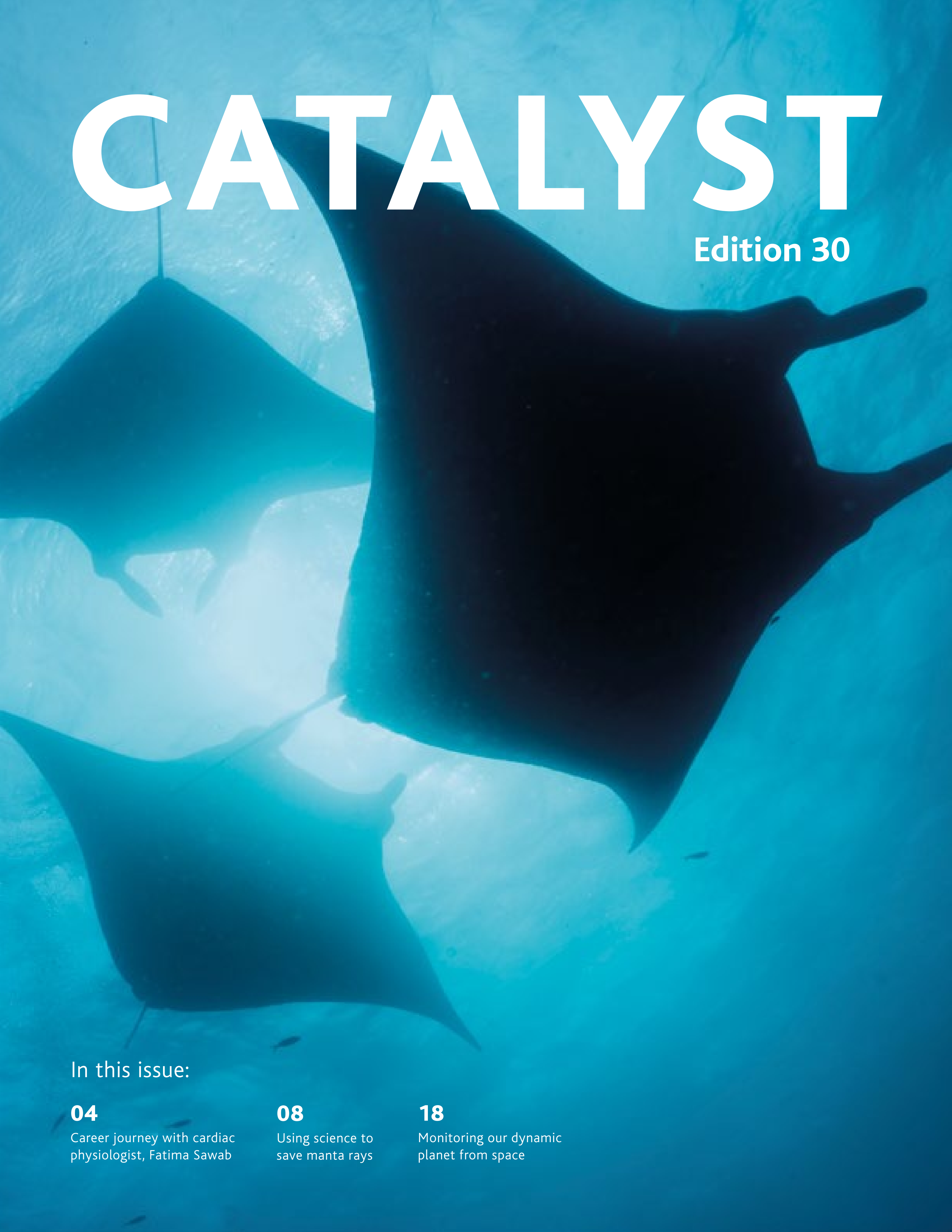

CATALYST

Edition 30

In this issue:

Welcome

Welcome to another edition of Catalyst - aimed at young people, we're proud to bring you cutting-edge research that sparks debate.

This edition we've got articles on: the microscopic bacteria that might help us to 'green' barren planets; an experiment spanning two continents that aims to investigate the fabric of the Universe; and the gentle manta ray - and how research is helping to protect this majestic species.

We hope you enjoy this edition, and if you have any ideas for future topics you'd like to see covered get in touch via our email: **catalyst@stem.org.uk.**

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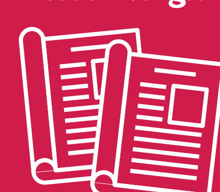

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Contents

Career journey with

Fatima Sawab

Q Introduce yourself – what is your name, place of work and job title?

A Hi! My name is Fatima Sawab and I am a cardiac physiologist at the Royal Brompton Hospital.

Q What did you want to be when you were little?

A When I was younger, I surprisingly wanted to become an actress. I regularly took ballet and tap dancing classes, and attended acting school. However, once I was introduced to science in secondary school, I set my sights on the world of healthcare instead.

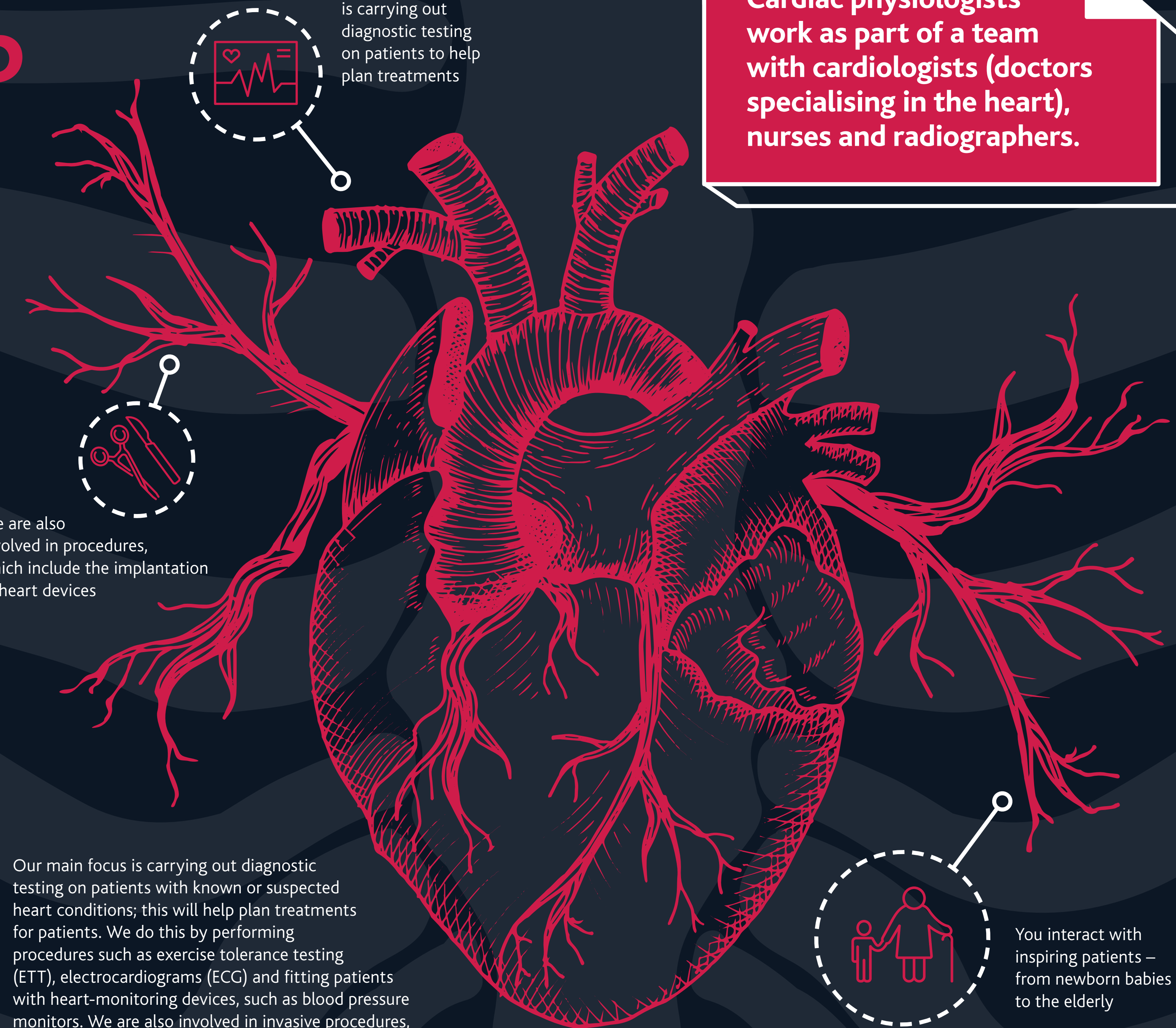
Q What is the main focus of your work?

A Cardiac physiologists work as part of a team, which consists of other healthcare professionals, such as cardiologists (doctors specialising in the heart), nurses and radiographers.

