

EUROPHYSICSNEWS

The magazine of the European Physical Society



the evolving world of **drones**

Software-Enhanced
Gamma-Ray Images

UNESCO's
Remote Lab Access

EPL: 40 years
as Your Letters Journal

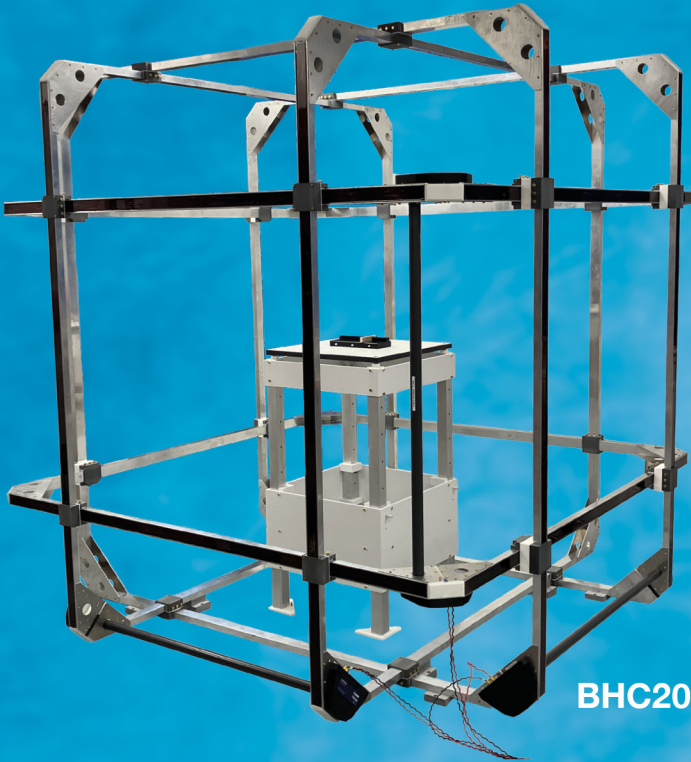


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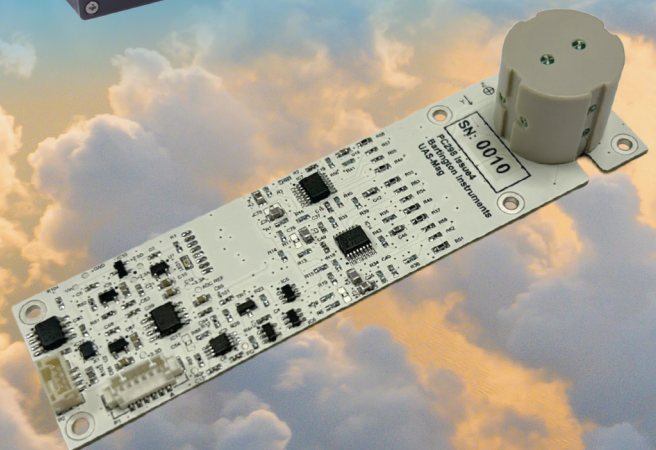
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Cover picture: Performing drone-assisted inspections of wind turbines
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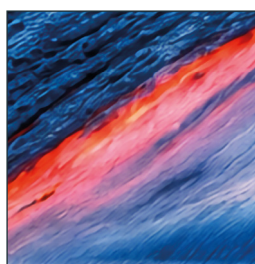
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Nanophysics essentials

Introduction to the nano-world

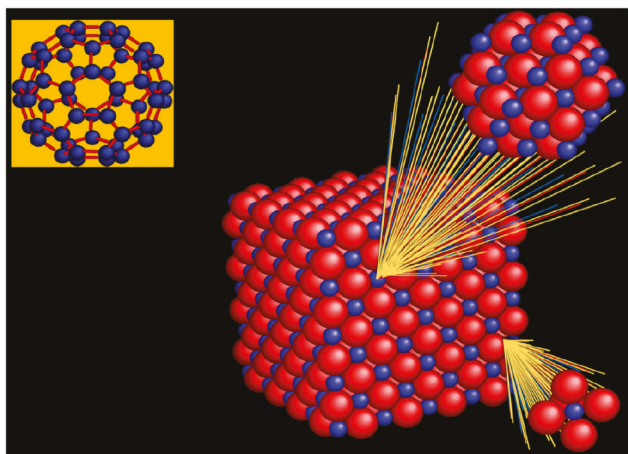
by Patrice Mélinon
and Michel Broyer

Current Natural Sciences

Patrice MÉLINON and Michel BROYER

Atomic Clusters

Introduction to the Nano World



Also available in ebook
For sale on
laboutique.edpsciences.fr

ISBN 978-2-7598-3457-0
414 illustrated pages
Price (paper) : 108 €

The aim of this book is to describe the basic principles governing nanophysics. It is devoted to aggregates or nanoparticles in the ground state. The authors show how the physics and chemistry of atoms influence the properties of nano-objects. They also describe how the properties of macroscopic materials are modified when their size decreases.





[EPS EDITORIAL]

Time to hand over the sextant

DOI: <https://doi.org/10.1051/epn/2026301>

Two years ago, I was entrusted with a sextant—a symbol, I believe, meant to remind me to know where we are and where we are headed. Today, I pass this sextant on to my successor, Prof. Jose Maria De Teresa. This is the perfect moment to reflect on what we have accomplished together with the Executive Committee during my mandate.

My foremost ambition was to amplify the voice of European physicists in the increasingly urgent debate on energy. In that spirit, the EPS published a document reflecting the collective scientific expertise of our community, designed to serve as a strategic reference for European decision-makers. This publication represents a major achievement for the EPS, considering the diversity of perspectives within the community and the extensive, constructive discussions that shaped the final text, while reconciling at times conflicting viewpoints. As an important complement to the paper, we organised a conference in Brussels in April 2026, featuring high-quality contributions from academia, industry, and policymakers, followed by insightful panel discussions.

My second priority was to help adapt higher education to the rapidly evolving demands of the professional world. To this end, the EPS published a paper on education that reflects current realities and emerging perspectives on Physics Bachelor Programmes. Through this initiative, the EPS reaffirmed its commitment to serving society and shaping future generation of physicists by promoting excellence, relevance, and inclusivity in university-level education.

To further contribute to scientific policy in Europe, the EPS also released a report intended to help guide both European and national policies by demonstrating how physics research can generate concrete economic and societal benefits.

On the occasion of the International Year of Quantum Science and Technology, the EPS, together with several national physical societies, issued a declaration accompanied by an EPS statement on international collaboration in quantum science and technology.

Through a broad range of events and initiatives, we have maintained and strengthened the role of the EPS both in Europe and internationally. To make science more accessible and attractive, we established revised EPS prize and awards regulations, with stronger commitments to diversity within selection committees and among nominees. In addition, the EPS released a diversity statement that underscores our dedication to ensuring equal opportunities for all, regardless of gender, race, ethnicity, age, or socioeconomic background.

Finally, the EPS launched a completely new website -- an important step forward enhancing the visibility and image of our Society. Several significant organisational improvements were also implemented at EPS headquarters in Mulhouse.

As anticipated, serving as President of the EPS has been both demanding and rewarding. Over the past two years, I have devoted considerable time, energy, and determination to transforming the goals I outlined at the Council meeting in Porto in May 2023 into concrete achievements. These successes are the result of collaboration, dedication, and a shared vision. I am grateful to all those whose support made this possible.

I extend my sincere thanks to the members of the EPS Executive Committee for their commitment and support, as well as to our Divisions, Groups, and Committees for the excellence of their work. I also warmly thank the EPS Secretariat in Mulhouse, and especially our Secretary General Dr. Anne Pawsey, for their collaboration and dedication.

Serving as EPS President has been both an honour and a privilege. I leave this role inspired by the creativity, commitment, and strength of our community, confident that the EPS will continue to advance physics, support future generations of scientists, and contribute meaningfully to society. I extend my warmest wishes to my successor, and I am confident that his presidency will further strengthen the mission and impact of the European Physical Society. ■

■ **Mairi Sakellariadou,**
EPS President

A student-driven conference shaping the future of optics and matter: **NW-MYROM 2026**

■ Marta Gómez-Gómez, Marc Espinosa Edo, Arturo Mena-López, Yago Radziunas-Salinas, Pau Arcos-Calderón, Celtia Jabares, Mia Martín-Rodríguez, Mario García-Hernández, Marta Rodríguez-Lorenzo, Jorge Rodríguez-Pérez, María Sánchez-Gómez, David Tofiño-Muñoz
 ■ DOI: <https://doi.org/10.1051/epn/2026302>

One of the most valuable experiences in the early stages of a scientific career is the opportunity to connect with peers, exchange ideas, and explore future collaborations. Conferences play a crucial role in this process, but what happens when such an event is entirely organized by students?

From April 16th to 18th 2026, the North Western Meeting of Young Researchers in Optics and Matter (NW-MYROM) returned for its third edition in Salamanca, Spain. What began as a joint initiative between the EPS Young Minds sections of Santiago de Compostela (LUZADA) and Salamanca (OSAL), originally focused on optics and photonics, has now evolved into a broader platform that also embraces materials and related areas of physics. At the same time, the event has expanded its network to include additional student groups, such as the EPS Young Minds section of Valladolid (Physics League) and the OPTICA Student Chapter of the Basque Country (Fotonekin). More than just a scientific meeting, NW-MYROM has grown into a collaborative, student-driven space where young researchers, from undergraduate to PhD level, can actively participate, present their work, and build meaningful connections within the scientific community.

What makes NW-MYROM different?

Unlike many scientific conferences embedded within larger senior events, NW-MYROM is entirely driven by students and early-career researchers. This model allows participants to take an active role not only in presenting their work, but also in shaping the scientific program and the overall experience of the event. As a result, the meeting creates a more open and approachable environment, where discussions feel closer and more interactive, and where young researchers can engage more directly with both peers and invited speakers.

How did we organize it?

Organizing a conference of this scale as students is both a challenge and a learning experience. The preparation of NW-MYROM 2026 started in September 2025, several months in advance, and required continuous coordination between different student groups based in different cities. To keep the process on track, regular online meetings were held every two weeks, where tasks were distributed, short-term goals were set, and progress was shared among the team. Balancing the organization with academic responsibilities was one of the main challenges, but it also became a valuable learning experience in teamwork and communication.

What did the scientific program look like?

The aim of this conference was to approach early-stage students to such a broad concept as Academia. NW-MYROM included a wide set of scientific

activities, including the visit to cutting-edge facilities, such as the Centro de Láseres Pulsados (CLPU) and two research laboratories (ALF-USAL & QMADE labs) where students could exchange insightful ideas with researchers in the field. Besides, there was a space for scientific talks, comprising 4 senior talks given by researchers linked to the 4 organising Student chapters. From the students' side, they had the opportunity to both give their first short presentation and defend their first scientific poster. These experiences, held in a friendly and near atmosphere, broadened the mind of many participants and inspired them to pursue an academic path.

How did the meeting support professional development?

In addition to the purely scientific sessions, a roundtable was organized to present different career perspectives from both academia and industry. The aim was to show younger

▲ FIG. 1: The first day integrated a visit to the cutting-edge Centro de Láseres Pulsados (CLPU).





▲ FIG. 2: The poster sessions aimed that students could defend their early scientific work in a relaxed atmosphere.

generations the possible career paths available after graduation. Moderated by Yann Amouroux, the roundtable included two speakers from academia, Carlos Hernández García (USAL) and Gabriel Pérez Callejo (UVa), and two from industry, Christina Graham (MeetOptics) and Guillermo Gil (Tecnalia). Interdisciplinary talks were also presented. The first was given by Casandra Pablos (USAL), who provided useful stress management tools for young researchers and students. Additionally, to demonstrate that people with visual impairments can equally engage in scientific dissemination and research, Enrique Pérez (Instituto de Astrofísica de Andalucía) spoke about the challenges he overcomes every day and how light beautifully becomes music. Furthermore, a networking activity was organized, consisting of traditional games such as charades, rope jumping, and a sack race, to foster team-building and improve communication skills, so important in the professional environment.

Can a conference go beyond academia?

Of course! Taking advantage of the organizers' backgrounds as part of student groups, the event finished with an outreach activity in one of the most popular squares in Salamanca. During the morning, all four student groups together with members

from the OPTICA Student Chapter of Valencia (Photonets UV), brought experiments like a bed of nails, Van de Graaff generator, diffraction glasses, optical fibers,

a quantum cryptography kit, and a model of a human eye with simulations of various conditions. Beyond bringing physics closer to the general public in Salamanca, this final activity served as an excellent opportunity to share outreach ideas and experiments between sections, as well as closing the conference in a memorable way.

Was it worth it?

Without any doubt, the North Western Meeting of Young Researchers in Optics and Matter has been an absolute success. And not only because we have carried out a very diverse program where everyone had a good time and, at the same time, they got new ideas and feelings. The most valuable teaching of this event has been the strong teamwork between sections and how we have managed every aspect of the meeting to demonstrate that students are the best option to organize a conference for students. We are truly excited to see how this initiative has grown, to meet familiar faces again as well as new ones, and to become, at each edition, a bigger family. ■

▲ FIG. 3: Group photo of the organizer committee during the outreach event.



UNESCO's Remote Lab Access Initiative, Petra Rudolf's point of view

– DOI: <https://doi.org/10.1051/epn/2026303>

The UNESCO Remote Access to Laboratory Equipment initiative, known as UNESRALE, is a global programme designed to expand equitable access to advanced scientific infrastructure for researchers in under-resourced regions, particularly in Africa and the Global South. We interviewed Petra Rudolf, former EPS President, to learn more about this initiative, which she actively supports.

Antigone Marino: Could you outline what this initiative entails?

