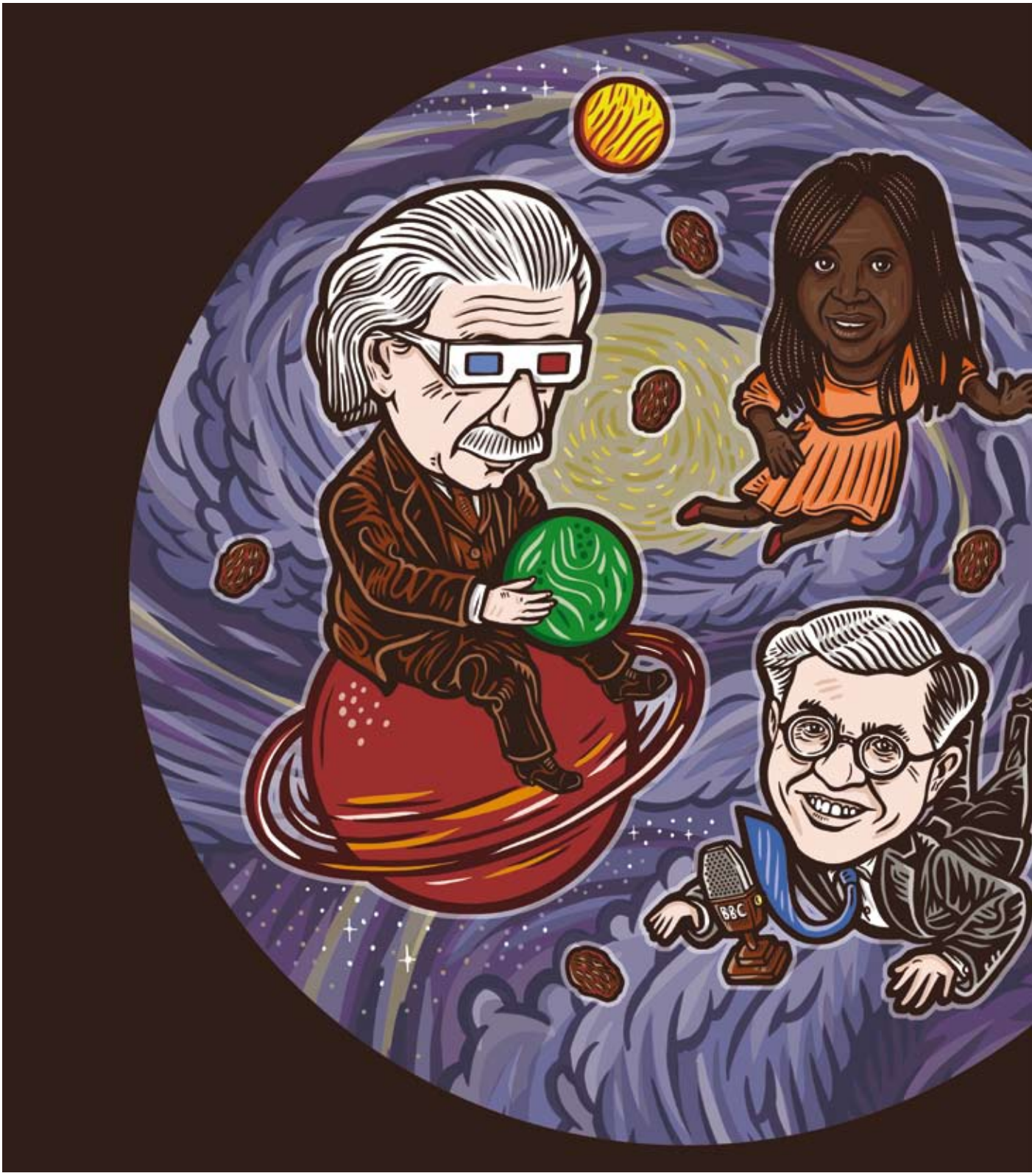


MATTHEW GREEN. IN THE PICTURE ARE ALBERT EINSTEIN, MAGGIE ADERIN-POCOCK AND SIR FRED HOYLE

Ten cosmic myths

Why is the sky at night dark? What does gravity do? How big is the universe? Does time go forwards or backwards? The answers may surprise you . . .

By Marcus Chown

Myth 1
The Big Bang happened in a particular place

The term Big Bang was coined by the British astronomer Sir Fred Hoyle in a BBC radio broadcast in 1949. It stuck, despite the fact that it conveys a totally misleading image of an "explosion". In reality, the Big Bang was utterly different from any explosion we are familiar with.

