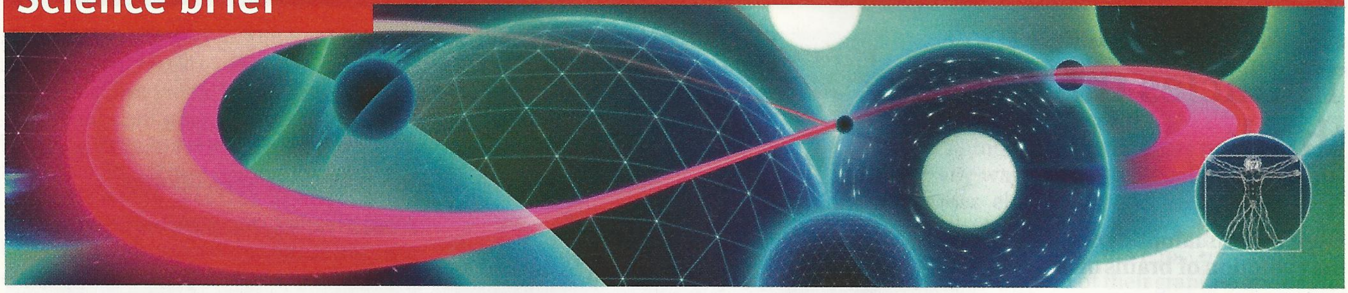


Is the universe alone?

Multiversal truths

In our second brief on scientific mysteries, we ask whether the world might make more sense if other universes existed

THE expansion of the universe, starting with the Big Bang, is a well-attested physical phenomenon. But over the past 400 years the universe has also undergone a different sort of expansion—a mental one. This began with a big bang too, the shattering in the early 17th century by astronomers such as Galileo Galilei and Johannes Kepler of the crystal spheres hitherto supposed to have held heavenly bodies on their proper courses. That led people to realise the so-called fixed stars, the celestial backdrop on which the movement of the planets is played out, are vastly farther away than had been believed, which led in turn to an understanding that the Milky Way, as seen in the night sky, is actually the view from Earth of a gigantic system of stars, of which the sun is a single, lowly member.

For a time the Galaxy, as this star system became known from the Greek name for the Milky Way, was thought to be the whole universe. Then, about 100 years ago, as telescopes grew in size and power, astronomers came to realise it is only one of many such groups of stars, and the mental picture expanded again, to where it is today—namely a galaxy-filled space which dates back 13.8 billion years, and whose evolution through that period is now understood in some detail.

But the question of what constitutes universality has not been laid to rest. Some physicists suspect that just as the Galaxy—once thought unique—is merely an example of a general phenomenon, so too the universe may not be reality's final frontier. Their idea is that there is not so much a universe as a multiverse. Indeed, there may be more than one sort of multiverse. These are grand claims, and hard to test. But, if true, they might solve some of the most puzzling questions of existence.

One of the leading proponents of multiverses is Max Tegmark of the Massachusetts Institute of Technology. Dr Tegmark suggests a fourfold classification of possible types of multiverse. It has to be said that only three of these four seem comprehensible to mere mortals. But they are a good place to start.

A video to accompany this brief is available at economist.com/sb2015

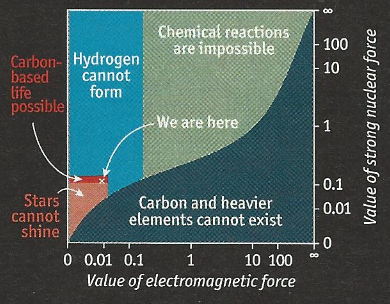
Worlds within worlds

The simplest Tegmark multiverse is an infinite extension of the familiar. Modern telescopes can see a long way, but the finite speed of light, and the finite age of the universe, mean they can peer only at things within a limited radius. Were space static, this horizon, known as the Hubble radius, would be 13.8 billion light-years away. In fact, because of the expansion of space after the Big Bang, the Hubble radius is 42 billion light-years.

How far things stretch beyond the Hubble radius no one knows. But some theories suggest they stretch to infinity. If that were true, then all permitted arrangements of matter might exist somewhere. They might even exist in infinite numbers. There might be an infinite number of Earths with readers reading this article on them. In effect, these places, cut off from one another by their own Hubble radii, would be isolated universes as the term is currently understood by science.

