βluesci

Cambridge University science magazine

Lent 2020
Issue 47
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FOCUS
Our Place in the Universe

Waste in Science • Rockets
Aphasia • Science Fiction

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βluesci
Cambridge University science magazine

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BlueSci was established in 2004 to provide a student forum for science communication. As the longest running science magazine in Cambridge, *BlueSci* publishes the best science writing from across the University each term. We combine high quality writing with stunning images to provide fascinating yet accessible science to everyone. But *BlueSci* does not stop there. At *www.bluesci.co.uk*, we have extra articles, regular news stories, podcasts and science films to inform and entertain between print issues. Produced entirely by members of the University, the diversity of expertise and talent combine to produce a unique science experience

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Our Place in the Universe

When I was accepted for the role of Issue editor for *BlueSci*, I was not quite sure what approach to take. Is there really something novel that I can contribute to the world of popular science magazines, or even to this particular magazine? I doubted it. Yet, I could use this opportunity to help reinforce narratives that I support and would like to encounter more often.

I cared about aesthetics. I wanted to make an issue that anyone – science-inclined or not – would be tempted to pick up and leaf through. I wanted a cohesive colour palette and stylistically engaging writing. In terms of the central concept, I decided I wanted something that 1) specifically related to the Cambridge research scene, since *BlueSci* is a Cambridge-based magazine 2) was open-ended enough to encompass a wide range of scientific disciplines and 3) could easily be abstracted into non-scientific literature and art. The Cambridge professor Didier Queloz had recently been one of the three Physics Nobel Prize winners for his work on, in the words of the Nobel Committee, *Our Place in the Universe*. This title fell in line with all three objectives.

We have tried to structure the issue like a voyage that circles *Our Place in the Universe*. It comprises four intertwined themes. The first stresses the importance of language as a permeating fabric that allows us to establish, communicate and imagine both real as well as otherworldly relations. *Locked Out of My Own House*, *The Astronaut* and *The Other in Science Fiction* fall under this category.

The second part of the magazine shifts onto our ecological place on Earth. *A Look at the Modern Interactions between Humans* and *Crops and Trash Talk: Tackling Waste in Science* offer two different accounts relating to our ecological footprint as a species and as scientists. How have we been influencing our ecosystem and what steps can we take to become less pernicious to the environment?

The third section adopts perhaps the most obvious interpretation of *Our Place in the Universe*: where do we stand, both in space and in time, with respect to the physical Universe? *Charting the Skies, Land and Seas* explains how and why we map our surroundings, *From cannons to Apollo: Rockets Through the Ages* covers the exploratory nature of spaceflight and its limitations. The *FOCUS* explains in simple terms 2019's Physics Nobel prize-winning research on exoplanet detection and the Big Bang. *Going Deep to Reach the Stars* relativises space by uncovering how the deepest parts of our oceans can be used to study the further reaches of outer space.

To finish, we go back to our more conceptual beginning. *Unintelligent Design: Uncovering Bias in Artificial Intelligence* and *How the Cambridge Philosophical Society Shaped Modern Science*, both situated at the end of the magazine, link philosophical thought to real-life scientific implementations. Indeed, the objective is, after reading these pieces as a whole that readers not only feel more informed, but also, and especially, feel more questioning about where they stand and where they want to be in relation to their world. In general, where are we, and where are we going?

Robots or aliens taking over, natural disasters, humans being ambitious, materialistic, and greedy self-saboteurs… In a world full of wonder, it is a shame that the future is so often portrayed - whatever the cause - as a rigid, bleak place. This cannot be the only narrative in our collective imaginarium! The tone of this issue – supported in the writing and highlighted by the delicate pastel colours – is overall one of cautious positivity. We cannot afford to be cynical, especially in times of pessimistic uncertainty. Together, we should work to draw a future that we would be excited to live in. *Bent*, as the Catalan poet Jesús Lizano would put it. A genuine utopia full of diverse plants, animals, and humans – a future full of life

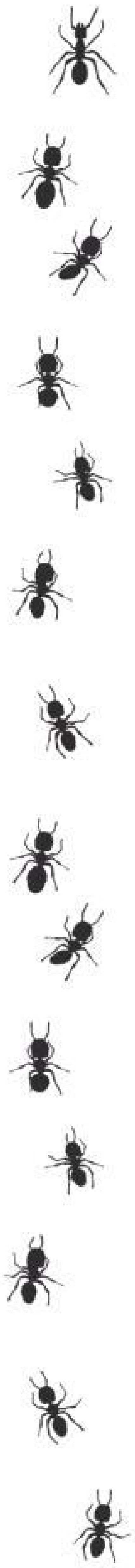
Laia Serratosa Capdevila
Issue Editor #47

On the Cover

A colourful agglomeration of overgrown or undersized animals on a planet that resembles, but is not quite, the Earth we know and love. Elements such as water, air and fire, all merging into a sky that could be interpreted, interchangeably, as sunrise or sunset. The colours and particularly the sky is inspired by Hokusai's prints. Further artistic influences include Brasilian artist and poet José Borges, and Ukranian illustrator Daria Hlazatova. Darkness is often used in art to create confusion, fear or nostalgia. Light, instead, often depicts curiosity and knowledge in the form of 'enlightenment'. I think, in a sense, this is what this issue is about: portraying the Universe as full of unknowns, and thus full of potential for light and colour. This illustration was inspired to some extent by every single article included in the issue - from crops to octopus dreams - and especially relates to the Pavillion in its world of fantastical possibilities. Humans were kept out of the picture to leave the magazine's central concept, *Our Place in the Universe*, as an open question

Aina Serratosa Capdevila
Cover Artist

News



Humans placed in suspended animation

From the enchanted slumbers of Sleeping Beauty and Snow White to the cryogenic chambers of Prometheus and Passengers, we have long been fascinated by the concept of suspended animation. Now, in a ground-breaking clinical trial at the University of Maryland Medical Centre, doctors are using this fantastical technique as an experimental therapy for patients who have suffered acute trauma, such as a stab wound or gunshot. Given the nature of their injuries, these individuals must be operated on within a limited time window, often just a few minutes. By directly injecting ice-cold saline solution into the heart or a major artery, a patient's body can be rapidly cooled to ~10°C, thus halting metabolic activity and buying doctors up to two precious hours to repair the damage. Post-surgery, the patient is warmed up using a machine that mechanically circulates and oxygenates their blood. Whilst this technique, formally known as emergency preservation and resuscitation (EPR), could revolutionize the treatment of severe trauma, key challenges remain unsolved. The long-term physiological consequences of prolonged oxygen deprivation, as a result of cryogenic stasis, are unclear, as is the likelihood of reperfusion injury and multi-organ failure once a patient is "defrosted". Current efforts are underway to develop drugs which can minimise potential detrimental side-effects and extend the period of time for which an individual can be suspended. Their efficacy, as well as the therapeutic value of EPR, will be revealed in a forthcoming publication from the team in Maryland in 2020 SD

Nineteenth century fever

The normal temperature of the human body is 37°C – or so you thought. That baseline was established in 1851, after a German doctor painstakingly gathered millions of temperature records. Yet, modern studies consistently yield a lower estimate, around 36.6°C. Does this difference come from 21st century thermometers being ever so slightly better than their 19th century counterparts, or have humans somehow lost 0.4°C over the centuries? A Stanford university group examined the question by pouring over US body temperature records starting back in the 1860's - turns out, the army keeps a close eye on biological measures from certain recruits. The study shows that human temperatures have declined steadily by 0.03°C per birth decade. Are we slowly turning into cold-bloodied mutants then? Not so fast. This change possibly reflects a drop in our resting metabolic rate, the amount of calories we burn just to stay alive. This may partly come from improvements in general health, as the American population became less plagued by chronic infections that cause inflammation and quietly 'rev up' the body, such as tuberculosis, syphilis or gum disease EL

Why are there no ant traffic jams?

If you have ever been stuck in a traffic jam and wondered if there was a better way, you might be interested to learn that yes, there is, and you can thank the ants who figured it out. Researchers at Toulouse University, Arizona State, and the University of Adelaide recently described how ants manage to move as a collective in a steady bidirectional stream, even at very high densities. Replicating how Argentine ants, their ant of choice, have to travel back and forth from a food source to their nest, the researchers set up a bridge between the ants' home and some tasty sucrose solution. They showed that even with a bridge width of just 5 mm, colonies of 26500 ants were able to maintain flow back and forth across the bridge to gather food. A few key factors seemed important in achieving this feat: the ants adjusted their speed based on crowding, restrained themselves from entering crowded paths, and kept small talk to a minimum if they did collide. Human traffic starts slowing at just 40% capacity, but these ants soldiered on at even 80%. Unidirectional roads mean we might not start copying the ants just yet, but once autonomous cars come in perhaps we should look to these cooperatively-minded critters for suggestions EH

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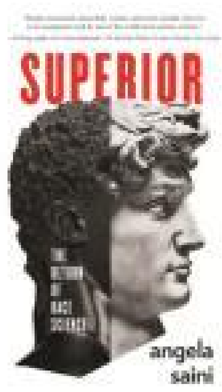
Reviews

Gender, Race and Power in Science - Angela Saini

Fourth Estate Books 2017

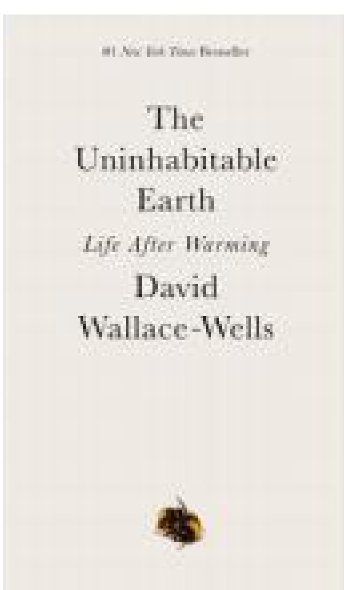


Beacon Press 2019

In November, award-winning author Angela Saini delivered the University College London Women's 2019 Flagship Lecture, addressing the impact of social attitudes towards gender and race in scientific research. Using her best-selling books, 'Inferior' and 'Superior' as a framework, Saini powerfully argued against biological essentialism with a number of real-life case studies. For example, a recent study reported that black women in the UK are five times more likely to die in childbirth than white women. This is likely attributable to the false belief that black patients have a higher pain threshold and consequently receive substandard antenatal care. In another example, Saini showed that using metrics such as weight rather than sex would be much more appropriate for drug prescription. Essentially, some scientific research inappropriately hallmarks race- and sex-based distinctions, and biological similarities between members of the human species far outweigh the differences. Saini agreed that some biological differences do exist, but she urged the scientific community to challenge their own biases when conducting research. By establishing solid hypotheses and rigorous controls, we can debunk the divisive myths of gender and race science. This would, undoubtedly, benefit the population as a whole SB

"Essentially, whilst some scientific research inappropriately hallmarks race- and sex-based distinctions, biological similarities between members of the human species far outweigh the differences"

The Uninhabitable Earth - David Wallace-Wells

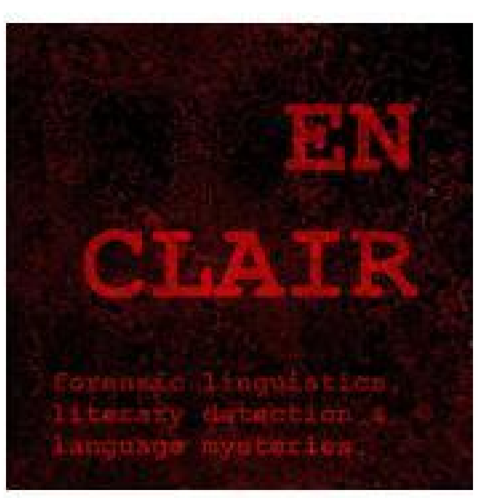


Penguin 2019

If the opening line "it is worse, much worse, than you think" of David Wallace-Wells' *The Uninhabitable Earth* is not enough to get you thinking about the threat of climate change, the rest of his powerfully blunt and often terrifying writing will. Wallace-Wells walks us through the twelve 'Elements of Chaos' we will encounter as a species if current carbon emissions are not brought under control. Whilst his relentless delivery of facts meticulously collated from scientific studies is at times distressing to read, it feels necessary in sight of the current climate emergency. Covering a range of subjects from drought, increased disease burden and economic collapse, the first section of the book outlines the fragility of the systems upon which we so heavily rely. In the latter part of the book, Wallace-Wells takes a slightly more political stance, detailing his opinions on capitalism and ethics. This political turn may not be of interest to everyone but the unflinching descriptions in the first section more than make up for it. Although the book does not offer us detailed solutions to the crisis, the bleak picture Wallace-Wells paints of a world forever changed by our actions is almost definitely a wake-up call for all of its readers HW

"Whilst [the author's] relentless delivery of facts meticulously collated from scientific studies is at times distressing to read, it feels necessary in sight of the current climate emergency"

En Clair - Adam Rodman



@DrClaireH 2019

En Clair is a podcast which blends together language and true crime to explore the little-understood world of forensic linguistics. Each episode gives an accessible and fine-grained analysis of the role played by language in various crimes, mysteries, and code-breaking endeavours. The wide range of topics ensures each episode is uniquely interesting. Some of the areas covered include the Yorkshire Ripper, the Pendle Witch Trials, and the infamous diaries of Belle de Jour. The narration is delivered by the insightful, and very funny, Dr Claire Hardacker, a linguist at Lancaster University. The scripts are detailed and nuanced, with *Case Notes* posted alongside each episode containing sources cited and materials for further reading, should the listener want to dig a little deeper into the cases discussed. Available on most major podcast streaming platforms, *En Clair* has just finished its first season, consisting of 15 episodes. The second season is currently under construction and will hopefully contain as gripping a series of language mysteries as the first AD

"...the areas covered include the Yorkshire Ripper, the Pendle Witch Trials, and the infamous diaries of Belle de Jour"

Locked Out of My Own House

Anna Serrichio looks into overcoming language difficulties in aphasia

Imagine having a conversation with a friend about something on your mind when suddenly you can't find the words for what you want to say. Similar to forgetting where you saved a file on your computer, you know exactly what you're looking for, but you just can't remember how to access it. Anomia, or the inability to recall words, is the defining feature of aphasia, an acquired language disorder commonly resulting from left hemisphere stroke.