Petra Rudolf: The concept of remote access to scientific equipment emerged from discussions led by UNESCO with its partners in the aftermath of the COVID-19 pandemic. These discussions explored alternatives to traditional open laboratory models, where researchers were typically trained through on-site, hands-on access to equipment. The idea of researchers in the Global South sending their samples, a technician in the host laboratory can mount and prepare them, while the measurements themselves can be conducted remotely, was tempting. In this way, data acquisition can take place from anywhere in the world, often during periods when the instrument would otherwise be idle.

In February 2023, UNESCO formalized this vision by signing a Memorandum of Understanding (MoU) with the International Union of Crystallography (IUCr) and the Centre National de la Recherche Scientifique (CNRS). This partnership aimed to provide early-career African scientists with remote access to single-crystal X-ray diffractometers located at the University of Lorraine in France.

Building on the initial success of this collaboration, the Section for Basic Sciences, Research, Innovation and Engineering at UNESCO, led by Amal Kasry, the Chief of the Section, launched the UNESRALE Initiative (<https://www.unesco.org/en/basic-sciences-engineering/remote-access>). This initiative seeks to scale up the model by increasing the



range of accessible equipment and expanding its reach to a broader community of researchers across Africa and other regions in need of scientific resources.

AM: How is this concept implemented in practice?

PR: To operationalise the initiative, UNESCO has identified suitable partners who can offer access to their equipment and/or computational resources and launched calls for access that are based on selection and merit. In some collaborations, researchers in the Global South act as a liaison and will ultimately perform measurements on behalf of colleagues at their home institution. In all cases, researchers were encouraged to share the knowledge they have gained and utilize the remote access to equipment for research and educational purposes. Importantly, the application is not for a single experiment, but for sustained access to the facility over an extended period.

For example, in a recent call concerning access to a single-crystal X-ray diffractometer, researchers from fourteen African UNESCO Member States were trained, illustrating the targeted effort to broaden participation across the continent.

The selected liaison investigator spends approximately one month at the host laboratory, acquiring hands-on experience in measurement protocols, data analysis, and interpretation. Upon returning home, this individual becomes the local expert, coordinating and conducting measurements remotely for their institution. However, with other techniques, full remote modalities are currently done, including remote access to high-performance computing, quantum computing and microscopy.

▲
**Portrait
by Reyer
Boxem**

AM: What are the benefits for the instrument owners participating in this scheme?

PR: First and foremost, there is the intrinsic reward of enabling scientists—particularly in Africa and other under-resourced regions—to access advanced instrumentation without the need to travel. Access to state-of-the-art facilities remains a major bottleneck in many parts of the world, contributing to a persistent knowledge gap between North and South. This initiative directly addresses that imbalance.

By 2026, the UNESRALE Initiative had facilitated remote access and training for 39 participants across seven different scientific techniques, in collaboration with eight partners. The indirect beneficiaries number extend to 200.

AM: How have you personally contributed to the initiative?

PR: I have supported it in several ways. Upon my retirement, I invited colleagues to contribute to the initiative in lieu of personal gifts. While the amount raised was modest, I hope that if many others adopt a similar approach, these individual contributions will collectively have a meaningful impact. For those who would like to financially support the initiative, here is the link: https://www.paypal.com/donate/?hosted_button_id=GEMF5KRTNQ5XY

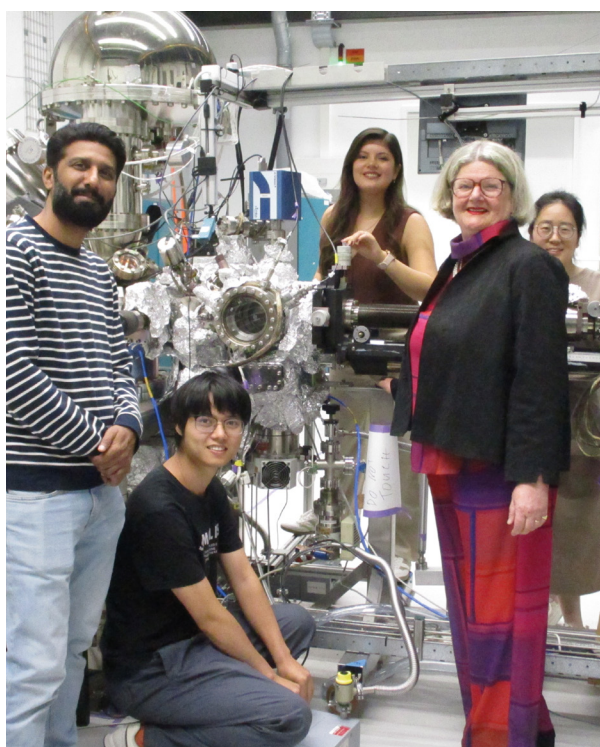
Secondly, my successor, Antonija Grubišić Čabo, together with her technician Dominic Gerlach, is currently preparing our X-ray photoelectron spectrometer for remote operation within the framework of the initiative. At present, a former PhD student of mine—now a professor in Latin America—is conducting test measurements on samples she sent to Groningen. This serves to refine the workflow and resolve any remaining technical issues. Once fully operational in remote access, the instrument will be made available through UNESCO's programme.

Finally, I actively promote the initiative at European conferences to encourage instrument owners to participate, and at conferences in Africa to raise awareness among potential users.

If these efforts ultimately contribute to mitigating brain drain—by enabling talented scientists to pursue high-level research without leaving their home countries—I would consider that a particularly meaningful outcome. ■

■ **Antigone Marino,**

National Research Council (CNR)



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Advanced software sharpens scintillation images of low-energy gamma rays

DOI: <https://doi.org/10.1051/epn/2026304>

By combining a monolithic scintillation detector with analytical and machine learning methods, researchers have pushed its resolution beyond the limits of its hardware when measuring low-energy gamma rays.

Scintillation detectors are vital tools in fields ranging from medical imaging to fundamental physics. When excited by ionizing radiation, they emit pulses of light which can be converted into electrical signals, allowing researchers to precisely determine the energy and intensity of incoming radiation. So far, however, most detector designs have been limited to segmented crystals, which are both complex to manufacture and leave dead spaces between segments that limit their efficiency. While the problem is now being addressed in measurements of higher-energy radiation, low-energy detectors have fallen behind.

In a new study published in EPJ Techniques and Instrumentation, researchers have demonstrated how low-energy gamma rays can be precisely measured using scintillation detectors made from continuous, monolithic crystals. Carried out by Gabriel Turturica, Bogdan Temelie, and Violeta Iancu at the Extreme Light Infrastructure – Nuclear Physics (ELI-NP), Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, the approach could unlock new capabilities for radiation detection across a diverse array of fields.

The ELI-NP is part of the Extreme Light Infrastructure (ELI): a network of high-power laser facilities in Romania, Hungary, and the Czech Republic, which use powerful lasers to generate ultra-short pulses of high-energy photons, electrons, protons, and neutrons. To date, it is the largest and most advanced high-power laser infrastructure anywhere in the world.

Using the ELI-NP's resources, Turturica, Temelie, and Iancu coupled a thin, monolithic scintillating crystal to a silicon photomultiplier array, which vastly amplifies the electrical signal produced by incident light. Alongside this, the team developed two computational methods to analyse the detector's pixellated readout.

By analysing how light intensity is distributed across clusters of neighbouring pixels, each method aimed to identify the precise position within the crystal where an incoming gamma ray deposited its energy – achieving resolutions finer than a single pixel. While this has already been achieved in previous studies, it has always involved higher-energy gamma ray photons, which created far more distinctive intensity distributions. To capture the more subtle distributions created by lower-energy photons, a more purposeful approach would be needed.

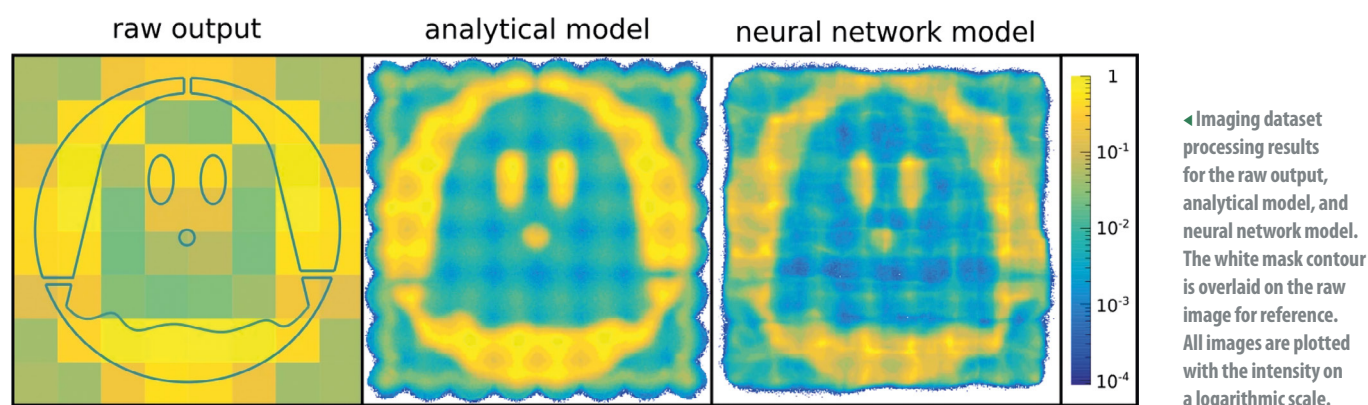
The team tested two different methods: using an analytical model, they applied a mathematical formula describing how light spreads across the pixel array, then fitted the observed intensity pattern to estimate the interaction position. Alternatively, using a neural network, they trained a model to learn the relationship between intensity patterns and interaction positions from data, then applied it to new measurements.

Both approaches proved highly effective, allowing the detector to localise photon-crystal interactions at resolutions far exceeding those of the raw pixel array. The results clearly demonstrate how software can overcome inherent hardware limitations, enabling low-energy gamma ray imaging at resolutions beyond those offered by the detector hardware alone.

This could ultimately enhance radiation imaging capabilities across areas as wide-ranging as nuclear spectroscopy, industrial inspection, and medical imaging techniques, including CT and PET scans. ■

Reference

- [1] G.V. Turturica, B. Temelie, & V. Iancu, *EPJ Techn Instrum* **13**, 1 (2026) <https://doi.org/10.1140/epjti/s40485-026-00120-2>



EPL: 40 Years as Your Letters Journal



Celebrating 40 years of EPL
1986–2026

DOI: <https://doi.org/10.1051/epn/2026305>

With a palpable sense of breathless urgency, an announcement headed “Your Letters Journal” appeared in the June 1985 issue of *Europhysics News* [1] to herald the birth of *Europhysics Letters* – a journal that belongs to the international community of physics researchers. Forty years on, we at EPL (as it is now called) thought it appropriate to pause and reflect on the unique qualities that deliver on this initial promise.

Independent, not-for-profit

With the rise of the internet and a multiplicity of new channels for disseminating scientific research, scientists are increasingly debating the question of who owns and controls these outputs. Already in 1985 the European Physical Society (EPS) had an answer to this question, made concrete through the ownership and governance structure of its fledgling journal.

“The coownership governance model of EPL (*Europhysics Letters*) – originally created by and today shared by multiple European physical societies – offers a strong advantage in serving the physics research community by aligning the journal’s strategic direction with the collective interests of the discipline. This structure ensures editorial independence, scientific breadth and community trust, as the journal’s strategy is shaped by a diverse set of learned societies representing different subfields, geographies and research cultures. It also reinforces EPL’s mission to prioritise scientific quality and rapid dissemination, while enabling reinvestment of surpluses back into the community through society activities.”
– EPLA Board of Directors

Although the details have changed over the years, a single common thread runs throughout: partnership. At present, the journal is directed by the not-for-profit EPL Association, with the European, Italian and French Physical Societies and the UK’s

Institute of Physics as the major partners. A further thirteen national physical societies are also represented on the EPLA Board of Directors.

The European dimension

The integrity of the scientific record has also come under intense scrutiny over the past four decades. At EPL, this integrity is assured by sitting under the scientific direction of the EPS, responsible for the appointment of the Editor-in-Chief and the editorial board members who handle manuscripts. It is this collective effort that the Euro- prefix in the journal’s original name was intended to signify. The journal has always served the entire international physics community, and today over half of the published Letters originate from China, India or the United States. In rebranding as EPL in 2007, the journal further affirmed its position as a globally trusted venue for high-quality research.

By scientists, for scientists

EPL publishes letters across all topics in physics, and right from inception the journal has taken the view, articulated in the aphorism attributed to George Marx, that physics is what physicists do. Vital in keeping this spirit alive is an editorial board that is drawn from the same body as the journal’s authors and readers: practising research physicists. At EPL, members of the editorial board are called Co-Editors, this unusual term reflecting the partnership they form in asserting the scope of the journal and maintaining high scientific standards through rigorous peer review. We are furthermore guided by our experiences as authors and reviewers, acting with the professionalism and integrity we expect of editors when performing those other roles.

We refresh the editorial board annually, and with an upper limit on any Co-Editor’s maximum term, the journal continually moves the times and remains relevant. Three Deputy Editors assist the Editor-in-Chief in strategic matters and in commissioning the journal’s unique series of Perspectives, these being brief, accessible points of view on research at the frontiers of physics.

“What makes EPL special is that it is run by scientists and supported by an Editorial Office who know and understand our community with all its quirks! These staff are astoundingly efficient and possess an encyclopaedic memory of relevant interactions in EPL history; their advice is always timely (and good-humoured!) and their role indispensable even, or perhaps especially, in the age of artificial intelligence.” – Rosemary Harris, Deputy Editor

“I would highlight the Perspectives series: the fact that these are commissioned from a curated list of researchers and that invited authors are given genuine leeway to offer a personal point of view rather than a conventional review.” – Pablo Cornaglia, Deputy Editor

“EPL has a team of Co-Editors that is outstanding in its number, variety and quality; this allows EPL to competently cover virtually all areas of physics and ensure a fair and efficient refereeing process.”
– Dario Benedetti, Deputy Editor

The personal touch

With an editorial board spread across the globe, operating in different time-zones and around their other scientific activities, much precise coordination is required. Following submission, a paper's journey begins at the EPS Editorial Office in Mulhouse, France, and after careful checking is presented to a qualified Co-Editor for consideration. The Editorial Office staff keep editors, reviewers and

"For me, EPL has always stood for a particularly productive combination of qualities – high standards, intellectual openness, and opportunity. It is an ideal home for innovative physics: work that is technically strong, fresh in its perspective, ambitious in its implications, and capable of stimulating activity across established boundaries. Serving as a Co-Editor of EPL places one at the very heart of scientific development, close to the questions, methods, and emerging results that matter most. It is like having one of the finest seats in the theatre of science, seeing important discoveries before they formally enter the literature."

