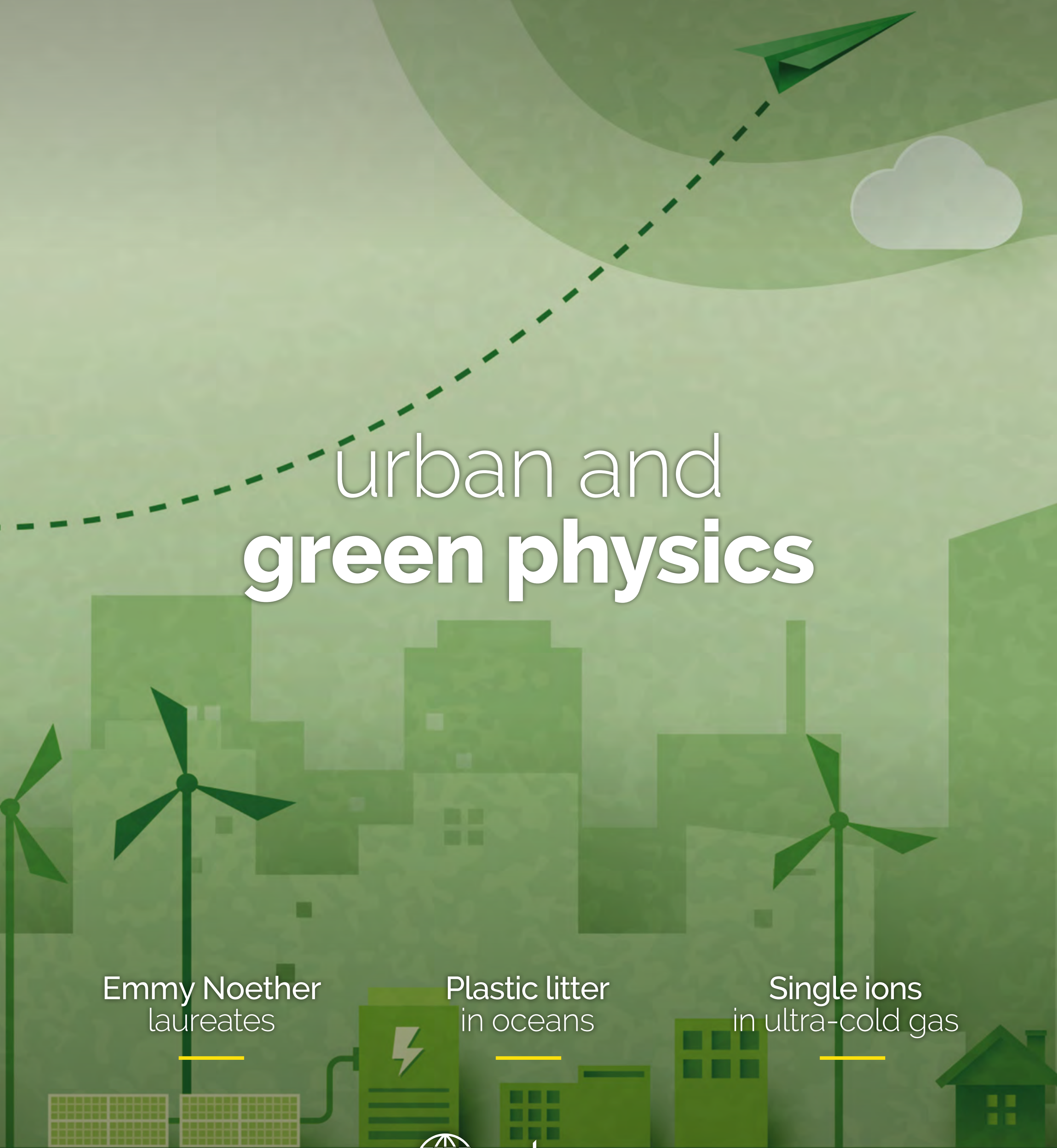
EUROPHYSICSNEWS

The magazine of the European Physical Society



urban and green physics

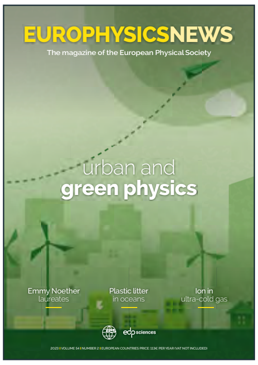
Emmy Noether laureates

Plastic litter in oceans

Single ions in ultra-cold gas

EPS edp sciences

2023 I VOLUME 54 I NUMBER 2 I EUROPEAN COUNTRIES PRICE: 113€ PER YEAR (VAT NOT INCLUDED)



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Cover picture: Urban and green physics. ©iStockPhoto

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Heating and cooling European buildings with lake

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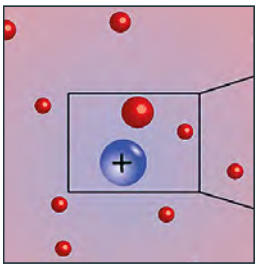
Plastic litter in the oceans



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A single ion immersed in an ultracold gas

[EPS EDITORIAL]

Second EPS Forum: Welcome to Berlin in 2024!

The European Physical Society (EPS) has set up a new event called the EPS Forum. The objective of the Forum is to bring all the constitutive bodies of the EPS (Member Societies, Divisions and Groups, Associate Members) to work together on the organisation of a general meeting distributed over the two days preceding the day of the EPS Council.

Therefore, between the 2nd and 4th of June 2022, the EPS held its first Forum at the International Conference Center of Sorbonne University in Paris, France. The EPS Forum offered a series of conferences, round tables and workshops on several topics in physics, from sustainable energies to biophysics. The first day of the Forum fostered direct exchanges between young physicists and stakeholders of physics-based industrial companies. The second day hosted a scientific colloquium highlighting the latest achievements in selected topics. The EPS Executive Committee then commissioned a survey of participants. Nearly 60% of the respondents agreed that the Forum's objectives were met and a majority of them requested to have a regular event every two years. Taking their responses into account, the Executive Committee decided in September 2022 to create a committee in charge of fixing the budget and possible conference venues for the next edition of the Forum. My wish was to implement this second edition in the German capital - Berlin - after Paris, following the historical axis of the construction of Europe. After exploring several options, the most suitable venue was Freie Universität Berlin. It was moreover concluded that locating the Forum in March 2024, between the DPG meeting and the teaching German period, could be the best choice. In January 2023 the Executive Committee unanimously decided that the second edition of the Forum would take place at the Henry Ford Building of Freie Universität Berlin (FUB) between the 25th and 27th March 2024.

The physics department at FUB strongly supports the organisation of the EPS Forum. A local organising committee, made up of Christiane Koch and Kirill Bolotin – Thanks to both of them – already participates actively in the monthly preparatory meetings of this event. At the same time, all EPS bodies have again been contacted to delegate representatives to work on the Forum programme together with the EPS secretariat and Forum Committee members. To date, the organisation and programme committees of the second EPS Forum are made up of 35 volunteers delegated by 5 Member Societies, 6 Divisions or Groups and 1 representative of the Associate Members. The Young Minds Action Committee, which will hold its Leadership Meeting in Berlin in 2024 simultaneously with the Forum, has also joined us. In addition, we welcome the President of the International Association of Physics Students who will strengthen the representation of the young generation of physicists.

As in 2022, the second Forum in Berlin is expected to gather about 500 participants including a majority of PhD students, postdocs and early-career researchers who will be introduced to exciting research opportunities in large companies and start-ups involved in the following fields of science and technology:

- Atom molecular and optical physics for quantum technologies
- Applications of nuclear and particle physics to society
- Condensed matter and applications to industry
- Energy and brain-related applications
- Photonics.

The first day of this event - "physics meets industry" - will bring doctoral students and post-doctoral fellows closer to physics-based companies and the industry sector. The second day will consist of a general conference addressing the above fields from a more fundamental point of view and featuring high-profile scientists. Outstanding physicists, including Nobel and Wolf Prize laureates, already agreed to participate. For this occasion, the EPS will support the travel and lodging expenses of 100 students.

I look forward to meeting you at the second EPS FORUM in Berlin. ■

Luc Bergé,
EPS President

EPS Young Minds

Young Minds promotes early career involvement in publishing at the European Physical Journal Meeting

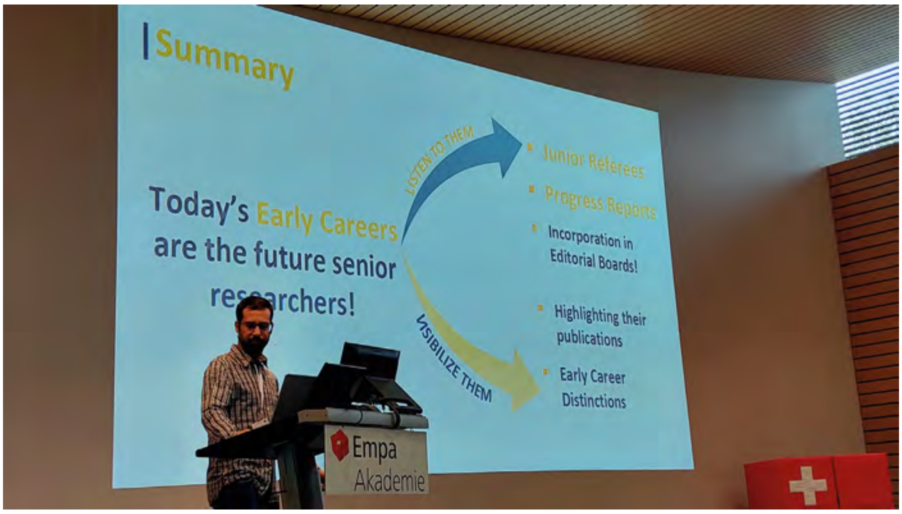
Carlos Damián Rodríguez Fernández, Tanausú Hernández Yanes and Mattia Ostinato

Listening and giving voice to early career researchers is one of the main goals of the Young Minds Programme. Recently, the Young Mind's Action Committee had the honour to be invited to participate in the 25th-anniversary meeting of the Scientific Advisory Committee of the European Physical Journal (EPJ) that was held in Zürich, Switzerland, on 20-21 April 2023.

This encounter gathered representatives of different national physical societies, EPJ editors, and EPJ publishers (Springer, EDP Sciences and Società Italiana di Fisica) and we took the chance to talk about the view of early careers of scientific publishing.

A survey was specially designed to collect the feelings of the Young Minds members on this topic. In particular, the Young Minds members were asked about the strongest and weakest points of how science is published today and also what kind of novel practices they would like to see in a future editorial landscape. The answers received came from more than 10 different European countries and they belonged mainly to PhD students who already had experience in publishing.

The survey results were highly interesting and revealed widely held opinions of European early career researchers on different issues. For instance, the criteria behind the choice of where and why they publish the results of their research: early career researchers use the impact factor as the principal metric for choosing their journal, while their motivation for publishing is two-fold, they are looking to contribute to the collective effort of science but also they want to push their careers via publishing relevant results. Furthermore, the most appreciated features of scientific publishing



▲ Carlos Damián Rodríguez Fernández presenting the results and conclusions from the survey taken by Young Minds members about scientific publishing at the EPJ Meeting in Zürich, Switzerland.

are the recent emergence of open-access journals, public scientific repositories and the constructive way in which peer review works.

However, early careers also expressed some criticism regarding some aspects of how science is published. For instance, journal fees are deemed excessive and the mechanism by which authors effectively pay twice, for publishing and accessing their own articles, is considered abusive. Another recurrent point is the misuse of bibliometrics in evaluating scientific work, which reduces careers to an h-index, forcing authors to "publish or perish". A final negative aspect is the low probability of publishing "negative" results, meaning those that differ from the expectations or end up only excluding a possible protocol in the chase for a given outcome. Although these findings are not outstanding, they could be helpful for other scientists to address their research.

Participants proposed several possible actions to improve the integration of early career researchers within the publishing world. For example, actively involving early career researchers in the reviewing processes and, along the same line, awarding revision tasks with grants, training or distinctions. Many people also felt that incorporating early career researchers in decision-making bodies like editorial boards could be beneficial in the long run. Concerning the aforementioned "negative" results, a proposed idea was to start a progress report journal or repository in which to publish them.

The Young Minds Programme laid on the table all these points at the EPJ SAC meeting, proposing two strategic action lines. The first proposal was creating a junior referee program, consisting in actively involving early career researchers to act as reviewers and recognise their dedication through an award program. Specific reward proposals include offering training, distinctions or grants. The second proposal was the creation of a European progress report journal where to publish technical documents, protocols and reports of progress that could interest other researchers and enrich scientific knowledge despite the immediate impact of the results.

The ideas proposed by Young Minds were carefully listened to. It motivated a long discussion about the relevance of including early careers in reviewing processes and the suitability of publishing progress reports in the Q&A round. The next day, there were several parallel working sessions to identify relevant actions to improve the journals. Each working group synthesised their main conclusions in a common session. The impact of the Young Minds intervention was clear since the idea of initiating a program for early career reviewers popped up several times. In fact, we could say that it was considered one of the most relevant action lines emerging from the 25th EPJ SAC annual meeting.

From the Young Minds Action Committee, we expect this contribution to have long-lasting and very positive effects on the future of EPJ, both for early career and senior scientists. The feedback received proves the beneficial effects of involving early career researchers in the crucial processes of the scientific world, which is the aim of the Young Minds Programme. ■

The EPS Emmy Noether Distinction 2022

The EPS Emmy Noether Distinction 2022 was awarded to Monika Ritsch-Marte and to Ilaria Zardo. Congratulations!

2022 EPS Emmy Noether Distinction – Full Career

Monika Ritsch-Marte is researcher at the Institute of Biomedical Physics, Dept. of Physiology & Medical Physics, Medical University of Innsbruck Austria. She is distinguished *"for exceptional contributions to optical microscopy and manipulation methods and for the promotion of women's careers in physics."*

Monika Ritsch-Marte, the founder of the Biomedical Optics group (Medical University Innsbruck) has contributed exceptionally to the development and application of microscopic methods and optical tweezers.

As one of the world's leading authorities on the control and use of structured beams for optical imaging, she has pioneered the use of holographic techniques. She has also contributed to the development of optical tweezers, in particular their application to the imaging and manipulation of living matter.

Her research group has pioneered the use of spatial light modulators in the form of liquid-crystal displays in optical microscopy. Spatial light modulators allow rapid switching between different microscopy modalities (bright field, dark field, phase contrast) without the need to change any hardware components. She has pioneered and developed the use of spiral phase contrast [1] using controllable vector beams [2], and, in particular, edge contrast enhancement based on holographic Fourier plane filtering of the microscopic image.

