NewScientist
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THE EXISTENTIAL ISSUE

The staggering mysteries of being

(and how to cope with them)

HOW COULD OUR COSMOS HAVE COME FROM NOTHING?

WHY IS THE UNIVERSE JUST RIGHT FOR LIFE?

ARE WE UTTERLY ALONE?

WHAT'S THE ORIGIN OF MY CONSCIOUSNESS?

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WILL HUMANS EVOLVE INTO ANOTHER SPECIES?

ARE THERE PARALLEL UNIVERSES?

HOW WILL IT ALL END?

Introduction by
Stephen Hawking

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Where did we come from?

There is only one way to find the answer, says Stephen Hawking

WHY are we here? Where did we come from? According to the Boshongo people of central Africa, before us there was only darkness, water and the great god Bumba. One day Bumba, in pain from a stomach ache, vomited up the sun. The sun evaporated some of the water, leaving land. Still in discomfort, Bumba vomited up the moon, the stars and then the leopard, the crocodile, the turtle, and finally, humans.

This creation myth, like many others, wrestles with the kinds of questions that we all still ask today. Fortunately, as will become clear from this special issue of *New Scientist*, we now have a tool to provide the answers: science.

When it come to these mysteries of existence the first scientific evidence was discovered about 80 years ago, when Edwin Hubble began to make observations in the 1920s with the 100-inch telescope on Mount Wilson in Los Angeles County.

To his surprise, Hubble found that nearly all the galaxies were moving away from us. Moreover, the more distant the galaxies, the faster they were moving away. The expansion of the universe was one of the most important intellectual discoveries of all time.

> **"If the early universe had been completely smooth, there would be no stars and life couldn't have arisen"**

This finding transformed the debate about whether the universe had a beginning. If galaxies are moving apart now, they must therefore have been closer together in the past. If their speed had been constant, they would all have been on top of one another billions of years ago. Was this how the universe began? At that time many scientists were unhappy with the universe having a beginning because it seemed to imply that physics had broken down.

DIMITRIOS KAMBOURIS/WIREIMAGE/GETTY

PROFILE
Stephen Hawking is the director of research at the Department of Applied Mathematics and Theoretical Physics, University of Cambridge. His next book, written for children with his daughter Lucy Hawking, is *George and the Big Bang*

One would have to invoke an outside agency, which for convenience one can call God, to determine how the universe began. They therefore advanced theories in which the universe was expanding at the present time, but didn't have a beginning. Perhaps the best known was proposed in 1948, and called the steady state theory.

According to this theory, the universe would have existed for ever and would have looked the same at all times. This last property had the great virtue of being a prediction that could be tested, a critical ingredient of the scientific method. And it was found lacking.

Observational evidence to confirm the idea that the universe had a very dense beginning came in October 1965, with the discovery of a faint background of microwaves throughout space. The only reasonable interpretation is that this background is radiation left over from an early hot and dense state. As the universe expanded, the radiation would have cooled until it is just the remnant we see today.

Theory backed this idea too. With Roger Penrose I showed that if Einstein's general theory of relativity is correct, there would be a singularity, a point of infinite density and space-time curvature, where time has a beginning.

The universe started off in the big bang, expanding faster and faster. This is called inflation and it turns out that inflation in the early cosmos was much more rapid: the universe doubled in size many times in a tiny fraction of a second.

Inflation made the universe very large and very smooth and flat. However, it was not completely smooth: there were tiny variations from place to place. These variations caused minute differences in the temperature of the early universe, which we can see in the cosmic microwave background.

The variations mean that some regions will be expanding slightly less fast. The slower regions eventually stop expanding and collapse again to form galaxies and stars. And, in turn, solar systems.

We owe our existence to these variations. If the early universe had been completely smooth, there would be no stars and so life could not have developed. We are the product of primordial quantum fluctuations.

As will become clear (see page 27), many huge mysteries remain. Still, we are steadily edging closer to answering the age-old questions. Where did we come from? And are we the only beings in the universe who can ask these questions? ■

THE EXISTENTIAL ISSUE

It's lucky you're here

13.7 billion years ago, the universe was born in a cosmic fireball. Roughly 10 billion years later, the planet we call Earth gave birth to life, which eventually led to you. The probability of that sequence of events is absolutely minuscule, and yet it still happened.

Take a step back from the unlikeliness of your own personal existence and things get even more mind-boggling. Why does the universe exist at all? Why is it fine-tuned to human life? Why does it seem to be telling us that there are other universes out there, even other yous?

In the next 16 pages, we confront these mysteries of existence and others, from the possibility that the universe is a hologram to the near-certainty that you are a zombie

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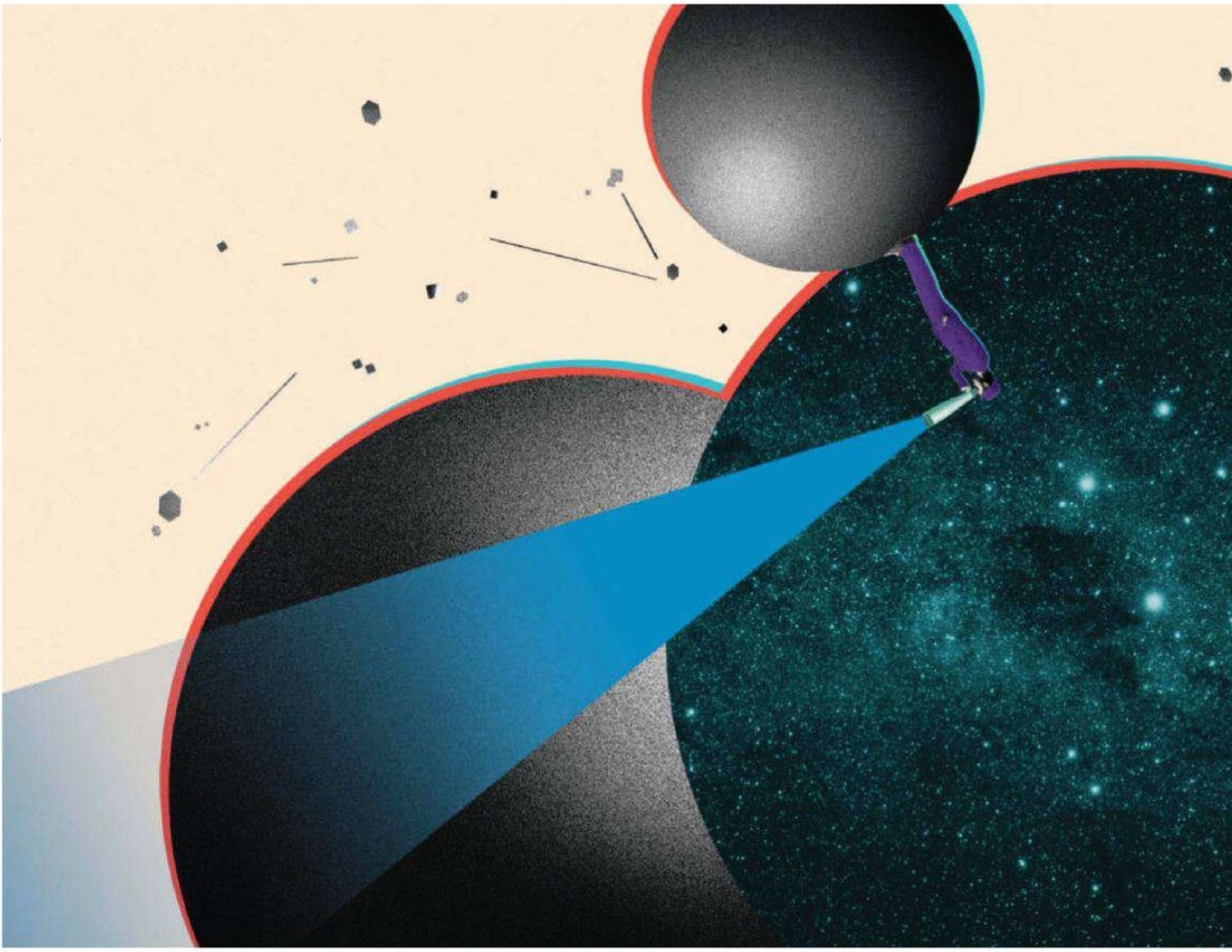

Why is there something rather than nothing?

AS DOUGLAS ADAMS once wrote: "The universe is big. Really big." And yet if our theory of the big bang is right, the universe was once a lot smaller. Indeed, at one point it was non-existent. Around 13.7 billion years ago time and space spontaneously sprang from the void. How did that happen?

Or to put it another way: why does anything exist at all? It's a big question, perhaps the biggest. The idea that the universe simply appeared out of nothing is difficult enough; trying to conceive of nothingness is perhaps even harder.

It is also a very reasonable question to ask from a scientific perspective. After all, some basic physics suggests that you and the rest of the universe are overwhelmingly unlikely to exist. The second law of thermodynamics, that most existentially resonant of physical laws, says that disorder, or entropy, always tends to increase. Entropy measures the number of ways you can rearrange a system's components without changing its overall appearance. The molecules in a hot gas, for example, can be arranged in many different ways to create the same overall temperature and pressure, making the gas a high-entropy system. In contrast, you can't rearrange the molecules of a living thing very much without turning it into a non-living thing, so you are a low-entropy system.