– Matjaž Perc, Co-Editor 2015-22

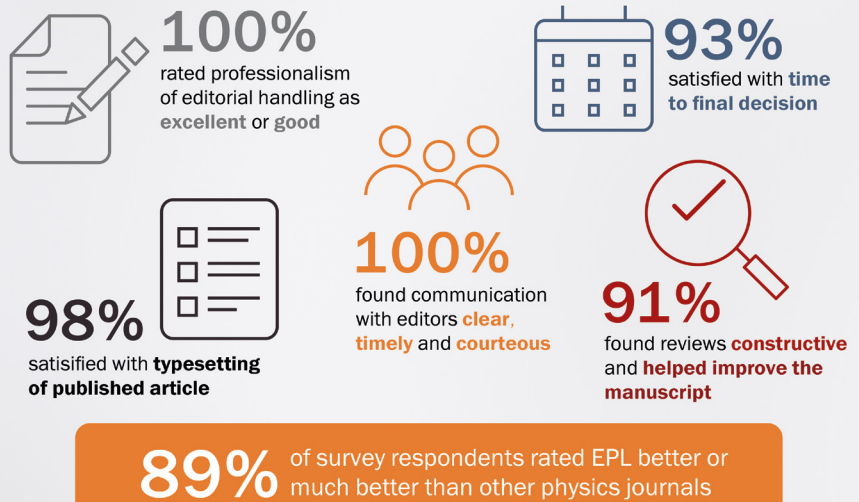
"I like that EPL really goes for great novel physics and creative ideas rather than looking at potential citation rates of an article after acceptance. Being a Co-Editors gives bright young people a chance, at the same time supported by very established senior scientists."

– Christian Beck, Co-Editor 2015-21

"The motivation, in part, for the creation of EPL was as a European counterpart to PRL. It still served that function when I was a Co-Editor: PRL was still seen as the place where large collaborations, particularly in particle physics and astronomy, published their results, and EPL seemed more attuned to those of us not working in these areas and carrying out theoretical work. This was especially true in my area of statistical mechanics."

– Alan McKane, Co-Editor 2011-14

Editorial Process



authors informed throughout the review process. Accepted papers pass to the SIF Production Team in Bologna, Italy, for copy editing and typesetting before being published by IOP Publishing in Bristol, UK.

It is crucial that we hide the complexity of this process from authors as much as possible. To see if we succeed, we have started gathering feedback from authors of accepted manuscripts [2]. Figure 1 shows that this is overwhelmingly the case: 89% of respondents find EPL's editorial process superior to that of other physics journals. This appreciation is echoed by the authors

▲ FIG. 1: Infographic arising from the author feedback survey.

"With its dedicated Editorial Office, EPL offers a premium service to authors and reviewers. Supported by highly active Co-Editors and an engaged leadership team, we provide a personalised publishing partnership. Join the EPL family to experience it!"

– Frédéric Burr, EPL Staff Editor

▼ FIG. 2: An EPL article featured in *Physics World*.

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Loop quantum cosmology may explain smoothness of cosmic microwave background

Repulsive gravity at the quantum scale would have flattened out inhomogeneities in the early universe

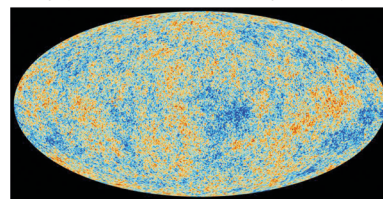


FIG. 1: The cosmic microwave background, as imaged by the European Space Agency's Planck mission.

In classical physics, gravity is universally attractive. At the quantum level, however, this may not always be the case. If quantum gravity is present within an inflationary universe – at the centre of a black hole, for example, or during the very earliest moments of the universe – space-time becomes curved at scales that approach the Planck length. This is the fundamental quantum unit of distance, and is around 10^{35} times smaller than a proton.

In these extremely curved regions, the classical theory of gravity – Einstein's general theory of relativity – breaks down. However, research in loop quantum cosmology offers a possible solution. It suggests that gravity, instead of being purely attractive, becomes repulsive. Consequently, loop quantum cosmology predicts that our present universe began in a so-called 'big bounce', rather than the Big Bang singularity predicted by general relativity.

In a recent paper published in *EPL*, Edward Wilson-Lewis, a mathematical physicist at the University of New Brunswick, Canada, explores the interplay

between loop quantum cosmology and a phenomenon sometimes described as 'the echo of the Big Bang': the cosmic microwave background (CMB). This background radiation pervades the entire visible universe, and it stems from the moment the universe became cool enough for neutral atoms to form. At this point, light was suddenly able to travel through space without being continually scattered by the plasma of electrons and light nuclei that existed before. It is this freely traveling light that makes up the CMB, so studying it offers clues to what the early universe was like.

What was the motivation for your research?

One vision of the CMB holds that the early universe (that is, the universe as it was when the CMB formed) was extremely homogeneous, with relative anisotropies of the order of one part in 10^5 . Classical general relativity has trouble explaining this homogeneity on its own, because a perfectly attractive version of gravity tends to drive

things in the opposite direction. This is because if a region has higher density than the surrounding area, then according to general relativity, that region will become even denser: there is more mass in that region and therefore particles surrounding it will be attracted to it. Indeed, this is how the small inhomogeneities we do see in the CMB grew over time to form stars and galaxies today.

The main way this gets resolved in classical general relativity is to suggest that the universe experienced an episode of super-rapid growth in its earliest moments. This super-rapid growth is known as inflation, and it can suffice to generate homogeneous regions. However, in general, this requires a very large amount of inflation (much more than is typically considered in most models).

Alternatively, if for some reason there happens to be a region that is moderately homogeneous when inflation starts, this region will increase exponentially in size while the surrounding further homogenizes.



Comment: Edward Wilson-Lewis explains loop quantum gravity to study quantum effects in the very early universe.

This second possibility requires a little more than a minimal amount of inflation, but not much more.

My goal in this work was to explore whether, if gravity becomes repulsive in the deep quantum regime (as is the case in loop quantum cosmology), this will tend to flatten regions of higher density, leading to inhomogeneities being smoothed out. In other words, one of the main objectives of this work was to find out whether quantum gravity could be the source of the high degree of homogeneity observed in the CMB.

What did you do in the paper?

In this paper, I studied spherical symmetry (space-times coupled to dust) in simple models for matter in loop quantum cosmology. These space-times have homogeneities in the radial direction. They therefore provide an ideal arena to explore whether homogeneities can occur that are completely smooth in the angular directions (which, in general, are very hard to handle).

Loop quantum cosmology predicts several kinds of quantum effects. One of these effects is that space-time, at the quantum level, is discrete: there are gaps in space-time just as there are quanta of matter. This has implications for the geometry of space-time to the matter itself. If we take into account the discrete nature of quantum geometry, this has implications for the geometry of space-time to the matter itself. If we take into account the discrete nature of quantum geometry, this has implications for the geometry of space-time to the matter itself. If we take into account the discrete nature of quantum geometry, this has implications for the geometry of space-time to the matter itself.

These modifications are captured by so-called effective equations, and in the paper I solved these equations numerically for a

It is important to extend this work in several directions to check the robustness of the homogenization effect in loop quantum cosmology

wide range of initial conditions. From this, I found that while homogenization doesn't occur everywhere, it does occur in some regions. These homogenized regions can then be blown up to cosmological scales by inflation (and inflation will further homogenize them). Therefore, this quantum gravity homogenization process could indeed explain the homogeneity observed in the CMB.

What do you plan to do next?

It is important to extend this work in several directions to check the robustness of the homogenization effect in loop quantum cosmology. The restriction to spherical symmetry should be relaxed, although this will be challenging from a mathematical perspective. It will also be important to go beyond dust as a description of matter. The simplicity of dust makes calculations easier, but it is not particularly realistic.

Other relevant forms of matter include radiation and the so-called inflaton field, which is a type of matter that can cause inflation to occur. That said, in cosmology, the physics is to some extent independent of the universe's matter content, at least at a qualitative level. This is because while different types of matter content may dilute more rapidly than others in an expanding universe, and the universe may expand at different rates depending on its matter content, the main properties of the cosmological dynamics (for example, the expanding universe, the occurrence of an initial singularity and so on) within general relativity are independent of the specific matter being considered.

Therefore, one can reasonably expect that the quantitative predictions will depend on the matter content, but the qualitative features (in particular, that small regions are homogenized by quantum gravity) will remain the same. Still, further research is needed in particular that small regions are homogenized by quantum gravity will remain the same. Still, further research is needed to test this expectation.

EPL A LETTERS JOURNAL EDITED BY FRÉDÉRIC BURR
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This article was written by Physics World as part of the EPL 50th anniversary celebration. Read more on physicsworld.com.

"The partnership with Physics World was a valuable opportunity to have my research highlighted, and as a result my research article received a lot more attention, especially from a more general audience, than it would have otherwise. I was told there were over 2400 page views after 5 days of going live and I imagine that number has grown since then."

– Edward Wilson Ewing, EPL Contributor and current Co-Editor

"It was exciting to see a scientific paper become podcast. It was our first such experience, and it was a success. The pleasant informal chat we had with Margaret Harris was magically turned into a piece that was listened to by thousands... It amplified the reach of our work and reinforced our intention to stimulate curiosity in ecological applications of statistical physics."

– Silvia De Monte and Ada Altieri, EPL Contributors

"We had a very fruitful interaction with science journalist Margaret Harris at Physics World about our research on airborne wind energy which was instrumental in highlighting broader implications."

– Antonio Celani, EPL Contributor

"Describing my work on epidemics and pandemics was a really nice opportunity

to communicate to a broader physics audience. I think it is a great idea to do these pieces that is another level of science dissemination, somewhere between a paper for technical specialists and lay public communication, which necessarily is somewhat 'dumbed-down'."

– Bhavin Khatri, EPL Contributor

"I had an extremely positive experience with EPL and Physics World. We discussed our invited Perspective on animate droplets on a Physics World podcast. This collaboration was very professional and was an effective and fun way to amplify our scientific ideas and their reach beyond the traditional journal format."

– Giorgio Volpe, EPL Contributor

"I've been impressed by the enthusiasm of the EPL authors I've worked with as part of the EPL/Physics World sponsored content programme. They're truly excited not only about the science they're doing, but about the prospect of communicating that science with people in the wider physics community. At a time when scientific research is under increased pressure from many directions, this is particularly important and refreshing to see."

– Margaret Harris, Online Editor, Physics World

Physics World (coincidentally also published by IOP Publishing) as our partner to showcase treasured highlights [5]. Here we don't merely communicate cutting-edge science in a more accessible way. We also go behind the scenes to glimpse into human aspects of research that are often overlooked: where the inspiration came from, what was involved in doing the work and where the field is going.

To the next forty years

In drawing together this reflection of EPL's special place among physics journals, one thing has become abundantly clear. The journal succeeds not just because of the high quality of the published research, but because of the support and commitment to our values from the community that sits behind it. You might be aware from recent announcements that a new chapter in EPL's history is about to open, with production and publication of accepted manuscripts being taken over by OUP. Our experience in working in partnership with organisations that share our values promises a smooth transition for all of us involved with EPL. ■

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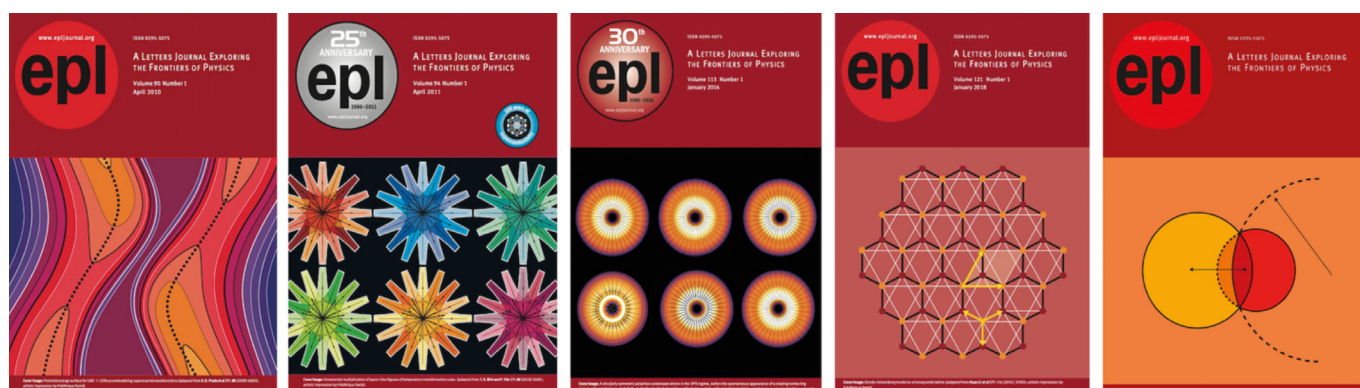
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▼ FIG. 3: A selection of EPL covers from 2010 to 2019, illustrating a decade of scientific diversity.

we have reconnected with during our anniversary year as we revisit highlights from the decade 2010-19 [3], this bringing us up to speed with developments since our 25th anniversary retrospective [4].

