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THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

**Focus on exoplanets**  
**Vitrimers**

**EPS and Open Science: an update**  
**Anniversary of PAO**  
**Emmy Noether Distinction**

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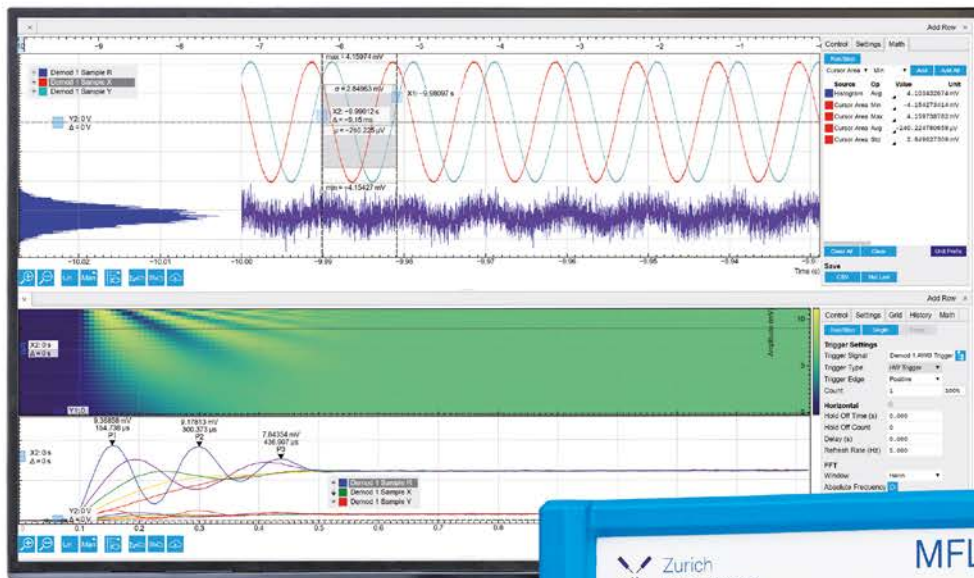


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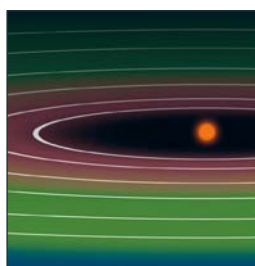
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**Cover picture:** This artist's impression shows several of the planets orbiting the ultra-cool red dwarf star TRAPPIST-1. New observations, when combined with very sophisticated analysis, have now yielded good estimates of the densities of all seven of the Earth-sized planets and suggest that they are rich in volatile materials, probably water. © ESO/M. Kornmesser



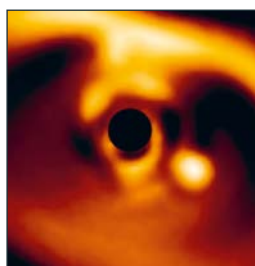
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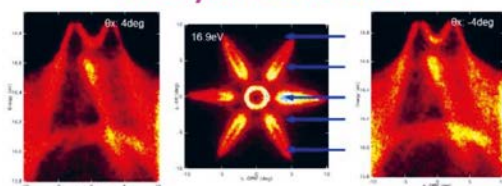
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[EDITORIAL]

## Careers with a Physics Degree

**In 1990, the World Wide Web (WWW) was invented at CERN by the physicist Tim Berners-Lee. The objective at the time was to create a network for sharing information between physicists around the world. But that network changed the life of everybody. It impacted our lives, and improved our access to information.**

**W**e all have now at our fingertips a “macroscope” where we can search for input to make decisions and conduct our social life and work. The internet is the most compelling example of how careers in physics can lead to unexpected turns and be truly transformative at a global level. The internet took the place of the *Encyclopédie* of the Enlightenment. For Diderot, the *Encyclopédie* aimed at changing how people thought. The online information is much broader than information in print and its diffusion is almost instantaneous. This is indeed changing very quickly how people think, and it is also changing their professions.

Throughout human history, professions were established to cope with unequal distribution of knowledge, of both *know-what* and *know-how*. A single human being cannot know or do everything, and many professions became increasingly specialised. Nowadays, the internet, as well as the use of nano-devices and new materials, are changing many professions again.

Medicine is a showcase. For instance, telemedicine is growing, gene editing promises to prevent and cure diseases, 3D printing is making the fabrication of implants simpler and more precise, and, as predicted by Richard Feynman, in the future nano-robots will be surgeons that we will literally eat. Once these resources will be largely available and automatised, general practitioners will be more needed than specialists.

Also the profession of the physicist is being re-shaped. Increasingly, more value is given to large-scale simulations of complex systems than analyses based on simplified models. Humans have intrinsic limitations in interpreting large volumes of data. But with machine learning and artificial intelligence algorithms, physicists can work with big data sets in a great

variety of problems, making them more like general practitioners than specialists. Available information on large groups can be used to model social behaviour and hopefully lead to the early detection of potentially critical situations, such as the spread of epidemics. In the natural world, new systems of monitoring the earth's oceans and atmosphere produce massive amounts of data that contain the clues to predict catastrophic events. In these processes, ethics and law will become closely intertwined with physics. Max Planck, Enrico Fermi and Lise Meitner, among others, belonged to the last generation of physicists that tackled both experimental and theoretical problems. Nowadays, the normal path in the training of a physicist, from generalist to specialist, is inverting. The general tools of physics tend to bring back the “general” physicist. The alliance of physics to computation and data analytics accentuates this trend.

This 4<sup>th</sup> Industrial Revolution brought new technologies that blend the physical, digital and biological worlds, impacting all fields, industry and the economy, and may even change our views on what it means to be human. On the brink of this revolution, universities started offering degrees in Engineering Physics, or a track in Engineering Physics within Engineering Sciences degrees. Stanford and Harvard in the US and KTH in Sweden are examples. In Portugal, all Science and Engineering Schools, including *Instituto Superior Técnico* (IST) at the University of Lisbon, created such a degree in the mid 1980's. Engineering Physics is a form of crafting physics into innovative applications and industrial research. Computational, analytic and experimental tools are the basis of Physics and Engineering Physics training. Majors in Engineering Physics are featured as delivering professionals to work on forefront

ideas in technology and science, in either industry or academia. The presented areas of work include aerospace, biophysics, medical physics, renewable energy, quantum information, and materials development. IST graduates in Portugal, where industry provides only very few scientific jobs, very often find career opportunities in science policy and government, science writing, software engineering, banking and risk analysis, consulting in health care, telecommunications, and financing sectors. Many of them created start-up companies in bioengineering technologies and renewable energy production, and others hold academic positions, frequently abroad.

If interdisciplinarity is essential in engineering physics, it is no less so in physics. For instance, links between astroparticle, nuclear and particle physics are needed for questions on dark matter as well as on the physics of gravitational waves. On the technological front, investigating the invisible “extremely small” provides instruments useful for medical applications and radiation safety. In physics, as in other professions, the 4<sup>th</sup> Industrial Revolution is challenging the paradigm of specialisation. It embraces Richard Feynman's vision: “A poet once said, ‘The whole universe is in a glass of wine.’ (...) But it is true that if we look at a glass of wine closely enough we see the entire universe. If our small minds, for convenience, divide this glass of wine, this universe, into parts — physics, biology, geology, astronomy, psychology, and so on — remember that nature does not know it! So let us put it all back together, not forgetting ultimately what it is for.” ■

■ **Teresa Peña,**  
IST, Universidade de Lisboa,  
Department of Physics and  
Department of Nuclear Sciences  
and Engineering, and LIP



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**Science Editor:** Ferenc Igloi (HU)

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**Executive Editor:** David Lee

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**Graphic designer:** Xavier de Araujo

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## Vitrimers: combining the best of both polymeric worlds

**Vitrimers are a promising new type of polymer glasses that combine the recyclability of thermoplastics with the high mechanical performance of thermosets. At the heart of their exceptional material properties lies highly unusual glass-forming behaviour.**

Polymers are conventionally classified as either thermosetting or thermoplastic, depending on whether the polymer chains are covalently cross-linked or not. Each class has its own advantages: thermoplastics are generally easily malleable and recyclable, whereas cross-linked thermosets are insoluble and mechanically robust. With the recent advent of vitrimers—a polymer glass invented by Ludwik Leibler and co-workers [1]—it is now possible to combine the best of both polymeric worlds. Vitrimers are covalently cross-linked polymer networks, but the cross-linking bonds can swap reversibly by thermally activated reactions. This enables vitrimers to behave as viscoelastic liquids at high temperatures and as rigid thermosets at low temperatures, culminating in a recyclable yet high-performance plastic with vast application potential.

### Fragility

The exceptional processability and recyclability of vitrimers is manifested in the so-called fragility—an empirical property that quantifies how rapidly a glass-forming material changes from liquid to amorphous solid upon cooling. Materials in the ‘fragile’ category solidify rather abruptly, whereas ‘strong’ glass formers vitrify in a more gradual manner. Curiously, while many glassy polymers are fragile, vitrimers turn out to be ‘superstrong’, solidifying even more gradually than the prototypical strong glass-former silica. This behaviour not only constitutes a striking departure from conventional glassy phenomenology, but it also explains in part why vitrimers are so easy to process: a superstrong fragility implies a very broad glass-transition-temperature range, creating a large temperature window in which the material can be molded and (re)shaped.



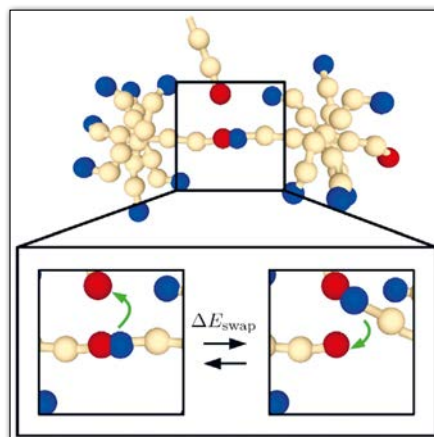
▲ Vitrimer samples.   CNRS Phototh que / ESPCI / Cyril FR SILLON

## In-silico vitrimers

How can we better understand the remarkable glass-forming properties of vitrimers from a molecular perspective? A recent study addresses this question using computer simulations and theory [2]. First, to mimic vitrimers *in silico*, a coarse-grained simulation model was developed that represents vitrimers as cross-linked star-polymer networks; the vitrimeric bond-swapping functionality was implemented through a three-body potential that preserves the total number of bonds. Interestingly, the simulations could reproduce the anomalous superstrong fragility of experimental vitrimeric materials, thus capturing the main phenomenology of vitrimers in a minimal computational model. But the simulations also predicted another effect: by increasing the bulk density by a factor of 2–3, the simulated vitrimers were found to solidify as a strong or even fragile glass former upon cooling. This suggests that the bulk density may provide a suitable control parameter to tune the vitrimer fragility and even induce a superstrong-to-fragile crossover—a prediction that will hopefully also be tested in experiment.

## Linking structure to glassy dynamics

Next, to elucidate the microstructural origins of the vitrimeric fragility, the simulation results were subjected to a theoretical analysis. To this end, an approximate but purely first-principles-based theory of the glass transition was employed—so-called Mode-Coupling Theory (MCT). Briefly, this theory seeks to predict the glassy relaxation dynamics of a material (as a function of time, temperature, density, and wavevector  $k$ ) using only simple microstructural information—such as the static structure factor  $S(k)$ —as input. Hence, MCT provides a fit-parameter-free framework to rationally relate structural properties to dynamical ones. By taking the simulated static structure factors of the vitrimers as input, MCT could predict the same fragilities as observed in simulation: fragile vitrimer behaviour at high densities, strong behaviour at intermediate densities, and superstrong behaviour at low densities. This result is *a priori* surprising, as MCT is conventionally assumed to



▲ Vitrimer simulation model [2].

only account for fragile behaviour. Furthermore, the striking agreement between theory and simulation made it possible to establish a direct link between the vitrimer microstructure and the fragility—a link that still remains elusive for most glass-forming materials.

## Suppressed cage effect

A detailed analysis of the MCT results revealed the physical origin of the anomalous fragility of vitrimers, as well as of the superstrong-to-fragile crossover induced by increasing the bulk density. The key underlying structural property was found to be the main peak of the static structure factor,  $S(k_0)$ , where  $k_0$  corresponds to the average (inverse) nearest-neighbour distance. Briefly, within conventional MCT, a growing  $S(k_0)$  peak gives rise to the so-called cage effect: particles become trapped in local cages formed by their nearest-neighbours, causing a non-linear dynamical slowdown and eventual kinetic arrest across all length scales. It was found that a significant growth of  $S(k_0)$  upon cooling indeed led to a rapid

slowdown of the vitrimer dynamics, most notably in the high-density (fragile) regime. Interestingly, however, at low vitrimer densities, the temperature-dependent growth of  $S(k_0)$  became anomalously weak—almost logarithmic with inverse temperature—, thus causing a *suppression* of the cage effect. This in turn resulted in a far more gradual dynamical slowdown and an extremely low fragility. The same MCT analysis also provided an explanation for the observed fragile-to-superstrong crossover in simulation: as the bulk density decreased, nearest-neighbour correlations encoded in  $S(k_0)$  became less sensitive to temperature variations, leading to a weakening of the cage effect and a manifestly lower fragility.

The results of this study [2] reveal some unusual aspects of glass formation in a model system of vitrimers. It is hoped that future experiments will test some of these predictions, in particular the role of the density as a tunable fragility parameter, and the anomalously weak growth behaviour of the static structure factor in superstrong materials. Such a combined experimental and theoretical approach holds exciting potential for the ultimate rational design of the next generation of recyclable high-performance polymer materials. ■

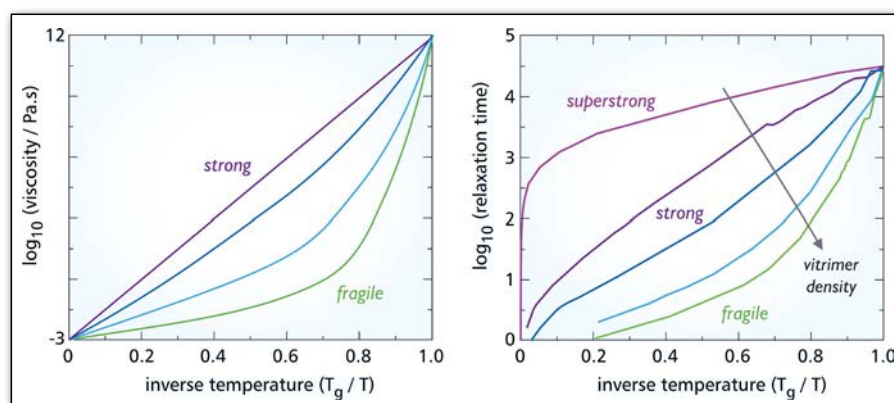
■ Liesbeth M. C. Janssen

Eindhoven University of Technology,  
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- [2] S. Ciarella, R.A. Biezemans, and L.M.C. Janssen, *Proc. Natl. Acad. Sci. USA* **116**, 25013 (2019).

▼ Conventional fragility classification (left) and vitrimer fragilities obtained from simulation (right) [2].



# Doubt cast on 'dark energy'

The observed acceleration of the Hubble expansion rate has been attributed to a mysterious 'dark energy' which supposedly makes up about 70% of the universe. A new analysis of 740 supernovae shows that this acceleration is a local effect – it is directed along the same direction we appear to be moving with respect to the cosmic microwave background, which exhibits a similar dipole anisotropy. Thus a Cosmological Constant or dark energy cannot be invoked as explanation for cosmic acceleration.