Together with her group, she also actively works in the field of non-linear microscopy and has developed a non-scanning (wide field) variant of the chemically selective coherent anti-Stokes Raman scattering (CARS) technique.

She currently develops methods of optical manipulation of ever-larger particles, among which the optical "macro-tweezers" system, a large volume dual-beam mirror trap, suitable to trap and guide swimming micro-organisms without inducing any optical damage.

2022 EPS Emmy Noether Distinction – Mid-career

Ilaria Zardo works at the Department of Physics, University of Basel, Switzerland. She is distinguished *"for her contributions in the methodology of characterizing nanoscale materials and the consequent discovery of their new functional properties."*

Ilaria Zardo's work provided key new insights in semiconductor nanostructures. In particular, she has made very substantial contributions to the understanding of polytypism, the possibility of a same material adopting different crystalline structures. This can arise as a result of different growth conditions or methods, or of the material's reduced physical dimensions: a material structure unstable in bulk form may be stable upon synthesis as a thin film, a nanorod or nanowire, or a nanoparticle. Thus, Ilaria Zardo was among the first to grow silicon in a hexagonal structure [3], and was the first to demonstrate, through the design of a novel and unique experimental set-up, that polytypism enables fundamentally new functional properties. For example, Gallium Phosphide GaP transforms into a direct bandgap semiconductor when crystallised in the wurtzite phase.

Key to her scientific success is her innovative use of Raman spectroscopy of nanowire systems, and the combination of theory and experiment to do so. She was the first to derive the optical selection rules for a range of III-V compounds such as GaAs, InAs and AlAs.

She also predicted and experimentally confirmed which additional modes should be detected when the wurtzite phase appears instead of the common zinc blende. Ilaria Zardo introduced her insights into the field of thermal transport, demonstrating the ability to engineer phonons (*i.e.* crystal lattice vibration modes) in polytype nanowires, leading to the field of nanophononics, and enabling novel applications in thermal management, electronic devices (phonon circuits), and quantum computing.

More info:

- EPS Emmy Noether Distinction
- Monika Ritsch-Marte Research Group
- Ilaria Zardo Research Group and announce on the website nanoscience.unibas.ch

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[2] https://scholar.google.at/citations?view_op=view_citation&hl=en&user=attixk4AAAAJ&citation_for_view=attixk4AAAAJ:GpOSJs1ZbLkC

[3] https://pubs.acs.org/doi/10.1021/acs.nanolett.5b01939

Investigating gender equality in urban cycling

New research looks at why cycling has a low uptake among women in urban areas.

Over recent years not only has cycling proved itself to be an outdoor activity with tremendous health benefits, but it has also presented itself as a useful tool in the quest to find an environmentally friendly method of urban transportation.

Despite the increasing popularity of cycling, many countries still have a negligible uptake in the pursuit and this is even more pronounced when considering how many women engage in cycling. To this day, a mostly unexplained gender gap exists in cycling.

A new paper in *EPJ Data Science* by the University of Turin Department of Computer Science researcher Alice Battiston and her co-authors attempts to understand the determinants behind the gender gap in cycling on a large scale.

"We studied the strength of association between cycling uptake by women compared to men and several characteristics of western cities, both at a macro and microscopic level," Battiston said. "At a macroscopic level, we showed that the cycling uptake of women is typically larger in flatter cities with a safer urban environment, such as cities with large low-speed limit zones and fewer 'blind'-intersections or three-way crossings."

Battiston and the team found the macroscopic result had a direct counterpart on a smaller scale. She explained that delving deeper into street-level features, the data showed that New York City streets with protected cycling infrastructure are up to four times more likely to have a large influx of women than streets with no cycleway.

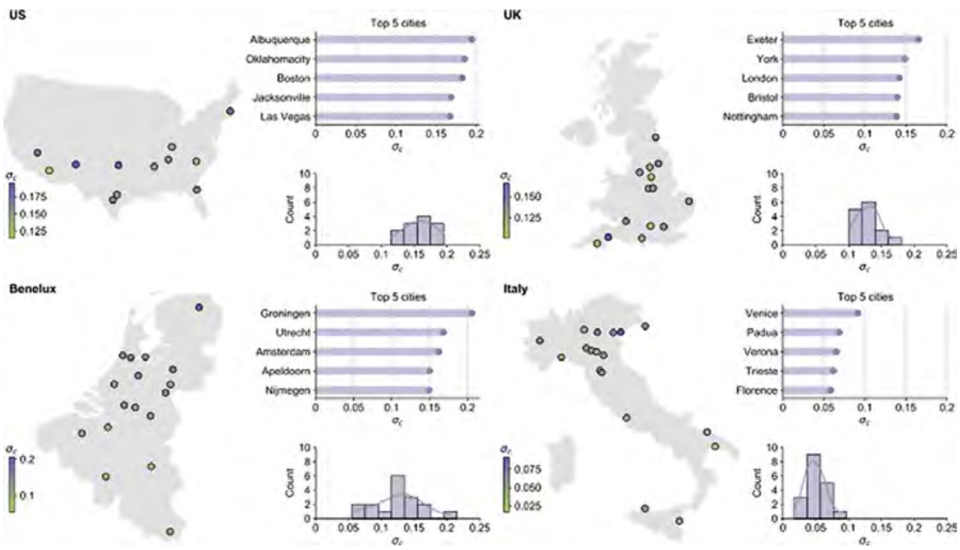
"This result is not limited to the city of New York but can be generalised to the vast majority of the cities in our sample," she continued.

To reach their conclusions, the researchers used data from over 60 cities in the West from the US to Europe from several sources. Information on cycling behaviour for the study was extracted from the heatmaps of activity provided by the sport-tracking application Strava, which as of 2018 had around 36 million users.

"The most surprising thing I found during my research was not really coming from the research activity itself, but from the reaction of people around me when I would talk about the study," Battiston said. "I received the entire spectrum of reactions. Most people would agree on the importance of improving the quality of the cycling-dedicated infrastructure to ensure even the most vulnerable or risk-averse demographic group could start cycling."

She added that a few people were scared by the impact that changes to the urban environment would have on their daily life.

"While purely anecdotal, it reminded me once more that human beings are reluctant to change, and therefore co-creation processes actively engaging local communities are crucial to ensure urban interventions are really effective," Battiston concluded. "Future studies in experimental settings could shed light on causal relationships and the impact of specific urban interventions."

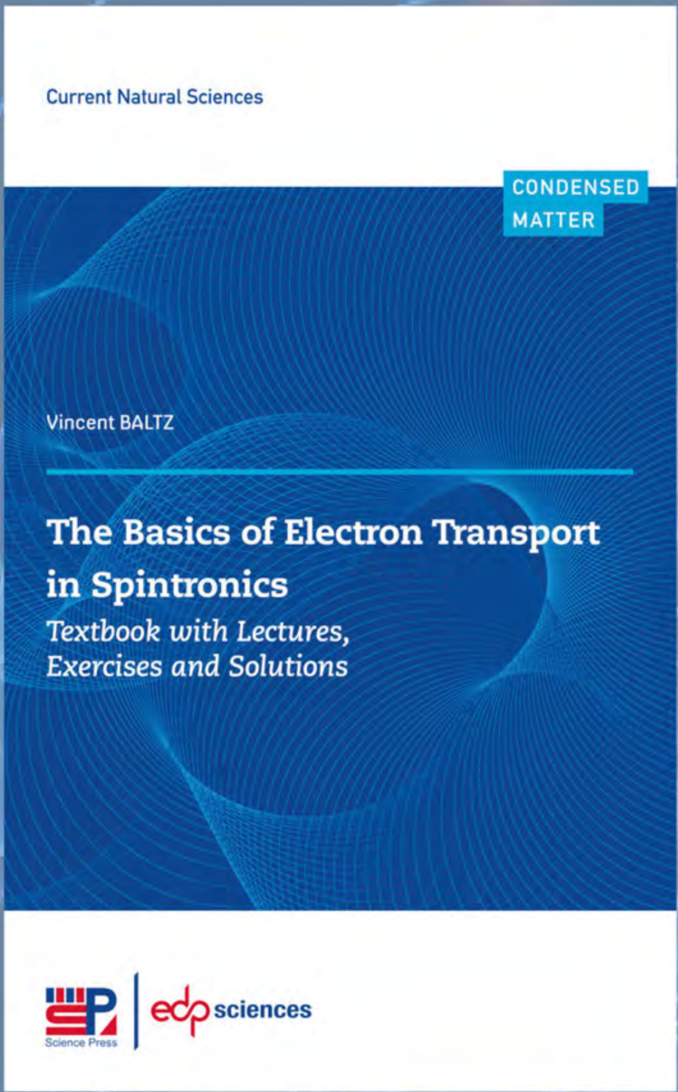


▲ An overview of the gender gap in recreational cycling across cities included in the study according to Strava. Credit: A. Battison *et al.*, (2023)

Reference

[1] A. Battiston, L. Napoli, P. Bajardi *et al.*, Revealing the determinants of gender inequality in urban cycling with large-scale data, *EPJ Data Sci.* 12, 9 (2023). https://doi.org/10.1140/epjds/s13688-023-00385-7

The Basics of Electron Transport in Spintronics



BY
Vincent BALTZ

ISBN : 978-2-7598-2917-0
168 illustrated pages
Price : 95 €

Here is the ideal book to grasp the basic concepts of spin-dependent electron transport and to develop a deep physical understanding of the subject. A careful selection of key notions provides a concise and effective framework. Learning how to use these notions is successfully supported by ten extended exercises with complete solutions. Common terms and specialist jargon are clearly explained, and the way in which subtleties complicate phenomena, without altering their physical basis, is pedagogically addressed.

Vincent BALTZ, PhD, HDR, is a CNRS researcher and group leader at SPINTEC (CNRS/CEA/UGA/GINP), one of the largest laboratories dedicated to spintronics. He has been conducting research in magnetism and spintronics for over 20 years, is familiar with master's, doctoral and post-doctoral supervision, teaches at the BSc and MSc levels and is a regular author of scientific publications.

Inclusion of women

Inclusion of women in science and society has many different faces. We selected three examples covering inclusion in physics in the Netherlands, a IUPAP statement in support of female students in Afghanistan and an article introducing inequality in the urban environment. If you want to know how EPS supports inclusion of women in physics read about the 'Emmy Noether Distinction' in the EPS NEWS section.

AMOLF wins the NNV Diversity Prize 2022

The AMOLF research institute in Amsterdam has been awarded with the NNV Diversity Prize. The bi-annual prize is awarded by the Netherlands' Physical Society (NNV) to the physics institution in the Netherlands that demonstrates the most successful implementation of equality, diversity and inclusion. To select the winner of the prize in 2022, the jury visited three self-nominated research institutions. At each institute, in three separate sessions with students, with staff and with the management, the jury assessed the status of implementation of diversity and inclusion. The awarding ceremony took place in April 2023 at the traditional meeting of the national physics leadership at the evening preceding the national NWO Physics conference, that spans all physics aspects and is the biggest physics conference in the Netherlands.
The mission of the AMOLF institute is to initiate and perform leading fundamental research on the physics of complex forms of matter and to create new functional materials, in partnership with academia and industry. It was nominated for the Diversity Prize for the second time. The jury noted that significant progress was made since the last nomination in 2020, including the implementation of measures described in the 'Gender Equality Plan 2018-2022'. The institute's 'Diversity and Inclusion Plan 2022-2026' has a broader definition of diversity. Explicit numerical targets are provided for enhancing the fraction of women at all levels in the institute. Other KPIs include (compulsory) training of all newly hired employees and the organisation of diversity awareness events. The jury was particularly impressed by the genuine enthusiasm of young staff and students at AMOLF for the inclusive working environment. The jury appreciated the enthusiasm and determination of the management to make AMOLF a diverse and inclusive research institute.
Noortje de Graaf, director of NNV states: "The NNV is committed to increasing diversity in the Dutch physics community. By awarding a prize to an institution that achieves good results, we approach the topic in a positive way. The prize is highly appreciated by the institutes, the winners are very proud of it and they advertise it a lot. In this way it is ensured that the topics of inclusion and diversity are positively put in the spotlight. The winning institute receives a plaque that they attach to the building on a prominent spot, which ensures permanent attention."
https://www.nnv.nl/NNV-Diversiteitsprijs/, https://www.nwophysics.nl/, https://amolf.nl ■

IUPAP statement on ban on women from higher education in Afghanistan

In February 2023, the executive council of the International Union of Pure and Applied Physics (IUPAP) issued a statement on the ban of women from higher education in Afghanistan.

"The decree by the Afghanistan authorities in December 2022 suspending higher education for women in Afghanistan is deeply concerning and is yet another erosion of the rights of women in Afghanistan. This is in stark contrast to the aims of the current International Year of Basic Sciences for Sustainable Development, where across the world scientists are striving to ensure that science is available (to) and of benefit to everyone. This equally applies to education. IUPAP condemns the suspension of Afghan women rights to education and stands in strong support of the International Science Council statement urging a reversal of the ban. Throughout its 100 year history, IUPAP has spoken out not only against injustices and human rights violations of physicists and scientists, but has consistently sought to support the oppressed communities across the world. IUPAP continues to embrace and promote scientific collaboration across the world as a driver for peace."

https://iupap.org/wp-content/uploads/2023/02/Statement-on-ban-on-women-from-higher-education-in-Afghanistan.pdf

https://iupap.org/2023/02/07/statement-on-ban-on-women-from-higher-education-in-afghanistan/ ■

Women and the city

Searching the web for news about women and urban sciences, we found this interesting news item at the news section of the CNRS website.

'Is the city a neutral place? The answer, according to geographers, is a resounding "no". Conceived by men, the city is a male space that disadvantages women every day. From urban design to public facilities, not to mention sexual harassment, the streets are paved with gender inequalities.'

Although not a physics issue, the article nicely introduces inequality in the urban environment.

https://news.cnrs.fr/articles/women-and-the-city ■

New research facilities

For a summer feeling we present two examples of new research facilities being installed. An underwater lab in the Mediterranean Sea near the coast of Toulon, France and a new radio-telescope in Namibia.