Reaching a wider audience

As part of our service to the community, EPL is now bringing our authors' research to audiences beyond our immediate readership. After careful deliberation we selected



From control to collective intelligence

by Olivier Dauchot,

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DOI: <https://doi.org/10.1051/epn/2026306>

Drones have rapidly moved from technological curiosities to highly capable autonomous systems, transforming fields as diverse as environmental monitoring, infrastructure inspection, entertainment, and, increasingly, warfare. What makes them so compelling is not merely their mechanical sophistication, but the broader scientific questions they raise.

At first sight, the challenge seems to be one of control. How do we make a flying machine perceive its environment, make decisions, and execute them reliably? As Carlo Bosio and Mark Mueller illustrate in this issue, autonomy is already a remarkable systems-engineering achievement, where mechanics, sensing, computation and control must be carefully integrated. But as soon as one moves from individual drones to swarms, the problem changes in nature.

As stressed by Gábor Vásárhelyi centralized architecture offers predictability, global optimization, and clear human oversight. Such systems have demonstrated extraordinary capabilities, from coordinated drone shows involving thousands of units to highly reliable industrial deployments. Yet nature teaches us a very different lesson. Fish schools, bird flocks, insect swarms, or human crowds do not rely on a central planner. Coordination emerges from local interactions, imperfect information, and decentralized decisions. As explored in this issue, the scientific community is increasingly drawing inspiration from such natural systems to design drone swarms capable of robust, decentralized coordination.

The contrast between centralized and decentralized control is intellectually stimulating, but perhaps it is not the deepest one. Both remain, ultimately, paradigms of control. Whether decisions are imposed from above or negotiated locally, the behavioural rules remain fixed by design. The next conceptual leap may lie elsewhere: in systems able not merely to follow prescribed rules, but to modify them through experience. This is where social learning enters the picture.

In many biological systems, information propagates socially: through imitation, communication, shared environmental traces, or collective inference. A group becomes more capable than its members because experience becomes a distributed collective resource. The question is no longer simply how to coordinate agents, but how to allow a collective to adapt, discover, and improve under uncertainty. In such systems, intelligence is not localized in a central controller, nor entirely within each unit. It emerges in the interactions themselves.

Once phrased this way, the implications go far beyond drones. The same conceptual questions now arise across material science, robotics, and complex engineered systems. Can a material adapt its function rather than merely execute a design?

Physicists may find these questions familiar. After all, our discipline has long sought to understand how collective behaviour emerges from local interactions. From this point of view, collective intelligence is a form of collective behaviour that emerge from social interactions.

This opens extraordinary possibilities. Adaptive robotic collectives, intelligent metamaterials, autonomous infrastructures, responsive biohybrid systems: the prospect is not simply to build machines that act, but systems that become.

And yet, in the case of drones, this promise comes with an unavoidable shadow. The same technologies that may improve disaster response, environmental exploration, or collective logistics are also rapidly reshaping modern conflict. Autonomous swarms can extend human capabilities—but also amplify destruction, reduce accountability, and shift critical decisions ever further from direct human control. As often in physics-driven innovation, the scientific questions are fascinating, the technological possibilities immense, but the societal consequences impossible to ignore. ■



DESIGN OF AUTONOMOUS DRONES

■ Carlo Bosio and Mark W. Mueller – DOI: <https://doi.org/10.1051/eprn/2026307>

■ University of California, Berkeley, USA

Drones are fundamentally changing fields such as transportation, environmental monitoring, and warfare [1]. Keys to their widespread use is their increasing levels of autonomy and their low cost. In this feature, we give insights into how autonomous drones are designed and where the technology is headed.

What is a drone?

Modern aerial robots (commonly known as “drones”) are tightly integrated physical systems in which structure, propulsion, sensing, computation, and control must all work together reliably to achieve autonomous flight.

They come in many different shapes and sizes, but all share the basic design principles and components. The two most common types of drones are multirotors and fixed-wing aircraft, the main difference between the two being how the vertical force needed to counteract gravity is produced. In the case of multirotors, thrust is produced by multiple rotating propellers (typically, 4 or more), while in the case of fixed-wing drones it is produced by a wing translating in air at high speed.

While full-scale helicopters offer similar vertical capabilities to multirotors, they are rare at smaller scales due to their high mechanical complexity – specifically the swash-plate rotor linkages. Multirotors replace these complex mechanical parts with electronics and algorithms, a trade-off that scales more favorably in terms of cost and reliability.

Multirotors and fixed-wing drone designs are motivated by different needs: the ability to hover in place and high maneuverability in the first case, long range, flight time, and speed in the second. Hybrid designs combining the two design principles exist, enabling Vertical Take-Off and Landing (VTOL) capabilities

as well as long range flight. Fig. 2 shows a quadcopter, one of the most common drone designs, with the fundamental structural, actuation and autonomy stack components.

At its core, a quadcopter has four motors with parallel axes and four propellers – two spinning clockwise and two counterclockwise. The motors are driven by Electronic Speed Controllers (ESCs), which convert low-level logic signals from the flight controller into three-phase alternating current (AC) signals modulating the motor angular velocity. The main power source is typically a Lithium-polymer battery, owing to these batteries’ high power density.

The flight controller is the main circuit board processing onboard sensor measurements and running high-frequency (but typically low-complexity) feedback control algorithms. A typical flight stack may include:

- Inertial sensors – Rate gyroscopes and Accelerometers: Essential for measuring angular velocity and linear proper acceleration.
- GPS: Providing the spatial telemetry required for global positioning.
- Higher-level autonomy sensors, such as cameras or LiDAR.

Typically, the use of high-throughput sensors such as cameras and LiDAR requires more computationally-intensive algorithms, which require the addition of a more powerful companion computer onboard.

► FIG. 1:

Drone examples. Left: a custom-assembled research quadcopter autonomously coating a solar panel (from [2]). Right: a fixed-wing drone for tornado monitoring (from [3]). The quadcopter maneuverability and ability to hover enable precise navigation in cluttered spaces. The fixed-wing energy efficiency enables long range missions.



Design trade-offs

Drone designs are typically a compromise between competing design objectives, such as endurance, agility, robustness, and cost. The main parameter affecting a drone's performance is its mass. Reducing the total mass usually leads to improvements towards different design objectives at the same time.

In applications where flight time or range are the main objectives, such as environmental monitoring or payload transportation, efficiency and power consumption are the main aspects to optimize. Central to this is, for example, the relationship between propeller diameter and propulsive efficiency. All else being equal, larger propellers are more energy efficient than smaller propellers – the same momentum flux over a larger propeller disk area leads to lower induced air velocity and thus less power.

The battery mass is proportional to the stored energy, however, increasing the battery size does not necessarily increase flight time. For a given vehicle, there is an optimal value of battery mass beyond which the energy cost of carrying the additional weight outweighs the added capacity, causing total flight time to decrease.

In applications where speed and maneuverability are the primary objectives – such as drone racing – the design is dictated by rotational inertia and actuator authority. Minimizing the vehicle's inertia allows for higher angular accelerations. The drive toward low inertia inherently favors compact airframes, which offers the secondary benefit of reduced aerodynamic drag when in forward flight, thereby increasing cruise speed. High thrust-to-weight ratio and

actuator authority enable the drone to sustain aggressive aerobatic maneuvers and produce high accelerations.

In situations requiring precise control, such as landing or payload pick-up and drop-off, robustness to disturbances (*e.g.*, wind gusts) is the main performance metric. In this case, higher mass and inertia make a system less sensitive to external forces, but may also reduce actuator effectiveness (due *e.g.* to smaller margins from saturation). Control authority is, in general, a crucial aspect for robustness. Robustness to collisions is another aspect of practical interest, for which a typical approach is adding an outer protective structure to the vehicle [4].

These general design principles can be extended to specific application-driven needs. Interesting examples are morphing drones, which are able to change their shape based on the desired operating regime, and switch on the fly between a more agile and a more robust configuration.

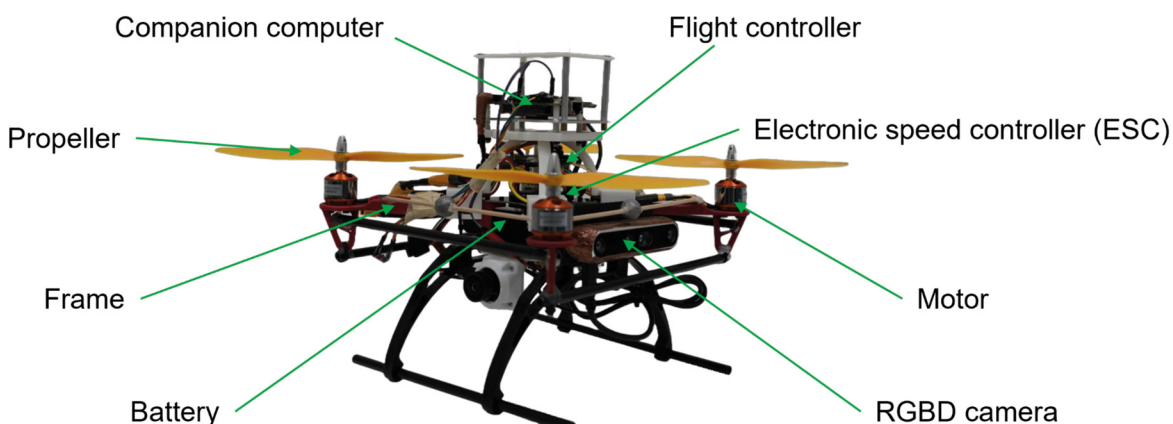
In general, drone design has a deep interplay with the autonomy stack. Sensor placement affects the system inertia as well as localization performances. Similarly, actuator placement affects mass properties as well as control authority and robustness to disturbances. Further, a smart morphology design can drastically simplify the control algorithms, for instance, adding an external collision-resilient structure to a drone allows to simplify collision avoidance algorithms.

Automated design

Autonomous drone design is a complex multi-objective optimization problem, requiring a holistic, system-level approach. Autonomy necessitates a hardware-software

► FIG. 2:

Diagram of a custom research quadcopter and its main components.



co-design strategy where every component is tightly integrated, and enables rapid development cycles unconstrained by the safety requirements of human-on-board aviation. Unlike traditional aerospace engineering – often having decade-long development timelines – autonomous drones leverage rapid prototyping, high-fidelity physics simulations, and advanced control algorithms to achieve fast design iterations and testing. Consequently, drones are evolving into bespoke tools that can be tailored to the specific requirements of a given mission.

This design shift raises a fundamental question for the future of the ecosystem: can modern optimization and machine learning frameworks automate the synthesis of task-specific drone designs? [5,6,7] By treating the design process as an end-to-end pipeline – generating candidate architectures, testing and discarding sub-optimal configurations via simulation, and autonomously validating the best performing designs in the real world – we can drastically compress the design cycle. Such an automated paradigm would not only optimize performance but accelerate the deployment of autonomous systems into increasingly more complex and unstructured environments. ■

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Carlo Bosio is a PhD Student in at UC Berkeley. His research interests are in robotics, optimization, and computational design. He received a BSc and MSc in Mechanical Engineering from the University of Pisa, Italy.



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DRONE SWARMS: IS THE FUTURE CENTRALIZED OR DECENTRALIZED?

■ Gábor Vásárhelyi^{1,2} – vasarhelyi@hal.elte.hu – DOI: <https://doi.org/10.1051/epn/2026308>

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Drone swarms are disruptively transforming our life. While most scientists envision future drone swarms in decentralized bee-like self-organization, the largest real-world swarms in drone shows or military operations evolved to be centrally controlled. This article examines this discrepancy, comparing advantages, limitations, and practical applications of centralized and decentralized drone operations.

▲ FIG 1:
Drone show at the
Malta International
Fireworks Festival,
2026 (1000
drones). Credits:
Pyroemotions, Malta

With our research team we have spent the last decades developing large autonomous drone swarms inspired by biological self-organization [1], the natural basis of collective behavior observed all around us. We developed reliable decentralized drone control models and demonstrated their stability using 50–100 real outdoor quadcopters and up to 5000 simulated ones in bird-like flocking experiments [2] and dense aerial traffic scenarios [3].

Through our research projects and our strong commitment to bio-inspired systems, we blindly believed from the very beginning that decentralization represented the inevitable and only future of drone swarms. To respond to the significant interest in the scientific concepts and technological capabilities behind our work, we founded a university spin-off in 2015, but the real market demand for large-scale decentralized autonomous drone swarms did not truly arrive ever since in practical applications.

In the meantime, real market opportunities for drone fleets emerged in the entertainment industry, where drone shows became a disruptive new tool for marketing and storytelling at large outdoor events [4]. As a result, we gradually evolved into a drone show company and later became the developers of the open-source drone show and swarm control platform, Skybrush [5]. Since competition in this field primarily focuses on scaling swarm size at minimal cost while delivering precisely choreographed performances, this journey ultimately provided us with extensive practical experience in the centralized control of some of the largest drone swarms ever flown.

Based on this dual expertise, the following discussion compares centralized and decentralized control schemes from the operator's perspective and explores why fully controlled drone systems have so far gained far wider adoption than autonomous ones.

Decentralized control

Decentralized control means that low-level decisions regarding a drone's flight and actions are not issued by a central control unit but are instead made by the drone itself based on its own state estimation of the environment, nearby drones, and its own condition [6]. In such systems, drones must be fully autonomous, as their safety depends entirely on their own decision-making.

Decentralization is particularly effective when operators can delegate responsibility to the drones themselves, especially during flight scenarios that require real-time adaptation of trajectories or actions beyond what a human operator could manage alone. In this sense, decentralization can be understood as a form of teamwork with shared responsibilities between humans and robots.