Our main focus is carrying out diagnostic testing on patients with known or suspected heart conditions; this will help plan treatments for patients. We do this by performing procedures such as exercise tolerance testing (ETT), electrocardiograms (ECG) and fitting patients with heart-monitoring devices, such as blood pressure monitors. We are also involved in invasive procedures, which include the implantation of heart devices, such as pacemakers or implantable cardioverter defibrillators (ICDs). Other invasive procedures we are involved in include percutaneous coronary interventions (PCI) which involve a cardiologist placing a stent into a blocked artery of the heart in order to open it up.

Q How does your work affect our lives or society?

A We are involved in the lives of various people who suffer from a range of heart problems – from newborn babies to the elderly. Our work involves helping patients reach a diagnosis and/or treatment plan. This hopefully allows patients to lead their lives as fully as possible.



Cardiac physiologists work as part of a team with cardiologists (doctors specialising in the heart), nurses and radiographers.

Q Talk us through an average workday...

A The beauty of working in healthcare is that no two days are the same! I have the opportunity to work in different clinical environments which keeps my job exciting. For instance, one day I may perform exercise tests in the morning and carry out ECGs in the ECG clinic in the afternoon. On another day, I might be in the catheter labs (this is a specialised lab where cardiologists insert catheters into the structures of the heart for diagnostic information). For each case I would gather a patient history, apply an ECG, provide catheters and other equipment for the procedure, as well as monitor the patient.

Q What's the best thing about your job?

A There are actually two things about my job that stand out for me. The first is meeting and interacting with inspiring patients of various ages and backgrounds. Being able to contribute in their journey to a diagnosis is a very rewarding experience for me. The second best thing would be the many opportunities to learn something new, which helps my knowledge in cardiology grow over time.

Q When and why did you decide to become a cardiac physiologist?

A I decided to choose my university degree in cardiac physiology in 2014 after my own personal experience as a patient. After going through testing and meeting with various members of staff, I decided that I wanted to understand what was happening to me. I also wanted to be able to contribute to the world of cardiology and my degree provided me with these opportunities.

Q What sort of personality or passions do you need to have to pursue your career?

A I would say that a passion for working with people and creating a positive impact on their lives is important. Furthermore, a passion for science would be beneficial.

Q What qualifications did you need to gain to succeed in your career?

A I undertook a university degree in BSc Healthcare Science (Cardiac Physiology), but prior to this I completed my A levels and GCSEs.

"The beauty of working in healthcare is that no two days are the same!"

Q Are there alternative routes into your profession – such as apprenticeship schemes?

A To the best of my knowledge (as this is the route that I have taken), a university degree in cardiac physiology is required. However, checking individual requirements from each university is important. Visiting the NHS Health Careers website is also a useful resource for this information.

Q Did you do any work experience in your field? If so did this help you decide what you wanted to do?

A I personally did not carry out work experience in this field as a student, as I had gained my insight by being a patient; it was this experience that motivated me to pursue this career.

Q Do you have any career highlights?

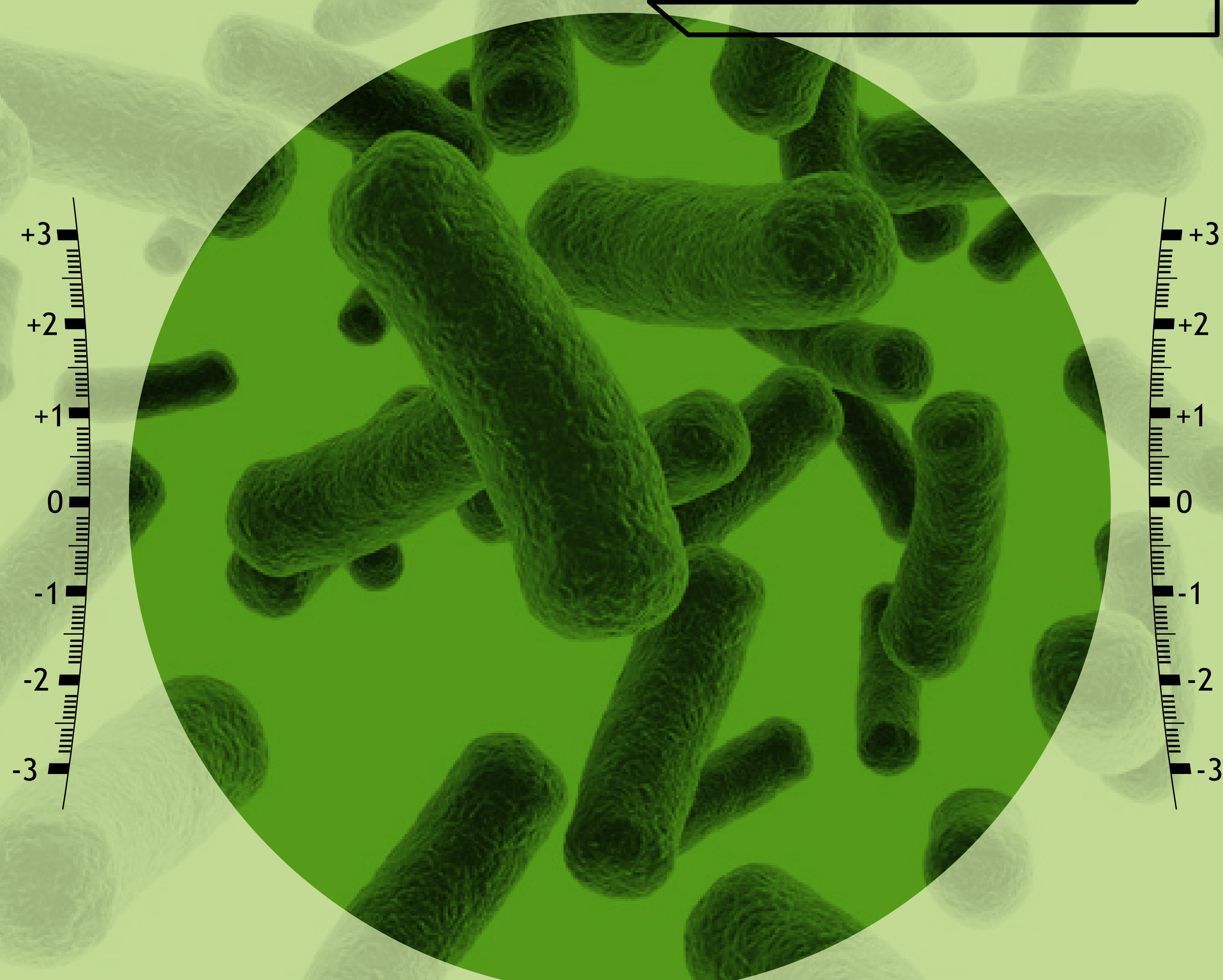
A I have recently graduated and have just started my career, but my greatest personal achievement so far is being awarded first class honours in my degree.

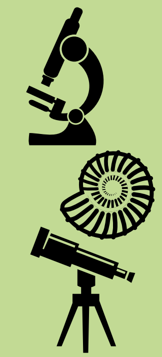
Bringing wastelands to life –

how extremophiles could help us 'green' other planets

By Hanna Landenmark
PhD student at the UK Centre for Astrobiology, The University of Edinburgh

Astrobiology is an exciting, emerging research field which incorporates virtually every science under the Sun (pun intended). Finding an appropriate and comprehensive definition of astrobiology can be a challenge for a topic concerned with the study of life in the universe. Few researchers would class themselves as pure astrobiologists, as their research is often linked to multiple areas and sits at the interface of many of the classical sciences, such as chemistry, biology, geosciences, astronomy and physics. In the broader sense, if you've ever wondered about the rest of the Universe and whether we are truly alone, you've already ventured into the realm of astrobiology.





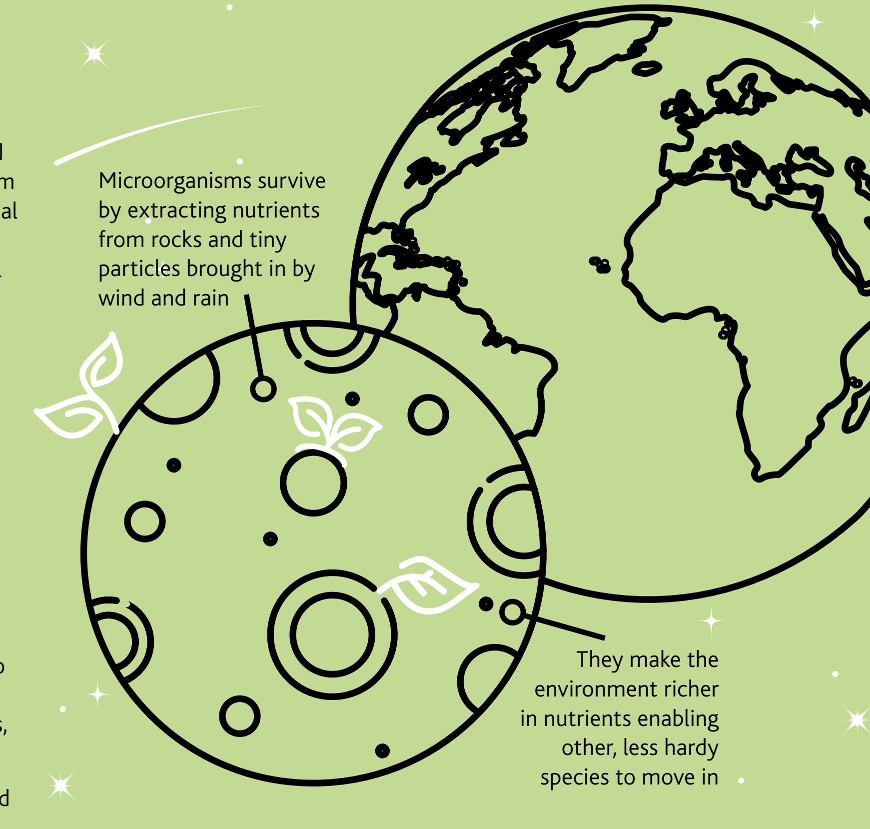
The day-to-day life of an astrobiologist varies greatly. Some are microbiologists and spend their day characterising microbes from extreme environments, such as hydrothermal vents or very salty lakes. Others are geoscientists and could be creating artificial fossils in the lab or studying the imprint of early microbes in rocks. Physicists-or-engineers-turned-astrobiologists could be sleeping during the day and working overnight to gather data from telescopes on exoplanets orbiting other stars.

