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Highlights of EPL
Research in the spotlight

May 2026

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40
years of EPL

LATEST ARTICLE

Animate droplets
From active to autonomous

Airborne wind energy
Insights from machine learning

Staying the course
How to end a future pandemic

Understanding the natural world
Statistical physics predicts patterns

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LATEST ARTICLE

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Three scientists share a fascination with droplets that are "animate" – that is, capable of responding to their surroundings in ways that resemble the behaviour of living organisms. (Courtesy: iStock/Aliaksandr Martsinkevich) **p14**

Highlights of EPL
Research in the spotlight

Produced by *Physics World* on behalf of *Europhysics Letters*

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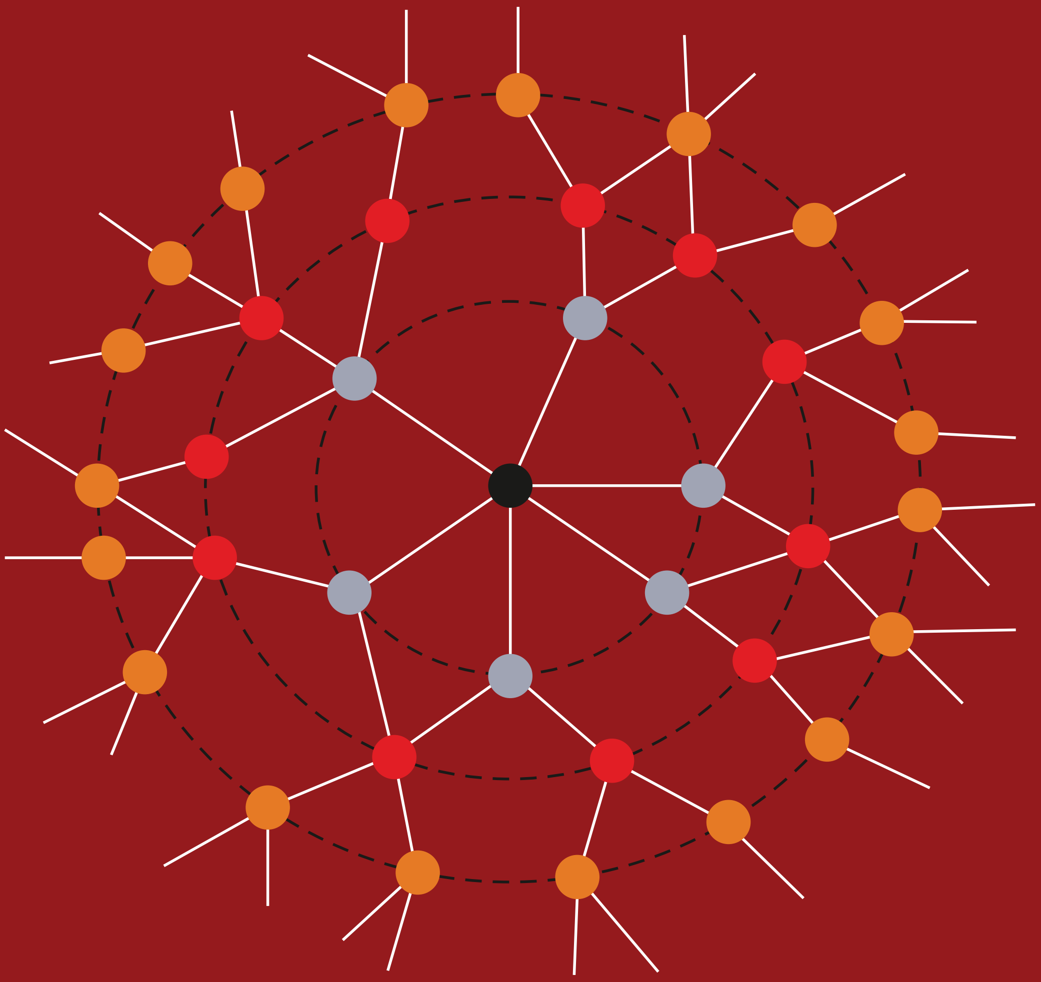
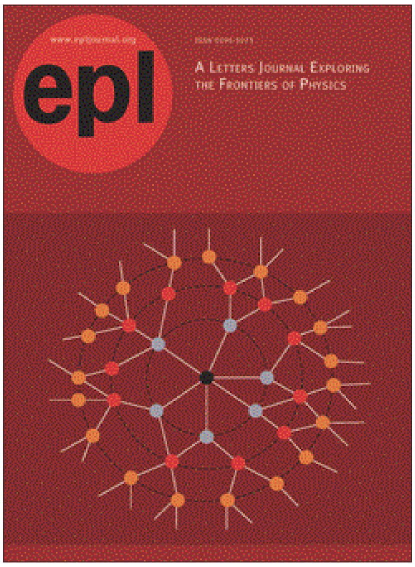
EPL is published under the scientific policy and control of the European Physical Society by EDP Sciences, IOP Publishing and Società Italiana di Fisica.