*This article is an edited version of a news item at the website of the Mathematical, Physical and Life Science Division of the University of Oxford. Permission for publication in EPN was given by S. Sarkar.*

## The Cosmological Constant problem

The cosmological standard model rests on the assumption that the Universe is isotropic around all observers. This 'Cosmological Principle' is an extension of the 'Copernican Principle' – namely that we are not privileged observers. It affords a vast simplification in the mathematical construction of the cosmological model using Einstein's theory of General Relativity. However, when observational data are interpreted within this framework we are led to the astonishing conclusion that about 70% of the universe is constituted of Einstein's Cosmological Constant or more generally 'dark energy'. This has been interpreted as due to quantum zero-point fluctuations of the vacuum but the associated energy scale is set by  $H_0$ , the present rate of expansion of the universe, which is a factor of  $10^{44}$  below the energy scale of

the Standard Model of particle physics – the well-established quantum field theory that precisely describes all subatomic phenomena. Its zero-point fluctuations have therefore a huge energy density which would have prevented the universe from reaching its present age and size if they were to indeed influence the expansion rate via gravity.

## The "Why now?" problem

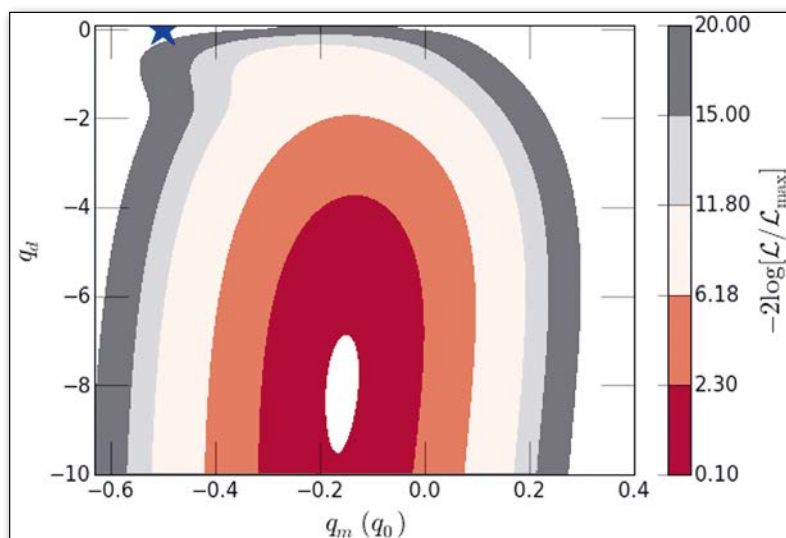
To this well-known 'Cosmological Constant problem' must be added the 'Why now?' problem, namely why has dark energy come to dominate the universe only recently? It was negligible at early times, for example at an age of  $\sim 400,000$  years when the primordial plasma cooled enough for atoms to form and the cosmic microwave background (CMB) radiation was released. Hence, the CMB is not directly sensitive to dark energy.



## A Cosmological Constant or dark energy cannot be invoked as explanation for cosmic acceleration

### Using a data sample of 740 supernovae

It is against this background that Jacques Colin & Roya Mohayaee (Institut d'Astrophysique, Paris), Mohamed Rameez (Niels Bohr Institute, Copenhagen) and Subir Sarkar (University of Oxford), set out to examine whether dark energy really exists. The primary evidence – rewarded with the 2011 Nobel prize in Physics – concerns the "discovery of the accelerated expansion of the universe through observations of distant supernovae" in 1998 by two teams of astronomers. This was based on observations of only about 60 Type Ia supernovae but meanwhile the sample has grown to 740 objects scattered over the sky for which the data is public ('Joint Lightcurve Analysis' catalogue). The researchers looked to see if the inferred acceleration of the Hubble expansion rate is in fact uniform over the sky. First they worked out the supernova redshifts and apparent magnitudes as measured (in the heliocentric system), undoing the corrections that had been made in the JLA catalogue for local 'peculiar' (non-Hubble) velocities. This had been done in an attempt to determine their values in the 'CMB frame' in which the universe should look isotropic – however previous work by the team had shown already that such



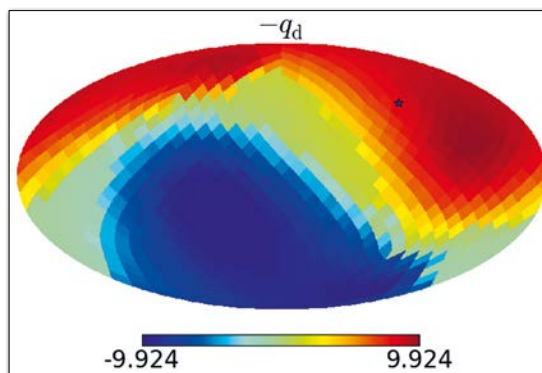
**FIG 1.** The cosmic 'deceleration parameter' inferred from the JLA catalogue of Type Ia supernovae is negative (i.e. the expansion rate is accelerating), but as seen in the left panel it is mainly a dipole ( $q_d$ ) i.e. in a specific direction, while its monopole ( $q_m$ ) component is close to zero. The current 'standard cosmological model' (indicated by a blue star) which has  $q_m = -0.55$ ,  $q_d = 0$ , is excluded at over  $4\sigma$ .



corrections are suspect because these peculiar velocities do not fall off with increasing distance as they should, so there is no convergence to the CMB frame even as far out as a billion light years. Whether the CMB dipole is of kinematic origin is itself in doubt, as e.g. high redshift radio sources exhibit one that is 4 times bigger.

## Dark energy

When the researchers analysed the reconstructed data employing the standard 'Maximum Likelihood Estimator' to quantify the most probable values of the parameters they made an astonishing finding. The supernova data indicate, with a statistical significance of  $3.9\sigma$  a clear dipole anisotropy in the inferred acceleration (see figure 1) in the same direction as we are moving locally, which is indicated by a similar, well-known, dipole in the CMB. By contrast any isotropic acceleration (which can be ascribed to dark energy) is about 50 times smaller and consistent with being zero at only  $1.4\sigma$ .



## Unexpected local flow

This data-driven analysis supports the theoretical idea propounded by Christos Tsagas (University of Thessaloniki) that we infer acceleration because we are not Copernican observers but are embedded in a local 'bulk flow' (shared by nearby galaxies). This is unexpected in the standard cosmological model and the reason for such a flow remains unexplained. But independently of that it appears that the acceleration is an artefact of our local flow and cannot be attributed to a Cosmological Constant or dark energy.

▲ FIG 2. Within uncertainties the acceleration vector is aligned with the dipole ( $q_d$ ) in the cosmic microwave background radiation (indicated as a black star).

## More data expected

Forthcoming observations will be able to confirm or rule out this finding. The forthcoming *Large Synoptic Survey Telescope* will measure many more supernovae and be able to check at even higher significance if the dipole in fact exists. The *Dark Energy Spectroscopic Instrument* and *Euclid* satellite will measure the subtle imprint of 'Baryon Acoustic Oscillations' in the distribution of galaxies precisely and test the standard cosmological model further. The *European Extremely Large Telescope* will measure the 'redshift drift' of distant sources over time and thus make a direct measurement of the expansion history of the universe. ■

## Reference:

- [1] J. Colin, R. Mohayaee, M. Rameez & S. Sarkar, *Astronomy & Astrophysics Letters* **631** (2019) L13 (<https://doi.org/10.1051/0004-6361/201936373>)

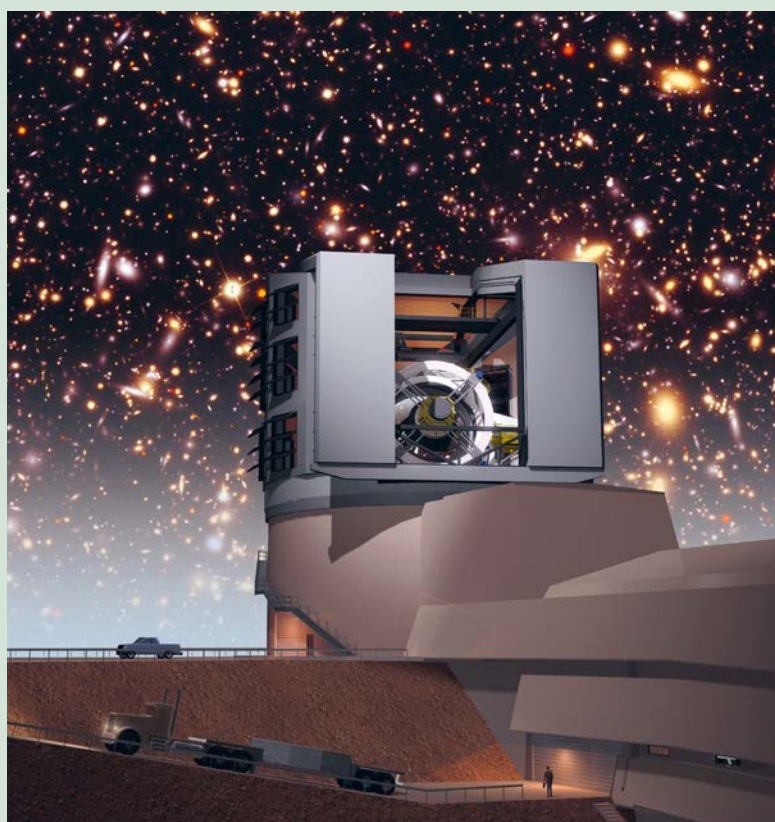
## THE VERA C. RUBIN OBSERVATORY - FORMERLY LSST

On 6 January 2020 it was announced that the Large Synoptic Survey Telescope (LSST) was named the Vera C. Rubin Observatory in honour of the famous astronomer who provided important evidence of the existence of dark matter. It is the first US National Observatory named after a woman. The Vera C. Rubin Observatory, currently under construction in Chile, will allow for studying dark energy and dark matter by measuring gravitational lensing, baryon acoustic oscillations and photometry of type Ia supernovae as function of redshift. With the telescope, astronomers will conduct a deep survey over a large area of the sky by making repeated images of the visible sky every night during ten years. It will build astronomical catalogs thousands of times larger than ever previously been compiled. The data will become available for everyone interested. The telescope is scheduled for science operation early 2022. Scientific motivation and design details can be found in <https://arxiv.org/pdf/0805.2366.pdf>. ■

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# Heinz Billing Prize for the advancement of scientific computation awarded for Binary Neutron Star Simulations

## A new era in astronomy

The first direct detection of gravitational waves from the collision of two black holes in 2015 and the combined gravitational wave and electromagnetic wave observation of a binary neutron star merger in 2017 inaugurated a new era in astronomy and astrophysics. The Nobel Prize in Physics, the Special Breakthrough Prize in Fundamental Physics, and numerous other awards recognized the importance of these scientific achievements. Similarly, the fact that I received the Heinz Billing Prize for the advancement of scientific computation for my work in numerical relativity is yet another proof for the rising importance of gravitational wave astronomy.

## How do we simulate binary neutron stars?

Modeling matter at densities higher than inside an atomic nucleus is among the most challenging problems in theoretical physics. In fact, cold matter at supranuclear densities cannot be produced and tested by any experiment on Earth, but such conditions are created inside neutron stars – ultracompact objects formed at the end of their stellar evolution. This makes neutron stars, in particular neutron star collisions, a perfect laboratory to study matter at its extreme limit. To study these mergers, one needs to solve the equations of general relativity combined with the equations of general relativistic hydrodynamics. No analytical solution exists for this problem, thus, numerical relativity simulations are inevitable to model and to understand the ongoing physical processes and the emitted radiation in the form of gravitational and electromagnetic waves. Even a single simulation is challenging and runs for weeks or up to months on a supercomputer. We collected and released results of several hundred simulations and created the first publicly available database for binary neutron star simulations. In total, about 200 million CPU hours were used for

our work in the last few years. Although we can simulate generic binary neutron star systems, numerical relativity simulations are computationally too expensive to be directly used for the interpretation of gravitational wave signals. Typically, one needs to compute hundreds of millions of templates spanning thousands of gravitational wave cycles to extract the parameters from possible detections. Even with the best supercomputers in the world, this is not affordable. Therefore, based on our most accurate simulations, colleagues and I developed an analytical framework that produces an approximation of the gravitational

it is of crucial importance as a numerical relativist to visualize complicated physical processes to allow an easier understanding. Therefore, I produced several animations that have not only been of scientific interest but have also been used by hundreds of newspapers and various television shows. Thus, our simulations turned out to be a perfect tool to attract the interest of the public community.

## How to obtain an award as a junior scientist and what is it worth?

As with most prizes and awards, you cannot apply directly for the Heinz Billing prize. You need to get nominated by a senior scientist, which is already well known and



**An award helps to keep you motivated and to give your best** ”

wave signal ten billion times faster than numerical relativity simulations. The approximation is accurate enough to be directly employed to analyze gravitational-wave signals, which makes the new framework a key ingredient in the analysis of gravitational waves. In addition to the development of efficient gravitational-wave models, our large set of numerical simulations allowed us to connect the observed electromagnetic signals in the optical, infrared, and ultraviolet bands to the properties of the neutron stars, which led to a better understanding of the internal structure of the stars. Finally,

established in the community. In most cases, this is your former Ph.D. supervisor, your employer, or sometimes a scientist who knows your work through common projects. In my case, I was nominated by my former employer Prof. Dr. Alessandra Buonanno, who is a director of the Max Planck Institute for Gravitational Physics. Although the Heinz Billing prize is endowed with 5000 Euros, the biggest benefit is the recognition of the own work. This is crucial at an early career stage, when one does not have a long track record and is undecided whether one should continue in academia. Clearly, every kind of award improves your chances on the job market and increases the success rate for future applications. Therefore, it helps to keep you motivated and to give your best. ■

■ **Tim Dietrich,**

*Marie Skłodowska-Curie  
Fellow at Nikhef, Amsterdam*



# Cristiane Morais Smith

## awarded the Emmy Noether Distinction

**Cristiane Morais Smith, a Full Professor at the University of Utrecht, has been awarded the prestigious Emmy Noether Distinction of the European Physical Society for her outstanding scientific contributions to the theory of condensed matter physics, in particular to the understanding of topological phases in two-dimensional atomic and electronic systems.**



**D**uring the last years, she made very important contributions to several topics, but one could summarise them by mentioning “*her seminal contributions to the understanding and design of quantum simulators in ultracold atoms and electronic systems, aiming at unveiling novel quantum states of matter.*”

Born in Brazil, her scientific career is strongly connected to Europe, where she studied and worked during the last 27 years. She started her physics studies in Brazil, but performed a large part of her PhD at ETH Zurich, Switzerland, was a visiting scientist at ICTP Trieste, Italy, did a postdoc in Hamburg, Germany and in Fribourg, Switzerland, where she received the Professor Award of the Swiss National Science Foundation and became an Associate Professor in 2001. Since 2004 she holds a full Professor Chair in Condensed Matter Physics at Utrecht University, the Netherlands, where she established a well-known research group in the field of strongly correlated systems. Morais Smith advances the field by using analytical techniques to deepen our theoretical understanding and by closely collaborating with experimentalists such as Andreas Hemmerich (Hamburg), in the area of cold atoms or with the group

of Daniel Vanmaekelbergh and Ingmar Swart (Utrecht), on the design of novel nano-lattices. In 2008, she was awarded the prestigious VICI Prize by the Netherlands Research Organization (NWO). Moreover, three years ago she was a recipient of the Dresselhaus Prize “for her outstanding contribution to the understanding of topological phases in two-dimensional atomic and electronic systems” by Hamburg University, Germany. Prof. Morais Smith speaks seven European languages and collaborates actively with top researchers in France, Spain, Italy, Germany, the Netherlands and Sweden.