Meanwhile, there are researchers on field trips collecting data all over the world, from snow algae near the poles, to drought-resistant organisms in scorching deserts. There are even people working on the social science aspects of astrobiology, such as thinking about the laws that prevent potential planetary cross-contamination, or doing psychological studies on groups of volunteers who simulate working on a Mars base. If you were to join any of these research groups, one thing is certain: you'd be working in a team of scientists from very different backgrounds, all bringing their expertise to the table.

Even though astrobiology might seem fundamentally concerned with life beyond the Earth, many of the discoveries are equally important for advancing our understanding of life on our own planet. One example is studying how land masses become colonised by life, in other words, how we go from barren, desolate stretches of rock to soils and lush vegetation. Even though Earth's land masses have been colonised for a very long time, this process still occurs today, as volcanoes create new lava fields that slowly cool and are colonised by bacteria, archaea (another type of microorganism), fungi and plants. For instance, one of the most famous volcanic eruptions in the last decade was the Icelandic Eyjafjallajökull, which shut down air traffic across most of Europe, and created extensive lava flows in the surrounding area.

The first colonisers to inhabit these hostile environments have to be extremely hardy to establish themselves, and have to survive by using nutrients extracted from rocks and whatever tiny particles are brought in by wind and rain. At the same time, if you're living on a rock surface, you're exposed to the elements, and have to be able to survive wetting and drying cycles, wind, UV radiation and drastic temperature fluctuations. Thankfully, many microorganisms are very versatile and adapted to exactly these kinds of alterations, and have no problem colonising newly exposed rock – in fact, some species thrive while living a little on the edge. Over time, the first colonisers will weather the rock surface and make the environment a little less hostile and richer in nutrients, enabling other, less hardy species to move in.

Terraforming is the concept of changing other planets or moons to more Earth-like conditions.



Over time, volcanic rocks turn into rich, fertile soils that are excellent for agriculture. This type of research can help us understand how land was colonised on the early Earth, and can also give clues to similar potential phenomena on Mars.

Much in the same vein, there has been a lot of thought about how microorganisms could be utilised to facilitate human space exploration, for example for food production in space environments. People have suggested that microorganisms could be used in terraforming – the concept of changing other planets or moons to more Earth-like conditions. One step could be to use ecosystems of microorganisms from Earth that are well known for their capabilities to break down rocks to accelerate soil formation or extract useful elements.

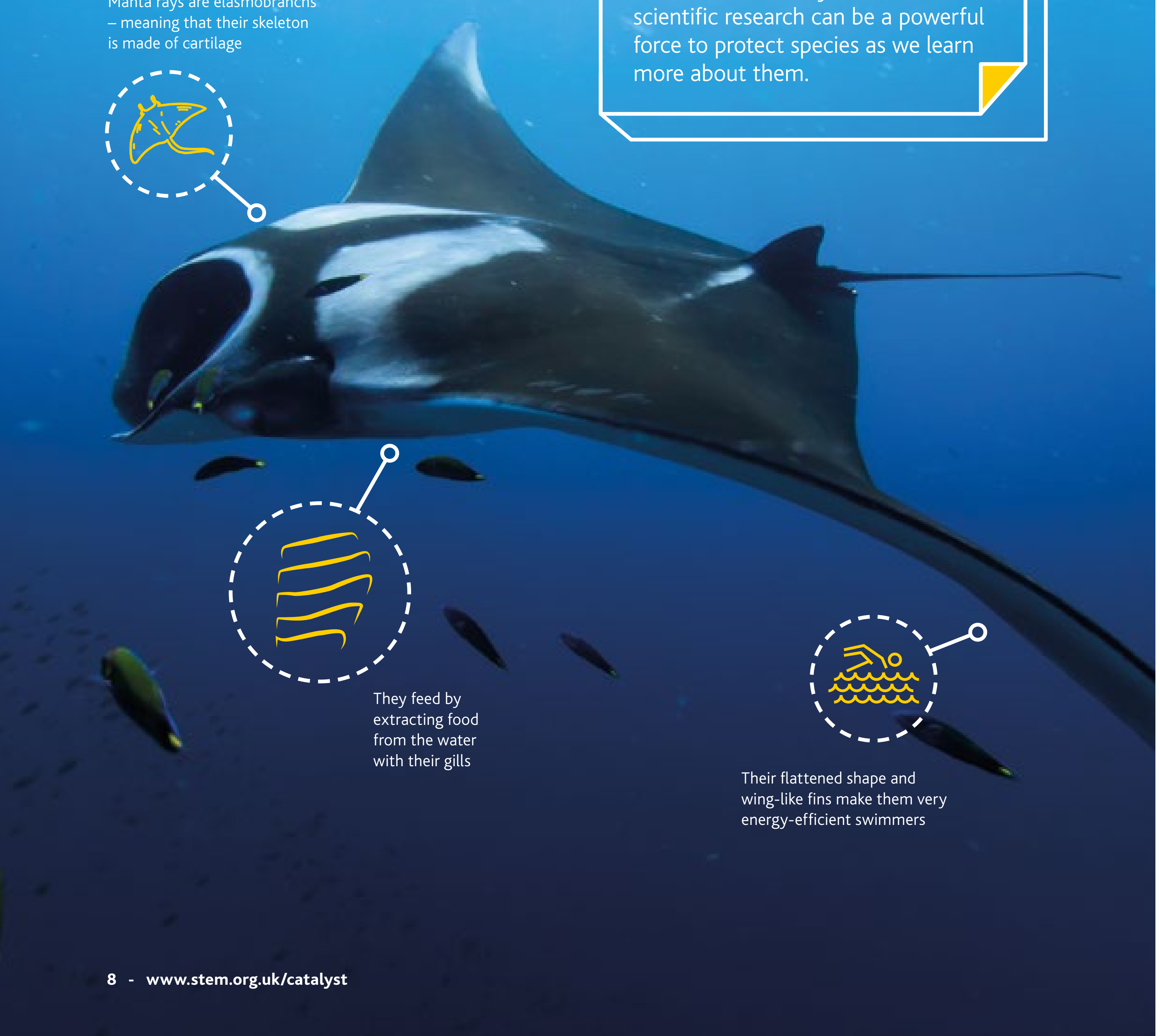
There are, however, many obstacles to consider – many conditions need to be right for terrestrial microbes to survive in these novel environments, such as access to all necessary nutrients, clement temperatures and protection from harmful radiation. There are also ethical questions to consider: do humans have a right to alter other planetary bodies that could potentially already host life, perhaps in a way that we don't recognise, or where life could emerge in the future if left to its own devices? These fascinating questions continue to inspire both professionals and the public, ensuring that terraforming remains a compelling topic of research and conversation.

If you are interested in studying astrobiology and tackling some of these questions yourself, there are many routes to take. Although there are currently no undergraduate degrees in astrobiology in the UK, many universities offer introductory courses that give an overview of the topic. Being a very interdisciplinary subject, it is possible to study virtually any STEM subject in school or university before embarking on a research career within the scope of astrobiology. So, whether you are interested in questions involving tiny microbes, or the future of human space exploration and colonisation, there's something within astrobiology for everyone.

Using science to save manta rays

By Caroline Wood
Researcher PHD Student and Freelance Science Communicator at University of Sheffield

Gliding like ghosts through the oceans...manta rays are fascinating, mysterious creatures but these captivating animals are under threat and populations across the world have plummeted over recent years. However, their story shows how scientific research can be a powerful force to protect species as we learn more about them.



