Thomas Hertog

We Are Not Angels

A few years ago, while I was traveling in Central Asia, Stephen Hawking sent me an email asking me to return to Cambridge. He had an idea he wanted to share with me.

When I arrived back in Cambridge, I found him as I often did: surrounded by books, working at a dysfunctional desktop, and with a picture of Marilyn Monroe on the wall. By then, he had already lost his natural voice, but he communicated through his computer system.

That was why he had called me back from my travels.

> *"I have changed my mind," he told me. "A Brief History of Time is written from the wrong perspective. We are not angels who view the universe from the outside."*

Speaking with Hawking was often like consulting the oracle of Delphi—slow, and at times rather enigmatic. But on this occasion, I immediately understood what he was getting at.

My PhD with him had ended on something of a cliffhanger, a puzzle we had not been able to solve. Now, suddenly, there was a sense of a eureka moment—something that would launch us on an entirely new path.

The starting point

"A Brief History of Time", Hawking's great book from the 1980s, was built on a particular epistemology – a philosophy of science. It assumed that the laws of nature are fixed, eternal, immutable, transcending the physical universe itself. These laws, cast in mathematical relationships, were thought to describe how the universe came into being, how it evolved, and why it is the way it is.

The philosophy was straightforward: you begin with the laws, and from them physics follows. From physics, eventually, arise chemistry, biology, and the full spectrum of complexity. This was the great idea – the philosophical highlight – of A Brief History of Time.

The book even offered a mathematical model that embodied this vision. But in the final step, something went wrong. The model of the creation of the universe, as it appears in A Brief History of Time, produces only an empty, sterile cosmos – lifeless, dark, devoid of galaxies or anything resembling the universe we actually inhabit.

For a long time, the central question in theoretical physics was: which of our assumptions should we be willing to let go of? Many suggestions were made, and Steven and I wrestled with this for years. Eventually, we concluded that it was the starting point itself that had to change – the assumption that the laws of nature exist as prior truths, from which all of physics follows.

There is something strange in that assumption. It goes back centuries. Newton himself regarded the laws of nature as divine truths. That idea became ingrained in physics. But gradually, we began to wonder, as Hawking's remark signaled: what if we let go of this age-old Archimedean standpoint – the notion that we can observe the universe as if from outside it?

Turn cosmology inside out

This is not a question that arises in laboratory physics. In the lab, you are indeed outside your experiment. But in cosmology, where the subject of study is the entire universe, that assumption collapses. There is no "outside." And so we asked ourselves: what if we turn cosmology inside out? What if we construct theories that explicitly incorporate our human viewpoint here on Earth, as observers within the universe?

Pursuing that idea took years of work. In some sense, On the Origin of Time is a sequel to A Brief History of Time. It tells the story of how Hawking changed his mind over the course of twenty years. From an epistemological standpoint, what we did was to invert the old picture. Rather than positing laws of nature as eternal truths, we began with our perspective as observers within the physical universe. From there, we deduced the laws of nature as patterns that describe its unfolding history.

Of course, this yields laws that are fundamentally different from the immutable truths imagined by Newton. They are mutable, evolving. An abstract diagram that represents the earliest stages of the universe at the level of physical laws resembles a branching tree. At the top, you find the familiar laws of physics. But as you trace it backward in time, these laws begin to unify. Distinctions between particles and forces dissolve. Physics itself simplifies.

The laws of nature are patterns we extract from our observations. As you move back toward the extreme conditions of the Big Bang, those patterns – the very structure we call the laws of nature – begin to dissolve. Ultimately, even space and time themselves lose their specificity.

This way of looking at the early universe inevitably recalls another field of science: biology. This tree of laws – a deeper layer of evolution unfolding at the level of physics itself in the earliest stages of the cosmos. As the universe expands and cools, this structure becomes fixed – it crystallizes, much like water freezing into ice.

This perspective turns the traditional question of the ultimate origin – the Big Bang – upside down. Just as the tree of life might have branched differently, so too could the tree of laws have evolved along other paths. In that sense, the very question of origins conceals the origin of the question itself.

This is profoundly different from the older picture, where immutable laws of nature precede the universe and dictate its unfolding. Instead, by placing ourselves inside the universe and looking backward, we reconstruct its history – much as biologists reconstruct evolutionary lineages. In physics it is quantum theory, which plays a role akin to variation and selection in biology.

It is only through an accumulation of observations and measurements of the universe that one concrete picture of the past crystallizes from this set of possibilities. In this sense, quantum theory functions a little like Tom Riddle's blank diary in Harry Potter: it contains every answer, but only responds when questioned.