A Letters journal serving all areas of physics and its related fields.

Europhysics Letters (EPL) publishes the highest quality research from around the world, and provides authors with fast, fair and constructive peer review thanks to an Editorial Board of active scientists, who are experts in their respective fields.

EPL celebrates 40 years

We are pleased to present this collection of articles that showcase thought-provoking physics research recently published in EPL, a letters journal at the frontiers of physics that operates under the scientific direction of the European Physical Society.

Richard Blythe
Editor-in-chief
Europhysics Letters

Despite the many changes in scientific publishing since the journal was founded 40 years ago, EPL has been unwavering in its commitment to the international community of physics researchers. Key to this support is an editorial board drawn from this self-same community: practising research physicists whose expertise allows them to spot the most exciting developments in their field. Regular renewal of the board ensures that we constantly move with the times.

One of the most important trends that we have identified recently is that as more and more scientific research is conducted and published, it is becoming increasingly easy for readers to miss important developments, and increasingly hard for authors to be heard. It is in this spirit that EPL's editors are now working with *Physics World* to draw greater attention to certain papers that are both scientifically strong and likely to resonate with a broad spectrum of physicists.

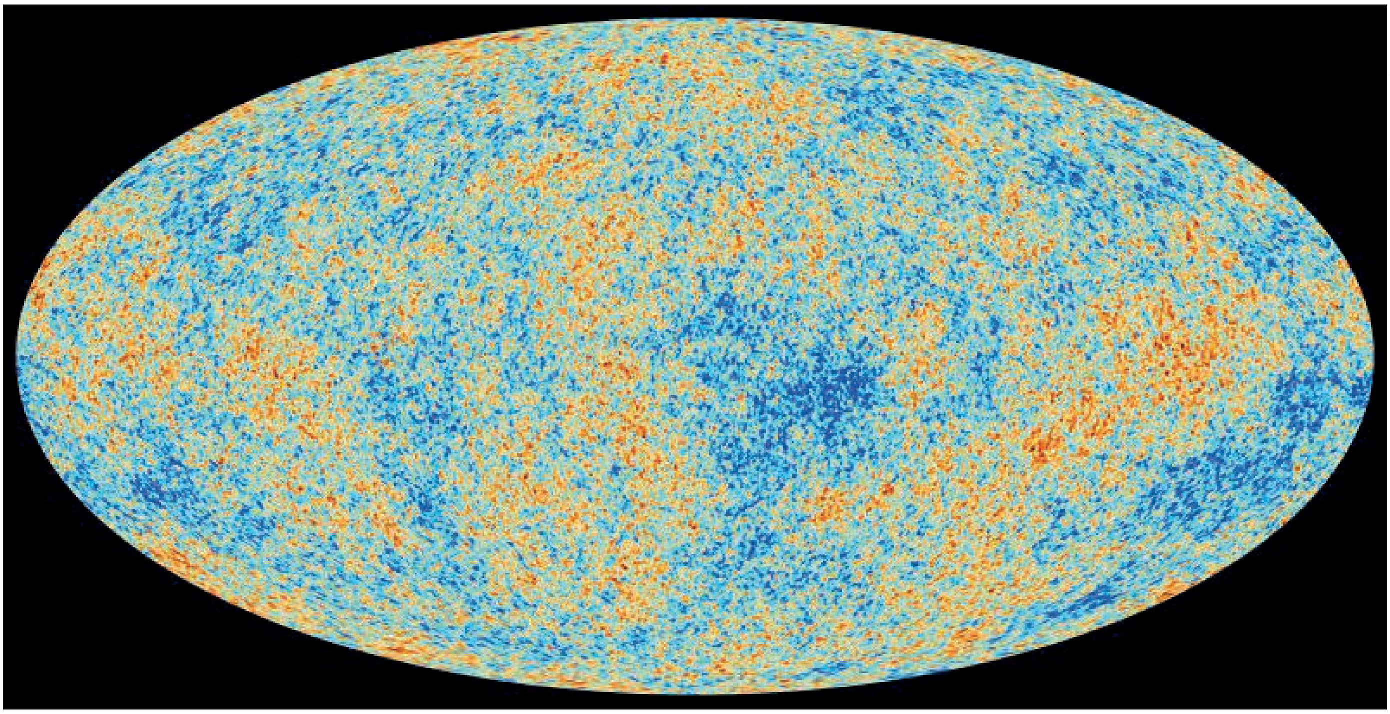
This collection brings together the articles that have been published so far as part of this collaboration, and will be updated as the programme continues. As you will see, the topics covered range from fundamental theories about the universe to practical applications of contemporary physics research across multiple disciplines. This reflects EPL's mission as a journal that spans the whole of physics, including ways in which physics thinking is brought to bear on important questions in other fields.