Different forms of aphasia vary in the extent to which different language skills are affected: fluent, or receptive aphasias mainly impair a person's language comprehension, while nonfluent, or expressive aphasias mainly impair a person's language production. Different forms of aphasia also vary in the forms of errors they cause in each individual. These can be semantic (related to meaning), phonemic (difficulty with pronunciation), or neologistic (using made up words), to name a few.

Despite these variations, all aphasias selectively affect a person's ability to functionally communicate with others. Since language is such an important aspect of our lives - allowing us to navigate the world and connect with others - the loss of language can be devastating for people affected by aphasia. Impairments in the ability to express ourselves can lead to feelings of isolation and disconnection, in addition to impacting our sense of identity. "When you can't find a word," writes stroke survivor Lauren Marks about her experience with aphasia, "it's like you are locked out of your own house".

The brain's plasticity often allows the neural pathways supporting language to be recovered through repeated exposure and practice at home along with speech therapy. However, communication is highly complex. Language production requires the ability to retrieve words and use them to form sentences, while language comprehension requires understanding the meanings of words, phrases, and sentences. Which aspects of language should be targeted to best support individuals and provide them the tools they need to express themselves? What strategies should be used to support learning and recall over time? Recent research in Speech and Language Pathology has focused on finding effective approaches for treating specific language deficits in individuals with aphasia and enabling them to communicate with others more effectively in their everyday lives.

Since words are the basic units of meaning in language, and because the primary deficit of aphasia is anomia, many treatments have focused on supporting effective word retrieval. Semantic Feature Analysis (SFA) is a treatment based on the lexical retrieval theory that once a concept is activated, related semantic features are also activated, resulting in spreading activation to other concepts with shared semantic features. If you hear the word "apple", for example, you might also think of "fruit", "red" and "banana". SFA involves asking individuals to name features of a target object. How big or small is the object? What color is it? Where can you find it? Is it something you eat? What does it do? By generating features related to the target word's function, use, appearance, and related properties, people engage in a deeper semantic processing that facilitates word retrieval over time. This can sometimes carry-over to facilitate word-finding of new words that haven't previously been targeted during treatment.

The use of SFA also teaches individuals a helpful strategy for overcoming breakdowns in communication when they are unable to recall a specific word through what is known as circumlocution. This refers to the use of descriptions to communicate an idea. If you cannot think of the word "tiger", for example, you might say "a big cat with stripes that roars". Although circumlocution is generally an inefficient means of communicating something, it can provide an alternative way of overcoming communication blocks when people feel stuck and unable to express themselves. If the inability to remember a word locks you out of your own house, circumlocution is like finding a different way in through a basement door or window. It also emphasizes the importance of persistence in the recovery of language abilities, reminding people who struggle with verbal expression that their determined efforts allow communication to still be possible even during moments of difficulty, and that the imperfect use of words is better than not using any words at all.

Effective language production depends not only on the ability to retrieve words, but to combine them appropriately to form sentences by following the language's grammatical rules. Expressing relationships between entities, such as cause and effect or changes of state, involves following correct syntax in addition to using the right words. (Consider the difference between 'The dog chases the cat' and 'The cat chases the dog', or why the sentence 'The teeth brush the dentist' does not make sense). Expressing such relationships by increased lexical retrieval of verbs and improved argument structure is the main focus of an approach known as Verb Network Strengthening Treatment (VNeST).

In this treatment, individuals are asked to generate agents and patients for a given verb, creating verb phrases that follow the subject-verb-object sentence structure in English. For example, given the verb 'measure', different agents and patients can be used to create sentences such as 'The baker measures the flour' and 'The carpenter measures the wood'. Verbs prime semantically related words (for example, the verb 'sweep' can readily trigger the noun 'dust'). Individuals then expand on their verb phrases by answering different wh- questions (e.g. Why was the baker measuring the flour? Where was the carpenter measuring wood?). This is thought to further activate the semantic network related to that verb, helping people improve their word-finding and sentence structure.

SFA and VNeST are just two examples of a multitude and variety of aphasia treatments that are currently being researched and implemented in various clinical settings to help people with aphasia in their rehabilitation. Other approaches have facilitated language recovery through emphasizing different modalities, such as incorporating spelling to support reading and writing, and practicing pronunciation of words to improve speech. Just as every house has a different lock requiring its own key, each individual will require a personalised strategy. Hopefully, by using a combination of approaches, speech and language pathologists can equip individuals with aphasia with the tools required to communicate with others and more comfortably navigate the complex fabric of language that permeates the world

Aphasia is inability, or impaired ability, to understand or produce written or spoken language, as a result of brain damage. It is most commonly caused by stroke

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Anna Serrichio is a Speech and Language Pathologist at NYU Langone Hospital. Artwork by Rita Sasidharan

A Look at the Modern Interactions between Humans and Crops

Eleanor McCartney highlights the importance of agrobiodiversity in our changing world

THE RELATIONSHIP BETWEEN humans and the plants we cultivate is complex. Plants helped make humans as we are today, and in return we have picked and adapted them to suit our needs by making use of their genetic diversity. Right now, we rely on plant foods to provide about 80% of our calories directly, as well as to feed livestock. In the wake of an expanding human population and climate change, our ability to preserve and foment crop diversity will thus determine the future of human survival. However, changes over the past century have led to an increase in crop production, but a decrease in crop varieties. Once lost, this genetic diversity cannot be recovered. To understand what can be done to ensure a healthy future for humans through resilient crop production, we can look at how this intricate relationship - between humans and our crops - began.

When Africa shifted from dense forest to grassland millions of years ago, hominids adapted and began walking upright, cooperating to hunt and gather food. As they became more intelligent and started using tools, there was an increase in the number of different plants they could eat. There is evidence that 15,000 years ago humans consumed a broad range of plants, including grasses, legumes and pines. About 10,000 years ago, humans started domesticating some of these plants and for the following millennia, continued to place them under selection pressures until they became unrecognisable from the wild plants. A wild plant might be favoured by dispersing its seeds widely, whilst the opposite is true in crops and so they became easy to harvest. Domestication was dependent on the genetic variation of plants, and as Darwin wrote in The Variation of Animals and Plants Under Domestication, "if organic beings had not possessed an inherent tendency to vary, man could have done nothing".

In the 1960s, the explosive growth of the human population led biologists to predict a mass starvation, believing that population growth would outpace agricultural growth. In the 1968 book The Population Bomb, Paul Ehrlich predicted that over four billion people would die from widespread famine by the 1980s. However, the development of high-yielding crop varieties by research organisations such as the International Maize and Wheat Improvement Centre and the International Rice Research Institute (IRRI) - as well as the increased use of fertilisers, pesticides and modern irrigation techniques - drove a critical increase in agricultural production. Changes in diet followed. With the increased production and the introduction of an international crop trade, anyone could access crops from all over the world. Yet, the world's reliance on these high-yielding crop varieties has come at a cost: the loss of our crops' genetic diversity. Farmers have specialised on a narrower number of crops and cultivated fewer traditional crop varieties. For instance, since the commercialisation of apples, the United States of America has lost over 80% of its apple types. India's cultivated rice varieties have dropped from 100,000 in the twentieth century to less than 10,000 today. This global phenomenon is exacerbated by the fact that the majority of crop production is used to feed livestock which may eat a very narrow diet.

Cultivating and preserving genetically diverse crops can help us mitigate modern problems such as deforestation and, ultimately, climate change. A 2014 meta-analysis by Klümper and Qaim found that adopting genetically modified crop varieties led, on average, to a 22% yield increase. Indeed, cultivating crop varieties such as those resistant to pests can increase the productivity of a field and requires less pesticides, thus altogether reducing the amount of resources and land required for the same crop yield. Using crops of this type could reduce deforestation at no yield cost, and indirectly help us reduce our carbon footprint by ensuring that CO_2 absorbing forests remain intact.

Whilst we can hope to limit climate change, it is critical that we develop crop varieties that can cope with higher temperatures, reduced water access and other environmental extremes. Environmental conditions are predicted to change faster than crops are able to naturally adapt. One rice variety, 'scuba,' released in South East Asia, can withstand complete flooding for two weeks. This was produced by IRRI in the Philippines, using an Indian landrace gene. IRRI stores over 130,000 accessions, or types, of rice which allows them to harness the power of diversity. Nevertheless, breeding new varieties can take up to ten years, making this an urgent task.

Such breeding projects rely on conserved genetic diversity. There are two distinct but complementary agrobiodiversity conservation strategies: *in situ* and *ex situ* conservation. *In situ* conservation involves traditional farmers continuing to grow the crops of their ancestors in the field, while *ex situ* conservation primarily involves the mammoth task of collecting varieties of crops and related wild species and keeping them frozen and dried in genebanks. These genebanks work at a worldwide scale, providing each country and region with the domestic and international resources they require. The Food and Agriculture Organization of the United Nations estimates that two million unique accessions are conserved *ex situ* in over 1,750 facilities. In 2004, the Global Crop Diversity Trust (Crop Trust) was established to recognise their importance and permanently support worldwide conservation and supply efforts.

The ultimate back-up genebank is the Svalbard Global Seed Vault, built deep inside the permafrost of Spitsbergen, a Norwegian island. Seeds are only taken out of the Vault in emergencies. One such emergency occurred in 2015 during the Syrian Civil War, when the International Center for Agricultural Research in the Dry Areas (ICARDA) formerly based in Syria was forced to relocate. ICARDA retrieved their seed duplicates from the Vault in order to re-establish their Syria-based collection in Morocco and Lebanon.

The UK is home to the largest and most genetically diverse collection of wild plant species in the world, the Millennium Seed Bank, coordinated by the Royal Botanic Gardens, Kew. Recently, Kew and their partners have been gathering the wild relatives of the World's 29 major crop species. Not only do these wild plants possess unique traits that could improve crop hardiness, but they are also at risk of going extinct. These missions are currently a race against climate change, with 22% of these wild plants estimated to go extinct by 2055.

Humans are dependent on natural genetic variation, especially in crop breeding, to survive environmental changes. The problem is that we do not know exactly which food security challenges we will face in the future, so we need crop diversity as insurance. The amazing genetic diversity that has evolved over millennia cannot simply be rebuilt by modern genetic modification techniques, and we cannot reverse the loss of genetic diversity from the last decades, but we can preserve what remains. With the establishment of the Crop Trust, the world recognised the need for crop diversity conservation and put this into organised action. However, much more remains to be done. As individuals we can support agrobiodiversity by eating less meat, cooking with diverse ingredients, going to farmers' markets and looking for seasonal produce, as well as asking supermarkets to stock more varieties of fruit and vegetables. Ultimately, we should care about our food. After all, if we do not take care of our plant species right now, they will not be able to take care of us in the future

Eleanor McCartney is a genetics PhD student at Pembroke College. Artwork by Eva Pillai

Small-scale plant cultivation may have begun as long as 23,000 years ago, while large scale cultivation is more commonly thought to have begun 12,000 years ago in an area that now comprises Iraq, the Levant, parts of Turkey and Iran

Trash Talk: Tackling Waste in Science

Ruby Coates discusses the issue of plastic waste in science with sustainable labs co-ordinator **Martin Howes**

The issue of plastic waste is one that affects every single one of the 7.7 billion people on Earth, as well as the countless other species that we share our planet with. Globally, 380 million tonnes of plastic are produced yearly, with approximately 8 million tonnes of plastic entering the ocean each year. This problem was brought to public attention in the landmark 2017 series "Blue Planet II" narrated by David Attenborough, bringing about a change that has since been dubbed as the "Blue Planet" effect.