A multi-functional laboratory at the bottom of the Mediterranean Sea

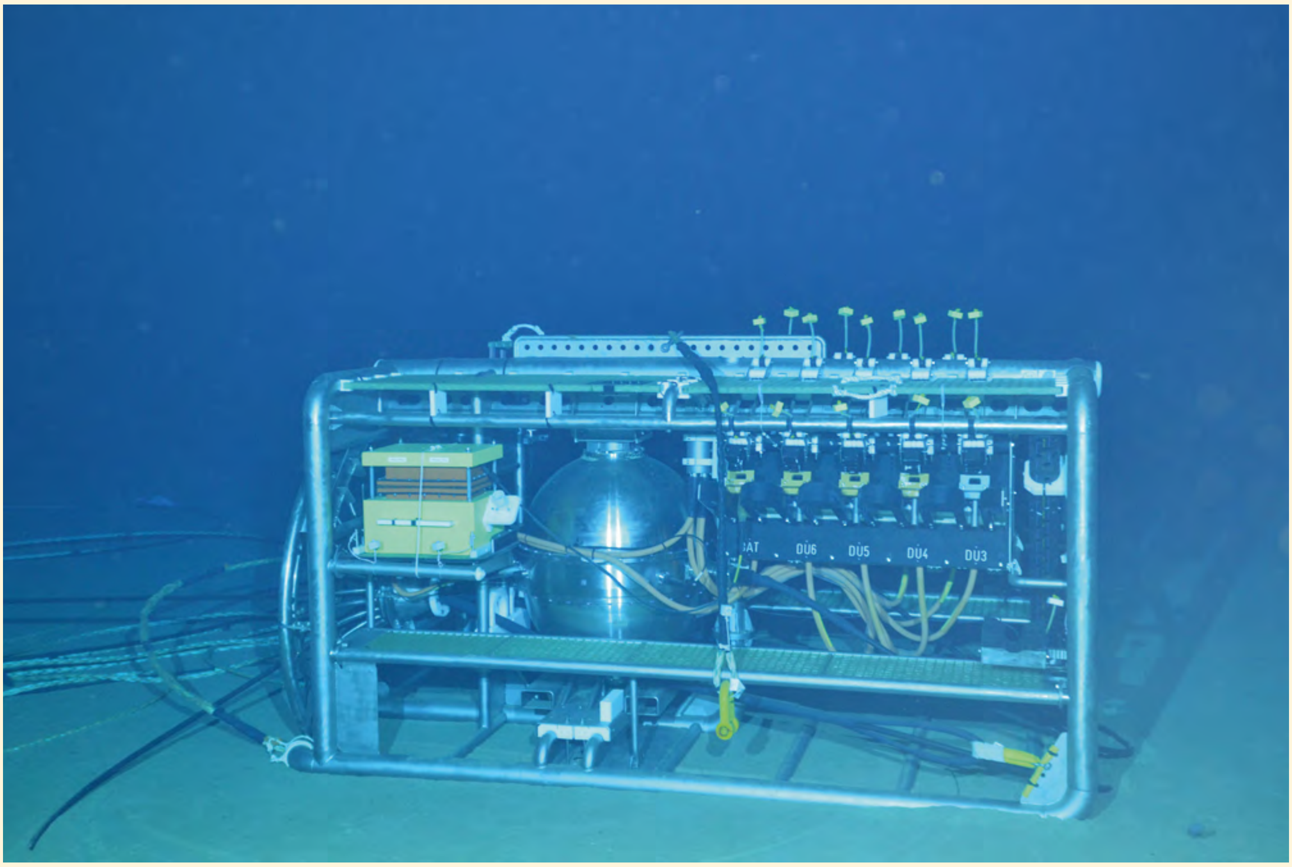
About 40 kilometres off the coast of Toulon, France, an underwater research lab is being built. The Laboratoire Sous-marin Provence Mèditerraneé (LSPM) is located at a depth of about 2500 metres and will be remotely operated 24/7. Several instruments will be connected to sub-sea junction boxes for electrical power and for data transmission (figure 1). The junction boxes are connected to the control station on shore in La Seyne-sur-Mer.

Currently, two junction boxes are dedicated to the ORCA detector of the KM3NeT neutrino telescope. With ORCA it will be possible to study neutrino oscillations and to determine the neutrino mass hierarchy using cosmic rays. A third junction box is dedicated to Earth and Sea Science studies. A broadband seismograph is placed on the sea-bed and connected to the network of LSPM. In addition one of the optical fibres in the 40-kilometre cable to the control station is used for acoustic monitoring of seismic events. An array of hydrophones records the sound of whales and dolphins.

Recently, a robot called of BathyBot has been installed. The robot is equipped with sensors to measure various parameters of the local deep-sea water, such as temperature, oxygen and carbon dioxide concentrations, current speed and direction and salinity and particle concentration in the sea-water. The robot, which has an integrated camera, is controlled from the control station and can move over the sea-floor.

With the current collection of sensors connected to its junction boxes and more to come, LSPM is a truly interdisciplinary research infrastructure for the study of the abyss in the deep sea as well for the observation of neutrinos from distant sources in our Universe. ■

https://www.cnrs.fr/en/laboratory-bottom-mediterranean-probing-sea-and-sky



▲ Junction box at the sea floor at 2500 metre depth. Credit: KM3NeT Collaboration.

Africa Millimetre Telescope

▲ FIG. 1: Image of the black hole in the centre of Mercier 87 (www.eso.org/public/images/eso1907a/). Credit EHT Collaboration.

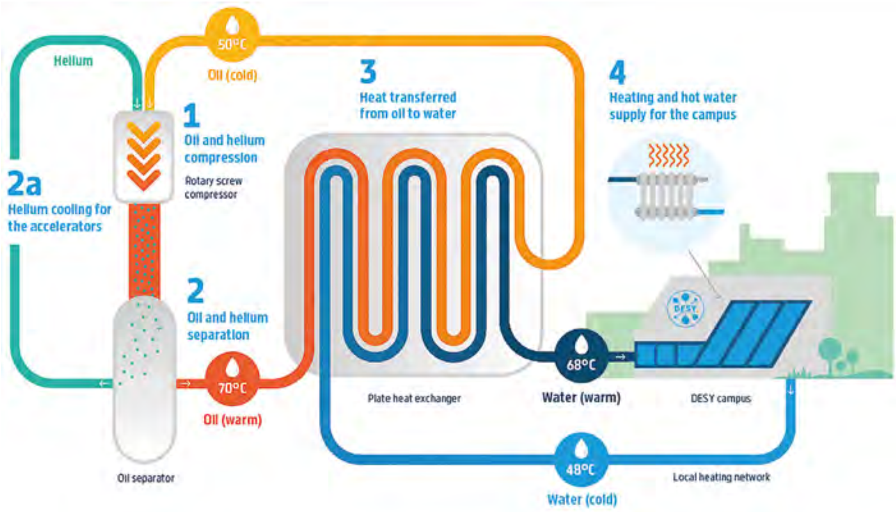
The Event Horizon Telescope (EHT) is a worldwide network of eight ground-based radio telescopes designed to capture images of black holes [1]. In April 2019, EHT published the first image of a black hole (figure 1). It concerned a supermassive black hole in the centre of Messier 87, a massive galaxy nearby the Virgo galaxy cluster. In May 2022, EHT published an image of the supermassive black hole at the centre of our own Milky way. Teams at the Radboud University Nijmegen and the University of Namibia aim at the extension of the EHT network with a telescope in Namibia, the Africa Millimetre Telescope (AMT) [2]. A decommissioned 15-meter single-dish radio telescope (figure 2), currently located in Chili, will be dismantled, upgraded and shipped to Namibia, where it will be installed at the Gamsberg. With the AMT included in the EHT network, it will be possible to study the dynamics around black holes and to monitor the black hole horizon and the plasma jets they eject. We will be presented with 'videos in colour' of black holes. ■

[1] https://eventhorizontelescope.org
[2] https://www.ru.nl/astrophysics/black-hole/africa-millimetre-telescope

▼ FIG. 2: The Swedish-ESO Submillimetre Telescope (SEST) located in Chili. The Telescope was decommissioned in 2003. © ESO/A. Ghizzi Panizza.

Fast particles heat laboratories and offices

DESY wants to make consistent use of waste heat from accelerators and computer centres.



▲ The waste heat recycling system at DESY: the accelerators and their support systems on campus can be used to warm the entire campus. So far a third of the campus is heated in this way.

DESY's particle accelerators are very energy-hungry. Not only acceleration, but above all deflection by large magnets consumes large amounts of electricity. And although the superconducting accelerators FLASH and European XFEL are highly efficient thanks to their technology, they have to be cooled down to two degrees above absolute zero – the helium liquefaction necessary for this also swallows up energy. All in all, DESY needs about as much electricity as a small district in Hamburg.

But in future, this energy, which currently has to be simply cooled away, at least in part, will be used to heat buildings. The Helmholtz Association recently pledged funding of around 8 million euros for the project, which consists of several large packages of measures. Implementation is scheduled to begin this summer.

"A large part of our consumed electricity is ultimately converted into heat. But we need the energy to be able to do our research. Soon we will completely recycle this surplus residual heat for heating buildings," Denise Völker, sustainability manager at DESY, explains the concept. For this purpose, cooling systems from accelerators and computer centres are to be connected to a kind of local heating network and supply the DESY heating systems. This is already happening with the waste heat from helium liquefaction, which is used to heat about a third of the Hamburg campus. The problem: While the cooling water from helium liquefaction is very warm at around 75 degrees and has been able to be fed into the heating system without any problems for quite some time, the temperature of the cooling water that comes directly from the accelerators is much lower – it is around 35 degrees.

"This allows the underfloor heating to operate well in well-insulated buildings," says Völker, "but in our old existing buildings with radiators we need higher flow temperatures." Therefore, for example, the cooling circuit of the PETRA III accelerator, which was previously cooled in hybrid dry coolers with air, is to be connected to a huge heat pump that raises the heat from the cooling water to higher temperatures. "This is done with electricity again, fortunately green electricity in our case, but afterwards we can then also use the accelerator waste heat across the board," explains Völker. And with great potential: DESY will be able to heat itself almost completely and would only have to resort to district heating in exceptional cases. The calculated savings are more than 500,000 euros per year. The investment of a good two million euros for the heat pump, building and all connections would therefore have paid for itself after about four years.

A longer-term part of the project is the direct use of low-temperature waste heat, which is possible in new buildings. For this purpose, a low-temperature heating network is being set up on the DESY campus in Bahrenfeld, which can supply the new buildings and the DESYUM visitor centre in particular. Surface heating systems are planned in these buildings, which will make it possible to use the waste heat without having to raise the temperature. "In the south of the campus, we are also planning a connection to a local heating network, which we could later use to supply Science City Hamburg Bahrenfeld, which is currently being planned," says Denise Völker. "So in the long term, not only research will benefit greatly from the operation of our accelerators, but also our neighbourhood."

At the DESY site in Zeuthen, the use of waste heat for heating and hot water supply is also planned - here, however, it will not come from accelerators, but from the computer centre. A good 800,000 euros will be invested in this project, which will be completed this year. The estimated annual savings are over 300,000 euros. This is not a drop in the ocean, says Denise Völker: "It would be ideal if we could set up sustainability projects in such a way that we put the money saved into new energy efficiency and renovation projects. Then the improvement of our environmental balance would pay for itself in the long run." ■

(Copy of the news item published 05-06-2023 on the DESY website)

Environmental sustainability in basic research

Early June, the HECAP+ initiative published an interesting report on how the community of basic research could improve on the environmental impact of their research activities [1].

This is the abstract of the report: "The climate crisis and the degradation of the world's ecosystems require humanity to take immediate action. The international scientific community has a responsibility to limit the negative environmental impacts of basic research.

The HECAP+ communities (High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics) make use of common and similar experimental infrastructure, such as accelerators and observatories, and rely similarly on the processing of big data. Our communities therefore face similar challenges to improving the sustainability of our research. This document aims to reflect on the environmental impacts of our work practices and research infrastructure, to highlight best practice, to make recommendations for positive changes, and to identify the opportunities and challenges that such changes present for wider aspects of social responsibility."

In the statement of intent, the whole physics community is invited to comment: "This reflective document was developed as part of a grassroots initiative Striving towards Environmental Sustainability in High Energy Physics, Cosmology and Astroparticle Physics.

Its focus is not to stipulate the research that our communities should undertake, nor to debate its intrinsic value. Rather, it is intended to be a synthesis of current data, best practices, and research in climate science and sustainability, as applied to our fields to the best of our ability as physicists, and a reflection on the roles that our communities can play in limiting negative environmental impacts due to our research work and scientific culture.

The scope of the document is inspired by the holistic approach of annual environmental reports of major institutes, which include emissions directly related to research and collateral emissions, such as from personal commutes and institutional catering. Any imbalance in its content, in part, reflects imbalances in the availability of reliable data and resources relating to the environmental impact of aspects of our communities' activities. Redressing this imbalance will require input from across our communities, in particular to identify the technical challenges of limiting the environmental impacts of our current and future research infrastructure.

While this document is primarily framed from the perspectives of high energy physics, cosmology, astroparticle physics, and hadron and nuclear physics (HECAP+), much of its discussion applies to basic research more generally.

Its broad scope is intended to provide a first step toward greater coordination across the community in efforts to address environmental sustainability, and it is hoped that it may serve as a useful reference for our and other fields.

Comments on this document are welcome. Please get in touch with us via the online platform at: https://sustainable-hecap-plus.github.io/, where you will also find the latest version of the document. Individual endorsement of this document can be made at: https://indico.cern.ch/e/sustainable-hecap-plus. For institutional endorsements, please email us directly at sustainable-hecap-plus@proton.me." ■

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Licensing the Web

Thirty years ago, on 30 April 1993, CERN publicly released the World Wide Web, the tool at first proposed by Tim Berners-Lee in 1989 to facilitate the sharing of information among scientists and institutions working on CERN data. Walter Hoogland, CERN's Director of Research at the time and Helmut Weber, Director of Administration signed a document granting relinquishing all intellectual property rights to the code and granting permission for anyone to use, duplicate, modify and redistribute it. It reflected the core values of CERN of open collaboration for the benefit of society. The Web's release has allowed it to become an integral part of daily life for billions of people worldwide. Later, CERN released a subsequent version of the software under an open source license, which allowed anyone to use and modify the Web freely while still retaining the copyright. Today, CERN continues to promote openness and sharing through its Open Science Policy.

"Most people would agree that the public release was the best thing we could have done, and that it was the source of the success of the World Wide Web," says Walter Hoogland, "apart from, of course, the World Wide Web itself!"

https://home.cern/news/news/computing/30-years-free-and-open-web ■

HEATING AND COOLING
EUROPEAN BUILDINGS WITH LAKES?