The Goldilocks zone

Consequences of varying physical constants



Source: Luke Barnes, University of Sydney

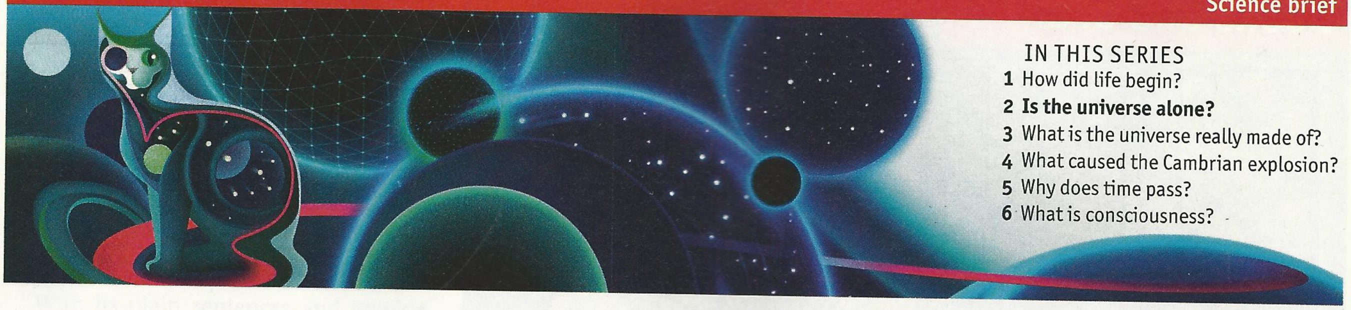
That may sound mind-boggling, but it is pedestrian compared with the second type of Tegmark multiverse. The first type assumes the laws of physics are the same everywhere. The second suggests they can vary from one universe to another. Tinkering with physics's laws would change the nature of reality, so these universes would be different—perhaps very different—from each other.

In the third type of Tegmark multiverse, as in the first, the laws of physics are the same from one to another. In this type, though, the component universes are continually separating from each other as time passes. At every moment within such a multiverse, all possible futures allowed by the uncertainties of quantum mechanics actually happen somewhere, and that somewhere constitutes a new universe.

The final type of multiverse Dr Tegmark proposes is one in which any and all coherent systems of mathematics describe a physical reality of some sort. What this translates to in practice is hard to conceive of. It is more the province of metaphysics than physics. But the other three types of multiverse, though they push the bounds of physical theory, do not overstep them. Moreover, if the second and third type did turn out to be true, each would solve a profound problem of reality that is hard to deal with if the observable universe really is the be-all and end-all of everything.

Believers in a type-two multiverse think each of the universes within it began with something like the Big Bang that gave birth to the universe familiar to human beings. The Big Bang's defining characteristic was a phenomenon called inflation. A very short time after the universe came into existence it underwent a very large expansion. By very short, physicists mean within a trillionth of a trillionth of a trillionth of a second of the beginning. By very large, they mean, possibly, infinite.

The idea of inflation was proposed in 1979 by Alan Guth. In the years after Dr Guth published his idea Andrei Linde extended it to suggest that the universe emerged from what he called an inflationary field. But if this field can spawn the universe humans see, there is no reason why it cannot spawn others. There is also no reason why the universes so spawned should have the same laws of physics as one another. Indeed, there is quite a good



reason why they should not.

This reason was worked out a decade or so ago by several physicists, including Leonard Susskind, of Stanford University, and Martin Rees, Britain's Astronomer Royal. They observed that the equations of string theory, the deepest sort of explanation for the way matter and energy are organised into particles and fields, have a lot of possible solutions. Some correspond to what observable reality has to offer. Most do not. But Dr Susskind and Lord Rees suggest that those other solutions do describe reality in other universes.

This idea is intellectually pleasing because it bears on a puzzling problem: why are conditions in the observable universe so finely tuned to the needs of mankind? Fiddle only slightly with some of physics's constants, such as the strength of electromagnetism or the strength of the force that binds atomic nuclei, and the resulting universe would be unable to sustain humans, or anything resembling them (see chart on previous page).