Prof. Morais Smith is also actively establishing research bridges between Europe and other countries overseas. She was awarded a Special Visiting Professor Fellowship by the Brazilian Agency CNPq from 2013-2016, and two years in a row she was awarded the High-End Foreigner Expert (HEFE) visiting Professorship from the Chinese Government. She is currently an Associate Faculty of the Wilczek Quantum Center, a member of the Advisory Board and a Fellow of the Tsung-Dao Lee Institute in Shanghai. Her recognition in the international scientific

community can be judged from the many (~300) invited and plenary talks she has been giving.

Apart from her excellent contributions to science, Cristiane Morais Smith is also a passionate teacher who attracts many students to her group by her enthusiasm and passion for science, which has already led to 22 Bachelor, 42 Master and 23 PhD theses. Many of her students have received prizes for their work and have found excellent positions in academia and industry all over the world. In addition, she is very engaged in outreach activities, combining Science and Art and participating in movies in which she is capable of conveying her enthusiasm and passion for science in a contagious manner. She is a role model for all her colleagues, and especially, for the few young female researchers, who represent less than 15% in our field in Europe. The 2019 Emmy Noether Distinction is therefore a well deserved highlight in her brilliant career. ■

■ **Gloria Platero**, *Instituto de Ciencia de Materiales de Madrid, CSIC*

■ **Theo Rasing**, *Radboud University Institute for Molecules and Materials*





# The 20<sup>th</sup> anniversary of the Pierre Auger Observatory

## A Success Story for International Science

In mid-November 2019 over 200 scientists and their guests made their way to Malargüe, a small, remote city nestled between the Andes and a vast expanse of the Argentine pampa. The occasion was the celebration of the 20<sup>th</sup> anniversary of the ground-breaking for the Pierre Auger Observatory that featured a scientific symposium and celebration ceremony. Also celebrated was the start of a major upgrade, AugerPrime, that will extend the productive life of the world's largest and most sensitive ultra-high energy cosmic ray observatory by another decade.

**T**he Pierre Auger Observatory was conceived at the 1991 International Cosmic Ray Conference in Dublin by particle physicist Jim Cronin from the University of Chicago and cosmic ray physicist Alan Watson from the University of Leeds. The objective was to uncover the mystery of the origin and nature of the rare, but enormously energetic cosmic rays. It was clear to them that only a detector of unprecedented size would provide enough exposure to answer questions raised by nearly a century of earlier study.

### Hybrid detector

The Pierre Auger Observatory design, developed in 1995 at a six-month Design Workshop, consists of a “hybrid” detector system consisting of a 3000 km<sup>2</sup> array of 1600 particle detectors overlooked by 27 optical telescopes. These complementary detector techniques record particle cascades initiated in the upper atmosphere by ultra-high energy cosmic ray particles. The surface array records the footprint of the shower particles on the surface while, on dark nights, the telescopes record the faint fluorescence light produced as the shower cascades through the atmosphere.

“**AugerPrime upgrade promises new insight**”

### Leadership

The leadership of Cronin, Watson and others soon attracted a collaboration of skilled and committed researchers from 17 countries. A unique organisational structure, also a product of the Design Workshop, was formed and in which no region, country, or institution dominates and where decisions

are made by consensus. Strong leadership, a cohesive collaboration of scientists, strong international and local support, and an effective organisation have ensured the last 20 years of success for the Observatory.

### Scientific results

The Auger Observatory has carried out studies of the energy spectrum, mass composition, and arrival directions of the highest energy cosmic rays. The data have produced a detailed energy

▲ Night sky at the Pierre Auger site

► Celebrating the 20<sup>th</sup> Anniversary of the Pierre Auger Observatory



spectrum from  $10^{17}$  eV to above  $4 \times 10^{19}$  eV where a clear suppression has been established. A large-scale  $\sim 7\%$  dipole anisotropy is found at energies above  $8 \times 10^{18}$  eV with the transition from galactic to extragalactic sources appearing at  $1\text{--}2 \times 10^{18}$  eV. There are indications of an anisotropic distribution of the arrival directions of particles with energies above  $5.5 \times 10^{19}$  eV, though no discrete sources can yet be identified. A deficit in the simulations of approximately 40% in the shower muon content in the energy range  $3 \times 10^{17}$  eV to  $2 \times 10^{18}$  eV has been measured relative to the current shower models indicating an incomplete understanding of particle production early in the cascade development at these ultra-high energies. Competitive limits have also been placed on neutrino and gamma ray fluxes.

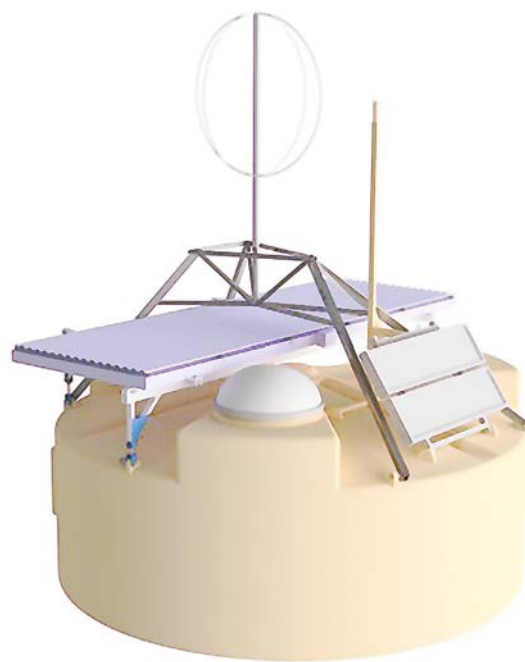
## Unexpected

One of the most unexpected results was the evolution of the mass composition of cosmic rays in the energy range from  $10^{17.2}$  to  $10^{19.5}$  eV. Interpreting the observed longitudinal shower profiles with LHC-tuned interaction models, the composition appears consistent with a large fraction of protons at  $10^{18}$  eV but then becomes heavier with increasing energy. Data indicate that, in addition to the GZK-like propagation effect, this flux suppression at the highest energies may also

result from the astrophysical sources reaching a limit in their ability to accelerate the highest-energy primary particles. Auger lacks statistics for composition analysis at energies above  $5 \times 10^{19}$  eV, in the spectral region of the flux suppression where the arrival directions of cosmic rays appear to correlate with nearby matter. Knowing the composition at this energy scale is crucial and is a key objective of planned upgrade.

## AugerPrime

The AugerPrime upgrade includes  $3.8 \text{ m}^2$  scintillation detectors above the existing water Cerenkov detectors, upgraded electronics, extended dynamic range for the water Cerenkov detectors, a radio antenna to measure radio emission of showers, and a limited (61 detector position) area of underground muon detectors. The objective of AugerPrime is to untangle the constituents of high-energy air showers to investigate the composition of the primary cosmic rays as well as hadronic interactions at the highest energies. Isolation of light primaries will enable charged particle astronomy. The upgrade will also extend the flux limits on gamma ray and neutrino-initiated showers at these energies. At high zenith angles the radio detector together with the water Cerenkov detector will allow increased sensitivity to neutrinos. Triple hybrid events



▲ Upgraded surface detector for AugerPrime

that include the fluorescence detector will also be possible. With this sensitivity to gamma rays and neutrinos, and the ability to isolate light primaries, Auger will be able to play a strong role in the era of multimessenger astronomy.

▼ Surface detector and fluorescence detector

▼ Celebrating the 20<sup>th</sup> Anniversary of the Pierre Auger Observatory

## Ready for the future

While celebrating 20 years of success, the Auger collaboration looks forward to the future where the AugerPrime upgrade promises new insights into the mysteries of the highest energy cosmic rays. ■

■ Paul Mantsch, *Fermilab*





## For all those *not* reading this column

On 22 October 2019 a report[1] commissioned by the EPS was released on the contribution of physics to the European[2] economy. I find it quite shocking that this report has remained largely unnoticed. It was not in the news on TV, nor on the radio, nor could I find it in the newspapers. And that despite my effort to retweet it to my 439 followers! For those who did not read it, here the ultra-short version: the report states that 16% of the European economy is physics industry based. While the figure is not unfamiliar to me, it nevertheless struck me as very relevant to underline the need for adequate ‘public’ support for physics research and education. However, if only a few people, like you and I, just take note of this number and all others don’t really care, the report will have zero impact. It deserves better.

The message, the importance of physics-based industry, may appear straightforward, but the underpinning of it is far from simple. The definition of “physics industries”, which in this case is very transparently given as a list of NACE[3] codes in an appendix, may provoke questions as to when an industry is physics based. Changes in assignment of codes with respect to the previous version of this report[4], which appeared in 2013, testify to the intrinsic uncertainty in assigning “physics based” to certain types of industry, but also shows how little the outcome depends on the details of this assignment.



### Friend raising before fund raising for physics

Then, there may be an issue with the status of the document itself. Very transparently again, the report starts with saying that the study was commissioned by the EPS from the Centre for Economics and Business Research (Cebr), a consultancy organisation that supplies independent economic forecasting and analysis to private firms and public organisations. The fact that the EPS commissioned the study possibly creates an impression of self-interest. It would be very helpful if the study were to be advocated publicly by parties other than the EPS, such as by the physics-based industry itself and other economists than those of Cebr. The physics-based industry, large and small alike, could add weight to the study by subscribing to it and publicly drawing attention to its findings.

In the previous issue, EPS president, Petra Rudolf, stressed the need for funding of physics education and research, with the Cebr report as an important argument.

I would advocate the idea of friend raising before fund raising. With the report being accepted by as many (possibly new) friends as possible, it will be much easier to make the funding argument at a later stage. Public funding is the domain of politicians. The surest way to win the hearts and minds of the politicians is public attention (and pressure). However, despite the presentation of the report to the press in October last year, we did not do very well on that account.

Contemporary standard tools to attract public attention are yellow vests, tractors, going viral on the social media and strikes. Striking scientists, however, are an ineffective curiosity. The social media have the potential of generating wide attention, but in all my disconnectedness (wrong bubble) I myself failed. You may have a try, but when was the last time a physicist reporting on economic impact went viral? Large public demonstrations have proven effective if accompanied by major disruptive public action. Surely, physicists possess the means for such action. Fortunately, for all of mankind, violent actions are rather alien to our professional group.

A civilised alternative uniting some of the above characteristics is to massively address the traditional media, newspapers and periodicals. For maximum effect this should be done at, or around, the same date. We are all pressed for time, but this year we have the extra day, 29<sup>th</sup> February 2020. To all readers: Please send a letter to at least one newspaper and one periodical on this leap day to draw attention to the Cebr report and the importance of physics for the European economy. Just refrain from asking money this time around. For the sake of all new friends *not* reading this column. ■

■ **Sijbrand de Jong,**

*Radboud University, Nijmegen*

### References

- [1] The Importance of Physics to the Economics of Europa, *A study by Cebr for the period 2011-2016*, Cebr – Centre for Economics and Business Research for the European Physical Society, 22 October 2019, [https://www.eps.org/resource/resmgr/policy/eps\\_pp\\_physics\\_ecov5\\_full.pdf](https://www.eps.org/resource/resmgr/policy/eps_pp_physics_ecov5_full.pdf), with an executive summary in [https://www.eps.org/resource/resmgr/policy/eps\\_pp\\_physics\\_ecov5\\_abs.pdf](https://www.eps.org/resource/resmgr/policy/eps_pp_physics_ecov5_abs.pdf).
- [2] Europe is defined here as the EU28 plus Iceland, Norway and Switzerland.
- [3] Nomenclature statistique des activités économiques dans la Communauté européenne.
- [4] For the previous version of the report, see <https://cebr.com/reports/economic-importance-of-physics>



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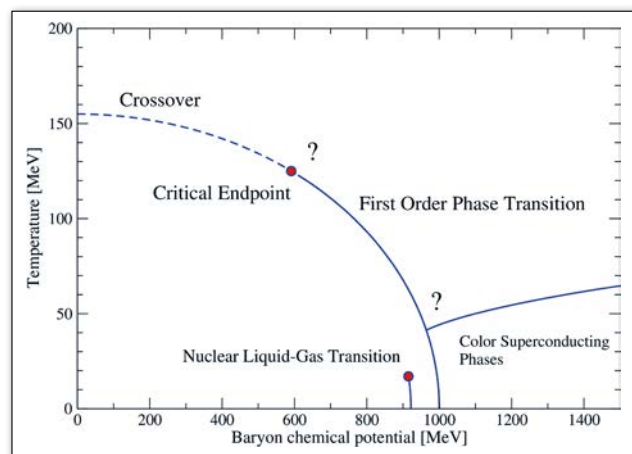
# Highlights from European journals

## NUCLEAR PHYSICS

### Validity of the Silver-Blaze property for QCD at finite chemical potential

The properties of the theory of strong interactions, QCD, at finite chemical potential are of great interest for at least two reasons:

- (i) Model studies suggest a potentially rich landscape of different phases with highly interesting analogies to those found in solid state physics;
- (ii) the resulting thermodynamic properties have far reaching consequences for the physics of neutron stars and neutron star mergers.



▲ Sketch of the QCD phase diagram in the temperature and baryon chemical potential plane.

Investigating the properties of light scalar and pseudo-scalar quark-antiquark bound states at finite chemical potential by solving coupled sets of Dyson-Schwinger equations, the meson masses, wave functions, and decay constants are computed, as well as changes in the quark dressing functions for chemical potentials below the first-order chiral phase transition while tracing charge-conjugation parity breaking. Eventually, we confirm the validity of the Silver-Blaze property: in observables all dependencies of coloured quantities (propagators, wave-functions, etc.) on chemical potential cancel out and we observe constant masses and decay constants up to and into the coexistence region of the first-order chiral phase transition. ■

■ **P. J. Gunkela, C.S. Fischerb and P. Isserstedtc**, 'Quarks and light (pseudo-)scalar mesons at finite chemical potential', *Eur. Phys. J. A* **55**, 169 (2019), DOI 10.1140/epja/i2019-12868-1

## MATERIAL SCIENCE

### Determining the shapes of atomic clusters

By considering the crystal structures of atomic clusters in new ways, researchers may be able to better assess whether the groups have distinctive shapes, or whether they are amorphous.

Too large to be classed as molecules, but too small to be bulk solids, atomic clusters can range in size from a few dozen to several hundred atoms. The structures can be used for a diverse range of applications, which requires a detailed knowledge of their shapes. These are easy to describe using mathematics in some cases; while in others, their morphologies are far more irregular. However, current models typically ignore this level of detail; often defining clusters as simple ball-shaped structures. In research published in *EPJB*, José M. Cabrera-Trujillo and colleagues at the Autonomous University of San Luis Potosí in Mexico propose a new method of identifying the morphologies of atomic clusters. They have now confirmed that the distinctive geometric shapes of some clusters, as well as the irregularity of amorphous structures, can be fully identified mathematically. ■

■ **J.M. Cabrera-Trujillo, J.M. Montejano-Carrizales and C.G. Galván**,

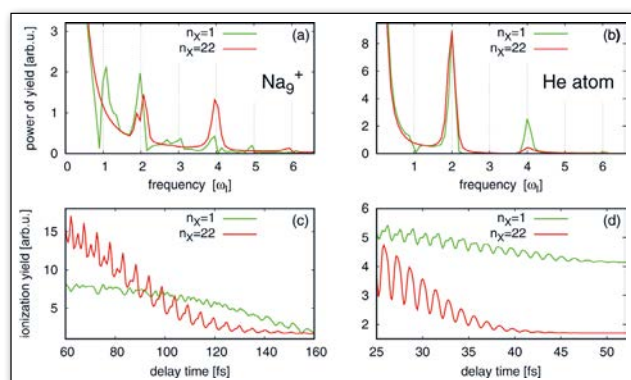
'Amorphicity and Structural Changes in Binary Clusters', *Eur. Phys. J. B* **92**, 237 (2019), <https://doi.org/10.1140/epjb/e2019-100312-4>

## LASER PHYSICS

### Inhibitory neurons retrieving physical properties from two-colour laser experiments

Useful information about ultrafast light-matter interactions is buried deep in the signals produced by two-colour pump-probe experiments, and requires sophisticated techniques to disentangle it.