Margaret Harris
Online editor
Physics World

The crowded research landscape that Richard describes is a challenge for science journalists, too. Fortunately, EPL attracts authors who are passionate about physics and skilled in explaining it; for *Physics World*, making their acquaintance has been a highlight of this programme. I hope you enjoy reading about the work of these standout scientists as much as I enjoyed discussing it with them – and, based on their feedback to EPL, as much as they enjoyed the chance to share it with a wider audience.

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



ESA and the Planck Collaboration

First light 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 vast quantities of matter are present within an infinitesimally small volume – 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^{20} 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 on loop quantum cosmology offers a possible solution. It suggests that gravity, in effect, becomes repulsive. Consequently, loop quantum cosmology predicts that our present universe began in a so-called "cosmic bounce", rather than the Big Bang singularity predicted by general relativity.

In a recent paper published in *EPL*, Edward Wilson-Ewing, 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 freshly liberated 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?

Observations of the CMB show 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 10^4. Classical general relativity has trouble explaining this homogeneity on its own, because a purely attractive version of gravity tends to drive things in the opposite direction. This is because if a region has a 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).

Alternately, 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 also becoming further homogenized.

University of New Brunswick

Cosmologist Edward Wilson-Ewing uses loop quantum gravity to study quantum effects in the very early universe.

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

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 dilute 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 spherically symmetric space–times coupled to dust (a simple model for matter) in loop quantum cosmology. These space–times are known as Lemaître–Tolman–Bondi space–times, and they allow arbitrarily large inhomogeneities in the radial direction. They therefore provide an ideal arena to explore whether homogenization can occur: they are simple enough to be mathematically tractable, while still allowing for large inhomogeneities (which, in general, are very hard to handle).

Loop quantum cosmology predicts several leading-order quantum effects. One of these effects is that space–time, at the quantum level, is discrete: there are quanta of geometry just as there are quanta of matter. This has implications for the equations of motion, which relate the geometry of space–time to the matter in it: if we take into account the discrete nature of quantum geometry, we have to modify the equations of motion.

These modifications are captured by so-called effective equations, and in the paper I solved these equations numerically for a wide range of initial conditions. From this, I found that while homogenization doesn't occur everywhere, it always occurs 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.

I therefore think it is reasonable to 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 to test this expectation 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 to test this expectation.

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From rabbits and foxes to the human gut microbiome, physics is helping us understand the natural world

This episode of the *Physics World Weekly* podcast is a conversation with two physicists, **Ada Altieri** and **Silvia De Monte**, who are using their expertise in statistical physics to understand the behaviour of ecological communities.

Physics World Weekly Podcast

From rabbits and foxes to the human gut microbiome, physics is ...

A century ago, pioneering scientists such as Alfred Lotka and Vito Volterra showed that statistical physics techniques could explain – and even predict – patterns that ecologists observe in nature. At first, this work focused on simple ecosystems containing just one or two species (such as rabbits and foxes), which are relatively easy to model.