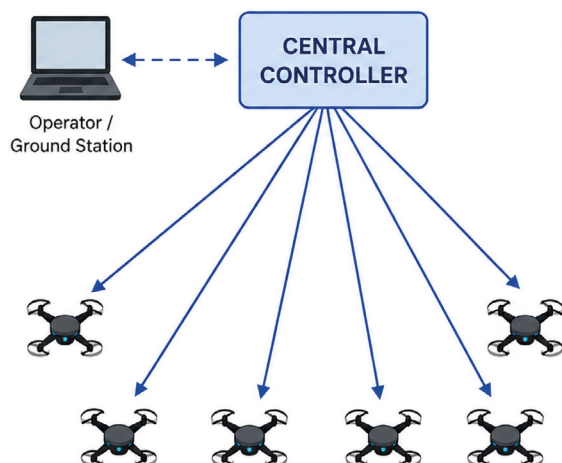
However, in decentralized drone swarm systems, operators must also understand that they define only the “what” of the operation, not the “how”. In truly decentralized systems, the operator provides a high-level mission briefing—describing what to do, what to search for, and how to interact with the environment—while the detailed execution is left to the swarm [7]. Individual drones are not treated as unique agents but as interchangeable units; trajectories are not pre-planned, and only a limited set of global parameters, such as the operational area or preferred flight speed, are shared. The drones then negotiate and coordinate their actual flight plans among themselves in real time.

Note that this mode of operation is only “locally rational” rather than globally optimal, and from a control perspective it is inherently less transparent and predictable. Due to the ambiguity that real-time interactions define system behavior, formally guaranteeing safety, correctness, or regulatory compliance becomes significantly more difficult. These characteristics can also increase the perceived stress level of operators, authorities and customers, and this is particularly true in the broader historical context of commercial drones, where users have been conditioned from the very beginning to view the drone as a service unit fully under their control. Few drone operators are willing to give up this status quo, especially when already facing the increased complexity associated with the transition from operating a single drone to managing entire drone swarms.

Drone-to-drone communication in decentralized systems is often kept broadcast-only, as this minimizes communication delays and naturally favors reliability among nearby drones (communication power decays quickly with distance). This local interaction structure can enhance overall stability and make the system more ●●●

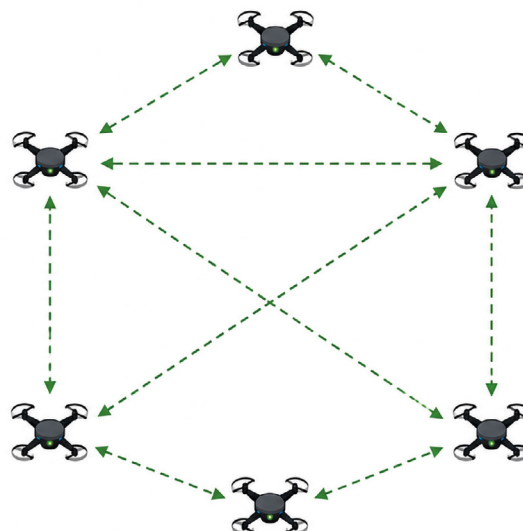
CENTRALIZED CONTROL

One central unit makes decisions and assigns commands to all drones.



DECENTRALIZED CONTROL

Each drone makes decisions based on local information and communicates with neighbors.



◀ FIG 2: Communication architecture of centralized and decentralized systems. Credits: OpenAI ChatGPT (GPT-5.5).

●●● resilient to communication outages from a ground control station. However, this approach also introduces additional challenges. In broadcast-only communication schemes, explicit acknowledgements are absent, requiring drones to rely more heavily on onboard mechanisms to infer whether their messages have been successfully received and processed by others [8].

A critical demand of decentralized systems is the ability of each agent to take care of itself also in failsafe modes out of the context of normal operations, and this requires an even higher level of self-awareness together with complex failsafe logic. Operators of manually controlled drones often underestimate the complexity of such autonomy, as they naturally compensate for unexpected behavior—such as incorrect altitude, unstable movement, or proximity to obstacles—through their own vision and manual intervention, often without realizing how much intelligent decision-making and situational awareness these corrective actions require.

Decentralized systems are also often described as highly scalable due to the absence of centrally overloaded infrastructure. However, in practice, scaling such systems is one of the most challenging problems, largely due to emergent phenomena arising from the complex and often unpredictable, chaotic dynamics of locally interacting swarm systems. Similarly, they are frequently characterized as robust and redundant, which ensures graceful degradation in case of individual failures. Yet their inherently non-deterministic nature can also work against

robustness, and redundancy can, in principle, be achieved within centralized architectures as well.

Centralized control

By centralized control, we refer to a system in which a ground station prepares the flight operation before deployment or adapts it during flight, while continuously specifying exact actions for each drone based on globally collected information. When functioning properly, centralized control is considerably less stressful for the human operator. Centralized control often gets portrayed as “less elegant” than decentralized swarms, but in practice it has a set of very strong, very pragmatic advantages—especially when reliability, certification, and human oversight matter more than biological inspiration [9]. While my admiration and respect for nature and its intriguing complexity will never diminish, there are important details in which we can simply do better than that with technology.

Centralized systems are inherently more predictable because a single entity defines all trajectories and decisions. A central planner can take a full “bird’s-eye view” of the swarm. This allows for globally optimized trajectories, energy usage, coverage patterns, or collision avoidance strategies that individual agents could not easily compute on their own [10]. In such systems, swarm behavior can be fully deterministic in both space and time. Individual drones follow dedicated flight paths that can be monitored reliably. This makes missions repeatable, which is crucial for applications like aerial

▼ **TABLE 1:**
Brief comparison of
centralized
and decentralized
systems.

ASPECT	CENTRALIZED CONTROL	DECENTRALIZED CONTROL
Decision-making	All decisions made by a ground station or central planner	Decisions made locally by each drone, onboard
Control philosophy	Top-down, explicitly commanded behavior	Bottom-up, emergent behavior from local interactions
Predictability	High; behavior is deterministic in space and time	Lower; behavior can be non-deterministic and emergent
Global optimization	Strong capability for globally optimal planning	Limited; optimization is local and distributed
Scalability	Limited by computation and communication load on central unit	High in principle, but complex in practice due to interactions
Robustness to agent failure	Moderate; individual failures manageable, but central node is critical	High; no single point of failure at control level
Communication structure	Hierarchical, drone-to-ground dominant, strong dependence on reliable link to central station	Local, often peer-to-peer or broadcast-based, less dependent on long-range communication, more on local links
System complexity location	Centralized (ground station / controller)	Distributed across all agents
Onboard intelligence required	Low; drones execute predefined commands	High; drones must make autonomous decisions
Hardware cost per drone	Lower (simpler agents possible)	Higher (more computation and sensing onboard)
Verification & certification	Easier to test, simulate, and certify	Difficult due to emergent and nonlinear behavior
Failure mode	Potential single point of failure	Gradual degradation rather than collapse
Operator role	Direct control of “what and how”	Defines only “what”; system determines “how”
Adaptability to local changes	Slower; requires central re-planning	Fast; local real-time adaptation
Typical applications	Surveying, inspection, precision agriculture, drone shows	Research systems, exploration, dynamic environments

cinematography, surveying, inspection, or testing, where identical conditions must be reproduced.

Because all decisions originate from one control logic, it is much easier to analyze, test, and certify system behavior. This is a major advantage in aviation contexts, where regulatory compliance and safety guarantees are essential. Centralized control keeps humans firmly in the decision loop. Responsibility, control, and traceability are clearly defined, which is important both legally and operationally. When something goes wrong, it is easier to understand why. While decentralized systems rely on emergent behavior, centralized systems rely on engineered redundancy and explicit fail-safe logic. This can be more predictable in safety-critical environments, even if it introduces a single point of failure at the system level.

A major and many times underestimated advantage of centrally controlled systems is that in this architecture, drones can remain relatively simple, as they do not need to communicate with each other or make complex local decisions. This reduction in onboard complexity can significantly lower unit costs, which becomes a critical advantage when scaling swarm size.

Finally, from a highly practical perspective, while admiring the elegance of decentralization during system design, one must also ask whether such additional complexity is truly necessary. With the current state of technology, centrally controlled systems can already scale to several thousand units while maintaining highly stable communication networks over typical operational distances and achieving centimeter-level navigation. As demonstrated by the world's largest drone swarms in the context of drone shows, such systems can be implemented and operated with remarkable reliability and simplicity.

Summary

As we can see, both centralized and decentralized control architectures have their own advantages, disadvantages, and appropriate application areas. The main aspects of these control architectures can be seen in Table I.

Overall, in most practical systems, a hybrid strategy is likely to be the most effective solution. Decentralization should be applied only where it provides clear benefits—such as last-minute collision avoidance, local conflict resolution, truly adaptive cooperative tasks or preprocessing locally sensed data—while the rest of the system should retain as much deterministic centralized control as possible. ■

About the Author



Gábor Vásárhelyi received his degree in engineering physics from BME, Hungary, in 2003, and earned his PhD in infobionics from PPKE ITK, Hungary, in 2007. He is a researcher at Department of Biological Physics at ELTE and CEO of CollMot Robotics Ltd.

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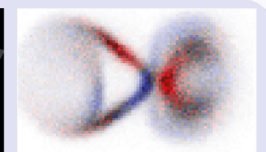
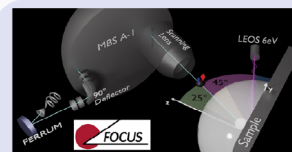
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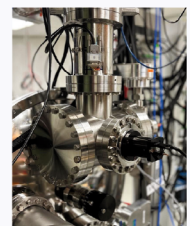
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THE RISE OF INTELLIGENT DRONE SWARMS

■ **Guy Theraulaz¹, Gautier Hattenberger²** – DOI: <https://doi.org/10.1051/epn/2026309>

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In Michael Crichton's *Prey* [1], a cloud of nano-robots escapes human control and becomes something far more unsettling than a machine. It stretches, contracts, reorganizes, and even hunts. It behaves like a living swarm endowed with a form of collective intelligence, even though no single unit possesses a brain (see Striking image). The story was fiction, yet it captured an idea that has become increasingly important in complexity science. When many simple agents interact locally, complex and sometimes surprising behavior can emerge at the level of the group.

▲ From fiction to reality, early visions of autonomous swarms imagined self-organizing clouds of nano-robots, while today similar collective dynamics are explored with real drones interacting through simple local rules (AI-generated picture).

Today, the agents are no longer imaginary nano-bots. They are real drones moving through the air. And one of the most interesting questions in modern collective robotics is how to make these swarms not only coordinated, but also adaptive, robust, and able to reorganize when conditions change.

This idea did not come from engineering alone. Over the past twenty years, researchers have studied how animals move together. Fish schools, bird flocks, insect swarms, and even human crowds have been explored as systems of active matter, meaning groups of self-propelled individuals that self-organize through local interactions rather than central control [2]. One key lesson stands out. Large-scale coordination does not require global knowledge. A fish does not know the shape of the whole school, and a bird does not follow a leader's detailed plan. Instead, each individual reacts

to nearby neighbors using simple interaction rules. These include a tendency to align with others, to keep some distance, and to stay close enough to remain part of the group.

For physicists, this has led to powerful ideas about order and disorder, fluctuations, and phase transitions [3]. For roboticists, it suggests something more practical. Swarms of drones might be controlled using similar principles. This is appealing because animal groups show a remarkable mix of stability and flexibility. They can move as one, change direction quickly, pass through cluttered environments, and recover from disturbances. These are exactly the properties needed for drone swarms in real-world tasks such as monitoring forests, inspecting damaged infrastructure, or exploring complex environments.

The goal is not to copy nature for its own sake. It is to understand how simple local interactions can produce

useful collective behavior, and then use those ideas in engineered systems [4]. This approach is now shaping many areas of robotics. In underwater vehicles, for example, researchers have turned to fish and marine animals to design more agile and efficient machines, rather than relying only on rigid torpedo-like shapes [5]. In both air and water, biological structures such as wings, feathers, and fins have inspired new ways to control fluid flow, improving lift, reducing drag, and enhancing maneuverability, especially for small vehicles.

On the collective side, progress has been just as striking. Drone swarms are increasingly designed to operate without central control. Each unit relies on local information and interacts with nearby neighbors. This reduces the need for heavy communication and makes the system more robust. Experiments with groups of quadcopters have shown that stable flocking is possible even in challenging conditions, including wind, delays, and sensing noise. Other approaches push minimalism further by relying only on vision. In such systems, robots coordinate without GPS, without explicit communication, and without measuring exact positions or velocities, yet they still manage to move together in a coherent way. In parallel, distributed swarm strategies have been developed to adapt spatial coverage in real time, allowing drones to focus on areas of interest while maintaining overall coordination.

Across these studies, a common idea emerges. Robust collective behavior does not require perfect information. It depends more on how agents interact than on how much they know.

A clear example comes from our recent work on bio-inspired drone swarms [6]. In this system, each drone interacts with only a few most influential neighbors and follows two simple rules, alignment and attraction similar as those used by schooling fish (fig. 1). By changing the strength of these interactions, we observed different collective states. In one case, the swarm remains cohesive but loosely organized. In another, it becomes highly aligned and moves as a tight, coordinated group. Between these two states lies a transition region where the system behaves in a very different way (fig. 2).

Near this transition, the swarm is in a critical state and becomes highly sensitive and reactive. Small disturbances can lead to large collective responses. This is a familiar idea in physics, where systems near a phase transition show strong fluctuations and high responsiveness [7]. What is remarkable here is that the same idea appears in a group of flying robots. Experiments with real drones show that when the swarm operates near this transition, it reacts more strongly to disturbances. When an intruder approaches, the group can quickly turn, spread out, and reorganize, then return to a coherent state within a short time (fig. 3).

This suggests a useful design principle. By tuning interaction rules inspired by animal groups, drone swarms can be placed in a regime where they are both stable and

responsive. Stability ensures that the group does not break apart. Responsiveness allows it to react quickly when needed. These two properties are often seen as opposites, yet near a transition they can coexist.