By the same logic, nothingness is the highest entropy state around – you can shuffle it around all you want and it still looks like nothing.

Given this law, it is hard to see how nothing could ever be turned into something, let alone something as big as a universe. But entropy is only part of the story. The other consideration is symmetry – a quality

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Also in this section

that appears to exert profound influence on the physical universe wherever it crops up. Nothingness is very symmetrical indeed. "There's no telling one part from another, so it has total symmetry," says physicist Frank Wilczek of the Massachusetts Institute of Technology.

And as physicists have learned over the past few decades, symmetries are made to be broken. Wilczek's own speciality is quantum chromodynamics, the theory that describes how quarks behave deep within atomic nuclei. It tells us that nothingness is a precarious state of affairs. "You can form a state that has no quarks and antiquarks in it, and it's totally unstable," says Wilczek. "It spontaneously starts producing quark-antiquark pairs." The perfect symmetry of nothingness is broken. That leads to an unexpected conclusion, says Victor Stenger, a physicist at the University of Colorado in Boulder: despite entropy, "something is the more natural state than nothing".

"Perhaps the big bang was just nothingness doing what comes naturally"

"According to quantum theory, there is no state of 'emptiness'," agrees Frank Close of the University of Oxford. Emptiness would have precisely zero energy, far too exacting a requirement for the uncertain quantum world. Instead, a vacuum is actually filled with a roiling broth of particles that pop in and out of existence. In that sense this magazine, you, me, the moon and everything else in our universe are just excitations of the quantum vacuum.

Before the big bang

Might something similar account for the origin of the universe itself? Quite plausibly, says Wilczek. "There is no barrier between nothing and a rich universe full of matter," he says. Perhaps the big bang was just nothingness doing what comes naturally.

This, of course, raises the question of what came before the big bang, and how long it lasted. Unfortunately at this point basic ideas begin to fail us; the concept "before" becomes meaningless. In the words of Stephen Hawking, it's like asking what is north of the north pole.

Even so, there is an even more mind-blowing consequence of the idea that something can come from nothing: perhaps nothingness itself cannot exist.

Here's why. Quantum uncertainty allows a trade-off between time and energy, so something that lasts a long time must have little energy. To explain how our universe has lasted for the billions of years that it has taken galaxies to form, solar systems to coalesce and life to evolve into bipeds who ask how something came from nothing, its total energy must be extraordinarily low.

That fits with the generally accepted view of the universe's early moments, which sees space-time undergoing a brief burst of expansion immediately after the big bang. This heady period, known as inflation, flooded the universe with energy. But according to Einstein's general theory of relativity, more space-time also means more gravity. Gravity's attractive pull represents negative energy that can cancel out inflation's positive energy – essentially constructing a cosmos for nothing. "I like to say that the universe is the ultimate free lunch," says Alan Guth, a cosmologist at MIT who came up with the inflation theory 30 years ago.

Physicists used to worry that creating something from nothing would violate all sorts of physical laws such as the conservation of energy. But if there is zero overall energy to conserve, the problem evaporates – and a universe that simply popped out of nothing becomes not just plausible, but probable. "Maybe a better way of saying it is that something *is* nothing," says Guth.

None of this really gets us off the hook, however. Our understanding of creation relies on the validity of the laws of physics, particularly quantum uncertainty. But that implies that the laws of physics were somehow encoded into the fabric of our universe before it existed. How can physical laws exist outside of space and time and without a cause of their own? Or, to put it another way, why is there something rather than nothing?

Amanda Gefter ■

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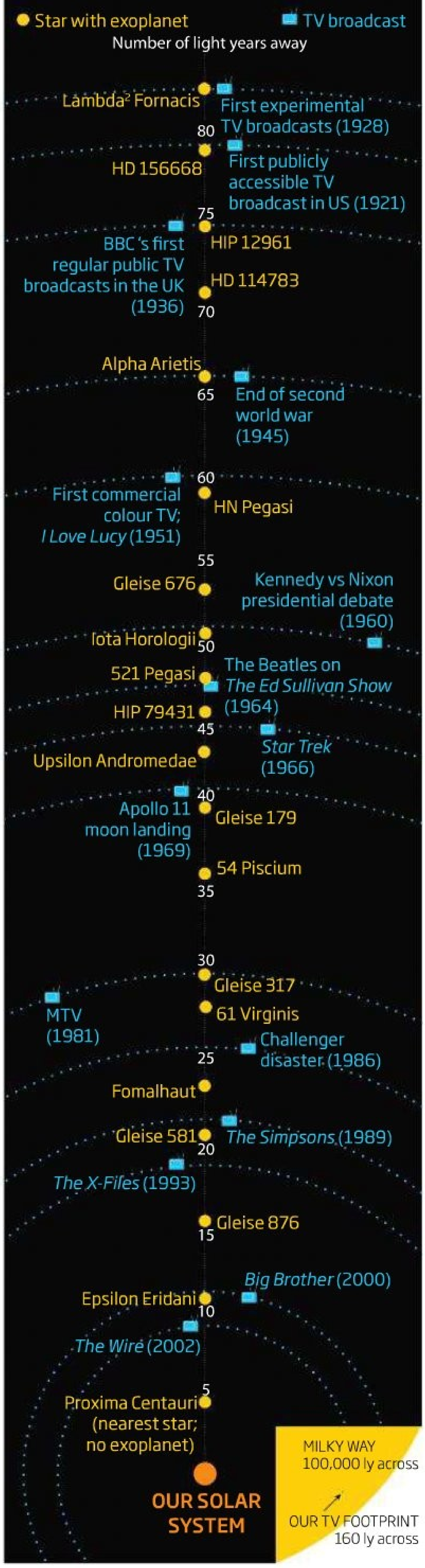
BROADCASTING TO THE STARS

TV signals from Earth are travelling outwards at light speed. If aliens are out there, here's what they are watching



Are we alone?

HAVE you ever looked up at the night sky and wondered if somebody, or something, is looking back? If perhaps somewhere out there, the mysterious spark we call life has flickered into existence?

Intuitively, it feels as if we can't be alone. For every one of the 2000 stars you can see with your naked eye, there are another 50 million in our galaxy, which is one of 100 billion galaxies. In other words, the star we orbit is just one of 10,000 billion billion in the cosmos. Surely there is another blue dot out there – a home to intelligent life like us? The simple fact is, we don't know.

One way to estimate the number of intelligent civilisations was devised by astronomer Frank Drake. His equation takes into account the rate of star formation, the fraction of those stars with planets and the likelihood that life, intelligent life, and intelligent creatures capable of communicating with us, will arise.

It is now possible to put numbers on some of those factors. We know that about 20 stars are born in the Milky Way every year and we have spotted more than 560 planets around stars other than the sun. About a quarter of stars harbour a planet similar in mass to Earth (*Science*, vol 330, p 653).

But estimating the biological factors is little more than guesswork. We know that life is incredibly adaptable once it emerges, but not how good it is at getting started in the first place.

Unique planet

Some astronomers believe life is almost inevitable on any habitable planet. Others suspect simple life is common, but intelligent life exceedingly rare. A few believe that our planet is unique. "Life may or may not form easily," says physicist Paul Davies of Arizona State University in Tempe. "We're completely in the dark."

So much for equations. What about evidence? Finding life on Mars probably won't help, as it would very likely share its origin with Earthlings. "Impacts have undoubtedly conveyed microorganisms back and forth," says Davies. "Mars and Earth are not independent ecosystems."

Discovering life on Titan would be more revealing. Titan is the only other place in the solar system with liquid on its surface – albeit lakes of ethane. "We are starting to think that if there is life on Titan it would have a separate origin," says Dirk Schulze-Makuch at Washington State University in Pullman. "If we can find a separate origin we can say 'OK, there's a lot of life in the universe'."

Discovering alien microbes in our solar system would be some sort of proof that we are not alone, but what we really want to know is whether there is another intelligence out there. For 50 years astronomers have swept the skies with radio telescopes for any hint of a message. So far, nothing.

But that doesn't mean ET isn't there. It just might not know we're here. The only evidence of our existence that reaches beyond the solar system are radio signals and light from our cities. "We've only been broadcasting powerful radio signals since the second world war," says Seth Shostak of the SETI Institute in Mountain View, California. So our calling card has leaked j ust 70 light years into space, a drop in the ocean. If the Milky Way was the size of London and Earth was at the base of Nelson's Column, our radio signals would still not have left Trafalgar Square.

"It's probably safe to say that even if the local galaxy is choc-a-bloc with aliens, none of them know that *Homo sapiens* is here," says Shostak. That also works in reverse. Given the size of the universe and the speed of light, most stars and planets are simply out of range.

It is also possible that intelligent life is separated from us by time. After all, human intelligence has only existed for a minuscule fraction of Earth's history and may just be a fleeting phase (see page 39). It may be too much of a stretch to hope that a nearby planet not only harbours intelligent life, but that it does so right now.

But let's say we did make contact with aliens. How would we react? NASA has plans, and most religions claim they would be able to absorb the idea, but the bottom line is we won't know until it happens.