Nowadays, though, researchers such as Altieri and De Monte are turning their attention to far more complex communities. One example is the collection of unicellular organisms known as protists that live among plankton in the ocean. Another, closer to home, is the "microbiome" in the human gut, which may contain hundreds or even thousands of species of bacteria.

Modelling these highly interconnected communities is hugely challenging. But as Altieri and De Monte explain, the potential rewards – from identifying "tipping points" in fragile ecosystems to developing new treatments for gut disorders such as irritable bowel syndrome and Crohn's disease – are great.

This discussion is based on a Perspective article that Altieri (an associate professor at the Laboratory for Matter and Complex Systems at the Université Paris Cité, France) and De Monte (a senior research scientist at the Institute of Biology in the École Normale Supérieure in Paris and the Max Planck Institute for Evolutionary Biology in Ploen, Germany) wrote for the journal *EPL*, which sponsors this episode of the podcast.

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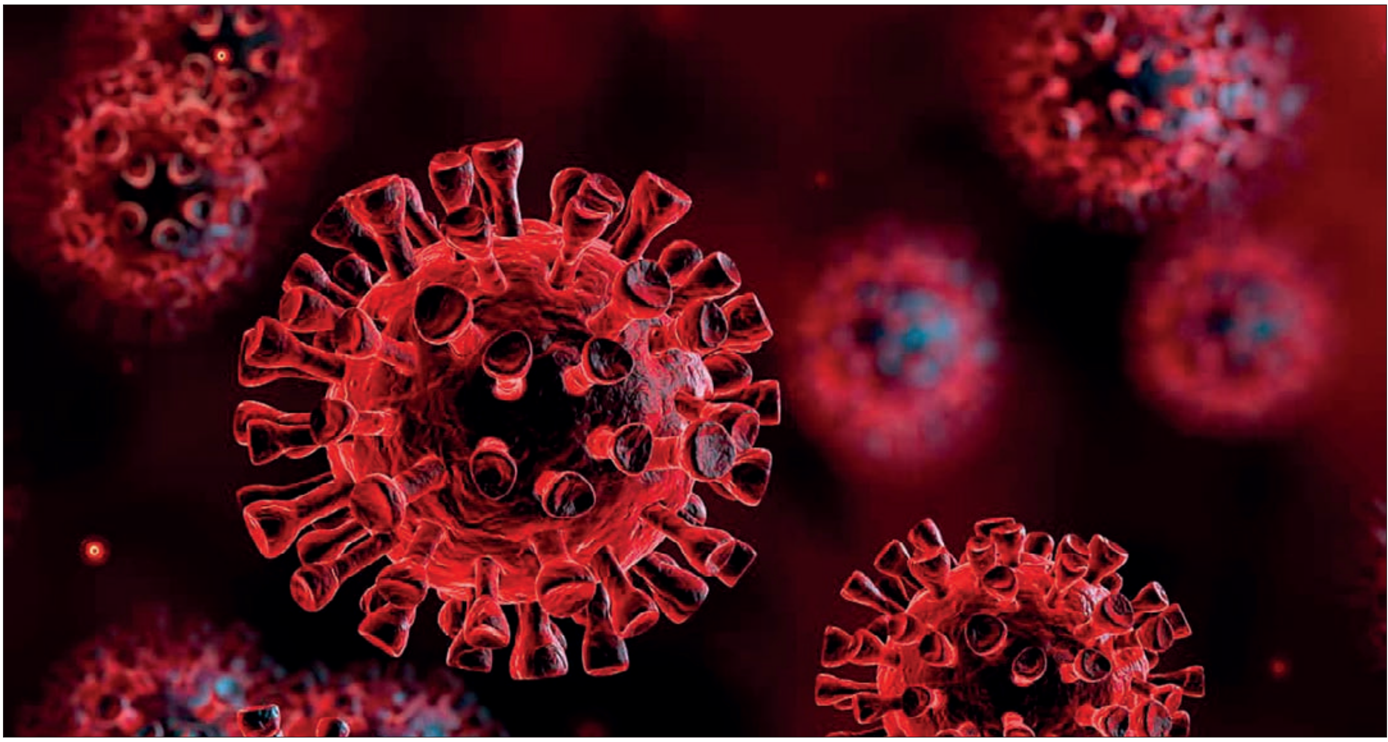
Staying the course with lockdowns could end future pandemics in months



iStock/RomoloTavani

Survivors Artist's impression of Sars-CoV-2 virions, which cause COVID-19.