When photons of light interact with particles of matter, a diverse variety of physical processes can unfold in ultrafast timescales. To explore them, physicists currently use 'two-colour pump-probe' experiments, in which an ultrashort, infrared laser pulse is first fired at a material, causing its constituent electrons to move.



▲ Extracting ionisation yields following ultrafast interactions.

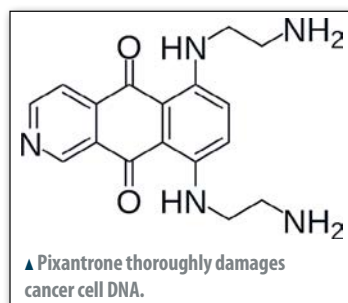
After a controllable delay, this pulse is followed by a train of similarly short, extreme-ultraviolet pulses, ionising the material. By measuring the total ionisation following the pulses along with the resulting electron energy spectra, physicists can theoretically learn more about ultrafast, light-matter interactions. In new research published in *EPJD*, an international team of physicists, led by Eric Suraud at the University of Toulouse, discovered that these signals are in fact dominated by the less interesting interplay between electrons and the initial infrared laser. They show that more useful information is buried deeper within these signals. ■

■ **T. Brabec, P. M. Dinh, C. Z. Gao, C. R. McDonald, P.-G. Reinhard and E. Suraud,**

'Physical mechanisms encoded in photoionization yield from IR+XUV setups', *European Physical Journal D* **73**, 212 (2019), DOI: 10.1140/epjd/e2019-90507-4

## APPLIED PHYSICS

### Advanced cancer drug shrinks and intercalates DNA



**Experiments and statistical models reveal that the recently developed cancer drug Pixantrone forces itself inside the double helix structure of DNA molecules, then shrinks their backbones.**

Because of the harmful side-effects of chemotherapy, and the increasing resistance to drugs found in many cancer cells, it is critical for researchers to continually search for new ways to update current cancer treatments. Recently, a drug named Pixantrone (PIX) was developed, which is far less damaging to the heart than previous, less advanced compounds. PIX is now used to treat cancers including non-Hodgkin's lymphoma and leukaemia, but a detailed knowledge of the

molecular processes it uses to destroy cancer cells has been lacking so far. In a new study published in *EPJE*, Marcio Rocha and colleagues at the Federal University of Viçosa in Brazil uncovered the molecular mechanisms involved in PIX's interactions with cancer DNA in precise detail. They found that the drug first forces itself between the strands of the DNA molecule's double helix, prising them apart; then compacts the structures by partially neutralising their phosphate backbones. ■

■ **C.H.M. Lima, J.M. Caquito jr, R.M. de Oliveira and M.S. Rocha**

'Pixantrone anticancer drug as a DNA ligand: Depicting the mechanism of action at single molecule level', *Eur. Phys. J. E* **42**, 130 (2019), DOI 10.1140/epje/i2019-11895-6

## HISTORY

### Unpacking the mystery of Feynman's reference amplifier

**A review of lectures given by Feynman between 1946 and 1971 showcase the strong influence that his involvement in the Manhattan Project held on his research, while revealing an intriguing mystery surrounding one particular amplifier device.**



▲ Feynman's research strongly influenced modern physics. Credit/copyright: The Nobel Foundation, public domain.

Richard Feynman was one of the 20<sup>th</sup> century's most celebrated physicists. In 1943, he began his career in the Manhattan Project, where one of his tasks was to develop a device which could count the neutrons produced by nuclear reactions. Neutron signals emerging from counters must be strongly amplified to achieve this, but in the 1940s, practical amplification devices were hindered by their distorted signals. To overcome the issue, Feynman proposed a theoretical

'reference amplifier', which could provide amplifiers with a standard signal to be compared with. Through analysis published in *EPJ H*, researchers at the University of Naples, Italy, propose that this line of research exemplifies the influence which Feynman's involvement in the Manhattan Project held over his later teaching and research. ■

■ **V. d'Alessandro, S. Daliento, M. Di Mauro, S. Esposito and A. Naddeo**

'Searching for a response: the intriguing mystery of Feynman's theoretical reference amplifier', *European Physical Journal H* **44**, 331 (2019), DOI 10.1140/epjh/e2019-90071-6



## BIOPHYSICS

## Cell motility in a compressible gel

**Cell motility is crucial to biological functions ranging from wound healing to immune response.**

**Spontaneous movement and deformation are physically driven by the cell cytoskeleton.**

The cytoskeleton consists of protein filaments and motors which constantly consume chemical energy (ATP) and convert it to work. In particular, actin filaments interact with myosin motors to generate contraction forces in the cell, which drive cell motion and division. Most of the research has focused, both experimentally and theoretically, on cell migration on a two-dimensional substrate (crawling), providing a detailed outline of some basic migration mechanisms. However, some cells, such as breast tumor cells, can also “swim” in a straight line inside a 3D tissue or a polymeric fluid, in the absence of substrates. The authors present a minimal model for pattern formation within a compressible actomyosin gel, which is numerically solved both in 2D and 3D. Contractility leads to the emergence of an actomyosin droplet within a low-density background. This droplet then becomes self-motile for sufficiently large motor contractility. Simulations also show that compressibility has the effect to facilitate motility, as it decreases the value of the isotropic contractile stress beyond which the droplet starts to move. ■

■ **G. Negro et al.,**

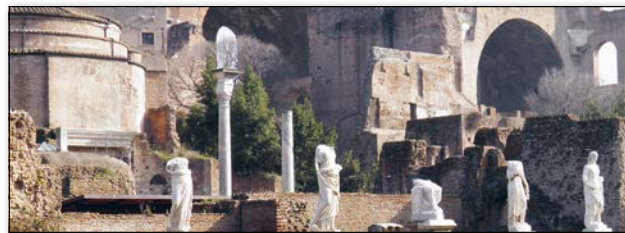
'Hydrodynamics of contraction-based motility in a compressible active fluid', *EPL* **127**, 58001 (2019).

## APPLIED PHYSICS

## Science reveals improvements in Roman building techniques

**A variety of scientific techniques have been combined to highlight improvements in the technologies employed by the Romans in successive modifications to the Atrium Vestae in Rome.**

The Romans were some of the most sophisticated builders of the ancient world. Over the centuries, they adopted an increasingly advanced set of materials and technologies to create their famous structures. To distinguish the time periods over which these improvements took place, historians and archaeologists typically measure the colours, shapes and consistencies of the bricks and mortar used by the Romans, along with historical sources. In new research published in EPJ Plus, Francesca Rosi and colleagues at the Italian National Research Council improved on these techniques through scientific analysis of



▲ The Atrium Vestae in Rome. © Carole Raddato from Frankfurt, Germany [CC BY-SA 2.0 (<https://creativecommons.org/licenses/by-sa/2.0/>)]

the materials used to build the Roman Forum's *Atrium Vestae*. They found that successive phases of modification to the building saw improvements including higher quality raw materials, higher brick firing temperatures, and better ratios between carbonate and silicate building materials. ■

■ **E. Boccalon, F. Rosi, M. Vagnini and A. Romani**

'Multitechnique approach for unveiling the technological evolution in building materials during the Roman Imperial age: the Atrium Vestae in Rome', *Eur. Phys. J. Plus* **134**, 528 (2019), DOI 10.1140/epjp/i2019-12936-y.

## CONDENSED MATTER

## Multiple magnon modes in a magnetic Weyl semimetal

**An area of interest in condensed matter physics is topological Weyl semimetals (WSMs). There are only a few candidates of magnetically ordered materials for the realisation of WSMs, like the kagome-lattice ferromagnet  $\text{Co}_3\text{Sn}_2\text{S}_2$ .**

Novel magnon branches are predicted in magnetic Weyl semimetals, which can be understood as a result of the coupling between two magnetic moments mediated by Weyl fermions. Here, we experimentally investigate electron transport in the kagome-lattice ferromagnet  $\text{Co}_3\text{Sn}_2\text{S}_2$ , which is regarded as a time-reversal symmetry broken Weyl semimetal candidate. We demonstrate  $dV/dI$  curves with pronounced asymmetric  $dV/dI$  spikes, similar to those attributed to current-induced spin-wave excitations in ferromagnetic multilayers. In contrast to multilayers, we observe several  $dV/dI$  spikes' sequences at low,  $\approx 10^4 \text{ A/cm}^2$ , current densities for a thick single-crystal  $\text{Co}_3\text{Sn}_2\text{S}_2$  flake in the regime of fully spin-polarised bulk. The spikes at low current densities can be attributed to novel magnon branches in magnetic Weyl semimetals, which are predicted due to the coupling between two magnetic moments mediated by Weyl fermions. The presence of spin-transfer effects at low current densities in  $\text{Co}_3\text{Sn}_2\text{S}_2$  makes the material attractive for applications in spintronics. ■

■ **O. O. Shvetsov et al.,**

'Multiple magnon modes in the  $\text{Co}_3\text{Sn}_2\text{S}_2$  Weyl semimetal candidate', *EPL* **127**, 57002 (2019).

## PHOTONICS

## Focusing surface acoustic waves into an optomechanical nanobeam

Cavity optomechanics (OM) is a topical issue of growing interest due to the potential applications ranging from sensing and communications to quantum information technology. However, the number of phonons created in a cavity by an external optical fibre remains relatively low. An alternative way to induce large phonon population is the use of a phonon pump by transforming an RF signal into surface acoustic waves (SAW). In a simulation work, we demonstrated an efficient focusing and conversion of SAW generated by focusing interdigital transducers (IDT) on piezoelectric aluminum nitride film deposited on silicon on insulator (SOI) into the guided modes of a silicon nanobeam. For a straight nanobeam, we achieve an efficiency of -22dB and displacements about 50pm when applying a voltage of 1V to the IDT. When the nanobeam is structured to form a phononic crystal with a cavity, the guided modes excite some localized modes around 2 GHz inside the cavity with a magnitude of the vibrational motions around 1nm. The preliminary experiments confirm the simulations.

Work is supported by the European Commission through project PHENOMEN, Grant Agreement No. 713450. ■

■ **A. V. Korovin *et al.*,**

'Conversion between surface acoustic waves and guided modes of a quasi-periodic structured nanobeam', *J. Phys. D: Appl. Phys.* **52**, 32LT01 (2019).

## NUCLEAR PHYSICS

## NSD2019 Conference Proceedings



▲ NSD2019 group photo

The fourth International Conference on Nuclear Structure and Dynamics NSD2019 was held in Venice on May 13-17, 2019. The conference belongs to a series of conferences devoted to the most recent experimental and theoretical advances in the field of nuclear structure and reactions. The focus was on topics covering most of the research areas in low energy

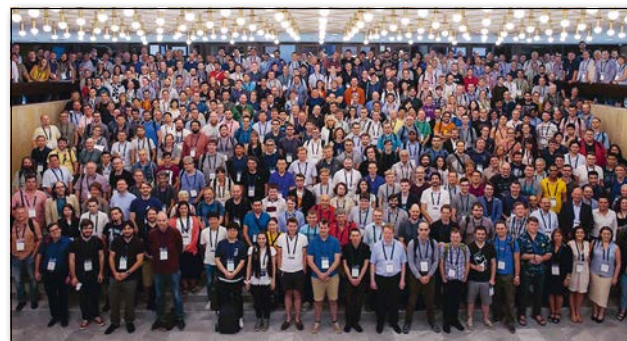
nuclear physics: Nuclear structure and reactions far from stability, Collective phenomena and symmetries, Dynamics and thermodynamics of light and heavy nuclei, Sub and near barrier reactions, Fusion and fission dynamics, Ab-initio calculations, cluster models and shell model, Nuclear energy density functionals, Nuclear astrophysics, Fundamental interactions. Important new results were outlined in the various subfields, spanning the whole range from neutron-deficient to neutron-rich nuclei and from light to heavy ions. ■

■ **G. de Angelis and L. Corradi (Eds.),**

'IV International Conference on Nuclear Structure and Dynamics (NSD2019), Venice, Italy, May 13-17, 2019', *EPJ Web of Conferences* **223** (2019), ISBN: 978-2-7598-9084-2.

## COMPUTING

## CHEP2018 Conference Proceedings



The 23<sup>rd</sup> International Conference on Computing in High Energy and Nuclear Physics was held in the National Palace of Culture, Sofia, Bulgaria from 9<sup>th</sup> to 13<sup>th</sup> of July 2018. The program consisted of 27 plenary, 323 parallel presentations and 188 posters. The plenary talks covered topics such as HPC and cloud computing, machine learning in High Energy Physics (HEP), overviews of experiment software for data acquisition, high level triggering, reconstruction and analysis, experience from astro-particle and neutrino physics, as well as broader subjects like multithreading and vectorization in HEP, use of blockchains, quantum computing, software citation mechanisms. Progress on common and widely used tools and packages in HEP such as ROOT, EOS and CVMFS was also presented. A dedicated talk and a panel discussion were devoted to the implementation of a successful diversity program in the field of HEP and nuclear physics computing. ■

■ **A. Forti, L. Betev, M. Litmaath, O. Smirnova and P. Hristov (Eds.),**

'23<sup>rd</sup> International Conference on Computing in High Energy and Nuclear Physics (CHEP 2018), Sofia, Bulgaria, July 9-13, 2018', *EPJ Web of Conferences* **214** (2019).

# Interview with Cristiane Morais Smith

On the occasion of receiving the EPS Emmy Noether Distinction, we asked Cristiane Morais Smith about her current work, her view on diversity in the physics community and the impact of the distinction.

In 2004, Cristiane de Morais Smith came to Utrecht University in the Netherlands to build a group working on the theory of strongly-correlated systems. On our question why she chose to work in the Netherlands she answered: "Actually, it happened more or less by chance. I wanted to get a job in a place where I did not know anyone because I did not want to be helped. I wanted to get a position all by myself. I saw an announcement of a position in the Netherlands, and given the high status of the country in the scientific scenario, I thought that it would be an ideal place to work."

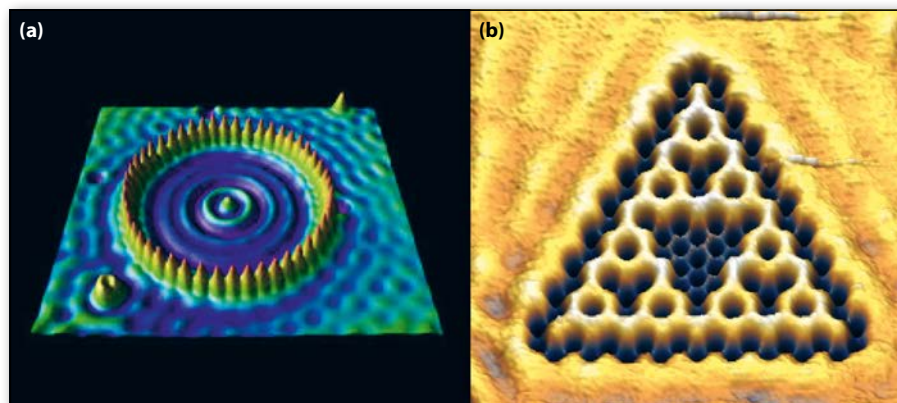
## Current research

Recently, in collaboration with experimentalists at Utrecht University, her group has been working on the development of a platform for quantum simulations in electronic systems. "Sixty years ago, Feynman proposed that we could build matter in a bottom-up approach to simulate model Hamiltonians that are supposed to describe complex materials, or even to build metamaterials. Although the field of quantum simulators has been flourishing in ultracold atoms for about 20 years, and in photonics for about 15 years, almost nothing was done involving electrons. We are actively contributing to the field." With this collaboration in Utrecht, the group aims at establishing a new kind of quantum simulator platform, involving electrons. The endeavour is based on the pioneering experiment performed by the group of Don Eigler (Almaden), in which iron (Fe) atoms were manipulated using the tip of a scanning tunneling microscope on the surface state of Cu(111) to build a quantum corral [1] (see Fig. 1a). Later on, the same technique was used by the group of Hari Manoharan (Stanford) to build *molecular graphene* [2]. The manipulation of the atoms on top of Cu are performed on the nanometer scale and

there is a large flexibility with respect to the structure that could be built. "Indeed, we have shown that despite the fact that the underlying lattice is triangular and the COs can only be put on top of a copper atom, one can control the geometry of the lattice and build square or Lieb lattices [3]. In addition, one can control the *dimensionality* of the object formed, going even into fractal dimensions [4] (see Fig. 1b). One can also manipulate the *orbital degrees of freedom*, which can be selected in real space and separated in energy [5]. We have shown that this setup can be used to generate and control topological states, and have realised a *higher-order topological insulator* [6]. My group has been performing the theoretical calculations (muffin tin and tight binding) and most of the conceptual development of the projects, and we are recognised by the community as being among the pioneers of this emerging field. A next step is to *realise interactions* in this single-particle system. Although the CO on copper platform consists of free electrons, one can simulate two-body interactions in 1D by appropriately designing a non-interacting 2D system. This is being currently investigated, theoretically and experimentally. Preliminary results seem to confirm the theoretical predictions."