To summarize: we have two magnificent sketches. The first is Darwin's earliest drawing of the Tree of Life in 1836, made upon his return from the Galápagos. The second is Georges Lemaître's sketch of the expanding universe in the 1930s, the seed of the Big Bang theory. For over a century, science treated these two domains – biology and cosmology – as ontologically separate. Biology was concerned with emergent, contingent laws, grounded in DNA. Cosmology, by contrast, was founded on the belief in fixed, immutable laws.

An attempt to crack open physics

The hypothesis Hawking and I developed is that this separation was a mistake. Biology and cosmology are not divided by different ontological categories but are two manifestations of a single grand evolutionary process. Both must be understood from within, by looking backward, reconstructing history, and adopting a fundamentally historical viewpoint – even in physics itself.

After Steven's death in 2018, his ashes were laid to rest in Westminster Abbey, between the graves of Newton and Darwin – an uncannily fitting place for a thinker who bridged their legacies. But the key question that remains is this: how do we do it in physics? How do we truly turn cosmology inside out? How can we derive this new perspective from within the equations themselves?

Because this, in the end, was really the goal – from both a philosophical and an epistemological perspective. The story I have been outlining is, in essence, an attempt to crack open physics itself.

Physics, as we know it, is about evolution and dynamics. It is built on equations of motion: Schrödinger's equation, Newton's laws, Einstein's equations. All of them describe how systems change over time. But crucially, the laws of nature are not usually concerned with origins. They do not determine initial or boundary conditions, nor do they account for the role of observation and measurement. In the physics of the laboratory, such things lie outside the laws.

What I have been suggesting is that if we probe more deeply into the nature of these laws – if we push them to the very edges of reality, to the Big Bang itself – we are forced to enlarge our conception of what we mean by a "law of nature." This broader notion must include not only the genesis of the laws but also the observers ourselves.

At the Big Bang, we encounter a different kind of physics altogether. On a technical level, it is the confrontation between quantum theory and gravity. The microscopic and the macroscopic worlds collide because, at the origin, the vast universe is compressed into the smallest scales. Yet what we are proposing is that this unification is more than a simple merger of large and small. In the struggle between quantum theory and gravity lies something deeper: a wider conception of physics that embraces the emergence of the laws themselves, and with them, our own place within the story.

And it is this broader vision of physics that I want to explore further.

Black holes

Stephen Hawking often worked in a characteristic way. He would study the Big Bang – the early evolution of the universe, which remains our main concern – until he reached a dead end. Then, rather than stop, he would shift to a different system – a simpler, more accessible model. A kind of thought experiment from which he hoped to extract lessons that could eventually be applied back to cosmology.

That system, of course, is the black hole. Before returning to the Big Bang, I want to tell you how the struggle between quantum theory and gravity unfolds in black holes – another arena where the very large and the very small collide.

Black holes are a direct prediction of Einstein's theory of relativity – his great theory of gravity. At its core, relativity describes a dialogue between two sides of reality. On the one hand, there is the shape of space itself, captured mathematically. On the other, there is matter and energy – the particles and "stuff" that fill space. And the crucial element of Einstein's theory is the equal sign connecting the two: matter tells space how to curve, and curved space tells matter how to move. That interplay is what we call gravity.

Here is how it works in practice. The mass of the Earth slightly bends the fabric of space in its neighborhood, creating a kind of invisible valley. This valley holds us to the ground and keeps the Moon in orbit. For Einstein, space was no longer an abstract, metaphysical arena – as Newton had imagined – but something physical, deformable, and bendable, much like the electromagnetic field.

Einstein's theory was a triumph. But it also raised a troubling possibility. What happens if you cram more and more matter into a smaller and smaller region? Imagine shrinking the Earth to the size of a marble. Einstein's equations then insist that the valley in space would deepen without limit. At some point, space itself would collapse, snapping into a bottomless sink – a black hole, an infinite abyss in the very fabric of spacetime.

Interestingly, Einstein himself did not like the idea of black holes. He once remarked that they were "where God divided by zero," and insisted they could not exist in nature.

Today, a black hole appears as a dark disc, the mark of a rupture in the fabric of spacetime. Things become especially fascinating when two black holes orbit one another. Einstein's equations then predict that the fabric of space must respond by producing ripples – gravitational waves. These waves are not made of particles; they are oscillations of space itself, traveling at the speed of light and passing effortlessly through everything. In reality, the effect is extremely subtle – space is very stiff – so the ripples are tiny perturbations. But they are profound nonetheless.