As a theoretical and mathematical physicist at Imperial College London, UK, Bhavin Khatri spent years using statistical physics to understand how organisms evolve. Then the COVID-19 pandemic struck, and like many other scientists, he began searching for ways to apply his skills to the crisis. This led him to realize that the equations he was using to study evolution could be repurposed to model the spread of the virus – and, crucially, to understand how it could be curtailed.

In a paper published in *EPL*, Khatri models the spread of a SARS-CoV-2-like virus using branching process theory, which he'd previously used to study how advantageous alleles (variations in a genetic sequence) become more prevalent in a population. He then uses this model to assess the duration that interventions such as lockdowns would need to be applied in order to completely eliminate infections, with the strength of the intervention measured in terms of the number of people each infected person goes on to infect (the virus' effective reproduction number, R).

Tantalizingly, the paper concludes that applying such interventions worldwide in June 2020 could have eliminated the COVID virus by January 2021, several months before the widespread availability of vaccines reduced its impact on healthcare systems and led governments to lift restrictions on social contact. *Physics World* spoke to Khatri to learn more about his research and its implications for future pandemics.

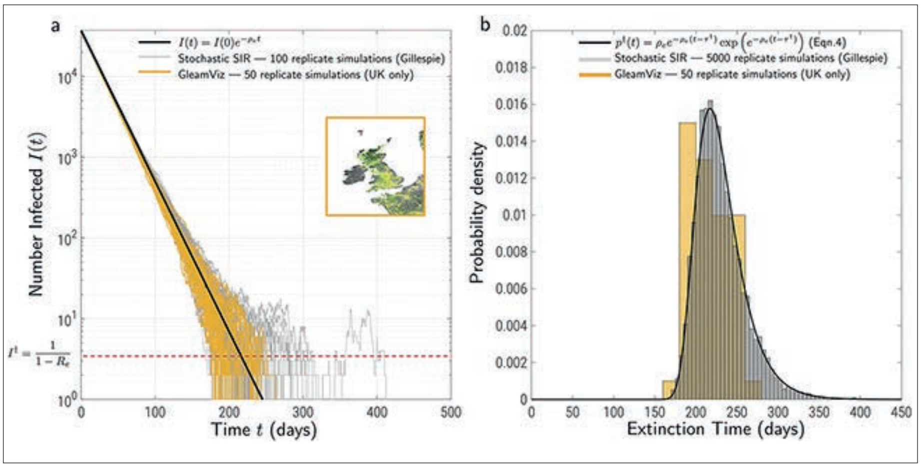
What are the most important findings in your work?

One important finding is that we can accurately calculate the distribution of times required for a virus to become extinct by making a relatively simple approximation. This approximation amounts to assuming that people have relatively little population-level "herd" immunity to the virus – exactly the situation that many countries, including the UK, faced in March 2020.

Making this approximation meant I could reduce the three coupled differential equations of the well-known SIR model (which models pandemics via the interplay between Susceptible, Infected and Recovered individuals) to a single differential equation for the number of infected individuals in the population. This single equation turned out to be the same one that physics students learn when studying radioactive decay. I then used the discrete stochastic version of exponential decay and standard approaches in branching process theory to calculate the distribution of extinction times.

Alongside the formal theory, I also used my experience in population genetic theory to develop an intuitive approach for calculating the mean of this extinction time distribution. In population genetics, when a mutation is sufficiently rare, changes in its number of copies in the population are dominated by randomness. This is true even if the mutation has a large selective advantage: it has to grow by chance to sufficient critical size – on the order of 1/(selection strength) – for selection to take hold.

The same logic works in reverse when applied to a declining number of infec-



Simulation trajectories a) A plot of the decline in the number of infected individuals over time. b) Probability density of extinction times for the same parameters as in a), showing that the most likely extinction times are measured in months. (Courtesy: Bhavin S. Khatri 2025 *EPL* **152** 11003 DOI 10.1209/0295-5075/ae0c31 CC-BY 4.0 https://creativecommons.org/licenses/by/4.0/).

tions. Initially, they will decline deterministically, but once they go below a threshold number of individuals, changes in infection numbers become random. Using the properties of such random walks, I calculated an expression for the threshold number and the mean duration of the stochastic phase. These agree well with the formal branching process calculation.