## Proud

Morais Smith is proud of the collaborative work of her group on several subjects and with several experimental and theoretical groups in Utrecht, Sweden, Brazil, and Germany. "But a work that I consider really original is our formulation of a thermodynamic description of topological phase transitions. This work was done completely in my group, by some very bright PhD students, and I am very proud of it because nobody thought that this could be possible. Topological systems have metallic states at the boundary, and this seems to be in contradiction with the thermodynamic limit, in which one studies infinite systems. Nevertheless, we found a way to circumvent that..." As a theoretical physicist she enjoys working with experimentalists. "I have a deep respect for experimental work, since it brings the connection to the real world. I collaborate extensively with experimentalists, and learn a lot from them, as probably became clear from the answers above. Experiments are for me a motivation to do a new theory, but I also want to go beyond and predict something else, that could stimulate my colleagues to perform further experiments. One of the highlights in



▲ FIG. 1: (a) A quantum corral is realized by depositing Fe adatoms (yellow-red dots) in a ring on the surface of Cu(111) [1]. The corresponding electronic waves (blue) are then visible in the confined geometry. (b) Local density of electronic states in a Sierpinski triangle, generated by patterning CO molecules (black dots) on the surface of Cu(111) [4].



connection with theoretical predictions is a work we did in 2004. It is a mean-field calculation of the electron-solid phases in a quantum Hall system, and I did not expect it to work very precisely in experiments. However, 6 months after we published the theoretical results, the group of Dan Tsui measured exactly what we had predicted, and even the numbers worked out well. I was enchanted.”

### Role model

Morais Smith makes an effort of being a good role model and accepts many invitations for conferences. At many occasions she is the only woman giving an invited talk. “Every time when I think that it is too much, and I could stay calm at home, I think: but if I do not go, maybe there are no female speakers.... And I feel an urge to accept the invitation. Fortunately, things are improving during the last years, and now there are more female colleagues who are invited. But the numbers are still low.” Participating in committees or boards she keeps a keen eye on the participation of women in physics. “As a member of the International Advisory Council of the T. D. Lee Institute in Shanghai Jiao Tong University, I recently suggested that they could create a prestigious Fellowship with the name of Madame Wu, to honour this brilliant physicist who deserved a Nobel Prize but unfortunately did not get it, and stimulate further Chinese women to follow her example. I was delighted when I learned that the Director, Prof. Frank Wilczek decided to accept the suggestion and implement it.” She stresses the importance of being a role model not only for physicists but for women in general and in particular for women in minority groups. “One day I had a wonderful experience in my office at the University of Utrecht. We had a very intelligent cleaning lady who came originally from Morocco. She entered my office and told me that she had decided to pursue her studies at the University, and that she wanted to let me know that I was her source of inspiration. Her husband was not very happy about it, since she also had a child, but she was determined to do so. I was enchanted! I think that when someone like me sits in a professor chair, it implicitly tells everyone that they can also. And this is very positive.”



▲ FIG. 2: Cristiane Morais Smith (with red scarf) amidst (part of) her research group.

### Diversity and Inclusion

Currently, her group comprises many Dutch students, but still a student from Russia and some from Brazil. She had more than 100 students in total, including Bachelor theses, Master theses, PhD students and postdocs, and from very different countries, like Malaysia, Italy, Germany, Spain, France, Switzerland, Norway, Ukraine, Serbia, Brazil, and Argentina. “But the majority is from the Netherlands, since I work there. I also have several female students, at all levels (Salma Ismaili for the Bachelor theses, Silke Schonecker for the Master, and Jette van den Broeke and Mariya Lizunova for the PhD). Unfortunately, many of them were not there the day when the professional photographer could take the group photo [see the picture] .... It is really a pity!” As a Brazilian, she makes an effort to attract PhD students and Postdocs from Brazil. She hopes to be a hub in Europe for Brazilian physicists or scientists from South America in general. “I kept a strong scientific link with Brazil and have already formed 3 Brazilian professors, and I hope to form more. At the moment, there is a professor and 2 PhD students visiting my group with Brazilian fellowships. Two more are going to arrive in 2020. I was awarded a Special Visiting Professor position in the framework of the Science Without Borders Program between 2013-2016 for a collaboration with the group of Eduardo Marino in Rio de Janeiro. Recently, we were awarded a NUFFIC/CAPES proposal for a collaboration

between Brazil and the Netherlands, from 2018-2021. I am very glad to get support for this very prolific collaboration and I am glad to establish these links.”

### Emmy Noether Distinction

Cristiane Morais Smith has received prestigious grants and prizes, but even so considers the Emmy Noether Distinction very important as recognition of her work “....and it really warms the heart!!! Especially because Emmy Noether has always impressed me so much...every time when I lectured about her life, I had tears in my eyes. She was an incredible woman.”

We asked whether she knew that she was nominated for the Emmy Noether Distinction. Her answer is encouraging for others who consider nominating their outstanding female colleagues: “Yes, I knew it. My colleagues had informed me and I was delighted to learn that they were making time in their busy lives to do that.”

■ Els de Wolf, *EPN Editor*

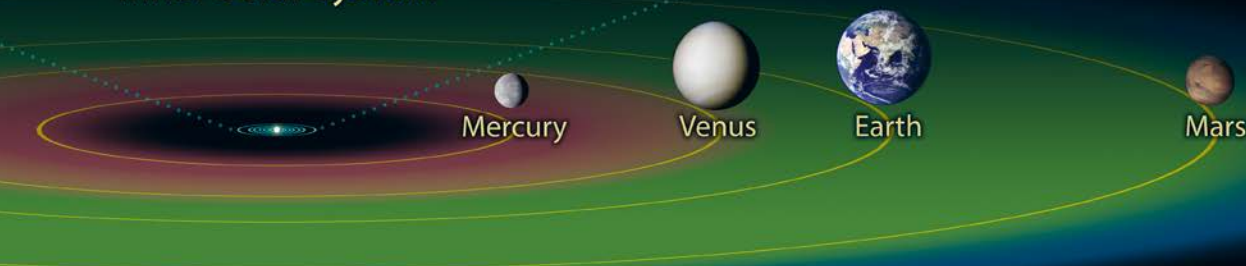
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## TRAPPIST-1 System



## Inner Solar System



Illustration

# EXTRASOLAR PLANETS: FROM DUST TO NEW WORLDS

■ Barbara Ercolano – <https://doi.org/10.1051/epn/2020101>

■ Ludwig-Maximilians-Universitaet – University Observatory Munich (USM) – Scheinerstr 1 – D-81679, Munich, Germany

Thousands of exoplanets have been discovered and the search for life outside Earth is at the forefront of astrophysical research. The planets we observe show a mind-blowing diversity that current theories strive to explain as part of the quest to assess the chances of finding life outside the Earth.

▲ The Trappist 1 system, discovered by the Kepler mission, which comprises 7 terrestrial in the habitable zone of their host star.  
© NASA/JPL-Caltech

**T**his year's Nobel prize in Physics went to Michel Mayor and Didier Queloz, who discovered the first extrasolar planet orbiting a Sun-like star. 51 Pegasi b, is a gas-giant with a mass approximately half of that of Jupiter. Unlike Jupiter in our Solar System, however, this planet orbits very close to its host star, 100 times closer than Jupiter to our Sun, earning it the classification of "hot Jupiter". One year on 51 Pegasi b lasts only just over 4 days compared to nearly 12 years on Jupiter.

The combination of large masses and small semi-major axes of hot Jupiters makes them easier to discover through their gravitational interaction with their host stars. The

stellar "wobble" induced by the fact that planet and host star orbit around their common centre of mass is detectable via the observation of bright stellar spectral lines which appear periodically blue- or red-shifted as the planet pulls the star towards and away from us. This observation however requires extremely stable instruments, spectrographs able to resolve the tiny radial velocity component of the star. In the case of 51 Pegasi this velocity is 55 m/s, however a planet like Jupiter orbiting the Sun at 5 au is expected to provide a signal of 12.5 m/s, while **the Earth orbiting at 1 astronomical unit (au) from the Sun only produces a signal of 9 cm/s, which is slower than the average walking speed of humans on Earth of roughly 1.5 m/s.**

For the detection of the first planet we have to thank the ability of Michel Mayor and his then student Didier Queloz, who were able to build for the first time a spectrograph capable of producing the extremely precise measurements required to detect planets and measure their approximate mass. Since 1995, the discovery year of the first planet, this field has been growing exponentially with new planets being discovered at an ever increasing rate via a variety of methods (Figure 1). Today we know of more than 4000 extra-solar planets and it is expected that current missions like the Transiting Exoplanet Survey Satellite (TESS) will discover thousands more via the “transit” method.

During a transit a planets can be detected by the shadow it casts onto the disc of the host star as its orbit crosses our line of sight to the star. By observing the brightness of a star over a long time, the presence of a planet may be thus inferred by the periodic dimming of the stellar light. Space missions like Kepler have been extremely successful in detecting planets even as small as the Earth, orbiting their host stars at distances where the temperature on their surface could be suitable for sustaining liquid water at their surface. This so-called circumstellar habitable zone or goldilocks zone is the distance of a planet to its host where the temperature might be just right for life to emerge.

To date several terrestrial planets with orbits in the habitable zone of their host stars have been discovered. Figure 2 shows an artist impression of the Trappist 1 system, which was initially discovered by the transit method. This system comprises seven terrestrial planets, three of which thought to be in the habitable zone of the host star. However the Trappist 1 system, and many other discovered habitable zone planets orbit stars that are significantly smaller and thus cooler than our Sun, so-called M-stars. Habitable zones of M-stars are very close to the star itself, as the energy required to keep water liquid on the surface of the planet is only available there. This is potentially a problem for life evolving on such planets as tidal locking may occur, which means that the rotation period of the planet around its axis equals its revolution period around the star. In this case the planet will always keep the same face towards the star, analogous to the Earth-Moon system. Temperatures on the opposite sides of tidally locked planets may be very different causing extreme climates. It is currently unclear if life could develop and thrive on tidally locked planets, which do not have a day-night cycle. Perhaps an even more worrying aspect about M-star planet hosts is their high magnetic activity, which produces strong flares of high energy radiation, which is detrimental to the retention of planetary atmosphere as well as cellular life as we know it on Earth. M-stars, which were the prime targets of the Kepler mission and are very abundant in our Galaxy, might not be the best environment to search for signs of

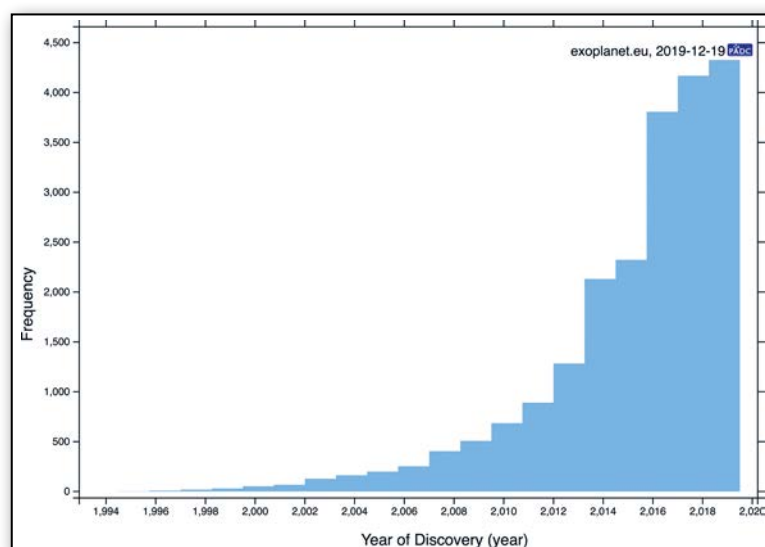
life outside our Solar System after all. The TESS mission will focus instead on planets transiting solar-type stars.

The prime motivation for exoplanet finding missions is the question of whether the Earth may be a unique and special place for life in our Universe. This question continues to be the driving force behind many observational campaigns and theoretical investigations in the field. While a partial answer may have been provided by the recent exoplanet surveys, which have shown that, **statistically speaking, most stars in the Milky Way have planetary companions** [1], other surveys have also highlighted the diversity of exoplanetary systems [2]. This prompted the further question of how did these planets form, and whether some may end up looking like our own and being able to host life.

Diversity and habitability are a consequence of the process of planet formation and subsequent evolution, which is dictated by the physical conditions of the environment where they form. Planets form from the dust and gas contained in the circumstellar discs surrounding nearly all young low- to intermediate-mass stars. These planet-forming disks are a by-product of the star-formation process, since the gravitational collapse of rotating star-forming clumps necessarily needs to redistribute angular momentum. So all stars are born with circumstellar discs, meaning that all stars have at least the potential to host a planetary system. Indeed this theoretical prediction is in line with the observation that on average all stars in our Galaxy host a planet.

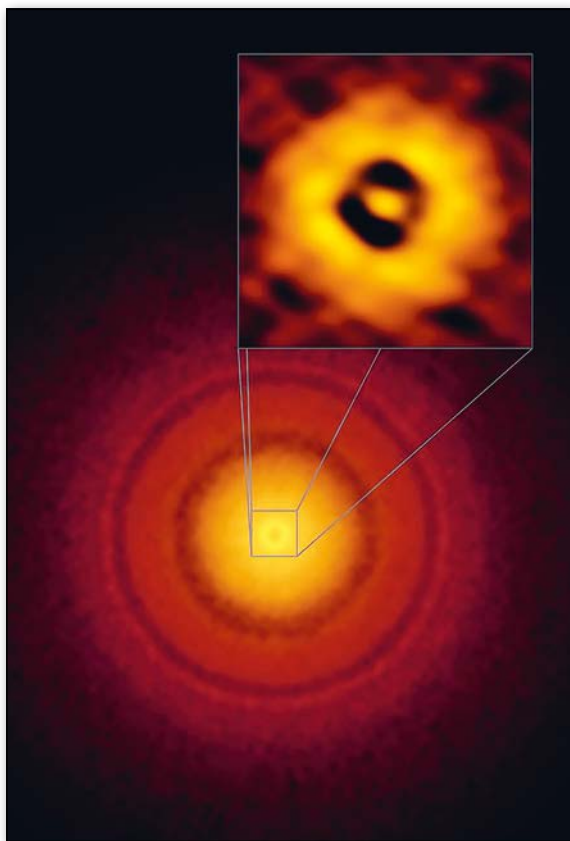
Currently, the favourite paradigm for the formation of planets is the so-called core accretion model. In this model micron size dust grains, embedded in the gaseous circumstellar disc, collide against each other and, in some cases, they stick to each other, growing to larger sizes. This “bottom-up” growth process brings dust grains along a journey over at least 12 orders of magnitude as they reach the sizes of thousands of kilometer. This journey is not easy. Not every collision results in

▼ FIG. 1: Cumulative distribution of confirmed extrasolar planets. Since the discovery of the first gas giant orbiting a Sun-like star, the rate of discovery has been increasing, with peaks corresponding to the data releases of large space missions like Kepler. © exoplanet.eu





► **FIG. 2:**  
Atacama Large  
Millimeter continuum  
image of TW Hydra.  
The outer rings are  
thought to have been  
carved by forming  
planets, while the  
central cavity has  
been created by  
photoevaporation  
from the central  
star. © S. Andrews  
(Harvard-  
Smithsonian  
CfA), ALMA (ESO/  
NAOJ/NRAO)



sticking, depending on the velocity of the collision, particles may fragment or just bounce against each other, making the growth process extremely slow. However planet formation has to happen during the lifetime of the circumstellar disc, which holds the reservoir of material from which planets form.

