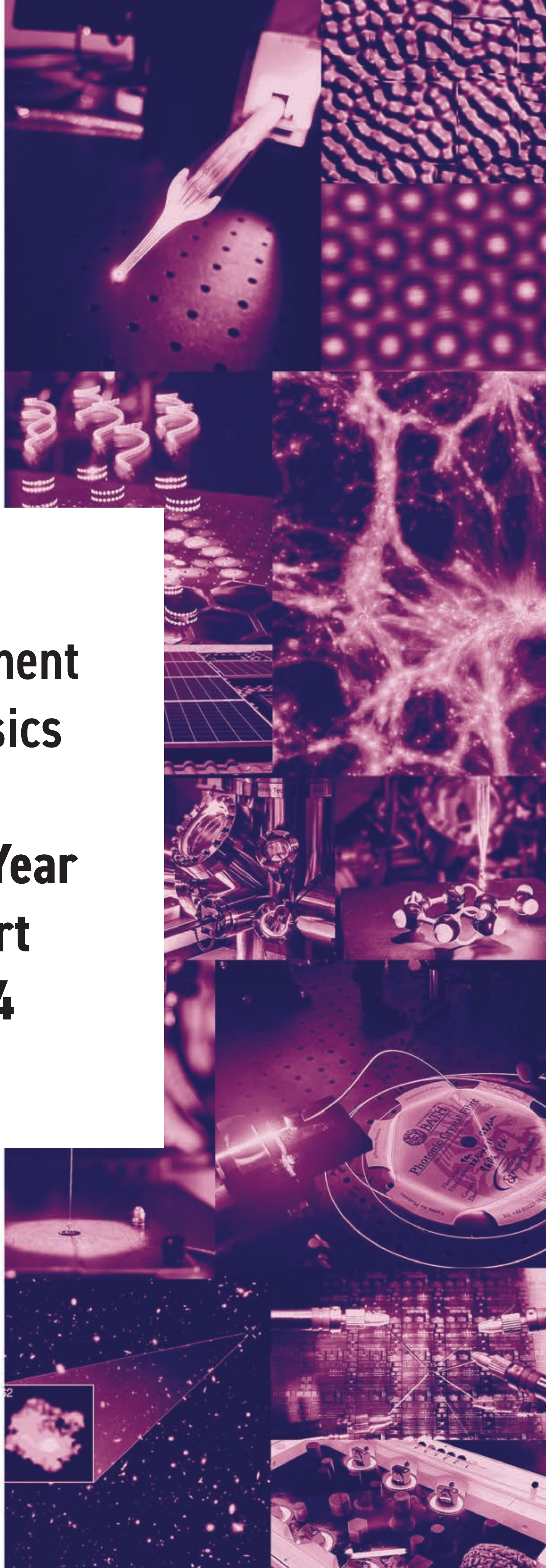
UNIVERSITY OF BATH

PHYSICS at BATH

Department of Physics

End of Year Report 2024



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Completing our transformation

Year 2024 has been pivotal as we completed our departure from the 3 West building, with efforts made to ensure a smooth transition and to set a strong foundation for our future – several high-quality new labs were built to host our world-class research programmes. Most of our research groups have been strategically restructured to foster collegiate and impactful work. We have welcomed many new colleagues, whose presence already had a notable effect on the department. In the corridors, showcasing our achievements and our inventions, additional visual identity elements have appeared. At the Eureka conference, science and industry aligned, to drive stronger, lasting partnerships. Our curriculum keeps transforming through all the undergraduate degree programmes. This report highlights key episodes of the last year. It shows our dedication to collegiality and shared ambition. It also reflects an upward trend for us, with many more days for science just around the corner.

Prof Ventsislav Valev
Head of Department

Today is a great day for science!

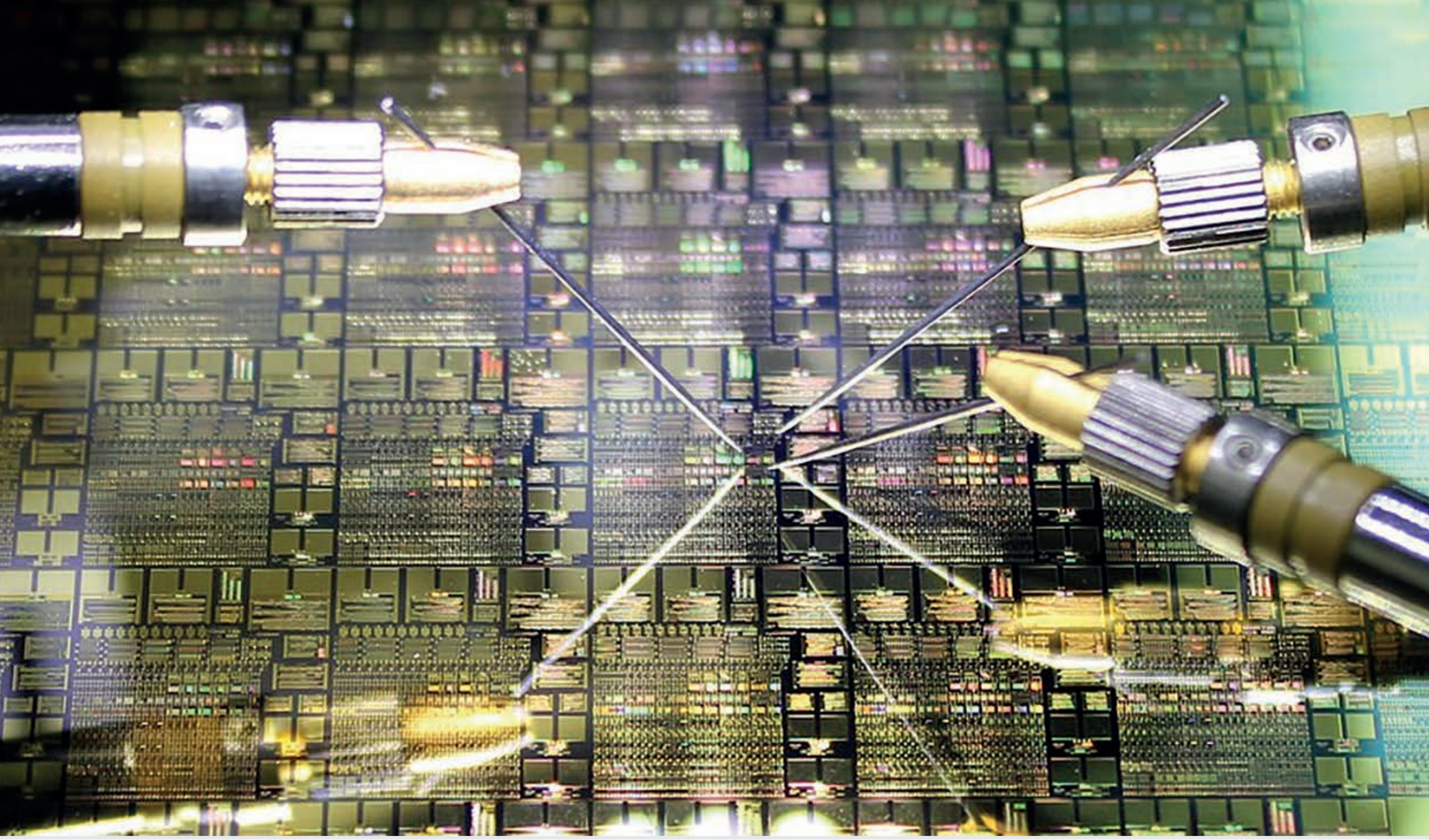
Our Vision for Physics in Bath – **update**

Actions we have accomplished so far are represented in green, things we are currently working on in blue.

The year is 2028, the national Research Excellence Framework results are just in and we have hit all our targets. For outputs, impact and environment, we are in the top 10 UK physics departments. Our grant income has steadily increased over the years. An ever-larger proportion of our research income now comes from sources other than the Research Councils. We consistently score very high in student satisfaction surveys and we comfortably recruit strong undergraduate students to meet our targets. We are committed to delivering exceptional courses. We are recognised as a leading department of physics education and research, capable of coordinating large initiatives, such as centres for doctoral training. Our reach is global. We lead numerous partnerships with nearby universities within the South West. Our leaders are focussed on strategy, implementation and above all, on delivering results.

Building upon our culture is the priority

To meet our strategic growth targets, we have increased our productivity by creating a vibrant community. All staff feel valued, with clear roles and career paths. Our staff enjoy each other's company. We have a (re)generator room – our staff often have energizing discussions there to generate great ideas. It is also a place to drink coffee, relax and revitalise. Our staff have the opportunity to have lunch together and many of them do. When they have a problem or need support, there is always someone they can talk to. We collectively celebrate our successes and our events are inclusive. All staff feel empowered to bring their distinctive contributions to develop and deliver the vision. Diversity brings different perspectives and viewpoints that help us to increase our impact and reach. Our community includes the undergraduate and postgraduate students and there are Department events dedicated to each learning stage. We have created a community record – a department yearly report that staff can bring home at the end of the calendar year. There, one can read about our activities, our research and teaching successes, our new department members, etc. The report also goes to our extended community, including partners and alumni of the department. A library of all previous reports is available in our meeting room.



Research funding is diversified

Over recent years, our funding has diversified. The majority of our research income is now from sources other than the Research Councils, such as: business and industry, Innovate UK, the Royal Society, the Leverhulme Trust, West of England Combined Authority, the Wellcome Trust, the Royal Academy of Engineering, the British Embassies, Research England, Bath and North East Somerset Council, DSTL, DASA, etc. We regularly exchange visiting postdoctoral researchers and PhD students with partners abroad. Our increased research power softens the vagaries of Government research funding. Within our grant portfolio, our academics are leading large research programs. Growing resilience to failure has been the key. We support each other in overcoming rejections and we take failure as scientists – it is data! It is never personal. Our increased research power means that rejections have a short-term effect on morale and grant applications are swiftly redeveloped into new proposals.

Our environment is refurbished

From the west car park, the physics building is immediately recognisable and inviting. We are now working in a completely refreshed environment and we are all together, in the same building. Once inside, there is an immediate impression that this is a place of learning. The corridors and meeting room walls are lined up with items that celebrate our successes: prizes, prominent research papers, cover arts and prototypes are all present. Display items also demonstrate the career possibilities that Physics offers (we have a section on the wall with alumni photographs), as well as spin-out successes and prominent collaborative work. Office doors are personalized with laser cut doorplates that highlight our achievements. The meeting room is a place of inspiration. Visitors are impressed with the attention to detail and want to work in a place like our building.

Our labs are inspiring and world-leading

Inspiration takes different forms. Walking into some of our labs feels like being on a glamorous science fiction movie set (with lasers, robots, space vacuum, quantum computers). Others are places of contemplation – this is where the first hollow core fibre was made, the first Hall probe microscope built, etc. Our safety measures and signage tell everyone that our labs are special places and that we care for people. The labs host unique and cutting edge equipment operated by scores of students, postdoctoral researchers, and expert technical staff. Our researchers also have access to world-leading shared facilities (including observational satellites and high performance computing machines). In the words of Nicolaas Bloembergen (Physics Nobel 1981): “When you use new technology, new things are bound to happen.” Following this recipe for scientific discoveries, our unique equipment and our access to world-leading facilities routinely produce high-impact research results.

We create impressive narratives

For most of our exciting research, there are outreach activities, with narratives and props to explain the science to visitors. A public engagement professional is in charge of lab tours and of organising meetings with academics (both theorists and experimentalists). Some of our visitors have been fund managers, industry partners, editors, higher management, and we regularly host visits from our alumni. Many are very impressed and the visits have changed the perceptions of key partners. As a result, our academics are much more confident about submitting ambitious grant applications and manuscripts. Consequently, our success rates have increased.

Our leadership is shared and empowering

Leadership and management are distributed throughout the department through effective delegation processes. A senior department manager ensures that our administrative processes run smoothly. A Deputy Head of Department complements the Head of Department’s expertise. The Head of Department draws expertise from training, feedback, mentorship, experience. The Head of Department focusses on strategy and on meeting the key performance indicator targets for the department. Throughout the department, delegation improves our staff’s leadership and management skills. The process benefits their research teams and their teaching. It also prepares them for taking on larger responsibilities within the department. Our staff look forward to their Career Conversations, which are recognised as useful to achieve their career goals. Teamwork and volunteering within the Department are a valued integral part of the career conversations and promotion processes. Department meetings tell stories of colleagues who are leading initiatives of strategic importance for our community.

We concentrate on guided learning

In our undergraduate programmes, our focus is on the effective guidance of learning. This shows in our student satisfaction survey results. We are committed to delivering exceptional courses. We have star teachers and teaching awards reflect that fact. Our teaching labs are inviting playgrounds where even parents visiting on open days want to start a physics degree. We have attracted a large number of overseas students. All researchers are enthusiastically participating in the learning process. Our learning spaces are stimulating environments. Our courses are continuously refreshed and remain fit for the future. All the overheads of preparing new courses and new assessments have freed time for research. At the end of each year, we offer student prizes to our best students to reward their efforts, to build their confidence and to strengthen their CVs as they launch their professional lives. The number of our PhD students has increased. Our PhD students benefit from visits to internationally leading research institutions abroad and, in turn, we host PhD student visits from these institutions.

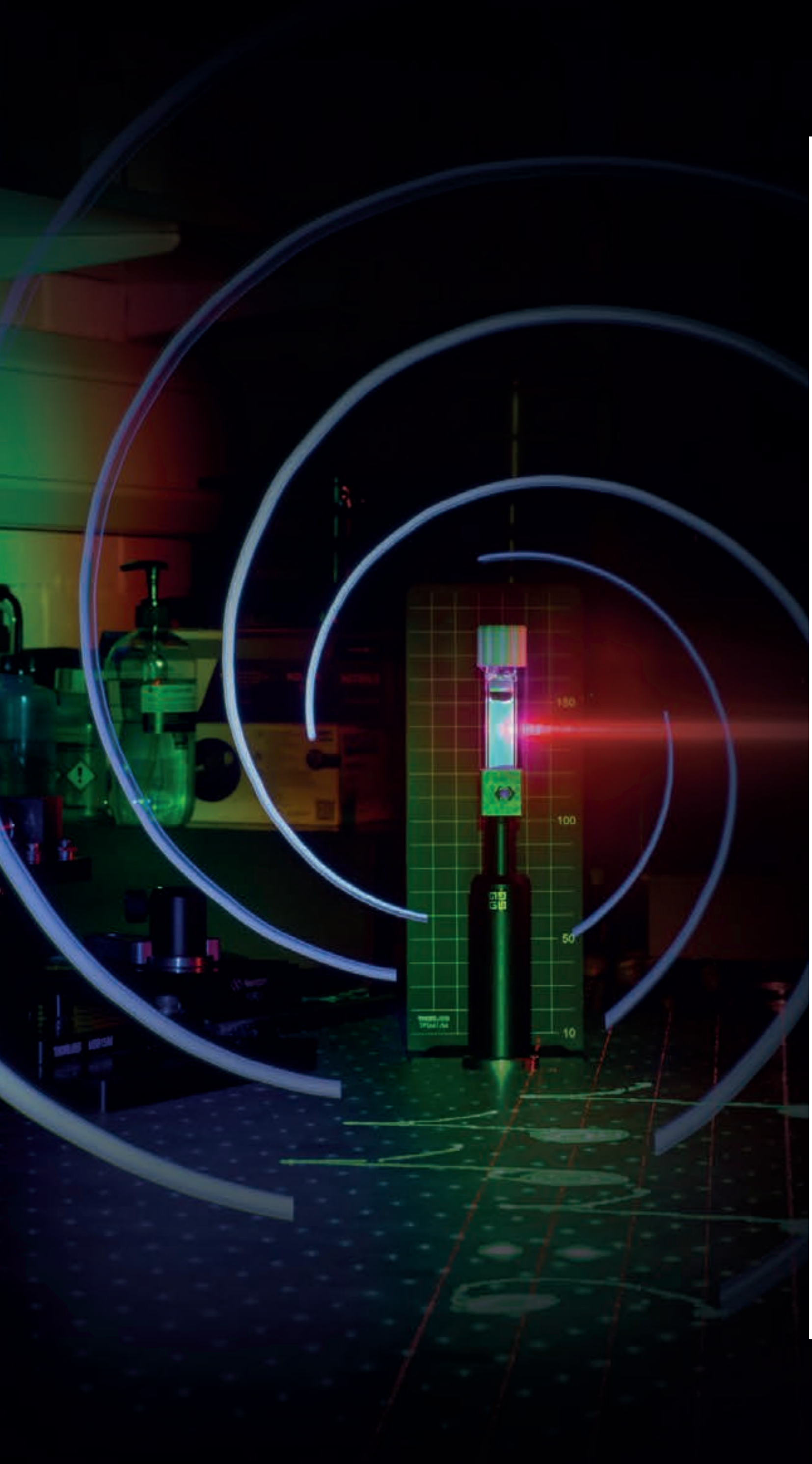
We focus on key media

The media seek out our expertise and our work is often reported in key media including those that publish university rankings, such as *The Guardian, The Times, The Daily Telegraph, Financial Times*.