Sven Eggimann[1], Jacopo Vivian[2] and Massimo Fiorentini[3] – DOI: https://doi.org/10.1051/epn/2023301

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Lake-source thermal district networks can save energy and emission for heating and cooling buildings. However, where and to what degree such systems could be an effective solution is unclear. We simulated that covering 17% of the cooling demand and 7% of the combined heating and cooling demand near European lakes is economically feasible and does not cause severe lake water temperature alterations in most cases.

Climate change is increasing the global demand for cooling, and novel approaches must be pursued to sustainably satisfy this need. Lakes are one underexplored source to assist in the efficient supply of both heating and cooling. In Europe, lakes commonly have a deep-water temperature that is considerably lower than the ambient air in summer, while being slightly higher during winter. The temperature difference between ambient air and the deep lake layer (hypolimnion) can be used to provide free (direct) cooling in summer, as well as to increase the efficiency of heat pumps when heating is required.

Lake-source district systems

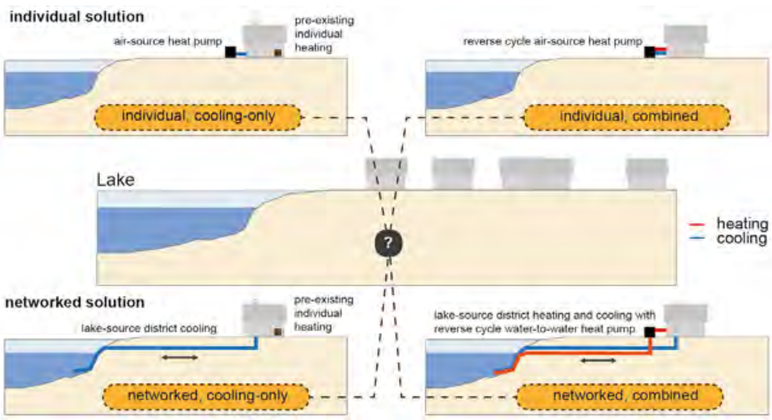
A district near a lake could be served by an energy system that can be configured in four ways: buildings can be individually cooled by an air-source chiller or heated and cooled by a reverse-cycle heat pump, in a decentralized way. Alternatively, networked solutions can exploit lake water either for cooling (cooling-only) or both heating and cooling (combined). These system configurations are shown in Figure 1. Lake-source heating or cooling is in principle applicable to any building type. However, more energy-efficient building constructions are more suited compared to less efficient buildings, as they require a lower heating supply temperature (we assumed 40°C) and their cooling-to-heating demand fraction is higher, making better use of the additional efficiency that lake-source systems can provide.

It is challenging to establish the exact conditions under which a lake-source centralized system (*i.e.* district network system) can outperform a decentralized system. Important variables that influence the economic viability of either system are the lifetime of the system, its capital and operational cost, and other exogenous variables, such as the electricity price, costs associated with CO_2 emissions, and interest rates. From an ecological point of view, implementing lake-source district systems affects the lake temperature. For this reason, the thermal response of the water bodies was modelled with and without heat injection and extraction from heating and cooling operations. Economic constraints, the availability of large lakes, and the availability and spatial distribution of building energy demand near lakes were also considered. Also, when deciding on the potential implementation, it is essential to relate operational savings to the required capital costs.

A techno-economic and ecologic modelling approach

We combined several methodological steps to identify, design and evaluate the techno-economic feasibility of thermal districts for each European country. In a recent study (Eggimann *et al.* 2023), geospatial analysis, graph-based network modelling, techno-economic accounting and thermal lake modelling were combined to estimate the efficiency of lake-source district systems and to evaluate the impact on lake water temperature. We combined lake data from the HydroLAKES database and OpenStreetMap to obtain geometric lake and building data. Climate data (weather files) were sourced from MeteoNorm. We used a validated lake model, Simstrat, to calibrate our simplified thermal lake model (for more detail on our methodological approach, we refer to Eggimann *et al.* 2023). Our approach allows us to carry out a realistic estimation of the potential of using lakes to heat and cool buildings at a larger geographical scale. The average daily building (thermal) energy demand was estimated using the spatial data combined with an energy signature calculation outlined in Eggimann *et al.* (2022) for Switzerland and extrapolated to other European countries using construction properties reported • • •

▲ **FIG. 1:** Four technological system configurations of how buildings situated close to a water body can be cooled and/or heated.



in TABULA (episcope.eu). Only lakes with a minimum size of 400 hectares (or 0.028 km^3 of water volume) and buildings within 1.5 km of lakeshores were considered (nearly 2'000 lakes). The energy demand for heating and cooling near the considered lakes is shown in Figure 2.

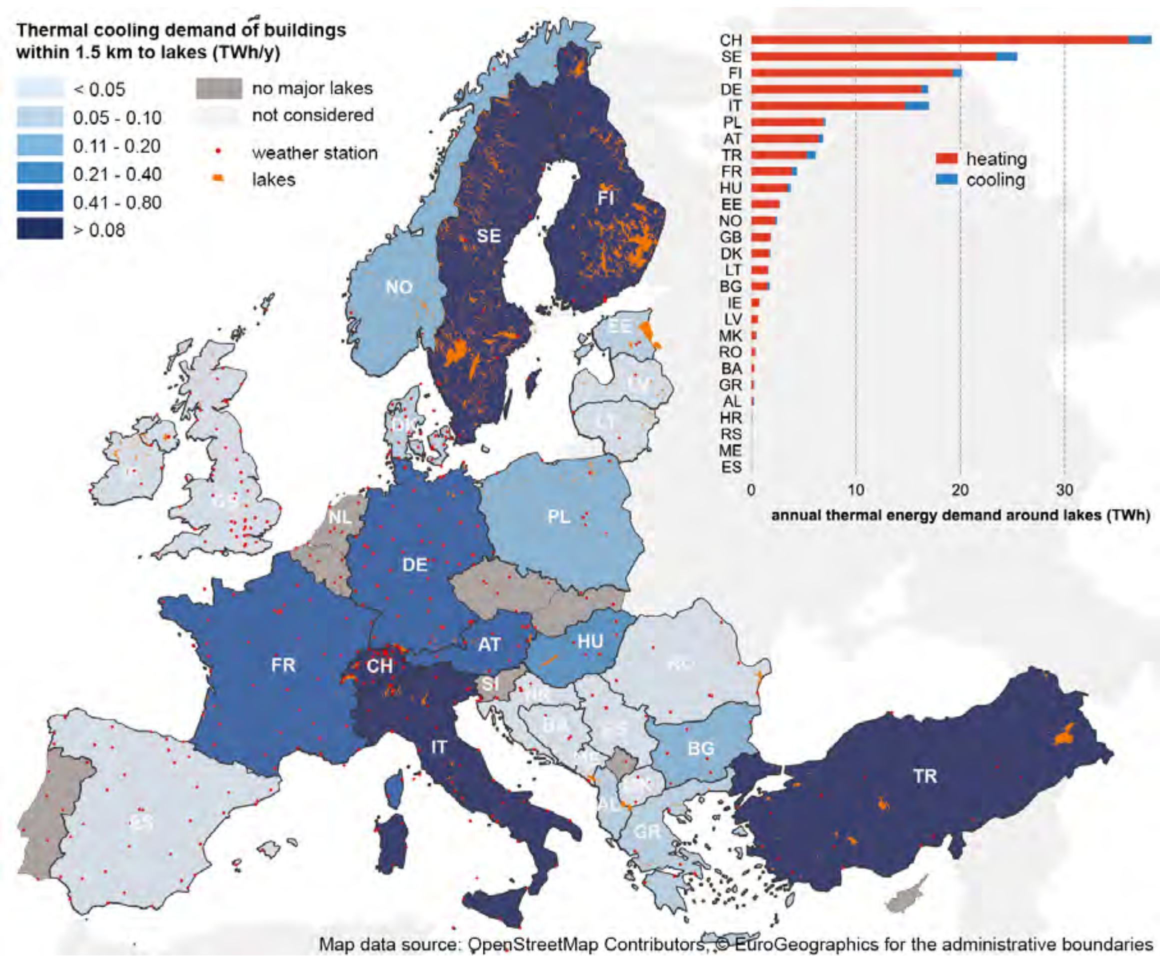
Country-specific potential of lake-source heating and cooling

For every European country, we simulated how much of the building demand can be covered by an economically viable lake-source system. Figure 3 shows results for the base scenario in Eggimann *et al.* (2023) assuming current climatic conditions. The total thermal energy demand of buildings around European lakes was estimated as ~11 TWh for cooling and ~150 TWh for heating. From these demands, the annual techno-economic potential was simulated to be 1.9 TWh for cooling-only systems, and 11.3 TWh for combined systems. The corresponding electricity savings were estimated to be 0.36 TWh in the cooling-only case and 0.78 TWh for the combined one.

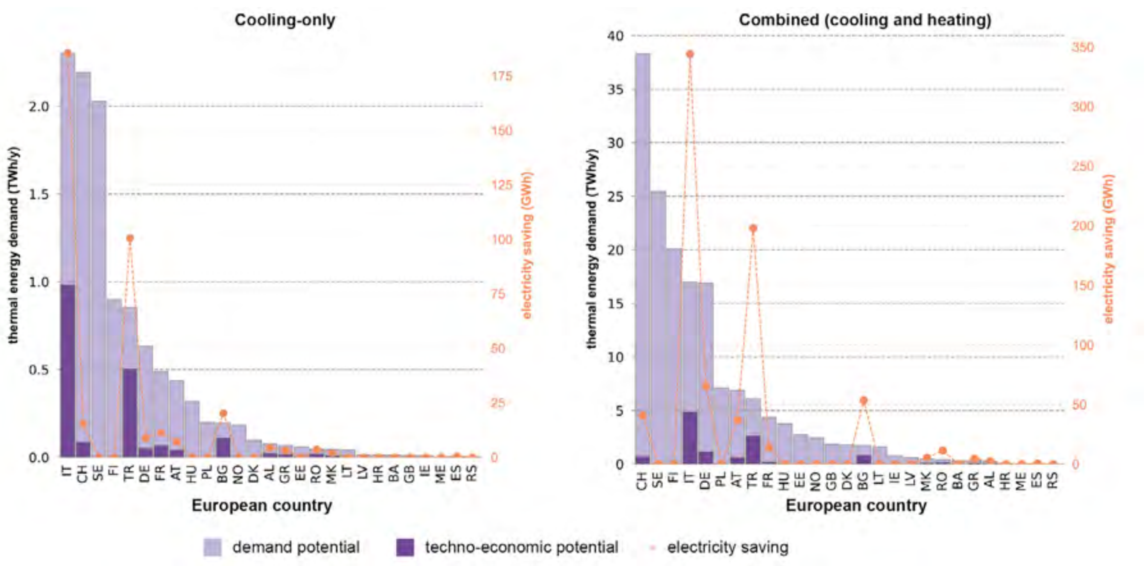
The distribution of our identified techno-economic potential is heterogeneous. When including technical and economic constraints in the analysis, lake-source systems show significant benefits only in a few countries, such as Italy, Turkey, Bulgaria, Switzerland, France and Germany. When the combined case is considered, a much larger heating and cooling demand potential was observed. Switzerland was found to have the highest energy demand to be potentially covered, with nearly 40 TWh per year, but due to techno-economic factors, only a relatively small portion of the demand can be feasibly covered by lake-source systems. Countries where electricity is expensive compared to capital costs are found to be more suitable for a profitable development of this infrastructure to exploit lakes (*e.g.* Italy, Germany and Turkey). Lake-source district systems were therefore found to be less viable in countries that, despite a large demand potential to be covered, had a lower relative electricity price (*e.g.* Switzerland). Another problem that might reduce the techno-economic potential of these systems is the availability of lakes that do not freeze over longer periods of time, such as in Sweden and Finland, which were deemed unsuitable in our study. Finally, our lake thermal model simulations showed that in most cases, the maximum temperature increase would be less than 0.5°C if all techno-economically feasible systems were implemented.

Lessons learnt

We have provided a first combined exploration of technological, ecological and economic dimensions to evaluate the potential of using lakes as a source for district heating and cooling systems at the European



▼ **FIG. 2:** Overview of the total annual thermal energy demand of buildings around European lakes. Original image source: Eggimann *et al.* (2023).



▾ **FIG. 3:** The simulated techno-economic potential for lake heating and cooling in Europe. The annual demand potential and the techno-economic potential are shown for using lakes for cooling-only (left) and combined heating and cooling (right). Values are shown for the base scenario from Eggimann et al. (2023) assuming a scenario with an interest rate of 4% and electricity prices twice as high as in the year 2021.

scale. Lake-source thermal networks are constrained foremost by the availability of lakes. However, also the spatial distribution of energy demand determines how much energy or emissions can be saved. The thermal energy demand of buildings near lakes considerably exceeds the techno-economically feasible potential. An estimated 17% of the cooling demand near European lakes can be covered by viable cooling-only lake-source systems. For combined systems, the viable demand is estimated at 7% of the total available combined heating and cooling demand. Annual electricity savings of 0.4 TWh (cooling-only) and 0.8 TWh (combined) is simulated for Europe. These electricity savings can be converted into CO_2 savings by assuming current CO_2 emission intensity of electricity, resulting in yearly CO_2 savings of 128 and 270 kt respectively.

The expansion of district thermal networks is a common strategy in many European countries to improve the efficiency of delivering heating and cooling to buildings. Based on our study, we find that integrating lakes can increase the attractiveness of such systems, particularly in Italy, Germany, Switzerland and Turkey. Even if the economic performance of these district systems is comparable to the one of individually heated and cooled buildings via heat pumps, the implementation of lake-source district heating would still lead to energy and CO_2 emissions savings due to the availability of free-cooling and a more efficient heat pump operation in winter. These savings add to the benefits of replacing current fossil fuel-based systems (*e.g.* oil or gas boilers) with heat pumps.