In practical terms, the main result of this theoretical work is to show that for sufficiently strong lockdowns (where, on average, only one of every two infected individuals goes on to infect another person, $R=0.5$), this distribution of extinction times was narrow enough to ensure that the COVID pandemic virus would have gone extinct in a matter of months, or at most a year.

How realistic is this counterfactual scenario of eliminating SARS-CoV-2 within a year?

Leaving politics and the likelihood of social acceptance aside for the moment, *if* a sufficiently strong lockdown could have been maintained for a period of roughly six months across the globe, then I am confident that the virus could have been reduced to very low levels, or even made extinct.

The question then is: is this a stable situation? From the perspective of a single nation, if the rest of the world still has infections, then that nation either needs to maintain its lockdown or be prepared to re-impose it if there are new imported cases. From a global perspective, a COVID-free world should be a stable state, unless an animal reservoir of infections causes re-infections in humans.

Modelling the decline of a virus Theoretical physicist and biologist Bhavin Khatri.

As for the practical success of such a strategy, that depends on politics and the willingness of individuals to remain in lockdown. Clearly, this is not in the model. One thing I do discuss, though, is that this strategy becomes far more difficult once more infectious variants of SARS-CoV-2 evolve. However, the problem I was working on before this one (which I eventually published in *PNAS*) concerned the probability of evolutionary rescue or resistance, and that work suggests that evolution of new COVID variants reduces significantly when there are fewer infections. So an elimination strategy should also be more robust against the evolution of new variants. What lessons would you like experts (and the public) to take from this work when considering future pandemic scenarios?

I'd like them to conclude that pandemics with similar properties are, in principle, controllable to small levels of infection – or complete extinction – on timescales of months, not years, and that controlling them minimizes the chance of new variants evolving. So, although the question of the political and social will to enact such an elimination strategy is not in the scope of the paper, I think if epidemiologists, policy experts, politicians and the public understood that lockdowns have a finite time horizon, then it is more likely that this strategy could be adopted in the future.

I should also say that my work makes no comment on the social harms of lockdowns, which shouldn't be minimized and would need to be weighed against the potential benefits.

What do you plan to do next?

I think the most interesting next avenue will be to develop theory that lets us better understand the stability of the extinct state at the national and global level, under various assumptions about declining infections in other countries that adopted different strategies and the role of an animal reservoir.

It would also be interesting to explore the role of "superspreaders", or infected individuals who infect many other people. There's evidence that many infections spread primarily through relatively few superspreaders, and heuristic arguments suggest that taking this into account would decrease the time to extinction compared to the estimates in this paper.

I've also had a long-term interest in understanding the evolution of viruses from the lens of what are known as genotype phenotype maps, where we consider the non-trivial and often redundant mapping from genetic sequences to function, where the role of stochasticity in evolution can be described by statistical physics analogies. For the evolution of the antibodies that help us avoid virus antigens, this would be a driven system, and theories of non-equilibrium statistical physics could play a role in answering questions about the evolution of new variants.

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Reinforcement learning could help airborne wind energy take off

When people think of wind energy, they usually think of windmill-like turbines dotted among hills or lined up on offshore platforms. But there is also another kind of wind energy, one that replaces stationary, earthbound generators with tethered kites that harvest energy as they soar through the sky

iStock/David Steinbrede

Sophisticated control mechanisms Airborne wind energy systems generate electricity from devices that soar through the sky like birds, in contrast to conventional, Earth-bound turbines, but controlling them is a challenge.