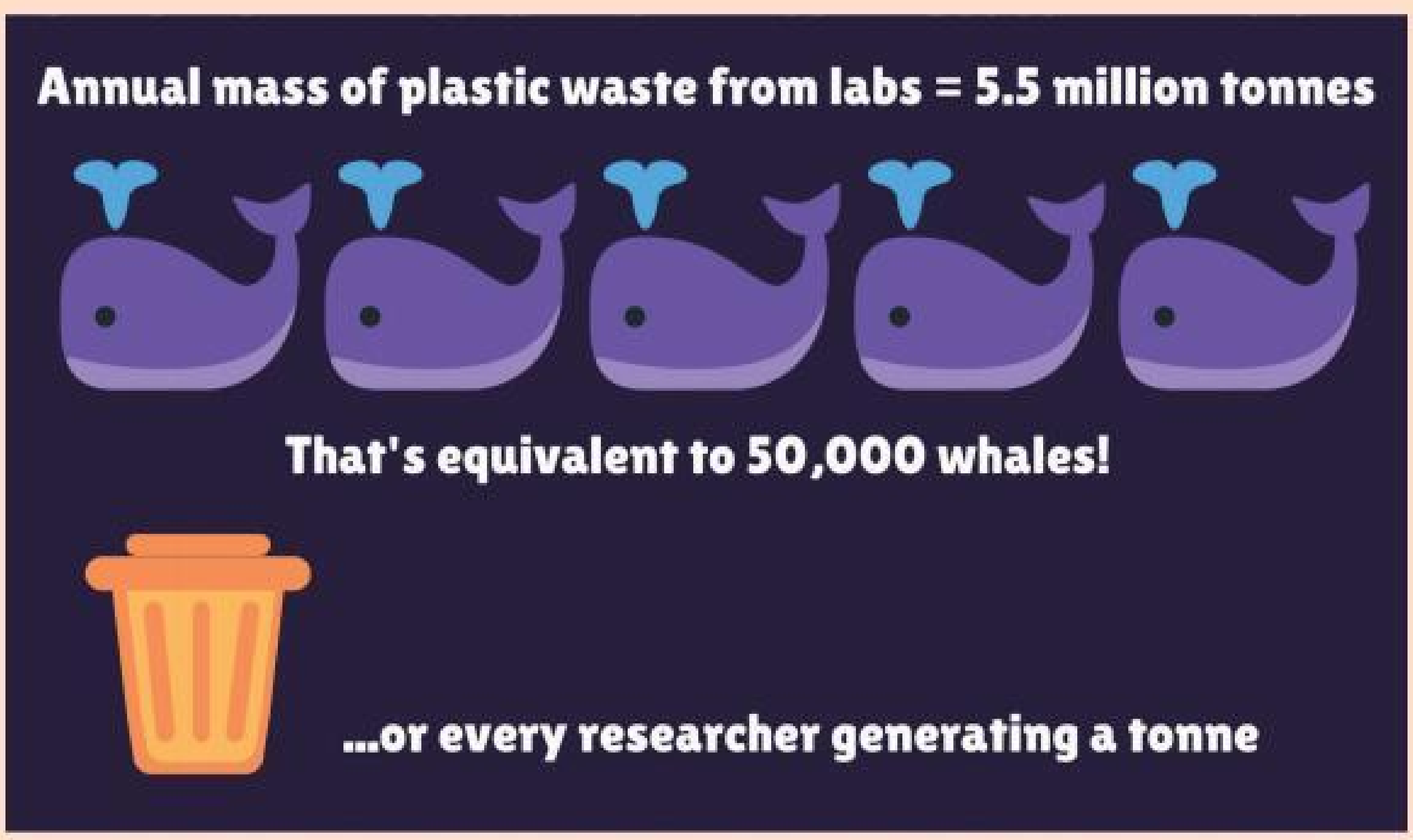
Raising awareness about where our discarded plastic ends up has spurred huge efforts at individual and societal levels, both aiming to reduce the amount of plastic we use. Aside from public plastic use, eyes are now turning to how waste is managed within scientific research. This is especially true in the biological sciences, which is arguably the biggest offender when it comes to single-use plastic.

As a researcher in biosciences, I display a remarkable difference in behaviour between my home and working life. In the morning at home, I diligently rinse out my yoghurt pot before dropping it into the recycling bin, carefully fill my reusable water bottle and tuck my reusable shopping bags into my rucksack. The moment I step into the lab, everything turns on its head. I use multiple pairs of nitrile gloves at least every few hours and hundreds of plastic pipette tips, petri dishes and tubes, all discarded after a single use. In biological labs, sterility is key, at the expense of everything else. Plastic allows a convenient, cost-effective and safe way to complete biological research and also minimise chances of contamination. Unfortunately, due to the hazardous nature of this waste, very little of it can be recycled. Whilst the scale of plastic disposal has become commonplace for people who work in labs daily, it would likely horrify any outsider.

In fact, researchers at the University of Exeter estimated that 5.5 million tonnes of lab plastic waste are generated per year in medical, biological and agricultural research – equivalent in weight to nearly 50,000 blue whales. When broken down to an individual level this equates to nearly a tonne of plastic waste generated per researcher every year. Considering these numbers, it is clear that plastic waste needs to be tackled from the lab bench all the way up to an institutional level.

Waste management is taken very seriously at the University of Cambridge, with a dedicated Green Labs initiative to encourage researchers to actively reduce the environmental impact of their research. Speaking to Martin Howes, Sustainable Labs Co-ordinator for the University of Cambridge, it is clear that plastic is on the minds of many scientists. "Particularly in the last six months I've noticed an increase in enquiries from lab users across the University (…) to find out what they can do to tackle the excessive plastic waste being generated by their research," says Martin.

According to Martin, what matters is how bioscientists can reduce the amount of plastic they use whilst simultaneously working in an efficient, cost-effective and sterile manner. One approach we discussed is the switch from plasticware to glassware. Recently, University College London and the University of Leeds have launched initiatives to reduce the amount of single use plastic in laboratories by phasing out single-use lab plastics and encouraging the use of alternatives such as glass petri dishes and culture flasks which can be cleaned, sterilised and reused. Similarly, the Tobacco Exposure Biomarkers lab in the Centre for



Disease Control in the USA has implemented a new strategy that involves washing and re-sterilising used pipette tips. The strategy has resulted in the reuse of 60% of the 11,000 pipette tips used by the lab weekly.

Aside from reducing and reusing plastic in the lab, Martin explains that researchers can also take advantage of several take-back schemes offered by suppliers such as those for polystyrene boxes, which are used to protect temperature-sensitive deliveries. An internal study conducted by Cancer Research UK (Cambridge Institute) found that the institute processed 16.5 m^3 polystyrene each month. This in turn drove an impressive effort to return as many polystyrene boxes as possible back to suppliers whilst promoting reuse within labs.

Martin points out that another simple way of reducing plastic waste in the lab is to opt for products from companies who are actively reducing the amount of their packaging as well as volume of plastic in their products. Indeed, the choices bioscientists make as consumers have the power to push suppliers to design products that generate less waste. One example includes DNA and RNA preparation kits from New England Biolabs, which now use up to 44% less plastic than their competitors. Encouraging plastic-conscious purchasing within the lab will make an impact, especially considering that active bioscience labs make multiple outgoing orders every day.

The nature of Martin's role as Sustainable Labs Co-ordinator means that he is often in direct contact with suppliers about the issue of plastic waste and sustainability. "Overall, suppliers do appear to be waking up to this issue. It is a mixed bag, but I am encouraged that many are now responding positively to the increasing environmental demands of their customers. It is up to us as consumers to maintain this pressure and make sure that suppliers pay more than lip-service to these issues."

In light of this, some suppliers have even begun developing biodegradable products that can be used in laboratories. For instance, nitrile gloves from the company SHOWA have been shown to biodegrade within five years. Whilst such products would be difficult to introduce into hazardous laboratories where contaminated gloves require sterilisation, those with less stringent safety requirements could adopt products such as these.

It seems that plenty can be done to reduce plastic waste in labs, but Martin points out that some of the solutions may come with their own set of issues. For example, due to the increase in single-use plastic in laboratories worldwide, resources including glassware washers and personnel to run and maintain them are likely to have been minimised. Reversion back to a greater reliance on glassware would require a significant amount of reorganisation and investment, especially in newer institutions that may not have the infrastructure to support such a movement if executed on a large scale. Also, the amount of energy and water required to clean and re-sterilise reusable resources must be factored in. Similarly, although take-back schemes including those for polystyrene boxes allow a second or even third life for the containers, it is important to bear in mind the environmental cost of fuel for the delivery of empty boxes back to suppliers as well as the work that is necessary to determine if the boxes are fit for reuse.

Martin therefore believes that initiatives to reduce plastic use in the lab need to be carefully designed to ensure that high quality research can be carried out at the lowest cost to the environment. He adds that sustainable research doesn't just end at plastic waste. "There is a lot of work that must be done on improving the sustainability in lab practices. Lab spaces are extremely energy and water intensive. Increasing utility use efficiency in our labs is vital if we are to meet our carbon reduction obligations as a University" Martin says. "The threshold of what is considered the acceptable direct cost of research to the environment [is] shifting" β

Ruby Coates is a microbiology PhD student at Darwin College. Artwork by Lisha Zhong

If you are interested in increasing the sustainability of your lab, please visit: www.environment.admin.cam.ac.uk/green-labs

Charting the Skies, Land and Seas

James Craig reviews the history of map making

Over 2600 years ago, the Babylonians crafted the Imago Mundi, a clay tablet depicting the first map of the world. Flash forward to the modern day, and humanity's fascination with cartography — be it sea-weathered scrolls leading to unforetold treasures or Google Maps simply pointing us in the direction of our next coffee — has shown little signs of waning. Be it motivated by war and the struggle for power, by the search for wealth and resources or by the human passion for exploration, charting our place in the universe has been a mainstay of cultures the world over. Progress in science and technology has not only seen the accuracy of charts improve, but also fuelled a huge growth in their scope. Geologists can now map rock units to look at the world beneath our feet while astrophysicists fervently look outwards to develop increasingly detailed atlases of the cosmos. Elsewhere, scientists have begun exploring the structures of the deep ocean, a domain that, though part of the Earth, so often seems to belong to a whole other planet.

Charting the Heavens

The Earth's surface was not the first area to be mapped. This honour is rather afforded to the heavens. Cave paintings of constellations and other celestial objects were first produced over 17,000 years ago in Eastern Europe. Indeed, humans had been speculatively creating images and models of the cosmos long before Galileo's development of the telescope unlocked the heavens to human exploration. However, it was only in the 16th century that the charting of the skies flourished into a useful tool that shed real light on the universe and its formation. At that time, Flemish polymath Gerardus Mercator crafted the map of the world most familiar to us today. He followed the formulation of his mathematical projection of the globe by attempting to produce a map of the cosmos, and coined the term 'atlas' in the process.

Not unlike those 16th century pioneers and many before them, astrophysicists today seek to understand the creation of the universe via the mapping of the cosmos. Charts illustrating the distribution of dark matter, the cosmic microwave background and even simply the shapes of galaxies and nebulae help to rationalise otherwise overwhelming problems and gradually lift the curtain on underlying physical processes. Just this year, researchers at the University of Warsaw were able to make use of the light from distant but incredibly bright pulsating stars called cepheids to develop a model of the galaxy. This model surprisingly suggests that the Milky Way is in fact not the flat disc shape it was believed to be, but rather a disc warped into an S shape. Such warping suggests the Milky Way may have interacted with other smaller galaxies or perhaps with dark matter in the past.

Looking Inside the Earth

Science has not only allowed mankind to look outwards; with the use of new technology, geologists are becoming increasingly able to chart the structures and patterns beneath our feet. To learn more about how mapping has aided our geological understanding, I spoke to Dr Owen Weller, a lecturer in the Department of Earth Sciences at the University of Cambridge who has been involved in mapping projects with the Geological Survey of Canada. Weller explains that maps are crucial for yielding context from observations, allowing patterns to be identified and links to be made across both time and space. For example, his recent work mapping Baffin Island can be linked to phenomena as tangible as present-day processes in the Himalayas or past processes as ancient and elusive as the origins of plate tectonics.

When asked about what has changed since the first geological map of Britain, made just over 200 years ago, Weller praises GPS technologies and computer software for improving mapping accuracy. Both advancements allow for increasing location precision and the compilation of larger datasets. To fully understand and interpret the deeper structures from a surface map, a sequence of ages must be known. Weller explained: "To make maps most useful, geochronology is required. A seminal moment in mapping was the development of radiometric dating to place absolute age constraints on rock assemblages". Though it does not particularly aid the creation of maps, absolute dating hugely enhances geologists' interpretation of them. Dating reveals to geologists the order in which rocks were formed - essential information if one is to truly understand the geological events of the past. Looking to the future, Owen suggested that space-based geophysics and remote-sensing will be key tools in the mapper's arsenal as both allow for huge areas to be mapped quickly and efficiently through satellite observation. Despite all these changes, Weller keenly points out that ultimately, field geologists cannot be replaced, as direct observations will always be fundamental to mapping. Geological mapping can't get far without a hand lens and a hammer.