Most likely we'll never find out. Even if Earth is not the only planet with intelligent life, we appear destined to live out our entire existence as if it were – but with a nagging feeling that it can't be. How's that for existential uncertainty? **Valerie Jamieson** ■

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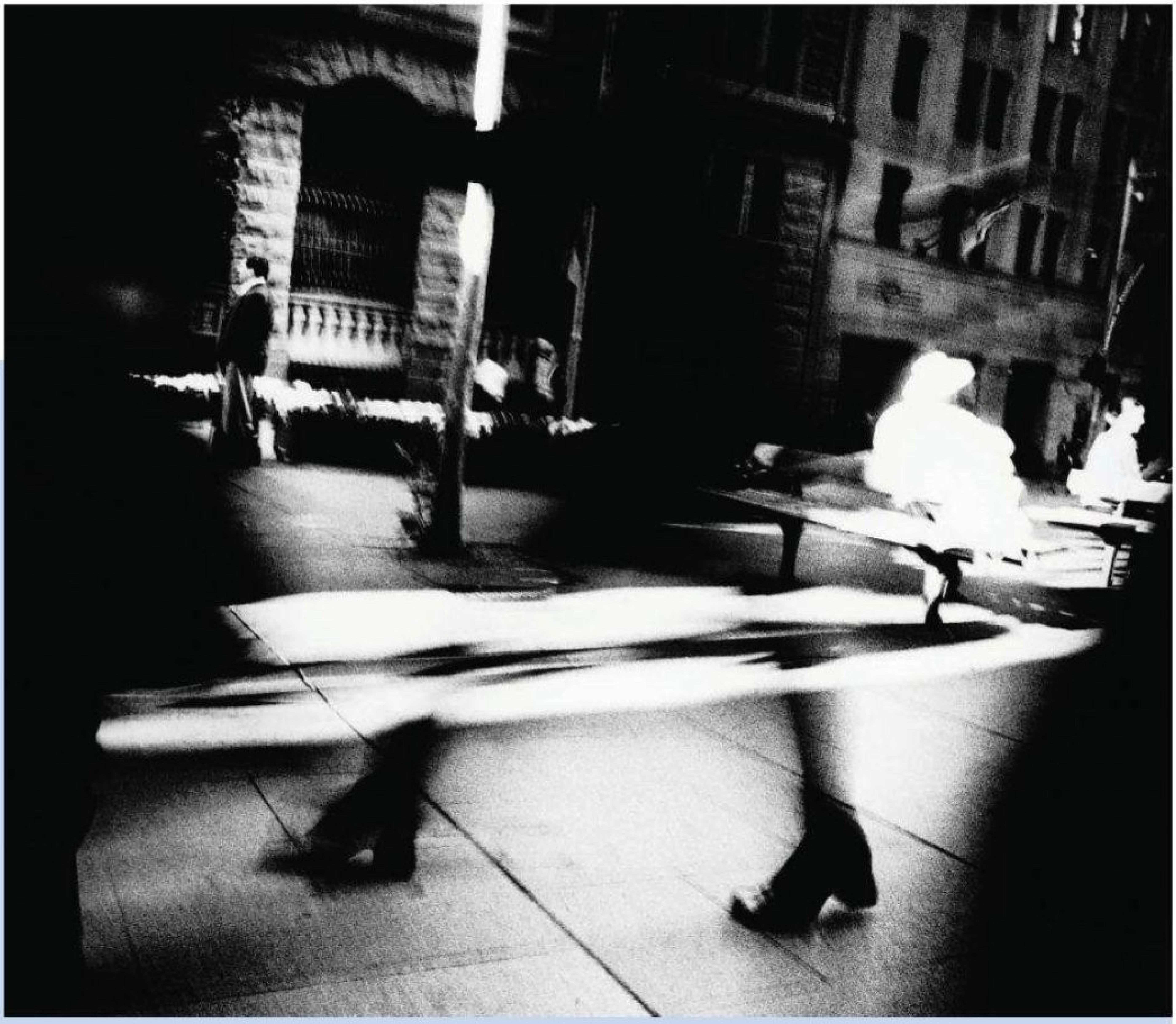


TRENT PARKE/MAGNUM PHOTOS

"The entire 3D universe we experience may be encoded in a 2D surface"

Am I a hologram?

TAKE a look around you. The walls, the chair you're sitting in, your own body – they all seem real and solid. Yet there is a possibility that everything we see in the universe – including you and me – may be nothing more than a hologram.

It sounds preposterous, yet there is already some evidence that it may be true, and we could know for sure within a couple of years. If it does turn out to be the case, it would turn our common-sense conception of reality inside out.

The idea has a long history, stemming from an apparent paradox posed by Stephen Hawking's work in the 1970s. He discovered that black holes slowly radiate their mass away. This Hawking radiation appears to carry no information, however, raising the question of what happens to the information that described the original star once the black hole evaporates. It is a cornerstone of physics that information cannot be destroyed.

In 1972 Jacob Bekenstein at the Hebrew University of Jerusalem, Israel, showed that the information content of a black hole is proportional to the two-dimensional surface area of its event horizon – the point-of-no-return for in-falling light or matter. Later, string theorists managed to show how the original star's information could be encoded in tiny lumps and bumps on the event horizon, which would then imprint it on the Hawking radiation departing the black hole.

This solved the paradox, but theoretical physicists Leonard Susskind and Gerard 't Hooft decided to take the idea a step further: if a three-dimensional star could be encoded on a black hole's 2D event horizon, maybe the same could be true of the whole universe. The universe does, after all, have a horizon 42 billion light years away, beyond which point light would not have had time to reach us since the big › bang. Susskind and 't Hooft suggested that this 2D "surface" may encode the entire 3D universe that we experience – much like the 3D hologram that is projected from your credit card.

It sounds crazy, but we have already seen a sign that it may be true. Theoretical physicists have long suspected that space-time is pixelated, or grainy. Since a 2D surface cannot store sufficient information to render a 3D object perfectly, these pixels would be bigger in a hologram. "Being in the [holographic] universe is like being in a 3D movie," says Craig Hogan of Fermilab in Batavia, Illinois. "On a large scale, it looks smooth and three-dimensional, but if you get close to the screen, you can tell that it is flat and pixelated."

Quantum fluctuation

Hogan recently looked at readings from an exquisitely sensitive motion-detector in Hanover, Germany, which was built to detect gravitational waves – ripples in the fabric of space-time. The GEO600 experiment has yet to find one, but in 2008 an unexpected jitter left the team scratching their heads, until Hogan suggested that it might arise from "quantum fluctuations" due to the graininess of space-time. By rights, these should be far too small to detect, so the fact that they are big enough to show up on GEO600's readings is tentative supporting evidence that the universe really is a hologram, he says.

Bekenstein is cautious: "The holographic idea is only a hypothesis, supported by some special cases." Better evidence may come from a dedicated instrument being built at Fermilab, which Hogan expects to be up and running within a couple of years.

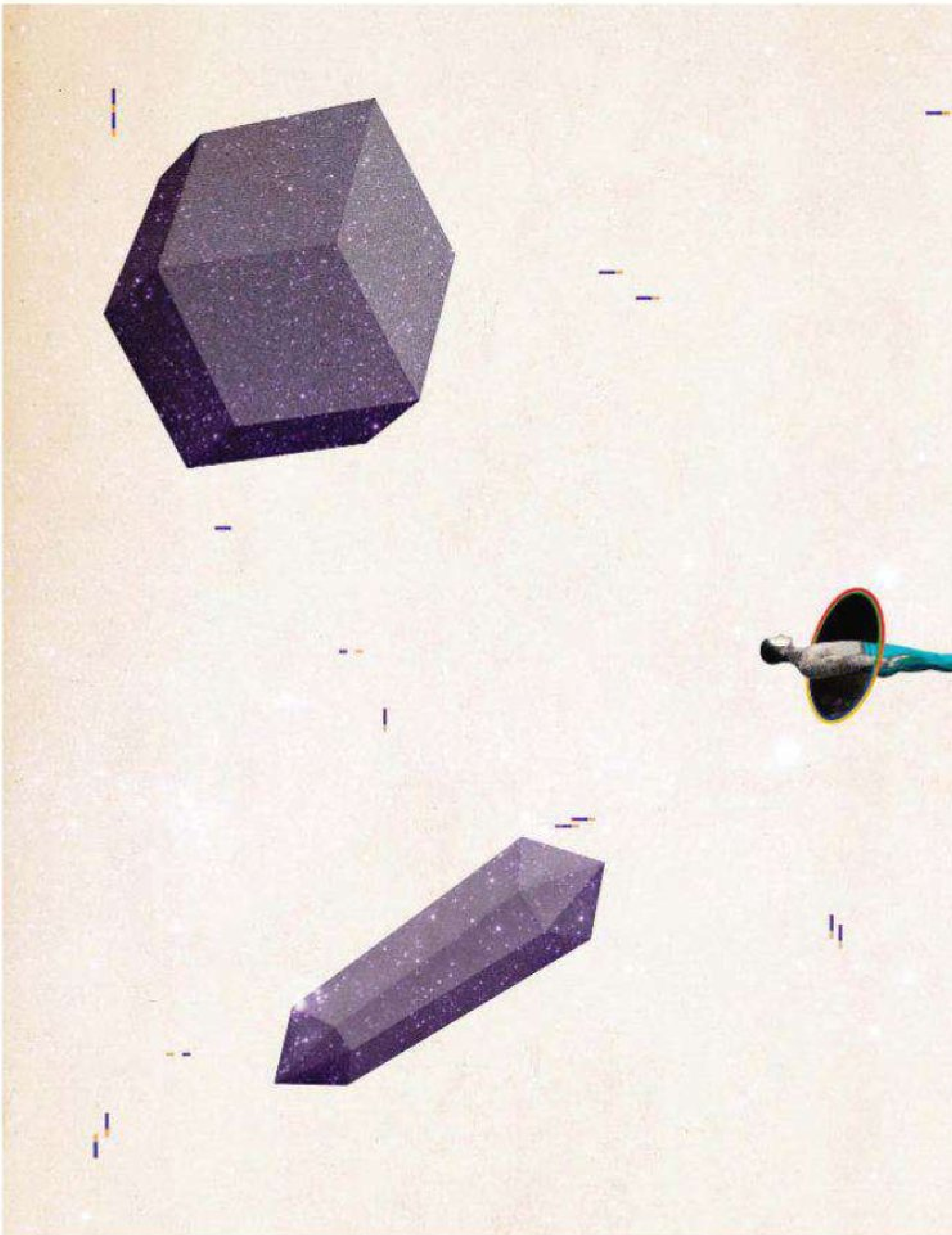
A positive result would challenge every assumption we have about the world we live in. It would show that everything is a projection of something occurring on a flat surface billions of light years away from where we perceive ourselves to be. As yet we have no idea what that "something" might be, or how it could manifest itself as a world in which we can do the school run or catch a movie at the cinema. Maybe it would make no difference to the way we live our lives, but somehow I doubt it. Marcus Chown ■