This insight has practical implications. A swarm might operate in a stable mode during routine movement. When rapid adaptation is required, for example during exploration or in response to a threat, it could shift toward a more responsive state. This does not require complex global control. It only requires adjusting local interaction strengths.

These ideas connect with broader developments in robotics. Distributed predictive control has shown how swarms can move safely through cluttered environments while coordinating locally and adapting to uncertainty [8]. High-speed planning methods now allow swarms to navigate unknown environments while avoiding obstacles and maintaining coordination [9]. At the same time, miniature flying robots have demonstrated that autonomous swarming is possible in real outdoor settings without external infrastructure, relying only on onboard sensing and decentralized control [10].

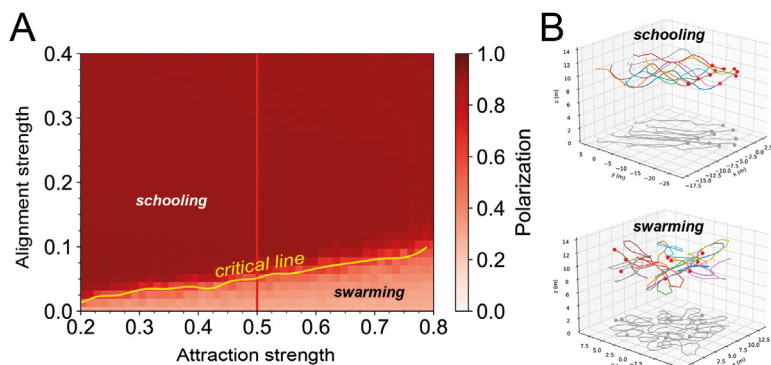
Taken together, these advances show that the field is moving from simple models to real-world system. Drone swarms are no longer just simulations. They are becoming practical tools.

Looking ahead, the most exciting developments may come from a shift in perspective. Until now, much of the work has focused on self-organization based on fixed rules. But many natural systems go further [7]. They process information, adapt to changing conditions, and adjust their behavior over time. This has led to the idea of intelligent active matter, where collective motion is linked to sensing, inference, and decision-making.

For drone swarms, this opens new possibilities. Future systems may not only maintain formation or avoid collisions. They may detect changes in their environment, adjust their interaction patterns, and switch between different modes of behavior just as fish schools. They may use memory, ●●●

▼ FIG. 1:
Test of the bio-inspired flocking model using a swarm of Tello EDU drones in the indoor drone flight arena of the French National School of Civil Aviation in Toulouse, France (David Villa, Sciencelimage, CBI, CNRS, Toulouse).





▲ FIG. 2: A. Phase diagram showing emergent collective states of a drone swarm as alignment and attraction vary. Different collective behaviors emerge as interaction strengths change, ranging from loosely organized swarms (swarming state) to highly aligned motion (schooling state), with a transition region where the system becomes highly sensitive and responsive to disturbances (critical state). B. 3D-trajectories and their projections on the XY plane of the collective states displayed by a swarm of 10 Bebop 2 Parrot drones flying in free space.

● ● ● learning, or prediction to improve performance. In such systems, intelligence would not reside in a single unit, but in the collective dynamics of the group.

This brings us back to the vision suggested by Prey. Crichton imagined a swarm that behaved as more than the sum of its parts [1]. Today, science is beginning to turn that idea into reality, not in a dramatic or dangerous way, but in a controlled and constructive one. Physics provides the tools to understand how collective animal behavior emerges. Biology offers examples that have been refined over millions of years. Robotics makes it possible to test and apply these ideas.

The challenge now is not only to make drones fly together, but to design swarms that can adapt, respond, and perhaps one day show forms of collective intelligence. When that happens, emergent dynamics in drone swarms will not just be a technical achievement. They will also offer a new way to think about how complex behavior arises from simple interaction rules. ■

About the Authors



Guy Theraulaz is Senior Research Director at the French National Centre for Scientific Research (CNRS), Toulouse. Trained in biology, he studies collective behavior across animals and humans, combining experiments, modeling, and robotics. Co-author of seminal books, he pioneered research on swarm intelligence and self-organization.

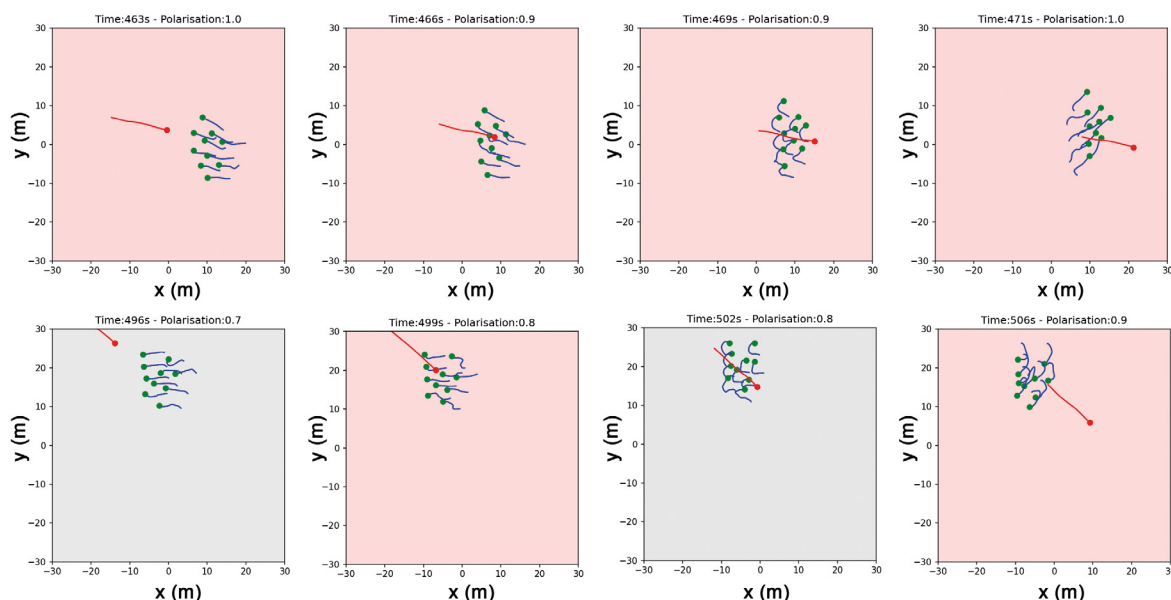


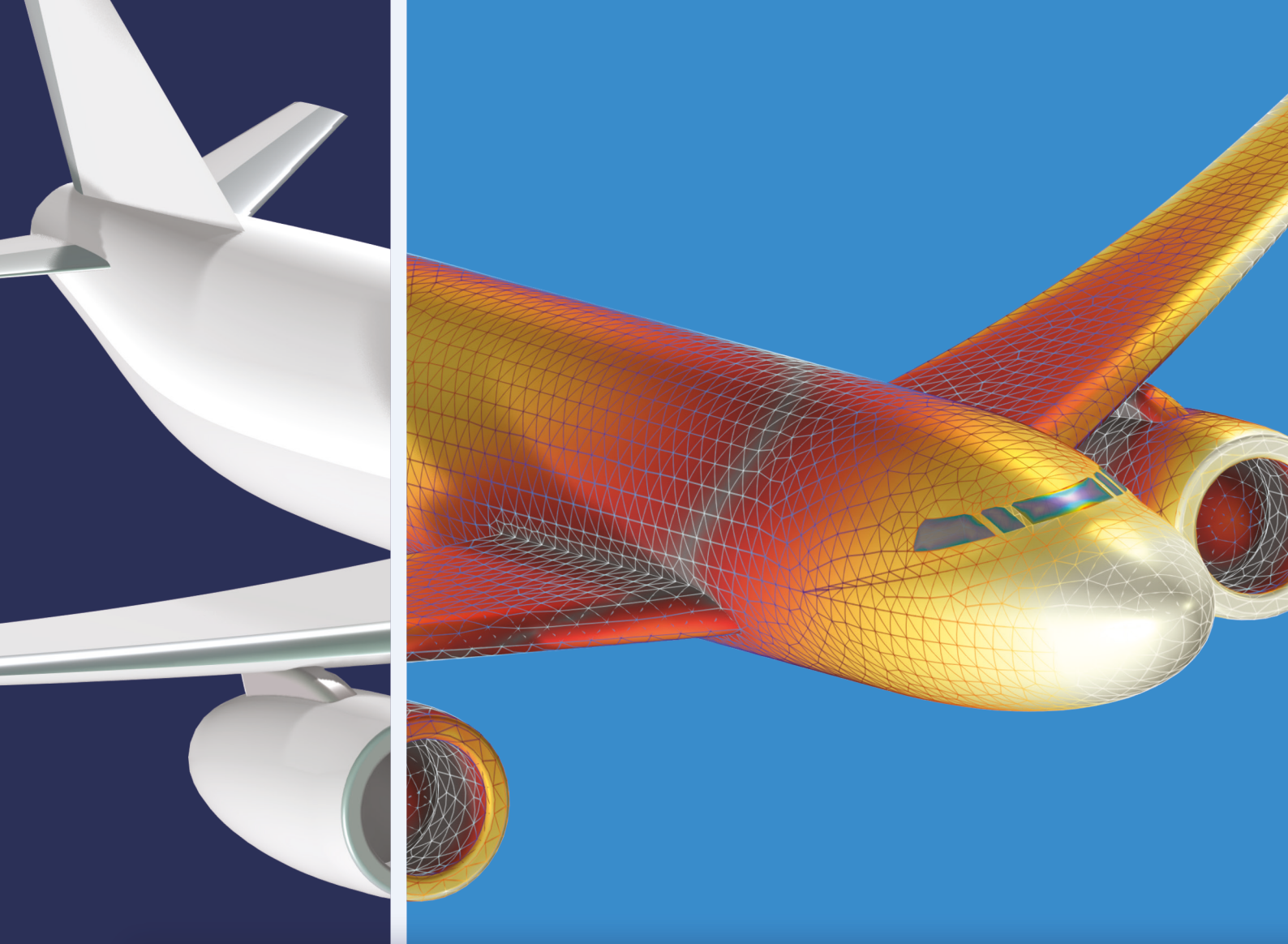
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► FIG. 3: Sequence of snapshots from experiments showing a drone swarm (green dots) in a critical state reacting to an approaching intruder (red dot), with rapid reconfiguration followed by recovery of alignment. The drone swarm operating near a transition regime reacts strongly to a disturbance, reorganizing quickly before returning to a coherent state, illustrating the balance between stability and responsiveness.





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WHEN DRONES LEARN FROM EACH OTHER: **SOCIAL LEARNING IN AERIAL SWARMS**

■ Marco Dorigo and Mary Katherine Heinrich – DOI: <https://doi.org/10.1051/ePN/2026310>

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Imagine a fleet of small drones exploring a disaster zone. No one tells them what to do. They have no prior knowledge of the site. Yet, within minutes, they have mapped the area, located the survivors, and divided the tasks among themselves—without ever connecting to a central computer. How? They learned from each other, on the fly.

This image is, of course, still idealised. Today's drone swarms are not yet capable of such fluid collective adaptation in the wild. But the direction is clear. As drones become cheaper, lighter, and more capable, the focus is shifting from the autonomy of individual drones to the collective behaviour of drone swarms. The issue is no longer only how to make a drone fly autonomously. It is how to make many drones operate together in a way that remains adaptive, scalable, and robust when conditions are uncertain and changing [1, 2].

For most of the history of robotics, a robot was essentially a solitary machine. Even when several robots were deployed together, each typically executed its own plan. The idea that robots might benefit from observing one another, exploiting each other's discoveries and adjusting their behaviours based on what others had learned, was more a speculative possibility than a practical design

principle. The solitary view works well as long as the robot is the natural unit of action. It becomes less convincing when the task itself calls for many robots operating together.

That is where aerial swarms become useful. A swarm of drones can do things that a single drone cannot do well: cover large areas quickly, inspect expansive infrastructure, monitor dynamic environments, or search in parallel. But once we move from one drone to many, coordination becomes the central problem. Defining in advance how each drone should behave becomes increasingly difficult as the swarm grows and the environment becomes less predictable. A central controller may simplify coordination, but it also creates a single point of failure, scales poorly, and often requires a global view of the system that can be difficult to obtain.

Social learning offers one possible way of addressing this problem. In biology, social learning [3, 4] is a

process by which an individual emulates others rather than discovering everything alone. Birds can learn routes from one another. Fish can emulate informed neighbours. Social insects exploit signals produced by nestmates or traces left in the environment. Humans, of course, rely on social learning on a massive scale [5].

For a swarm of drones, the same general idea applies. When a drone observes the action of another drone, it might copy that action directly, or imitate a larger behaviour, strategy, or discovery inferred from that action. If one drone discovers a safe passage, a promising search area, a landing site, or a region of interest, the rest of the swarm should be able to benefit from that discovery quickly, or the collective wastes time. If emulation spreads effectively through local observations, the swarm could become more efficient, more adaptive, and more robust.

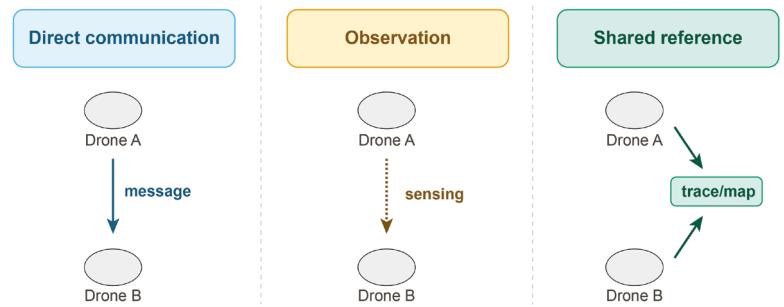
What matters is that drones can benefit from each other's experience without losing the diversity and autonomy needed to keep exploring. The challenge is therefore not simply to learn socially by observing others, but to do so while preserving independent action and independent learning.