Besides being a tool for geographical exploration, geological mapping is also, perhaps more importantly, a valuable tool for assessing hazards and resources. Orientations of fault lines and the structures in bedrock can, via the use of a map, be analysed over a huge area to locate likely sources of mineral ores or to assess the likelihood of a seismic event in an area. Although often popularly perceived to have had its heyday, geological mapping is in fact still a hugely relevant discipline as the Earth becomes increasingly depleted of energy resources and as construction projects are undertaken in new and bold locations.

In the past century, geoscientists have begun to build up a picture of not only the rocks on the continents, but also those beneath the ocean. Such is the elusiveness of the seafloor, that in many locations we have a better understanding of the topography of Mars. The first bathymetric mapping endeavour was undertaken in the early 20th century using 'echo sounding', a technique which uses the reflection times of transmitted sound pulses, and the speed of sound in water (~1500 m/s) to calculate depth. Paralleling geological mapping, advancements in GPS and the onset of data-compiling software has allowed a great increase in accuracy since these early experiments, allowing for highly detailed models of the seafloor surface to be produced.

One such modern and highly accurate method to be employed is Airborne Laser Bathymetry (ALB). ALB uses short pulses of light to measure distances. Such a method can be carried out from an aircraft, allowing for research to be conducted at a much greater pace than sound wave-based mapping which takes place from sea vessels. The detailed models produced give an insight into ocean processes for physicists, geologists, chemists and biologists alike. For example, bathymetric data along the mid-Atlantic ridge is used by geologists to track the movements of the continents and was key evidence in support of the theory of continental drift. This type of inference from ocean depth to plate tectonics is a wonderful example of how mapping helps reveal patterns and improve human understanding of otherwise impenetrable systems. Ocean depth is also intimately linked with the local ecosystem, since temperature, light level and nutrient concentration dictate an environment's habitability. Biological oceanographers therefore use bathymetric surveys to predict where fish and other organisms will live, breed and migrate. Studying bathymetric data is vital in the midst of the climate crisis, helping scientists better understand how many facets of the Earth system are changing, including rates of beach erosion, land subsidence and sea-level rise.

Our fascination with maps spans both the distant past and the foreseeable future. Long before the development of formal written language or numerical systems, we crudely began charting the universe, smearing fantastical patterns onto cave walls and etching them into stone. Today, technological advancements have transformed cartography into a fundamental tool for making sense of the physical world at various scales, from the depths of the oceans to the heights of the heavens. Beyond this, science and technology have totally transformed the scope and detail of cartography, offering these fields a perfect synergy. We have created ultra-precise maps of Antarctic ice sheet topography and developed cosmic "hotspot" guides pinpointing the remnants of exploded stars. The question is: Where will exploration take us next?

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A medieval recreation of the first semi-accurate World map. Ptolemy, who produced a map of the World from the perspective of Hellenistic society in about 150 AD, in his work Geographia

Our Place in the Universe

Maeve Madigan, Philip Clarke and João Melo explain the central concepts behind the 2019 Physics Nobel Prize. The first half of the prize, awarded for the detection of a planet orbiting a star like our own, teaches us about our cosmological neighbourhood as it is today. The second half, awarded for research on the understanding of our cosmological history, teaches us about where the Universe as we know it came from

Our night sky is speckled by starlight. A rich pattern is formed in our field of view by light that has travelled from distant stars in our galaxy and beyond. Yet, sometimes it is the surrounding darkness of space that draws our curiosity. An exoplanet, a planet orbiting a star outside of the solar system, does not emit its own light. In fact, even starlight reflected from the exoplanet does not provide a clear signal: the exoplanet is completely overwhelmed by the star and appears billions of times fainter, effectively hiding from us in the dark night sky. There is more to this apparent darkness than meets the eye.

We know our place in the universe is not a lonely one: from the gas giant of Jupiter to the small rocky Mercury, we share our Sun with a diverse range of planets. Who is to say that such planets cannot exist elsewhere? Until the 1990s, the detection of exoplanets was hindered by our inability to observe them directly. This changed with the development of indirect detection methods. These asked: if we cannot see exoplanets, can we infer their existence from their effects on neighbouring stars? By answering this question astrophysicists have begun to unveil, one by one, the numerous planetary inhabitants of our rich and busy galaxy.

How can a small exoplanet have a significant enough effect on their neighbouring star that it can be detected here on earth? Although we may think of the force of gravity as pulling the exoplanet into orbit around the star, the star feels an equal pull from the exoplanet. The result of this force is to induce a small variation in the motion of the star, producing a periodic 'wobble'. Each stellar wobble coincides with an orbit of the exoplanet. If we can measure this motion and how often it occurs, we can learn something about the existence of an exoplanet as well as its mass and orbit.

In 1995, Michel Mayor and Didier Queloz used this to successfully identify the existence of an exoplanet orbiting the star 51 Pegasi at a distance of 50 light years from Earth. Although a few exoplanets had already been detected, this was the first observation of an exoplanet orbiting a Sun-like star. This discovery provided tantalising evidence of the possibility that other planetary systems like our own may exist, and earned them half of the 2019 Nobel Prize.

Whether this planetary system was really anything like our solar system is questionable, however. The exoplanet that they found was a hot Jupiter - a large planet of Jupiter-scale mass, orbiting closer to its star than Mercury's distance from the Sun. The formation of such a heavy planet so close to the star was not predicted by existing models of planetary formation, which were based on the only example we had: our solar system. Mayor and Queloz's discovery led us to the theory that such Jupiter-sized exoplanets can form far from their star before migrating inwards to a short-distance orbit.

The news set fire to the field of exoplanet detection, bringing an influx of brand new observations. Yet, by studying only the stellar wobble, detections were limited to Jupiter-sized exoplanets heavy enough to create a noticeable variation in the star's motion. It wasn't until the launch of the Kepler space telescope in 2009 that we began to find exoplanets of our own size. Instead of studying the motion of a star, Kepler watched the brightness of the star's light. As a planet passed in front of the star, Kepler detected its transit as a slight dimming in this brightness. This method had the potential to detect the presence of planets of much lower masses, and it did: even within the 10-day trial run of Kepler, a candidate Earth-sized exoplanet was found and later confirmed. Since then, Kepler has detected over 2000 exoplanets. Among these is Kepler-22b, a milestone for astronomy: at a distance of over 500 light-years from Earth, this is the first Earth-sized exoplanet found orbiting within the habitable zone of its star.

With over 4000 exoplanets confirmed less than 30 years after the first exoplanet detection, we can confidently say that exoplanets are not rare in our galaxy. The PLANET collaboration in 2012 concluded that in the Milky Way we are more likely to find a star with an orbiting exoplanet than one without. These predictions suggest that our neighbourhood is far busier than we could have imagined.

What if we wanted to look past the Milky Way? What value is there in observing other galaxies when so much of the Milky Way is yet to be studied? This was answered as early as the 1930s, when astronomers began to study the rotation curves of distant galaxies. These curves tell us how quickly the constituents of galaxies rotate, starting from the matter at the centre of a galaxy and moving out to the galactic halo. From observations it was known that most of the visible matter is clustered at the galaxy's centre. The gravitational interactions of such a large quantity of mass, however, should lead to high velocities near this centre, while the stars positioned further away were expected to move much more slowly.

This is not what astronomers observed. The galaxy rotation curves flattened unexpectedly at distances far from the centre, suggesting that something was causing these galaxies' outer parts to move quicker than anticipated. By the 1970s enough data had been gathered to postulate that this phenomenon may be caused by the presence of additional undetected matter distributed throughout the galaxy. Among the many contributors to this conclusion was James Peebles, recipient of the second half of the 2019 Nobel Prize. The missing piece of the puzzle was dark matter. Unlike exoplanets, which appear dark next to their brightly shining stars, dark matter appears completely invisible; a ray of light passes straight through as if it were not there. This is not as foreign a concept as one might think: our own Milky Way is home to vast quantities of dark matter.

Earth is not alone in the universe - we are not even in a quiet neighbourhood. The confirmation of this simple fact has relied on decades of development of a diverse range of experimental techniques, uncovering clusters of dark matter in galaxies and planetary systems orbiting the stars in our sky. Not only are we not alone, but we are not even particularly unique. And although our place in the universe may not be as special as we would like, it is a place that provides a spectacular view of the structures that surround us. It is by looking away from our place in the universe that we have begun to truly understand it, placing it in context with the rich and exciting variety of the universe nearby.

What more can we say about this wider context? How much is there to discover, even beyond the plethora of exoplanets?

From planets, zoom out, and we see stars arranged into galaxies. Taking an even broader view, we see galaxies arranged in clusters, which are themselves lined up in superclusters, collections of tendrils. But there is an end to this hierarchy. Zoom out even further, to the point where galaxies are only dots, and we see a universe that is roughly the same from region to region, with no structure, center or edge.

Have our familiar starry skies, and these structures they're embedded in, always existed? The most successful model of the universe that we have, the Big Bang model, answers with an emphatic no. This model has been subject to rigorous and precise tests, and the successes of these tests are what gives us confidence in its grand story, a story that James Peebles played a central part in developing. This is not just the story of our place in space, but also of our place in time.

Stories have characters, and our first character is space itself. Here it has a central role, it expands. As the space between galaxies expands, the average distance between galaxies increases and the wavelength of light travelling between them stretches. In 1929, by observing the reddened light of distant galaxies, Edwin Hubble showed that this was true of our sky, and any astronomer on any exoplanet in the universe would find the same result.

After this discovery, some physicists attempted to reconcile this expansion with an unchanging universe; a steady state, whose skies were always filled with stars. This is a simple idea, but it makes concrete, testable predictions. The light we collect in our telescopes has to travel to reach us, so by looking further away, we see the universe as it was in the past. Steady state models predict that this doesn't matter. If the universe was always the same, even looking back in time, we should see a universe that matches what we see nearby.

That does not happen. An important clue leading to this conclusion was announced by Penzias and Wilson in 1965. They had discovered a mysterious radiation seemingly perfectly uniform in temperature across the sky. The uniformity meant that it had nothing to do with our sun or even our galaxy; it had to be cosmic in origin.

Enter James Peebles and his collaborators. Publishing simultaneously with the Penzias–Wilson result, they showed that a changing universe could naturally explain this mysterious radiation, unlike the steady state universe. They explored the idea that this cosmic radiation was left over from an earlier epoch of the universe, one that was much hotter and densely packed. As the universe expanded, the radiation would have cooled until it reached its current temperature of a mere three degrees above absolute zero.

The Penzias–Wilson discovery was cosmic background radiation at a particular microwave frequency. Making the simple assumption that the early epoch was in equilibrium, physicists could then make a precise prediction: they could calculate the intensity at other frequencies. This would be confirmed to spectacular precision as more measurements of this "cosmic microwave background" (CMB) radiation were made.

The early epoch they pictured, which would become known as the "Big Bang fireball", was a smooth soup. There were no stars, and even if there had been, there was no empty space for the starlight to sail through. The CMB radiation is made up of particles of light, or photons, which in this epoch had extremely high energies, causing them to strip electrons from atoms, turning the matter (that would eventually make us) into a plasma that pushed and pulled against the radiation.

The distribution of the photons and plasma was extremely uniform, but not perfectly so. Some regions started off packed slightly denser and thus had a stronger gravity, pulling the matter and radiation of nearby regions inwards. However, this gravitational collapse was halted by the compressed radiation's pressure, and the contest between the two caused the radiation to ripple with pressure waves. Another component of this primeval soup was dark matter. It had no pressure to stall the gravitational collapse of its dense regions, so instead of rippling, it began to form clumps.

Eventually, the radiation's temperature fell so low that electrons and protons in the plasma could safely combine to form neutral atoms, no longer pushing and pulling against radiation. The radiation began to travel freely through the newly transparent universe, leaving visible matter behind and releasing the CMB that we see today. Peebles, in a 1970 paper, explored the transition between these two very different eras: the first few hundred thousand years when photons could travel only very short distances (before interacting with electrons and protons), to the last few billion years, where photons can travel extremely long distances (stopping only when they collide with an astronomer, for example).

The exciting realisation was that the billions of years that have passed since that epochal transition might not have erased this evidence. The visible matter dropped by pressure waves in the earlier era seeded the formation of some of the galaxies we can see today, and could have left an imprint on their distribution. Indeed, in 2005 the SDSS collaboration presented a detection of such an imprint. Along with the measurements of the CMB, this incredible detection formed another pillar of evidence for the hot Big Bang model.

While the foundations of this story are set, there is still much more to understand. After the fireball, the formation of structure began in earnest with the first stars and galaxies. While signals of early galaxy evolution have been detected since the 1960s in the form of quasars, there are so far no uncontroversial detections of the much fainter signals of the first stars. As they first lit up the dark universe, their radiation output is thought to have left an imprint on the CMB, but this tiny signal is very difficult to extract.

Even if it is not yet on solid ground, the work of those teams aiming to detect the universe's first stars is a pioneering addition to a proud lineage of cosmological research. It is one example of modern theoretical and experimental work that continues to add to our understanding of a distant history filled with plasma, whose non-uniformities eventually seeded the galaxies, stars and planets in our familiar transparent universe. The diverse array of confirmations of this cosmic story, thanks to Peebles and many others, teach us that the humility of the steady state theory was not justified. Emerging from the exotic, mysterious, very early universe comes our place, with stars and sunlight.