In a conventional explosion, shrapnel flies outwards into a pre-existing space. But, in the case of the Big Bang, there was no pre-existing space. All space – not to mention matter, energy, and even time – burst into being and began expanding spontaneously. Also, in a conventional

explosion, stuff flies outwards from a single point in space. The Big Bang, however, did not occur at a particular location. Every point of space exploded away from every other point in space.

It has become conventional to liken the expansion – which continues today with the galaxies like our own Milky Way flying apart from each other – to the rising of a cake studded with raisins. As the cake swells, every raisin recedes from every other raisin, and none is the centre of the expansion. The analogy with our universe is not, of course, perfect since a cake has an edge and the universe, as far as we know, does not. It either goes on for ever or folds back on itself just like a higher-dimensional version of the surface of a football.

The key thing to remember is that we, as three-dimensional beings, can never completely grasp a four-dimensional thing. And the universe is a 4D thing, extending in three dimensions of space and one of time, or, as Einstein realised, four dimensions of a curious blend known as "space-time". Consequently, we can only ever catch glimpses – for instance, the one afforded by the image of the rising cake. If you are finding all this hard to grasp, therefore, welcome to the club.

Myth 2

If the universe is expanding, the Solar System must be expanding too

The universe is certainly expanding but you yourself are not expanding. Neither is the Earth, nor our Solar System, nor our Milky Way, nor the Local Group of galaxies of which the Milky Way is a prominent member. To understand why, you need to know something about the nature of the universe's expansion.

As the American astronomer Edwin Hubble discovered in 1929, the farther apart two galaxies are, the faster they are flying apart from each other. In fact, two galaxies that are twice as far apart as two others will be receding twice as fast; three times as far apart, three times as fast; and so on. What this tells us is that the expansion of the universe becomes ever more powerful and irresistible the larger the scale.

Bearing this in mind, this is what happened after the Big Bang: gradually, things began to congeal out of the expanding and cooling debris. The agent was gravity, a force of mutual attraction between all pieces of matter. It caused clumps of debris to begin to shrink, becoming ever denser. But there was a proviso. On the smaller scales – masses equivalent to stars and galaxies and even galaxy clusters – gravity was strong enough to overcome cosmic expansion. However, on the larger scales – masses bigger than a galaxy cluster – the expansion was irresistible. It won out over gravity.

This is why we live in a universe where clusters of galaxies continue to fly apart from each other, carried like driftwood in the cosmic flow, whereas smaller objects – individual galaxies, the Solar System, the Earth – are bound together by gravity and take no part in cosmic expansion.

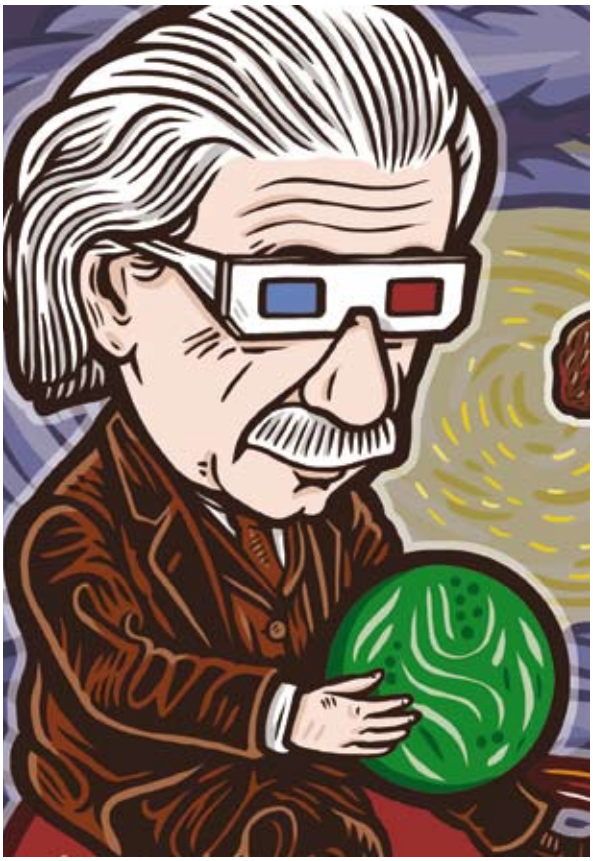
Myth 3

Since the universe is 13.82 billion years old, it is 13.82 billion light years to its edge

The fact that the universe was born 13.82 billion years ago means that we can see only those objects – galaxies and stars – whose light has taken less than 13.82 billion years to reach us. For this reason, our universe is bounded by a "light horizon". Think of it as like the surface of a soap bubble. Inside the bubble – a region we call the "observable universe" – are all objects whose light has had time to reach us since the Big Bang. This amounts to about 100 billion galaxies. Outside the bubble are objects we cannot currently see because their light is still travelling across space to us. For all we know, there may be an infinite amount of the universe beyond the horizon.