In our simulations, climate change was shown to increase the techno-economical potential of lake-source district systems of both types (combined and cooling-only). Future studies could consider additional interesting potential water bodies as viable energy sources, such as coastal waters, aquifers or rivers. The potential of using the sea for cooling and heating in countries with cities close to the seashore remains to be explored. However, last year's heat waves also revealed that heat injection in rivers is ecologically challenging and could lead to problems such as curtailment of power generation. ■

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NEAR ROOM-TEMPERATURE
THERMOMAGNETIC ENERGY HARVESTING

J. H. Belo[1], J. S. Amaral[2] and J. O. Ventura[1] – DOI: https://doi.org/10.1051/epn/2023302
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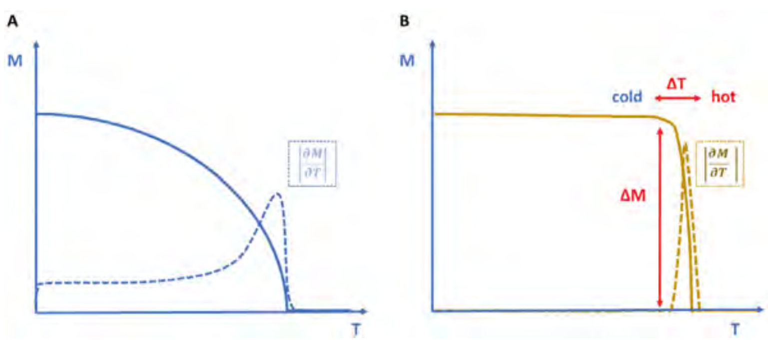
The rise of global energy demand and the effects of climate change make efficient energy generation one of the main global challenges. Thermomagnetic energy harvesting is a process that allows the genaration of electrical power in the presence of small temperature gradients near room temperature. Ongoing advances rely on improving materials and devices, in hopes of reaching widespread use of this technology, hence reducing our carbon footprint. In this work, the main concepts behind thermomagnetic energy harvesting will be described, focusing on ongoing challenges and recent reports of new approaches and device designs for this promising technology.

While crucial to the progress we have accomplished as a species, the continuous rise in global energy demand has also resulted in one of the largest threats ever faced by mankind: climate change and global warning. Although world nations have pleaded to reduce greenhouse gas emissions and limit global warming to 2 °C in the Paris Agreement of 2015, the climate actions implemented so far are still insufficient for compliance with this target. Furthermore, even if such a goal is achieved, it will not prevent a surge in heat waves, droughts or extreme weather. Therefore, new technologies able to generate electrical energy in a green and sustainable manner are needed for humanity to reach a carbon-neutral world. The conversion of thermal energy, the energy into which all others eventually transform, to useful electrical power can help counterbalance the increasing energy demand. In fact, a large portion of the produced energy is converted to thermal energy just below 120 °C [1], which is then mostly discarded as wasted heat. The most common technology able to harvest such low-grade thermal energy employs thermoelectrics, based on the Seebeck effect, which suffers from low efficiency (below 5%), limiting their widespread applicability. In contrast, the use of thermomagnetic materials, and their associated thermomagnetic effect, is a viable and promising alternative to thermoelectrics.

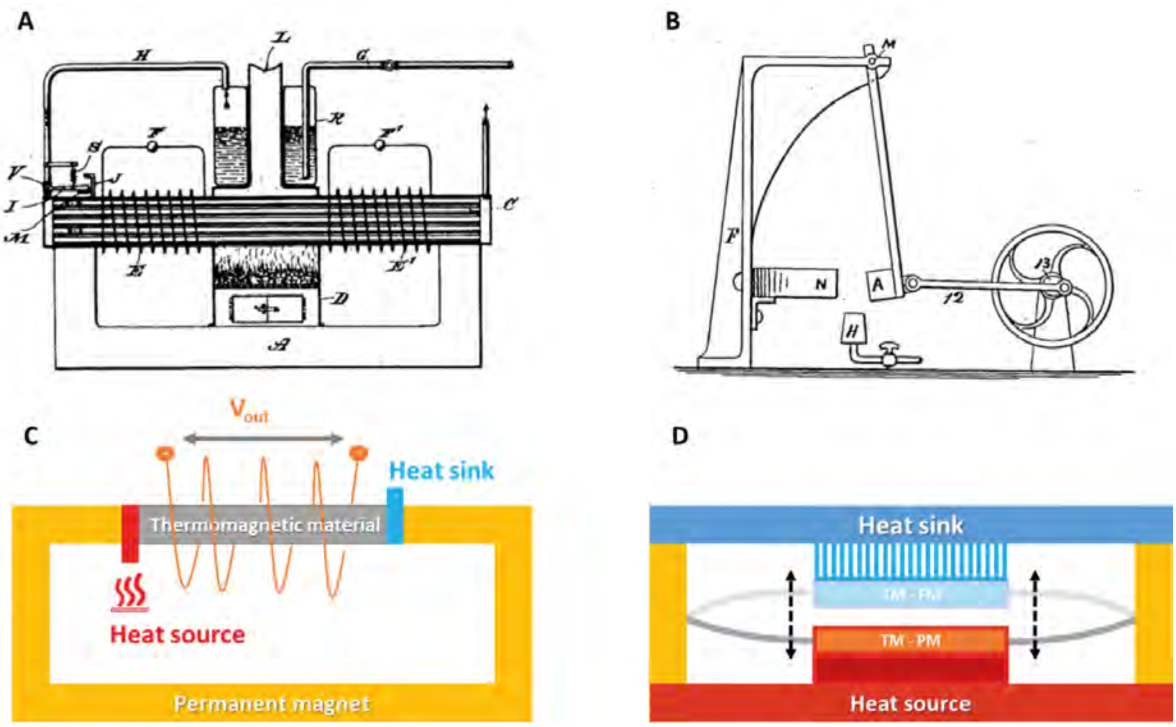
▾ **FIG. 1: Dependence of magnetization, M, (solid) and of magnetization temperature derivative, |dM/dT|, (dashed lines) on temperature for (A) a second-order phase transition ferromagnet and (B) a first-order phase transition ferromagnet, showing operating temperature range and correspondent magnetization change from a cold or hot thermal contact.**



The thermomagnetic effect

A magnetic material that at a certain temperature (T) shows spontaneous magnetization (M), such as a ferromagnet or ferrimagnet, can undergo, when surpassing a critical temperature (T_C), a transition to a magnetically disordered state with no spontaneous magnetization (paramagnetic state). This transition, depending on its nature, can be broad or sharp, either of second- or first-order, as schematically shown in Figure 1.

This thermomagnetic effect can be employed for energy conversion and harvesting in two distinct ways. In so-called active devices, there is a direct energy conversion in which the variation of the magnetization with temperature, and therefore of the associated magnetic flux, induces a voltage in a coil according to Faraday's law. These devices then rely on cyclic temperature variations and complex pump and valve systems. On the other hand, in passive thermomagnetic devices, the magnetization change is transduced into an intermediate mechanical motion (either linear or rotary) that can then



▲ **FIG. 2:** 19th century thermomagnetic device designs of Nikola Tesla: (A) Electrical generator based on the magnetic flux change of a ferromagnet in alternating contact with cold and hot sources, with surrounding pick-up coils [3] and (B) thermomagnetic engine, where the circular movement of a piston is produced from the cyclic magnetization/demagnetization of a thermomagnetic material subjected to a magnetic field and to a heat source [4]. Diagrams of a (C) active thermomagnetic device, or thermomagnetic generator, in which electrical energy is generated directly from the magnetization variation and (D) passive thermomagnetic device, or thermomagnetic motor, in which thermal energy is converted into a linear or rotary mechanical motion.

be converted into electrical energy using an appropriate mechanism (such as electromagnetic induction, the piezoelectric or triboelectric effects [2]). Devices based on these effects are not new; Nikola Tesla patented designs for thermo-magnetic generators and motors in 1889 and 1890, as shown in Figure 2.

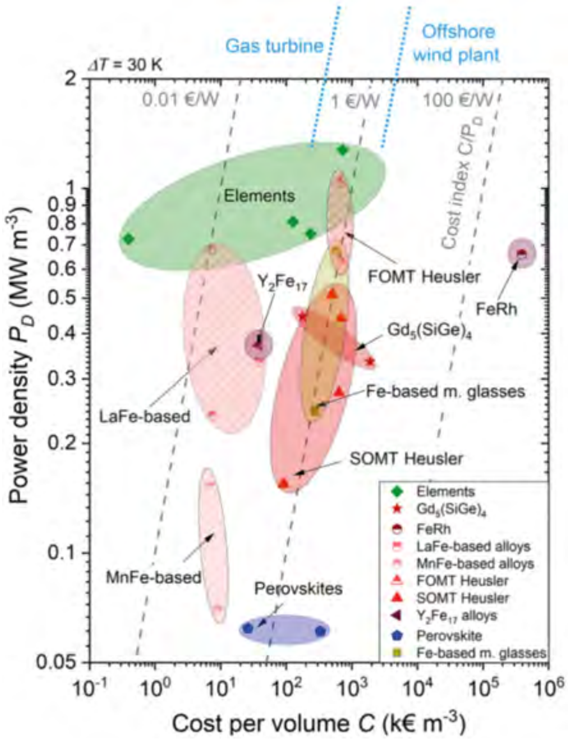
Optimized Thermomagnetic Materials

The performance of a thermomagnetic device is directly linked to the magnetic and thermal properties of the active (thermomagnetic) material. As the thermomagnetic effect is stronger for larger dM/dT values, then first-order phase transition ferromagnets with tuned T_C values, such as $Gd_5(Si,Ge)_4$, $La(Fe,Si)_{13}$, Mn-Fe-P-Si and Heusler alloys have greater potential to lead to better performance devices, when compared to the use of second-order phase transition ferromagnets, such as Gd and other elemental alloys, as shown in Figure 3.

Besides the all-important matter of cost, other material properties such as specific heat and thermal conductivity must be considered in device design. These play a crucial role on heat exchange kinetics, with impact on device working frequency, and, consequently, energy generation. Also, despite their larger dM/dT, first-order phase transition materials typically exhibit magnetic and thermal irreversibility (hysteresis) which lead to losses that can be detrimental to the final device efficiency. The chemical and structural stability of these materials can also be a concern for device longevity.

Devices

State-of-the-art thermomagnetic devices are being developed using both passive and active concepts and second- and first-order phase transition thermomagnetic materials. In Figure 4, some selected devices are shown. At the industrial scale, a thermomagnetic generator operating 24/7 using low temperature waste heat from a biomass power plant has been reported [6], reaching a 1 kW maximum mechanical power output (Figure 4A). At the tabletop scale, a room temperature thermomagnetic regenerator is shown in Figure 4B where performance was enhanced by exploring multiple magnetic circuit topologies. This device presents several permanent magnet (PM) placements, La-Fe-Co-Si thermomagnetic materials and pickup coils, and has shown an electrical output power of 1.24 mW [7]. At the millimeter scale, Figure 4C shows a thermomagnetic generator designed and built based on a ferromagnetic Ni-Mn-Ga Heusler alloy film mounted on a flexible cantilever, also holding a pickup coil [8]. The assembly is placed under a heatable PM, at a temperature higher than the T_C of the alloy. Cyclic movement is achieved due to temperature-driven magnetization/demagnetization and corresponding changes to the magnetic force between the magnet and alloy, opposing the cantilever weight, resulting in a power density of 0.1 $W.cm^{-3}$. Figure 4D shows a hybrid passive device relying on heat and cold sources at constant temperatures. In this example, a PM is placed near the heat source at the top while the ● ● ●



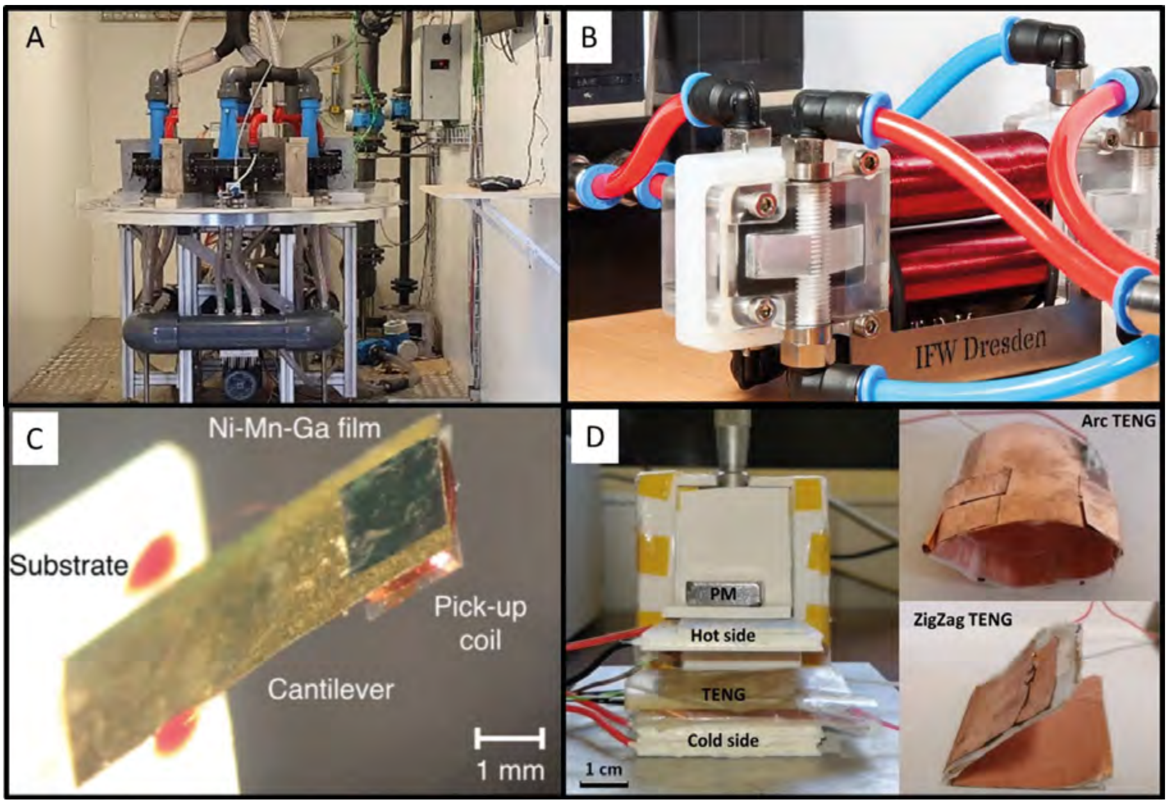
▸ **FIG. 3:** Analysis of Power density versus cost for several families of thermomagnetic materials, for a temperature difference of 30 K [5]. Reprinted (adapted or reprinted in part) with permission from Reference [4]. Copyright 2021, AIP Publishing.

heat sink is placed at the bottom part. When the thermomagnetic material (Gd) is in the ferromagnetic state, it is attracted by the magnet to the heat source, where its temperature increases. The resulting transition to the paramagnetic state breaks the magnetic force, making the plate fall into the heat sink, where it cools down again. This cycle is repeated in a sustainable manner as long as the temperature gradient is maintained. To generate electrical power, a mechanical-to-electrical transduction mechanism was added. In this case, a triboelectric nanogenerator (TENG), relying on the conjugation of electrostatic induction and the triboelectric effect, was placed in the bottom part to efficiently convert the low-frequency movement of the thermomagnetic material [2]. A maximum power density of 54.7 $\mu W.m^{-2}$ was achieved, a value 35 times higher than that obtained using a conventional coil. Other assembling and conversion mechanisms, *e.g.* based on piezoelectric membranes, have also been reported [9].