So here we have the black hole – first predicted in 1915. Einstein was not happy with this prediction. And the reason is clear: if a ray of light enters the "throat" of this gravitational sink, it can never escape. That is why we see a black disc at the center: it is the region from which even light cannot get out. Around it lies a boundary, an invisible surface. Cross that threshold, and escape becomes impossible – you are pulled inexorably downward. Stay outside, and you are safe. Within this surface, however, Einstein's theory tells us that nothing can escape.

It took nearly fifty years, until the 1960s, for physicists to convince themselves that black holes truly exist in nature. The red circle around the dark core is not the end of the world, but rather the threshold to a deeper abyss within.

And what lies inside? Once you cross the boundary, there is no turning back. You are forced to move inward, as if space and time have exchanged roles. Inside the black hole, "down" becomes as relentless as the passage of time itself. At the very center lies the singularity – not so much a place as an ending. There, time itself comes to an end.

In 1975, Stephen Hawking made a remarkable discovery. He showed that if you add quantum uncertainty to the picture of a black hole – specifically, if you consider quantum effects near the horizon, the surface of no return – something unexpected happens.

Quantum theory predicts that pairs of particles and antiparticles constantly flicker in and out of existence, even in empty space. Near a black hole's horizon, one particle of such a pair can fall in while the other escapes. The result is that black holes are not completely black – they radiate, ever so faintly.

This became Hawking's most famous result. He even calculated the temperature of a black hole, and that very equation is now engraved on his tombstone in Westminster Abbey. It's never been tested directly – the radiation is far too weak – but physicists believe it because it unites every major branch of physics. In a single formula, you find Planck's constant from quantum mechanics, the speed of light from relativity, Newton's constant from gravity, and Boltzmann's constant from thermodynamics – all tied together with the mass of the black hole.

For a black hole the size of the Sun, the temperature is incredibly tiny, but crucially, it is not zero. And temperature means something important: it implies internal structure. As Boltzmann's famous entropy equation shows, if something has a temperature, it must also have entropy. And entropy, in turn, is linked to the number of possible microscopic configurations – to information.

The holograms

What does this mean for black holes? When you calculate, you find they contain an enormous amount of information. In fact, they are the most efficient information storage devices in the universe. All the data stored in Google's vast server farms could fit easily inside a black hole no larger than a millimeter. If Moore's law of computing power continued for a few more centuries, we'd eventually hit the limit: the ultimate "iPhone" would be a tiny black hole in your pocket. There would be no model after that.

But here's the puzzle. From Einstein's classical perspective, a black hole is astonishingly simple – just a region of empty spacetime, defined only by its mass, charge, and spin. Yet from a quantum perspective, it is the most complex object imaginable, crammed with microscopic information. How can it be both? Perhaps Einstein's theory is blind to what happens inside the horizon.

And then comes the deeper twist. Because black holes radiate, they slowly shrink. Given enough time, they evaporate completely. But what happens to the information they contain? If the black hole disappears, is that information lost forever? Sent to another universe? Destroyed?

That would violate one of the most sacred principles in physics: information cannot be destroyed. It can be scrambled, transformed, hidden in ashes, but never fundamentally lost.

Physicists emphasize the conservation of information because it underpins the predictability of physics. The principle means that while a system may evolve from one state to another, changing form or shape, the past and future should still be recoverable through the equations that govern it. Without this conservation, physics would not only become unpredictable but fundamentally unreliable – not just probabilistic, as in quantum theory, but entirely indeterminate.

And so emerged one of the greatest puzzles in modern physics – born at the meeting point of quantum theory and gravity: the black hole information paradox.

We’re not entirely sure yet, but we have strong evidence for a resolution to the black hole puzzle. The key idea is that the information in a black hole was never really inside. Instead, everything that can be known about a black hole – its full information content – is stored in bits and qubits on the horizon, that red circle marking its surface.

Quantum theory, in other words, gives us a new perspective. Einstein told us that a black hole is a hole in spacetime, with time ending at the center. But quantum theory tells us something very different: the entropy of a black hole is proportional to the area of its horizon, not to the volume of its interior.

That’s unlike any other physical object we know. Take a library, for instance – its information content is proportional to the number of books, to the volume inside. But not so for a black hole. From a quantum perspective, all the information lies on its surface. It doesn’t really have an interior. Black holes, in this sense, are holograms. That’s the major lesson from decades of work at the intersection of quantum theory and gravity.

This echoes the allegory of Plato’s Cave. But there is a crucial difference: in physics, we have evidence that the holographic description captures the actual details, not just shadows. So the natural next question is: if black holes are holograms, could the entire universe be a hologram too?