Why me?

THINK for a moment about a time before you were born. Where were you? Now think ahead to a time after your death. Where will you be? The brutal answer is: nowhere. Your life is a brief foray on Earth that started one day for no reason and will inevitably end.

But what a foray. Like the whole universe, your consciousness popped into existence out of nothingness and has evolved into a rich and complex entity full of wonder and mystery.

Contemplating this leads to a host of mind-boggling questions. What are the odds of my consciousness existing at all? How can such a thing emerge from nothingness? Is there any possibility of it surviving my death? And what is consciousness anyway?


JIRAYU KOO

Answering these questions is incredibly difficult. Philosopher Thomas Nagel once asked, "What is it like to be a bat?" Your response might be to imagine flying around in the dark, seeing the world in the echoes of high-frequency sounds. But that isn't the answer Nagel was looking for. He wanted to emphasise that there is no way of knowing what it is like for a bat to feel like a bat. That, in essence, is the conundrum of consciousness.

Neuroscientists and philosophers fall into two broad camps. One thinks that consciousness is an emergent property of the brain and that once we fully understand the intricate workings of neuronal activity, consciousness will be laid bare. The other doubts it will be that simple. They agree that consciousness emerges from the brain, but argue that Nagel's question will always remain unanswered: knowing every detail of a bat's brain cannot tell us what it is like to be a bat. This is often called the "hard problem" of consciousness, and seems scientifically intractable – for now.

Meanwhile, "there are way too many so-called easy problems to worry about", says Anil Seth of the University of Sussex in Brighton, UK.

One is to look for signatures of consciousness in brain activity, in the hope that this takes us closer to understanding what it is. Various brain areas have been found to be active when we are conscious of something and quiet when we are not. For example, Stanislas Dehaene of the French National Institute of Health and Medical Research in Gif sur Yvette and colleagues have identified such regions in our frontal and parietal lobes (*Nature Neuroscience*, vol 8, p 1391).

"Once we understand the intricate workings of the brain, conscious experience will be laid bare"

Consciousness explained

This is consistent with a theory of consciousness proposed by Bernard Baars of the Neuroscience Institute in San Diego, California. He posited that most non-conscious experiences are processed in specialised local regions of the brain such as the visual cortex. We only become conscious of this activity when the information is broadcast to a network of neurons called the global workspace – perhaps the regions pinpointed by Dehaene.

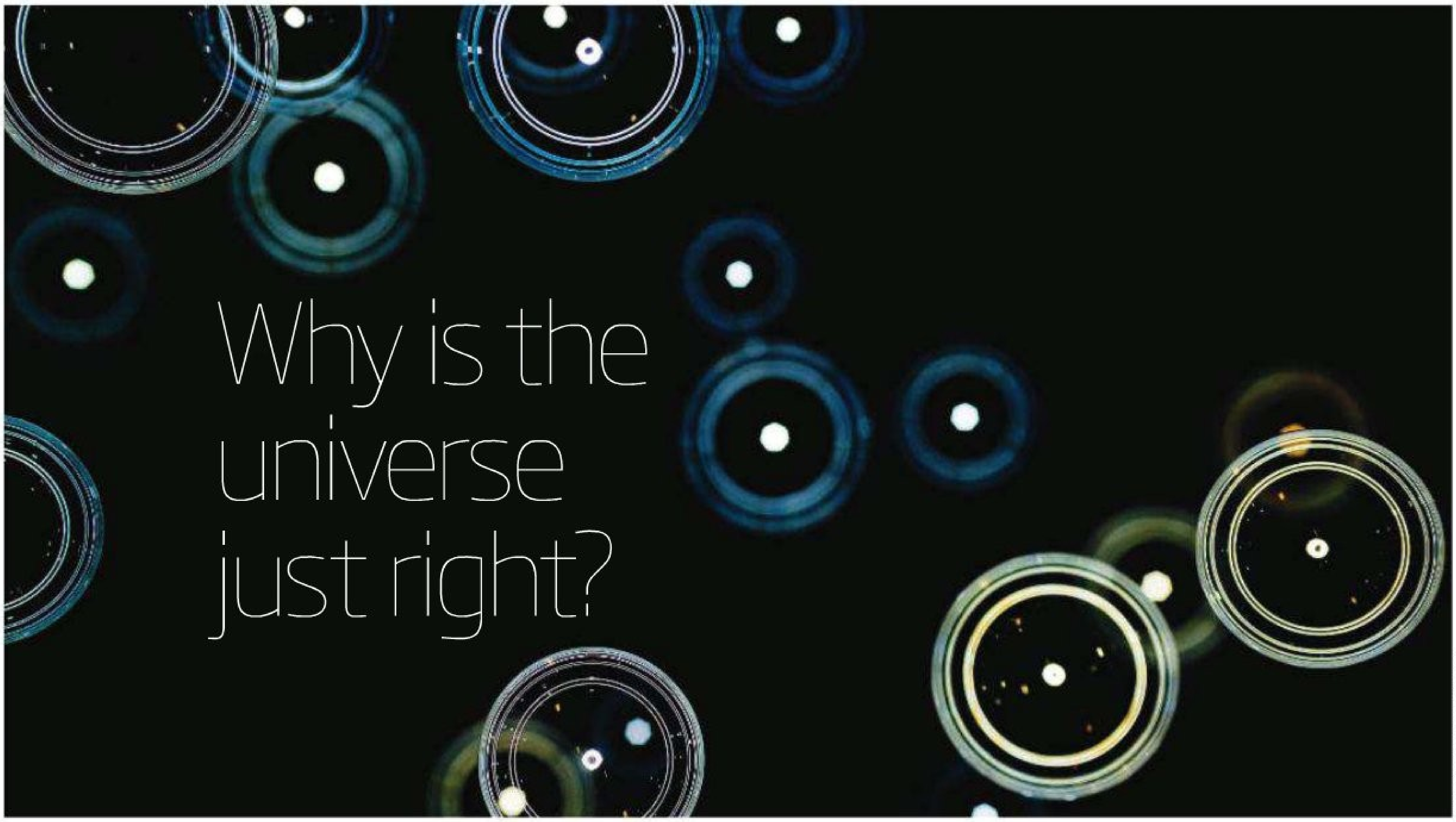
But others believe the theory is not telling the whole story. "Does global workspace theory really explain consciousness, or just the ability to report about consciousness?" asks Seth.

Even so, the idea that consciousness seems to be an emergent property of the brain can take us somewhere. For example, it makes the odds of your own consciousness existing the same as the odds of you being born at all, which is to say, very small. Just think of that next time you suffer angst about your impending return to nothingness.

As for whether individual consciousness can continue after death, "it is extremely unlikely that there would be any form of self-consciousness after the physical brain decays", says philosopher Thomas Metzinger of the Johannes Gutenberg University in Mainz, Germany.

Extremely unlikely, but not impossible. Giuilio Tononi of the University of Wisconsin-Madison argues that consciousness is the outcome of how complex matter, including the brain, integrates information. "According to Tononi's theory, if one could build a device or a system that integrated information exactly the same way as a living brain, it would generate the same conscious experiences," says Seth. Such a machine might allow your consciousness to survive death. But it would still not know what it is like to be a bat.

Anil Ananthaswamy ■



Why is the universe just right?

MARTIN SOEBY/GALLERYSTOCK

IT HAS been called the Goldilocks paradox. If the strong nuclear force which glues atomic nuclei together were only a few per cent stronger than it is, stars like the sun would exhaust their hydrogen fuel in less than a second. Our sun would have exploded long ago and there would be no life on Earth. If the weak nuclear force were a few per cent weaker, the heavy elements that make up most of our world wouldn't be here, and neither would you.