Manta rays are elasmobranchs – meaning that their skeleton is made of cartilage

They feed by extracting food from the water with their gills

Their flattened shape and wing-like fins make them very energy-efficient swimmers

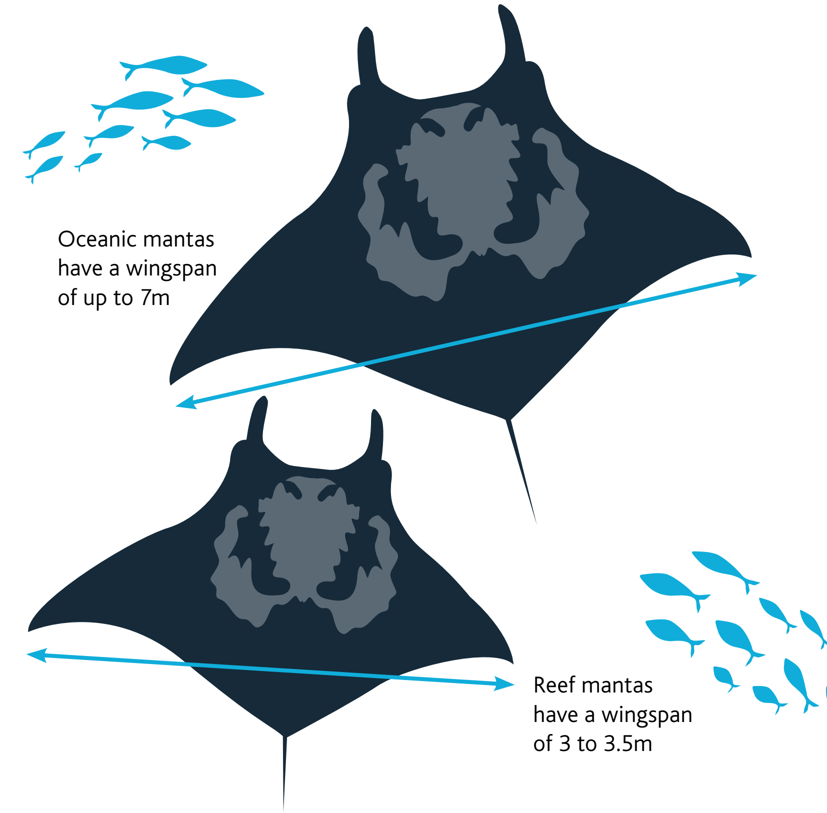
What are manta rays?

Like sharks and rays, mantas are elasmobranchs – meaning that their skeleton is made of cartilage. They belong to the family Mobulidae, which contains two genera: mobula and manta. For the mantas, there are two main species: reef mantas and oceanic mantas. Reef mantas are the smaller species (with a wingspan of 3 to 3.5m) and are found in shallow waters on coastal reefs or around islands.

Oceanic mantas are larger (up to 7m across) and tend to be found in the open ocean. Their natural lifespan is thought to be around 50 years, or even longer. Mobula rays are smaller cousins of mantas and there are currently thought to be nine species of these. Like mantas, they are found in tropical and sub-tropical oceans but are more shy and elusive, so much less is known about them.

Their main food source is zooplankton

Both mantas and mobulas are filter feeders and their main food source is zooplankton – tiny animals such as shrimps and copepods (tiny crustaceans) – which they extract from the water with their gills. Mantas have one of the largest brain sizes relative to their body and are highly intelligent, social creatures. Their flattened shape and wing-like fins make them very energy-efficient swimmers. They have elaborate courtship rituals and often show a real interest when they encounter human divers.



Oceanic mantas have a wingspan of up to 7m

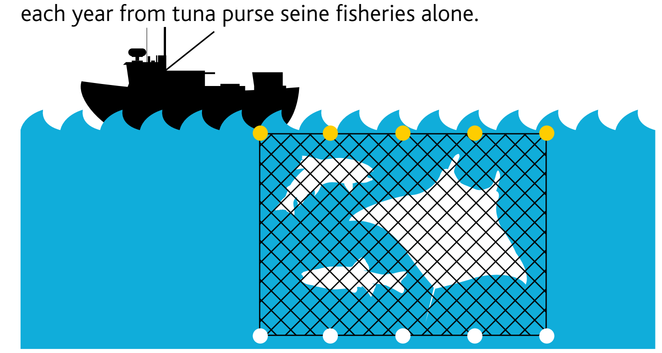
Reef mantas have a wingspan of 3 to 3.5m

The natural lifespan of oceanic mantas is thought to be around 50 years, or even longer.

Why are they endangered?

Manta and mobula populations have plummeted over recent years and in certain regions their populations have completely crashed. One reason for this is that every year thousands of mantas and mobulas are caught as by-catch to feed our growing demand for seafood. By-catch are fish that are caught unintentionally by commercial fishermen due to capture methods that aren't specific to the target species.

Mantas often fall victim to destructive fishing techniques – such as purse seine nets and longlines – that catch all sorts of sea life besides the target species. Mantas are particularly vulnerable to being caught up in lines as they cannot swim backwards and free themselves. Most by-catch is ultimately discarded, dead, over the side of the fishing vessel. It is estimated that 13,000 mobulids are caught as by-catch each year from tuna purse seine fisheries alone.



Recently, mantas and mobulas have also been specifically targeted by the Chinese medicine industry. Although they have never been a traditional part of Chinese medicine, a huge demand has developed for the feathery gill plates, which mantas use to filter plankton from the water. It is claimed that eating gill plates can help purify the blood of toxins and also combat diseases such as cancer, asthma and skin rashes – although there is no scientific evidence for this. Demand is now so high that gills can fetch up to $500 per kg. According to the charity WildAid, an estimated 147,000 mobulas were killed in 2013 to supply the Guangzhou Chinese market.

Female mantas give birth to a single pup at a time after a gestation period of almost a year. It can take 10 to 15 years for a manta to reach maturity. This makes them a classic K species – as opposed to R species (such as rabbits), which typically produce multiple offspring that mature early, but have a short life expectancy. Elephants and humans are both examples of K species. Long-term studies conducted in the Maldives suggest that mature females only average one pregnancy every five to six years. This means that wild manta populations can only recover very slowly.

Using research to protect these giants

In 2011, The Manta Trust was established to coordinate global efforts to save these iconic species through campaigning, education and research. Many aspects of the lives of mantas remain a mystery, including their movements and areas which are important for feeding and breeding. After years of photographically tracking and tagging individuals, researchers are beginning to unravel these secrets.

It's now known that reef mantas in particular return to specific sites year after year. These include 'cleaning stations': areas of reefs with populations of 'cleaner fishes', which feed on parasites and dead skin on the mantas' bodies. Feeding sites where the ocean currents create super-abundances of plankton are also important. These can attract dozens of mantas at a time and generate a 'feeding frenzy', with the mantas forming feeding chains to cooperatively harvest as much plankton as possible.

Knowing where these places are is the first step towards safeguarding them. A particular success story is Hanifaru Bay in the Maldives, a vital feeding ground for reef mantas. In 2009, this area was almost completely dredged to make way for a new airport – until The Manta Trust stepped in. Using scientific data and photographs collected by the Maldivian Manta Ray Project, they were able to demonstrate to the government how important it was to protect this unique area. As a result, the airport was relocated and Hanifaru Bay instead became the first Marine Protected Area (MPA) in the Maldives.

In Indonesia, The Manta Trust is collaborating with Conservation International to run community transition programmes, particularly in areas with a tradition of hunting manta rays. The aim is to help transition local fishers into scientific officers, using their fishing and seamanship skills to collect data on the marine animals and ecosystems in their region. By making live manta rays more valuable to local communities than dead ones, it is hoped that this will help safeguard their future.

International protection

In 2013, The Manta Trust successfully campaigned for both species of manta rays to be listed on the Convention on International Trade in Endangered Species (CITES) – this aims to control the international trade of animal and plant species, where this threatens their survival. In 2016, The Manta Trust called for mobulas to also be added to CITES – given that most of the delegates at the conference had never heard of a mobula, the Trust knew they had a challenge on their hands. Using virtual reality headsets and captivating cinematography, they were able to give the delegates the experience of swimming underwater with these graceful creatures. This proved to be so compelling that mobulas were duly added to the CITES convention.

Female mantas give birth to a single pup at a time after a gestation period of almost a year.

Hope for the future

The case of the mantas and mobulas shows just how important a role research, education and awareness can play in protecting endangered species. As The Manta Trust has demonstrated, when this information is used to inspire the public and create arguments for legal protection, powerful change can happen. Hopefully this will help to safeguard the mantas for years to come so that future generations can also dream of swimming with these gentle giants.

Ways that you can help protect manta rays

The Manta Trust – learn more about manta rays and how The Manta Trust is working to save them.
www.mantatrust.org

WildAid – this organisation aims to end the trade in products from endangered animals by reducing the demand for these from consumers. Their strategies include campaigning for legal protection and producing compelling media messages.
www.wildaid.org

Good Fish Guide – the Marine Conservation Society has created an online guide to sustainable fish, to help you eat responsibly.
www.goodfishguide.org

Perception:

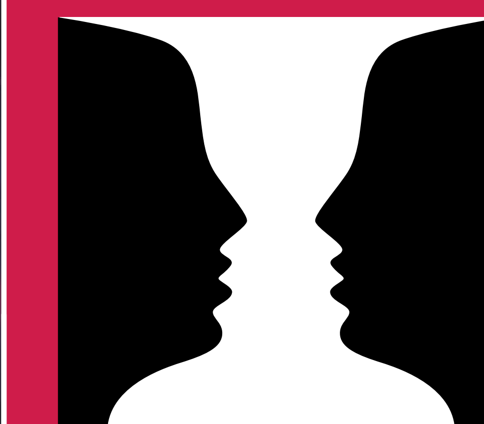
how our brain builds a picture of the world around us

By Dr Maxine Sherman
Research Fellow in Cognitive Neuroscience, University of Sussex

It's easy to rely on our senses and imagine that they are perfectly accurate. We often rely on our vision – but signals that enter through our eyes are just electrical signals. These signals are noisy, without colour and without depth. When our brain first receives a signal from the eyes the image is actually upside down, and our brain needs to 'flip' it for us before building an accurate picture of the world. And what about our hearing or sense of touch? Can we trust the way our brain interprets the world?