We collaborate strongly with the university press office. Numerous activities regularly appear on the university website news sections.

Prizes and awards have accured our credibility

Our Physics website demonstrates our partnerships and global reach. Many of our staff have received prestigious awards from the *Institute of Physics* and other learned societies, according to their career stage. Most of our staff have been elected Fellows of the *Institute of Physics* and many have been elected Fellows of other learned societies. The accrued prestige for our department lends credibility to our grant applications and to our manuscript submissions. As a result, our application success rates have increased. We now spend less writing grant applications and more time doing the science that increases our credibility even more.



Sponsorship levels in the department

At the entrance of the building, we gratefully display a list of our sponsors, who have helped to make this vision a reality. Sponsorships include:

- Undergraduate student placements at companies
- Prizes for PhD students
- Sponsorships for our Student Societies
- Company involvement via doctoral training centre bids
- Sponsorship for research workshops with key national and international partners
- Individual pieces of research equipment that can be share between academics in the department
- Teaching labs kit funded externally, e.g. by alumni or by innovation in teaching programmes (e.g. in the maker lab or telescope)
- Sponsorship for producing a software version of the maker lab, with emphasise on robotics and programming hardware.
- Sponsorship for commissioning inspirational art work
  for the department
- Company funded PhD studentships
- Sponsorship for named personal or research Chairs,
  e.g. RAEng research chair
- Named laboratory
- Named research team or centre.

Highlights of 2024

Staff: Hellos and Goodbyes

In 2024 we've welcomed Dr Leah Murphy, Dr Tommi Juhani Isoniemi, Dr Eric Lundgren, Mr Nathan Roberts, Miss Anne Inkenhaag, Dr Sarthak Choudhury, Mr Alexander Flint, Miss Elektra Olivero Pistoletto, Dr Rox Middleton, Dr Eleanor Nichols, Dr David Billington, Dr Francesca Caloro, Dr Michele Pizzochero, Dr Martin Rey, Dr Marie Rider.

We also said goodbye to Dr Harry Wood, Dr Cameron McGarry, Dr Charlotte Parry, Dr Gary Mathlin, Dr Petros Androvitsaneas, Dr Nathan Roberts, Dr Dipti Chauhan, Dr Paramita Pal, Dr Alexander Flint, Ms Isabel Wells.

Research Grants and Fellowship

- Dr Philippe Blondel was awarded an EPSRC grant for "Bio-inspired Acoustic Tactical Navigation" (BATNav), developing acoustic sensors to navigate in constrained environments like tunnels or fire-fighting situations.
- Dr Habib Rostami was awarded EPSRC grant on Nonlinear Photonics in layered quantum materials as well as Royal Society grant of acoustoelectrics of layered quantum materials.
- Prof Alain Nogaret was awarded EPSRC IAA Proteocare grant.
- Prof Simon Bending was awarded an US Army Research Office grant "In-situ vortex manipulation and trapped flux removal in superconducting electronic devices".
- Prof Dmitry Skryabin was awarded an EPSRC-SFI grant "Towards power efficient microresonator frequency combs".
- Prof Tim Birks, Prof Jonathan Knight and Dr Jim Stone were awarded a Sumitomo Electric Industries grant "Low loss antiresonant hollow core fibres".
- Prof Tim Birks was also awarded funds for "Astronomical Photonic Reformatter Experiment For Infrared Science", and for a collaboration with a Future Leaders Fellow at Heriot-Watt University.
- Dr Peter Mosley was awarded an Air Force office of Scientific Research grants "Two-photon absorption in fibre-integrated resonators for single-photon sources and quantum gates" and "Topological photonic crystal fibre with a twist".

Outreach

- Dr Kristina Rusimova conducted 5 outreach workshops on the Science of Light at with primary school pupils in years 5 & 6.

Prizes

- Dr Carolin Villforth and Dr Nathan Roberts won Doctoral Recognition Awards.
- Prof Alain Nogaret won a GW4 epilepsy development award.

Conferences

- Dr Philippe Blondel chaired the International Conference on Underwater Acoustics at the University of Bath in June.
- The u-Care project which is a collaboration between Prof Tim Birks and those at the Universities of Heriot Watt and Edinburgh, took its science to the public at the Royal Society Summer Science exhibition in 2024, which was co-organised by Dr Kerrianne Harrington.
- The University of Bath's Physics Department organised the fourth Eureka conference, Eureka 2024.
- Dr Kristina Rusimova secured funding for and organised an international Rank Prize Symposium on the topic of "Ultrafast meets Ultrasmall: Exploring the Uncharted Territory of Quantum Dynamics" in the Lake District.
- Dr David Tsang run an "Extreme Matter in Extreme Stars" workshop at the Lorentz Centerin in September, funded by the Lorentz Center, Royal Astronomical Society, and CNRS. The workshop brought together around 75 researchers from nuclear physics and astrophysics to discuss how to probe extreme nuclear matter, using the extreme nature of Neutron stars.

Spin off companies

Dr Jim Stone is the Chief Technical Officer of Prothea Technologies, a new spin-out company from the Universities of Bath and Edinburgh, which launched in April with a mission to enable lung cancer biopsy and treatment in a single visit. The firm has attracted €12M (£10.3M) of investment as it seeks to develop a medical device to quickly diagnose lung cancer lesions using a combined endoscope and image-processing system capable of examining the molecular structure of lung lesions. The team also wants to develop a laser-ablation catheter to treat lesions immediately after diagnosis, reducing time-to-treatment from weeks to minutes, relieving hospital pressures and improving patient outcomes.

Other

- Photonics researchers from the Department are a part of the QCi3 Hub (Quantum Computing via Integrated and Interconnected Implementations), which formally began on 1st December 2024. Our researchers will be working closely with those from 17 other institutes across the UK and some 30 industrial partners to identify and develop real-world applications of quantum computing, including focusing on design for new materials, chemicals, fluid simulation techniques and machine learning.
- Horizon 2020 project AHEAD2020 draws to a close after a successful five-year run bringing together high-energy astrophysics across Europe.
- BiD4BEST, a project studying black hole accretion and galaxy evolution using big data, is wrapping up. This large EU project spanned 10 universities and research institutes as well as industrial partners and resulted in over 20 published papers. 13 PhD students worked across the project, many of whom have now graduated. The project was lead by Prof. Shankar (Southampton), with Bath represented by Dr Carolin Villforth and PhD student Mathilda Avirett-Mackenzie.
- Ceryx Medical implements the first Phase I clinical study of its Cysoni pacemaker in patients recovering from heart surgery.
- Dr Adelina Ilie had two patent applications with Transdermal Diagnostics Ltd. progressed to PCT level: new PCT application covering 2 new patents was filed and novelty accepted.
- Dr Adelina Ilie's EPSRC IAA "A non-invasive transdermal platform for multi-analyte monitoring" has completed in Dec 2024 with the demonstration of another biomarker (to add to glucose) to be detected non-invasively by the proprietary monitoring technology. She was also awarded two rounds of beam time at the Diamond Light Source for 2024/2025 on work on novel 2D materials.

Congratulations!

to all PhDs who have received their award in 2024:

Hesameddin Mohammadi
Will Davis
Zhen Jieh Lim
Nathan Roberts
William Campbell
Vladislav Pankratov
Shaula Garibbo
Matthew Tomlinson
Ben Olohan
Matthew Cook

Welcome to our New Staff

Martin Rey, Lecturer

I am Martin Rey, a new staff member at astrophysics. My research focusses on understanding how galaxies form and evolve in our Universe, from the very first stars after the Big Bang to the diversity of galaxies we observe today. I have broad interests ranging from theoretical cosmology, star formation and evolution, the nature of dark matter, the build up of the chemical elements across the Universe, and scaling huge hydrodynamical simulations on supercomputers. I also come from an aerospace engineering background and have successfully led a satellite project sent to space a couple of years ago :)

Here is some fun icebreaker trivia about me: I am a keen long-distance sailor — I actually own a boat and was considering sailing all my possessions to the UK to take the job in Bath. I have recently grown into climbing (anyone knows gyms or outdoor spots around here?) and have tried virtually every racket sport there is if anyone fancies a game. I consider myself quite social, but usually a terrible partner for pub quizzes (I tend to improve after the first round though). I am originally from the south of France and can take good-hearted French-British banter.

David Billington, Lecturer

Following my PhD in Bristol where I focused on experimental and theoretical determinations of Fermi surface geometries, I worked for three years as a postdoc at the SPring-8 synchrotron in Japan utilising soft x-ray spectromicroscopy techniques to image magnetic domains in Nd-Fe-B magnets. Over the last four years, I have been a postdoc in Cardiff researching novel techniques for studying quantum states in bulk crystals. Outside of work, I enjoy making music with friends where I usually play bass guitar or jazz piano.

Elektra Olivero Pistoletto, Teaching Technician

I couldn't stay away from the university, so after finishing my Master's in Physics with Astrophysics here at Bath, I've come back as a teaching technician. My passion for astrophysics (and philosophy) runs alongside a love of all things theatre and I take every opportunity I can to perform in or tech productions! I also really enjoy playing the cello and reading, and I'm always happy to converse about classical music or literature.

Rox Middleton, Lecturer

I'm an experimental optics researcher looking at photonic structures in plants (& other optical biomaterials insects, algae, etc.) My research focus was originally in photonic crystals, helicoidal multilayers and ordered structure, I now focus more on measuring and modelling disorder in optical materials. I'll be building a lab around optical microscopy and angular-resolved measurements & plant wax self-assembly. I also like working in electron microscopy, computational optics, UV and IR imaging and materials chemistry. I have a pedagogical interest in outreach evaluation, and especially like unusual outreach work and have an ongoing project on the experience of beauty in science and arts. Outside of work I'm a member of the queer community in Bristol and I paint portraits.

Marie Rider, Lecturer

Hi everyone! I've just started as a theorist in the NanoBioPhotonics group, and really enjoy working on theory-experiment collaborations as I think that's when science gets really fun! I'm interested in how light and matter interact at small scales - to both understand a little better how the universe works, and learn how we can apply our knowledge to make planet-friendly technologies. At the moment I'm particularly interested in how we can use strong coupling between light and molecular systems to enhance energy transport in molecular devices. When I'm not doing physics, I love traveling and being outside. I've lived in Canada, the US, Austria and the UK - now that I'm in Bath, I'm trying to hike a bit of the Cotswold Way each weekend.

Francesca Caloro, Lecturer

Hello everyone, I'm Francesca (she/her) and I'm very pleased to join the Department of Physics. In the last years, I worked on momentum-space conformal field theory, integral representations for Feynman integrals and hypergeometric functions. My interest in education led me to always be involved in teaching, and now here I am.

More broadly, I am passionate about symmetries and their breaking in any field, from physics to Bach's scores! In my spare time I read/write, play the piano and play badminton.

Eleanor Nichols, Lecturer

Hello! I'm Eleanor one of the new teaching lecturers in the department. Before joining Bath, I did my PhD in quantum optics at the University of Cambridge. When not messing around with lasers, magnets and cryogens, I enjoy baking (I'm sure I'll be bringing in some samples soon!), board games/DnD and playing with my dog Teddy. I'm looking forward to meeting everyone and getting involved in the department!

Michele Pizzochero, Lecturer

Michele Pizzochero is a Lecturer in Theoretical Physics. His research is centered on the electronic structure of atomically thin crystals from ab initio calculations. Before joining the University of Bath, Michele worked as a Research Associate and Postdoctoral Fellow at Harvard University, where he held an individual fellowship from the Swiss National Science Foundation. Michele obtained his Ph.D. in Physics from the Swiss Federal Institute of Technology in Lausanne (EPFL) and his M.Sc. in Chemistry from the University of Milan. When not trying to solve the Schrödinger equation, you can find him running across Somerset.

University of Bath Physoc at the FUSE conference

by Emily McManus, Physoc Chair

This past November, two committee members from the University of Bath Physoc—Emily McManus and Anthony White—travelled to the University of St Andrews for the annual Forum of University Societies Event (FUSE). Organized by the Institute of Physics, FUSE is a yearly conference designed for student-led physics and astronomy societies affiliated with the IOP.

This year's conference placed a major focus on collaboration, exploring how societies can work together—whether with other local societies, within their own universities, or with their respective departments. Over the course of two days, Bath Physoc showcased what Physoc at Bath is all about while learning from the experiences and initiatives of other societies.

The societies showcase was another standout moment, where Emily and Anthony had the chance to represent Bath Physoc and exchange ideas with peers from across the UK. The passion and commitment of the attendees highlighted the dynamic community cultivated through events like FUSE.

Attending FUSE provided invaluable inspiration and practical ideas that could help shape the future of Physoc at Bath. From new approaches to engaging students beyond lecture halls to strategies for fostering stronger ties with the Physics Department, the conference highlighted numerous opportunities for the society to evolve and expand its impact. The focus on collaboration emphasized the importance of partnerships—not only with other societies but also within the university and the wider physics community. A special thanks also goes to Paul Snow from the University of Bath Physics Department for assisting with the logistics of attending this invaluable opportunity.