Circumstellar discs are observed to evolve and finally disperse over a timescale of a few million years, which is comparable to the timescales for planet formation by the core accretion process. This implies that the processes driving the evolution and dispersal of discs play a crucial role in shaping new planetary systems and likely contribute to the observed diversity of exoplanets. Studies show that discs mostly disperse from the inside-out via the formation of so-called transition discs *i.e.* discs that have an evacuated inner cavity. These relatively rare objects may be discs caught on the last gasps of their lives and may thus provide key insights on the mechanism responsible for their evolution.

Disc dispersal is thought to be driven by the high energy radiation, particularly X-ray, emitted from the central star, which plays a key role in shaping the evolution of discs and of their planetary progeny. X-rays penetrate the disc, ionising and heating the gas, which then flows away in a thermally unbound and centrifugally accelerated disc wind. This process of disc photoevaporation ultimately causes the dispersal of the circumstellar disc. The Atacama Large Millimeter Array has provided us with exquisite spatially resolved images of transition discs, where the dispersal process

and the planet formation process may be occurring simultaneously as in the case of our nearest neighbour, TW Hydra, shown in Figure 3. The outer disc rings have probably been carved out by forming planets, while the central cavity results from the onset of the photoevaporation process, which will finally cause the demise of the disc and pose an end to the planet formation process in this disc [3].

The award of this year's Nobel Prize in Physics to exoplanet science is really just the beginning. The era of exoplanet discovery is giving place to a new era of exoplanet characterisation, with new missions, in the near future, designed to determine the physical properties of these far away worlds as well as starting to study their atmospheric composition in the search for biomarkers (*e.g.* CHEOPS and Ariel). Biomarkers are gas of biological origins that may hint at the presence of life. At the same time theory is advancing fast to explain how these planets may have formed in their natal circumstellar discs and what role the central star plays in determining the habitability of a system. The next two decades will certainly be full of exciting discoveries in this field, which addresses fundamental questions concerning where we came from and what are the perspectives for the emergence of life elsewhere in the Universe.

### About the Author



**Barbara Ercolano** is a Professor of Theoretical Astrophysics at the Ludwig Maximilians University of Munich and leads a DFG Research Unit on transition discs, that are believed to be the natal environments of forming planets. Barbara Ercolano is also a Principal Investigator in the new Origin Excellence Cluster, which is an interdisciplinary Institute joining Astrophysics, Biophysics and Particle Physics in the quest to understand the Origin of the Universe and the building blocks of Life.

She holds a doctoral degree from University College London. She successively held a research position at the Harvard-Smithsonian Center for Astrophysics in Cambridge (MA, USA), an STFC Advanced Fellowship at the Institute of Astronomy of Cambridge University and University College London (UK), and was a lecturer at the University of Exeter (UK). Barbara Ercolano is the 2010 winner of the Fowler Award in Astronomy of the Royal Astronomical Society.

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# PLANETS ORBITING OTHER STARS

## THE SEARCH FOR EXTRATERRESTRIAL LIFE

■ Ignas Snellen – Leiden Observatory, Leiden University, The Netherlands – <https://doi.org/10.1051/epn/2020102>

**Since the Nobel-prize-winning discovery of a planet orbiting a sun-like star, the field of extrasolar planets is undergoing a true revolution. Thousands of planets have been found, of which some may be like Earth. Could there be biological activity on any of these, and how do we find out?**

Since the age of Copernicus and Galilei we know that Earth does not form the center of the Universe. We since have found out that it orbits the Sun as one of multiple planets. The Sun is a normal star in the outskirts of the Milky Way, and the Milky Way is one of the billions of galaxies in the observable universe. It may be argued that our home planet is nothing special, and that the universe is teeming with life. In reality, however, the Earth may be quite unique. Circumstances may need to be just right for life to form and evolve, in particular for highly evolved species which may require a stable planetary climate for billions of years. We simply do not know. The search for extraterrestrial life is an important philosophical endeavour, which will shed light on the place of humanity in the cosmos. *Are we alone?*

A particularly complicating aspect of the search for life is that we do not know much about what to expect. Life on Earth is the only reference available. Although many scenarios have been proposed, we do not know how life on Earth initially formed. Also, we cannot yet form living organisms from scratch in the lab. Still, any

extraterrestrial organism should obey the laws of chemistry and physics – at least in a scientific context – and any biological function requires complex chemistry. Carbon-based molecules are generally seen as the only way to provide the intricate building blocks for this [1].

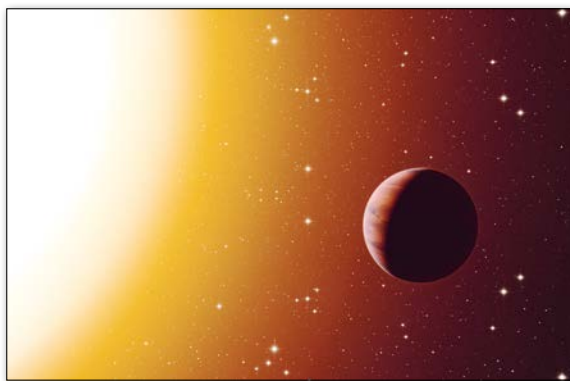
### Follow the water

We also know that water has been playing a crucial role in the origin and development of life on Earth. Astronomers jump at this aspect. We can identify places in the universe where liquid water could exist, on the surfaces of rocky planets at the right distances from their host stars [2]. These may be places where life can form and evolve. This does not mean that life does not exist in other locations, even in our own solar system, such as deep underground on Mars, or in the sub-surface oceans of some moons of Jupiter and Saturn.

In the case of exoplanets, however, we need to be able to recognize biological activity from interstellar distances, meaning that it must significantly alter the chemical structure of its planet's atmosphere and/or surface – which can potentially be observed from many light years

▲ Artistic rendering of the European Extremely Large Telescope currently under construction to be operational in the mid 2020s. (Credit: ESO, L. Calçada, ACe consortium)





► FIG. 1:  
Artist's impression  
of a hot Jupiter  
(© ESO, L. calçada).

away. This is what astronomers will focus on in the next decade(s). Do rocky exoplanets have atmospheres? What are the main constituencies of these atmospheres? Are the planets wet or dry? Do we understand the atmospheric and geological processes involved? Can we identify gases that may be produced by biological activity, such as molecular oxygen on Earth? Ultimately, we will need a deep understanding of a planet's origin and evolution to make a conclusive case for extraterrestrial biological activity, requiring intensive collaborations between many scientific disciplines, including chemistry, geology, climatology and biology.

### Planets everywhere

So, where are we now, and where do we go from here? Since the Nobel-Prize discovery [3], planets have been found everywhere. The two most successful methods are the radial velocity and transit techniques. The first measures the reflex motion of a star around a system's center of mass. This can reveal a planet's orbit, and a lower limit to its mass (depending on the orientation of the orbit). For the second method, the orientation of the planet's orbit needs to be nearly edge-on. The planet then regularly occults a part of the star, resulting in a small dip in the amount of starlight that we see. This reveals the size and orbit of the planet, and in combination with the radial velocity method, also its mass and mean density – providing first clues about its composition.

▼ FIG. 2:  
Artist's impression  
of the surface of  
exoplanet Proxima  
Centauri b. (© ESO/  
M. Kornmesser)



After 25 years of discoveries, we know that planets are very common. About one in ten stars harbour a gas giant like Jupiter, about one in three have Neptune-size planets, and most stars harbour Earth-mass objects. The latter is particularly pronounced around low-mass stars. Our nearest neighbour, Proxima Centauri at about 4 light years, has a small planet [4] in an 11-day orbit. Since the star is more than a thousand times less luminous than our Sun, the planet receives as much stellar energy as if it were a planet in an orbit between that of the Earth and Mars. Very exciting is also the nearby TRAPPIST-1 system [5], which harbors seven sister planets, all about the size of the Earth, and of which at least three could have a climate allowing liquid water on their surfaces. Therefore, even very nearby, we already know of several planetary systems where life possibly could form and evolve. Do note, however, that it is not clear whether the, in some aspects, harsh circumstances around red dwarf stars allow the onset biological activity [6].

### Atmospheres

Studying the atmospheres of exoplanets is a whole different ball-game. Almost all planets found to date have been discovered without identifying a single photon from the planets themselves. For atmospheric studies this can no longer be the case – planet light needs to be separated from that of the star, with the latter being many orders of magnitude brighter.

There are basically two families of methods to accomplish this. The first has so far been the most successful and involves transiting systems, making use of temporal variations in how we see the planet. When a planet transits a star, in addition to occulting part of the stellar surface, starlight also filters through the planet atmosphere, leaving an imprint of atomic and molecular absorption and scattering. In addition, half an orbit later, the planet is occulted by the star, meaning that for a few hours the planet's light (either intrinsic thermal emission or starlight reflected off the planet's atmosphere) is missing and can be accounted for. Also during the rest of the orbit, varying parts of the dayside and nightside of the planet are visible, resulting in variations that reveal its heat distribution which can constrain global climate circulation models.

Making direct images of exoplanets, by angularly separating the planet from the star in the sky, is still very difficult. Ground-based telescopes require adaptive optics to mitigate the disturbing influence of our atmosphere, to approach their theoretical angular resolution. This is needed in combination with coronagraphy to block the star light such that a faint orbiting planet can be seen. Telescopes in space have the advantage not to need the former, but are costly, and are therefore smaller and have significantly less resolution, limiting their performance [7].



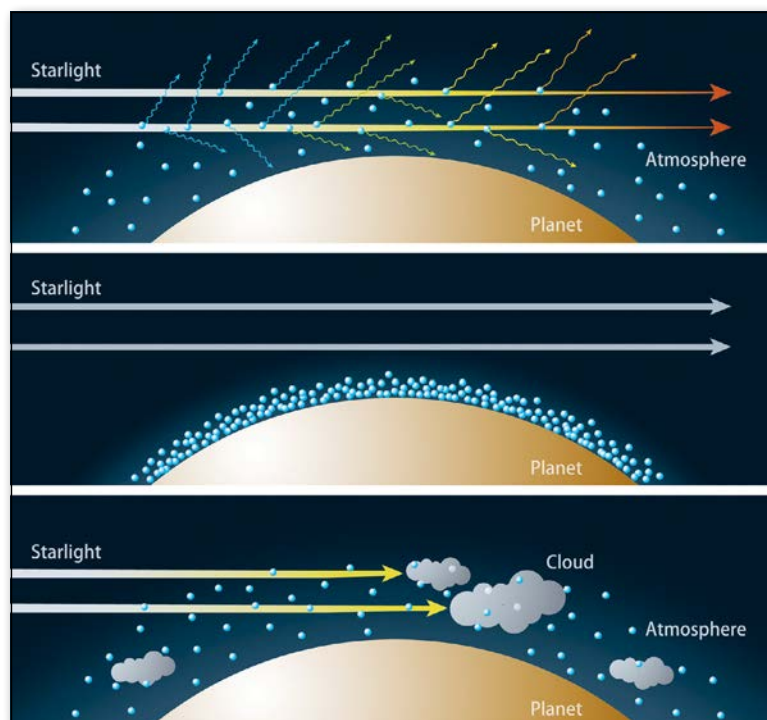
Most atmospheric characterization has been limited to warm gas giant planets, which have the largest atmospheric scale heights and therefore strongest transit signals, and emit most thermal emission. For direct imaging this needs to be accompanied by a large enough orbital distance to assure angular separation from their host stars, which means that only young gas giants, which are still hot from their formation, can be probed. So far, several different molecules, such as carbon monoxide and water have been identified with both families of methods, in addition to several atoms and ions, and evidence for Rayleigh scattering and the presence of clouds and hazes. Also, vertical and longitudinal temperature structures have been measured, including thermal inversions and atmospheric escape processes.

In the exoplanet group at Leiden University we focus on the use of ground-based telescopes for atmospheric characterization. In particular, performing transit and direct imaging observations at very high spectral resolving powers ( $\lambda/\Delta\lambda \sim 100,000$ ) is very effective, revealing the tens to hundreds or thousands of individual rotational-vibrational lines of molecules. This has several advantages. Molecules are uniquely identified, even if their spectral bands overlap. Furthermore, the ground-based calibration is significantly more straightforward in this way, and the spectral features from the planet, our own atmosphere, and the star can be disentangled because of their different Doppler shifts – even if each exhibit features from the same molecule. This has been shown to be very powerful and probes exoplanet atmospheres in unique ways, also being sensitive to exoplanet atmospheric winds and spin rotation [8, 9]. Ultimately, this can also be used to target molecular oxygen, a biomarker gas, in nearby rocky exoplanets – the possible exoplanet-based oxygen and that in our own atmospheres will be separated in velocity and can be distinguished from each other.

## En route to finding life

Atmospheric observations are currently still limited to gas giants, including a recent detection of water vapour in the atmosphere of a temperate mini-Neptune [10, 11]. But this will soon change. Astronomers around the world are eagerly awaiting the launch of the James Webb Space Telescope in 2021 – the successor of Hubble. It will target TRAPPIST-1 planets to see whether they have atmospheres, and if so, get a handle on their constituencies. This will be a major step forward, providing a first assessment of the climates of rocky planets around small red dwarf stars.

Personally, I am even more excited about the next-generation of ground-based telescopes, in particular the 39 meter European Extremely Large Telescope, which is being built in the Atacama Desert of northern Chile (first light in 2026). One of its first light instruments is METIS [12], a mid-infrared spectrograph with high spectral resolving power perfectly designed for atmospheric observations. METIS, and the second-generation



optical spectrograph HIRES, can reveal possible water vapour, carbon dioxide, methane, and ultimately oxygen in the atmosphere of our nearest neighbour Proxima Centauri b. A very exciting prospect. If common, and nature is kind to us, we may find the first clues of extra-terrestrial life within this decade. ■

## About the Author



**Ignas Snellen** is a professor in astronomy at Leiden University in the Netherlands. He is an expert in the atmospheric characterization of extrasolar planets.

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**▲ FIG. 3:** Schematic relation between the composition and structure of an exoplanet atmosphere and the observed transmission spectrum. Starlight travels through the planet atmosphere and is being scattered by molecules at certain wavelengths (top), is largely unaltered because of the small scale height of the atmosphere (middle), or absorbed by clouds (bottom). (Credit: NAOJ)



pushing these actions forward within their communities. In addition, the OSPP called upon all Member States and stakeholders to:

1. Appoint national coordinators and task forces for the implementation of open science;
2. Ensure an interoperable scholarly infrastructure in Europe for better sharing of metadata between disciplines and countries;
3. Ensure that the Human Resource Strategy for Researchers (HRS4R) reflects best open science practices on research integrity, researcher evaluation and the public availability of research outputs;
4. Foster open science literacy from primary school through the whole educational system;
5. Implement a Europe-wide campaign to raise awareness and communicate the benefits of open science among decision makers, research and education bodies, private sector, industrial and citizen organisations.