How does our brain 'decide' what to see?

The majority of cognitive psychologists and neuroscientists think of perception as a kind of decision-making process implemented by the brain. The idea is that the brain decides between several or many possible environmental states that cause the sensory signals detected by our sensory organs. Sometimes these causes can be rather ambiguous, as shown in Rubin's face-vase illusion below. Depending on how we interpret the image we could perceive two people facing each other or a white vase against a black background. These two 'percepts' are like two competing possibilities that the brain must choose between: did our eyes receive signals from two faces or from a vase?

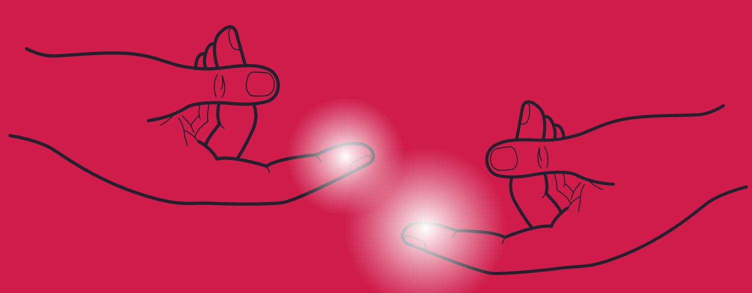


Beyond our conscious perception

Imagine that you are at a loud party, and it is so noisy that you cannot hear what others are saying. If somebody says your name it is likely to capture your attention and lead you to pick up on it, despite being unable to hear the rest of the conversation. This phenomenon is one manifestation of the so-called 'cocktail party' effect. It raises an important issue: for your name to have captured your attention you must have heard it being spoken, because strangers' names do not capture your attention. But how did this happen if you cannot hear what people are saying?

Effects such as these are taken as evidence of unconscious perception. Unconscious perception refers to the detection of external stimuli by the brain that go on to influence our behaviour (in this example, our attention), yet which remain outside of our awareness. Their detection means that they have been perceived, but the absence of us knowing or feeling their detection means they are unconscious. A key question in psychology and neuroscience is why are we aware of some stimuli but not others? Which features or processes warrant access to awareness?

Back in 1884, two scientists, Pierce and Jastrow, designed an experiment to test unconscious perception. They applied pressure to participants' fingers and then increased or decreased it very slightly. They asked participants to describe if they were feeling more or less pressure, and how confident they were in their answers. The research showed that participants were able to sense the changes in pressure, but they had no confidence in their judgements. The experiment appears to suggest that we can sometimes perceive things we are not conscious of.



Research suggests that we are more likely to be aware of something that:

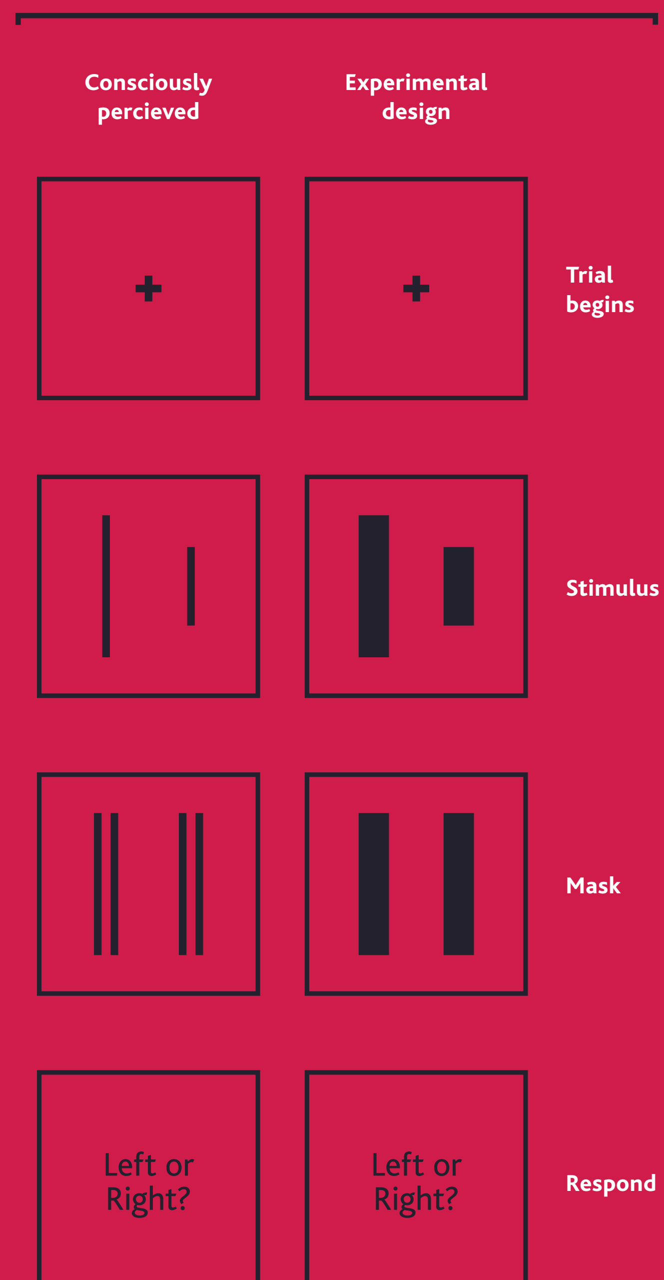
- we're focusing on
- we are expecting
- stands out
- we are holding in our working memory

However, we can still miss things under these circumstances, and be aware of things even without these factors.

Testing our consciousness

Unconscious perception is often investigated with a technique called 'masking' – in these experiments participants will sit at a computer and will be briefly presented with a stimulus. The stimulus is then quickly covered with a 'mask' that renders the stimulus invisible, and the participants will be asked to make a judgement about the stimulus.

In 1974 Tony Marcel used masked words to test unconscious perception. A word such as 'salt' would be shown to participants, then swiftly 'masked'. Next, participants would be asked to choose between two words, for example 'pepper' (which is linked to 'salt') and 'lotus' (which is unrelated to 'salt'). Participants were more likely to choose the related word, indicating that even though they could not consciously 'see' the first word, it nonetheless influenced their choice.



The study of perception investigates how our brain builds a 'picture' of the outside world.

What brain disorders can tell us

Another way to explore consciousness is to study the behaviour of patients with brain damage in regions linked to visual consciousness to see if visual consciousness is impaired. One such condition is 'blindsight' – individuals with this condition have damage to a part of the brain called the striate cortex, which is dedicated to early visual processing. Although their eyes are healthy, these patients are unable to consciously see. However, tests seem to indicate that their unconscious vision is somewhat preserved.


Striate cortex

In one experiment, a test subject, referred to as 'TN', was asked to navigate a hallway. TN did not know that experimenters had placed obstacles in his way, but remarkably he still moved around them. Research such as this shows that people with blindsight can still perceive things unconsciously.

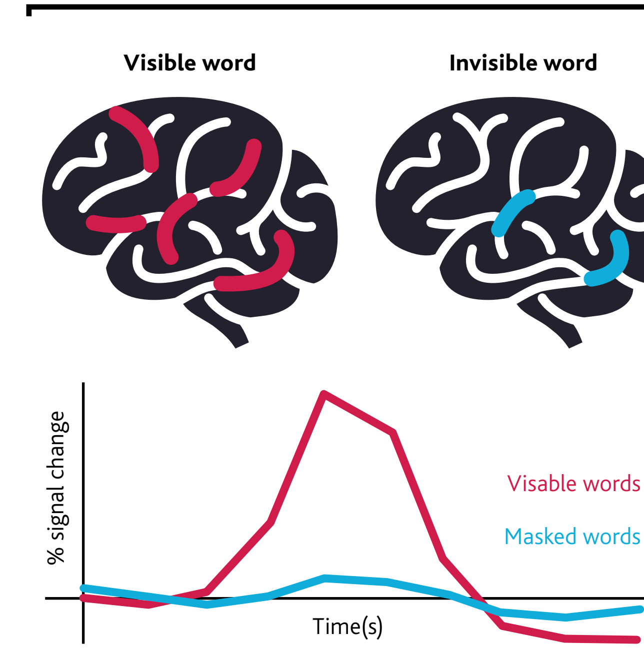
Looking at perception in the brain

So what can we do without awareness? And what happens in the brain when objects are only unconsciously perceived? Finding the answers to these questions would tell us more about what consciousness is 'for' and about the parts of the brain are involved in building our conscious experience.