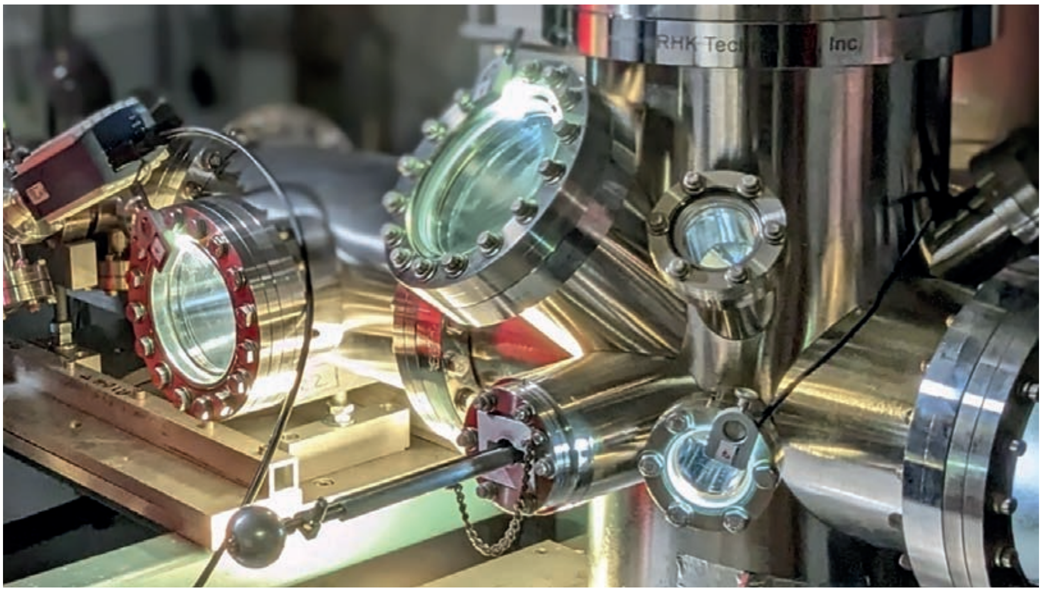
FUSE 2024 was a truly memorable event that brought together a dynamic network of student societies, inspiring collaboration and innovation in physics and astronomy. The connections made and ideas generated during the conference promise to shape the future of Physoc at Bath in exciting and meaningful ways.

Nathan Roberts and Carolin Villforth win Doctoral Recognition Awards

Physics' PhD Student Nathan Roberts and Director of Studies Carolin Villforth win Doctoral Recognition Awards.

The Doctoral Recognition Awards, organised by the Doctoral College, recognise students and staff who have contributed to enhancing the doctoral student experience. This year, two members of the Department of Physics received Doctoral Recognition awards. Dr Nathan Roberts, a recent PhD graduate in the Department was recognized for his contribution to the PhD community as Chair of the Staff Student Liaison Committee as well as his role within the Bath Optica Student Chapter. Senior lecturer, Dr Carolin Villforth, was recognised for her work as Director of Studies supporting PhD students in the department and creating a supportive research environment.

Scanning probe microscopy and nanoscale imaging



The scanning tunnelling microscope reveals the surface of materials at an atomic level.

Scanning probe microscopes let us study surfaces at the nanoscale level. But how do they work and why do we need them? Physics researchers tell us more.

Whether we're developing the solar panels of tomorrow, miniaturising electronics, or finding new ways to power homes, we need to take a close-up look at the materials we're working with.

Scanning probe microscopy lets us look at specimens right down to the individual atoms they're made from.

Conventional microscopes use light and magnifying lenses to enlarge specimens so they can be seen by eye, either through a viewfinder or camera. As atoms and molecules are very much smaller than even the smallest light wavelengths, we can't use light to see them.

Instead, scanning probe microscopes work almost like a record player.

A sharp tip – in some cases measuring just an atom or two across – is moved across the surface of a material. When the tip interacts with the surface - for example, if it detects an electric current - it records the measurement and maps it. As the tip scans the surface, it builds up an image line by line from the measurements, until the features of the entire surface have been recorded.

Depending on the tip used, different properties of the material can be measured, and different images of the surface can be created.

Scanning tunnelling microscopy

Scanning probe microscopy found its feet in the early 80s, with the invention of scanning tunnelling microscopes (STM). Their resolution and function vary, but they all work using the same principle.

Instead of pushing the tip into a surface like a record player needle, the tip is lowered until there is a gap of a single atom's width between the tip and the surface. When a power source is added, electrons flow down the tip and make a quantum leap across the atom-wide gap. Depending on how close or far away from the surface the tip is, more or less current

flows through the circuit. This creates a feedback loop, and the strength of the electric current measured can be used to build up an image of the surface.

Dr Peter Sloan and Dr Kristina Rusimova are taking this technology a step further. Not only are they using the microscope's electron beam to inspect surfaces, they're also using it to bombard atoms or molecules on them. By exciting molecules (firing electrons at them until some stick), Peter and Kristina can move molecules around and make or break bonds between them.

The team want to understand exactly how this happens and what we can do to control it. They've been putting their theories to the test to understand hot electron transport and single molecule dynamics.

When electrons in a semiconductor are excited with a large amount of energy, they become 'hot' and naturally want to lose this energy, fast. In the time taken for them to shed this energy, Peter has discovered the hot electrons shoot sideways a short distance. Measuring this distance has important implications for developing the solar cells of the future.

Solar panels are often made of the semiconductor silicon, and hot electrons are created when light hits them. Electrons are excited with a huge amount of energy and put a lot of this energy into moving a short distance, very quickly. Any energy not lost in this movement is collected and used as green electricity. If we could capture this initial burst of energy as soon as the electrons start moving, solar energy generation could be made far more efficient. These effects are being modelled by Prof Alison Walker and Jamie Lerpiniere.

Kristina is also using the technology to manipulate individual atoms and molecules. Instead of looking at how excited electrons move across a surface, she's using them to create chemical reactions at a molecular level.

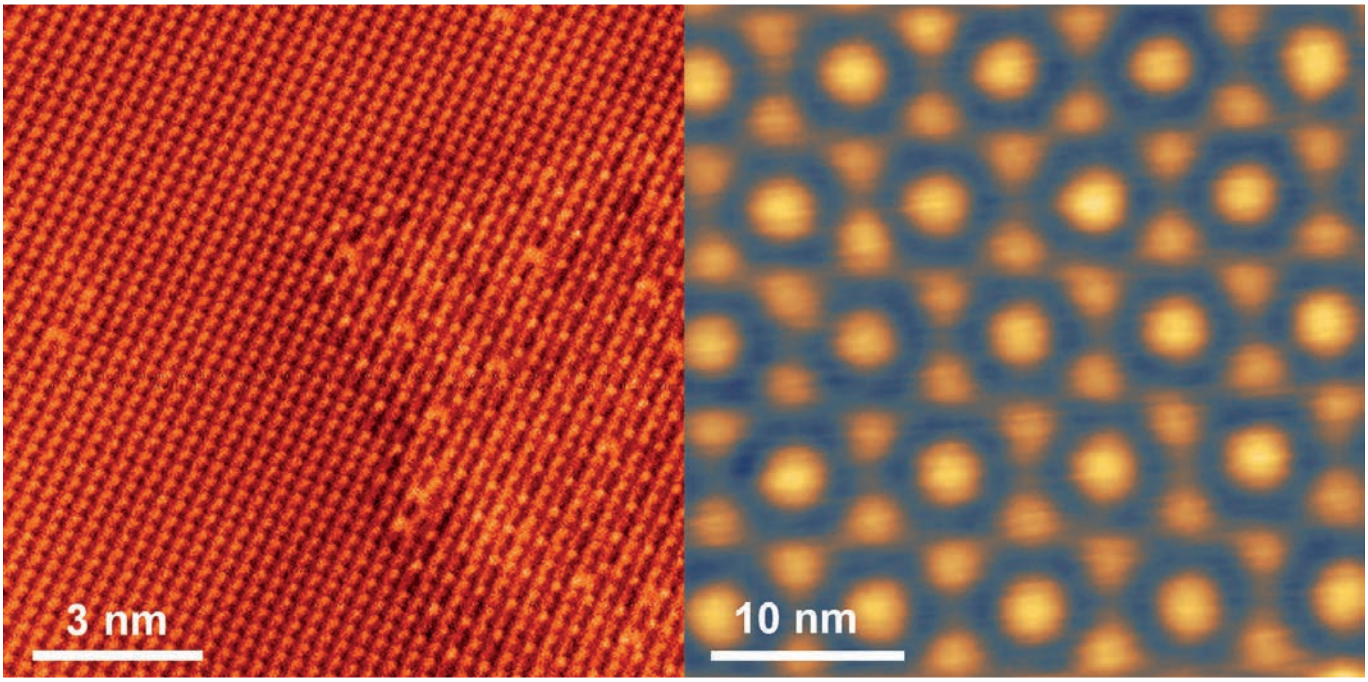
This is particularly useful when designing completely novel molecules that don't exist in nature. By exciting electrons and targeting specific molecular reactions, researchers can develop new drugs and even new materials.

In a UK-first, Kristina also wants to measure the amount of light given off by these reactions. Measuring light emissions would allow researchers to calculate a temporal element to reactions. This adds an extra dimension to the information scanning tunnelling microscopes provide.

Atomic force microscopy

A complementary imaging technique is a variation called atomic force microscopy (AFM). While both use surface probes, atomic force microscopy measures the attracting and repelling forces between atoms to build up an atomic map of the surface.

Where scanning tunnelling microscopy shows us the electronic properties of conductors and semiconductors, atomic force microscopy produces images that more closely reflect the physical structure of materials. As AFM doesn't rely on the flow of electrons, it also lets us take images of insulating materials at an atomic level.



Left: an atomically-resolved AFM image of the surface of an insulator, displaying a nano-engineered nanoscale pattern. Right: an STM image of a 2D material developed for spintronic applications, exhibiting a Moiré pattern.

Dr Adelina Ilie is engineering two-dimensional materials with bespoke properties. In her research, she synthesises 2D nanomaterials inside an ultra-high vacuum instrument. She can then investigate them using scanning probe microscopy without breaking the vacuum in the chamber and exposing them to contamination.

2D materials are stable materials that are a single atom thick. One of the most well-known is graphene, an atom-thick layer of carbon atoms, bonded together in a honeycomb pattern.

Adelina and her team are developing inorganic, graphene-like materials with uses in novel IT and computing systems. One such feature explores 'spintronics'. This is an emerging field that exploits an electron's spin, instead of its charge. Traditional electronics use 3D silicon transistors, which can only be made so small and operate on charge.

Spintronic devices are faster and more energy efficient than their charge-based cousins. This makes them ideal in helping address challenges like the global surge in energy consumption, something only predicted to worsen as new technologies – like Generative AI – become widespread.

When 2D materials are grown on a crystalline substrate, something called a Moiré pattern forms. Like the visual effect of rotating a grid on top of another and creating darker and lighter regions, here, the pattern shows the modulated electron density. Moiré patterns can alter the original properties of the 2D material, and this is something Adelina and her team use to tailor bespoke spintronic materials at the atomic level.

To probe such materials, the scanning tunnelling microscopy technique must be sensitive to the spins localised on the material's atomic sites. By using all these complementary imaging techniques and in-situ device integration, Adelina can build up a picture of these novel materials and reveal their unique functional properties.

Scanning Hall microscopy

Scanning probe microscopy found its feet in the early 80s, In another area of the department, Professor Simon Bending is also interested in creating new materials with improved properties.

Much like Adelina, he's using scanning probe microscopy as a feedback tool to learn more about the materials' properties. Simon, however, is homing in on the magnetic structures in materials to investigate the superconductors of the future.

The technique – scanning Hall microscopy – replaces the sharp tip with a 'Hall effect' sensor that detects magnetic fields. Made from a semi-conducting material, it has electrical contacts at either side and a current runs along it. When the sensor encounters a magnetic field, the electron flow bends towards one side or the other. This registers as a voltage at one pair of contacts. As the probe scans the surface of the material, these voltage peaks mark the location of strong magnetic fields, and a magnetic map builds up, line by line.

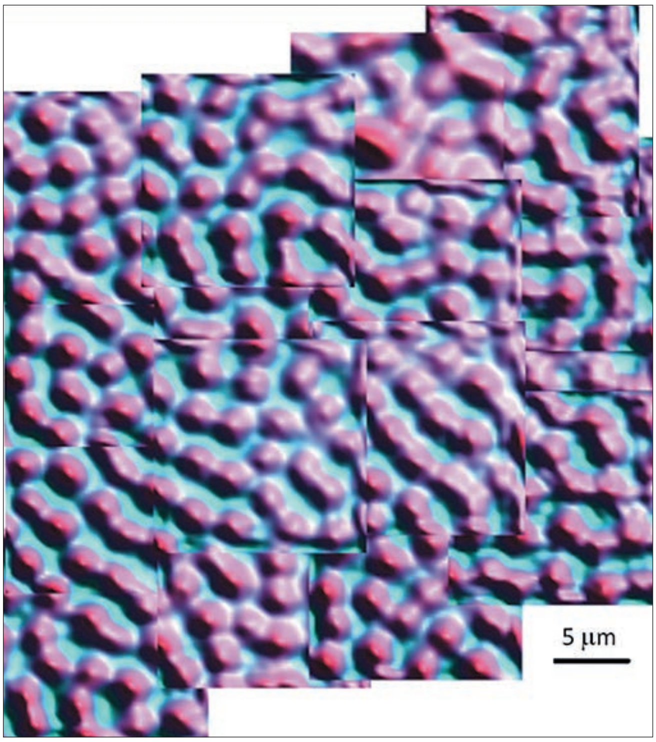
But what does this have to do with the next generation of superconductors? Superconductors are materials that when below a critical temperature, offer no electrical resistance. In principle, a superconducting wire loop could indefinitely sustain a current with no outside power source.

One of the biggest challenges in superconductor design is maximising the current they can carry while remaining in their unique 'zero-resistance, zero-dissipation' state. This all comes down to magnetism. Superconductors repel magnetic fields, but they're not completely impenetrable to them. All technologically important materials allow magnetic fields to penetrate in the form of tiny nanoscale tubes of flux called 'vortices'. These disrupt the flow of current through the superconductor and reduce their maximum current carrying capacity.

Scanning Hall microscopy allows the team to identify these tiny magnetic defects and tweak the material design to mitigate them. Researchers hope to develop a new generation of superconducting tapes that operate at much higher currents without losses. While still a long way from reality, an electrical grid using efficient superconducting tapes could deliver cleaner, greener power to our homes.

Looking to the future of his research field, Simon believes that scanning probe microscopy as a platform is probably as good as it needs to be, but the innovation lies in the development of new types of sensors that can be placed at the scanning tips.

For the Hall sensors, the team want to make them work more efficiently at higher temperatures. Currently, they only work well at cryogenic temperatures, making them ideal for scanning cold-loving superconductors. But if the team want to investigate ferromagnetic materials at room temperature, there is a clear need for improvement. Graphene sensors are currently being explored to satisfy this need.



A scanning Hall probe image showing superconducting vortices in a thin film of the superconducting material, magnesium diboride.

A pair of disc galaxies in the late stages of a merger. Credit: NASA.

What makes black holes grow and new stars form? Machine learning helps solve the mystery

by Vittoria D'Alessio

It takes more than a galaxy merger to make a black hole grow and new stars form: machine learning shows cold gas is needed too to initiate rapid growth.

When they are active, supermassive black holes play a crucial role in the way galaxies evolve. Until now, growth was thought to be triggered by the violent collision of two galaxies followed by their merger, however new research led by the University of Bath suggests galaxy mergers alone are not enough to fuel a black hole – a reservoir of cold gas at the centre the host galaxy is needed too.