The last meeting of the OSPP took place in Helsinki on 22 October 2019 and addressed mainly the analysis of its task force on new indicators monitoring and supporting the implementation of open science and the next deliverables of the OSPP until the end of its mandate in May 2020.

## Response of EPS

The EPS responded to some of the public consultations on the expert groups' reports and wrote additional position papers [12]. In particular, in its response on the report on 'Future of scholarly publishing and scholarly communication', it was stressed that – as a learned society and publisher – the EPS is indeed concerned with the four key functions: *registration, certification, dissemination and preservation*. EPS advocates that high-quality peer review must remain a core value in open access publishing. Further, the EPS stressed that the evaluation of researchers and research output must be based on true scientific merit and much less on bibliometric indices and journal prestige with its impact factor. Finally, whereas a strong role for the implementation of open access publishing is attributed by the expert groups to funding agencies, EPS reminded that physics has been at the forefront of disruptive innovations and new paradigms in scholarly communication, thanks to grassroots initiatives from its community such as SCOAP3 of the high energy and particle physics community.

## cOAlition S and Plan S

In September 2018, the "cOAlition S" consortium of European government funding agencies [13] launched the "Plan S" under the leadership of Science Europe, an initiative to ensure that by 2020 all scientific publications resulting from research funded by these bodies must be

published in compliant open access journals or repositories. The Plan S, motivated by the Berlin declaration (2003), and built on ten principles, was submitted for consultation to the stakeholders.

## Reactions on Plan S

The plan S generated an avalanche of more than 600 reactions, many claiming that its proposals were going too far, too quickly and were too risky for many researchers. EPS reacted like other organisations to Plan S; its main concerns are related to the pressure for not supporting hybrid journals any more in the future, the limitation of researchers' freedom in choosing where to publish, the exclusion of non-European stakeholders who play an important role in the publishing business, and the too short transition period planned until 2020.



## The EPS responded to public consultations on expert groups' reports

## Revised Plan S

As a reaction to the critics, cOAlition S published a revised version of the Plan S, maintaining most of its fundamental principles. Among others, these are that open access publishing should be immediate and without embargo, funders should commit to keep open access publications fees at a reasonable level and the support to hybrid journals should happen only if they are part of a transformative agreement with clearly defined endpoints. Among the main modifications in the revised version is an extension of the timeline by one year until 2021 and transformative agreements supported until 2024 with more possible options.

## Position of learned societies

In the revised Plan S, the position of the learned societies, as an essential component of the scholarly infrastructure and many of them relying on subscription revenue, has been well recognised. cOAlition S will help identifying the different models and practical aspects that would support Societies that engage in transformative agreement for their publications. Commercial publishers and library consortia are already signing such transformative agreements that allow researchers to read a publisher's paywalled content while publishing articles in its journals. The negotiation of such deals is rather complex and time consuming for small societies. In fact, 'big deals' are today one of the dominant business models in academic publishing but are also rather disputed as seen in Germany and other countries. Finally, more transparency in open access publication fees and their capping is also strongly emphasised in the revised version of Plan S.



## Challenges of Open Science

What are the barriers and challenges to adopting open science? Often mentioned are the lack of human resources, the additional costs in time and money, the loss of competitive advantage, the concern about extra scrutiny, the lack of policies and incentives, legal issues, copyright and authorship regulation, the still influential role of impact factor of 'prestigious' research journals needed for reputation and career advancement. Clearly, funding agencies and research performing institutions are in the driving seat when it comes to tackling many if not most of these issues. Things start to move, however, as exemplified by the recent call by Dutch public knowledge institutions and funders of research to change the research reward and incentive systems to better value researchers and scholarly output with new metrics [14]. Much work is also still required on the "research data side". Open research data is the second leg of 'open access to scientific information', next to the open access to peer-reviewed publications. Scientific research data include the data underlying publications and/or other data (such as curated but unpublished datasets or raw data). Making research results more accessible to all is seen as a major contribution to better and more efficient science, and to innovation in the public and private sectors, which are the main *raison d'être* of open science. It requires a definition of what data are for each scientific discipline or sub-discipline and raises questions of data management and preservation. It requires to balance openness with the protection of scientific information, commercialisation and Intellectual Property Rights (IPR), privacy concerns, and security. Hence, data may actually mean metadata allowing access to data under licenses in some cases.



**Making results accessible to all is a major contribution to better science**

## Acceptance of Open Science

Facing all these challenges successfully will determine the fate of open science. The real measure of success will be the adoption and acceptance of open science by the scientific community at large. Learned societies like EPS have a major role to play, at the interface between scientists and other stakeholders, to reach this objective.

In addition, EPS must face the future of its flagship scientific journal EPL (formerly Europhysics Letters). EPL is a hybrid letter journal with both subscription and partly open access covering all areas of physics. EPL is published under the scientific policy and control of the EPS by EDP Sciences, IOP Publishing and the Italian Physical Society for a partnership of 17 national

physical societies. Following the publication of Plan S and the new developments of open science, EPL is also under pressure to flip into a fully open access journal. Intensive discussion is ongoing to find the best strategy for its future, but one thing is clear: all EPS members and physicists in general should really consider publishing in this high-quality journal, regardless of impact factor and other metrics. EPL is a journal by physicists for physicists and deserve to be strongly supported by our community. ■

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# ACCRETION DISKS AROUND YOUNG STARS:

## THE CRADLES OF PLANET FORMATION

■ Dmitry A. Semenov<sup>1</sup> and Richard D. Teague<sup>2</sup> – DOI: <https://doi.org/10.1051/epn/2020104>

■ <sup>1</sup> Max Planck Institute for Astronomy – Heidelberg – Department of Chemistry – Ludwig Maximilian University – Munich – Germany

■ <sup>2</sup> Center for Astrophysics – Harvard and Smithsonian – Boston – USA

Protoplanetary disks around young stars are the birth sites of planetary systems like our own. Disks represent the gaseous dusty matter left after the formation of their central stars. The mass and luminosity of the star, initial disk mass and angular momentum, and gas viscosity govern disk evolution and accretion. Protoplanetary disks are the cosmic nurseries where microscopic dust grains grow into pebbles, planetesimals, and planets.

### Protoplanetary Disks as Analogues of Young Solar Systems

Protoplanetary disks are believed to be the environments where planets, their satellites as well as comets and asteroids are formed over a timescale of several million years (Myr). Diversity of protoplanetary disks allows us to better comprehend properties of and conditions in the protosolar nebula, out of which our own solar system has emerged [1–3]. Protoplanetary disks are found around young stars with masses between  $\sim 0.1$  and  $2.5$  solar masses ( $1M_{\text{Sun}} \approx 2 \times 10^{30}$  kg). These rotating disks are made of  $\sim 99\%$  gas and  $\sim 1\%$  dust (by mass) and have typical masses of  $\sim 0.01$ – $0.1M_{\text{Sun}}$ . Disks have sizes up

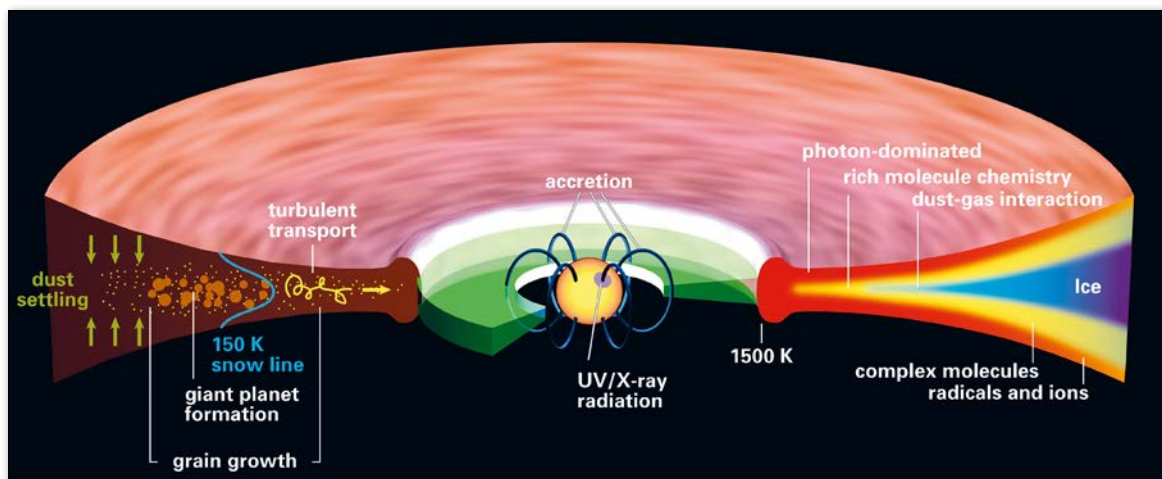
to  $\sim 1000$  au (1 au is the average distance between Earth and the Sun). For reference, Pluto orbits the Sun at  $\sim 40$  au distance, while the Oort cloud of comets is located at distances beyond 2,000–200,000 au.

Protoplanetary disks are a natural outcome of the star formation process. The  $\sim 10$  Myr evolution of a protoplanetary disk can be divided into three main stages. The newly born star is surrounded by a slowly rotating envelope of material which, due to the conservation of angular momentum, flattens out into a circumstellar disk. During the first  $\sim 0.1$ – $0.5$  Myr, the central star continues to grow in mass by accreting matter from the inner edge of the disk, which, in turn, is fed by the remains of the extended envelope. Secondly, when

▲ The first clear image of a young planet caught in the very act of formation in a protoplanetary disk PDS 70 (SPHERE instrument on ESO's Very Large Telescope). The planet is visible as a bright point to the right of the centre of the image, which is blacked out by the coronagraph mask used to block the blinding light of the central star.

► FIG. 1:

A protoplanetary disk around a young Sun-like star. The young star illuminates the disk atmosphere, which leads to the flaring vertical structure and strong gradients of physical conditions. The  $\mu\text{m}$ -sized dust grains are coupled to the gas and provide opaqueness to the disk matter. The mm-sized dust grains gravitationally settle toward the disk midplane, where they can further grow and drift toward the inner regions. From chemical perspective, a disk can be divided into three layers: (1) a cold midplane where molecules are frozen onto dust grains as ice, (2) a warmer intermediate layer where molecules form and remain in the gas, and (3) a hot irradiated atmosphere with atomic species. Reprinted with permission from [2]. Copyright 2013 American Chemical Society.



the external supply of matter from the envelope onto the disk comes to an end, the star reaches its final mass and the disk mass begins to decrease over a timescale of  $\sim 3 - 10$  Myr. Sometime during this entire process the onset of planet formation commences, however it is currently unclear when exactly it begins. During the clearing phase that lasts several Myr, the remaining disk is dispersed by the planet-disk dynamical interactions and photoevaporation by stellar radiation.

### Protoplanetary Disk Structure

Protoplanetary disks are accretion disks, which evolution was mathematically described in the “classical” theoretical studies [4–6]. Their fundamental physical properties are described by the conservation laws for energy and angular momentum. An accretion disk is a flat, rotating gaseous structure in orbital motion around the gravitational centre (a star). Usually the central star is much more massive than the disk, and the orbital motion of the gas at a radius  $R$  nearly follows the Kepler law:  $V_K = GM/R$  (where  $G$  is the gravitational constant and  $M_*$  is the mass of the star). The departure from the perfect Keplerian rotation is due to the thermal gradient, which makes gas orbital velocities to be slightly sub-Keplerian.

Accretion is the loss of potential energy via frictional dissipation. Accretion leads to a net transport of the disk matter toward the gravitational centre, while a minority of the matter carries angular momentum outside of the disk. Measured accretion rates from disks onto their central stars are low,  $\sim 10^{-12}$  to  $10^{-7} M_{\text{Sun}}/\text{yr}$  [7] unless a disk experiences an episodic burst of accretion (e.g., due to accretion of a massive gas clump). The frictional dissipation is provided by the viscous stresses. The molecular viscosity is too low to drive the disk accretion. Thus, other mechanisms like turbulence or disk winds have been invoked. The origin of disk turbulence or winds are not yet fully understood and likely caused by various (magneto)-hydrodynamical instabilities [8,9]. In massive, cold disks a gravitational instability can occur, driving efficient angular momentum transport and accretion via spiral arms.

Turbulent viscosity in disks is often parameterised by the so-called  $\alpha$  parameter:  $\nu = \alpha c_s H$ , where  $c_s$  is the thermal gas velocity (sound speed) and  $H$  is the scale height of the disk (local disk extend) [5]. Observations and advanced dynamical models of protoplanetary disks point to a weak subsonic turbulence with  $\alpha \sim 10^{-5} - 10^{-3}$  [10]. By knowing the  $\alpha$  parameter, the time evolution of the gas density distribution in a geometrically thin disk as a function of radius can be computed by solving for a 1D non-linear diffusion equation [6, 11].

Protoplanetary disks are characterised by the strong gradients of physical conditions and chemical composition, with cold and dense midplanes, warm upper layers, and hot, tenuous atmosphere (Fig. 1). The thermal disk structure is determined by the dissipation of accretion energy in the inner disk region, and by the reprocessing of the stellar and interstellar radiation in the rest of the disk. The dust and gas temperatures are coupled via collisions in dense layers, at particle densities above  $10^5 - 10^8 \text{ cm}^{-3}$ . The disk gas becomes hotter than the dust in the atmosphere, reaching temperatures  $> 10,000 \text{ K}$ . At intermediate heights, where dust grains begin to shield the disk matter from external high-energy radiation, the dust and gas temperatures become close to each other,  $20 - 500 \text{ K}$ . In the inner disk, midplanes temperatures can reach up to  $1,500 \text{ K}$  due to accretion heating, while outer midplane regions are cold,  $10 - 20 \text{ K}$ .

Disk gas density decreases very rapidly in the vertical direction. Assuming hydrostatic equilibrium between gravity and thermal pressure, the vertical gas density distribution can be approximated by a Gaussian function. The vertically integrated gas density also decreases radially outward. This often leads to a situation when more than a half of the disk mass is located inside the planet-forming zone at  $\lesssim 20 - 50 \text{ au}$ .

