** (Department of Mechanical and Aerospace Engineering, University of California San Diego, USA), for *'seminal contributions to the plasma physics of the scrape-off layer and divertor in magnetically confined fusion experiments, including the physics of "blobs", divertor plasma detachment, and dust, together with atomic physics effects',* and to **Xavier Garbet** (CEA/IRFM, Cadarache, France), for *'Important contributions to the theory of the mesoscopic dynamics of magnetically confined fusion plasmas: specifically, to understanding turbulence spreading, flux-driven gyrokinetic simulations, transport barriers, up-gradient transport and edge instabilities.'*

EPS NPD 2018-2021 PhD Prize

The EPS Plasma Physics Division Innovation Prize 2022 for technological, industrial, or societal applications of research in plasma physics was attributed to **Giuliano Giacalone** (Université de Paris-Saclay, France), for *'A matter of shape: seeing the deformation of atomic nuclei at high-energy colliders, November 2020',* to **Jonas Karthein** (University of Heidelberg, Germany), for *'Next-Generation Mass Spectrometry of Exotic Isotopes and Isomers, May 2020',* and to **Ágota Koszorús** (KU Lueven, Belgium), for *'Collinear Resonance Ionization Spectroscopy of potassium isotopes: crossing N=32, September 2019.'*

EPS Plasma Physics Division PhD Research Awards

The EPS Plasma Physics Division PhD Research Awards 2022 for outstanding doctoral theses was awarded to **Plamen Ivanov** (Oxford University, UK), for *'Zonally dominated dynamics and the transition to strong turbulence in ion-scale plasma turbulence'*, to **Alexis Marret** (Sorbonne University and Observatoire de Paris-PSL, France), for *'The non-resonant streaming instability: from theory to experiment'*, to **Valeria Perseo** (Greifswald University, Germany), for *'Impurity flow measurements with coherence imaging spectroscopy at Wendelstein 7-X'*, and to and **Martina Salvadori** (University of Rome "La Sapienza", Italy), for *'Advanced time-of-flight diagnostics for real-time characterization of ions accelerated by high energy lasers'*.

EPS Prize for Research in Laser Science and Applications

The EPS Prize for Research in Laser Science and Applications was awarded to **Sergey I. Bozhevolnyi** (University of Southern Denmark, Odense, Denmark), for *'Seminal contributions to surface-plasmon polaritons and the developments of plasmonic metasurfaces.'*

ESPD - joint European Solar Physics Division

The 2022 ESPD Patricia Edwin PhD Thesis Prize was awarded to **Juraj Lörinčik** (PhD carried out at Charles University, Prague, Czech Republic), for *'Significant contributions on observational analyses of 3D reconnection in solar flares, providing important verification of the recent predictions of the 3D extensions of the Standard solar flare model',* and to **Petra Kohutova** (University of Oslo, Oslo, Norway), for *'Important contributions to the understanding of thermal instability in the solar atmosphere, combining observations, theory, and modelling.'*

Giancarlo Noci Early Career Researcher Prize

The 2021 Gribov Medal was awarded to **Petra Kohutova** (University of Oslo, Norway), for *'Important contributions to the understanding of thermal instability in the solar atmosphere, combining observations, theory, and modelling.'*

Landau-Spitzer Award 2020 and 2022

Joint with the American Physical Society, the Landau-Spitzer Award 2020 and 2022 for an international team demonstrating sustained excellence in collaborative research have been awarded to **Riccardo Betti** (University of Rochester), **Alexis Casner** (University of Bordeaux-CNRS-CEA), **Xavier Ribeyre** (University of Bordeaux-CNRS-CEA) and **Wolfgang Theobald** (University of Rochester) for *'Major advancements of the shock ignition concept through collaborative experimental and simulation efforts in inertial confinement fusion research',* and to **Christopher Chen** (Queen Mary University London), **Gregory Howes** (University of Iowa) and **Kristopher Klein** (University of Arizona), for *'The theoretical development of the field-particle correlation technique and its application to spacecraft measurements directly showing that electron Landau damping plays a role in the dissipation of space plasma turbulence'.*

Lise Meitner Prize

The 2022 Lise Meitner Prize was awarded to **Philip Walker** (University of Surrey, UK), for *'outstanding work in the fields of experimental, theoretical or applied nuclear science'.*