The new study, published this week in the journal Monthly Notices of the Royal Astronomical Society is believed to be the first to use machine learning to classify galaxy mergers with the specific aim of exploring the relationship between galaxy mergers, supermassive black-hole accretion and star formation. Until now, mergers were classified (often incorrectly) through human observation alone.

"When humans look for galaxy mergers, they don't always know what they are looking at and they use a lot of intuition to decide if a merger has happened," said Mathilda Avirett-Mackenzie, PhD student in the Department of Physics at the University of Bath and first author on the research paper. The study was a collaboration between partners from BiD4BEST (Big Data Applications for Black Hole Evolution Studies), whose Innovative Training Network provides doctorial training in the formation of supermassive black holes.

She added: "By training a machine to classify mergers, you get a much more truthful reading of what galaxies are actually doing."

Supermassive black holes

Supermassive black holes are found in the centre of all massive galaxies (to give a sense of scale, the Milky Way, with around 200 billion stars, is only a medium-sized galaxy). These supersized black holes typically weigh between millions and billions of times the mass of our sun.

Through most of their lives, these black holes are quiescent, sitting quietly while matter orbits around them, and having little impact on the galaxy as a whole. But for brief phases in their lives (brief only on an astronomical scale, and most likely lasting millions to hundreds of millions of years), they use gravitation forces to draw large amounts of gas towards them (an event known as accretion), resulting in a bright disk that can outshine the entire galaxy.

It's these short phases of activity that are most important for galaxy evolution, as the massive amounts of energy released through accretion can impact how stars form in galaxies. For good reason then, establishing what causes a galaxy to move between its two states – quiescent and star-forming – is one of the greatest challenges in astrophysics.

"Determining the role of supermassive black holes in galaxy evolution is crucial in our studies of the universe," said Ms Avirett-Mackenzie

Human inspection vs machine learning

For decades, theoretical models have suggested black holes grow when galaxies merge. However, astrophysicists studying the connection between galaxy mergers and black-hole growth over many years have been challenging these models with a simple question: How do we reliably identify mergers of galaxies?

Visual inspection has been the most commonly used method. Human classifiers – either experts or members of the public – observe galaxies and identify high asymmetries or long tidal tails (thin, elongated regions of stars and interstellar gas that extend into space), both of which are associated with galaxy mergers.

However, this observational method is both time-consuming and unreliable, as it's easy for humans to make mistakes in their classifications. As a result, merger studies often yield contradictory results.

For the new Bath-led study, the researchers set themselves the challenge of improving the way mergers are classified by studying the connection between black-hole growth and galaxy evolution through the use of artificial intelligence.

Inspired by the human brain

They trained a neural network (a subset of machine learning inspired by the human brain and mimicking the way biological neurons signal to one another) on simulated galaxy mergers, then applied this model to galaxies observed in the cosmos.

By doing so, they were able to identify mergers without human biases and study the connection between galaxy mergers and black-hole growth. They showed that the neural network outperforms human classifiers in identifying mergers, and in fact, human classifiers tend to mistake regular galaxies for mergers.

Applying this new methodology, the researchers were able to show that mergers are not strongly associated with black-hole growth. Merger signatures are equally common in galaxies with and without accreting supermassive black holes.

Using an extremely large sample of approximately 8,000 accreting black-hole systems – which allowed the team to study the question in much more detail – it was found that mergers led to black-hole growth only in a very specific type of galaxies: star-forming galaxies containing significant amounts of cold gas.

This shows that galaxy mergers alone are not enough to fuel black holes: large amounts of cold gas must also be present to allow the black hole to grow.

Ms Avirett-Mackenzie said: "For galaxies to form stars, they must contain cold gas clouds that are able to collapse into stars. Highly energetic processes like supermassive black-hole accretion heats this gas up, either rendering it too energetic to collapse or blowing it out of the galaxy."

She added: "On a clear night, you can just about spot this process happening in real time with the Orion Nebula – a large, star-forming region in our galaxy and the closest of its kind to Earth – where you can see some stars that were formed recently and others that are still forming."

Dr Carolin Villforth, senior lecturer in the Department of Physics and Ms Avirett-Mackenzie's supervisor at Bath, said: "Until now, everyone was studying mergers the same way – through visual classification. With this method, when using expert classifiers that can spot more subtle features, we were only able to look at a couple of hundred galaxies, no more.

"Using machine learning instead opens up an entirely new and very exciting field where you can analyse thousands of galaxies at a time. You get consistent results over really large samples, and at any given moment, you can look at many different properties of a black hole."

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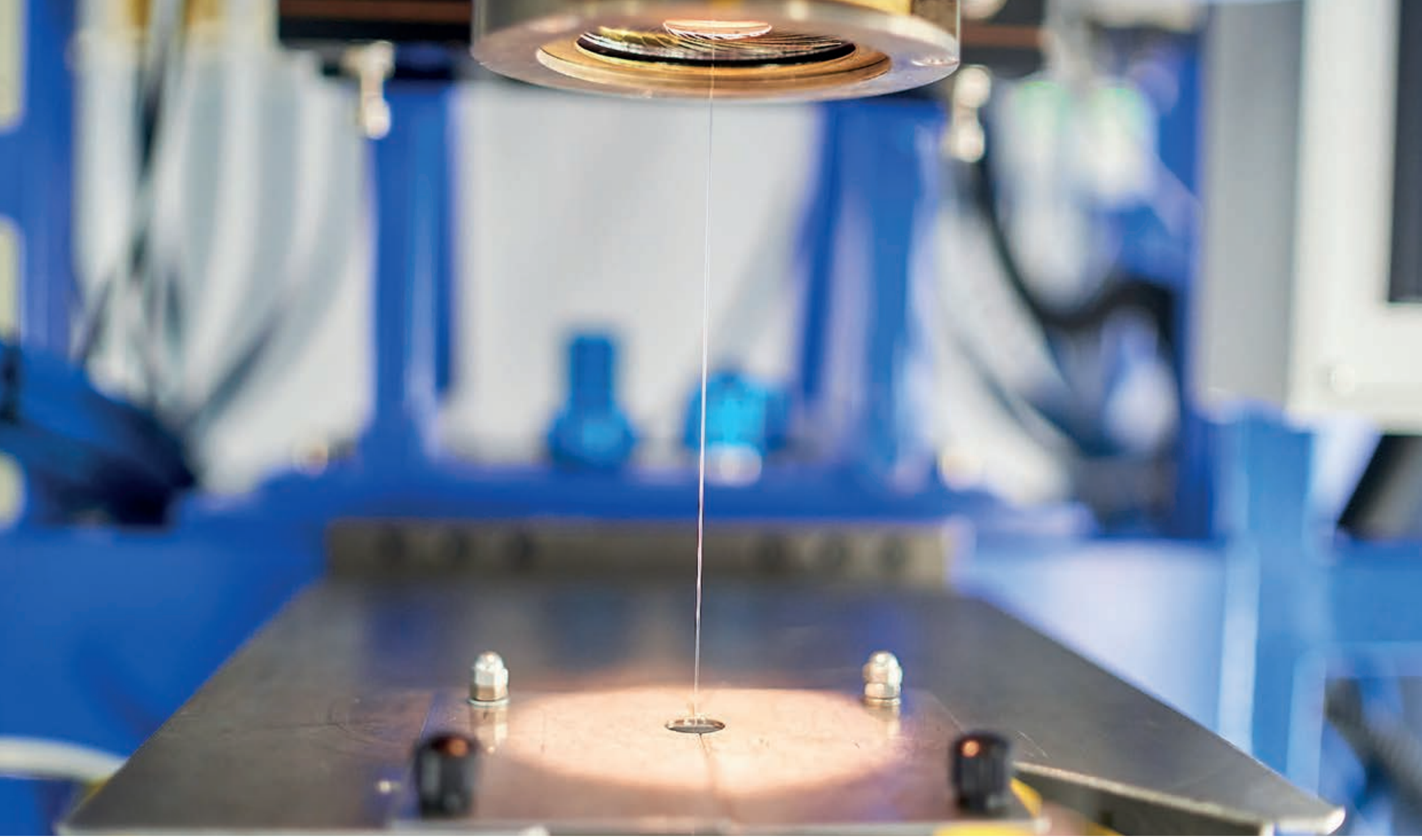

New University of Bath spin-out launches to improve lung cancer diagnosis and treatment

A new spin-out company from the Universities of Bath and Edinburgh has launched with a mission to enable lung cancer biopsy and treatment in a single visit.

Prothea Technologies, a new spin-out company from the Universities of Bath and Edinburgh, has launched with a mission to enable lung cancer biopsy and treatment in a single visit.

The firm has attracted €12M (£10.3M) of investment as it seeks to develop a medical device to quickly diagnose lung cancer lesions using a combined endoscope and image-processing system capable of examining the molecular structure of lung lesions. The team also wants to develop a laser-ablation catheter to treat lesions immediately after diagnosis, reducing time-to-treatment from weeks to minutes, relieving hospital pressures and improving patient outcomes.

Prothea Technologies combines extensive optical-fibre research expertise and intellectual property established at Bath, with medical and clinical expertise from the University of Edinburgh.

Dr Jim Stone from the Department of Physics at Bath will be Prothea's chief technical officer. He said: "Establishing Prothea Technologies is essential to bring our unique fibre optic technology into clinic so it can benefit patients.

"Prothea pulls together world-leading fibre-optic development from the University of Bath and clinical excellence from the University of Edinburgh, adding in commercial, insight, expertise and know-how to form a fantastic team.

"I'd like to thank everyone who has played their part to get us this far – our investors Earlybird Venture Capital and Merieux Equity Partners, with participation from NRW.BANK and Old College Capital. I'd also like to particularly thank the EPSRC (the Engineering and Physical Sciences Research Council), which funded significant academic research programmes and industrially focused grants."

Lung cancer is one of the most common types of cancer and is the world's deadliest form of cancer, responsible for more than two-million deaths per year. With its planned devices, the firm aims to tackle two challenges in the management of the disease: inaccurate biopsies and limited treatment options for small lesions in the lungs.

The funding raised will finance the company's first-in-human clinical trials for the real-time imaging and biopsy device, and move towards beginning trials for the laser ablation catheter.

The Company is led by chief executive officer and executive chair Crispin Simon – formerly president of the endoscopy division of the medical technology company Smith+Nephew – and Dr Kev Dhaliwal, professor of molecular imaging and healthcare technology and consultant in respiratory medicine at the Royal Infirmary of Edinburgh.

Mr Simon said: "We're delighted to have been able to combine a great team, multiple technology innovations and a strong investment syndicate, and look forward to putting our products at the service of doctors and their patients."

Professor Kev Dhaliwal, chief medical officer and chief scientific officer at Prothea, said: "Molecular-level data capture, combined with immediate therapy, holds huge potential in basic science and patient therapy. I'm grateful to the funders who have backed us over the years."

The University of Bath's EPSRC-funded Impact Acceleration Account (IAA) contributed to the technology development funding for Prothea Technologies which was spun-out with support from Research and Innovation Services (RIS) at the University of Bath.

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The nanotechnological revolution requires standardised 'screws' – here is a way to measure them

by Vittoria D'Alessio

Physicists at the University of Bath lead on the discovery of a new optical property that measures the twist in tiny helices.

A new nonlinear optical property of tiny particles has been discovered by an international team of scientists led by physicists at the University of Bath, with important implications for researchers working in fields as diverse as display technology, chemical catalysis and medicine.

The new property is seen when light passing through tiny particles – similar in size to the wavelength of light – is scattered at a colour that differs from that of illumination. The scattered light is at the 'second-harmonic frequency', meaning it's at twice the frequency of the illuminating light.

The study set out to explore the Tyndall effect – the phenomenon of light scattering from particles that are larger than nanoparticles but smaller than microparticles. Particles of this size include viruses and single cell organisms, such as bacteria.

When illuminated with white light, such particles appear blue (blue eyes also owe their colour to the Tyndall effect.

Second-harmonic Tyndall scattering

Inorganic particles dispersed in liquids are useful in many applications, including the adding of colour to paints and plastics, UV protection creams (zinc oxide and titanium dioxide scatter ultraviolet light but let visible light through), catalysis (to speed up or enable chemical reactions), and medical therapeutics (examples include encapsulating drugs and delivering them to their target; selectively cutting DNA, and killing viruses).

For all these applications, it's essential for researchers to characterise the particles' size and shape, accurately and in real-time.

Light is the best method to perform such analysis on particles in water, which is often the medium they are held in. When particles are illuminated, their scattered light holds information about both their size and geometry.

Several methods for analysing particle size depend on the Tyndall effect. Most methods rely on weak light sources (typically lamps) and the collected scattered light is of the same colour as the illumination. Other, more sophisticated methods rely on a laser light source. The new study takes scientists' understanding of light scattered by laser to the next level.

Explaining, Professor Ventsislav Valev, who led both the Bath team and the study, said: "When a laser – with long light wave – is used in Tyndall's experiment, light can be created at a different colour – with short wave – and then scattered. The new colour corresponds to twice the light vibration of illumination.

"This discovery was made in 1965 in the laboratories of Ford Motor Company and applies to particles of all sizes. But if a particle's size matches the Tyndall effect range, then the illuminating and the newly created light can be better separated in space. Basically, the Tyndall effect sorts light waves by size.

He added: "But one geometrical property has remained unobservable until now with this new study: chirality!"

Twisted molecules

Chirality is a fundamental geometrical property across practically all length scales. In humans and other living organisms, all the functional amino acids are chiral, and so are sugars, proteins, and so on. Chirality is expressed in the direction of a molecule's twist (clockwise or anticlockwise), akin to the twist of a DNA helix.

For the new study, team members from the United States fabricated silicon helices with length of about 270 nm, which corresponds in size to some viruses, large exosomes and bacteriophages.

Professor Valev said: "We discovered that when we illuminate these helices with chiral (or circularly polarised) laser light, the scattered light can tell us which way silicon helices wind up.

"One reason this is important is because silicon is the most abundant solid element on Earth, so every new property holds potential for sustainable and cost-effective applications.