Where physics enters the picture

At first glance, social learning in a swarm of drones may look like a topic belonging mainly to biology, robotics, or artificial intelligence. But the connection with physics becomes clearer once we ask a simple question: how does useful information spread through a group of moving agents under real physical constraints? This question matters because the main advantages of a swarm [6, 7]—covering large areas, distributing tasks, and remaining functional even if some drones fail—depend on whether drones can exploit each other's discoveries without relying on perfect communication or central coordination. In a swarm of drones, communication is not free, sensing is not perfect, movement continuously reshapes the interaction network, and energy is always limited. For these reasons, social learning in drone swarms is not just a matter of designing good decision processes or interaction rules. It is also a matter of understanding how information propagates in the time-varying interaction network of an embodied dynamical system.

A simple example makes the issue concrete. Imagine a swarm searching inside a partially collapsed building. One drone discovers a traversable, relatively safe corridor. How can this discovery be shared with the rest of the swarm?

Consider three illustrative possibilities. The first route is direct instruction: the drone explicitly informs others nearby of its discovery. The second is emulation based on observation: nearby drones infer that a useful route has been found, and bias their own actions or goals accordingly. The third is coordination through a shared representation of the environment, such as a temporary



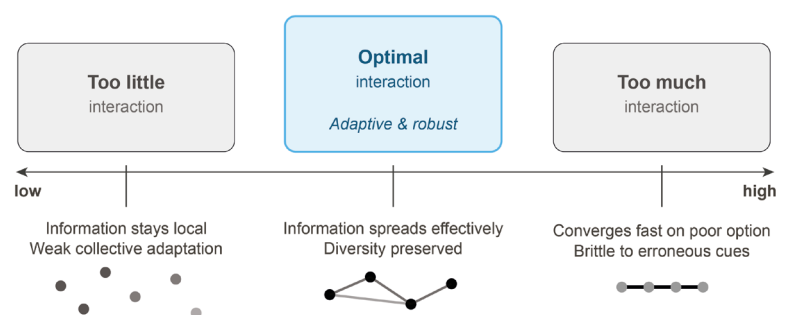
▲ FIG. 1: Three ways that information can spread in a drone swarm. Direct communication (left) is fast but might saturate the network when many drones send messages simultaneously. Observation (centre) is cheap but often ambiguous: nearby drones' states and behaviours must be inferred from sensor information. Shared environmental traces or distributed maps (right) enable efficient coordination but require safeguards against unrepresentative or outdated information that could mislead the group. The choice of mechanism depends on the task and on physical conditions.

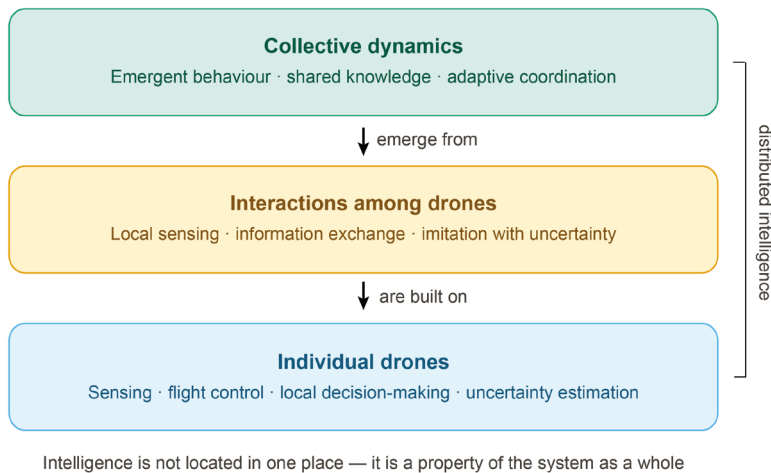
distributed map or a digital pheromone-like field marking promising regions.

These are three ways information can spread through the swarm, but they do not share the same properties (see Fig. 1). Direct communication can be effective, but it may saturate the network when many drones need to exchange messages. Observation is cheaper but usually more ambiguous. Shared maps or digital traces can be a powerful tool for asynchronous coordination, but they require some way of preventing unrepresentative or outdated information from misleading the group. The engineering question is therefore not which communication strategy is universally best. The right choice depends on the task and on the operational conditions.

The key issue for social learning is then one of balance. A swarm that emulates too little might fail to exploit collective discoveries. A swarm that emulates too much might converge too quickly on a poor option or might become fragile because all members follow the same misleading cue. Social learning is therefore not simply a matter of increasing connectivity or imitation. ●●●

▼ FIG. 2: The interaction trade-off: from incoherence to rigidity. The interaction trade-off in drone swarms, and its relevance to social learning. With too little interaction (left), useful discoveries remain confined to individual drones and the swarm fails to benefit collectively. With too much interaction (right), the swarm converges rapidly but becomes rigid: a single erroneous cue can propagate to all members and dominate collective behaviour. The design challenge is to operate in the intermediate regime (centre), where information spreads efficiently enough to support effective coordination while preserving the autonomy and diversity that allow the swarm to remain robust under changing conditions.



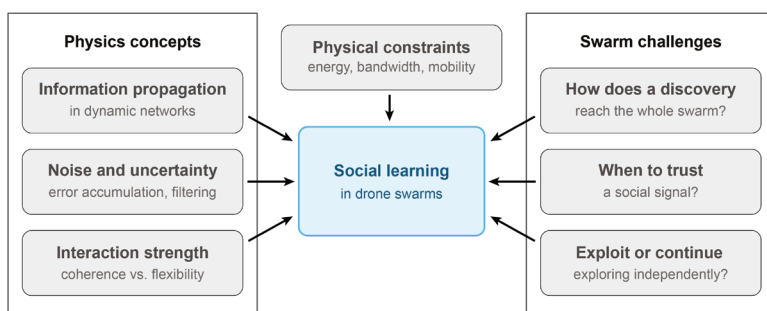


▲ **FIG. 3:** From individual intelligence to collective intelligence. In a swarm, intelligence is not concentrated in a single unit. It resides partly in each drone's individual capabilities (sensing, flight control, local decision making, and uncertainty estimation), partly in the interactions among drones (observing and exchanging information with nearby drones and imitation with uncertainty), and partly in the collective dynamics that emerge from those interactions (emergent behaviour, shared knowledge, and adaptive coordination). This layered structure means that the swarm can be more capable than any of its members, without requiring central control.

It is a matter of finding the right balance between independence and emulation.

Physicists are used to systems in which too little interaction between elements prevents coherent collective behaviour, while too much interaction suppresses flexibility. Something similar happens here (Fig. 2). With too much interaction between individuals, the swarm becomes overly rigid: it might converge quickly but also become brittle and overreact to poor cues. In social learning, the challenge is to achieve enough emulation for useful behaviours to spread, while preserving enough flexibility for the swarm to remain adaptive when conditions

▼ **FIG. 4:** The connection between physics and social learning in drone swarms. Core challenges of swarm social learning (right) relate to well-developed areas of physics (left). How a discovery propagates through a drone swarm is determined in part by how information spreads in a dynamic interaction network, in which the topology changes as drones move. A drone deciding whether to trust a social signal includes problems of noise, measurement error, and uncertainty propagation: the same concepts used to analyse imperfect sensors and stochastic processes. The exploitation–exploration trade-off of an individual drone in a swarm is closely related to the interaction problem underlying coherence in many-body systems. All these challenges are further shaped by physical constraints—energy budgets, communication bandwidth, and flight kinematics—which are inherent to the system rather than externally imposed. Physics does not resolve these challenges in drone swarms, but it provides concepts and formalisms to address them precisely.



Physics provides key concepts; the swarm is the target system

change. This matters because conditions in the field are rarely static: wind shifts, GPS availability varies, obstacles appear unexpectedly, and air and light conditions can alter visibility. In such circumstances, social learning must remain selective and able to adapt. An individual should not only be able to exploit what others have found; it should also retain the capacity to discount information that is unreliable and to learn independently.

This also means that not all observations should carry the same weight. The swarm should learn not only based on members' observations, but also on their reliability. This, too, reflects a physical aspect of the problem. Measurements are noisy, estimates propagate through the swarm, and errors can accumulate, cancel out, or amplify. If a swarm is designed as though all signals were equally reliable, it will often behave poorly. If uncertainty is treated as part of the observation, the collective can become much more robust.

Seen in this way, the issue is not only how individual drones emulate and observe, but also how the swarm as a whole combines partial and imperfect signals. Intelligence in such a system does not reside in one place. Part of it resides in each drone, part in the interactions among drones, and part in the collective dynamics that emerge from those interactions (Fig. 3).

Shifting the view from individual to collective intelligence also helps explain why comparisons with animal or human societies are so appealing [6, 8]. Biological inspiration can be useful, but it should not be taken too literally. Drones are not birds: biological metaphors can be valuable, but provided they are translated into algorithms with care.

Biology is useful in showing that robust social learning is possible under severe constraints, including partial information, delayed communication, noisy sensing, and limited memory. These are precisely the kinds of constraints that drone swarms face.

Why it matters now

Drone swarms are slowly moving from the laboratory toward operation in the wild and real applications [9–12]: inspection, environmental monitoring, agriculture, infrastructure maintenance, and emergency response. In all these domains, the challenge is not merely to make drones fly. It is to make groups of autonomous drones adapt in the field, under uncertainty, without requiring ideal communication conditions.

Social learning becomes attractive in these circumstances, but it is not a complete answer. It does not eliminate the need for reliable sensing, robust flight control, or careful human oversight. Nor does it guarantee desired collective outcomes: the same mechanisms that allow useful behaviours to spread can also allow mistakes to spread. The challenge is therefore to design social learning mechanisms so that the swarm can benefit from shared experience without opening up new vulnerabilities.

This is what makes the subject scientifically rich. At its core, social learning in drone swarms raises a deceptively simple question: how does useful information become a collective resource in a moving, noisy, energy-limited physical system? Once phrased in this way, the question clearly goes beyond drones.

The more general issue, increasingly important in science and engineering, is: under what conditions can a group become more capable than its members, not because of central control, but because of the interactions among them? Physics does not answer that question by itself. But it provides much of the language, many of the concepts, and several of the tools needed to address it well (Fig. 4). ■

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Challenges in Vacuum Measurement for Thermomechanical Material Testing

Thermomechanical analysis (TMA) relies on precise environmental control – especially vacuum conditions – to ensure reliable results. Even at low pressures, residual gases can affect measurements through adsorption, oxidation, and altered heat transfer, which is critical in high-precision and cryogenic applications.



A core challenge is accurate pressure measurement across a wide range—from rough vacuum ($\sim 10^2$ mbar) during evacuation to high vacuum ($\leq 10^{-6}$ mbar) during testing. No single sensor principle can cover this range with sufficient accuracy.

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THE LIQUID DAM: WHEN JAMMING SUSTAINS FLOW

■ Alexis Bougouin, Henri Lhuissier, Yoël Forterre and Bloen Metzger

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Most gravity-driven flows slow down as they spread — from honey on a table to lava on a volcano. It is a law of common experience. Here, we reveal a striking exception: dense shear-thickening suspensions form a *liquid dam* that advances at constant speed — independent of thickness, released volume, or even slope.



A flow that should not exist

Gravity-driven flows are expected to decelerate as they spread [1]. Pour honey on a plate, release mud down a slope, or watch lava advance: in every case the flow front slows down. This common observation results from a generic physical balance (see figure 1). In the overdamped limit, motion arises from a competition between hydrostatic pressure gradients, which drive the flow, and viscous or frictional stresses, which resist it. As spreading causes the layer to thin, the driving pressure gradient decreases while the basal (frictional) surface increases. Gravity-driven flows thus invariably slow down as they spread [2,3].

This argument is remarkably general. It applies not only to ordinary Newtonian liquids, but also to a broad class of complex fluids. Whether the rheology is shear-thinning, viscoplastic, or strongly nonlinear, theory predicts spreading laws in which the front velocity decreases with time. Rheology can change the form of the slowdown, but not the expectation of deceleration itself.

That is why shear-thickening suspensions are so surprising. When released onto a horizontal surface, they exhibit entirely different dynamics. Rather than maintaining a rounded shape and slowing down, the flow self-organizes into a steep moving front — a *liquid dam* — that propagates at constant speed, independent of layer thickness, released volume, and even slope angle [4]. This behavior is not a simple variant of conventional spreading, but a breakdown of its underlying logic: the front is no longer a passive consequence of the flow — it becomes the structure that controls it.

When a fluid becomes a solid

Some suspensions behave in a deeply counterintuitive way: the more strongly they are forced, the more they resist deformation. A familiar example is the mixture of cornstarch and water, often called ‘Oobleck’. When pressed softly, it flows like a liquid, but when struck suddenly, it responds like a solid.

This striking rheological behavior, known as discontinuous shear thickening or shear jamming, originates at the scale of individual grains (see figure 2 and [5,6]). At low stress, particles remain separated by microscopic repulsive forces, and the suspension flows easily, much like an ordinary viscous liquid with a viscosity $\eta_0(\phi)$ depending on the particle concentration ϕ . But when the applied stress exceeds a critical threshold $\tau_c(\phi)$, those repulsions can be overcome and particles come into direct frictional contact. The suspension then abruptly becomes much harder to deform, and may even jam into a transient solid-like state.