We have not yet reached the start of the story...

So far we've talked about how we look at the Milky Way to find planets different from our own, and how we look away from the Milky Way to probe even further back in time, up until the oldest light, the CMB. If this is the oldest light, how can we go further? It turns out imagination is quite powerful, and although we can't physically see it, we can use our minds to find traces of what came before the CMB.

The main idea behind the "Big Bang Model" does not surround some mystifying point in time where everything came from (you may have heard the word "singularity" thrown about) but something we have already explored: in the past the universe was denser and hotter. Therefore, the radiation floating about was so energetic that, right before the CMB was formed, it could rip the electrons out of an atom.

What if we push this idea further back? Surely there must have been a time when the universe was *so* hot that the photons could even rip a nucleus apart. We are talking of temperatures around 10 billion Kelvin (energies of about 1 MeV), nearly 300 thousand years before the CMB was emitted.

If we start here and run time forward we should see the first nuclei, i.e. the first elements being formed. This is what Peebles called the primeval fireball. And yes, this is the same Peebles as before, an instrumental figure in our understanding of the universe once again. Let's see how the story goes.

Initially there were protons and neutrons floating about in space interacting with each other and the radiation. At these temperatures/energies, protons and neutrons are spontaneously converted into each other; everything is in equilibrium.

After a while, a small instability builds up. The thing is, neutrons are ever so slightly heavier than protons, and, because $E=mc^2$, this means it costs slightly more energy to make a neutron than a proton. If the universe is hot enough this doesn't make a difference because the photons lying around can easily provide that excess energy. But, as the universe expands and cools down, this starts to matter and the number of neutrons starts decreasing. The cosmic clock is ticking fast, and in 15 minutes there won't be any neutrons left, which is a huge problem because we need them to build up nuclei. Once inside a nucleus they can sit happily, safe from decay.

So what do we need to form a nucleus? Well, the simplest thing we can do is form Deuterium, which is just a neutron and a proton stuck together, a heavier version of Hydrogen. By itself, Deuterium is not very useful, but it can be used to form Helium-4 (which has 2 protons and 2 neutrons), and from there we can go on to form heavier elements in a chain reaction (to form elements heavy enough to make up planets we actually require stars but that's a story for another time). Going from Deuterium to Helium is practically instantaneous.The real challenge is forming enough Deuterium in the first place.

You may think that all we have to do is wait until the photon's average energy is low enough that it won't break Deuterium apart. This would occur at around 5 minutes in. However, there is an important subtlety: there are A LOT of photons. Roughly, we have about 10 trillion photons per matter particle so even if the average is quite low, there are still quite a few sneaky outliers that could ruin everything, meaning we need to wait 10 minutes so not even a sneaky outlier can destroy our Deuterium nucleus. After that, there were still enough neutrons to make 1 Helium nucleus for every 3 Hydrogen nuclei in the universe. Actually measuring these abundances is extremely hard. The first few measurements were made in the 1960s. They have since been continually improved upon. And lo and behold, within experimental error, they agree with the theoretical prediction.

Notice how delicate a balance this is. We have the weak interaction controlling the decay of neutrons, the strong interaction controlling the energy difference between protons and neutrons and the energy required to produce Deuterium, all alongside gravity to control the expansion of the universe. Had any of these forces been different this balance would change quite dramatically. It is an astonishing consistency test of all these disparate areas of physics, a test we have passed with flying colours.

Alright, we've gone past when the first nuclei formed, surely this is it, right? We can't possibly go further back than this. In fairness, there are a few things we can infer from carefully looking at the CMB and the galaxy distribution about what happened at even earlier times, but no direct measurement. We can only explore this level of energy by smashing things together at incredibly high speeds, as we do at the Large Hadron Collider (LHC) in Geneva, Switzerland. So what do we expect?

At some point, the universe gets so hot that even protons and neutrons are ripped apart into their constituent quarks. Not even the strong force is strong enough to beat these photons at approximately 1 trillion Kelvin (~100 MeV). The hot soup that's formed goes by the name of quark-gluon plasma and it has been successfully recreated at the LHC.

Going even further back in time, the temperature is so high that the Higgs boson "melts" and can no longer do its job of giving mass to the fundamental particles. At this temperature of a quadrillion Kelvin (~100 GeV) every particle we know and love is massless, so they behave more like radiation than actual matter. The universe sure does look different from what we're used to.

Now this is definitely it. Beyond these energies we haven't tested our theories so we can't know if they stand or not. But, come on, aren't you curious to see what they say? At some point in the past the density and temperature of the universe becomes infinite! People called this the "Big Bang" and interpreted it as the beginning of time. You may be extending theories beyond their validity (and you should be), but the singularity seemed to always 'appear' when making a priori reasonable assumptions such as the existence of normal matter. The real problem was that this "Big Bang" does not fit the data. Now what most physicists believe is that there was some phase of extremely accelerated expansion called inflation, whose precise details are still a matter of heated debates.

One beautiful aspect of the idea of inflation is that it provides an origin for the tiny non-uniformities we mentioned earlier. In this story, these non-uniformities are actually quantum fluctuations that get stretched by extreme expansion, in turn seeding the gravitational collapse that begins our journey from a featureless universe to stars, galaxies, planets and exoplanets, and eventually humans to wonder at our place in it all

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Maeve Madigan, Philip Clarke and João Melo are PhD students studying theoretical physics in the Faculty of Maths. Artwork by Marzia Munafò

The Other in Science Fiction

Alex Bates and **Billy Gyngell** ask why we see too many hominids in science fiction

Browsing science fiction in Waterstones is a disorienting experience of fantastical covers and strained blurbs, but in examining them one finds a greater degree of similarity than one might expect of a genre that tries to unfetter the human imagination. There are a lot of Imperial galaxy-spanning civilisations, for example. A lot of wormholes and lasers. Not a few malevolent artificial bits of intelligence. And the alien biological intelligences we encounter tend to be rather human-shaped.

Why does the unimaginable look so recognisable? Let us say a Martian cylinder has landed in a field outside of Woking, Surrey. You rush to the scene. Would you be more or less struck to find that it disgorged smooth green 'Roswell aliens', or H.G. Wells' grey-ish hulks the size of a bear with tentacular mouths? It might not be at the top of your mind just then, but it would be profoundly odd if the evolution of non-Earthly life developed into something that looked like us. How far can the convergent evolution card stretch: Is it not strange that organisms that have developed in very different gravities and pressures, turn out to be human-sized? Should alien language resemble that of humans? Should they have a similar sense of morality? Heliocentrism may have replaced the Geocentric Model of the Universe, but the idea that we are at the centre of things seems to have never left our imaginations. If other life exists, then it will look and sound like us. Intergalactic hubris.

It is, of course, not so odd that writers come to converge on some shared concept of biological normality, even when evolution would not. This is because it is easier to build relatable characters for human audiences if you inject them with humanity. On-screen, it has historically been easier to costume-up hominid aliens than anything too exotic, not least for actors' comfort, and after excessive CGI use in the noughties and early 2010s, rubber-forehead aliens are back in fashion. Different media also require different levels of humanity in their characters. Cinema most often romanticises the human condition and requires humanness to visually connect with an audience, while video games feed of the strange and dramatic to excite and challenge players. Using human-like entities that differ in strange ways can also set up an uncanny valley situation, which might play better into the horror - e.g. *The Thing* - or empathy a writer is trying to summon. The classic Sci-Fi horror *Alien* has a vaguely humanoid figure kill the Nostromo's crew. The near-humanness of the xenomorph lends it greater terror, because the viewer gets the sense that its is not just satiated but gratified by its kills.

We can try to make sense of overly hominid universes even when their writers do not themselves provide us with an explanation. The Hominid Panspermia Theory, posited by *Discovery* magazine and made explicitly in universes like that of *Mass Effect,* supposes that in science fiction, humans or a precursor hominid species are the seed from which most other intelligent life forms emerge. Therefore, 'aliens' appear as distant cousins with slight cosmetic and cultural variations. This is the unwritten backstory to most of science fiction, and you can assume it to be the case unless told otherwise to ease any evolutionary qualms. Humans are the vermin-race of the stars; they are very fecund and never more than five klicks away.

Though this theory can provide a scientific basis for unexplained humanness, does the genre as a whole suffer from a poverty of imagination? A lot of mainstream Sci-Fi is rather swashbuckling. Humans are rarely the invaders, and if we encounter other beings it is under the guise of knowledge and adventure, or in the case of the *SS Enterprise*, to boldly go where no man has gone before, innocently spreading Judeo-Christain Values and Kirk's STDs across the galaxy. A military-industrial complex is a central premise for one of the most successful science fiction properties of all time; *Star Wars*. Even a long time ago, in a galaxy far far away, the worlds and creatures that inhabit them look and fight like us. The galaxy is ruled by a democratic senate, there is organised crime, a fascist regime and so on.

Like fantasy, Sci-Fi is a theoretically lawless genre, and yet it adheres to internal rules and structures easily recognised by its fans. Alien planets often have marketplaces, currency and drug epidemics. Martin Scorsese recently opined that *Marvel* films are closer to theme parks than they are to the movies he loves best. This is also true of the behemoth franchises in the science fiction world. As with *Marvel*, their popularity often derives from luring audiences in with narratives that trade on human conditions and histories; family feuds and empires and their rebellions, all touched up with the fantastical rather than immersed in it. It is a formula that works.

There are a few exceptions to this. In the 2016 film *Arrival*, the 'others' arrive in familiar fashion, not unlike in *War of the Worlds*, stopping over locations around the world and everyone braces themselves for an invasion. For the vast majority of the film, humanity scrambles to piece together their agenda, and in fact, it is our very assumption to project meaning and motive onto these beings that almost destroy us. These beings are nothing like the Wells' military hulks. The aliens experience time as a non-linear event, express themselves through inkblots that represent phrases and have few discernible features. They have no eyes, no arms, eight legs and their ships are not ships at all - they are bridges across time and we have a small part to play in ideas far bigger than our own.

In an attempt to imagine an intelligent otherness entirely at odds with humanity, the weird-fiction author China Mieville wrote *Embassytown*. The novel is set in a human outpost on the world of the Ariekei. The natives are 'insect-horse-coral-fan type things', whose anatomy and culture are often described through unexplained neologisms that make their otherness referable if disorientating. They speak an innate language in which it is not possible to lie and are intoxicated by those humans gifted enough to speak it with their human twist: the ability to tell untruths. It is an addiction that nearly brings their civilisation to its horse-like knees as the Ariekei learn to speak the metaphors that so tantalise them. However, *Embassytown*'s and *Arrival*'s primary means of making their audiences feel for their aliens is to use a human ambassador as a bridge. It is hard to deal in such dramatic otherness and retain a reader's empathy otherwise.