If gravity were a little weaker than it is, it would never have been able to crush the core of the sun sufficiently to ignite the nuclear reactions that create sunlight; a little stronger and, again, the sun would have burned all of its fuel billions of years ago. Once again, we could never have arisen.

"The most likely explanation of fine-tuning is that our universe is merely one of many"

Such instances of the fine-tuning of the laws of physics seem to abound. Many of the essential parameters of nature – the strengths of fundamental forces and the masses of fundamental particles – seem fixed at values that are "just right" for life to emerge. A whisker either way and we would not be here. It is as if the universe was made for us.

What are we to make of this? One possibility is that the universe was fine-tuned by a supreme being – God. Although many people like this explanation, scientists see no evidence that a supernatural entity is orchestrating the cosmos. The known laws of physics can explain the existence of the universe that we observe. To paraphrase astronomer Pierre-Simon Laplace when asked by Napoleon why his book *Mécanique Céleste* did not mention the creator: we have no need of that hypothesis.

Another possibility is that it simply couldn't be any other way. We find ourselves in a universe ruled by laws compatible with life because, well, how could we not?

This could seem to imply that our existence is an incredible slice of luck – of all the universes that could have existed, we got one capable of supporting intelligent life. But most physicists don't see it that way.

The most likely explanation for fine-tuning is possibly even more mind-expanding: that our universe is merely one of a vast ensemble of universes, each with different laws of physics. We find ourselves in one with laws suitable for life because, again, how could it be any other way?

The multiverse idea is not without theoretical backing. String theory, our best attempt yet at a theory of everything, predicts at least 10^{500} universes, each with different laws of physics. To put that number into perspective, there are an estimated 10^{25} grains of sand in the Sahara desert.

Fine-tuned fallacy

Another possibility is that there is nothing to explain. Some argue that the whole idea of fine-tuning is wrong. One vocal critic is Victor Stenger of the University of Colorado in Boulder, author of *The Fallacy of Fine-tuning*. His exhibit A concerns one of the pre-eminent examples of fine-tuning, the unlikeliness of the existence of anything other than hydrogen, helium and lithium.

All the heavy elements in your body, including carbon, nitrogen, oxygen and iron, were forged inside distant stars. In 1952, cosmologist Fred Hoyle argued that the existence of these elements depends on a huge cosmic

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coincidence. One of the key steps to their formation is the "triple alpha" process in which three helium nuclei fuse together to form a carbon-12 nucleus. For this reaction to occur, Hoyle proposed that the energy of the carbon-12 nucleus must be precisely equal to the combined energy of three helium nuclei at the typical temperature inside a red giant star. And so it is.

However, Stenger points out that in 1989 a team at the Technion-Israel Institute of Technology in Haifa showed that, actually, the carbon-12 energy level could have been significantly different and still resulted in the heavy elements required for life.

There are other problems with the fine-tuning argument. One is the fact that examples of fine-tuning are found by taking a single parameter – a force of nature, say, or a subatomic particle mass – and varying it while keeping everything else constant. This seems very unrealistic. The theory of everything, which alas we do not yet possess, is likely to show intimate connections between physical parameters. The effect of varying one may very well be compensated for by variations in another.

"The existence of elements other than hydrogen, helium and lithium depends on a coincidence"

Then there is the fact that we only have one example of life to go on, so how can we be so sure that different laws could not give rise to some other living system capable of pondering its own existence?

One example of fine-tuning, however, remains difficult to dismiss: the accelerating expansion of the universe by dark energy. Quantum theory predicts that the strength of this mysterious force should be about 10^{120} times larger than the value we observe.

This discrepancy seems extraordinarily fortuitous. According to Nobel prizewinner Steven Weinberg, if dark energy were not so tiny, galaxies could never have formed and we would not be here. The explanation Weinberg grudgingly accepts is that we must live in a universe with a "just right" value for dark energy. "The dark energy is still the only quantity that appears to require a multiverse explanation," admits Weinberg. "I don't see much evidence of fine-tuning of any other physical constants." **Marcus Chown** ■

A GOLDILOCKS UNIVERSE

The values of many fundamental constants appear to lie within narrow boundaries that allow life to exist. In 2000, the UK's Astronomer Royal Martin Rees boiled them down to six in his book *Just Six Numbers*

NUMBER
N, the ratio of the strengths of two fundamental forces, electromagnetism and gravity
VALUE
about 10^{36}
IN WHAT WAY IS IT FINE-TUNED?
N determines the minimum size of sun-like stars. It tells us how big an object must be before its gravity can overcome the repulsive electromagnetic forces that keep atomic nuclei apart, igniting nuclear fusion. A larger value would not matter very much, but if N were lower, stars would be smaller and burn through their fuel more quickly, making the evolution of life unlikely.

NUMBER
ε, the proportion of the mass of a hydrogen atom that is released as energy when it is fused into helium inside a star
VALUE
0.007
IN WHAT WAY IS IT FINE-TUNED?
The fusion of hydrogen into helium is the first step in forming heavier elements and thus makes complex chemistry, and life, possible. If ε were slightly smaller, nuclear fusion would be impossible and the universe would consist only of hydrogen. If it were slightly larger, all the universe's hydrogen would have been consumed during the big bang and stars would not exist.

NUMBER
Ω, the ratio of the actual density of matter in the universe to the theoretical "critical density" which would cause the universe to collapse eventually under its own gravity
VALUE
about 0.3
IN WHAT WAY IS IT FINE-TUNED?
Ω is one of the factors that determines how fast the universe expands. If it were higher, the universe would have collapsed long ago; if it were lower, expansion would have been too rapid to allow stars and galaxies to form.

NUMBER
λ, the cosmological constant, or the energy that arises from quantum fluctuations of the vacuum
VALUE
about 0.7
IN WHAT WAY IS IT FINE-TUNED?
λ is the leading contender for the mysterious force that is accelerating the expansion of the universe. A smaller value would not be a problem, but if it were much larger the universe would have expanded so rapidly that stars or galaxies would not have had time to form.

NUMBER
Q, the amount of energy it would take to break up a galactic supercluster as a proportion of the total energy stored in all of its matter
VALUE
about 10^{-5}
IN WHAT WAY IS IT FINE-TUNED?
Q is a proxy measure of the size of the tiny fluctuations in the early universe that were eventually amplified into stars and galaxies. If it were smaller the universe would be inert and structureless; larger and the universe would be dominated by black holes by now. Neither case would support life.

NUMBER
D, the number of spatial dimensions
VALUE
3
IN WHAT WAY IS IT FINE-TUNED?
With four spatial dimensions the orbits of planets would be unstable, while life would be impossible with just two.

How do I know I exist?

IN A nutshell, you don't.

Philosopher René Descartes hit the nail on the head when he wrote "cogito ergo sum". The only evidence you have that you exist as a self-aware being is your conscious experience of thinking about your existence. Beyond that you're on your own. You cannot access anyone else's conscious thoughts, so you will never know if they are self-aware.

That was in 1644 and little progress has been made since. If anything, we are even less sure about the reality of our own existence.

It is not so long ago that computers became powerful enough to let us create alternative worlds. We have countless games and simulations that are, effectively, worlds within our world. As technology improves, these simulated worlds will become ever more sophisticated. The "original" universe will eventually be populated by a near-infinite number of advanced, virtual civilisations. It is hard to imagine that they will not contain autonomous, conscious beings. Beings like you and me.

According to Nick Bostrom, a philosopher at the University of Oxford who first made this argument, this simple fact makes it entirely plausible that our reality is in fact a simulation run by entities from a more advanced civilisation.

How would we know? Bostrom points out that the only way we could be sure is if a message popped up in front of our eyes saying: "You are living in a computer simulation." Or, he says, if the operators transported you to their reality (which, of course, may itself be a simulation).

Although we are unlikely to get proof, we might find some hints about our reality. "I think it might be feasible to get evidence that would at least give weak clues," says Bostrom.

Economist Robin Hanson of George Mason University in Fairfax, Virginia, is not so sure. If we did find anything out, the operators could just rewind everything back to a point where the clue could be erased. "We won't ever notice if they don't want us to," Hanson says. Anyway, seeking the truth might even be asking for trouble. We could be accused of ruining our creators' fun and cause them to pull the plug.

Zombie invasion

Hanson has a slightly different take on the argument. "Small simulations should be far more numerous than large ones," he says. That's why he thinks it is far more likely that he lives in a simulation where he is the only conscious, interesting being. In other words, everyone else is an extra: a zombie, if you will. However, he would have no way of knowing, which brings us back to Descartes.

Of course, we do have access to a technology that would have looked like sorcery in Descartes's day: the ability to peer inside someone's head and read their thoughts. Unfortunately, that doesn't take us any nearer to knowing whether they are sentient. "Even if you measure brainwaves, you can never know exactly what experience they represent," says psychologist Bruce Hood at the University of Bristol, UK.