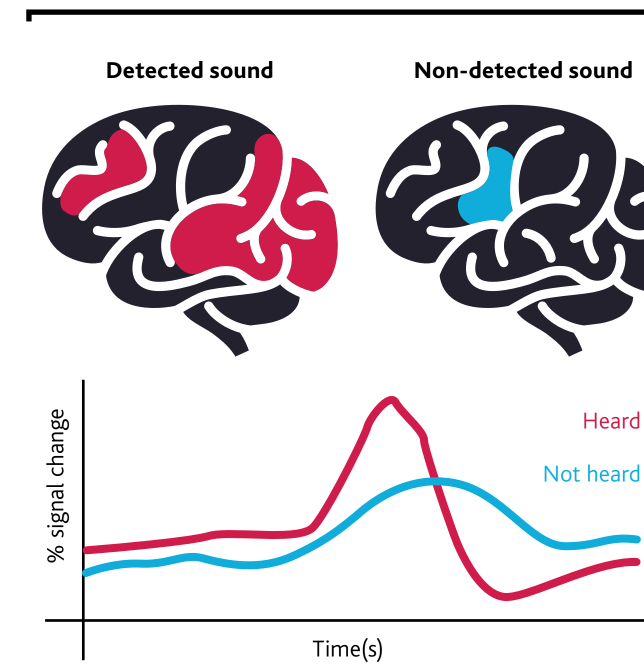
A great deal of evidence, for example from masking studies or patients with blindsight, suggests that we can perceive quite a lot without awareness. Researchers have found that certain regions in the brain are involved during conscious and unconscious perception. The parts of the brain that react unconsciously to stimuli match the parts of the brain usually used to process that type of information (for example, visual areas for vision; auditory areas for sounds; language areas for words).

However, a broader set of regions is involved when a stimulus is consciously perceived than when it is unconsciously perceived. When a sound is consciously heard we see activation of auditory, language and prefrontal-parietal regions; when the sound is not consciously heard, only auditory and language regions are activated.

Language



Auditory

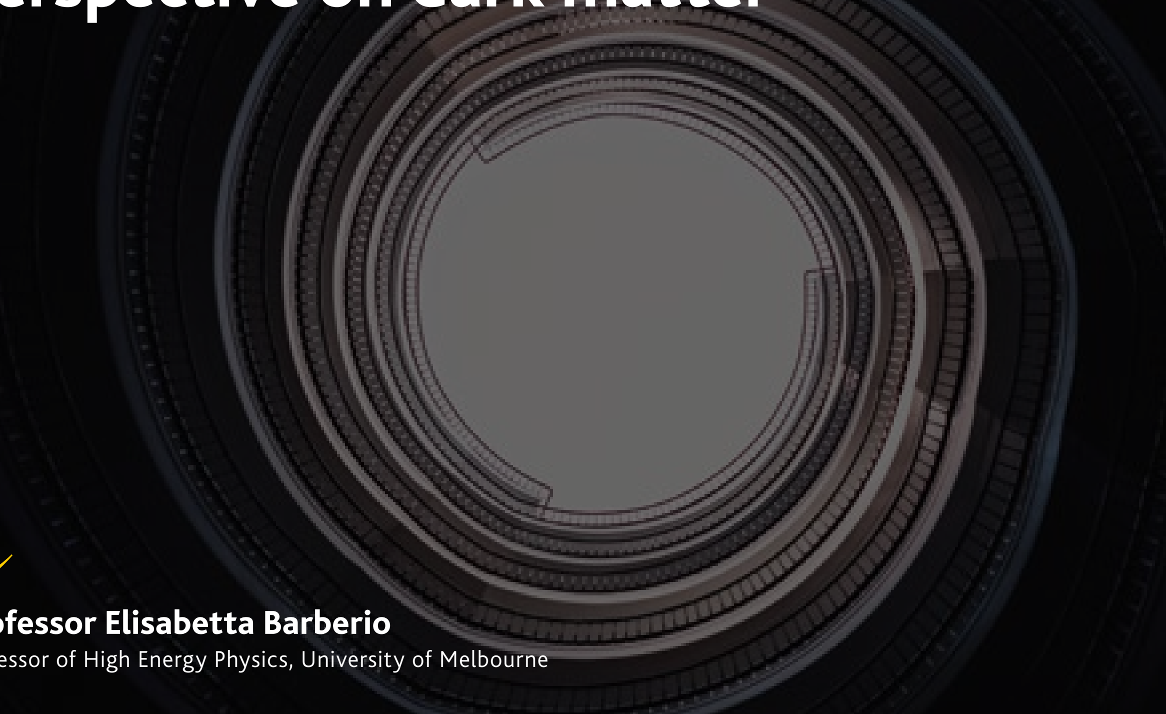


Perception is still a bit of a mystery

The study of perception investigates how our brain builds a 'picture' of the outside world; one that is useful to guide our behaviour. Scientists who study perception are really looking to find out how the brain processes and selects sensory signals to build a coherent and largely accurate picture of our environment – but many of the details remain unknown and there is still much research to be done.

A new unknown universe:

A southern hemisphere perspective on dark matter



Professor Elisabetta Barberio
Professor of High Energy Physics, University of Melbourne

> Astronomers in the first half of the 19th century found something unusual when they studied galaxies: the Universe contained more matter, or 'stuff', than was visible with any kind of astronomical instrument that observes light.

We now know that only 20% of the matter in the Universe is made of ordinary atomic matter (the 'stuff' that makes up all objects on Earth). The remainder is made up of dark matter. Definitive evidence of dark matter has come from many sources. But what this substance, that holds galaxies together and keeps the Universe from flying apart, is currently a mystery.

Particle and nuclear physicists have discovered the fundamental building blocks of atoms and refined the human concept of the physical world, connecting the smallest building blocks of matter to the cosmic web of galaxies and to the birth of the Universe (the Big Bang). But now, evidence for dark matter demands a revolutionary new vision of this new 'dark' universe.

Understanding this unknown 'new' universe means we need to discover the physics that underpins its fundamental nature. There are many theories suggesting what dark matter could be made of. One even suggests the existence of a 'hidden valley' - a parallel world made of dark matter having very little in common with matter we know. One very popular hypothesis suggests that dark matter is made of 'weakly interacting massive particles' (WIMPs). These are leftover materials from the Big Bang, passing through normal matter and leaving almost no trace. The astrophysical observations tell us about the macroscopic properties of dark matter (how it works across the Universe), terrestrial astroparticle physics experiments will tell us its quantum properties and which kind of particle, or particles, dark matter is made of.

> **Only 20% of the matter in the Universe is made of ordinary atomic matter.**

Light on dark matter

We are moving through a sea of dark matter as the galaxy rotates, as the solar system moves through the galaxy, and as the Earth rotates around the Sun. Sometimes, very rarely indeed, a dark matter particle will collide with the nucleus of an atom, and this can be detected in a carefully designed experiment.

Our lack of knowledge about the particle nature of dark matter makes for a challenging search. In the last decade, there has been impressive experimental progress to detect dark matter interactions with normal matter, with the development of new direct detection experiments. Most direct dark matter experiments attempt to reduce background 'noise' from other particles like cosmic rays to an absolute minimum and interpret any excess counts as a signal of dark matter. So far none of these experiments have had a positive result.

Looking at the sky from deep under the ground

Experiments aimed at detecting dark matter have to be designed carefully. Dark matter can sometimes be difficult to distinguish from environmental and cosmic background radiation. The only way to reduce these effects is to build the experiment in a deep underground site.

In order undertake the first direct-detection dark matter experiment in Australia we built the first-ever integrated underground laboratory in the Southern Hemisphere the Stawell Underground Physics Laboratory (SUPL).

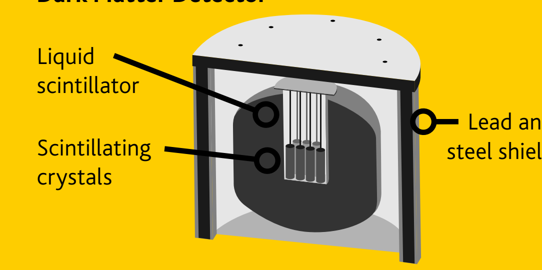
We are going to conduct a pair of linked experiments in the Northern and Southern Hemispheres, to search for the dark matter annual modulation signal, and at the same time rule out any seasonal environmental variation that might mimic the signal. This experiment, SABRE, is the first dual-sited direct-detection experiment. The Southern Hemisphere experiment will be located at SUPL in Australia, and the Northern Hemisphere experiment will be hosted at Laboratori Nazionali del Gran Sasso, Italy.

The Stawell Gold Mine is a dry, basalt rock mine, and reaches a depth of 1.6 km. The location and the nature of the mines make it ideal for a dark matter experiment. We have identified a cavern at 1025 metres underground, which could host a dark matter experiment and an integrated underground laboratory facility, and is at a similar to the average depth of the Gran Sasso National Laboratory in Italy.