Now, a light year is the distance light travels in a year (about 10 trillion kilometres). Consequently, the distance to the horizon would be 13.82 billion light years if the universe had expanded at the speed of light since its birth. It has not. For most of its history, it has expanded far more slowly than this. However – and this is the key – during its first split second, the universe expanded enormously faster than light. (This is permitted by Einstein's general theory of relativity of 1915, though not by his special theory of relativity of 1905.) The epoch of "inflation" is sometimes likened to the explosion of an H-bomb compared with the stick of dynamite of the sedate cosmic expansion that took over after. However, even this underestimates the tremendous violence of inflation.

Because of inflation, the distance to the edge of the observable universe is not 13.82 billion years but closer to 42 billion light years.



Myth 4
Gravity always sucks

Gravity is a "universal" force which acts between every piece of matter and every other piece of matter. There is a force of gravity, for instance, between you and the coins in your pocket, and between you and a person passing in the street (though, in both of these cases, the force is too weak to notice). There is a force of gravity between the Earth and the Moon and between the Sun and the Earth. And, in all these cases, the force is attractive. However, this need not always be so, as Einstein showed.

The "source" of gravity in Newton's theory is "mass". However, Einstein showed that it is really "energy", of which mass is merely one kind. Actually, Einstein showed that the source of gravity is energy + pressure. The energy in normal matter is enormous (think of how much is liberated by the destruction of a kilogram or so in a hydrogen bomb) and the pressure – the microscopic drumming of particles of matter on any container – is negligible in comparison. But say there exists a type of material where not only is the pressure bigger than the energy but it is also negative. In this case, the (energy + pressure) term that generates gravity in Einstein's theory might be reversed in sign, creating repulsive gravity.

Science fiction? Far from it. Since 1998, we have known that about 70 per cent of the mass-energy of the universe is in the form of "dark energy". It is invisible. It fills all of space. And it has repulsive gravity, which is speeding up the expansion of the universe. Contrary to what they tell you at school, gravity does not always suck. In fact, in most of the universe, it blows!

Myth 5
The sky at night is dark because the universe was born in a Big Bang

When Galileo, in Padua, turned his telescope on the heavens, he saw stars behind the stars behind the stars. Learning of this in 1610, the astronomer Johannes Kepler imagined an infinite universe in which stars march on for ever. It would mean that, between every two nearby stars, there would always be a more distant, faint star. And, just as looking into a pine forest you would see nothing but a solid wall of trees, looking out at the universe we should see nothing but a solid wall of stars. Far from being dark, reasoned Kepler, the night sky on Earth should be as bright as the surface of a typical star – as bright as daylight.

The mystery that the night sky is dark, when by rights it should be bright, became known in the 19th century as Olbers' paradox, after the German astronomer Heinrich Olbers who popularised it. Edgar Allan Poe suggested that the paradox was explained because the light from the most distant stars has not reached us yet. And it seemed he had been proved right in the mid-1960s, with the confirmation that the universe had started in a Big Bang. The sky at night is dark, went the reasoning, because we can see only the stars whose light has taken less than 13.82 billion years to get here – because the universe has not existed for ever but was born.

But, though this is the view of most astronomy books and most astronomers, it is wrong. What Kepler had not realised was that the stars have only finite reserves of energy, like batteries that can run down. Even if they turn all of that energy into starlight, that starlight, like a trickle of water which falls short of filling a bath, would be

insufficient to fill the universe with enough light to make the night sky on Earth as bright as day. The 400-year-old paradox was never a paradox. And the dark sky at night, sadly, tells us nothing about the Big Bang.

Myth 6
The Big Bang was the beginning of the universe

In the beginning was the vacuum, goes the modern story. It was a "quantum" thing, which means it was not empty but seething with energy. In addition, it was not the vacuum we have today. It was a higher energy form with some amazing properties. For instance, it had repulsive gravity (*see Myth 4*). This caused the vacuum to expand. And the more of it there was, the more was its repulsive gravity and the faster it expanded. Not only that but the more of it there was, the more energy it contained. Imagine having a stack of banknotes between your hands, pulling your hands apart, and finding ever more bank notes. That's the way this "inflationary" vacuum was. Not surprisingly, cosmologists refer to it as the "ultimate free lunch".

Like all things quantum, the inflationary vacuum was unpredictable. Here and there, and totally at random, it disintegrated, or "decayed", into normal, everyday vacuum. All across the ever-expanding sea of vacuum there formed bubbles. But the tremendous energy of the inflationary vacuum had to go somewhere when it decayed. And it did. It went into creating matter in each bubble and heating it to a ferocious temperature. It went into making big bangs. The universe we live in is inside one such big-bang bubble.