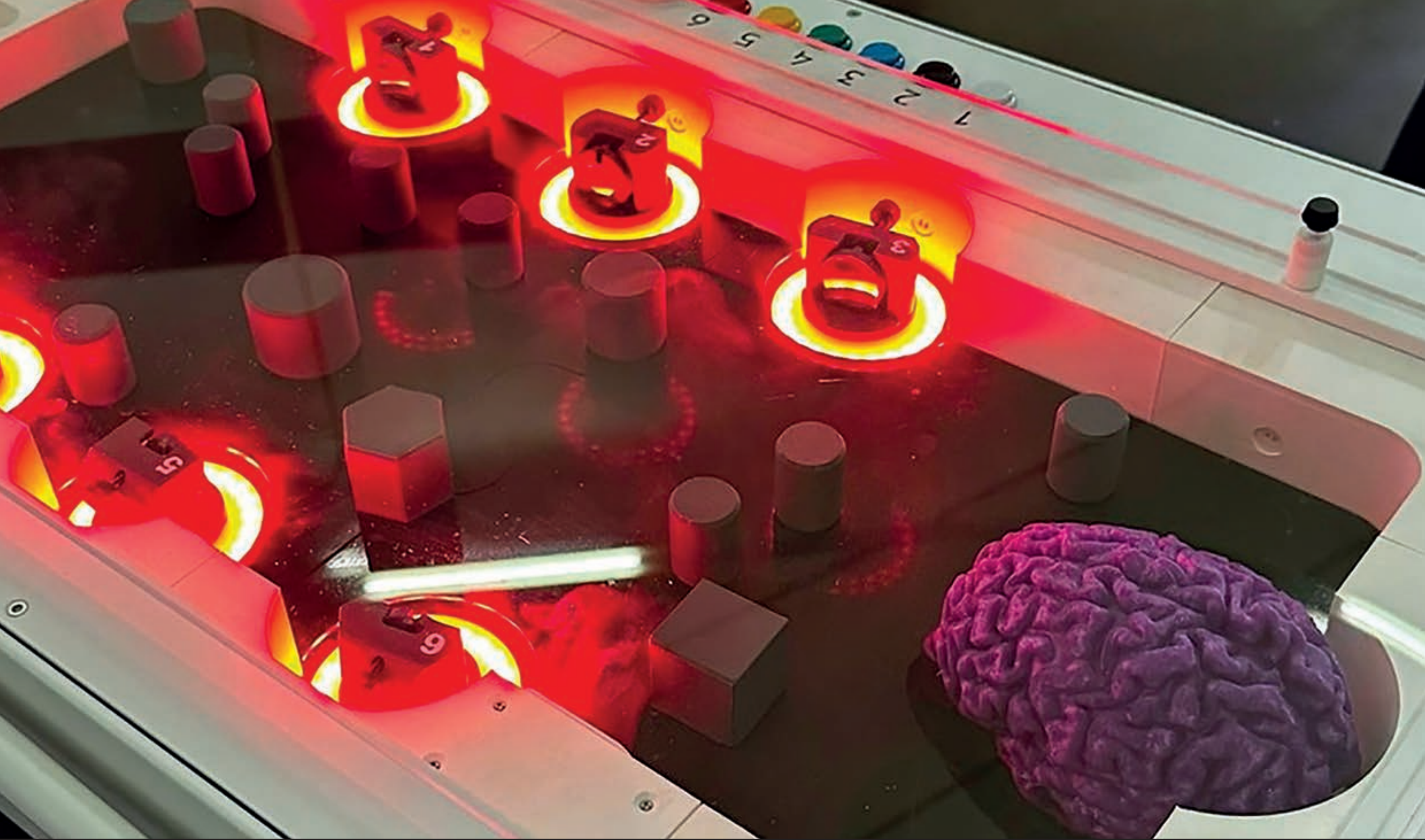
"Another reason is that measuring twist (chirality) is much needed for assembling inorganic materials from nanotechnological building blocks. The importance is similar to that of making and then being able to measure the thread of a standardised screw."

Looking ahead, Professor Valev said: "Now that we have a baseline for the properties of single helices in water, the next stage is to start modifying them and eventually building them into self-assembled materials."

PhD student Ben Olohan, first-author on the research publication, said: "The key here is that biological processes extend from molecules to cell assemblies and beyond. Compared to the length scales of Tyndall scattering, similar effects have been observed for much smaller and for much larger particles.

"So, this intermediate length scale effect had to exist, yet remained unobserved. This is why I kept looking hard for its demonstration. It feels very satisfying for my PhD project, to have found such a 'missing link' in science."

The research is published in the journal ACS Nano. It was funded by The Royal Society, the Leverhulme Trust, and the Engineering and Physical Science Research Council (EPSRC).



Routing lasers past obstacles is a key challenge in surgery.

UV or not UV? How deep UV light could revolutionise healthcare

by Vittoria D'Alessio

Find out how deep UV light could revolutionise healthcare at the Royal Society Summer Science Exhibition in London.

A special form of ultraviolet (UV) that can target cancerous cells with extreme precision, revolutionising healthcare in the future, is being introduced to the public at this week's Royal Society Science Exhibition in London.

The u-Care project – which brings together engineers, physicists, clinicians and biologists from Heriot-Watt University and the Universities of Bath and Edinburgh – aims to use deep UV light to cut away tumour cells without harming the surrounding healthy tissues.

By using optical fibres – like those that carry the internet – to deliver low wavelengths of UV light, the scientists hope to achieve ultraprecision surgery that could ensure complete resection of even the tiniest of tumours.

The team will be sharing their research with the public at the Royal Society Summer Science Exhibition in July, an annual celebration of cutting-edge research taking place across the UK.

14 flagship exhibits, 40 talks, 30 hands-on activities and more than 250 scientists inspired over 10,000 visitors, including school groups, families and science enthusiasts, over six days.

The u-Care exhibit, "UV or not UV?", will allow visitors to try their hand at being a laser physicist by aiming a laser at a target brain, design their own UV reactive wristbands, and marvel at a chandelier made from the 'drop-offs' from the optical fibre production process.

Robert Thomson, Professor of Photonics at Heriot-Watt University and u-Care project lead, said: "We urgently need to develop new therapies to target some of the biggest challenges facing medicine today – from the emergence of drug-resistant 'super-bugs' to finding ways of performing cellular precision surgery for cancers to improve patient outcomes.

"UV light could provide a solution to these looming public health crises.

"Presenting our research at the Royal Society's Summer Science Exhibition is an amazing opportunity to reach new audiences, talk about our work in-depth and inspire the next generation with this revolutionary research."

Professor William Wadsworth, who is a member of the Bath team, added: "We're really looking forward to presenting our research to visitors at the exhibition. Through this project, our PhD student Robbie Mears and post-doctoral researcher Dr Kerrianne Harrington have made exceptional progress in pushing the performance of hollow optical fibres in the deep ultraviolet.

"They have reached the point where the wavelengths of light are so short that the light cannot even travel through air because it is absorbed by oxygen and water molecules in the air."

Funded through the 'Transformative Healthcare Technologies for 2050' call from the Engineering and Physical Sciences Research Council (EPSRC) in 2020, the u-Care project is made up of 35 researchers spread across the three contributing universities.

Heading the Bath team is Professor Tim Birks. Also part of the team are Professor Jonathan Knight and Dr Jim Stone. All six researchers from the University of Bath are part of the Department of Physics.

Team u-Care will be exhibiting at the Royal Society, Carlton House Terrace, London from Wednesday July 3 until Sunday July 7, with a special 18+ lates evening on Tuesday 2 July

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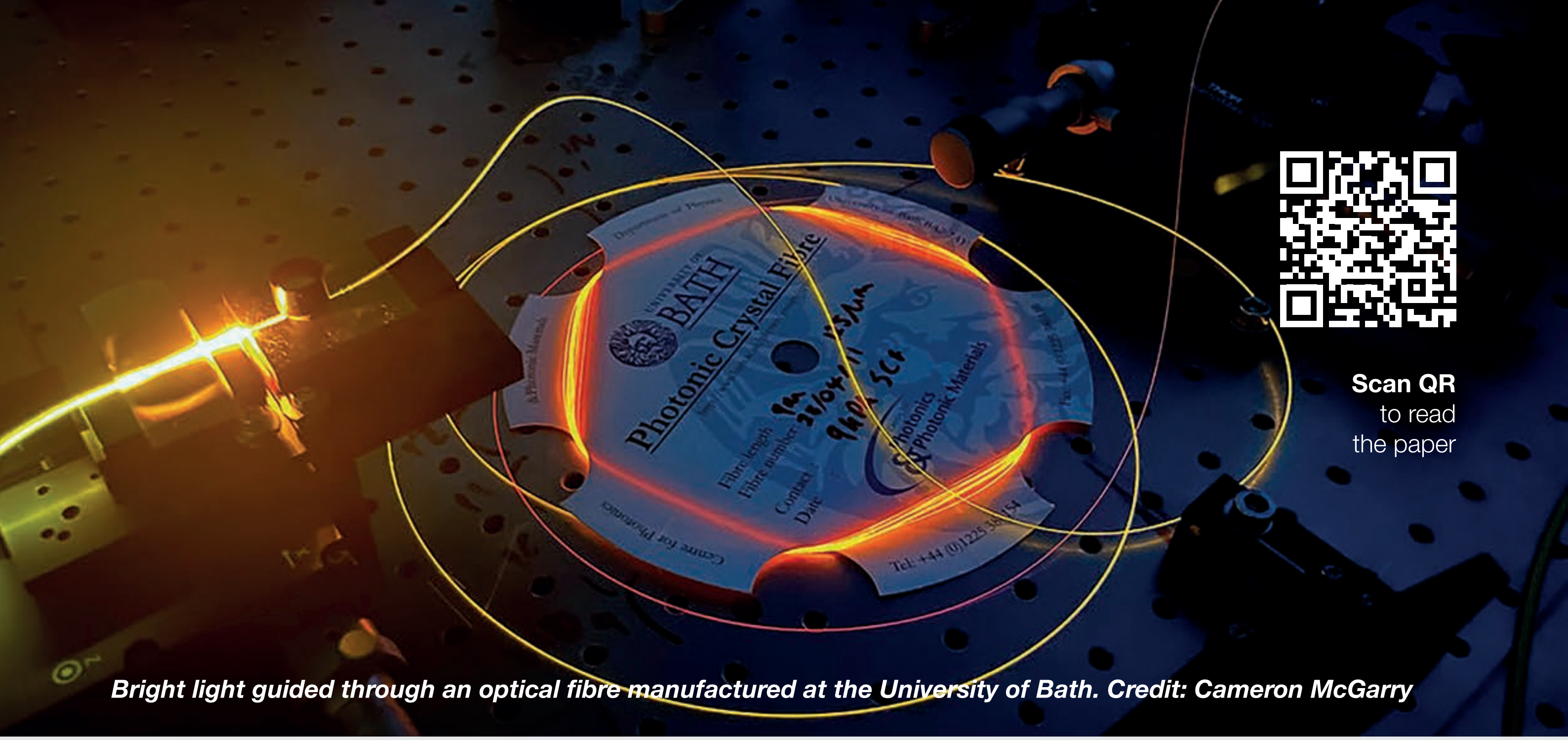

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Bright light guided through an optical fibre manufactured at the University of Bath. Credit: Cameron McGarry

Made at the University of Bath: Optical fibres fit for the age of quantum computing

by Vittoria D'Alessio

A new generation of specialty optical fibres has been developed by physicists at Bath to cope with the data transfer challenges expected from quantum computing.

Quantum technologies promise to provide unparalleled computational power, allowing us to solve complex logical problems, develop new medicines and provide unbreakable cryptographic techniques for secure communications. However, the cable networks used today to transmit information across the globe are likely to be sub-optimal for quantum communications, due to the solid cores of their optical fibres.

Unlike regular optical fibres, the speciality fibres fabricated at Bath have a micro-structured core, consisting of a complex pattern of air pockets running along the entire length of the fibre.

"The conventional optical fibres that are the workhorse of our telecommunications networks of today transmit light at wavelengths that are entirely governed by the losses of silica glass. However, these wavelengths are not compatible with the operational wavelengths of the single-photon sources, qubits, and active optical components, that are required for light-based quantum technologies." said Dr Kristina Rusimova from the Department of Physics at Bath.

Dr Rusimova and her colleagues describe the state-of-the-art fibres made at Bath, along with other recent and future developments in the emerging field of quantum computing, in an academic paper published today in Applied Physics Letters Quantum.

Dr Rusimova, who is lead senior author of the paper – known as a perspective – added: "Optical-fibre design and fabrication is at the forefront of the University of Bath Department of Physics research, and the optical fibres we are developing with quantum computers in mind are laying the foundations for the data transmission needs of tomorrow".

Quantum entanglement

Light is a promising medium for quantum computation. The individual particles of light, called photons, possess some uniquely quantum properties that can be harnessed by quantum technologies.

One such example is quantum entanglement, where two photons separated by a large distance not only hold information about one another but can also instantly influence each other's properties. Unlike the binary bits of classical computers (either a one or a zero), pairs of entangled photons can in fact exist as both a one and a zero at the same time, unleashing enormous amounts of computational power.

Dr Cameron McGarry, until recently a physicist at Bath and first-author of the paper, said: "A quantum internet is an essential ingredient in delivering on the vast promises of such emerging quantum technology.

"Much like the existing internet, a quantum internet will rely on optical fibres to deliver information from node to node. These optical fibres are likely to be very different to those that are used currently and will require different supporting technology to be useful."

In their perspective, the researchers discuss the associated challenges of the quantum internet from the viewpoint of optical fibre technology and present an array of potential solutions for scalability of a robust, wide-scale quantum network.

This encompasses both the fibres that will be used for long-range communication, and specialty fibres that will allow for quantum repeaters, integrated directly into the network in order to extend the distance over which this technology can operate.

Beyond connecting nodes

They also describe how speciality optical fibres can go beyond connecting nodes of a network to implementing quantum computation at the nodes themselves by acting as sources of entangled single photons, quantum wavelength converters, low-loss switches, or vessels for quantum memories.

Dr McGarry said: "Unlike the optical fibres that are standardly used for telecommunications, speciality fibres which are routinely fabricated at Bath have a micro-structured core, consisting of a complex pattern of air pockets running along the entire length of the fibre.

"The pattern of these air pockets is what allows researchers to manipulate the properties of the light inside the fibre and create entangled pairs of photons, change the colour of photons, or even trap individual atoms inside the fibres."

"Researchers around the world are making rapid and exciting advancements in the capabilities of microstructured optical fibres in ways that are of interest to industry," said Dr Kerrianne Harrington who is a postdoctoral researcher in the Department of Physics.

"Our perspective describes the exciting advances of these novel fibres and how they could be beneficial to future quantum technologies."

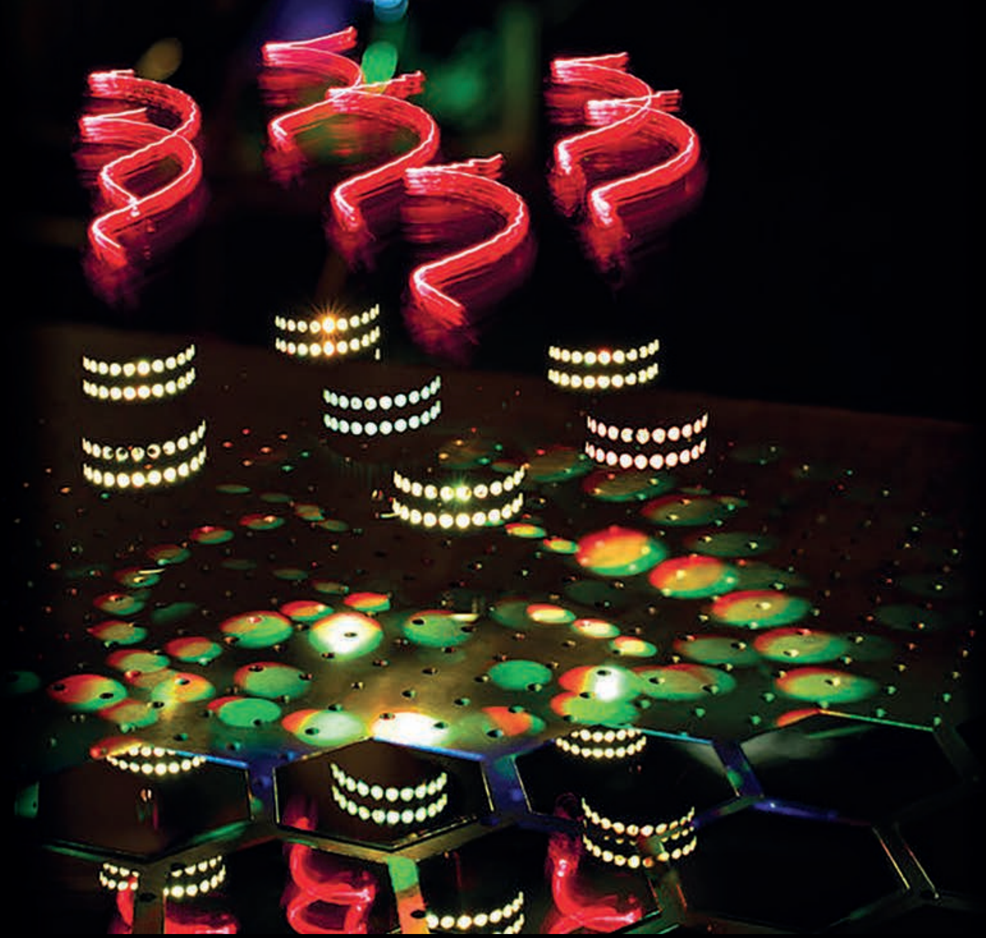
Dr Alex Davis, an EPSRC Quantum Career Acceleration Fellow at Bath, added: "It's the ability of fibres to tightly confine light and transport it over long distances that makes them useful.