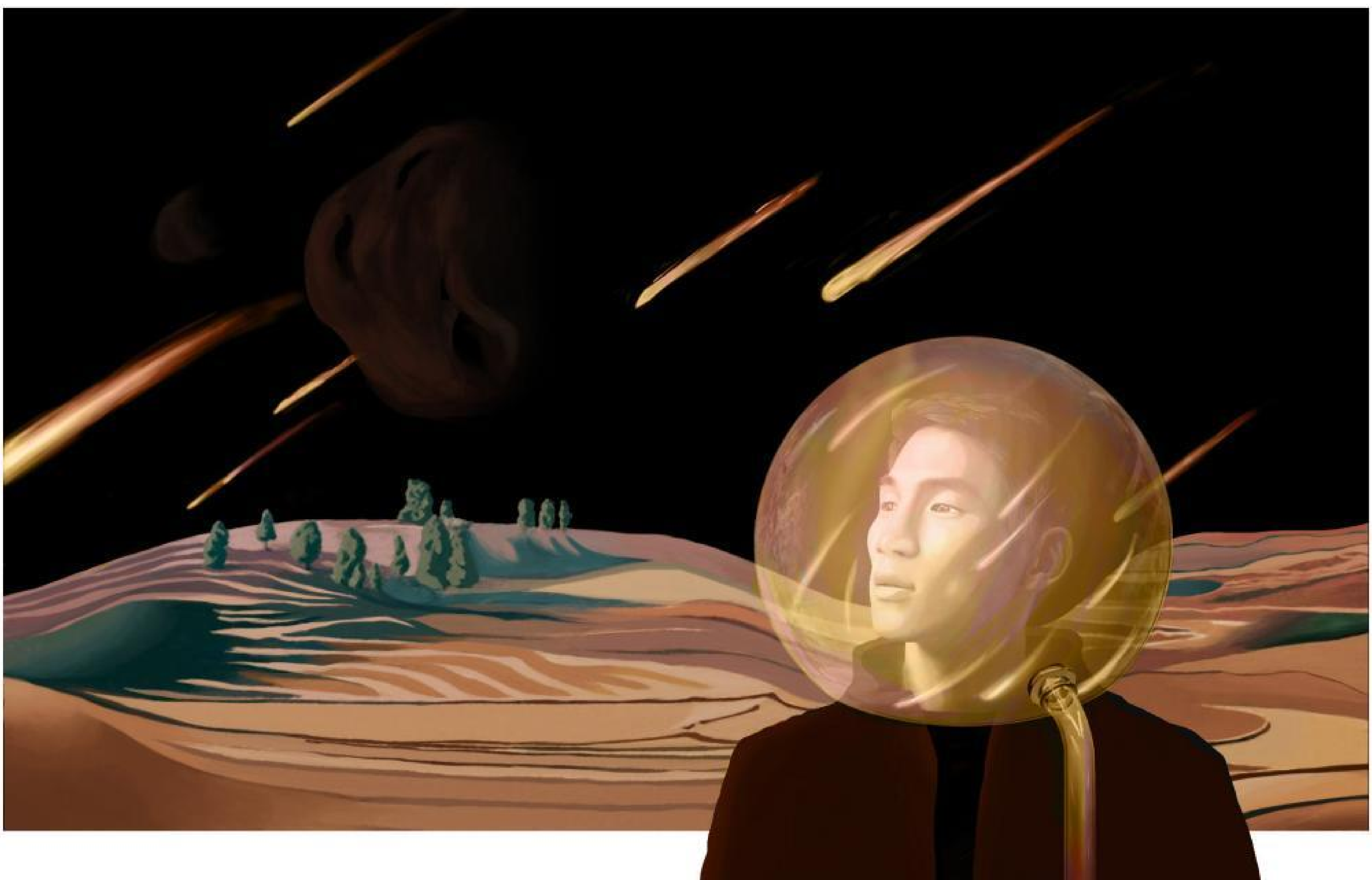
There has been a rich exploration of general AIs in Sci-Fi, from the collective personality of Legion in *Mass Effect*, to the benevolence and esoteric humour of the intelligent starships in Ian Banks' *Culture Series*. The authors have built AI characters that are relatable and very different from their human counterparts. Interest in this theme has grown as machine learning has taken over the real world. Perhaps, we are seeing a shift from malevolent AIs to more friendly ones in work like with *Moon*, *Her*, *Interstellar*, *Robot* and *Frank* and so on. We could also do with thinking more about how this can be achieved with alien life, without making it in our own image. Perhaps the trick is choosing a biological framework that an audience already somewhat understands and inflating it just enough. The Formics of *Enders' Game* and the Lovecraftian lesser Gods work because they make use of othernesses closer to home, namely insectoid hive minds and cephalopods. After success with *Alien*, its creators moved their titular monsters into the realm of hive mind communication and genetic engineering. The film series' popularity has run mainly off of its audiences' fascination with its xenomorphs rather than its human character building. However, we are yet to really 'feel' anything positive about, or be particularly compelled by, any individual xenomorph. This is the very tricky thing - the question is not just can we conceive of radically different intelligences, but how radical can we make our characters and still have them pull on our heartstrings β

Alex Bates is a PhD student at the MRC LMB. Billy Gyngell is a freelance writer. Artwork by Rosanna Rann

Clair de Lune

In September, October, November,
moody skies are as graceful as they would be on Mars.
If we were on Mars,
we'd watch comets falter across the Nile-green sky from our lawn chairs,
in silence,
lonesome with the elegance and detachment of those who are hatched from eggs:
the kind of people, if the word fits, who have never eaten tomatoes or seen doves,
whose white sneakers remain eternally immaculate,
who feel neither wonder nor sorrow
at their never-ending solitude,
happy to observe the eerie beauty of faraway starlings,
without seeking to read themselves among them.

Andreea Iulia Scridon




CAINA

The Astronaut

'Five billion years from now, the Earth will be frazzled by the heat of the sun and burn', the narrator of the documentary commented.

Georgie looked up at his sister immediately, his mouth hanging slightly open. She didn't look shocked or even surprised, or any different than she usually did. She wore the same sleepy teenage expression as always, in the dim light of the planetarium theatre.

'What?' she asked Georgie softly, raising her eyebrows.

'Five bajillion years from now, the earth will be furrazzled by the sun!' exclaimed Georgie in a whisper.

'Yeah, I know', replied Ella.

'I didn't know that', said Georgie.

'Don't worry; it's not going to happen during our lifetime'.

Ella had taken Georgie to the astronomy exposition. Georgie had talked excitedly and sang a song by Smokie softly to himself while looking out the bus window. Ella had told him to please be quiet because he was annoying the people behind us and they were giving her a dirty look. Georgie was quiet for a minute, and then Ella told him to shut up. Georgie didn't shut up. He also banged his Velcro sneakers on the chair in front of him.

'So what's gonna happen to the people on Earth in five bajillion years?' worried Georgie.

'Everyone's going to move to Mars. Remember, the red planet?' Ella took Georgie's hand and led him back into the day-light exposition, pointing to a diagram on the opposite wall.

'But there's no Paris on Mars', intervened Minnie, leaning over with a smile on her face. It had been her idea to invite Georgie.

Georgie liked Ella's friend. He liked that she was always nice to him and let him sit next to her when she came over and they watched TV. Her hair always smelled clean and looked shiny and she never-ever told him to go away like Ella did. He also liked that her name was like Mickey Mouse's wife.

'Maybe they could build the Eiffel Tower on Mars', suggested Georgie. Both girls smiled, and he felt safe in the darkness, like he belonged and was their friend. He would take Minnie to the city of lights one day, and they would walk together down the Shompselizay.

Georgie walked out barefoot onto the balcony wearing his Pokemon pajamas. The stone was cold under his feet and he shifted from foot to foot for a while. Suddenly, an idea occurred to him – visible by the expression of revelation and surprise on his small, chubby face – and he rushed into his room. Two minutes later, he was back on the balcony, this time wearing his brand new light-up sneakers. He was very very happy because the lights were like something you would wear on a spaceship or something – like stars! Plus they had Velcro, and that was good, cause shoelaces are really hard.

Georgie looked up at the moon, suddenly – as though it had spoken his name. It hung low over the horizon and was yellow as a country pumpkin.

'Maybe the little man who holds it up by a string fell asleep', thought Georgie to himself.

The little man who holds up the moon had fallen asleep. He dozed off in his cave full of lilacs, with his sharp nose nearly touching the collar of his red Pierrot blouse. Georgie knew that he lived there, on the margins of the city somewhere near the horizon, because he had had a dream once that he flew over the sleeping city to the cave full of lilacs, which are purple flowers. And there were bats there too, but they weren't scary. Anyway the little man who holds up the moon by the string must have lived there because it seemed just as far away.

Georgie squinted at the moon. He thought that maybe-just-maybe he could see the string of yarn that was holding it up. It looked like a delicious cottage pie, except it had holes. His mummy wouldn't give them a pie with holes in it, probably, even though she always covered her mouth with a napkin and said excuse my attempts when she served dinner with Georgie's daddy's mother.

'What are you doing up here?'
Georgie jumped at the sound of Ella's voice. He didn't say anything.

'You little lunatic', she teased.

'What does lunatick mean?' asked Georgie suspiciously, ready to swagger and wave his wooden sword.

'Crazy person', responded Ella smirking down at him.

'Hey! I'm not crazy!' Georgie exclaimed. Georgie knew he wasn't crazy…he didn't even know any kids that were crazy. He knew that crazy people were grown-ups who did the kind of stuff that kids were supposed to do.

'I was kidding. Actually, a lunatic is also somebody who stares at the moon for too long'. Ella's eyes flickered up towards the subject of the discussion as she said this. The light from it made her eyes glowy and enormous, as though the moon had taken her eyes away and replaced them with two miniature full moons. Georgie thought that her brown eyes resembled the amber that encased bugs from a bajillion years ago. They had seen those at the Natural History Museum once, another time.

'What's that got to do with crazy?' Georgie asked pouting. He hated when Ella made no sense, just like a grown-up.

'Well, it throws you off balance if you stare at it too long. Like when you go too hard and fast on a swing. Humans are made to be on the Earth'.
Georgie pondered this. He remembered what they said about Mars in the exposition. How would people live on another planet if what Ella said was true? Would they be sick and crazy all the time?

'You look tired, Georgie. Come inside', said Ella after a pause. She put her arm around him.

Another time, Ella had taken Georgie to a fair at a sea town, and she had bought him a bottle full of sand in many colors. He thought maybe the moon was covered with lots of layers of sand like that, and whenever the wind blew over it, it would reveal another layer – except this one would be green, while the one that blew away would be pink. He would maybe find out if that was true. He would be an astronaut and wear his light-up shoes. Maybe he would even be a lunatic ⓑ

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From Cannons to Apollo: Rockets Through the Ages

Lucy Hart discusses the history of space flight and what could lie ahead for this exciting field

From the latest *Star Wars* film to the 50th Moon Landing anniversary celebrations, you do not need to look far to find people excited by the idea of space travel. Interest in visiting planets other than our own is nothing new. In fact, the earliest known example of a novel featuring space travel was called 'A True Story' and was written in the second century AD by Lucian of Samosata. However, the idea of spaceflight as a scientific endeavour took longer to develop and it was not until 1865 in Jules Verne's 'From Earth to the Moon', that a realistic vision of spaceflight materialised in fiction.

Jules Verne's novel is the story of how Impey Barbicane uses his position as president of the Baltimore Gun Club to build the Columbiad, a cannon capable of firing people to the moon. Aside from being an early example of science fiction, the book is noteworthy due to the rigorous way in which Verne approached his subject matter. This enabled him to make a number of accurate predictions, including which state the first manned voyage would take off from! In fact, Verne's novel was so prescient that NASA decided to honour it by naming the Apollo 11 command module 'Columbia', after the Columbiad.

NASA was less eager to recognise the other precursor to its Apollo missions. The technology used to send the first men to the moon was a direct descendant of the V2 rockets used by Nazi Germany in World War II. After the war, the designers of the V2 rocket, Hermann Oberth and Werhner von Braun both moved to America where their work led to the development of the Saturn V rocket and so, indirectly, to the moon landings.

Oberth, along with Konstantin Tsiolkovsky and Robert H. Goddard are considered to be the fathers of modern rocketry. Tsiolkovsky formulated what is now known as the 'ideal rocket equation' which states:

$$\Delta v = v_e ln(\frac{m_0}{m_f})$$

In words this means that the amount by which a rocket can change its velocity (Δv), is limited by two factors. One is the exhaust velocity (v_e) - the velocity at which the exhaust comes out the back of the rocket. The other is the ratio of the rocket's initial mass (m_0) to its final mass (m_f). The equation is a consequence of the method by which a rocket propels itself. Rockets work by ejecting a portion of their mass, normally in the form of a fast-moving gas. When the gases are ejected, the rocket exerts a downward force on them. By Newton's Third Law, the gases must exert an equal and opposite force upwards on the rocket and this is the force that accelerates the rocket.

Tsiolkovsky's equation explains the need for multistage rockets. For a fixed exhaust velocity, the greater the ratio of the rocket's initial mass to its final mass, the larger the Δv it can achieve. Rockets need to achieve a Δv large enough that they can escape the Earth's gravitational pull. If one tried to achieve this Δv with a single stage rocket powered by conventional propellants, Tsiolkovsky's equation shows that a prohibitively large amount of the rocket's initial mass would have to be taken up by fuel, leaving little solid mass left over for the payload. In a multistage rocket, each stage contains its own engine and supply of fuel and once the stage has finished burning it detaches from the rest of the rocket. This has two consequences: first, the later stages start from a higher initial velocity and so have to achieve a smaller Δv to reach the final desired velocity. Second, later stages have less mass to accelerate as the useless mass of the previous stage's engine has been offloaded. Until recently, the fate of these early stages had been to fall back into the ocean or an uninhabited region of Earth. However, due to efforts to make spaceflight more commercially viable, these early stages are now being collected and reused.

Robert H. Goddard is remembered as the first man to ever launch a liquid-propellant rocket. In general, one can fuel a rocket using either

a liquid or a solid propellant. Solid-propellant rockets have a 'fuel cake' where the propellant and oxidiser have already been mixed. This solid fuel is then ignited to produce the gases that propel the rocket forward. The earliest forms of rockets, such as cannons, firework displays and Jules Verne's hypothetical Columbiad, worked in this manner. Liquid-propellant rockets contain both fuel and an oxidiser in a liquid state. These are then brought together in a combustion chamber where the ignition takes place.

Goddard is remembered because liquid-propellant rockets have several advantages over their predecessors, especially for applications to manned spaceflight. As the flow of fuel and oxidiser to the engine can be tightly regulated, it is possible to control exactly how much thrust is produced at any given time, which is vital in performing delicate space manoeuvres. Additionally, liquid-propellants tend to have a higher specific impulse than their solid counterparts. Specific impulse is a measure of how much thrust a given amount of propellant delivers to a rocket and is equal to the exhaust velocity. As specified by Tsiolkovsky's equation, a higher exhaust velocity results in a greater Δv, so rockets with higher specific impulses can afford to carry greater payloads. Lastly, liquid-propellant rockets have a much shorter turnaround time between uses than solid propellant rockets, making them more attractive to the likes of Elon Musk and SpaceX, who aim to develop space tourism.