In the modern picture, therefore, the Big Bang is not a one-off. It is merely one among countless others, going of like firecrackers across the length and breadth of the inflationary vacuum.

Myth 7
The universe we see in our telescopes is really out there

As Einstein predicted in his general theory of relativity of 1915, gravity bends light. The effect was confirmed in 1919 when the English astronomer Sir Arthur Eddington

observed stars close to the Sun in the sky during a total eclipse, when the bright solar disc was blotted out by the Moon. The stars, Eddington found, were not in their expected locations. Their light, as it passed close to the Sun on its journey to the Earth, had been bent from its normal path by the Sun's powerful gravity.

This effect, now known as "gravitational lensing", affects our view of a large part of the universe for the simple reason that the light from distant galaxies inevitably passes by other galaxies on its way to the Earth.

The light-bending effect of their gravity can be so dramatic that the images of distant galaxies are smeared out into great arcs of light or even shattered into multiple images. At the bare minimum, the effect subtly distorts the images of galaxies in the distant universe.

In short, much of what we see with our telescopes out in the depths of space is not really there. It is an illusion. A great cosmic mirage.

But the lensing effect of the gravity of intervening galaxies is not all bad. In some circumstances it can both focus and boost the brightness of distant galaxies otherwise too faint for us to ever see. It is as if nature helps us

out by adding its own gargantuan lens to our own puny astronomical instruments, creating a telescope of truly cosmic dimensions.

Myth 8
Time always goes forward

We associate the direction of time with the direction in which eggs break, castles crumble and people grow old. What all these changes have in common is a transition from an ordered to a disordered state. Technically, physicists call this an increase in "entropy".

The reason things can become more disordered is obviously that they were more ordered in the past. And, if we follow this reasoning to its logical conclusion, we find that the ultimate reason is that the universe began in a highly ordered state – the Big Bang. Think for a moment what this means. Eggs break, castles crumble and babies grow old because the universe is expanding from a Big Bang – because the most distant galaxies are flying away from us. How incredible is that?

But what would happen if the universe's expansion were to one day run out of steam and all of creation were to start shrinking down to a big crunch – a sort of mirror image of the Big Bang? Such a universe would be so far in the future that all the stars would have burned out. But, for speculation's sake, say there was a survivor. For them, the direction of time would reverse. Eggs would unbreak, castles would re-assemble, people would grow young. There is a twist, however. Although all processes in the universe would go backwards, so too would a survivor's mental processes by which they perceived the universe. Just as a double negative is a positive, the reverse-time, big-crunch world would appear exactly like a normal-time, Big-Bang world.

Myth 9
The universe we see with our telescopes exists "now"

Light is so extraordinarily fast that we never notice a delay between flicking a light switch and a room filling with light. Nevertheless, despite travelling at a whopping 300,000 kilometres a second, it takes light 1 1/4 seconds to come from the Moon, 8 1/2 minutes from the Sun and 4 1/4 years from the nearest star, Alpha Centauri. And, when we consider cosmic distances, they turn out to be so vast that light appears to crawl snail-like across them.

An astronomer looking out across the universe with a telescope is like someone looking out of their living room window and spying Victorians, and behind them Tudors, and behind them Romans and ancient Egyptians. The further across space astronomers see, the further back in time they drill. Although we can see the history of the universe, we can never know what the universe is like "now". In fact, the finite speed of light makes this an entirely meaningless concept.

What all this means is that, when we look at the most distant objects in the universe, they died long before the Earth was born. There are no super-bright "quasars" around today. They are nothing more than a cosmic afterimage. Most of the universe we see in our telescopes no longer exists.

Myth 10
The stuff science has been studying for 350 years is the important stuff

Only 4.9 per cent of the universe is made of atoms – the kind of stuff you and me and the stars and galaxies are made of. About six times as much – that is 26.8 per cent – is invisible, or "dark", matter. It reveals itself by tugging with its gravity on the visible stars and galaxies. No one knows what the dark matter is made of, though speculation ranges from hitherto undiscovered subatomic particles to fridge-sized black holes the mass of Jupiter.

But even the dark matter is trumped by the final component of the universe. About 68.3 per cent is "dark energy". It is invisible, it fills all of space and it has repulsive gravity. In fact, its repulsive gravity, which is speeding up the expansion of the universe, is what led to its discovery in 1998. Nobody knows what the dark energy is. In fact, our very best theory of physics – quantum theory – overestimates its energy density by a factor of 1 followed by 120 zeros!

What all this tells us is that the stuff science has been studying for the past 350 years is not the most important stuff. In fact it is but a minor component of the universe. The tip of the cosmic iceberg. What lurks beneath that tip nobody knows. Yet. ●

Marcus Chown's new book, What A Wonderful World: Life, the Universe and Everything in a Nutshell, *is published by Faber & Faber*