Future prospects

Besides price and performance metrics, a novel thermomagnetic device concept and design, together with the material employed, should have sustainability in mind. While rare-earth based magnets are now ubiquitous and applied thoroughly in prototype design and dimensioning, the use of rare-earth free magnets, particularly based on abundant Fe-based oxides, would be advantageous in terms of critical materials and device cost. This is an ongoing challenge for thermomagnetic device design, particularly for the development of new thermomagnetic materials, but also for the development of new permanent magnets.

The development of tricritical thermomagnetic materials is also an interesting prospect. These materials exist at the border between second- and first-order phase transitions, and can show a sharp magnetic transition with



▸ **FIG. 4:** Thermomagnetic generator devices, ranging from (A) large/industrial scale [6], (B) tabletop [7] down to (C) millimetric size [8], and (D) a tabletop hybrid thermomagnetic triboelectric device [2]. Reprinted (adapted or reprinted in part) with permission from reference [8]. Copyright 2021, AIP Publishing.

high dM/dT, while simultaneously avoiding magnetic/thermal hysteresis. Optimized thermal properties, such as specific heat and thermal conductivity, as well as smart material microstructuring or higher surface to volume ratio, to improve thermal exchange, are also poised to lead to significant advances towards high-performance devices.

Compared to thermoelectrics, thermomagnetic devices can be particularly competitive in terms of both cost per Watt and efficiency [5]. This is particularly accurate in the ultra-low temperature gradient region (below 10 °C), with power densities of 50 μW/cm^2 for temperature variations as small as 3 °C having already been achieved [10]. Therefore, thermomagnetic devices are, at this stage, especially suitable for the emerging Internet of Things (IoT), where miniaturized, low-power consumption sensors can be energized in a self-powered manner by energy harvesting technologies. ■

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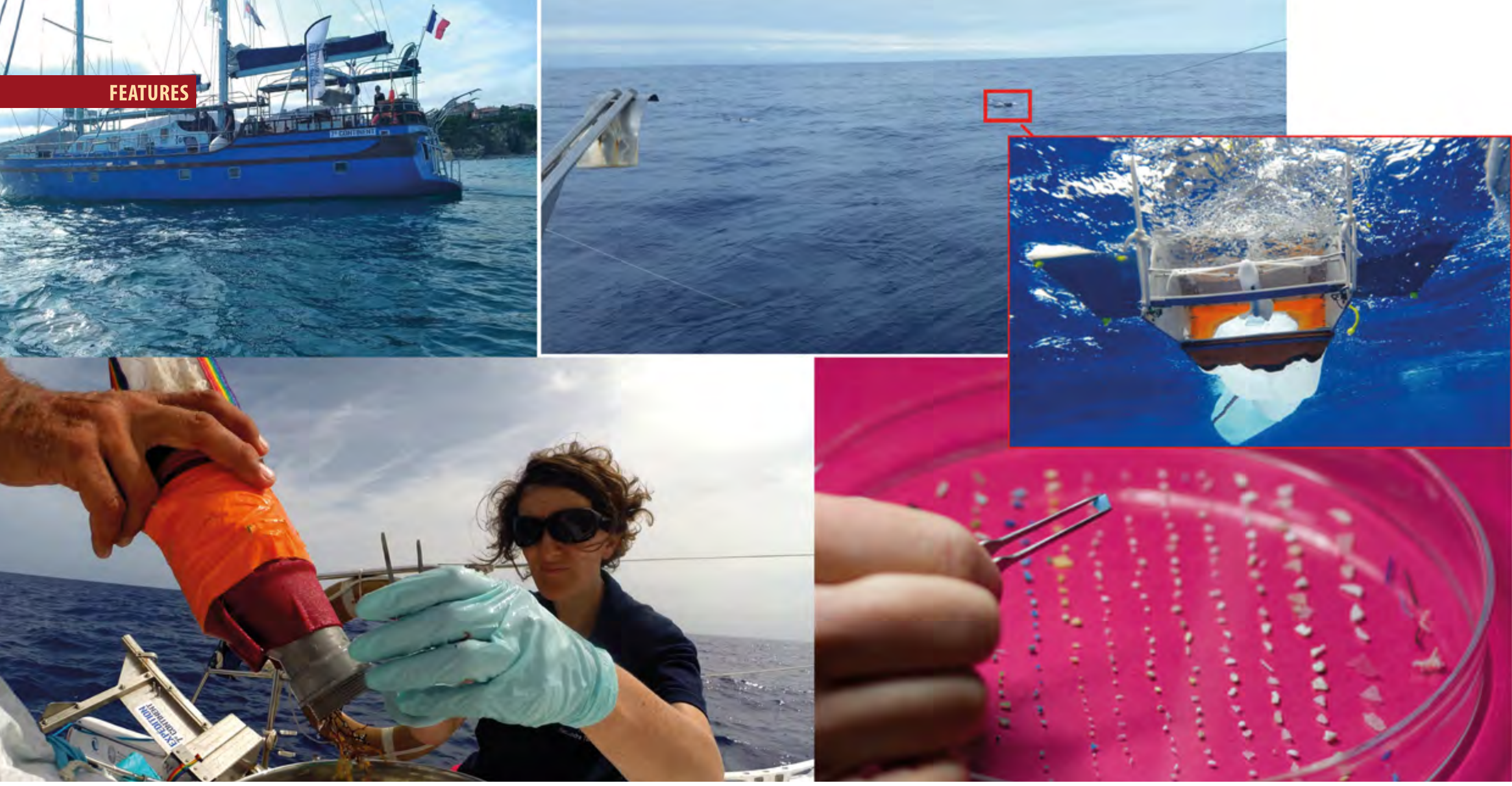


PLASTIC LITTER IN THE OCEANS. MOST OF IT HAS GONE MISSING, BUT IT MIGHT JUST BE TRANSFORMED… OR TRANSPORTED.

M. J. Mercier, M. Poulain-Zarcos, Y. Ourmières, J.F Ghiglione and A. ter Halle

DOI: https://doi.org/10.1051/epn/2023303

The balance between the leakage and abundance of plastic in the world's oceans remains a current topic of debate [1], which renders difficult the understanding of the cycle of plastic on Earth [2]. We discuss recent findings and their implications on the missing plastic waste paradigm.

▲ Crédits Marie Poulain-Zarcos, Vinci Sato ©Expédition Septème Continent

Oceanic plastic pollution is a major global issue: it is one of the 17 Sustainable Development Goals by the United Nations Organization (#14 "Life below water"), and one of the hot topics requiring stronger regulations according to the European Chemical Agency ("Microplastics"). In addition to many institutional and NGO initiatives to prevent more plastic to enter the environment, plastic pollution is also an important and active field of research gathering various research communities (biology, chemistry, ecotoxicology, economic and social sciences, oceanography and physics), with successful (online) gatherings of the MICRO community, leading to recommendations for policy makers [3]. A summary of the main results from the first observations of plastic in the middle of the Pacific in the early 1970s until the recent years can be found in [4].

Important knowledge gaps remain to be addressed quantitatively to better assess the extent and the impact of plastic pollution for marine life (quantity estimates, risk assessment, exposure rate). Here, we focus on the current state of understanding for the overall transport mechanism of plastic pollution in the oceans, as schematically described in Figure 1. The main challenge tackled here is to understand where the majority of floating plastic goes at sea.

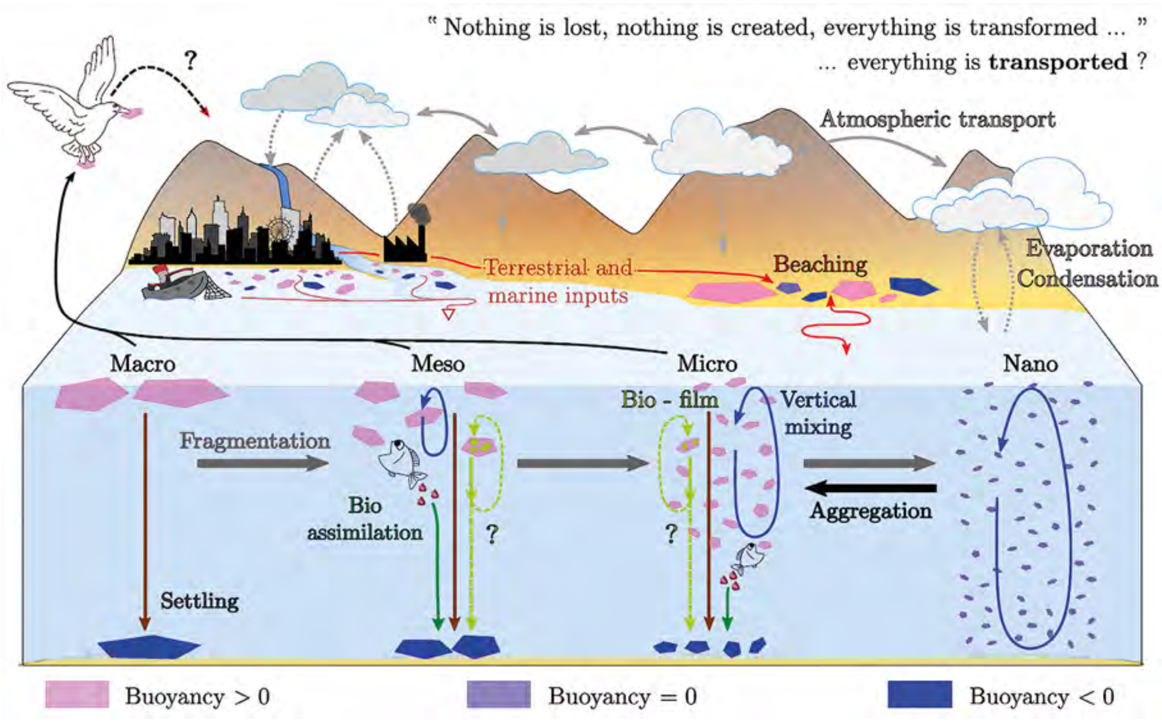
Plastic debris (or plastic litter) ending in the oceans come from various sources: rivers, coastal and offshore human activities, originating from mismanaged waste mainly [5], and more recently identified from airborne pollution [6]. The most recent estimates suggest that the mass of plastic entering the oceans was between 4.8 and 12.7 10^6 Tons for the sole year 2010, between 1.5 and 4% of the global industrial production [5]. Accumulation over the years could lead to figures 10 times larger.

Plastics with a great diversity of shapes, sizes, types and colors end up in the environment, reflecting the many sources of this pollution. The heavier plastics are rapidly integrated in sediments whereas the lighter plastics are transported over long distances and have long times of residency at the sea surface. Floating plastic is slowly transformed into altered material (due to UV radiation and mechanical constraints) that lead to fragmentation into smaller and smaller pieces. The weathered plastic debris loses its mechanical properties and is more subject to erosion and fragmentation [7], as illustrated in Figure 2. Deep chemical and morphological modifications drastically modify its physicochemical properties, the potential increase in toxicity is still unknown.

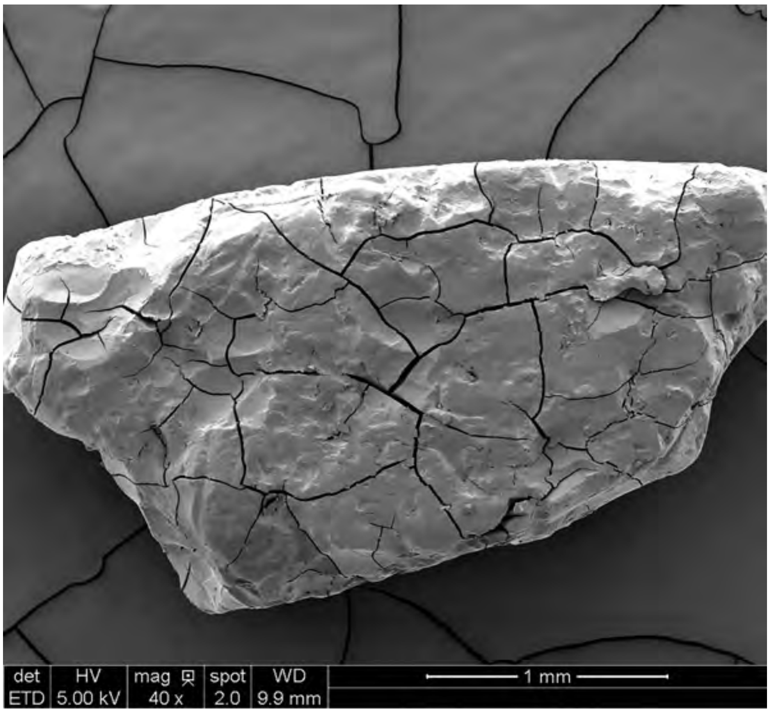
To assess the amount of floating plastic litter, samples are collected at the sea surface with neuston nets [4]. Samples cover a continuum of sizes ranging from large macroscopic debris (>5mm) to microplastics (between 25µm and 5mm). Even nanoplastics (<25µm) are found when collecting water samples [8]. Nevertheless, interpreting this continuum in terms of mass distribution is usually complex, because (i) samples analysis has not been consistently performed for this goal, (ii) the diversity of debris' shapes prevent from easily matching sizes to mass, and (iii) the smallest (and lightest) pieces with dimensions smaller than 300µm (mass smaller than 1mg) are more likely to be transported everywhere in the oceans. An example of the vertical distribution of microplastics in the range of depths [0-300]m is illustrated in Figure 3. Other processes can also affect the distribution of plastic particles, more than just fragmentation, we discuss them in the following.

Plastics at sea are rapidly colonized by a large diversity of microorganisms that form a biofilm on their surface [10]. Biofouling may decrease the buoyancy of most of the plastic debris by different processes. Microbial biofilms alone are sufficient to cause the sinking of small microplastic debris with surface area to volume ratios below 100, which correspond to thin plastic films, fragments or filaments with diameters less than 50µm [11]. For larger debris biofilms, they induce a decrease in hydrophobicity that favors the sink below the surface even though the pieces are still buoyant. It also facilitates adhesion of invertebrates, mainly calcifying organisms, and it could also alter the palatability of plastics, thus increasing ingestion by marine organisms and egestion of plastic together with fecal pellets that may sink together with plastic pieces [4]. Finally, biodeterioration processes occur on plastics that are part of the fragmentation process described earlier.

