

1. Journey from the Edge of Time

On 14 January 1990, the world's press featured a mottled red-and-blue image purporting to show nothing less than the birth of the universe. 'It was like looking at the face of God,' proclaimed the project's lead scientist, George Smoot. In the words of Stephen Hawking, the picture represented 'one of the greatest scientific discoveries of the century, if not all time'.

The subject of these superlatives was a colour-coded heat map of the sky produced by a satellite called COBE, for Cosmic Background Explorer. COBE had been tasked with surveying the fading afterglow of the Big Bang, a sea of microwaves that suffuses space and travels to us largely undisturbed

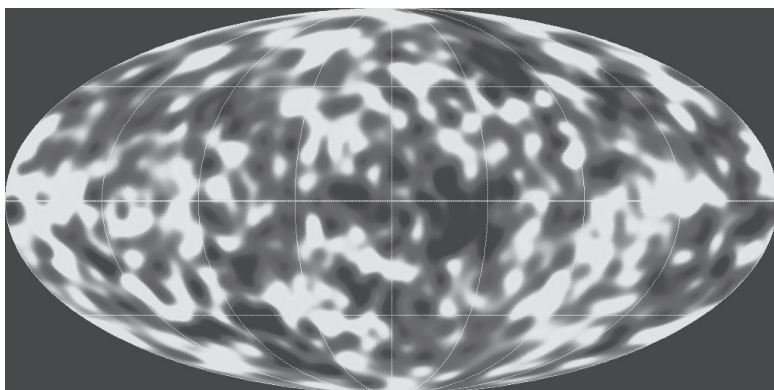


Figure 1. All-sky map of the Big Bang afterglow obtained by the satellite COBE.

from a time when the cosmos was a tiny fraction of its current age. The amorphous-looking splodges decorating the image indicated slightly hotter and cooler regions of the universe. Etched into this kaleidoscopic pattern were important clues about the birth pangs of the cosmos a split-second after its origin, at the very edge of time itself.

COBE ushered in a golden age of cosmology. In the three decades since, the field has been transformed from a speculative backwater to a precision science. Paradoxically, we now understand the history of the universe in its overall outline better than we understand the history of our own planet. Yet, to borrow from Churchill, this is not the end of cosmology. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

Cosmology might seem like a rarefied discipline, but in many indirect ways it touches everyone. We all have a need to know why the world is as it is and how we came to exist. Throughout history, societies have sought to address this need by producing creation myths: accounts which weren't explanations in the scientific sense but stories intended to place human beings in the context of a grander scheme. When cosmology emerged as a scholarly discipline among the ancient Greek philosophers two and a half millennia ago, it was given a name that derived from the same root as 'cosmetic', meaning beautiful, whole and complete; standing in opposition to chaos. The word implied that there was such a thing as 'a universe', a coherent and organized entity that can be understood by human reason. Further progress, however, had to await the scientific age two thousand years later, which unleashed a stream of dazzling discoveries. When in 1543 Copernicus declared the Earth goes around the sun, he

shattered the anthropocentric model of the cosmos that had prevailed for centuries. To be sure, the immediate effect on daily life was minor; there were no riots, no wars, no economic disruptions. Yet, over time, the knowledge that we are not located at the centre of the universe fundamentally transformed the context of all human existence. The impact was felt not only in science, but in religion, sociology and economics too.

Today we are poised to undergo a shift in perspective even more disruptive than that initiated by Copernicus. Future generations will look back at our era and envy those privileged to witness it first-hand. But beneath the catalogue of discovery lies a profound mystery. For some reason, on an unexceptional planet orbiting a run-of-the-mill star, a species of organism evolved that managed to work out how the world is put together. That surely tells us something deeply significant about our place in the natural order. But what?

2. The Search for the Key to the Universe

It's impossible to look up at the night sky and not be struck by the grandeur and beauty of the vista – the sweeping arc of the Milky Way, the myriad twinkling stars, the insistent, steadfast brightness of the planets. The sheer vastness and complexity are overwhelming. For millennia after millennia, our ancestors observed the same sky, and struggled to make sense of what they saw. What was the key to understanding it? How did the cosmos come to exist? What was the place of human beings in the grand scheme of things?

