

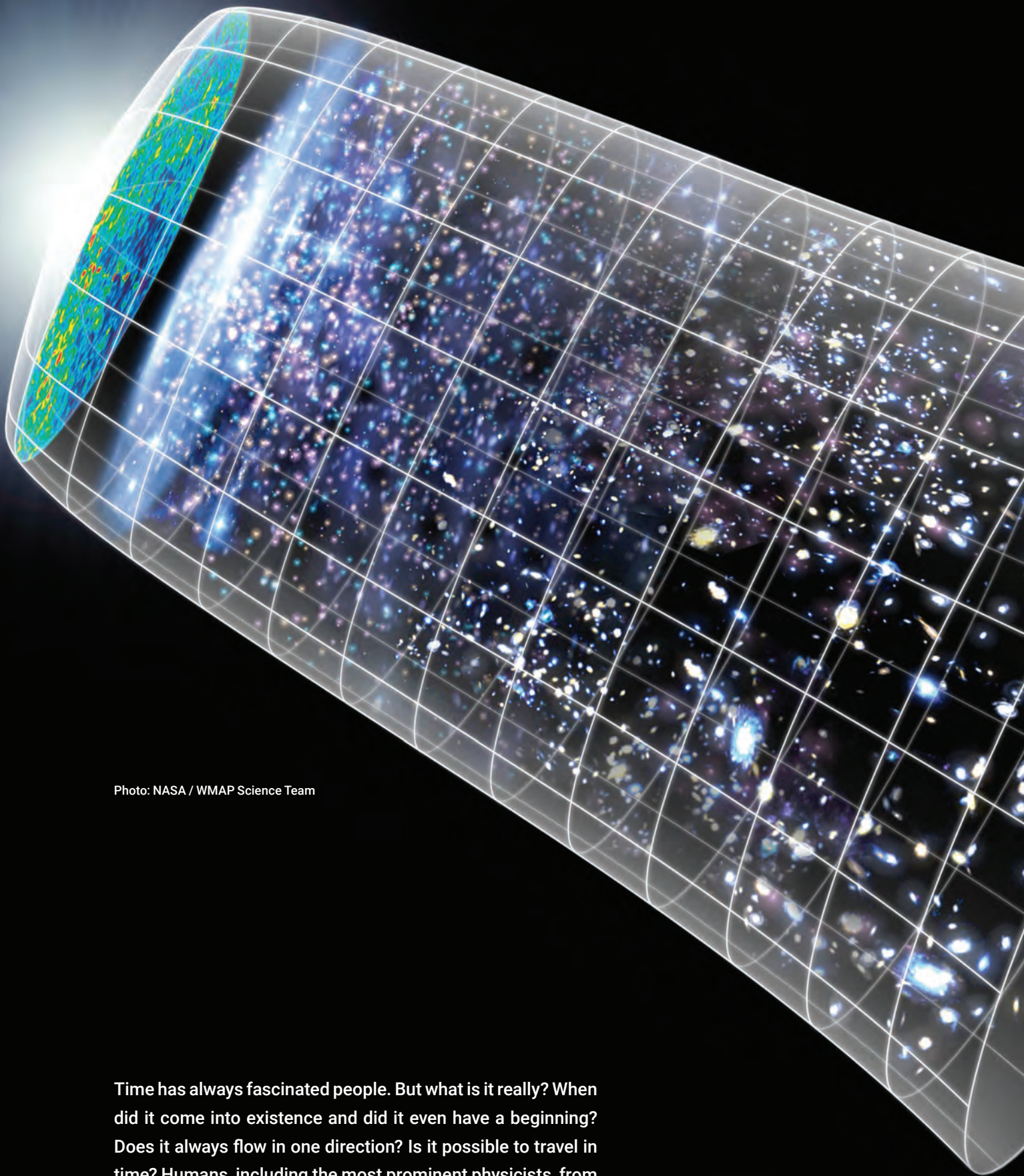


Photo: NASA / WMAP Science Team

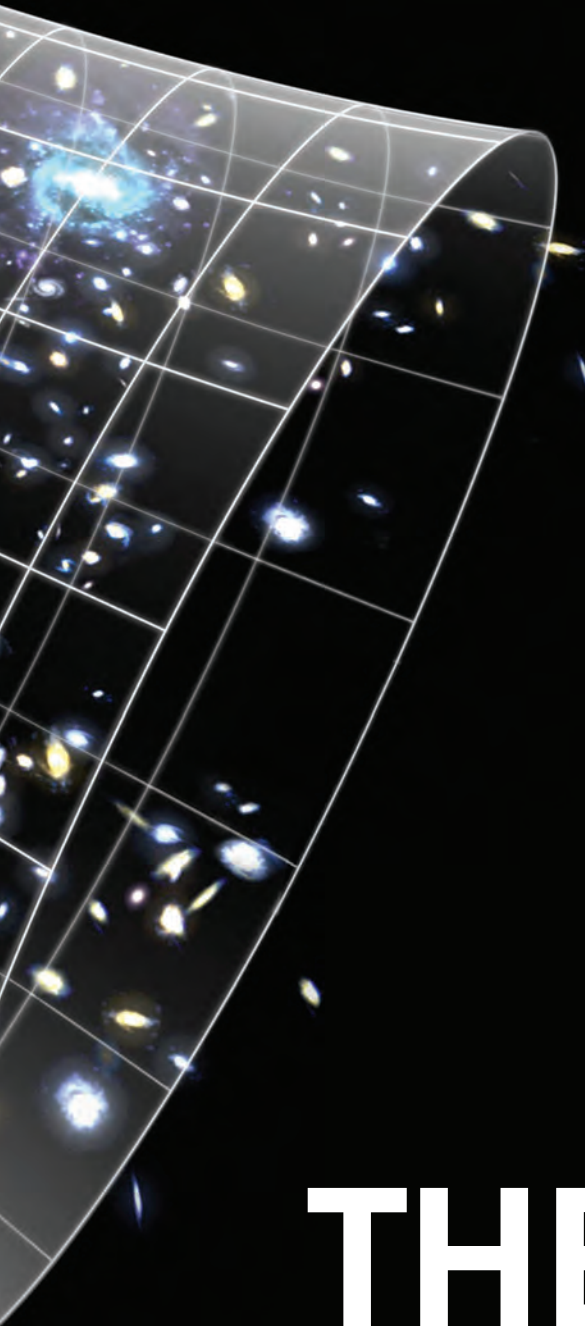
Time has always fascinated people. But what is it really? When did it come into existence and did it even have a beginning? Does it always flow in one direction? Is it possible to travel in time? Humans, including the most prominent physicists, from Albert Einstein to Stephen Hawking and Michio Kaku, have been searching for answers to these questions since time immemorial.



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THE PHYSICS OF SPACE-TIME TRAVEL

THE BIG BANG AND THE BEGINNING OF TIME

'According to our current knowledge, it is assumed that the universe was born about 13.8 billion years ago as a result of the so-called Big Bang. Contrary to its name, the universe did not begin with a blast, nor was there any such point from which something could have exploded', explains Prof. Jan Sładkowski, a physicist from the Institute of Physics of the University of Silesia in Katowice, adding, 'The universe began to expand rapidly from an unimaginably hot and infinitely dense state called the initial singularity. It was then, according to contemporary cosmological models, that space and time were born. Consequently, it is not possible to assert that there was anything prior to the Big Bang, despite the existence of various speculations'.

Time and space have been inextricably linked since the beginning of the universe. This gave rise to the concept of *space-time*. The term was coined by Hermann Minkowski, a German mathematician and physicist of Jewish origin, and Albert Einstein's teacher. In 1907, Minkowski proposed an interpretation of time as the fourth dimension.

In 1915, Albert Einstein published his general theory of relativity, which completely changed our understanding of gravity and the structure of the universe. In the new framework, gravity was no longer regarded as a classical force acting at a distance (as in Newtonian mechanics), but rather as a manifestation of the curvature of space-time due to mass and energy. Massive objects such as planets

and stars deform this four-dimensional structure like a ball that bends the surface of an elastic membrane, affecting the passage of time and the trajectories of moving bodies. In general relativity, as in special relativity, time and the chronology of events are not absolute. A clock located closer to a massive object (e.g. a black hole) ticks more slowly than a clock located in a weaker gravitational field. This is known as gravitational time dilation – a phenomenon confirmed experimentally e.g. by GPS satellites, which must take into account corrections resulting from relativistic effects in order to function properly. Einstein's theory became the foundation of modern cosmology and allowed us to describe how the universe evolved.