Other non-biological processes can make plastic pollution leave the sea surface. Waves and wind surface mixing put plastic debris in suspension in the water column. Theoretical models have been developed to correct surface mass concentrations of microplastics according to the sea state [12], that are valid for plastics • • •



◂ FIG. 1: Schematic view of various pathways for plastic debris in the ocean based on their properties, density and size.



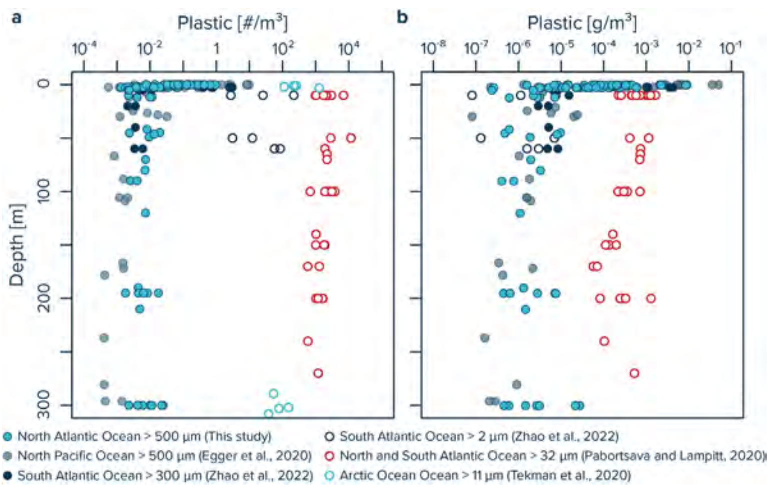
▲ **FIG. 2:** Infrared Image of a plastic piece collected in the North Atlantic Ocean.

larger than ~1 mm, resulting in a vertical distribution a few meters below the sea surface. Smaller plastic debris are mixed deeper (*cf.* Figure 3), where new oceanic processes can modify their transport, such as Langmuir cells for instance [13]. Recent studies have highlighted the importance of the beaching process, resulting in a permanent deposition along the coastlines. This process is difficult to calculate hence hardly estimated or taken into account [14]. Its consideration, based on a probabilistic approach due to the lack of data, could lead to a completely new design of the plastic accumulation maps (Figure 4).

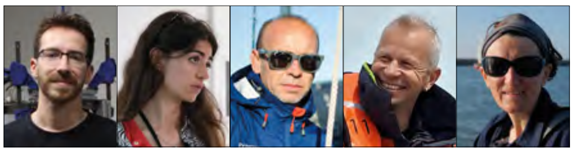
Ultimately, how to estimate the global concentration of plastics? Ocean general circulation models (OGCM) are used, by introducing virtual particles mimicking plastics that are either neutrally or positively buoyant. They can estimate the amount of plastic drifting on the sea surface and predict the main areas of accumulation. At the ocean-basin scale, these areas turn out to be the center of the main large systems of circulating ocean currents, called gyres. These gyres result from a coupling between wind-induced shear at the sea surface and the Coriolis force. However, OGCMs can hardly account for all the oceanic processes that transport plastic debris because of the wide variety of spatial (from mm to thousands of km) and temporal (from seconds to months) scales of oceanic processes [13]. Actual OGCMs parameterized for plastics transport are valuable tools to get general patterns of accumulation and transport processes at the ocean-basin scales, filling the gaps of insufficient in-situ campaigns. The remaining identified issues of such numerical methods are the lack of high resolution processes as described before, that can lead to a bias on the global concentrations. Furthermore, the initial conditions regarding the quantity and the spatial distribution of plastics inputs are still poorly known, imposing simulation scenarios to remain more qualitative than quantitative. Recent works try to explain the mismatch between plastic inputs and estimated global plastic concentrations, by considering more processes such as beaching, Stokes drift, vertical transport, *etc.* General consensus is far from being reached.

For now, the current global mass estimates of the floating plastic pollution based on surface samples alone are of the order of 0.1 to 0.2 10^6 Tons [4], whereas recent global mass estimates for the upper ocean ([0-300m]) suggest that this `hidden' contribution to plastic pollution (away from the surface) could reach 11 to 21 10^6 Tons [9]. The mass of plastic pollution trapped at the oceanic floors is estimated using the proportion of industrial production of plastic denser than seawater. As we make progress on these estimates for the plastic cycle, the hidden part of plastic pollution has significantly decreased but remains a key issue; it seems most likely to be transported everywhere in our environment, depending on the scale at which we search for it. ■

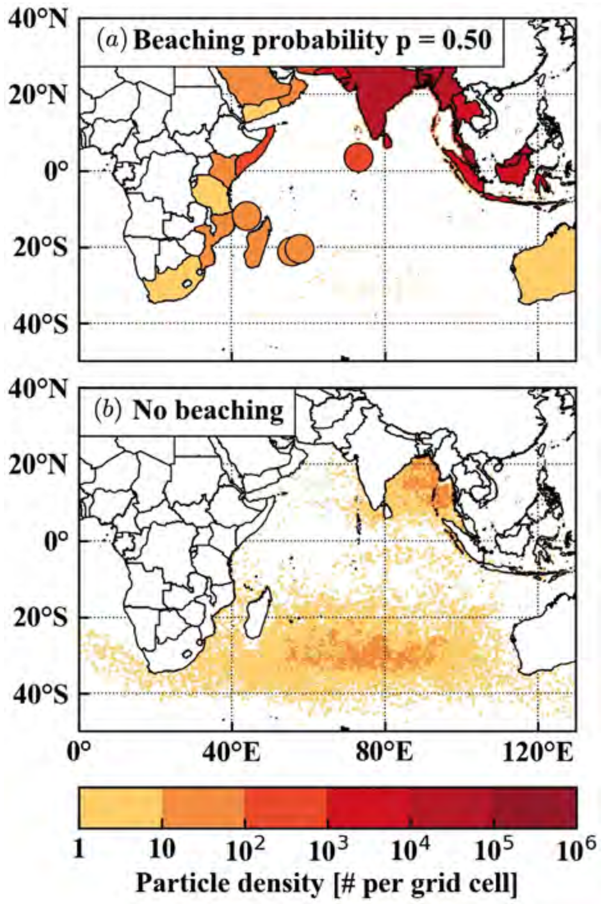
▼ **FIG. 3:** Recently measured depth concentration profiles in oceanic gyres for different plastic sizes (from [9])



About the Authors



M. J. Mercier and **M. Poulain-Zarcos** are specialized in fluid mechanics; **Y. Ourmières** in physical oceanography; **J.F Ghiglione** in microbial ecology and **A. Ter Halle** in physical chemistry. The French research team carries out multidisciplinary work to better understand plastic debris fate at sea. The team is engaged with a French NGO Expedition 7th Continent that organizes annually sampling campaigns from a sailing boat. The last three years, the campaigns were located in the Mediterranean sea.



▲ **FIG. 4:** Density of beached particles per country or island and density of particles in the ocean for particles released from river source locations in the Northern Hemisphere Indian Ocean after 21 years of simulation with (a) a beaching probability of 50 % and (b) no beaching (adapted from [14]).

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A SINGLE ION IMMERSED IN AN ULTRACOLD GAS: FROM COLD CHEMISTRY TO IMPURITY PHYSICS

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A single ion in an ultracold gas is a versatile experimental platform to study interactions between charged and neutral particles in a controllable manner. When the gas density is large enough, a single ion can be viewed as an impurity in a sea of ultracold atoms or molecules. On the other hand, that single ion can also undergo a chemical reaction with atoms or molecules in the gas. This article discusses the dynamics of a charged impurity in an ultracold bath and the interplay between cold chemistry and impurity physics.

Co-trapping charged and neutral particles to sub-Kelvin temperatures brings a plethora of well-controlled scenarios in which interactions between charged and neutral particles can be studied and efficiently controlled [1,2]. As a result, in recent years, atomic, molecular, and optical physics has experienced a revolution around those experimental platforms paving the way for a new field of research: cold chemistry, *i.e.*, the study of chemical reactions at temperatures $\lesssim$ 1K [1]. In the same vein, those systems provide a new avenue to study impurity physics in which the ion is considered an impurity in a bath of ultracold gas, either atomic or molecular.

When an ion approaches an atom or a molecule, the electric field of the ion induces a dipole moment on the neutral system, leading to a characteristic interaction potential, $V_{cn} \propto R^{-4}$, where R is the atom-ion distance. This interaction has a longer range than the van der Waals dispersion force between neutral systems. A longer-ranged interaction translates into a larger characteristic length scale, approaching the typical interparticle distances in ultracold gases leading to the formation of a charged polaron [3], in which the ion is dressed with a cloud of virtual phonons or collective excitations of the gas. Similarly, a single ion in an ultracold bath can bind to several particles of the bath. It thus forms a mesoscopic molecular ion that can be regarded as a many-body bound state, *i.e.*, a cluster-like structure whose properties rely on an exchange of atoms from the bath [4].

From a few-body perspective, longer-ranged interactions result inexorably in larger collisional cross sections and thereby a more significant reaction rate. In other words, charged-neutral reactions are faster than neutral interactions under the same temperature, pressure, and density conditions. Consequently, despite being many-body systems, charged polarons and mesoscopic molecular ions are definitively affected by charged-neutral chemical reactions, *i.e.*, few-body processes.

A single ion in an ultracold atomic bath

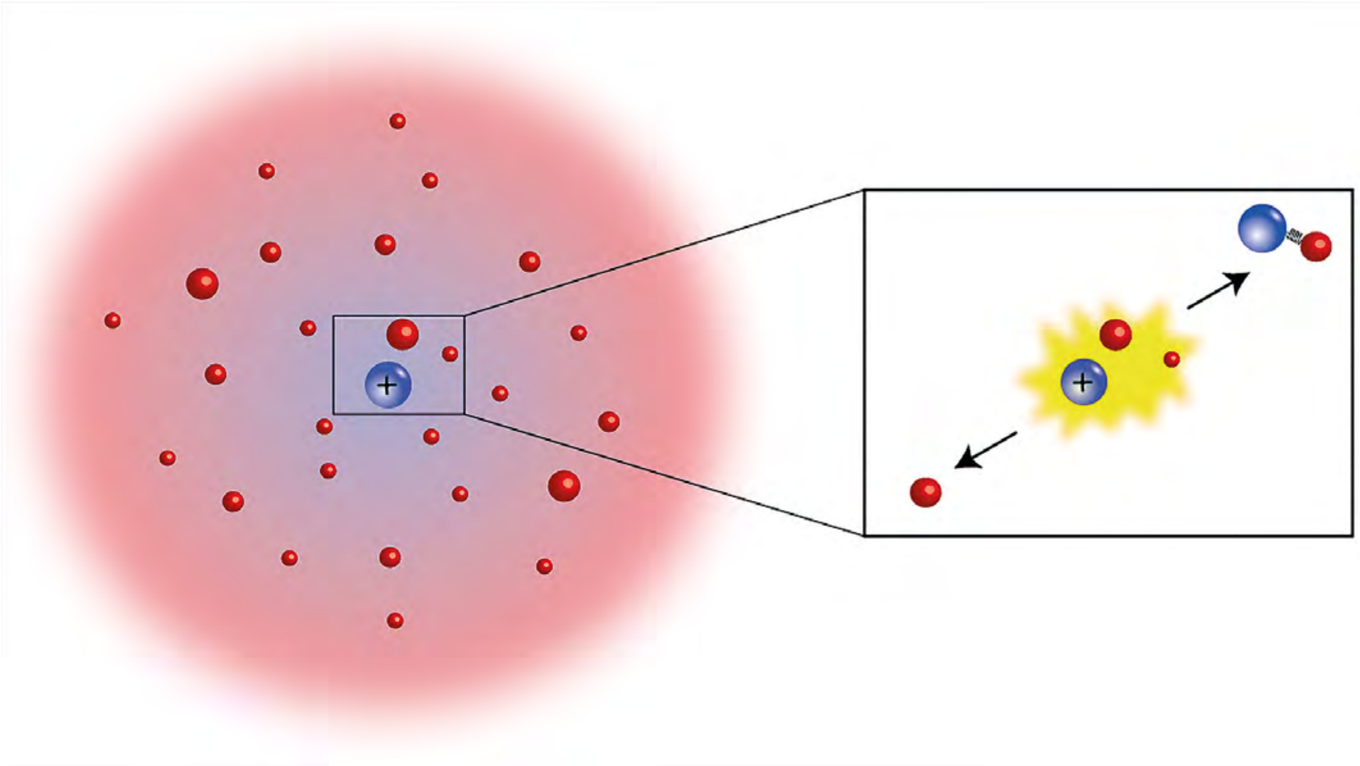
An ion A^+ reacts with the atoms of the atomic gas via ion-atom-atom three-body recombination (ternary association in chemistry): a three-body process in which two colliding partners combine into a bound molecule, as shown in Fig.1. There are two reaction products. One leads to the production of a molecular ion as

$$A^+ + B + B \rightarrow AB^+ + B, \quad (1)$$

and another leads to the formation of a neutral molecule given by

$$A^+ + B + B \rightarrow B_2 + A^+. \quad (2)$$

The formation of molecules via three-body recombination, either ionic or neutral, occurs in the short-range region where chemistry takes place. However, since the



▲ FIG. 1: A single ion in an ultracold atomic bath forms a charged polaron sketched by the blue cloud around the ion that identifies the portion of the bath directly affected by the ionic impurity. However, from a few-body perspective, the ion reacts with the particles or the gas via three-body recombination, shown in the zoom-in, with the subsequent formation of new reaction products.

charged-neutral interaction is longer-ranged than the van der Waals interaction, as shown in Fig.2, ion-atom-atom three-body recombination preferably forms molecular ions as a reaction product and its rate shows the temperature dependence as $k_3 \propto T^{-3/4}$ [5,6], which has been experimentally confirmed [7,8].