Chemically powered rockets, whether based on a solid or liquid-propellant, currently provide the best way of escaping the Earth's atmosphere as they have a high thrust-to-weight ratio. This is a measure of the thrust that a particular engine can provide divided by the total weight of that engine. In order to escape the Earth's gravitational pull, a rocket must have a thrust-to-weight ratio of greater than one. However, there are inherent limits to how far away from Earth we can travel using these means of propulsion since chemical reactions have a relatively low energy density. To really push out into space and explore the final frontier we need to move to new forms of propulsion.

Ion thrusters have been proposed as a viable alternative to chemical propulsion systems. These generate thrust by ionising the gas in the rocket's engine and then accelerating it to high velocities using electric fields. The acceleration that can be achieved depends on the ion's charge to mass ratio, which is large, and so relatively small electric fields can produce large accelerations. As the ions can be accelerated to such high velocities, the exhaust velocity is much greater than for chemically powered rockets and so a much larger Δv can be achieved. The downside to ion thrusters is that they have a low thrust-to-weight ratio. This means that, although the Δv of an ion thruster is large, in reality it will take a very long time to achieve that Δv. Solar sailing has also been proposed as an alternative mode of space travel. Like ion thrusters, this method is unable to generate large amounts of thrust but has the advantage that, once in space, these rockets would have to carry no fuel. This is because they are accelerated by the pressure exerted on their sails by the sun's radiation.

Both of these methods are similar as they are unable to escape the Earth's gravity well unaided, making them best suited to voyages between worlds. Due to their low thrust, it would take years for craft powered by these systems to build up any appreciable velocity. However, given that our nearest neighbouring star system is four light years away, time is not something that would be lacking in an interstellar voyage. To truly travel among the stars may take years or even lifetimes. However, in my opinion, the human desire to see and explore what is out there will overcome even this obstacle β

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Going Deep to Reach the Stars

Tatjana Baleta explores the deep sea and its relationship to outer space

Sixty-two feet below the turquoise waters off Key Largo, Florida, a helmeted figure explores the sea floor with gentle bounding steps. This 'aquanaut' is a member of NEEMO, the NASA Extreme Environment Mission Operations project, and has been living underwater for three weeks, training to one day be an astronaut in space.

A vast expanse of the unknown, cold, dark and inhospitable, the ocean mirrors space in many ways. Both environments feature low perceived gravity. Visiting either requires extensive planning and sophisticated equipment; many of the challenges aquanauts face underwater could be experienced on a mission to space, the Moon or Mars. These similarities make the ocean an excellent arena to practice space missions.

During NEEMO missions, home is the barnacle-encrusted "Aquarius", the world's only underwater research base. From a distance you would be forgiven for mistaking it for a shipwreck, but the inside resembles a space station. The only giveaway is the fish swimming past the windows. Here up to six aquanauts must share the four hundred square foot confined space, enduring not-so-private bathroom facilities, freeze-dried food and the mental strains these conditions bring.

Aquarius is an ambient pressure habitat, which means the pressure inside the capsule is the same as the surrounding water pressure – two and a half times greater than at sea level. At this wpressure the human body gradually becomes saturated with dissolved nitrogen. If a person returns to a lower pressure too quickly, the dissolved nitrogen forms life-threatening bubbles, blocking blood flow and disrupting nerves, an affliction known colloquially as "The Bends". After living underwater in the base it takes seventeen hours of decompression, during which time the pressure is gradually adjusted at a safe speed, before an aquanaut is clear to return to the surface. So, once in Aquarius, there is no quick escape back to land. This also means that, much like in space, mistakes or equipment failure can be fatal. In 2009, an aquanaut died when his breathing apparatus malfunctioned during a dive and in 1994 Aquarius had to be evacuated in fifteen foot seas when one of the generators caught fire.

Despite, or perhaps partially because of these risks, NEEMO missions offer opportunities to both train future astronauts and test new equipment and procedures. Inside Aquarius, this might include a new exercise machine or miniature scanning electron microscopes for the International Space Station. Outside, the neutral buoyancy in the aqueous environment provides an excellent simulation of the microgravity of space. Kitted up with dive gear and a thirty two pound helmet, aquanauts enter the ocean from Aquarius to practise moving, using tools and assembling apparatus as though on a weightless spacewalk. Aquanauts can also be weighted with lead cubes to mimic the gravity of other planets. Previous missions have tested the evacuation of an unconscious astronaut, or lengthy communications delays to mimic the forty minute minimum time it takes for a message and its reply to travel between Mars and Earth. NASA has been using water to simulate the weightlessness of space for decades – even Buzz Aldrin practiced in the pool.

The aquanauts themselves are test subjects too, providing data on the physiological effects of the inhospitable environment on the human body, as well as the mental and psychological effects of a typical mission. Just like on space missions, their days are tightly scheduled, detailed down to the last minute, and decisions are time-sensitive. Aquanauts are constantly under surveillance by mission control via two-way radio and video access, but physically isolated from the rest of the world. Last year neuroscientist Csilla Ari D'Agostino joined five other crew members at Aquarius, tracking their cognitive performance, including reaction time, memory, and decision-making, and collecting data about their sleep quality and stress. The results of this investigation have not yet been published.

When not in use as a proxy space station, Aquarius hosts teams of marine biologists. The easy access from the base to the neighbouring Conch Reef presents an invaluable opportunity to conduct research on marine life. Yet, Aquarius is situated relatively shallow. Delving deeper into the ocean could provide insight into the age-old question of whether we are alone in the universe. Given the parallels between the two extreme environments, scientists look to life in the deep sea to provide a hint of what alien life might look like. Even NASA is funding deep sea exploration to this end; their Systematic Underwater Biogeochemical Science and Exploration Analog (SUBSEA) project aims to determine how best to conduct future science-driven space exploration while also searching for deep sea life.

Indeed, hidden away from human eyes in the hypoxic environment of the ocean depths lies a world of intriguing and monstrous creatures. Stalking the frigid waters are fanged viperfish reminiscent of the movie Alien, and gulper eels with mouths larger than their own bodies. Giant scaled isopods, deep sea cousins of terrestrial woodlice, scavenge among feathery soft corals on the seafloor. To survive in this permanent darkness many animals have huge eyes, and some even make their own light to confuse predators or lure prey. Fish living at these depths have evolved altered protein structures to help them withstand pressures hundreds of times greater than that at the surface. Thousands of meters below water near volcanically active zones, ashy black gases rise in plumes from hydrothermal vents, heating the water to temperatures as high as over 400°C. The vents churn out rich minerals, attracting chemosynthetic bacteria which use inorganic molecules as a source of energy. These bacteria form the basis of a food web featuring a range of life from tube worms to cutthroat eels. The discovery that complex food chains can be supported by chemical energy, as opposed to light and photosynthesis has challenged previous assumptions about the limits of biology.

Water is held as the key ingredient for life as we know it, and there is now evidence of its presence on several moons in our solar system. A study published in Nature suggests Earth's first life forms may have lived in deep-sea hydrothermal vents. Similar vents are thought to exist on the moons of Jupiter and Saturn, and may have once been present on Mars. If life on Earth began in hydrothermal vents, could the same be possible on other planets? Just as the first discovery of these vents led biologists to rethink what is possible for life, so too must they remain open-minded in the search for life in space. While extreme deep sea environments show us the boundaries of biology on Earth, it may also be possible that life in space can take forms beyond our wildest imaginations.

In the thousands of years humans have spent exploring our world, perhaps it was inevitable that we would eventually push past the boundary of our own planet and into "the final frontier". It is fitting that we practice in the place that life started: the ocean

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Unintelligent Design: Uncovering Bias in Artificial Intelligence

Evan Wroe and **Felix Opolka** speak to **Dr Jennifer Cobbe** about the causes of bias in machine learning models and how the associated risks can be mitigated

WE ARE IN IN the midst of an artificial intelligence revolution. This might come as a surprise, since we have been trained by science fiction to expect an artificial intelligence revolution in the form of malevolent automatons taking over our streets. In reality, the artificial intelligence (AI) sector has been growing exponentially in the last decade, with increasing computer power and the expanding ubiquity of big data allowing AI systems to seep ever further into our everyday lives.

Artificial intelligence uses range from the seemingly benign - predictive text and route-finding - to the potentially sinister, with facial recognition software deployed in public spaces and algorithms being used to advise on prison sentences. At the moment, even the most adept AI systems are far from reaching human-like intelligence. With the swift progress in machine learning research however, computers can tackle increasingly difficult and nuanced tasks. With the potential for the creation of virtual life on the horizon, it is necessary to question what kind of intelligence we are creating.

In 2016, Microsoft unveiled a Twitter chatbot, named Tay, that had been 'taught', using public data, to partake in conversations by Microsoft's Technology and Research team. Part social research project, part AI research project, Tay was supposed to learn to converse better by interacting with people on Twitter. Within a day it had grown from an innocent chat bot delivering joke horoscopes into an account that was tweeting racist and misogynistic hate speech. The account was quickly taken down, amidst much embarrassment, but it had already revealed a worrying truth: left unchecked, AI has the capacity to replicate the worst aspects of humanity. Referred to as algorithmic bias, these systems can reproduce the injustices of the world we live in. As the AI sector moves forward, we are forced to consider what impact algorithmic bias has on the algorithms we use and, crucially, who it is impacting.

How do machine learning systems become biased?

Dr Jennifer Cobbe is the Coordinator of the Trust & Technology Initiative and Research Associate and Affiliated Lecturer in the Compliant and Accountable Systems Group in the Computer Laboratory, University of Cambridge. She points out two principal ways in which a machine learning system might develop a bias. First, while machine learning programs learn patterns by themselves, they are still designed by humans. "The assumptions and understanding of the people designing the system will always be embedded into the system", Dr Cobbe explains. For example, a model designer must decide whether to include certain information in the set of data that the model learns from. If these assumptions are misguided or incomplete, this may lead to the system treating a group of people unfairly. For example including gender in a model, increases the chance of the model discriminating based on that feature.

Second, these systems are often trained on historical data, which can contain evidence of historical marginalisation of groups of people. When learning from such data, the model will hence replicate any bias that is present in that data set. In 2015, technology giant Amazon experienced this first-hand with their recently developed tool for rating applicants based on their resumés. The program was trained on data from past applicants. Since the tech industry has long been dominated by men, male applicants made up the majority of the data set. This resulted in a system which was inherently biased against female applicants.

Given the severity of the problem, researchers have started looking into how to detect and possibly remove bias using statistical methods or by constraining the model. Their findings indicate that it is crucial for the model designers to ensure that their data set is balanced and their assumptions are as complete as possible to reduce bias. However, fully eliminating bias is difficult, if not impossible. The creators of Amazon's resumé scoring system trialled removal of gender information from resumés prior to application of the model. They found the model then used information such as membership of women's sports clubs to substitute immediate gender information and thus, still remained biased.

How avoidable is bias in machine learning models?

Many of these examples hint at a more fundamental problem with machine learning, which is that bias is inherent to any classifier. Dr Cobbe explains that models are, by definition, simplifications of a usually complex reality. "With machine learning, you are bound to use the next best model because the optimal model is computationally intractable." This is unproblematic when classifying mundane images. However, when applied to people, this means that AI systems judge individuals based on group-level characteristics and thus their decisions result in pigeonholing. Furthermore, when the group-level characteristics are the product of an unequal society, the resulting AI can reinforce this inequality.

For example, an algorithm in the USA is being used to advise judges on defendants' likelihood to reoffend, helping inform the severity of their sentencing. This algorithm, however, does not exist in a vacuum. The judicial system it is being used in is inherently racist, with Black Americans making up 37.4% of the prison population whilst only constituting 13.4% of the general population. The algorithm picks up on this and interprets it as black defendants being more likely to reoffend, reinforcing the bias in an already-broken system. Worse, the expectation of impartiality and objectivity from an algorithm means that this bias can be more readily accepted than if it were coming from a human judge.

What can we do when some degree of bias is actually inherent to machine learning models? "While we can try to reduce the impact that bias in an AI system has, we might also have to accept that we cannot use machine learning and have to rely on people in domains where the consequences are too dangerous", Dr Cobbe explains. This is usually the case when a machine learning system deals with people in social contexts and when its classification result can severely affect an individual's life.

How can we manage bias in machine learning models?

Ultimately, dealing with biased machine learning systems will come down to holding those who run the model accountable, especially in cases where models discriminate based on characteristics of individuals that are protected by law, like sex, age, or race. The European General Data Protection Regulation (GDPR) that went into effect in May 2018 has provisions on automated individual decision making, giving individuals the right to not be the subject of decisions based solely on machine learning algorithms. However, Dr Cobbe argues that this law does not go far enough and burdens individuals with defending themselves against bad automated decisions. Instead, legislation should enforce 'review-ability', meaning that model designers have to create systems such that they can easily be reviewed by authorities, making legislation more easily enforceable. This might include, for example, providing access to the training data and any explicit assumptions built into the system.