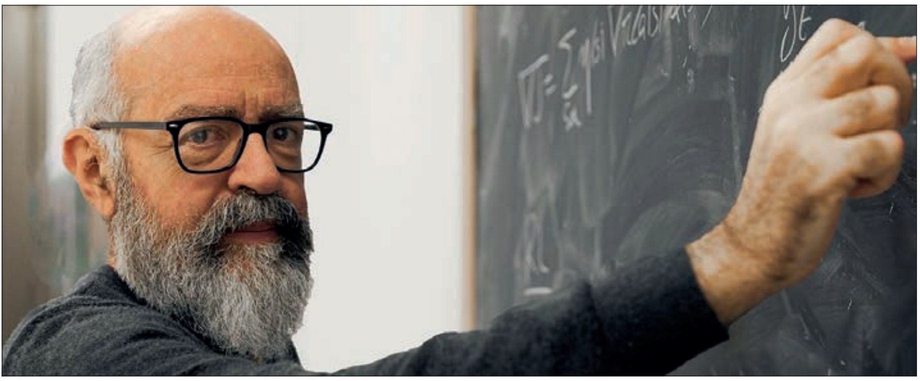
This airborne form of wind energy, or AWE, is not as well-developed as the terrestrial version, but in principle it has several advantages. Power-generating kites are much less massive than ground-based turbines, which reduces both their production costs and their impact on the landscape. They are also far easier to install in areas that lack well-developed road infrastructure. Finally, and perhaps most importantly, wind speeds are many times greater at high altitudes than they are near the ground, significantly enhancing the power densities available for kites to harvest.

There is, however, one major technical challenge for AWE, and it can be summed up in a single word: control. AWE technology is operationally more complex than conventional turbines, and the traditional method of controlling kites (known as model-predictive control) struggles to adapt to turbulent wind conditions. At best, this reduces the efficiency of energy generation. At worst, it makes it challenging to keep devices safe, stable and airborne.

In a paper published in *EPL*, Antonio Celani and his colleagues Lorenzo Basile and Maria Grazia Berni of the University of Trieste, Italy, and the Abdus Salam International Centre for Theoretical Physics (ICTP) propose an alternative control method based on reinforcement learning. In this form of machine learning, an agent learns to make decisions by interacting with its environment and receiving feedback in the form of "rewards" for good performance. This form of control, they say, should be better at adapting to the variable and uncertain conditions that power-generating kites encounter while airborne.

What was your motivation for doing this work?

Our interest originated from some previous work where we studied a fascinating bird behaviour called thermal soaring. Many birds, from the humble seagull to birds of prey and frigatebirds, exploit atmospheric currents to rise in the sky without flapping their wings, and then glide or swoop down. They then repeat this cycle of ascent and descent for hours, or even for weeks if they are migratory birds. They're able to do this because birds are very effective at extract-



Antonio Celani

Antonio Celani

We asked: can a reinforcement learning (RL) algorithm discover efficient, adaptive ways of controlling a kite in a turbulent environment to extract energy for human consumption?

ing energy from the atmosphere to turn it into potential energy, even though the atmospheric flow is turbulent, hence very dynamic and unpredictable.

In those works, we showed that we could use reinforcement learning to train virtual birds and also real toy gliders to soar. That got us wondering whether this same approach could be exported to AWE.

When we started looking at the literature, we saw that in most cases, the goal was to control the kite to follow a predetermined path, irrespective of the changing wind conditions. These cases typically used only simple models of atmospheric flow, and almost invariably ignored turbulence.

This is very different from what we see in birds, which adapt their trajectories on the fly depending on the strength and direction of the fluctuating wind they experience. This led us to ask: can a reinforcement learning (RL) algorithm discover efficient, adaptive ways of controlling a kite in a turbulent environment to extract energy for human consumption?

Lorenzo Basile

Lorenzo Basile

What is the most important advance in the paper?

We offer a proof of principle that it is indeed possible to do this using a minimal set of sensor inputs and control variables, plus an appropriately designed reward/punishment structure that guides trial-and-error learning. The algorithm we deploy finds a way to manoeuvre the kite such that it generates net energy over one cycle of operation. Most importantly, this strategy autonomously adapts to the ever-fluctuating conditions induced by turbulence.

The main point of RL is that it can learn to control a system just by interacting with the environment, without requiring any a priori knowledge of the dynamical laws that rule its behaviour. This is extremely useful when the systems are very complex, like the turbulent atmosphere and the aerodynamics of a kite.

What are the barriers to implementing RL in real AWE kites, and how might these barriers be overcome?

The virtual environment that we use in our paper to train the kite controller is very simplified, and in general the gap between simulations and reality is wide. We therefore regard the present work mostly as a stimulus for the AWE community to look deeper into alternatives to model-predictive control, like RL.

On the physics side, we found that some phases of an AWE generating cycle are very difficult for our system to learn, and they require a painful fine-tuning of the reward structure. This is especially true when the kite is close to the ground, where winds are weaker and errors are the most punishing. In those cases, it might be a wise choice to use other heuristic, hard-wired control strategies rather than RL.