The fine-tuning problem, as this puzzle is known, is solved by some by the invocation of a Creator who made things just right for people to evolve. If universes are commonplace, though, and the rules that govern them vary, then the fine-tuning problem—and thus the need for a human-friendly Creator—vanishes. It is no longer a fluke that at least one universe has the right conditions for intelligent life to emerge, since there are also zillions that do not. And it is inevitable that any intelligent life which did evolve would observe that it lived in a universe whose physical laws were just right to support its existence.

Type-two multiverses, then, offer an answer to the fine-tuning problem. Type-three multiverses similarly deal with one of 20th-century physics's kludges, the so-called Copenhagen interpretation of quantum theory. Indeed, they were devised for precisely that purpose.

Before 1900 physicists had, broadly, divided the universe into particles and waves. This division applied particularly to fundamental things like light (waves) and atoms (particles). In the 20th century's early decades, though, it became apparent that light waves sometimes behave like particles, and particles sometimes behave like waves. This "wave-particle duality" is one of the bases of quantum mechanics, and is described, mathematically, by what is known as a wave function.

As Erwin Schrödinger showed in the 1920s, in his well-known uncertainty principle, a wave function is pregnant with possibility about where the particle it describes actually is, and thus what it might do next. Some outcomes are more likely than others. But observation shows, of course, that only one outcome happens. Schrödinger, in collaboration with Niels Bohr, suggested that which it is, is somehow fixed by observing the particle. In the jargon, the act of observation "collapses" the wave function into a single outcome.

Although quantum behaviour was discovered by studying individual elementary particles, and light, it applies to all objects, however large. Schrödinger illustrated this with a famous thought experiment in which a cat sits in a box containing a lethal device, triggered by the decay of a single radioactive atom. Radioactive decay being a wave-function-governed phenomenon, this turns the cat, too, into a creature governed by quantum mechanics. Its wave function is in a state of being both dead and alive until the box is opened, the cat observed, and the wave function collapses one way or the other. Bohr and Schrödinger worked in Copenhagen at the time, and that city has become eponymous for their ideas.

In the 1950s, however, an American called Hugh Everett offered a different interpretation of what is going on. The universe itself, Everett observed, can be described by a wave function. He reasoned that, instead of the wave function—be it of a particle, of a cat in a box, or even of the whole universe—collapsing, all the outcomes these wave functions allow actually will occur. As a consequence, the universe is constantly undergoing multiple fission into daughter universes, each with its own reality (the cat is dead; the cat is alive). Any observer, though (or, rather, any future version of the same observer in one of these universes) will see only one outcome. From his point of view, the wave function will appear to have collapsed. But that is not what has really happened.

Bet your life?

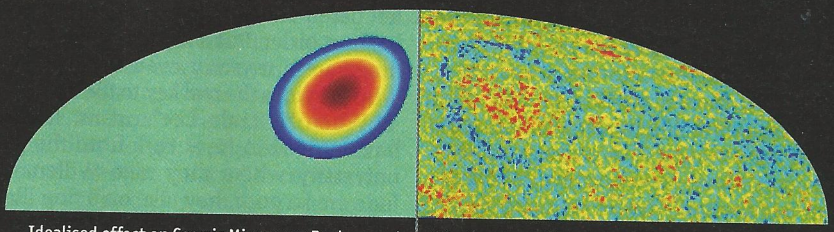
Intellectually, this is a more satisfying explanation than the Copenhagen interpretation, because no one has been able to explain clearly just how the act of observation causes a wave function to collapse. But is it true?

That, of course, is the crucial question for all versions of multiversal theory. And there are a few ideas about how it might be asked. Stephen Feeney of Imperial College, London, for example, wonders if universes in a type-two multiverse might butt up against each other, leaving imprints in each other's space, as adjoining soap bubbles might. Such imprints, he reasons, would show up in the cosmic microwave background created shortly after the Big Bang (see diagram)—though none has yet been found.

There is also an experiment which, though it would not prove the reality of a type-three multiverse, would certainly test the experimenter's belief in it. This experiment is Quantum Russian roulette, a version of Schrödinger's cat in which the experimenter stands in for the unfortunate animal. In some futures, he will be killed. In some, he will remain alive. But since, from his point of view, he will be aware only of the latter, he will always perceive that he survives. Any takers? ■

If worlds collide...

Coloured by temperature deviation from mean



Idealised effect on Cosmic Microwave Background (CMB) of a collision between type-two universes

What such a collision might actually look like in the real CMB

Source: Feeney *et al*, 2011