Rather than simply arresting the flow, this tendency to jam can give rise to remarkably rich dynamics. It produces impacts strong enough to run across cornstarch

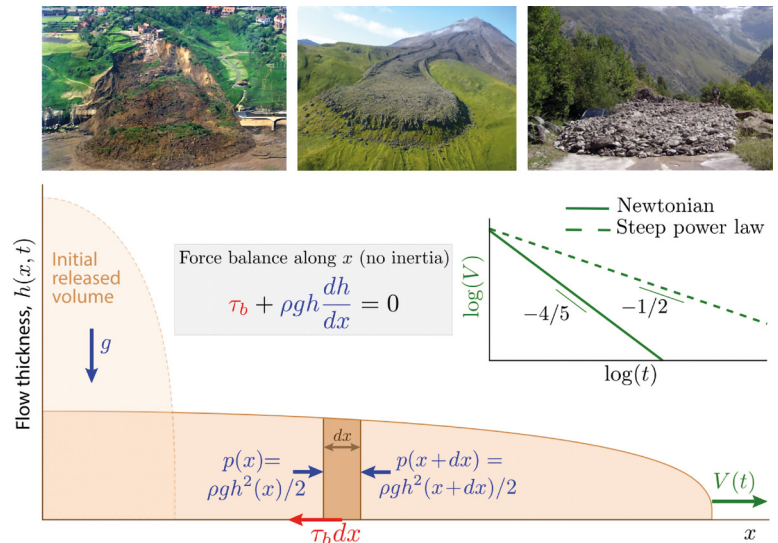
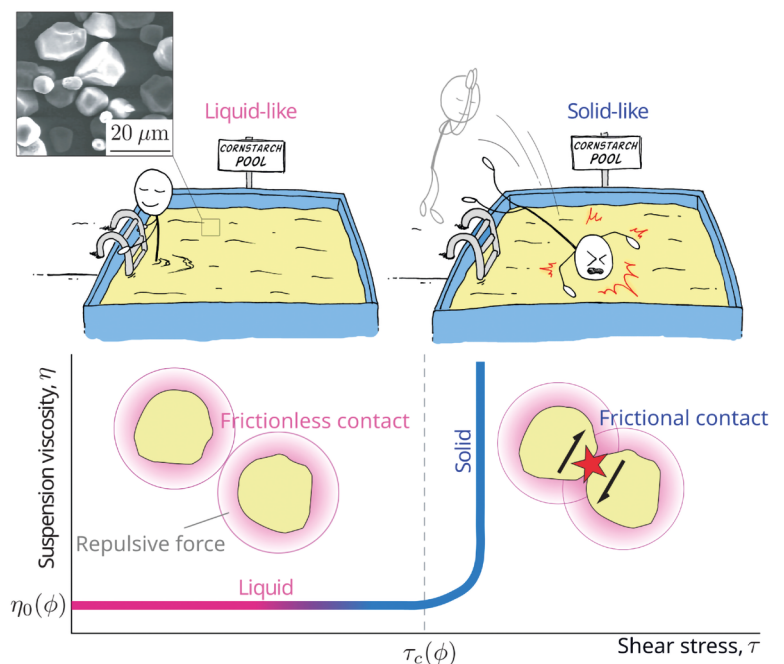


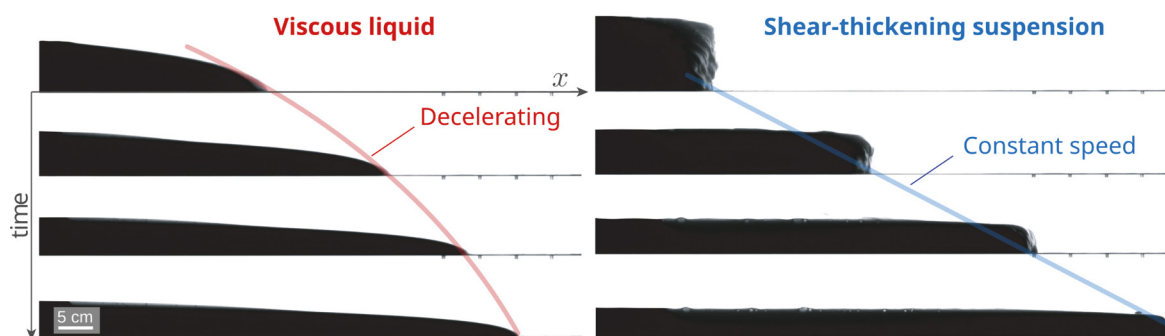
FIG. 1: (a) Examples of geophysical gravity-driven flows and their laboratory analogue: the dam-break configuration. In conventional spreading flows, a depth-averaged force balance on a fluid element of width dx shows that the hydrostatic pressure gradient arising from variations in flow thickness $h(x,t)$, is balanced by basal viscous or frictional stresses τ_b . As the layer thins, the driving pressure decreases and the front velocity $V(t)$ decays in time. Different fluid rheologies modify the resulting spreading power-law dynamics, but all predict decelerating fronts.

pools, as well as unusual resistance laws in pipes [7] and surface-wave instabilities in inclined flows [8]. In all these cases, jamming does not merely oppose motion — it organizes it. Gravity-driven spreading provides another striking example: shear-induced jamming does not stop motion, but instead creates a moving, load-bearing structure: a ‘liquid dam’.

FIG. 2: Cornstarch particles ($d \sim 15 \mu\text{m}$) suspended in water form a shear-thickening suspension. At low stress, particles interact through repulsive forces and the suspension remains liquid-like with a viscosity $\eta_0(\phi)$. Above a critical stress $\tau_c(\phi)$, frictional contacts emerge, the viscosity increases sharply, and the material can enter a jammed, solid-like state.



► FIG. 3: Successive flow profiles comparing the spreading of a Newtonian viscous liquid and a shear-thickening suspension, highlighting the contrast between conventional decelerating spreading and the constant-speed propagation of a liquid dam (adapted from [4]).



The liquid dam: when the front takes control

Our experiments reveal that dense shear-thickening suspensions spread in a fundamentally different way from ordinary fluids (see figure 3). Rather than spreading with a rounded shape and decelerating, the material self-organizes into a sharp, nearly vertical front that propagates at constant speed — a striking departure from conventional gravity-driven spreading.

The mechanism underlying this steady propagation was uncovered by measuring the free-surface velocity field, which reveals a localized overspeed at the front (see figure 4a). At the leading edge, particles jam into a dense frictional region (highlighted in blue) that supports much of the pressure generated by the fluid behind it. This jammed

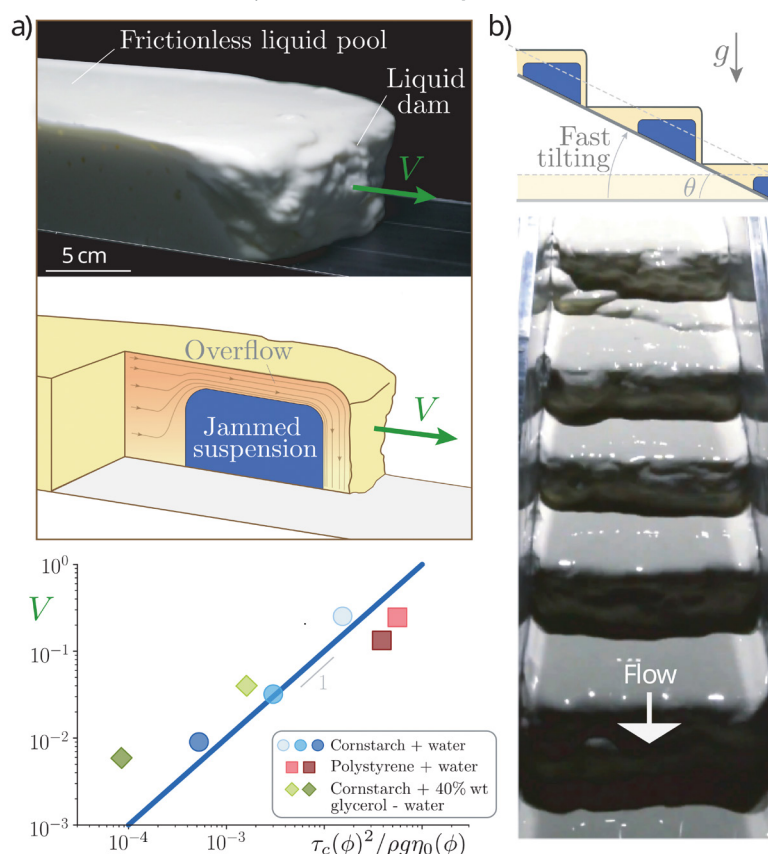
region acts as a moving dam. Meanwhile, a thin liquid-like layer near the free surface continuously overflows this barrier, sustaining the motion of the front.

This flow structure creates an unusual division of labor: the jammed region bears the load, while the overflow layer provides mobility. Together, they form a self-organized structure capable of propagating steadily without slowing down.

Combining mass conservation with force balance in the frontal region further shows that the propagation speed is not controlled by the flow thickness or the amount of released material, but instead by the suspension rheology — and consequently by the particle concentration ϕ — scaling as $V \sim \tau_c(\phi)^2 / \rho g \eta_0(\phi)$ (see figure 4a). In other words, the speed is selected by the material itself and, unlike conventional gravity-driven spreading, becomes independent of flow volume and geometry.

Remarkably, this prediction holds across different particle concentrations, suspension compositions, horizontal and inclined configurations, and even in spontaneously forming ‘stairwaves’, where multiple and successive liquid dams travel downslope (see figure 4b). Hence, the liquid dam defines a new regime of gravity-driven flow, not governed by conventional spreading dynamics but instead by a self-organized, moving jammed front.

▼ FIG. 4: (a) Photograph and schematic of the liquid dam: a jammed front acts as a moving barrier while a thin overflow layer sustains propagation. This simple physical picture predicts a front speed scaling as $V \sim \tau_c(\phi)^2 / \rho g \eta_0(\phi)$ and is validated across different shear-thickening suspensions. (b) Stairwaves: a train of liquid dams spontaneously forms when an initially horizontal layer is tilted, illustrating the robustness of the mechanism beyond dam-break flows (adapted from [4]).



Why it matters

The liquid dam reveals a previously unrecognized way in which complex fluids can move under gravity. In classical spreading, motion results from a balance between driving forces and dissipation distributed throughout the flow. Here, dissipation localizes in a self-organized jammed front that controls the propagation speed through material properties.

This shift in perspective may extend far beyond shear-thickening suspensions. Many geophysical and industrial materials — muds, debris slurries, fresh concrete, mineral tailings, dense food pastes — consist of particles suspended in liquid and can develop frictional interactions under stress. In such systems, front dynamics may play a far more active role than is usually assumed, particularly in geophysical settings. These results may help explain why some gravity-driven materials remain unexpectedly mobile — a longstanding puzzle in hazard dynamics. Although the dissipative front observed here arises from shear-thickening behavior — also proposed for crystal-rich lava, though not yet experimentally confirmed [8] — similar effects may arise

through other mechanisms, such as cooling-induced solidification in lava [9] or boulder segregation in debris flows [10,11]. In all these cases, the front may become the dominant source of resistance and control the flow dynamics.

More broadly, the liquid dam suggests that jamming is not only a route toward arrest and rigidity. It can also organize motion: solidification here does not stop the flow — it sustains it.



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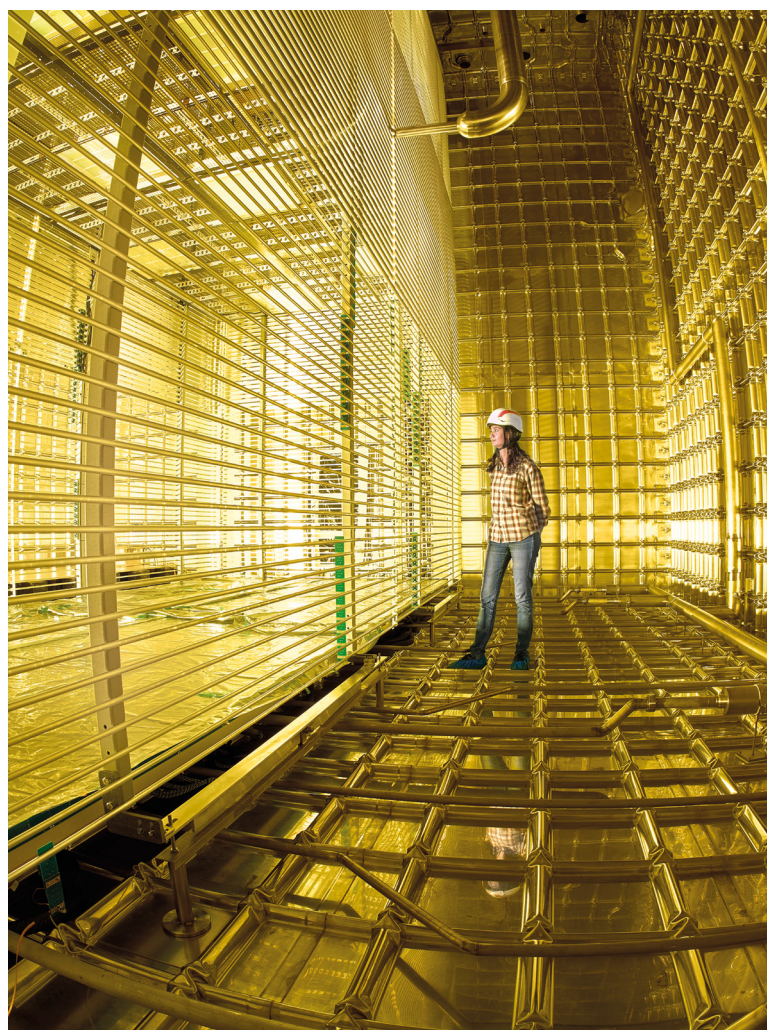
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The issue will feature contributions on neutrino mass measurements from the KATRIN experiment, including recent advances in the search for sterile neutrinos, one of the most intriguing candidates for physics beyond the Standard Model. It will also explore the rapidly evolving field of neutrino astronomy through the achievements of KM3NeT, the deep-sea research infrastructure opening new windows onto the high-energy Universe. In addition, the issue will present perspectives on neutrino oscillation physics and the scientific goals of the DUNE collaboration, one of the flagship projects designed to address fundamental questions on matter–antimatter asymmetry and neutrino properties.

This special issue is guest edited by Els de Wolf, former editor of EuroPhysics News and recipient of the EPS Gero Thomas Medal 2025.

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▲ Inside the protoDUNE detector, which is a small model for the future DUNE neutrino detector.
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