Dust evolution in disks leads to the dust density distribution that differs from the gas density distribution. Micron-sized dust grains remain collisionally coupled to the gas and follow the gas. They can grow through collisions into bigger millimeter-sized grains (pebbles),



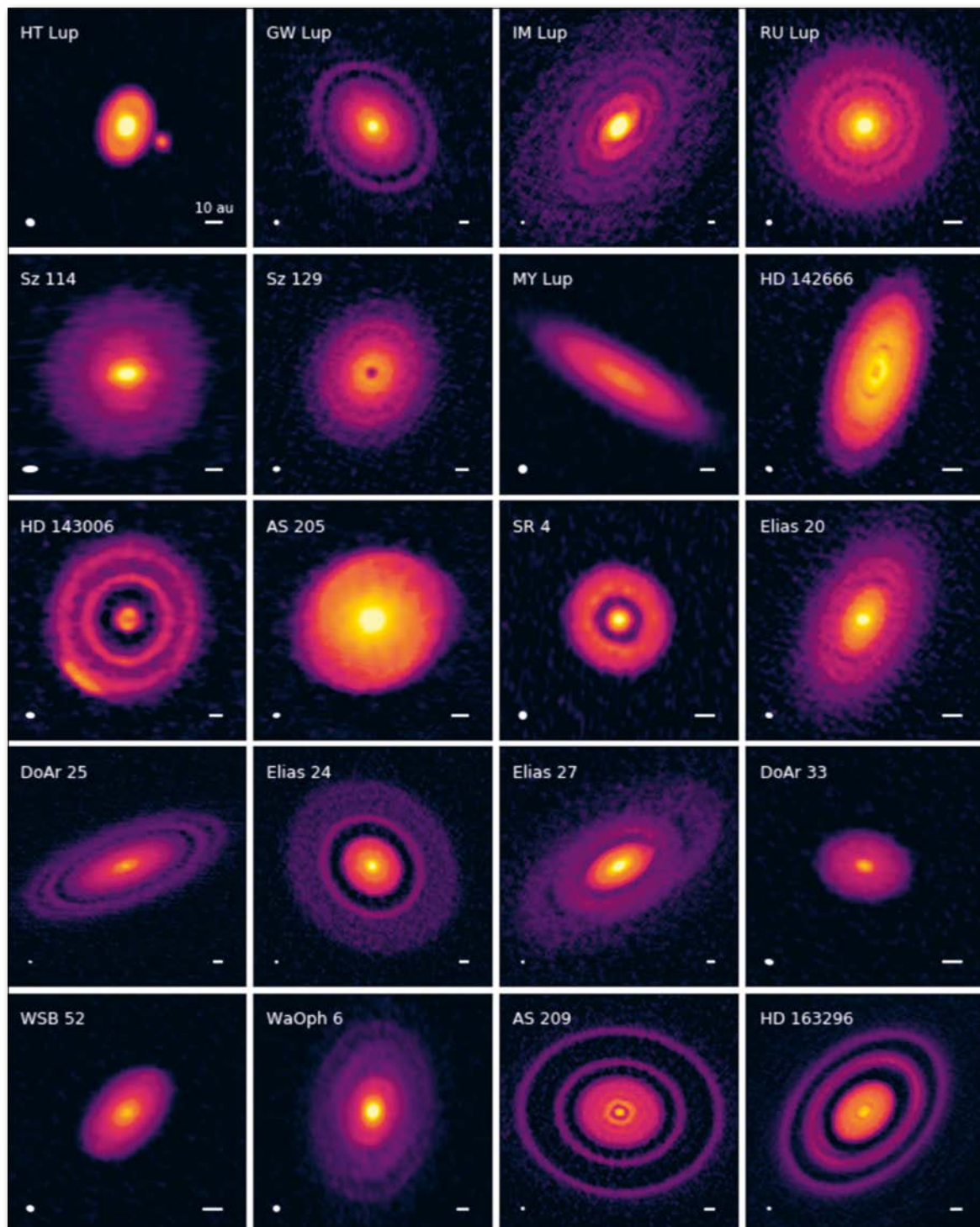
becoming partially decoupled from the gas and gravitationally settling toward the disk midplane. Pebbles experience a headwind from the gas due to the difference between their perfectly Keplerian velocities and the sub-Keplerian velocity of the gas. This leads to their rapid drift inward and loss, unless they are trapped between the disk gas gaps or grow far beyond 1 m in size. The most robust process for the dust growth beyond this 1 m barrier is the local accumulation of solids in turbulent eddies and other long-lived gas over-densities [12].

Later, these pebbles can grow into a swarm of km-sized planetesimals, first planetary embryos ( $\sim 100 - 1000$  km),

and planetary cores ( $>1000 - 3000$  km). According to the core-accretion scenario [13], giant planets like Jupiter can form when their solid cores grow above  $\sim 5 - 20$  Earth masses and able to gravitationally attract nearby gas. Otherwise, the planetary cores end up as rocky, Earth-like planets. The planet formation timescale cannot be much longer than the disk lifetime of a  $\sim 10$  Myr.

### Recent Developments

Recent progress in space-born and ground-based observatories like *ALMA*, *Herschel*, *NOEMA*, *Spitzer*, *VLT* provided images of hundreds of protoplanetary disks in thermal dust

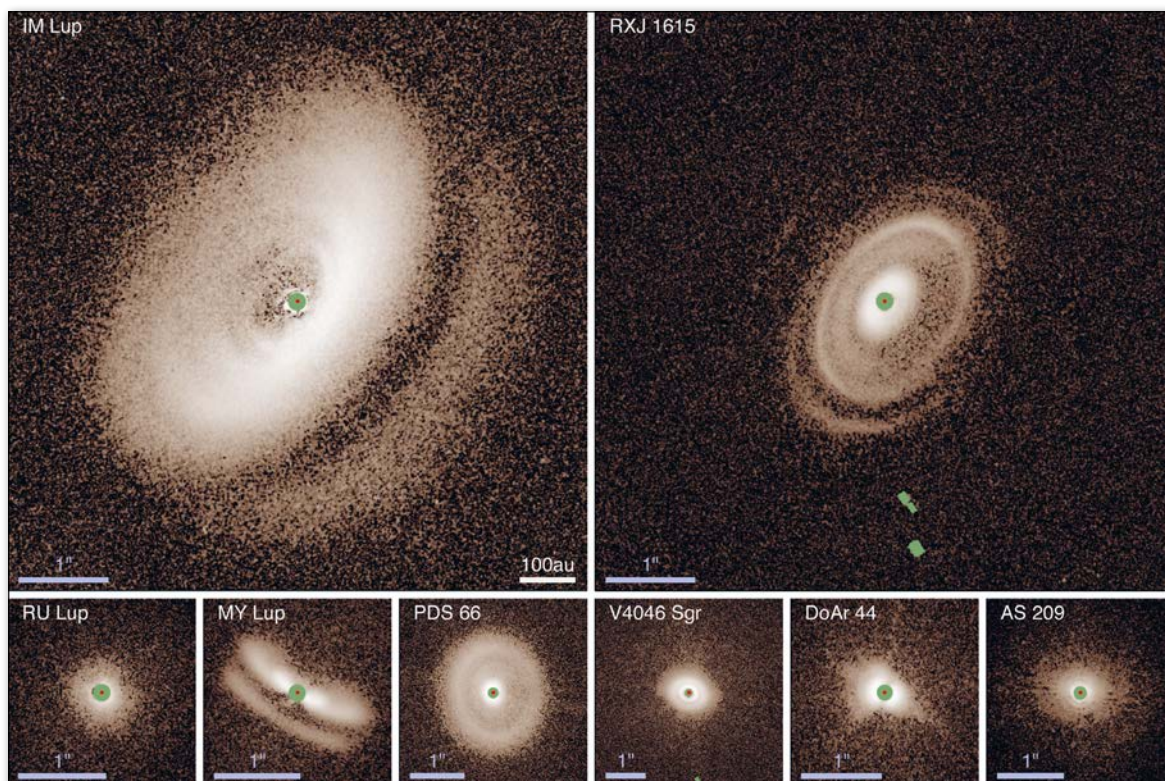


**FIG. 2:** Twenty protoplanetary disks observed at the wavelength of 1.25 mm with the Atacama Large Millimeter Array in Chile (DSHARP project; PI: Sean Andrews, Center for Astrophysics | Harvard and Smithsonian). What is visible in each panel is the continuum emission from  $\sim 1$  mm-sized dust grains, which gravitationally settled toward the disk center. The detector pixel sizes (lower left corner) and the 10 au scale bars (lower right corners) are shown in each panel, respectively. The dark gaps are believed to be gravitationally cleared by giant planets. Reprinted with permission from [14]. Copyright 2018 Astrophysical Journal.



► FIG. 3:

Near-infrared images of eight protoplanetary disks (SPHERE instrument at the Very Large Telescope in Chile). What is visible in each panel is the stellar light scattered by sub-micron-sized dust grains. The strong emission of the central star is blocked by the coronagraphic mask. The dark lanes are the disk midplanes where dust absorbs the stellar light. The images are rescaled to represent the same physical size. Green areas mark places where no information is available. Reprinted with permission from [15]. Copyright 2018 Astrophysical Journal.



continuum and numerous molecular emission lines (see Figs. 2, 3). Micron-sized grains are best observed at visual and near-infrared wavelengths via scattered stellar light. Solid-state ice and silicate emission bands, and vibrational transitions of gaseous molecules are observed at near- and mid-infrared wavelengths (from ground and space). Bigger mm-sized grains and molecular rotational transitions are observed at (sub-)millimeter wavelengths with radio interferometers such as *ALMA*, *NOEMA* and *eVLA*.

Surprisingly, a majority of disks observed at a high spatial resolution in dust continuum emission reveals a multitude of substructures like dark gaps, bright rings, spiral arms, *etc.*, which are indicative of planet formation (Fig. 2,3). These circularly-symmetric gaps and rings are likely caused by embedded planets, while spirals could be induced by external perturbers. Ongoing large chemical surveys with *ALMA* and *NOEMA* will allow us to characterise the gas content in protoplanetary disks and to better understand what molecules are being delivered onto the atmospheres of young, forming planets. Recently, the first direct discovery of young, massive Jupiter-like planets in a few Myr old protoplanetary disk PDS 70 has been reported [16, 17]. ■

### About the Authors



**Dmitry Semenov** is a staff scientist at the Max Planck Institute for Astronomy in Heidelberg. He is interested in high-resolution observations and numerical modeling of various physical and chemical processes in planet-forming disks, star-forming regions, molecular clouds.



**Richard Teague** is a Sub-Millimeter Array Fellow at the Center For Astrophysics | Harvard & Smithsonian. He studies the gas content of protoplanetary disks, searching for signatures of hidden, still-forming planets.

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The European Synchrotron Radiation Facility (ESRF) is a world-leading international scientific research institute. Since the 1990's it operates a storage ring as a dedicated source of synchrotron radiation in the hard X-ray region and experimental beamlines which use the most advanced technology in X-ray optics, detector design and information technology, to push experimental measurements to their practical limits. The ESRF welcomes close to 6000 scientists every year for experiments in fundamental and applied research, in fields such as biology, chemistry, earth and environmental sciences, cultural heritage, materials and surface science, and physics. The cutting-edge research carried out at ESRF results in about 1800 peer-reviewed scientific publications every year. ESRF is currently involved in 15 Horizon 2020 competitive grants.



## **DIRECTOR OF THE ESRF ACCELERATOR AND SOURCE DIVISION (ASD)**

### **5-YEAR APPOINTMENT**

The ESRF is a joint undertaking by twenty-two countries with the common interest to strengthen European research and to improve scientific cooperation across disciplinary and national boundaries. It is established as a "Société Civile" under French law.

The ESRF supports the use of its experimental facilities by the scientific communities of its partner countries within the budget decided yearly by the Council. The ESRF has an annual budget of 100 M€ and employs close to 700 international staff.

Since 2009, the ESRF is undergoing a major Upgrade Programme, which is foreseen to be completed in 2022. The second phase of this programme, which started in 2015, the so-called ESRF-Extremely Brilliant Source programme (ESRF-EBS), is centred on the construction of a revolutionary low-emittance light source that will increase the brilliance and coherence of the X-ray beams produced by a factor of 100: <https://www.esrf.eu/about/upgrade>. The facility has currently interrupted its operation until September 2020 in order to proceed with the commissioning of the new storage ring and the adaptation and upgrade of beamlines.

In terms of absolute performance, the new EBS storage ring of the ESRF will be in the coming years the most brilliant high-energy synchrotron radiation source worldwide. Such outstanding equipment is currently undergoing its commissioning phase and is expected to enter into the user-dedicated operation phase by late 2020.

### **THE FUNCTION:**

The ESRF Accelerator and Source Division (ASD) manages the ESRF accelerators complex (comprising the EBS radiation source), and the main objective of the Division in the coming years is to achieve, maintain and further improve the design goal parameters of the new EBS source, and to attain operation availability levels comparable to those attained with the previous storage ring. The ASD Director will have to lead and manage the programme of the ASD to ensure the successful accomplishment of the objective outlined above. He/she manages a dedicated budget to ensure the deployment of a strong preventive maintenance programme and is responsible for the implementation of a strategy for future developments, including new radiation sources, and the perpetuation of ESRF know-how, in relation both with the operation and the development of the radiation source.

The ASD Director reports directly to the Director General of the ESRF, in the same way as the Directors of Research and Administration. He/she directs the ASD, with responsibility for its annual budget. There are about 70 staff members in the Division, but the Director can also call on the technical assistance of both the Instrumentation Services & Development Division and the Technical Infrastructure Division.

### **QUALIFICATIONS AND EXPERIENCE:**

The successful candidate shall be an experienced accelerator scientist with proven knowledge in the management of large-scale accelerator complexes. Expertise in the operation and development of third-generation synchrotron light sources is an important asset. He/she should have proven leadership and managerial and project management skills, including the handling of finances and personnel.

### **APPLICATIONS:**

In order to apply to the position of Director of the Accelerator and Source Division at the ESRF, interested candidates are invited to address by e-mail their CV and motivation letter to the Chair of the Search Committee, Prof. Miguel Ángel García Aranda: [g\\_aranda@uma.es](mailto:g_aranda@uma.es)

**Deadline for returning applications: 08/03/2020**



# INTERACTIONS MATERIALS – MICROORGANISMS

## Concretes and Metals more Resistant to Biodeterioration

Under the direction of

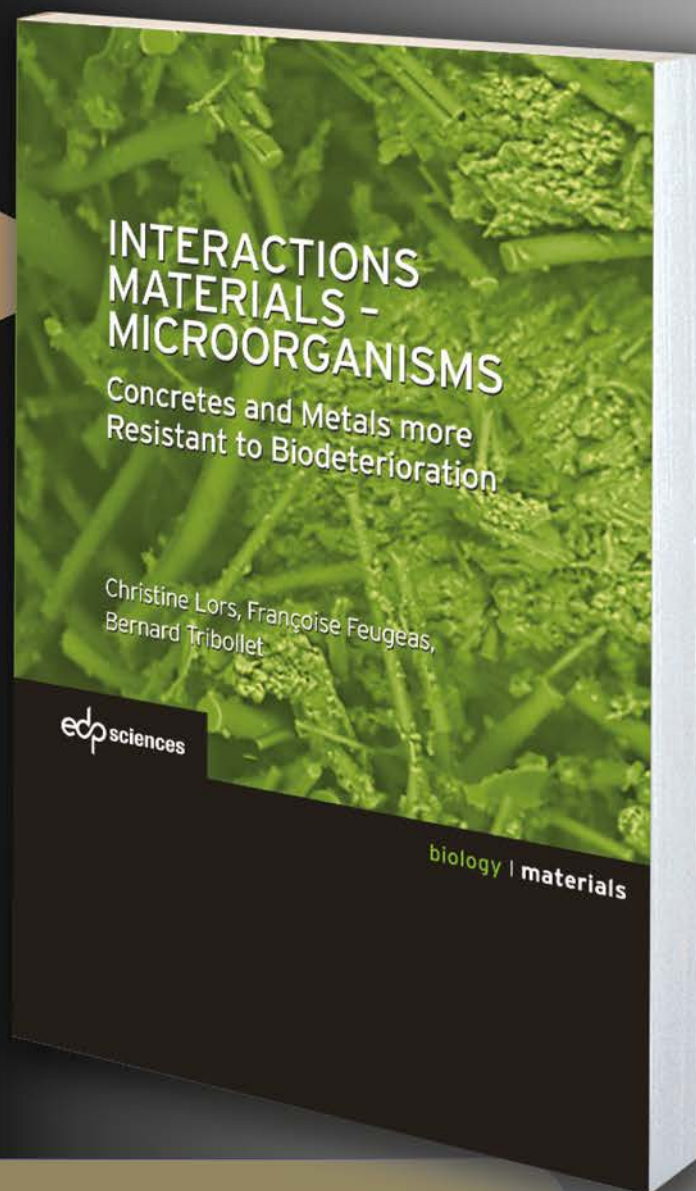
Christine LORS, Françoise FEUGEAS and Bernard TRIBOLLET

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