With machine learning spreading into more and more fields, it is important that the creators are aware of the dangers that biased AI systems pose. Those designing machine learning models must be mindful of the risks of accidentally imparting their own biases on the system as well as ensuring their models do not reproduce bias found in real-world data sets. If we keep this in mind, we can ensure that as AI make their way into more areas of our lives, they do not bring the biases of their creators with them β

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How the Cambridge Philosophical Society Shaped Modern Science

Zak Lakota-Baldwin

Two hundred years ago, there were no scientists in Cambridge. In fact, it would be over a decade before the word 'scientist' was even coined. Though it seems inconceivable now, as the University of Cambridge is one of the world's leading scientific institutions and admits around six hundred new Natural Sciences undergraduates every year, it was not long ago that most Cambridge academics saw science as little more than an amateur hobby. To understand the transformation in status that science went through, we must cast our eyes back to the origins of an often-overlooked society that played an instrumental role in its development – the Cambridge Philosophical Society.

If it seems odd that the first scientific society in Cambridge would have 'philosophical' in its name, consider this: Before the modern concept of science was developed in the nineteenth century, the study of nature and the physical world was known as natural philosophy. This tradition, reaching all the way back to Aristotle, should not be thought of simply as a precursor to modern science or an offshoot of philosophy. It was its own distinct discipline, initially without any rigorous mathematical grounding or formal experimental methodology, but nonetheless concerned with far-reaching questions about patterns in the processes of nature.

Although natural philosophy was respected, it enjoyed nothing like the special status that science does today. There was no professional community of university-trained natural philosophers, conducting their work in research institutions and publishing peer-reviewed papers which built up the body of accepted 'facts'. For the most part, natural philosophy was carried out by individual gentlemen, who were self-funded and did not employ standardised experimental methods or set systematic research goals. Even as new universities began to spring up throughout France and the German states in the early nineteenth century, providing institutional support for teaching and research in science, Oxford and Cambridge remained steadfastly unchanged by the scientific spirit invigorating their continental counterparts.

Before the modern concept of science was developed in the nineteenth century, the study of nature and the physical world was known as natural philosophy

The Cambridge of 1819, from which the Philosophical Society first emerged, would be virtually unrecognisable to anyone familiar with the university as it stands today. The constituent colleges were little more than finishing schools for the English clergy, teaching theology and classics to young Anglican men. Meanwhile the University itself was effectively a small administrative department whose only job was to award degrees. Certainly there was no science to be found in the formal Cambridge education. Lectures on topics such as natural history were entirely optional, and none of the content was examined.

It is little wonder that Cambridge at the start of the nineteenth century was an "intellectual backwater" as far as science was concerned. This pithy description comes courtesy of Dr Susannah Gibson, who has recently written a book – The Spirit of Inquiry – to commemorate the two hundredth anniversary of the Cambridge Philosophical Society and reflect on its profound influence on scientific thinking and research in Britain and beyond.

The story begins with the election of Adam Sedgwick to the post of Woodwardian Chair of Geology in 1818 – a slightly odd choice, given that Sedgwick had no formal geological training. To rectify his lack of expertise, Sedgwick promptly organised a trip to the Isle of Wight with his friend John Stevens Henslow so that he could learn the rudiments of practical geology and mapping. Returning to Cambridge, Sedgwick and Henslow were keen to share their geological findings with their colleagues – but who in Cambridge would care, let alone recognize the significance of their research? It quickly became apparent to the two men that they were going to have to take matters into their own hands, by founding a new scientific society for Cambridge. In the autumn of 1819, they held an open meeting in a lecture room beneath the old University Library, which any Cambridge graduate with an interest in science was welcome to attend. The result was the formation of the Cambridge Philosophical Society, an organisation which would bring like-minded researchers together to discuss the latest advances in science and foster a spirit of curiosity among the students.

The society soon came to be a hub of intellectual discourse, drawing in speakers across a dizzying range of topics. Scientific powerhouses including John Herschel, Charles Babbage and James Clerk Maxwell all made appearances at the society's early meetings, which continued uninterrupted every Monday (even through both World Wars) for the next two hundred years. Cambridge's first scientific library and Natural History Museum were both formed from the society's expansive collection of various books and specimens. Such was the success of the society that it received a Royal Charter from William IV in 1832, a milestone that was celebrated jubilantly. According to written correspondences from that time, the night began with a "blow-out" at the Eagle pub, after which society members retired to the rooms of a slightly reluctant Sedgwick and kept him up until the early hours of the morning.

Gibson has been particularly keen to stress the unique support that the Cambridge Philosophical Society provided to young researchers, giving them a platform to present their ideas – however unpolished – at a time when most other scientific societies tended to give precedence to established names. One such occasion was at a society meeting in 1835, when Henslow read out a letter sent to him by a recent Cambridge graduate on a far-flung voyage mapping the coastlines of South America. Though the purpose of the expedition was mainly to advance British maritime trade interests, the captain had sought a learned man to serve as the ship's naturalist, who could collect specimens and also provide intelligent conversation. The rest of the story is one of the most famous in the history of science, and it was thanks to his observations of Galapagos finches on this voyage that the young Charles Darwin was able to begin formulating his seminal theory of evolution by natural selection.

At the society meetings, bathed in flickering gaslight, audiences listened enraptured as Henslow recounted Darwin's adventures and transported them to distant lands that they would likely never see themselves. The letters proved to be so popular that the society began publishing them in print, making them Darwin's first work to reach a public audience. Darwin himself was initially alarmed by their publication, worrying that the letters weren't good enough to be widely read. However, he was pleasantly surprised to discover that they were very well received and later used this fact to convince his father – who previously believed Darwin's voyage on the HMS Beagle to be a waste of time – that he was well suited to the study of the natural world.

Two hundred years later, the Cambridge Philosophical Society continues to support young researchers through grants and prizes such as the Henslow Fellowship and the Sir Isaac Newton Bursary. Though the society is much transformed, with its collections dispersed across Cambridge and its buildings repurposed, it maintains the same spirit of inquiry that fuelled its creation and transformed the University of Cambridge into a scientific powerhouse. Students and researchers today should be mindful of the great effort and determination that was required to transform the public perception of science from a gentleman's pastime to a serious academic discipline. Just as Sedgwick and Henslow sought to move with the changing times, recognising the growing importance of science and jolting Cambridge out of its intellectual inertia, we too must be prepared to challenge conventions and engage with controversial ideas as they emerge. If we close our minds, we risk missing out on the next Darwin β

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Artwork by Serene Dhawan

Weird and Wonderful

Octopus Dreams

Dreams: we all have them. Sometimes we remember the contents in the morning, sometimes we even wonder what they could tell us about our subconscious. Well, we are not the only dreamers on earth. It is known that vertebrates, take dogs for instance, can dream. A recent PBS Nature video shows an octopus in an aquarium rapidly changing its colour whilst asleep – a rare sight, given that they usually sleep in underwater caves. Octopuses change colour through a set of pigment-containing and light-reflecting cells called 'chromatophores', situated directly below the surface of their skin. A complex network of nerve and muscle cells control their expansion and contraction to display different colour patterns, used in situations ranging from predator-prey camouflage to friendly social interactions. These mechanisms appear to be relatively controlled when an octopus changes their colour during the day, but what about when they sleep? Does the octopus dream? Not much is known about invertebrate sleep and experts are divided. For one, the change in colour could be due to random cellular activation, 'lack of control' so to speak. As octopuses sleep in dark caves, there is no direct disadvantage for this behaviour. On the other hand, this change in colour could be a sign of a dream, similar to rapid eye movement (also known as REM) in humans, where colour changes reflect the environment an octopus is dreaming of. Wouldn't that be great? FP

Crying Camels

In the unforgiving landscape of the Gobi Desert in southern Mongolia, Bactrian camels brave harsh seasons, and carry their offspring for 13 months. After the gestation period, things do not get any easier. Not only is there a high chance of newborn calf mortality but, due to the birth's arduous nature, mothers often reject their calves. This results in orphaned calves and grieving mothers, both in need of filial love. In order to create a connection between a mother and her rejected calf, or a mother and an orphan unrelated calf the nomadic people of the Gobi Desert have been using an ancient ritual for hundreds of years. A musician sings a monotone melody, accompanied by a traditional horsehead fiddle, called morin khuur. This ethereal music is adjusted according to the mother camel's reaction, gently coaxing her into accepting the calf. The ceremony is long, and comes to an end only when tears are visible in both camels' eyes. Of unknown origins, this mystical phenomenon is thought to mark the formation of a bond that connects mother camel and her calf for life. In maintaining herd numbers, vital for food and transportation, it also keeps the traditional Mongolian nomads alive GD

Feel like a God, look like a fool

We can now create our own universe using virtual reality (VR) and immerse ourselves in any type of environment we like. What could VR do to our brain if we 'lived' in a virtual environment for a prolonged time period? Many vertebrates including humans use a brain structure called the hippocampus for spatial navigation, and for mapping natural environments. A subset of neurons in the hippocampus exhibit spatial selectivity, firing maximally when an animal is physically at each individual neuron's preferred location. Neurophysicist Prof Mayank Mehta and his team were interested in studying whether the brain could create similar spatial maps in virtual environments. The researchers gave mice an immersive VR experience, in which they had to make sense of a virtual space solely based on visual cues. After years of experiments, they found that these hippocampal neurons no longer displayed spatial selectivity, and 60% of the hippocampus became inactive. When the mice were placed in a physical maze with the same visual cues, neuronal activities returned to normal. What will this mean for humans in an increasingly virtual future? YXN

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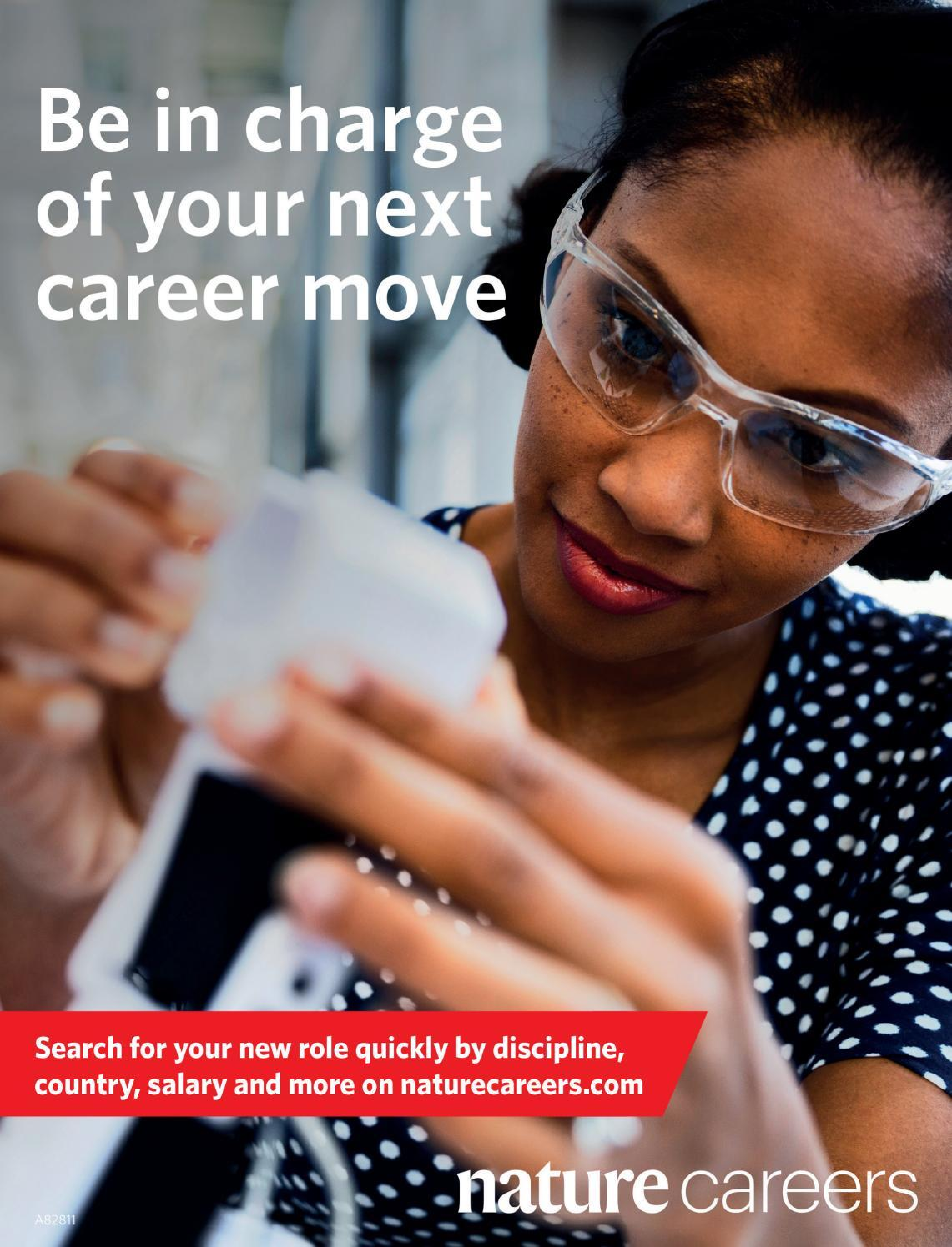
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