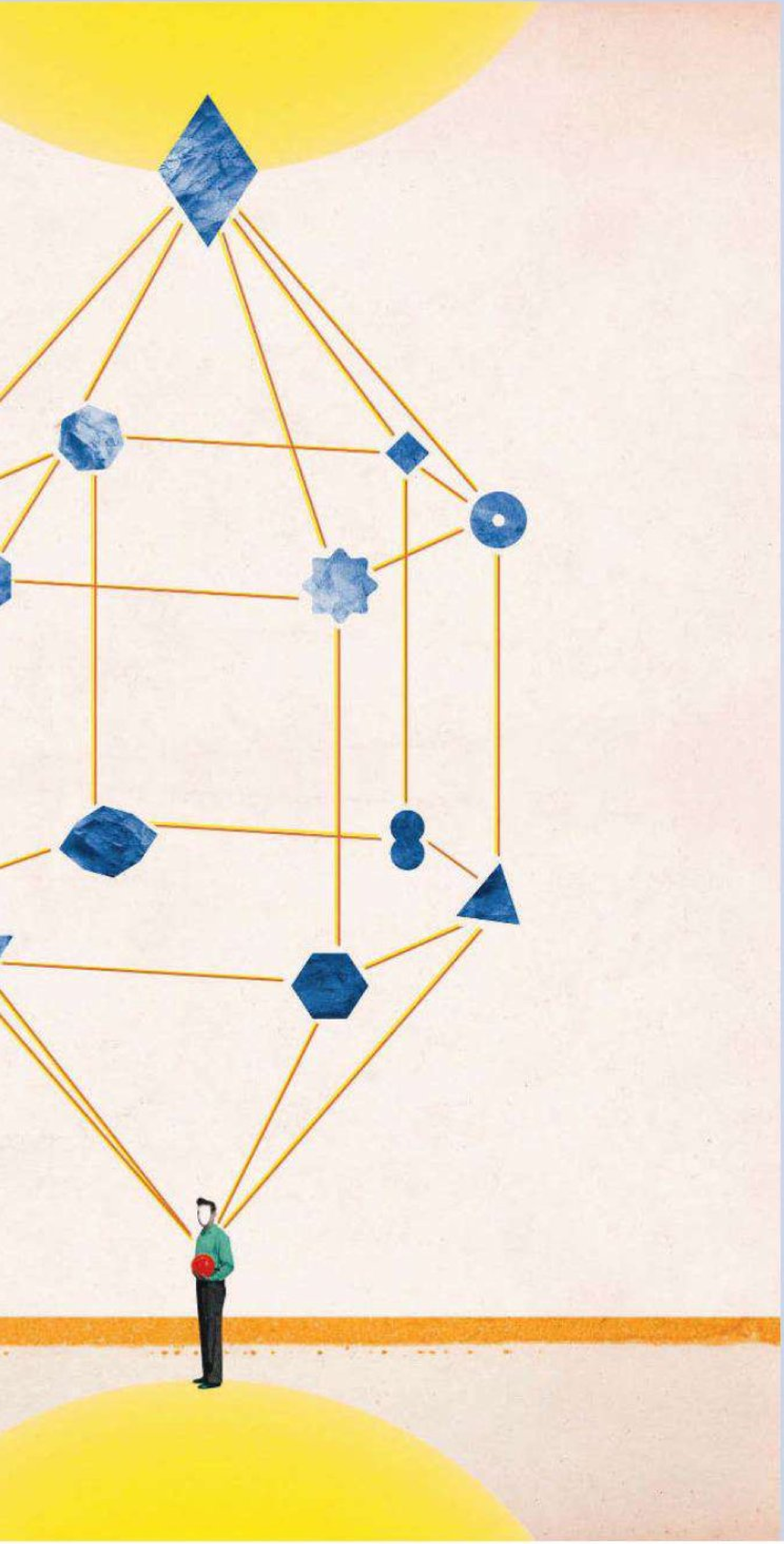
If anything, brain scanning has undermined Descartes's maxim. You, too, might be a zombie. "I happen to be one myself," says Stanford University philosopher Paul Skokowski. "And so, even if you don't realise it, are you."

"I happen to be a zombie myself and even if you don't realise it, so are you"

Skokowski's assertion is based on the belief, particularly common among neuroscientists who study brain scans, that we do not have free will. There is no ghost in the machine; our actions are driven by brain states that lie entirely beyond our control. "I think, therefore I am" might be an illusion.

So, it may well be that you live in a computer simulation in which you are the only self-aware creature. I could well be a zombie and so could you. Have an interesting day.

Michael Brooks ■



Is there more than one me?

FAR, far away, in a galaxy with a remarkable resemblance to the Milky Way, is a star that looks remarkably like the sun. And on the star's third planet, which looks like a twin of the Earth, lives someonewho, for all the world, is you. Not only do they look the same as you and lead an identical life, they are reading this exact same article – in fact, they are focused on this very line.

Weird? I've hardly started. In fact, there are an infinite number of galaxies that look just like our own, containing infinite copies of you and your loved ones leading lives, up until this moment, that are absolutely identical to yours.

The existence of these parallel worlds is not just idle speculation. It does not depend on exotic theories such as the multiverse or the "many worlds" interpretation of quantum mechanics, in which the universe constantly bifurcates. It is an unavoidable consequence of the standard theory of our universe.

"Parallel worlds are an unavoidable consequence of our standard theory"

All this needs some explanation. The furthest we can see is the distance light has been able to travel since the universe was born 13.7 billion years ago. Light from objects further away has not arrived yet. They are beyond our cosmic horizon.

Yet we know there is more to the universe. Radiation left over from the big bang appears to confirm that the cosmos went through a fleeting phase of superfast expansion known as inflation. And, according to inflation, there is effectively an infinite amount of universe out there.

So our observable universe is akin to a bubble and beyond it lies an infinite number of other bubbles that have a similarly restricted view. Each one experienced the same big bang we did and has the same laws of physics. Yet the initial conditions were slightly different, so different stars and galaxies congealed out of the cooling debris.

Despite this, finding another universe just like ours seems unlikely. Yet quantum mechanics tells a different story. Zoom in and you'll find that the universe is grainy, with space resembling a chessboard. ›

JIRAYU KOO

"If you could travel far enough you would come across a universe identical to ours"

Immediately after the big bang, our observable universe – our bubble – contained only a few "squares". So there were only a few places for the matter that seeded the formation of today's galaxies.

The neighbouring bubbles contained a slightly different arrangement of matter. So did their neighbours. And so on. But eventually you run out of possible ways to arrange the matter in the bubbles. Eventually you come across an identical bubble to ours. As a result, there are a finite number of ways history can play out. Given that the universe is infinite, there must be a infinite number of histories just like ours, plus an infinite number of different ones.

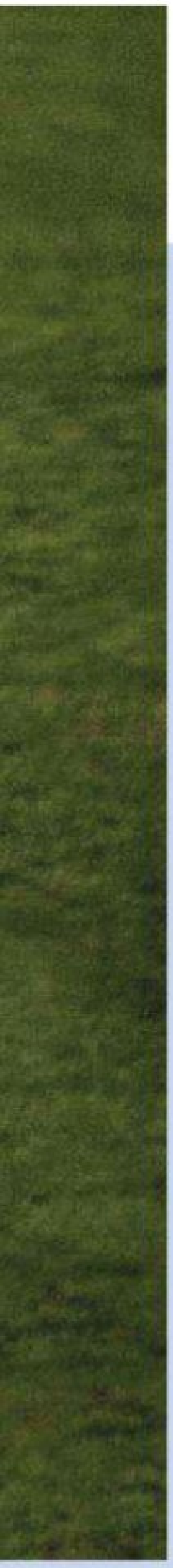
If you could travel far enough in any direction today, you would come across a universe identical to our observable universe right down to the last detail, including you. Max Tegmark at the Massachusetts Institute of Technology has worked out that to find your closest identical copy you would have to travel $10^{10^{28}}$ metres. That corresponds to 1 followed by 10 billion billion billion zeroes.

Sadly that means you will never be able to meet your other you. With each passing moment, more of the universe appears over the horizon. Yet by the time our observable universe had expanded to encompass your nearest doppelganger, all the stars will have long burned out.

Remarkably, the only way to evade this bizarre conclusion is if our standard pictures of cosmology and quantum theory are wrong. Unsettled? You're not alone. Cosmologist Alexander Vilenkin of Tufts University in Medford, Massachusetts, has been working on such ideas for more than 25 years. "I have never been happy with the idea that there are an infinite number of Alexander Vilenkins out there," he says. "Unfortunately, I think it is likely to be true."

It is worth reiterating that this is the most basic and uncontroversial of all conceptions of multiple universes. There are many other "multiverse" theories. For instance, string theory, which views the fundamental building blocks of matter as ultra-tiny, vibrating strings of mass-energy, predicts the existence of other universes. The fact that the universe is apparently fine-tuned for us may be telling us of the existence of other universes with different laws of physics (see page 34). And then there is the many worlds interpretation of quantum mechanics in which all possible histories and futures – including yours – play out in separate universes. Many worlds is a minority view but if it is true there is a universe somewhere where you are Wimbledon champion.

Tegmark has classified such multiverses into a hierarchy of ever bigger versions (arxiv.org/abs/astro-ph/0302131), but nobody yet knows if or how all these versions mesh together. The multiverse is an emerging idea; science in the making. The dust has yet to settle and give us – and our infinite doppelgangers – a consistent and clear picture. Marcus Chown ■



Will we die out?