Finally, in a virtual environment like the one we used to do the RL training in this work, it is possible to perform many trials. In real power kites, this approach is not feasible – it would take too long. However, techniques like offline RL might resolve this issue by interleaving a few field experiments where data are collected with extensive off-line optimization of the strategy. We successfully used this approach in our previous work to train real gliders for soaring.

What do you plan to do next?

We would like to explore the use of offline RL to optimize energy production for a small, real AWE system. In our opinion, the application to low-power systems is particularly relevant in contexts where access to the power grid is limited or uncertain. A lightweight, easily portable device that can produce even small amounts of energy might make a big difference in the everyday life of remote, rural communities, and more generally in the global south.

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Droplet scientists push the boundary between living and non-living matter

In this episode of the *Physics World Weekly* podcast, we hear from a trio of scientists with a common interest in the physics of droplets

Joe Forth, Rob Malinowski and Giorgio Volpe share a fascination with droplets that are "animate" – that is, capable of responding to their surroundings in ways that resemble the behaviour of living organisms.

As they explain in the podcast, systems must tick three boxes to qualify as animate. First, they must be active, able to use energy from their environment to do work and perform tasks. Second, they must be adaptive, able to move between different dynamical states in response to changes to their environment or their own internal states. Finally, they must be autonomous, able to process multiple inputs and choose how to respond to them without intervention from the outside world.

Incorporating all these behaviours into a droplet – or a system of many droplets – is challenging. The boundary between autonomous and non-autonomous systems is proving especially hard to overcome, and Volpe, Malinowski and Forth have a friendly disagreement over whether any droplet-based system has managed it yet.

Crosses disciplinary borders

Part of the challenge, they say, is that the field crosses disciplinary borders. Although Volpe thinks the community of droplet researchers is getting better at finding a common vocabulary for discussions, Forth jokes that it is still the case that "the chemists are scared of physics, the physicists are scared of chemists, everyone is scared of biology". The potential rewards of overcoming these fears are great, however, with possible future applications of animate droplets ranging from consumer products such as deodorant to oil spill clean-up.

This discussion is based on a Perspective article that Volpe (a professor of soft matter in the chemistry department at University College London, UK), Malinowski (a research fellow in soft matter physics in the same department) and Forth (a colloid scientist and lecturer in the chemistry department at the University of Liverpool, UK) wrote for the journal *EPL*, which sponsors this episode of the podcast.

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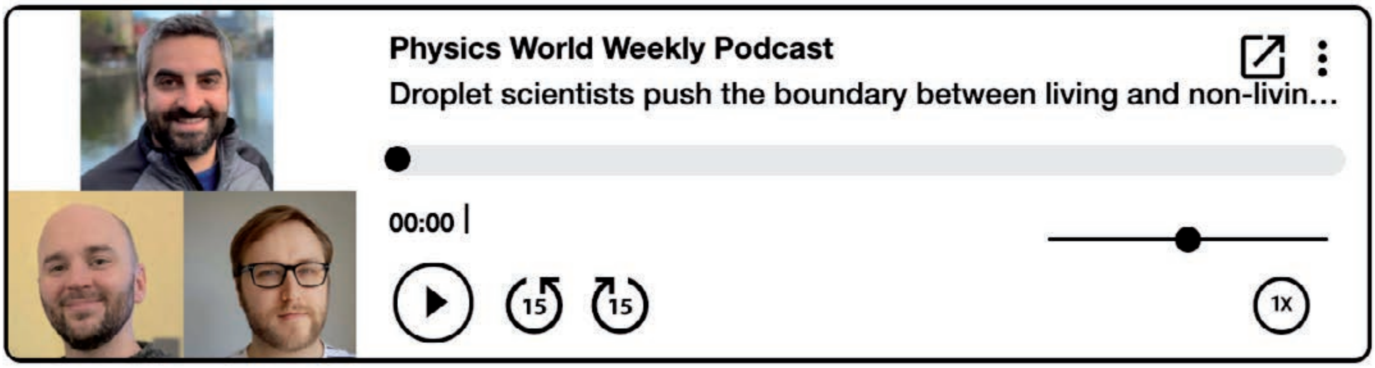
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