"As well as generating entangled photons, this allows us to generate more exotic quantum states of light with applications in quantum computing, precision sensing and impregnable message encryption."

Quantum advantage – the ability of a quantum device to perform a task more efficiently than a conventional computer – has yet to be conclusively demonstrated. The technological challenges identified in the perspective are likely to open new avenues of quantum research, and bring us closer to achieving this important milestone. The optical fibres fabricated at Bath are expected to help lay the foundations for the quantum computers of tomorrow.

The team of researchers at Bath also included senior lecturer, Dr Peter Mosely.

For industry enquiries regarding partnering with the University of please email partnerships@bath.ac.uk



Artistic representation of hyper-Raman optical activity. Credit: Ventsislav Valev and Kylian Valev

Physicists use light to probe deeper into the 'invisible' energy states of molecules

by Vittoria D'Alessio

A team led by scientists at the University of Bath discovers how light particles can be used to reveal the 'hidden' energy states of molecules.

A new optical phenomenon has been demonstrated by an international team of scientists led by physicists at the University of Bath, with significant potential impact in pharmaceutical science, security, forensics, environmental science, art conservation and medicine.

Molecules rotate and vibrate in very specific ways. When light shines on them it bounces and scatters. For every million light particles (photons), a single one changes colour. This change is the Raman effect. Collecting many of these colour-changing photons paints a picture of the energy states of molecules and identifies them.

Yet some molecular features (energy states) are invisible to the Raman effect. To reveal them and paint a more complete picture, 'hyper-Raman' is needed.

Hyper-Raman

The hyper-Raman effect is a more advanced phenomenon than simple Raman. It occurs when two photons impact the molecule simultaneously and then combine to create a single scattered photon that exhibits a Raman colour change.

Hyper-Raman can penetrate deeper into living tissue, it is less likely to damage molecules and it yields images with better contrast (less noise from autofluorescence). Importantly, while the hyper-Raman photons are even fewer than those in the case of Raman, their number can be greatly increased by the presence of tiny metal pieces (nanoparticles) close to the molecule.

Despite its significant advantages, so far hyper-Raman has not been able to study a key enabling property of life – chirality.

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Optical activity

In molecules, chirality refers to their sense of twist – in many ways similar to the helical structure of DNA. Many bio-molecules exhibit chirality, including proteins, RNA, sugars, amino acids, some vitamins, some steroids and several alkaloids.

Light too can be chiral and in 1979, the researchers David L. Andrews and Thiruiappah Thirunamachandran theorised that chiral light used for the hyper-Raman effect could deliver three-dimensional information about the molecules, to reveal their chirality.

However, this new effect – known as hyper-Raman optical activity – was expected to be very subtle, perhaps even impossible to measure. Experimentalists who failed to observe it struggled with the purity of their chiral light. Moreover, as the effect is very subtle, they tried using large laser powers, but this ended up damaging the molecules being studied.

Explaining, Professor Ventsislav Valev who led both the Bath team and the study, said: "While previous attempts aimed to measure the effect directly from chiral molecules, we took an indirect approach.

"We employed molecules that are not chiral by themselves, but we made them chiral by assembling them on a chiral scaffold. Specifically, we deposited molecules on tiny gold nanohelices that effectively conferred their twist (chirality) to the molecules.

"The gold nanohelices have another very significant benefit – they serve as tiny antennas and focus light onto the molecules. This process augments the hyper-Raman signal and helped us to detect it.

"Such nanohelices were not featured on the 1979 theory paper and in order to account for them we turned to none other than one of the original authors and pioneer of this research field."

Confirming a 45-year-old theory

Emeritus Professor Andrews from the University of East Anglia and co-author of the paper said: "It is very gratifying to see this work the experimental finally confirm our theoretical prediction, after all these years. The team from Bath have performed an outstanding experiment."

This new effect could serve to analyse the composition of pharmaceuticals and to control their quality. It can help identify the authenticity of products and reveal fakes. It could also serve to identify illegal drugs and explosives at customs or crime scenes.

It will aid detecting pollutants in environmental samples from air, water and soil. It could reveal the composition of pigments in art for conservation and restoration purposes, and it will likely find clinical applications for medical diagnosis by detecting disease-induced molecular changes.

Professor Valev said: "This research work has been a collaboration between chemical theory and experimental physics across many decades and across academics of all stages – from PhD student to Emeritus Professor.

"We hope it will inspire other scientists and that it will raise awareness that scientific progress often takes many decades."

Looking ahead he added: "Ours is the very first observation of a fundamental physical mechanism. There is a long way ahead until the effect can be implemented as a standard analytical tool that other scientist can adopt.

"We look forward to the journey, together with our collaborators from Renishaw PLC, a world-renowned manufacturer of Raman spectrometers."

Dr Robin Jones, first-author for the new research paper and a PhD student at Bath until recently, said: "Performing the experiments that showed the hyper-Raman optical activity effect has been my most rewarding academic experience. In retrospect, it seems that almost every step of my PhD was like a piece of the puzzle which fell into place to achieve the observation."

The research is published in the journal Nature Photonics. It was funded by The Royal Society, the Leverhulme Trust, and the Engineering and Physical Science Research Council (EPSRC).

Physics Department holds fourth Eureka conference focussed on Knowledge Exchange and Research Impact

Physicists at the University of Bath lead on the discovery of a new optical property that measures the twist in tiny helices.

The University of Bath's Physics Department organised the fourth Eureka conference, Eureka 2024: Academia meets Industry, in the Chancellors' Building on Thursday 11th July 2024. This one-day meeting was focussed on knowledge exchange and research impact, and provided a venue where companies small and large, start-up and established, could introduce their businesses, research challenges, and ideas for potential collaborations to academics from Bath and other GW4 universities. A broad range of scientific fields was represented at the conference including photonics, quantum technologies, medical science, advanced materials, nanoscience and theoretical physics.

Eureka 2024 attracted over 100 participants from GW4 universities, regional innovation centres and technology companies. These were able to showcase their expertise through oral pitches, posters and table-top exhibits.

The programme began with an introduction to knowledge exchange and impact at the University of Bath from Prof Jonathan Knight, Vice-President (Enterprise), who described key case studies drawn from optical fibre research in Physics. This was followed by presentations on research capabilities and impact generation in the Bath Nanoscience and Theoretical & Computational Physics Groups given by Prof Daniel Wolverson and Dr Habib Rostami respectively.

The second session of the day was an Industry Innovation Showcase in which members of GW4 innovation/accelerator centres were able to advertise their capabilities followed by promotional talks from three technology companies, Oxford instruments Plasma Technology, Quantum Design and The Training Marketplace. In a parallel two hour session, early career researchers were able to participate in a bespoke training programme supported by a grant from the University's Research Culture Fund. Organised by Andrea Kelly, SETsquared Centre Manager, and co-delivered by four Entrepreneurs in Residence, this targeted support for idea creation, protection and routes to exploitation.

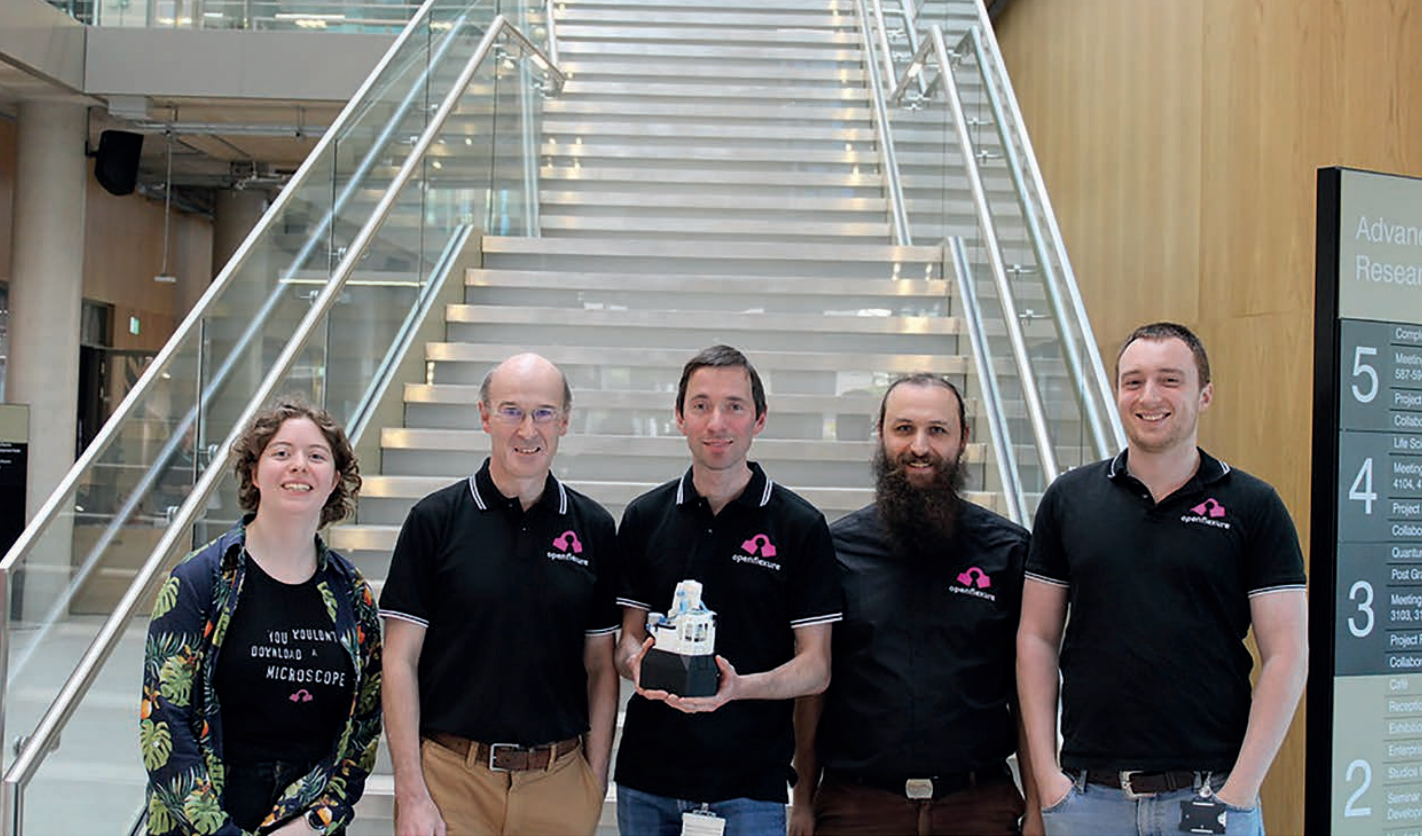
In the afternoon there were keynote lectures from Bruce Colley, Senior Investment Specialist at Innovate UK, explaining how they connect businesses to partners, customers and investors, and James Harrison, Technology Transfer Manager at RIS, who discussed important issues around IP protection, licencing and spin outs. Oksana Meleshykhina, Senior Technical Programme Manager at Microsoft, closed out the oral sessions with a presentation focussed on the empowerment of women working in high technology fields. This was followed by a round table Q&A session whose membership comprised stakeholders from all key areas of research, impact generation and commercialisation. These included the Centre for Process Innovation (CPI) catapult, Diamond Light Source (DLS), Elsevier, as well as LabCycle and Siloton start-ups.

As the last event of the day a poster session was held in parallel with a drinks reception. Three best early career researcher poster prizes were awarded that had been generously sponsored by Best Scientific and Optica. These were won by Will Smith, University of Bath (1st place), Tanya Kushwahaa, Cardiff University (2nd place) and Leah Murphy, University of Bath (3rd place). The jury for these awards consisted of Prof Ventsi Valev (University of Bath), Prof Ruth Oulton (University of Bristol), Prof Rob Hicken (University of Exeter), Dr Nicolas Abadia (Cardiff University).

Head of the Department of Physics, Professor Ventsi Valev said: "I am immensely proud of our department's successful organization of the EUREKA 2024 conference. This event has been a remarkable opportunity to bridge the gap between academic research and industrial application, fostering collaboration and innovation.

I want to extend my heartfelt congratulations and gratitude to all our colleagues whose dedication and hard work made this conference a resounding success. Together, we are shaping the future of Physics and creating valuable connections that will drive advancements in both academia and industry."

The Bath Knowledge Exchange Team and Research & Innovation Service representatives were on site all day to assist both companies and academics in their learning and information exchange and to provide support for kick-starting collaborations. The conference was sponsored by nine industrial companies, including Amplitude, Optica, Thorlabs, Renishaw, Quantum Design, SHI Cryogenics, Photon Lines Ltd, Best Scientific and Toptica.



The OpenFlexure core team (L-R: Freya Whiteford, William Wadsworth, Richard Bowman, Julian Stirling, Joe Knapper)

Microscope designed at the University of Bath wins international recognition

OpenFlexure Microscope has been selected as a Solver Team in MIT Solve's 2024 Global Challenges awards.

The OpenFlexwure Microscope project has been selected as one of the most promising solutions addressing MIT Solve's 2024 Global Challenges being named as a Solver team in the Global Health Equity Challenge category.

The OpenFlexure Microscope is a design for a digital robotic microscope that can be manufactured in sub-Saharan Africa and is currently undergoing evaluation for malaria and cancer diagnosis. The microscope was selected by Solve's expert judges from a pool of over 2,200 applicants from 130 countries.

The OpenFlexure Project was based at the University of Bath from 2017 to 2022. Since 2016 the project has been creating publicly available designs for laboratory grade microscopes that can be built anywhere in the world.

The novel microscope mechanism can be printed in plastic on a standard 3D printer. It delivers controlled motorised movements smaller than a red blood cell for accurate focusing and slide scanning.

Using an advanced algorithm similar to the panorama mode on a mobile phone, the microscope can create enormous high-resolution digital images.

The microscope has been designed in collaboration with teams across the world. As the plans are available for anyone to download online, the microscope has been replicated independently by individuals and organisations all over the world. The project doesn't track who is building them, so the ones which we know about are just a fraction of those that have been built.

Dr Richard Bowman, founder of the OpenFlexure project, previously led the project at the University of Bath and is now at the University of Glasgow.