The SABRE experiment

The essence of the SABRE experiment is that dark matter must interact very weakly with ordinary matter. Dark matter can collide with atoms, and if the target nucleus is in an atom of a scintillating crystal, such as sodium iodide doped with thallium - otherwise known as NaI (Tl) - then the recoiling nucleus can cause the atom to ionise. This releases electrons, and causes photons to be emitted when the electrons are reabsorbed. If we have photomultiplier tubes around the scintillating crystal then the photons will be absorbed, and an electronic pulse will be generated signalling the dark matter or nucleus collision. However, almost any other particle or photon colliding with the scintillating crystal will also cause an electronic pulse.

Dark Matter Detector



The most important thing about experiments like this is to carefully get rid of unwanted signals. Going deep underground reduces the flux of cosmic rays. Having a passive external shield of lead and steel helps, but is not enough. We also need an active background rejection and so we place the scintillator inside another scintillator to detect more strongly interacting particles coming from outside that would cause a signal in both of them.

This technique is called an 'active background detection' or an 'active veto'. Dark matter particles would only interact with one, since they interact so weakly. We also have to protect against radiation coming from inside the detector itself which can cause a signal, hence the need for ultrapure materials such as the ultrapure NaI scintillating crystal. Moreover, appropriate passive and active veto shielding (from muons, neutrons and gamma-rays) will also surround the experimental setup.

What next?

The SABRE experiment will either confirm that dark matter particles have been directly detected, or conclusively eliminate previous readings of dark matter. If we are able to confirm the discovery of dark mater, we will open a door on the new mysterious universe we cannot see.

From flatscreen TVs to your smartphone:

the element boron deserves more attention

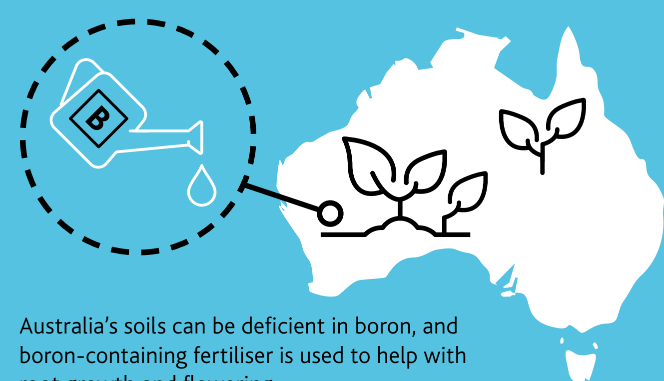
Zhenguo Huang
Senior Research Fellow in Energy, University of Wollongong

Each time you watch sport on a flatscreen television, or send a message by touching your smartphone screen, give thanks to an unsung hero of the periodic table: boron.

Boron, often wrongly labelled a 'boring' element, plays a versatile role in our lives.

It's the key ingredient in borosilicate glass, which is known for its exceptional resistance to thermal change and chemicals, and its ability to withstand impact. This means glass cookware can go into a hot oven straight from the freezer, and that lab equipment such as beakers and test tubes can withstand corrosion.

Neodymium magnets, in which boron plays a role in the formation of the crystal structure and retaining magnetisation, are among the strongest permanent magnets commercially available. Boron is also used to prepare detergents, buffer solution, insecticides, insulation and semiconductors.



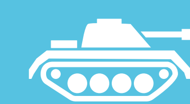
Australia's soils can be deficient in boron, and boron-containing fertiliser is used to help with root growth and flowering.

Although I research boron chemistry for energy conversion and storage, the element has a rich history with many practical applications.

What makes boron so special?

Due to its reactivity, boron naturally exists only in combination with other elements, forming boric acid and inorganic salts known as borates.

One key reason why boron is so versatile is its electron-deficient nature, which means it's very inclined to accept electrons from other elements and easily forms many interesting compounds with both metals and non-metals.

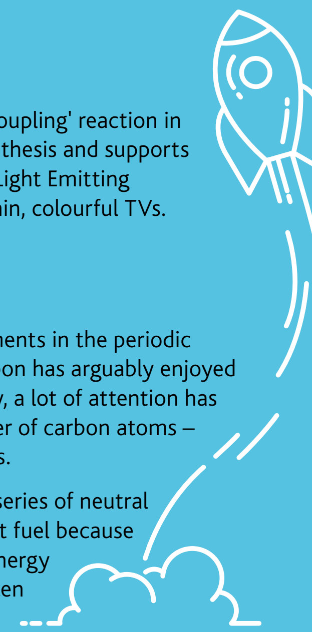


For example, metal borides, compounds formed between metal (M) and boron (B), such as rhenium diboride, have high hardness due to extensive B-B and M-B bonds. There's also boron carbide, which is an extremely hard and light ceramic used in bullet proof vests and tank armour.

Boron-10 (10B), a stable isotope that can be isolated by extensive distillation of volatile boron compounds, has led to Boron Neutron Capture Therapy (BNCT) that treats locally invasive malignant tumours, such as recurrent head and neck cancer.

Notably, the Nobel Prize for Chemistry has been awarded at least three times to scientists working in the field of boron chemistry.

One recent contribution is the 'Suzuki Coupling' reaction in 2010, which revolutionised chemical synthesis and supports product developments such as Organic Light Emitting Display (OLED), which can be used for thin, colourful TVs.



Boron versus carbon

Boron and carbon are neighbouring elements in the periodic table and are similar in many ways. Carbon has arguably enjoyed greater publicity, however. Most recently, a lot of attention has been paid to graphene – one atomic layer of carbon atoms – which has many potential high-tech uses.

Similar to hydrocarbons, boron forms a series of neutral boranes that were once studied as rocket fuel because they produce an enormous amount of energy when reacting with oxygen. But they often proved toxic and too difficult to control.

Elemental boron exists in 16 known 'allotropes' – different forms of the same element. Carbon has two common ones: diamond and graphite.

The difficulty in controlling the formation of desired boron allotropes slows down research. In contrast, carbon materials can be easily prepared and studied.

A pivotal role in energy conversion and storage

It is exciting to see scientists around the globe beavering away in labs, finding new ways to use this plucky little element.

Here are some of the big questions they're tackling:

1 Boron as a source of energy

Some researchers are examining whether we can get energy from boron using aneutronic fusion – a form of fusion power in which negligible amounts of neutrons are released.

2 Boron as an energy carrier

Compounds containing boron, nitrogen and hydrogen can effectively store and transfer hydrogen. This is important because hydrogen is an ideal candidate to store energy produced by wind farm and solar plants.

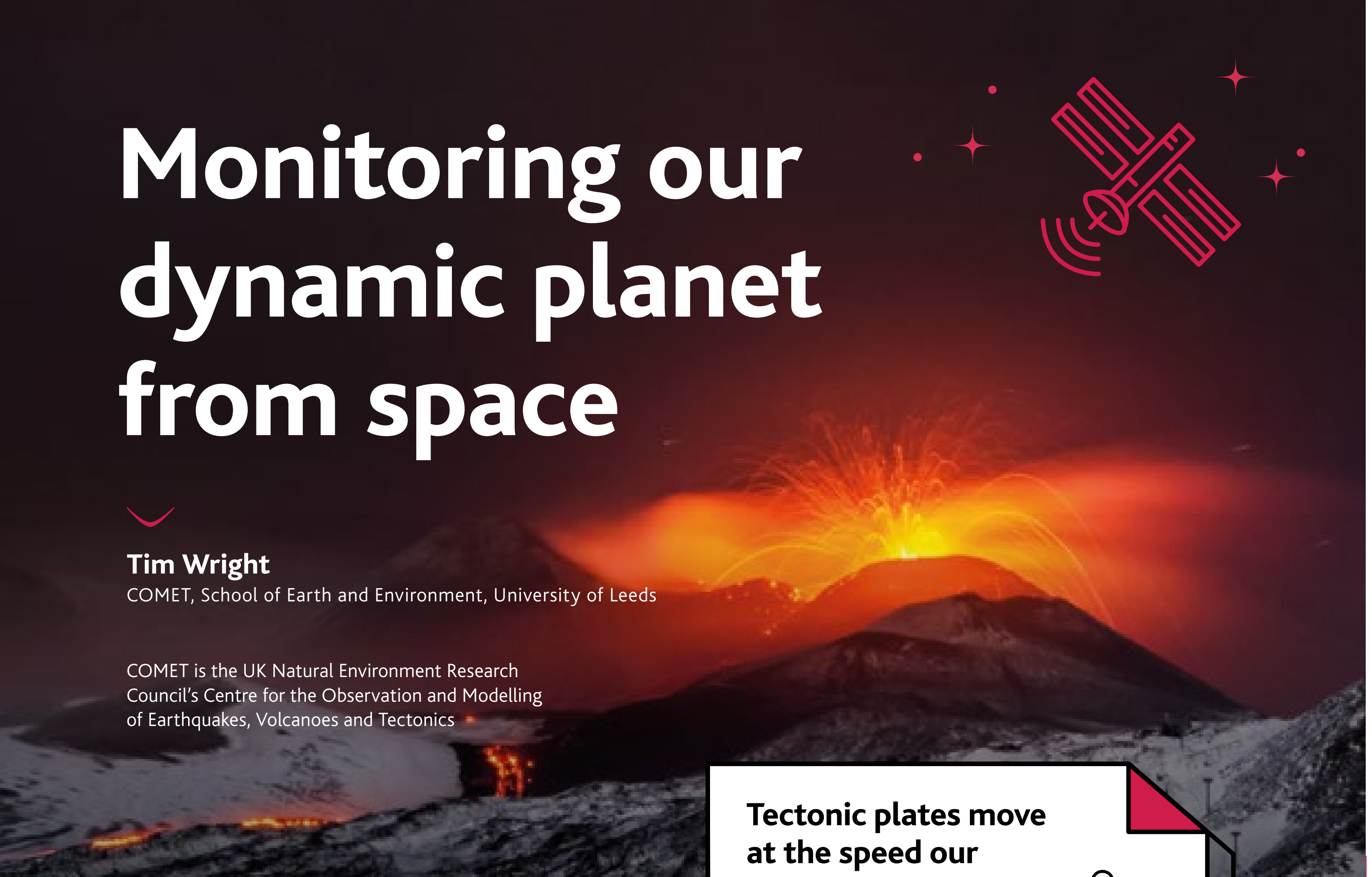
Sodium difluoro (oxalato) borate, on the other hand, can outperform some commercial compounds as an electrolyte salt for emerging sodium-ion batteries, which could be a great candidate for large-scale energy storage.