WRESTLING with mortality is difficult. But it is not just the prospect of personal annihilation that we have the dubious luxury of contemplating. One day, humanity itself will cease to exist. Like all species, we will either become extinct or evolve into something else. From a purely existential perspective the latter sounds infinitely preferable. So what are our chances?

First the good news: time is on our side. The average mammalian species lasts around 1 million years before it evolves into something else or dies out. By that reckoning, *Homo sapiens* has some 800,000 years to play with.

But that's assuming we are just another mammal. It is tempting to think that we have changed the game so drastically that the normal rules do not apply. Have we?

Let's deal with evolution first. There are two key ingredients: variation and selection. The key generator of variation is genetic mutation, and we certainly haven't broken free of that. "If anything, we are probably increasing the rate of mutational change," says Christopher Wills at the University of California, San Diego, noting that our world is awash with human-made mutagens.

But it is conceivable that we have changed the rules of natural selection. In general, individuals who are better adapted to their environment are more likely to survive and pass on their genes. Is that still true for humans when modern medicine and technology have increased everybody's ability to survive?

It seems that it is. Advances in genomic analysis make it clear that natural selection is still alive and kicking. One study found that around 1800 gene variations have become common in the past 50,000 years (*Nature*, vol 437, p 1299). Another study found that selection actually accelerated over this time, perhaps because by colonising the world and creating complex cultures we have subjected ourselves to a wide variety of new selection pressures (*Proceedings of the National Academy of Sciences*, vol 104, p 20753).

"There is no reason to think that humans will stop evolving," says Stephen Stearns at Yale University, whose research reveals continuing evolution in modern populations. "The only question is in what ways will we change as we continue to evolve."

"The only question is in what ways we will change as we continue to evolve"

LARS HANSEN/GALLERY STOCK

Without strong, universal forces shaping our entire species, we could evolve aimlessly, but even then the cumulative effects would be significant. Palaeoanthropologist Chris Stringer from the Natural History Museum in London foresees a distant future hundreds of thousands of years from now when our descendents have accrued so many genetic and physical changes that they could no longer interbreed with today's humans, and would therefore be a new species.

Presumably it would be recognisable as a hominin, but what exactly it might look like is anybody's guess.

Dramatic events

Dramatic events would speed things up. "A pandemic could swiftly reduce the human population by 90 per cent or more," says philosopher Dan Dennett from Tufts University in Medford, Massachusetts. Depending on who was able to survive, the humans that passed through this bottleneck could emerge as a new species.

Extreme climate change could have the same effect. And if some people left Earth and set up home elsewhere, speciation seems inevitable, says Wills.

Advances in reproductive technology might allow us to direct our own evolution by picking the characteristics we most desire for our offspring. We could even choose to become superhuman as advances in computing, robotics, biotechnology and nanotechnology enable us to rebuild and extend our bodies and brains. "Very few people will opt out completely," predicts futurologist Ray Kurzweil. "Kind of like the Amish today."

Of course extinction is also a possibility. In the wild, extinctions occur for a variety of reasons, with competition from other species, predation and loss of genetic diversity among the leading causes. Given our huge population and our dominance over other species none of these seem to be a threat.

But we may well do unto ourselves what we have done to so many other species and cause enough environmental destruction to drive ourselves to extinction. We also have no control over phenomena that have wreaked havoc in the past, such as asteroids, supervolcanoes and the like.

Meanwhile, our species' indomitable curiosity may lead us to create a new form of annihilation – perhaps with atomic particles, "grey goo" or a lethal bioengineered life form.

Although we can't predict our future, we can say one thing for certain: our existence is just a passing whim. **Kate Douglas** ■

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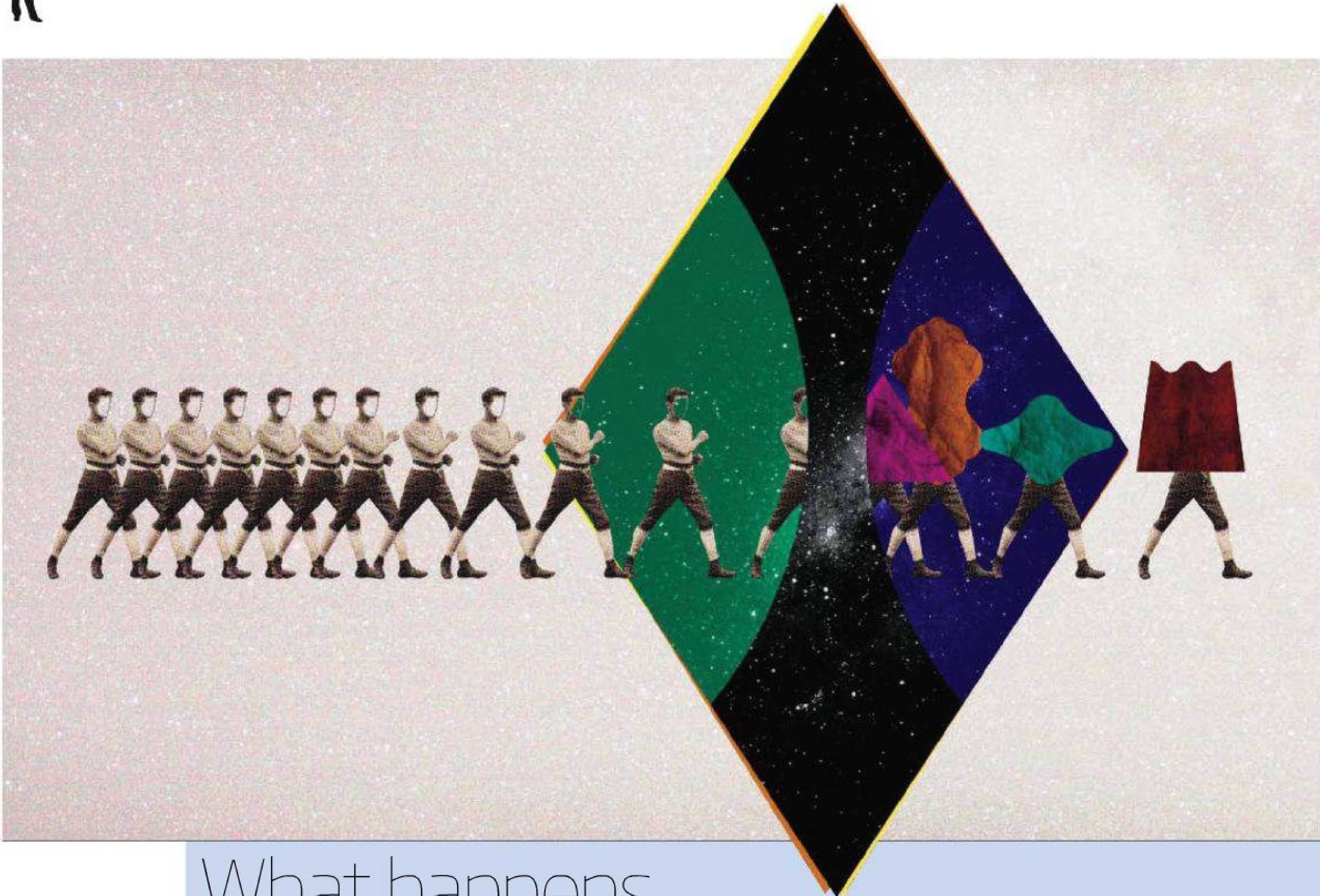

JIRAYU KOO

What happens when we become obsolete?

OUR brains are incredible. They are the most complicated things in the universe that we know of. And yet there is no reason to think that they are anything other than flesh-and-blood machines – which means we should able be build machines that can emulate them.

Artificial intelligences on a human level would probably not remain at that level for long. AIs are expected to become smarter than us before 2050 (*Technological Forecasting and Social Change*, vol 78, p 185). A few researchers even think it could happen in the next decade.

For the first time, we would no longer be the most intelligent beings on the planet. The consequences could be stupendous. In 1993, the mathematician and sci-fi author Vernor Vinge dubbed this point "the singularity", because he saw it as a turning point that would transform the world. So what will happen to us? Nobody really knows. "It's like cockroaches and dogs trying to predict the future of human technology," says Ben Goertzel, leader of OpenCog, an open source project to create AIs with general intelligence.

That hasn't stopped people from considering various scenarios (*Artificial Intelligence*, vol 171, p 1161). One distinct possibility is that AIs will exterminate us, which seems especially likely if the first are robots spawned in military labs.

Physicist and author David Deutsch of the University of Oxford has suggested that the way to avoid "a rogue AI apocalypse" is to welcome AIs into our existing institutions. But even if that were feasible, how could we compete with smarter and faster beings capable of working tirelessly 24/7 without ever getting tired or ill? They are likely to rapidly surpass all our scientific, technological and artistic achievements. Our precocious creations would soon end up owning the place.

One way or another, then, AIs look set to take over. One cause for optimism is that they will not be stuck on the planet like us fragile humans. A 1000-year trip to Epsilon Eridani is not so daunting if you can just turn yourself off until you get there. In fact, AIs may prefer to leave Earth. "They will probably work better in space, where it's supercool," says Goertzel.