He said: “We know that there are hundreds of microscope users on our forum, and many more who not on the forum. These users have told us they have built or used microscopes in over 50 countries, in all seven continents.”

Dr Bowman was invited to New York City to pitch to an audience of over 200 philanthropists, global leaders, and investors during Solve Challenge Finals, which took place on Monday 23 September, at the beginning of the United Nations General Assembly and Climate Week.

The project was selected as Solver Team for the Global Health Equity Challenge for technology that makes good health and access to quality healthcare more equitable for all.

The OpenFlexure Project received $10,000 from MIT Solve to scale impact and reach more lives, and a share of the $100,000 Health Equity Innovation Award. Additionally, the OpenFlexure Project will begin a nine-month support programme through MIT Solve and receive access to additional funding opportunities, resources, experts, and mentorship.

The OpenFlexure team hopes that this support from MIT Solve will enable the project to move from evaluating their devices, to supporting the production of medically certified microscopes.

Dr Julian Stirling, a core OpenFlexure developer based in Bath, won the 2022 Peter Troughton Research Prize for the project whilst he worked as a Research Associate at the University of Bath.

He said: “Some may argue that the fastest way to certification would have been to keep the design secret and to manufacture microscopes in the UK, but that would have only added to an existing global problem.

“The majority of medical devices coming from Europe and North America lie idle in sub-Saharan Africa.

“For a microscope to be reliable, it needs to have been designed for the environment it is being used in. Spare parts and specialised maintenance engineers must also be available locally.

“Enabling companies around the world to manufacture and maintain microscopes for their local market is the only way to ensure that microscopes remain functioning.”

The OpenFlexure Project is already working with manufacturers in Tanzania and Cameroon to help them build capacity to manufacture their own medical microscopes. Importantly, this manufacturing would be controlled and owned entirely by the local companies. Evaluation of the microscope for medical diagnosis is also ongoing in Tanzania, Rwanda, Brazil, and the Philippines. Baylor College of Medicine in Texas is also playing a critical role in the evaluation of the microscope’s performance.

Dr Bowman said: “We have refined the design and evaluated it through several research projects at the Universities, so we are confident in its performance. We have excellent partners around the globe who have demonstrated that high quality microscopes can be produced in their countries, and that these microscopes have clinical applications.

“Our participation in MIT Solve will help take the next step, connecting us to a network of support to help our manufacturing partners deliver locally manufactured and maintained microscopes with approval for medical use.”

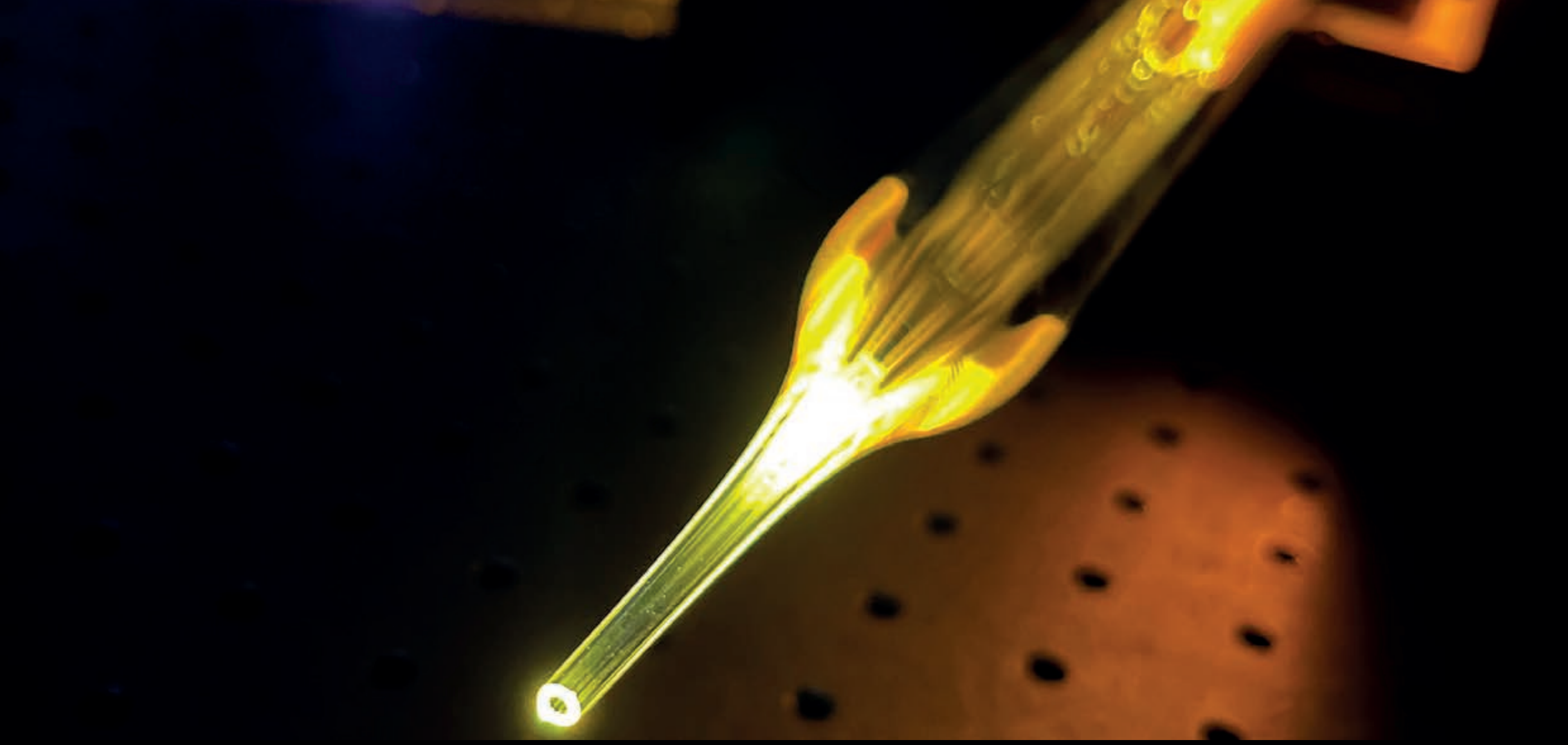
Professor William Wadsworth, part of the OpenFlexure core development team and based in the Department of Physics at the University of Bath, said: “I am delighted that the OpenFlexure Project has been selected as a Solver Team in the 2024 Global Health Equity challenge.

“This will help us to continue to develop the OpenFlexure Microscope for local manufacture as a medical diagnostic device in low resource areas.

“Open-source hardware embeds the ownership of local manufacture in their communities, which is a key driver of global equity.”

The OpenFlexure project has been funded by a number of funding bodies including the UKRI-EPSRC Impact Acceleration Account and the Royal Society.

Scan QR to find out more about the OpenFlexure Microscope project



Optical fibres developed at Bath will be used to deliver drugs deep into patients' lungs. Credit: Kerrianne Harrington

Funding of £27.6M to speed up the discovery of new drugs to cure lung infection and inflammation

by Vittoria D'Alessio

A partnership to help tackle the growing challenges of infections and inflammation of the lungs has been allocated a £27.6 million funding boost.

Lung conditions are a leading cause of illness and death globally, but finding new ways to treat them is both slow and costly. The process looks set to become both faster and cheaper, however, thanks to the new partnership project announced today. The initiative will use optical fibres developed at the University of Bath to discover new treatments for serious lung conditions.

The six-year collaboration will receive funding totalling £27.6 million, of which £11 million will come from the government via the UKRI Engineering and Physical Sciences Research Council (EPSRC) and £16.6 million from partner funders.

Lung infections (which include pneumonia, bronchitis and tuberculosis) and inflammatory conditions affect millions of people globally each year. They can result from bacterial, viral, and fungal infections, as well as environmental pollutants and chronic diseases like asthma and chronic obstructive pulmonary disease (COPD). The impact on public health is profound, leading to significant morbidity and mortality rates.

The new project – called Microtex – will seek to develop new technologies to identify both existing and new medicines that can treat lung conditions. The work unites engineering with robotics, AI chemistry, physics, biology and clinical medicine.

Microdosing

The team will deposit tiny amounts of candidate drugs to microscopically small parts of patients' lungs using a technique called Intra Target Microdosing (ITM). This technique will allow scientists to quickly and efficiently reject poor candidate drugs and highlight promising drugs at an early stage of development.

The project will implement ITM using a range of technologies. One will involve optical fibres designed at Bath. These flexible fibres will be able to access parts of the lungs that are unreachable with existing tools.

Microtex will also develop ways to take precise tissue samples from patients' lungs before and after treatment to test the effectiveness of the drugs that are delivered.

Professor Tim Birks from the Department of Physics and the Centre for Photonics and Photonic Materials at Bath will be leading the Bath side of the project. Dr James Stone from the Department of Physics will also be involved in this work.

Explaining how the optical fibres are expected to work, Professor Birks said: "In our labs, we design and make advanced optical fibres that are specifically intended for medical use. We have found a way to turn silica glass tubes into flexible fibre that can reach parts of the lungs existing tools cannot.

"The new project builds on this experience to develop fibres that meet the particular challenges of microdosing, including new ways to precisely deliver and extract tiny quantities of tissue and fluids in hard-to-reach locations in the body. It's an exciting opportunity to work with a broad team of expert scientists, engineers, patients and clinicians to transform the development of new medicines."

Researchers expect microdosing to limit the need for animal research, by allowing new drugs to be tested more safely for the first time in humans.

Five tech projects to improve global health

Microtex is one of five revolutionary healthcare tech projects that are being launched today with total funding of £118 million, which includes £54 million from the UKRI Engineering and Physical Sciences Research Council (EPSRC).

MicroTex is being led by the University of Edinburgh and will be based in the Baillie Gifford Pandemic Science Hub in the Institute of Regeneration and Repair. Other partners include Heriot-Watt University, LifeArc Rare Respiratory Diseases Centre, Baillie Gifford, patient groups, international and industrial collaborators.

Professor Ian Underwood, of the Institute of Integrated Micro and Nano Systems in the University of Edinburgh's School of Engineering, said: "By innovating at the microscale, the Edinburgh-led MicroTex hub is set to transform the fight against drug-resistant diseases, harnessing the power of advanced technology to accelerate the development of life-saving treatments. By bringing together experts across medicine, science and engineering, we will collaborate to develop solutions which will help safeguard the future of global health."

Professor Kev Dhaliwal, of the Baillie Gifford Pandemic Science Hub, Institute for Regeneration and Repair, Edinburgh BioQuarter, said: "In a post-Covid world, the urgency to outpace infectious and inflammatory diseases and be prepared for the next pandemic, has never been greater. The MicroTex hub will deliver a critical leap forward in this race. The hub brings together a highly diverse team of researchers and a wide range of partners to innovate, collaborate and transform drug development with microdosing."

EPSRC Executive Chair Professor Charlotte Deane said: "The five new hubs bring together a wealth of expertise from across academia, industry and charities to improve population health, transform disease prediction and diagnosis, and accelerate the development of new interventions.

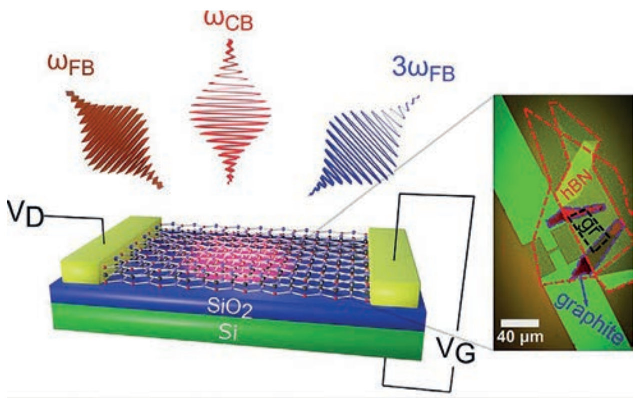
"They represent an exciting range of adventurous techniques and approaches that have great potential to improving the lives of millions of people here in the UK and across the world."

Scan QR
to learn more about optical fibre research at Bath

Ultrafast Control of Nonlinear Hot Dirac Electrons in Graphene: An International Collaboration

Dr. Habib Rostami, from the Department of Physics at the University of Bath, has co-authored this pioneering research published in Advanced Science.

Nonlinear optics explores how powerful light (e.g. lasers) interacts with materials, resulting in the output light changing colour (i.e. frequency) or behaving differently based on the intensity of the incoming light. This field is crucial for developing advanced technologies such as high-speed communication systems and laser-based applications. Nonlinear optical phenomena enable the manipulation of light in novel ways, leading to breakthroughs in fields like telecommunications, medical imaging, and quantum computing. Two-dimensional (2D) materials, such as graphene--a single layer of carbon atoms in a hexagonal lattice--exhibit unique properties due to their thinness and high surface area. Graphene's exceptional electronic properties, related to relativistic-like Dirac electrons and strong light-matter interactions, make it promising for nonlinear optical applications, including ultrafast photonics, optical modulators, saturable absorbers in ultrafast lasers, and quantum optics.



Dr. Habib Rostami, from the Department of Physics at the University of Bath, has co-authored pioneering research published in Advanced Science. This study involved an international collaboration between an experimental team at Friedrich Schiller University Jena in Germany and theoretical teams at the University of Pisa in Italy and the University of Bath in the UK. The research aimed to investigate the ultrafast opto-electronic and thermal tuning of nonlinear optics in graphene.

This study discovers a new way to control high-harmonic generation in a graphene-based field-effect transistor. The team investigated the impact of lattice temperature, electron doping, and all-optical ultrafast tuning of third-harmonic generation in a hexagonal boron nitride-encapsulated graphene opto-electronic device. They demonstrated up to 85% modulation depth along with gate-tuneable ultrafast dynamics, a significant improvement over previous static tuning. Furthermore, by changing the lattice temperature of graphene, the team could enhance the modulation of its optical response, achieving a modulation factor of up to 300%. The experimental fabrication and measurement took place at Friedrich Schiller University Jena. Dr. Rostami played a crucial role in the study by crafting theoretical models. These models were developed in collaboration with another theory team at the University of Pisa to elucidate new effects observed in graphene. This research opens the door to developing ultrafast switching of optoelectronic devices, potentially revolutionizing technologies such as high-speed internet and advanced computing.

Scan QR to read the full story

Advanced Functional Materials

Laboratory opens at the University of Bath

The lab was created thanks to £250,000 from the Garfield Weston Foundation and will develop materials to tackle challenges in healthcare and sustainability.

An Advanced Functional Materials Laboratory has opened at the University of Bath thanks to a generous £250,000 donation from the Garfield Weston Foundation.

In this new facility, researchers will design and develop novel materials to tackle some of the world's biggest challenges, including healthcare and climate change.

The laboratory, based in 5 West, is led by Professor Kamal Asadi – a globally recognised leader in the field of advanced functional materials.

Professor Asadi said: "This is an inherently interdisciplinary area of research, drawing on expertise from across the University and beyond, including physics, chemistry, engineering and health.

"Thanks to the Garfield Weston Foundation, we now have a dedicated hub for our research groups on campus and the facilities to strengthen our work in this area, as well as attract more talent from around the world."

Advanced functional materials will play a pivotal role in supporting the development of alternative sources of clean energy, such as solar and wind, to help reduce our reliance on fossil fuels and make the move towards a clean energy future. These materials are envisioned to deliver energy efficient electronics and to revolutionise areas in healthcare technologies.