3 Boron for heat conservation

Some solar water heating and solar power generation plants are using borosilicate collector tubes to harness reflected radiation from mirrors, so the steam turbines can be driven in a more efficient way.

We have also seen more stringent building standards with respect to heat conservation, promoting the use of borates for fiberglass insulation.

Impressed? Should boron get more of the spotlight? I'm sure we will see boron continue to be a star in our tech-driven society. From fertiliser to OLED screens, it's poised to have a big impact.



Monitoring our dynamic planet from space

Tim Wright
COMET, School of Earth and Environment, University of Leeds

COMET is the UK Natural Environment Research Council's Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics

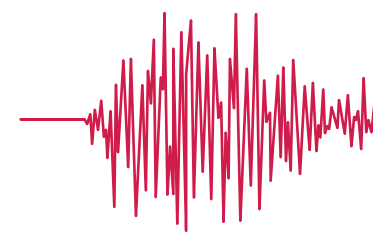
Tectonic plates move at the speed our fingernails grow

The ground beneath our feet is in constant motion. Tectonic plates – moving at the speed our fingernails grow – contort as they collide, scrape past each other or are pulled apart. Molten rock flows through complex subterranean networks. The ever-building stresses and pressures from these movements eventually have to be released – the result is earthquakes and volcanic eruptions. A new generation of satellites is allowing scientists to monitor the build-up of stresses prior to earthquakes and eruptions, providing vital information that can help communities to prepare.

The continents' crust, the upper 15km or so of the Earth's outer layer, is cold, brittle and riddled with lines of weakness, known as faults. When the upper crust is caught in a plate boundary zone it bends like a giant block of rubber, building up elastic stresses. When the stresses are higher than the frictional resistance on the faults within the crust, the faults slip and we experience earthquakes. If we want to say where earthquakes will occur, and roughly how often, we should be able to do this by simply measuring the warping of the crust. We have known this for more than 100 years, but only in the last ten years or so has this method become practical. Why has it taken so long? Because the movements are tiny. To measure the deformation around faults with sufficient accuracy to be useful for estimating future seismic hazard, we need to detect movements of points separated by 100 km that are as small as 1 mm each year.

The breakthroughs in measuring our deforming planet have been by-products of navigation and imaging satellites. Two methods have been particularly important. The first of these uses Global Navigation Satellite Systems like GPS, the US-operated system that so much of our modern lives now depends on. Since the early 1990s, scientists have been using the signals sent from GPS satellites to locate the position of thousands of marker points distributed across the planet. By recording the raw signals from the satellites, the location of these marker points can be pinned down to the nearest millimetre. By tracking these markers over time, we can measure the speed and direction of movement (the velocity) of the marker points. In the latest global compilation of these GPS velocities, there are nearly 20,000 points whose positions and velocities have been measured in an extraordinary effort by the scientific community.

The second satellite method uses radar images acquired by low Earth-orbiting satellites like the new EU/ESA Sentinel-1 constellation. These acquire new images every few days by beaming radar waves from the spacecraft and measuring the reflected energy to form an image. The time it takes the signals to return depends on the distance between the satellite and every point in the radar image; we can track changes in those distances very precisely using a technique called satellite radar interferometry (InSAR). Unlike GPS, InSAR works without instruments on the ground, and we get continuous maps of ground movement with a measurements every few tens of metres or better. To obtain motion maps with the 1 mm/yr accuracy needed for seismic hazard, however, we need to remove the 'noise' that comes from the changing atmosphere – this requires using data from hundreds of radar images, acquired over several years. Systems like Sentinel-1 are now gathering the vast data sets that are allowing us to map the deforming continents in incredible detail.

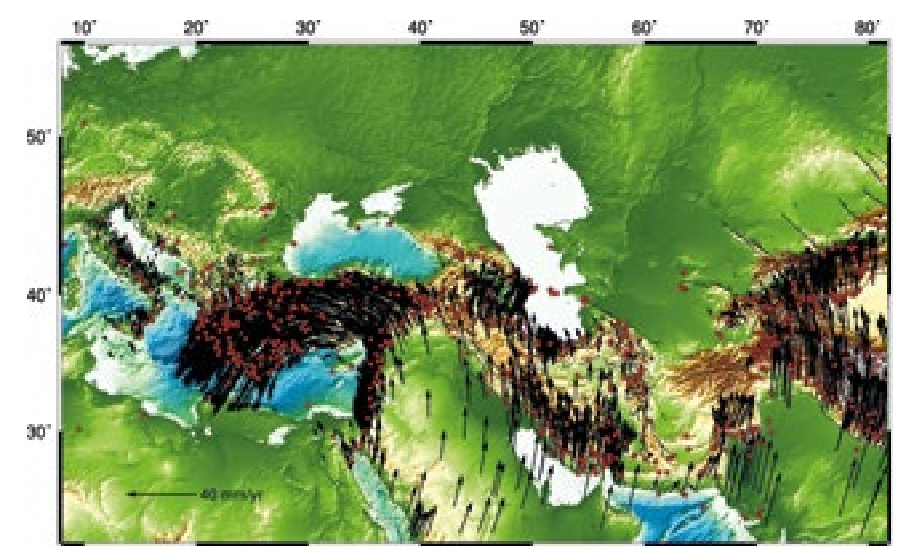


In 2015 an earthquake in Nepal recorded a magnitude of 7.8

Radar images can also have an immediate impact when an earthquake occurs – we can map how the ground moved in the earthquake and use this to work out which faults slipped and which faults remain locked and primed for future earthquakes. Just before midday (local time) on 25 April 2015, Nepal started shaking. An earthquake with a magnitude of 7.8 had occurred on the fault that lies underneath the entire country. Around 9,000 people lost their lives in this earthquake when buildings collapsed and landslides buried towns. Scientists obtained a blurry picture of what had happened using seismic waves emanating from the earthquake and recorded across the planet. But after Sentinel-1 had imaged the area with radar, four days after the quake, we were able to see precisely what had happened at depth. Surprisingly, the earthquake had not ruptured the entire fault – half of it remains unbroken. The data shows that the risk of earthquakes remains high – at some point in the future the rest of the fault plane will fail. The government, NGOs and local communities are working hard to prepare.

The ground also moves at volcanoes as molten rock moves in the subsurface prior to and during eruptions. Ground deformation at a volcano does not always mean an eruption is inevitable, however. On 18 March 2017, scientists at the Instituto Geofisico Escuela Politécnica National (IGEPN) in Quito, Ecuador, noticed increased seismic activity at Cerro Azul volcano in the Galapagos. Based on these small earthquakes, which often accompany magma movement, they issued a warning for a possible imminent eruption. Sentinel-1 acquired data before the start of the seismic activity on 7 and 8 March and again after the earthquakes had begun on 19 and 20 March. The results showed that magma was moving sideways within the crust, rather than approaching the surface. The data helped IGEPN reduce the hazard level.

We are now entering an era where deformation data is readily available for scientists and decision-makers. The organisation that I run, COMET, is now providing InSAR data from Sentinel-1 for large regions – within the next 12 months we expect to be monitoring all of the planet's tectonic belts and volcanoes. We expect the results to have a major impact on our understanding of our hazardous planet and to help communities and decision-makers prevent future earthquakes and eruptions from becoming disasters.



Earthquakes across the Earth

Each circle is a large earthquake and the arrows show the motion of points relative to the Eurasian plate, as measured with GPS. The collision of Africa, Arabia and India with Eurasia has created a wide deforming zone of thickened crust, high seismicity and high strain rates that stretches for up to 2,000km from the foothills of the Himalayas to the distant steppes of Mongolia.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