So we are not necessarily doomed to compete with AIs for energy and resources – a battle we are not likely win. With a galaxy to colonise, they may be content to let us keep our damp little planet. They might be as indifferent to us as we are to ants, or

"Artificial intelligences might be as indifferent to us as we are to ants"

manage Earth as a kind of nature reserve.

That might seem like a futile existence. But most people won't be too bothered by the knowledge that they are inferior, Goertzel thinks – not as long as there's sex, drugs and rock'n'roll. Some people will continue to do science and art for the sheer joy of it, regardless of how poor their work is in comparison to the machines'.

For Goertzel, the best case scenario would be that the AIs provide a "human reserve" for those who want to stay as they are, while offering those who want it the chance to slowly transform themselves into something more than humans. "You would want it to be a gradual change, so at each step of the way you still feel yourself."

Stay human and die, or transform into a near-immortal superintelligence – what a choice. Michael Le Page ■

Am I the same person I was yesterday?

IT'S THERE when we wake up and slips away when we fall asleep, maybe to reappear in our dreams. It's that feeling we have of being anchored in a body we own and control and perceive the world from within. It's the feeling of personal identity that stretches across time, from our first memories, via the here and now, to some imagined future. It's all of these tied into a coherent whole. It's our sense of self.

Humans have pondered the nature of the self for millennia. Is it real or an illusion? And if real, what is it, and where do we find it?

Different philosophical traditions have reached radically different conclusions. At one extreme is the Buddhist concept of "no self", in which you are merely a fleeting collection of thoughts and sensations. At the other are dualist ideas, most recently associated with the philosopher Karl Popper and Nobel laureate and neuroscientist John Eccles. They argued that the self exists as a separate "field" which interacts with and controls the brain.

Modern science, if anything, is leaning towards Buddhism. Our sense of self is not an entity in its own right, but emerges from general purpose processes in the brain.

Seth Gillihan and Martha Farah of the University of Pennsylvania in Philadelphia have proposed a view of the self that has three strands: the physical self (which arises from our sense of embodiment); the psychological self (which comprises our subjective point-of-view, our autobiographical memories and the ability to differentiate between self and others); and a higher level sense of agency, which attributes the actions of the physical self to the psychological self (*Psychological Bulletin*, vol 131, p 76).

We are now uncovering some of the brain processes underlying these strands. For instance, Olaf Blanke of the Swiss Federal Institute of Technology in Lausanne and colleagues have shown that the physical sense of self is centred on the temporo-parietal cortex. It integrates information from your senses to create a sense of embodiment, a feeling of being located in a particular body in a particular place. That feeling can be spectacularly disrupted if the temporo-parietal cortex receives contradictory inputs, causing it to generate out-of-body experiences (*New Scientist*, 10 October 2009, p 34).

Being in charge

It is proving harder to find the site of our sense of agency – that feeling of being in charge of our actions. In one functional MRI study volunteers with joysticks moved images around on a computer screen. When the volunteer felt he had initiated the action, the brain's anterior insula was activated but the right inferior parietal cortex lit up when the volunteer attributed the action to the experimenter (*Neuroimage*, vol 15, p 596).

But other researchers, using different experiments, have identified many more brain regions that seem to be responsible for the sense of agency.

Within the brain, it seems, the self is both everywhere and nowhere. "If you make a list [for what's needed for a sense of self], there is hardly a brain region untouched," says cognitive philosopher Thomas Metzinger of Johannes Gutenberg University in Mainz, Germany. Metzinger interprets this as meaning the self is an illusion. We are, he says, fooled by our brains into believing that we are substantial and unchanging.

Mental disorders also make it abundantly clear that this entity that we regard as inviolate is not so. For example, those suffering from schizophrenia harbour delusions that experiences and thoughts are being implanted in their brain by someone or something else. "In some sense, it's a disorder of the self, because these › people are doing things, but they are not feeling as if they themselves are doing them," says Anil Seth of the University of Sussex in the UK. "That's a disorder of agency."

Another striking condition is depersonalisation disorder, in which people feel a persistent sense of detachment from their body and thoughts. Even the narrative we have of ourselves as children growing up, becoming adults and growing old, which is carefully constructed from our bank of autobiographical memories, is error prone. Studies have shown that each time we recall an episode from our past, we remember the details differently, thus altering ourselves (*Physics of Life Reviews*, vol 7, p 88).

"Even the narrative we have of ourselves growing up is error prone"

So the self, despite its seeming constancy and solidity, is constantly changing. We are not the same person we were a year ago and we will be different tomorrow or a year from now. And the only reason we believe otherwise is because the brain does such a stellar job of pulling the wool over our eyes.
Anil Ananthaswamy ■

YOUR TEMPORARY BODY

YOUR lifelong sense of self is intimately tied to your body, but how much of that body stays with you for life? The answer is surprisingly little. If you live to be, say, 75 years old, the vast majority of your body will be younger than "you" are.

The cells lining your gut, for example, are replaced about every five days. The outer layer of your skin turns over every two weeks and you get a new set of red blood cells every four months. That is not so surprising given that these cells are on the frontline of wear and tear. But the rest of your body also needs a refit from time to time.

Using a variant of carbon dating, a team led by Jonas Frisén at the Karolinska Institute in Stockholm, Sweden, have discovered that the average age of a bone cell is 10 years, a muscle cell 15 years and a fat cell about 9.5 years. Your heart cells are on average six years younger than you; if you live beyond 50 about half of the cells in your heart will have been replaced.

The exception is your brain, most of which stays with you for life. But renewal happens here too. There are cells in your cerebellum and hippocampus that are younger than you.

All of which puts the idea of lifelong personal identity into perspective. Imagine being given a car on the day you are born. Over the next 70 years you gradually replace almost every part, from the tail pipe to the headlights. A few bits and pieces remain, but is it really the same car? Think about it. Graham Lawton ■

How will it all end?

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IT IS three weeks after the end of time, and at the Post-Universe Conference of Cosmology and Other Loose Ends, Professor Adams is standing in front of a restless audience telling them in smug tones what they already know. The universe ended in precisely the way that his own theory predicted, in a rather uncomfortable event known as the "Big Slurp".

Of course, by definition there can be no such meeting and no way to prove or disprove a theory about the end of all things. But this untestable question tugs at our morbid curiosity. In recent years physicists have been peering deep into the tea leaves of time to try to foretell our ultimate fate. Will the universe be finished off by a big freeze, a big rip, a big crunch... or a big something else?

"The foundations would be yanked from under us, we would cease to exist"

To make a first attempt at this long-range forecast, we can just extrapolate current trends. Today's universe is expanding, and the expansion is accelerating as the repulsive agent called dark energy takes hold. Projecting our ballooning universe into the future, we seem to be doomed to a dingy end. Most of known space will fly off into the darkness, isolating our local group of galaxies in its own lonely pocket universe. The stars will fade and eventually matter itself may fall apart as protons decay, leaving behind nothing but a wispy gas of fundamental particles, ever-more tenuous and ever colder.

Or it could be worse. We don't know what dark energy is, so we don't know whether it will remain constant into the distant future. The repulsion might get stronger as space expands. If this growing "phantom energy" really gets going, the eventual end will come in a split second of cosmic violence called the big rip, as planets, molecules and finally subatomic particles are shredded. Then again, some form of attractive cosmic force could arise to overpower today's repulsion and pull the galaxies back together again, crushing everything to a point of infinite density – a big crunch.

Fortunately, neither of these violent ends will happen any time soon. Observations show that dark energy is changing slowly if at all, implying that a big rip or big crunch is probably tens of billions of years away at least.

An even more disquieting possibility could be just around the corner, however. The very nature of space-time may be unstable. According to string theory, for example, the vacuum of space seems to be free to adopt any of a bewildering variety of different states, which would support different kinds of forces and particles, even different numbers of dimensions. Our apparently firm reality might suddenly decay into a state with lower energy. The foundations of our existence would suddenly be yanked from under us and we, along with any familiar forms of matter, would cease to exist.

Transmogrification

If the vacuum does decay, it will happen at some point in space first, and then race outwards in a spherical shock-front of grisly transmogrification travelling at just a tiny fraction less than the speed of light. In theory we would get some warning of approaching doom, but not a lot. "Much less than a microsecond," says cosmologist Alexander Vilenkin of Tufts University in Medford, Massachusetts. At this very moment a wave of ultimate weirdness might be turning the moon into ectoplasm and bearing down on Earth.

Vilenkin thinks that such an end is almost inevitable; that unless a big rip gets us first, the vacuum will eventually drop into a negative energy state. After the transformation, space would then exert strong gravity of its own, pulling what's left of the universe into a big crunch.

That, however, need not be the end of everything. If our own universe is merely one within an ever-branching and growing multiverse, as some theories predict, then the cosmos as a whole will endure even if each of its branches has a limited lifespan. And for our local universe there remains the hope of resurrection. Today's physical theories break down at a big crunch or a big rip, allowing the possibility that a new universe could rise from the ashes (in a big bounce, or some other big as-yet-unnamed thing). And in the case of a big freeze, there will be so much time to play with that a random quantum fluctuation might spark a whole new big bang. Perhaps that impossible cosmology conference could happen after all. Perhaps existence will never end. Stephen Battersby ■

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