PPCF Dendy Europe-Asia Pacific Award

The PPCF Dendy Europe-Asia Pacific Award 2020 for an international team demonstrating sustained excellence in collaborative research was awarded to **João Santos** (CELIA, University of Bordeaux France) and **Shinsuke Fujioka** (Institute of Laser Engineering, Osaka University, Japan), for *'Outstanding achievements in significantly magnetising the inner region of a coil by the generation of a strong (kilotesla) laser-driven magnetic field. The employment of capacitor-coil targets, driven by a high energy laser pulse, constitutes a pioneering step towards a new testbed for a broad range of laboratory applications. These span the fields of laser-driven inertial confinement fusion, laboratory astrophysics, high energy density laboratory plasmas, and laser-based particle acceleration'.*

Young Scientist Prize (YSP)

The 2022 Young Scientist Prize (YSP) was awarded to **Jordi Tura** (Leiden University, The Netherlands) for *'his pioneering work in quantum information theory, in particular on quantum non-locality in many-body systems'*.

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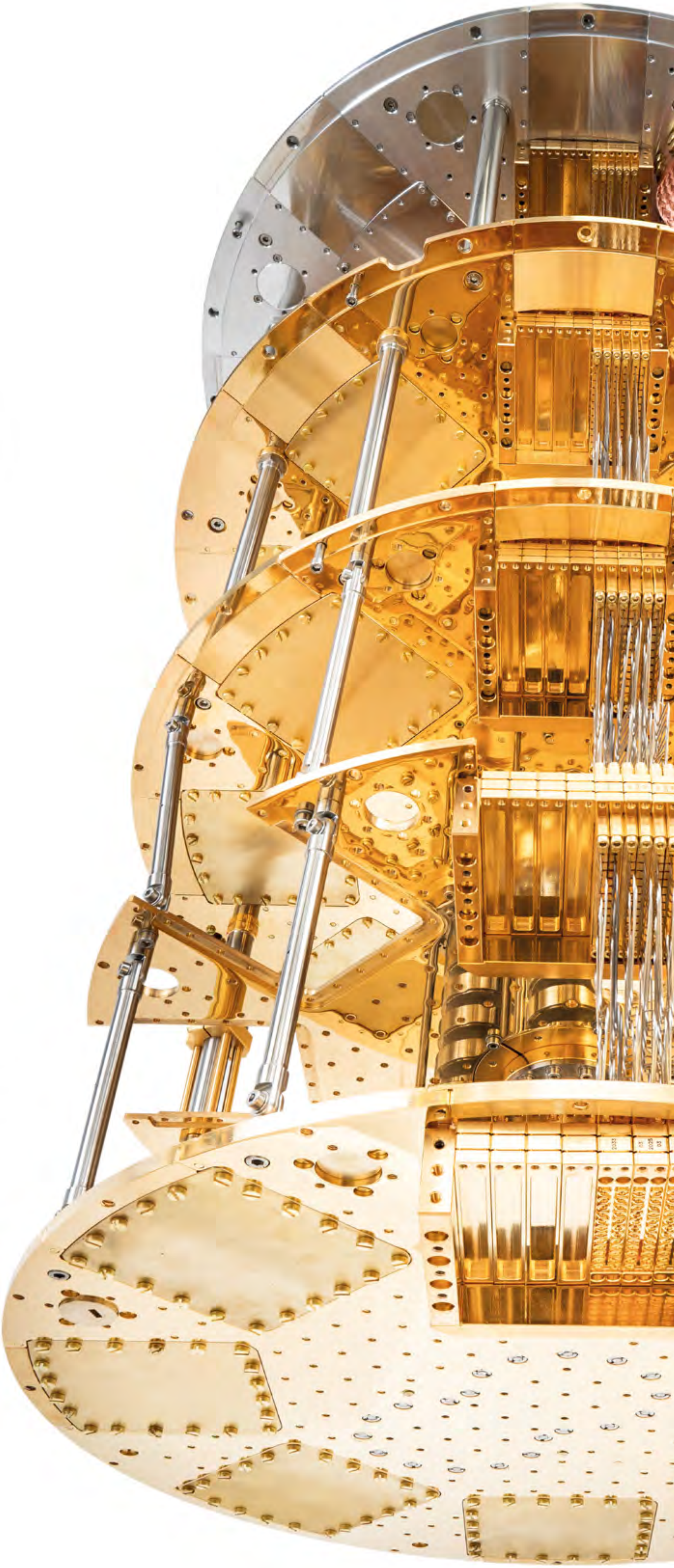

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