THE EVOLUTION OF THE UNIVERSE

'In fact, all our considerations about the evolution of the universe up to the point when it reached an age of approx. 380,000 years are pure speculation. Descriptions are only really reliable when they refer to a time when the universe was at least half a billion years old', notes the physicist. 'The observed large-scale homogeneity suggests that the universe must have undergone a phase of rapid expansion called inflation immediately after its birth, during which it doubled its dimensions every 10^{-37} seconds. The strangest and most speculative stage of the universe's evolution, the so-called Planck era, lasted until 10^{-43} seconds after the Big Bang. At this time, due to extremely high temperature and density, all four fundamental forces of nature (gravitational, electromagnetic, weak nuclear, and strong nuclear) could have been one superforce. The universe certainly did not resemble anything we can imagine, as our current knowledge and known theories (including general relativity and quantum mechanics) do not enable us to fully describe what could have happened in the Planck era. It is believed that this was a state in which space-time itself was a quantum phenomenon – full of fluctuations, instability, and probabilities'. About 10^{-43} seconds after the Big Bang, the universe cooled down enough for grav-

ity to separate from other forces. The appearance of the so-called Higgs field, associated with the Higgs boson, was a fundamental moment for the existence of the universe.

'It is believed that shortly after the end of cosmic inflation, when the universe was only a fraction of a second old, the Higgs field underwent a so-called spontaneous symmetry breaking, i.e. it "froze" in a specific energy state', explains Prof. Sładkowski. 'This had certain fundamental consequences – elementary particles considered in the so-called standard model, which previously ($t < 10^{-12}$ s) were massless, began to interact with the field and gain mass. However, it should be emphasised that this is our explanation of where the mass of particles comes from, but it remains a hypothesis, even though the confirmation of the existence of the Higgs boson was awarded with the Nobel Prize'. The first atomic nuclei began to appear between 1 second and 3 minutes after the Big Bang. They were mainly protons (hydrogen nuclei), deuterium, helium-4, and trace amounts of lithium-7 and possibly beryllium. When the temperature dropped to around 3,000 K, electrons began to combine with nuclei to form the first neutral atoms – primarily hydrogen (H) and helium (He). The so-called dark ages lasted from 380,000 to about 100

million years – there were no stars or galaxies yet, only a cold, thin fog of hydrogen and helium gas. Gravity slowly condensed local fluctuations of matter, leading to the collapse of the first gas clouds. Protogalaxies and star-forming clouds developed. The gas continued to condense and heat up until the first stars ignited.

'The first stars (known as Population III stars) were very different from the stars we know today. They were very massive and consisted only of hydrogen, helium, and lithium – they did not contain any heavier elements. They shone very brightly but lived only a short time – from a few million to several tens of millions of years – and ended their lives as supernovae or collapsed into black holes', explains the physicist from the University of Silesia. 'Heavier elements were formed inside the next generation of stars or supernova explosions (there is a theory that they were also formed in neutron star collisions), becoming the seed for the formation of planets and the elements of life'.

The first stars and galaxies emitted powerful radiation that ionised hydrogen atoms and distributed elements throughout the universe. Galaxies similar to the Milky Way began to form about 1–1.5 billion years after the Big Bang.

TIME TRAVEL

Although the theory of relativity allows us to regard time as a spatial dimension, i.e. as reversible to some extent, our everyday experience tells us otherwise – time flows in one direction. This direction is determined by the arrow of time, which is closely related to the second law of thermodynamics. According to this law, entropy – a measure of disorder – always increases. This is why we can remember the past but not the future, and why we cannot restore a broken egg to its pre-broken state. But do the laws of physics prohibit time travel? Here, the matter becomes more complex, and also more fascinating.

General relativity allows for solutions involving the so-called closed timelike curves, which are trajectories in space-time of a material point moving at a speed lower than the speed of light. ‘Closed’ refers to the fact that a point, while moving, can effectively return to the moment before it started its journey. This is the source of much speculation about the possibility of time travel.