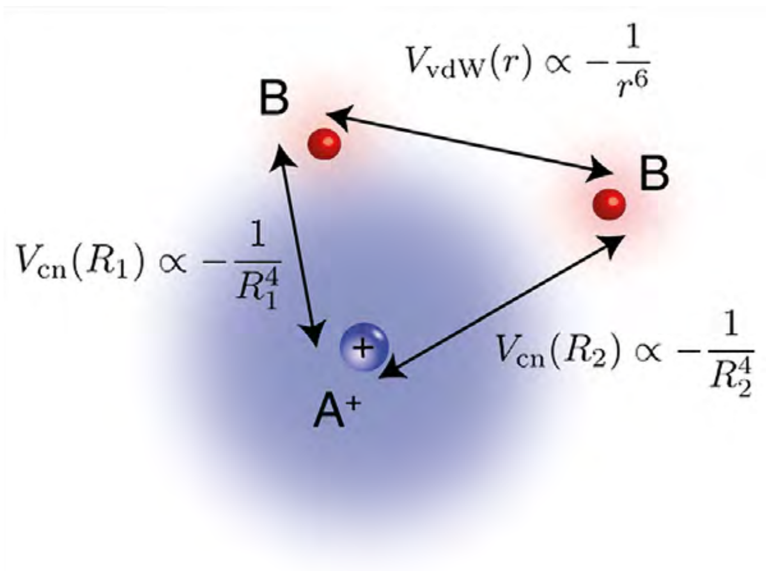
In many-body systems, reactive channels due to few-body processes may be considered decay channels when the particle treated as an impurity changes its nature as a result of the reaction, as is the case for ion-atom-atom three-body recombination. Every decay process has a characteristic lifetime, *i.e.*, the typical time-scale for the process to occur. In particular, the collision time gives the lifetime of the many-body decay channel: the typical time it takes the colliding bodies to reach the short-range region to react. For example, it is ~100μs for typical experimental conditions in atom-ion hybrid trap experiments [9].

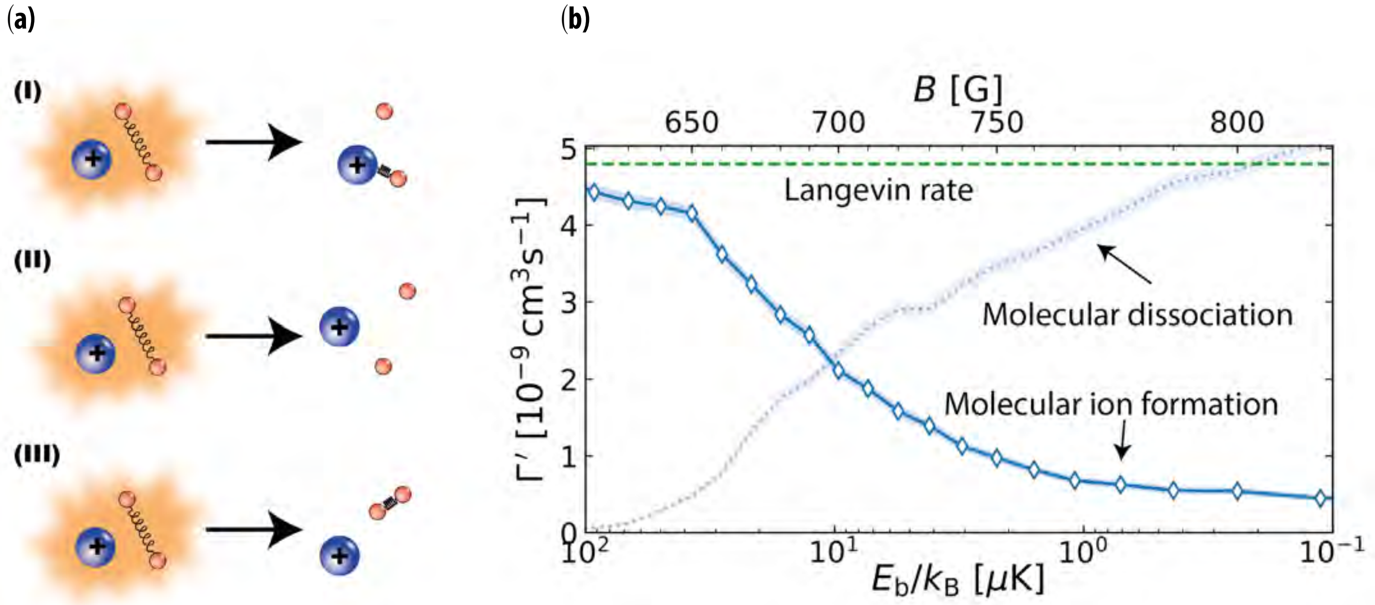
A single ion in an ultracold molecular bath

When a single ion is brought into contact with an ultracold gas of molecules, the ion can be considered an impurity in a bath with internal degrees of freedom. As a result, new and intriguing many-body phenomena may occur. Nevertheless, very little has been developed in this direction. On the contrary, such a scenario has been studied theoretically and recently experimentally from a few-body perspective [11].

An ion interacting with a molecule could react to form a molecular ion, as depicted in panel (I) of Fig.3. Furthermore, at energies above the binding energy of the molecule, the ion may dissociate the molecule, as depicted in panel (II) of Fig.3. Finally, the ion may induce a change in the internal state of the molecule, known as vibrational quenching, as shown in panel (III) of Fig.3. However, at temperatures $\lesssim$ 1 mK, vibrational •••

▼ FIG. 2: Ion-atom-atom three-body interactions. The shaded blue represents the characteristic length scale for charged-neutral interactions, whereas the red color stands for van der Waals interactions. reaction products.





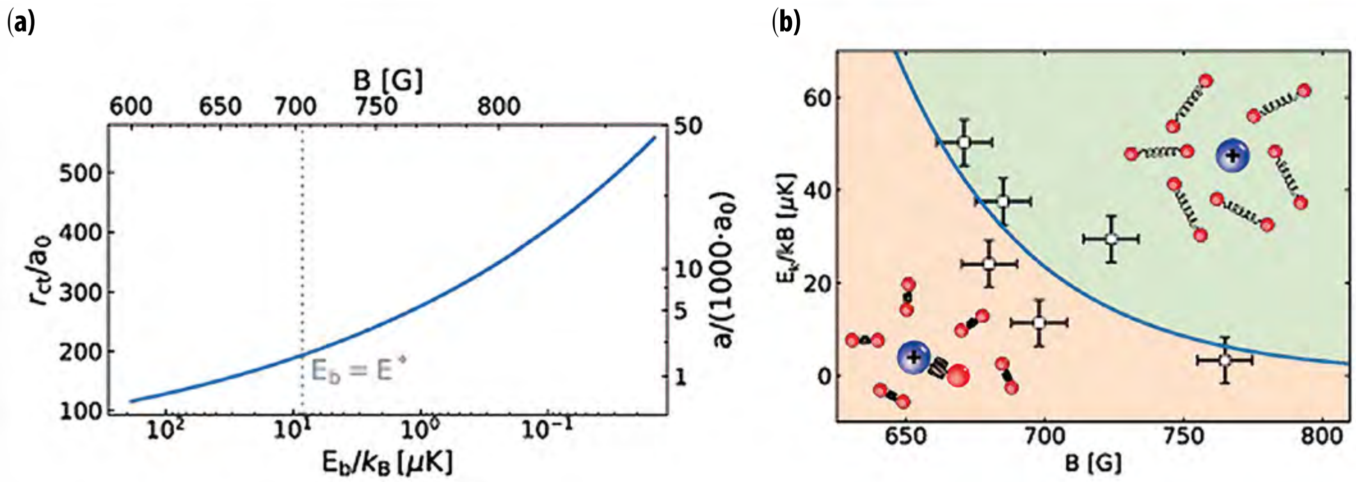
▸ **FIG. 3:** Few-body dynamics of an atomic ion colliding with a molecule. Panel (a) shows the possible reaction channels: (I) molecular ion formation; (II) molecular dissociation; (III) vibrational quenching. Panel (b) shows the reaction rate for the molecular dissociation and the molecular ion formation channel as a function of the binding energy in units of temperature (kB is the Boltzmann constant). The reaction is for Yb^+ interacting with a Li_2 molecule at a collision energy of 11 μK. The green-dashed line depicts the Langevin rate. Figure adapted from Ref. [10].

quenching is negligible due to the dominant nature of charged-neutral interactions. Therefore, there are only two possible outcomes: a molecular ion or two atoms and one free ion.

The relevance of each of these reaction products for a given collision energy depends on the molecular binding energy, as shown in panel (b) of Fig.3 for Yb^+-Li_2 collisions. In particular, the dominant reaction channel is molecular ion formation for deeply bound molecules (in comparison to the collision energy), whereas for weakly bound molecules molecular dissociation is the most relevant reaction channel [10]. Furthermore, the molecular ion formation rate saturates to the Langevin rate (the maximum possible rate for a charged-neutral interaction), which has been experimentally confirmed [11]. Therefore, by tuning the binding energy of the ultracold molecular gas, it is possible to control whether the ion reacts to form a molecular ion or, on the contrary, stays unchanged.

Feshbach molecules are weakly bound molecules whose binding energy depends on the applied external magnetic field, as shown in panel (a) of Fig. 4 for the Li_2 molecules. Therefore, controlling the collision energy and the external magnetic field, it is possible to draw a phase diagram for a charged impurity in an ultracold molecular gas, as shown in panel (b) of Fig.4 for the particular

▾ **FIG. 4:** Panel (a) shows the relationship between the binding energy of the molecule and the applied external field channeled by the presence of a broad Feshbach resonance in Li-Li scattering. Vertical-axes represent the Li-Li scattering length, a, and the classical turning point (the classical size of the molecule), r_{ct}, in atomic units of distance, *i.e.*, Bohr radii, a_0=0.529177×10^{-10}m. Panel (b) shows the "phase-diagram" of a single ion in an ultracold bath of weakly bound molecules. Figure adapted from Ref. [10].



> **As a result, to preserve the charged impurity, we need to have a gas of weakly bound molecules and as large collision energies as possible.**

case Yb^+ in an ultracold gas of Li_2 Feshbach molecules. As a result, to preserve the charged impurity, we need to have a gas of weakly bound molecules and as large collision energies as possible.

Outlook

A single ion in an ultracold gas is a platform to study many-body systems such as charged polarons and mesoscopic molecular ions. However, due to the very reactive nature of ion-atom interactions, it is required to approach the same system from a few-body physics standpoint. Therefore, it is necessary to work synergetically between many-body and few-body physics to reveal the true nature of many-body processes in atom-ion hybrid traps.

About the author

Jesús Pérez Ríos is an Assistant Professor at the Department of Physics and Astronomy of Stony Brook University (USA). His research focuses on the study of fundamental atomic and molecular processes at the interplay between atomic, molecular, and optical physics and other disciplines of physics and chemistry such as high energy physics, condensed matter physics, and chemical physics.

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europhysicsnews
2023 • Volume 54 • number 3

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ISSN 0531-7479 • ISSN 1432-1092 (electronic edition)

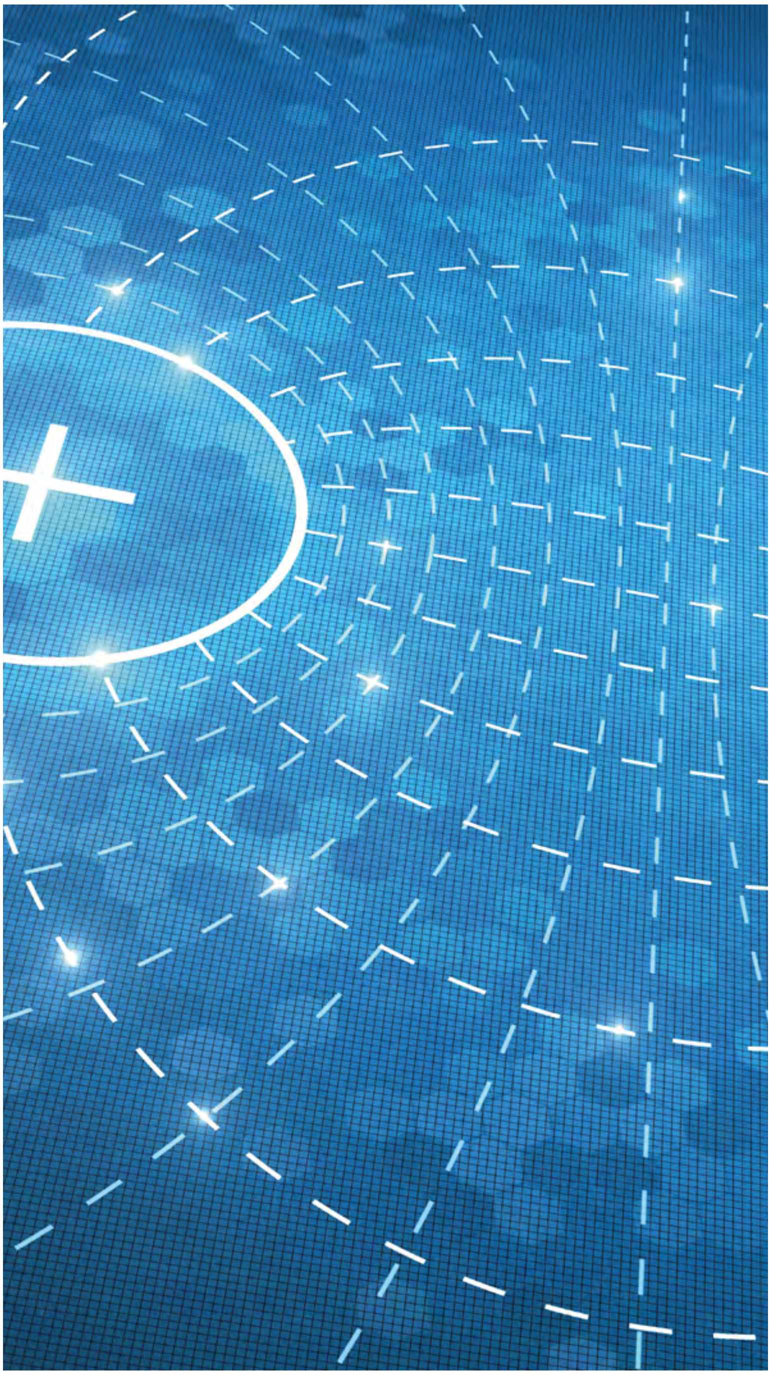
Printer: Fabrègue • Saint-Yrieix-la-Perche, France

Legal deposit: April 2023

Next EPN issue

For the last few years the first EPN-issue after the summer has a focus on physics and technology. This year is not different. The focus of the next session is magnetism and the technology in that research field. At the time of writing this outlook – it is still May – we have selected the front page picture, but have not yet received contributions. Indeed, contributions in the research field of magnetism are being sollicited. If you feel that you want to contribute, please contact Ferenc Igloi, science editor of EPN. You find his email in the colophon.

The next issue of EPN will come on-line around 15 September 2023 as a flipbook at www.epn.eps.org and as registered document at www.europhysics.org. ■



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