The team at the University of Bath are designing and developing new materials that can harvest energy that is otherwise wasted – such as vibrations from traffic and footfall – and convert this into electrical power with zero emissions.

These advanced materials could be used, for example, in clothing that would use body movements to power portable devices or even hospital gowns and wound dressings which can monitor vital signs and the recovery process.

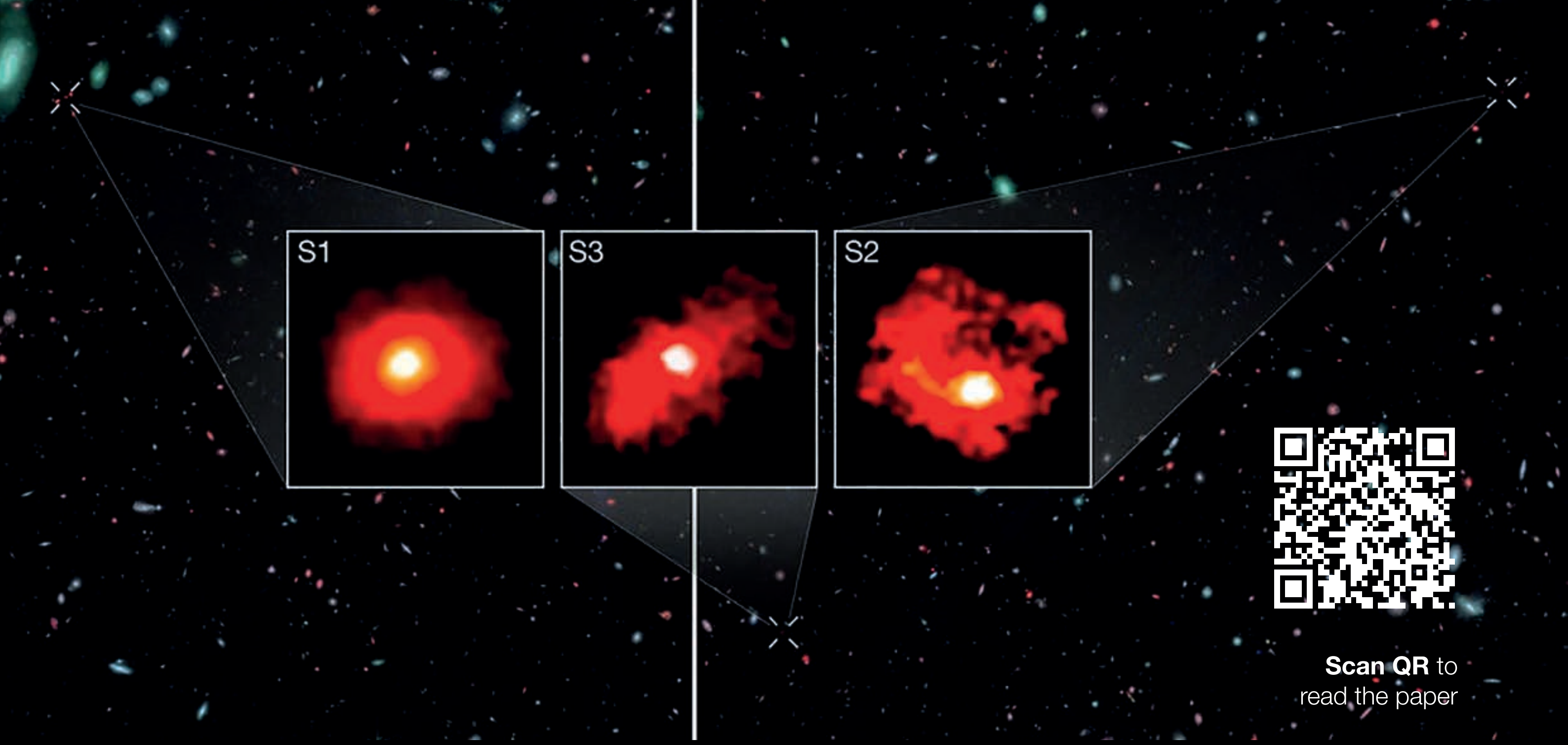
Director of the Garfield Weston Foundation, Philippa Charles, said: "The Trustees of the Garfield Weston Foundation were delighted to support this capital project. The Trustees commented on the importance of high-quality facilities to support vital research and attract talented researchers."

The Garfield Weston Foundation is a family founded grant-maker that supports a wide range of charities across the UK. Established in 1958, the Foundation is one of the largest and most respected charitable institutions in the UK and has donated over £1.4 billion in total.

The Foundation has previously supported the University of Bath's Milner Centre for Evolution and The Edge arts facility on campus.

Professor Ian White, Vice-Chancellor and President of the University of Bath, said: "We are very grateful to the Garfield Weston Foundation for their continued support.

"This generous grant will further our impactful work in advanced functional materials, which is a growing area of focus for the University due to its great potential to solve global challenges and spans our three strategic research themes: health and wellbeing, sustainability, and digital."



JWST image of the three Red Monsters. Credit: NASA/CSA/ESA, M. Xiao & P. A. Oesch (University of Geneva), G. Brammer (Niels Bohr Institute), Dawn JWST Archive

Astronomers discover mysterious 'Red Monster' galaxies in the early Universe

by Vittoria D'Alessio

An international team that includes the University of Bath has discovered three ultra-massive galaxies in the early Universe forming at unexpected speeds.

An international team that was led by the University of Geneva (UNIGE) and includes Professor Stijn Wuyts from the University of Bath has identified three ultra-massive galaxies – each nearly as massive as the Milky Way – that had already assembled within the first billion years after the Big Bang.

The researchers' results indicate that the formation of stars in the early Universe was far more efficient than previously thought, challenging existing galaxy formation models.

The surprising discovery – described today in the journal Nature – was made by the James Webb Space Telescope (JWST) as part of the JWST FRESCO programme.

The programme set out to systematically analyse a complete sample of emission-line galaxies (ELGs) within the first billion years of cosmic history. ELGs exhibit strong emission lines in their spectra (a spectrum is the range of different wavelengths of light emitted). These emission lines appear as bright lines at specific wavelengths, standing out against the darker background of the spectrum.

The presence of emission lines enabled the team to accurately pin down the distances to the galaxies in the sample. In turn, precise knowledge of the distances and emission line strengths allowed the researchers to reliably measure the amount of stars contained within the galaxies. Three stood out by their large stellar content.

"Finding three such massive beasts among the sample poses a tantalising puzzle", said Professor Wuyts, co-author of the Nature study and Hiroko Sherwin Chair in Extragalactic Astronomy at Bath's Department of Physics.

"Many processes in galaxy evolution have a tendency to introduce a rate-limiting step in how efficiently gas can convert into stars, yet somehow these Red Monsters appear to have swiftly evaded most of these hurdles."

Fast growing Red Monsters

Until now, it was believed that all galaxies formed gradually within large halos of dark matter. Dark matter halos capture gas (atoms and molecules) into gravitationally bound structures. Typically, 20% of this gas, at most, is converted into stars in galaxies. However, the new findings challenge this view, revealing that massive galaxies in the early Universe may have grown far more rapidly and efficiently than previously thought.

Detail in the FRESCO study was captured through 'slitless spectroscopy' with JWST's Near Infrared Camera, a surveying method that allows light to be captured and unravelled into its constituent wavelengths for all objects in a field of view. This makes it an excellent method for measuring accurate distances and physical characteristics of galaxies.

JWST's unparalleled capabilities have allowed astronomers to systematically study galaxies in the very distant and early Universe, providing insights into massive and dust-obscured galaxies. By analysing galaxies included in the FRESCO survey, scientists found that most galaxies fit existing models. However, they also found three surprisingly massive galaxies, with stellar masses comparable to today's Milky Way.

These are forming stars nearly twice as efficiently as lower mass galaxies from the same epoch or ordinary galaxies at later times in cosmic history. Due to their high dust content, which gives these three massive galaxies a distinct red appearance in JWST images, they have been named the three Red Monsters.

Dr Mengyuan Xiao, lead author of the new study and postdoctoral researcher at UNIGE, said: "Our findings are reshaping our understanding of galaxy formation in the early Universe."

Dr David Elbaz, director of research at CEA Paris-Saclay and collaborator on this project, said: "The massive properties of these Red Monsters were hardly determined before JWST, as they are optically invisible due to dust attenuation."

A Milestone in Galaxy Observations

Pascal Oesch, associate professor in the Department of Astronomy at the UNIGE, and principal investigator of the observation programme, said: "Our findings highlight the remarkable power of NIRCam/grism spectroscopy. The instrument on board the space telescope allows us to identify and study the growth of galaxies over time, and to obtain a clearer picture of how stellar mass accumulates over the course of cosmic history."

While these findings do not conflict with the standard cosmological model, they raise questions for galaxy formation theories, specifically the issue of 'too many, too massive' galaxies in the early Universe.

Current models may need to consider unique processes that allowed certain early massive galaxies to achieve such efficient star formation and thus form very rapidly, very early in the Universe. Future observations with JWST and the Atacama Large Millimeter Array (ALMA) telescope will provide further insights into these ultra-massive Red Monsters and reveal larger samples of such sources.

Dr Xiao said: "These results indicate that galaxies in the early Universe could form stars with unexpected efficiency. As we study these galaxies in more depth, they will offer new insights into the conditions that shaped the Universe's earliest epochs. The Red Monsters are just the beginning of a new era in our exploration of the early Universe."

Professor Wuyts added: "That is what is so great about astronomy, we're constantly being surprised by new discoveries. Already in its first few years of operation, JWST has thrown us a couple of curveballs. In more ways than one, it has shown us that some galaxies mature rapidly during the first chapters of cosmic history."

***An artist's representation of a scanning tunnelling microscope probing a toluene molecule.
Credit: Dr Kristina Rusimova, Hannah Martin, and Pieter Keenan***

Controlling matter at the atomic level: University of Bath breakthrough

Physicists are getting closer to controlling single-molecule chemical reactions – could this shape the future of pharmaceutical research?

Controlling matter at the atomic level has taken a major step forward, thanks to groundbreaking nanotechnology research by an international team of scientists led by physicists at the University of Bath.

This advancement has profound implications for fundamental scientific understanding. It is also likely to have important practical applications, such as transforming the way researchers develop new medications.

Controlling single-outcome single-molecule reactions is now almost routine in research laboratories across the world. For example, over a decade ago, researchers from the technology giant IBM showcased their ability to manipulate individual atoms by creating A boy and his atom, the world's smallest movie. In the film, single molecules, consisting of two atoms bonded together, were magnified 100-million times and positioned frame-by-frame to tell a stop-motion story on an atomic scale.

Achieving control over chemical reactions with multiple outcomes, however, has remained elusive. This matters because generally only some outcomes of a chemical reaction are useful.

For instance, during drug synthesis, a chemical process that results in 'cyclisation' produces the desired therapeutic compound while 'polymerisation', another outcome, leads to unwanted byproducts.

Being able to precisely control reactions to favour desired outcomes and reduce unwanted byproducts promises to improve the efficiency and sustainability of pharmaceutical processes.

Scanning tunnelling microscopy

The new study, published today in the prestigious journal Nature Communications, set out to demonstrate for the first time that competing chemical reaction outcomes can be influenced by using the atomic resolution of a scanning tunnelling microscope (STM).

Conventional microscopes use light and lenses to magnify specimens, allowing us to view them with the naked eye or a camera. However, when it comes to atoms and molecules, which are smaller than even the shortest wavelengths of visible light, traditional methods fall short.

To explore these tiny realms, scientists turn to a scanning tunnelling microscope, which operates much like a record player.

With a tip that can be as fine as a single atom, scanning tunnelling microscopes move across a material's surface, measuring properties such as electric current to map each point. However, rather than pressing the tip into the surface like a record player needle, the tip hovers just a single atom's width above it.

When connected to a power source, electrons travel down the tip and make a quantum leap across the atom-sized gap. The closer the tip is to the surface, the stronger the current; the farther away it is, the weaker the current. This well-defined relationship between tip distance and current allows the microscope to measure and map the surface of the atom or molecule based on the electric current strength. As the tip sweeps across the surface, it builds a precise, line-by-line image of the surface, revealing details invisible to conventional light microscopes.

Single-molecule reactions

Using the atomic precision of a scanning tunnelling microscope, scientists can go beyond mapping the surface of a molecule – they can both reposition single atoms and molecules, and influence and measure the likelihood of specific reaction pathways in individual molecules.

Explaining, Dr Kristina Rusimova, who led the study from the Department of Physics, said: "Typically, STM technology is employed to reposition individual atoms and molecules, enabling targeted chemical interactions, yet the ability to direct reactions with competing outcomes remained a challenge. These different outcomes happen with certain probabilities governed by quantum mechanics – rather like rolling a molecular die.

"Our latest research demonstrates that STM can control the probability of reaction outcomes by selectively manipulating charge states and specific resonances through targeted energy injection."

Dr Peter Sloan, senior lecturer in the Department of Physics and co-author of the study, said: "We used the STM tip to inject electrons into toluene molecules, prompting the breaking of chemical bonds and either a shift to a nearby site, or desorption.

"We found that the ratio of these two outcomes was controlled by the energy of the electrons injected. This energy dependence allowed us to achieve control over the probability of each reaction outcome through the targeted "heating" of an intermediate molecular state, guided by precise energy thresholds and molecular barriers."

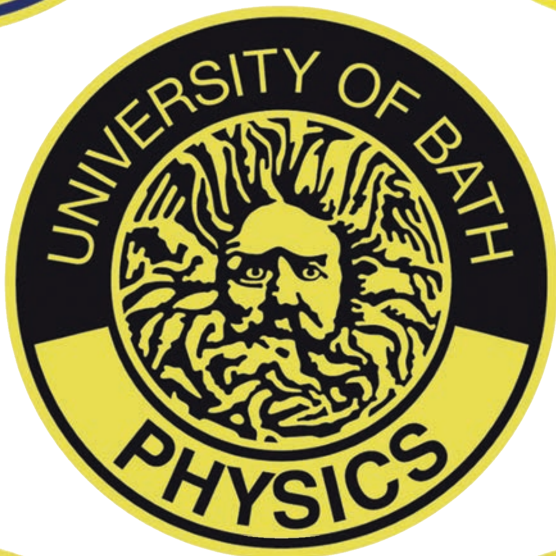
Physics PhD student Pieter Keenan, first-author on the research publication, said: "The key here was to maintain identical initial conditions for the test reactions—matching the precise injection site and excitation state – and then vary outcomes based solely on the energy of the injected electrons.

"Within a single molecule's response to the energy input, the differing reaction barriers drive the reaction outcome probabilities. Altering only the energy input allows us, with high precision, to make a reaction outcome more likely than another – in this way we can 'load the molecular dice'."

Professor Tillmann Klamroth from Potsdam University in Germany, added: "This study combines advanced theoretical modelling with experimental precision, leading to a pioneering understanding of the reactions' probabilities based on the molecular energy landscape. This paves the way for further advances in nanotechnology."

Looking ahead, Dr Rusimova said: "With applications in both basic and applied science, this advancement represents a major step toward fully programmable molecular systems. We expect techniques such as this to unlock new frontiers in molecular manufacturing, opening doors to innovations in medicine, clean energy, and beyond."

The research was funded by The Royal Society, and the Engineering and Physical Science Research Council (EPSRC).



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