One concept of time travel is the idea of a space-time tunnel (a wormhole). This is a hypothetical structure that connects two distant points in space-time (sort of

like a bent piece of paper). Its existence was considered by Albert Einstein and Nathan Rosen, who in 1935 proposed a theoretical description of the so-called bridge (today this structure is called the Einstein-Rosen bridge or Schwarzschild wormhole). In a sense, it is a mathematical ‘construction’ connecting two black holes (or rather, a black hole on one side and a white hole on the other). However, the structure is unstable and will most likely close before any information or particle can pass through it. For a wormhole to be stable and passable, it needs exotic matter (matter that repels itself gravitationally). There is no such matter in the Einstein-Rosen model and we know of no argument suggesting its existence. On top of that, it does not allow for time travel, only travel in space. Therefore, it is a beautiful construct, but more theoretical than physical.

In the 1980s, physicists Kip Thorne and Michael Morris proposed a different type of tunnel – stable and passable, later named the Morris-Thorne wormhole. This structure would also require exotic matter, however... this type of matter has not yet been observed anywhere in nature, although negative energy effects

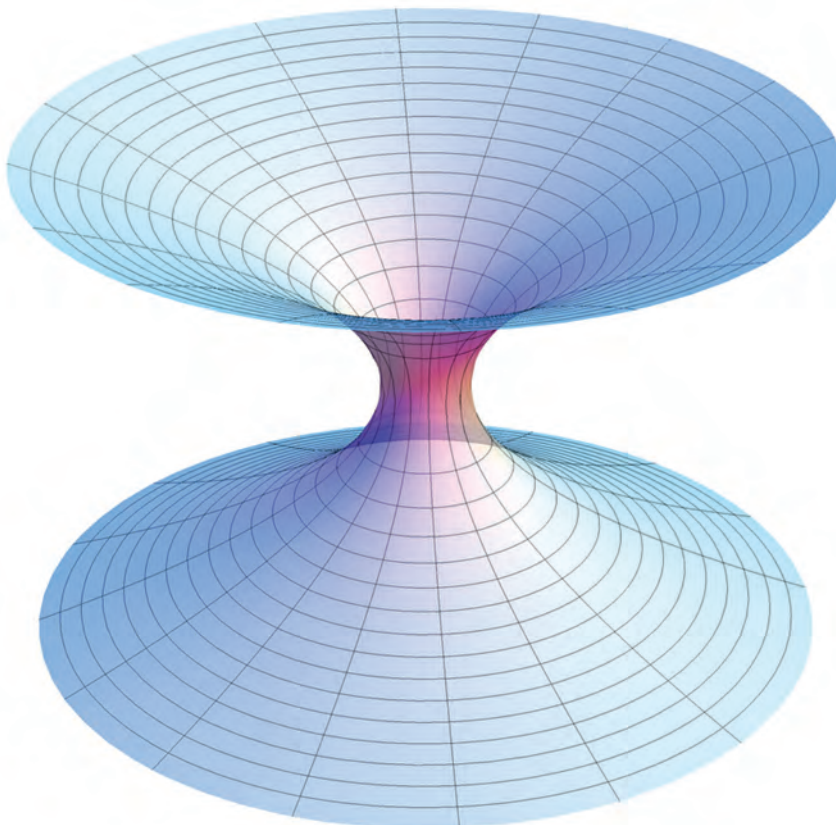
appear in some quantum phenomena (e.g. the Casimir effect).

Another physicist and string theory proponent Michio Kaku, also tackled the subject, repeatedly emphasising that although time travel is not contrary to the equations of general relativity, it remains technologically impossible. Kaku even described time travel as a ‘class I impossibility’.

In the 1990s, Stephen Hawking proposed the so-called chronology protection conjecture. According to it, the laws of physics should somehow prevent the formation of closed timelike curves – trajectories that lead to the past and might lead to paradoxes (such as killing your own grandfather before he was born). Hawking argued that quantum fluctuations near the entrance to a hypothetical wormhole would be so violent that they would end up immediately destroying the structure that could enable time travel. In other words, the universe would defend itself against the paradoxes associated with time travel.

So, is time travel possible? From the point of view of theoretical physics – perhaps. From a technological point of view – probably not, at least for now. The development of a hypothetical quantum theory of gravity and research into the nature of black holes and space-time may provide new information in the future.

‘We should also keep in mind that mathematical models reflecting our current knowledge will almost always be just mathematical models, even if they are capable of describing our environment very well. And what we call space-time today may not exist at all, but that’s a story for a completely different conversation’, concludes Prof. Jan Śladowski.



Einstein-Rosen bridge | Illustration by AllenMcC.
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