The holographic principle and the Big Bang

This brings us back to cosmology. Nearly a century ago, Georges Lemaître proposed the idea of a “primeval atom,” what we now call the Big Bang. He realized that if you run the universe backward in time, space shrinks until it reaches a moment when spacetime itself ceases to exist. The Big Bang was not an explosion in preexisting space; it was the origin of space and time themselves.

Einstein disliked this idea. At a conference in Brussels, he famously told Lemaître: “Your calculations are correct, Mr. Lemaître, but your physical insight is rubbish.” Why? Because when Einstein’s equations are run backward, they predict their own downfall at the Big Bang. His great law of nature seemed to undermine itself.

But Lemaître was right. Today we see beautiful images of the afterglow of the Big Bang: the cosmic microwave background. It’s a map of tiny temperature fluctuations, the seeds from which galaxies and stars formed as the universe expanded and cooled. Big Bang cosmology has been tested in detail – it works.

Yet, like with black holes, it raises a profound puzzle. From Einstein's perspective, the Big Bang singularity is beyond science; it's where the laws of nature break down. And yet it sits at the very foundation of cosmology. How did the universe begin? Why is it so finely tuned for life? Classical physics cannot answer.

Here again, quantum theory offers a new view. From a quantum perspective, if you run time backwards, you don't hit a singularity where everything collapses. Instead, space and time themselves become fuzzy, lose their identity, and can even merge, closing off the past. Just as with black holes, holography enters the picture: time may not be fundamental, but emergent.

The image that goes with this is simple but powerful. Imagine the universe projected onto a disc. The edge of the disc is a quantum description of the cosmos at some early moment, such as when the cosmic microwave background was released. Moving inward, you travel back in time, deeper and deeper, until you reach the Big Bang.

Just as with black holes, the holographic principle offers a radically new way of thinking about the origin of our universe.

Imagine projecting the expanding universe onto a disc. At the center is the Big Bang. The quantum description of the universe lives on the circle around it. Gravity and time – the past itself – emerge from that hologram.

The entanglement

How can a quantum perspective predict that time itself is emergent? Where does a hologram hide all the information of history?

The answer lies in entanglement. A quantum system stores information not just in individual bits – atoms, chips, or qubits – but also in the connections between them. Entangled states are a delocalized way of encoding information. That's exactly what quantum engineers are using as they build quantum computers.

From the last 30 years of physics, it seems nature itself is like a quantum computer. In fact, it looks as though nature has already mastered quantum error correction, while we are still fumbling to imitate it. Even space and time appear as emergent features – time, in particular, "popping out" of the quantum substrate.

Let's connect back to the beginning. We have this hologram – an abstract quantum representation of the universe at some early moment. How do we use it to go deeper into the past, closer to the Big Bang at the center of the disc? The trick is to read the hologram at different levels of resolution. By coarse-graining – taking a fuzzier and fuzzier view – you keep only the large-scale correlations, and that reconstruction takes you further back.

But there's a limit. As you coarse-grain more, you lose more information. Eventually, you run out of bits. From the quantum perspective, the Big Bang – the very origin of time – marks the limit of physics. It's not a singularity in the classical sense, but an epistemic horizon. Beyond it, there is no more information encoded.

This is the birth of a new kind of physics: one where information itself is central. This is exactly the spirit of the hypothesis that Stephen and I developed – that we must start from our observational situation, from the "fossils" of the universe around us, and work backward.

And the upshot is profound: the laws of nature are not eternal, immutable truths. Their origin coincides with the origin of time. Physics itself has limits. The Big Bang becomes an epistemic horizon.

This idea – that finitude applies even to the laws of nature – was anticipated by Hannah Arendt. She warned that science pursued from an Archimedean standpoint, as though from outside the universe, would ultimately be self-defeating. She argued that if science is to provide a true worldview, it must include our human condition – the fact that we are within the universe, not outside it.

In the 1950s and 60s, she found no such trace in physics. But I would dare say that the hypothesis Stephen and I developed is a response to her concern: a call from deep physics that even the laws of nature are anchored in our relation to the cosmos, not in some higher Platonic realm.

Stephen Hawking once said on this matter:
"Some people will be very disappointed if, in the end, there is no ultimate theory as some sort of solid foundation of all of reality. I used to belong to that camp. But I am now glad that our search for understanding will never come to an end, and that we will always have the challenge of new discovery. Without it, we would stagnate."

Stephen, who gradually lost the ability to communicate with other human beings because of his disease, ended up putting humanity at the very center of his cosmology.