For many ancient societies, making sense of the heavens was not merely a philosophical or spiritual quest; it was also a practical necessity. Knowing the movement of heavenly objects was critical for human well-being: not just for navigation, but seasonal migration, crop growing and timekeeping. Our distant ancestors' preoccupation with the cycles of the sun, moon and planets is obvious from the megalithic structures they built, some deliberately designed to align with astronomical events – events often imbued with divine significance and marked by elaborate ceremonies. The sky was regarded as the realm of supernatural agents. In some cultures, the sun, moon and planets themselves were treated as gods.

But the regularities evident in the movement of astronomical bodies suggested a very different concept of the heavens, not as the playground of the gods but a *mechanism*,

an elaborate system of moving parts. Once this notion became established, precision measurements were crucial to determine how the mechanism was organized and regulated. Arithmetic and geometry were now essential skills. Astronomers became powerful and important figures in society, alongside priests and emperors. Their careful measurements and analysis gradually revealed order and harmony, number and form, in the celestial activity. Many theoretical models were constructed over the centuries. A well-known distillation of earlier ideas was compiled by the second-century CE Greek astronomer Claudius Ptolemaeus. Ptolemaic cosmology featured a complicated system of nested spheres, turning around the Earth at different speeds.

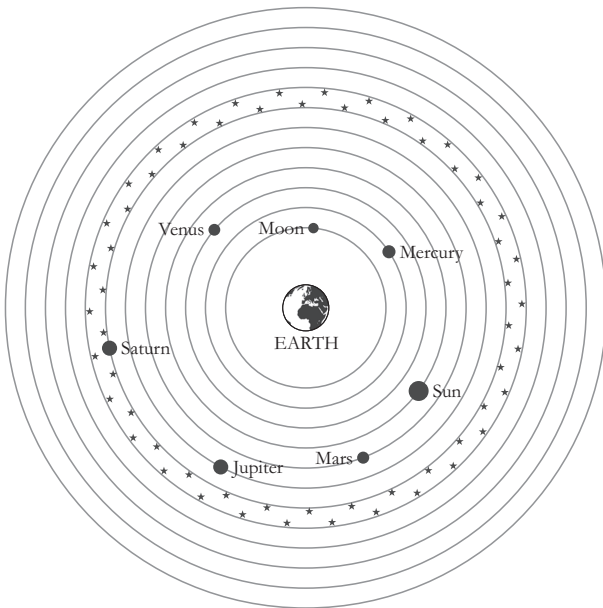


Figure 2. The universe according to Ptolemy, with Earth at the centre.

The mechanistic models of the universe were on the right track, but the theological dimension was never eliminated entirely. There was ever the vexatious issue of origins. How did the great cosmic contraption come to exist in the first place? Was there a Prime Mover who set the complex mechanism in motion? A supernatural Creator who conjured order out of chaos? A god who made the universe from nothing? No attempt was made in these early models to link the motion of astronomical objects with the motion of material bodies on Earth. Heaven and Earth, each filled with movement, remained separate domains. This view persisted through much of the Medieval period, until the seventeenth century. Then, suddenly, humankind's understanding of the universe was transformed. A small band of visionary 'natural philosophers' came to realize that the key to the universe was not to be found in divine agency, nor in the geometry of the cosmic architecture itself. Rather, it resides in *laws of nature* that transcend the physical world and occupy an abstract plane, invisible to the senses but nevertheless within the grasp of human reason. Number and form, beloved of the ancient philosophers, are manifested not just in specific physical objects and systems, but interwoven into the very laws of nature themselves, forming a mosaic of subtle patterns encrypted in a kind of cosmic code. It was a stunning conceptual pivot, marking a transition from mere *description* of the world to *explanation*. The quantum leap in comprehension accompanying this transition was poetically expressed by Galileo in 1632: 'The great book of nature is written in the language of mathematics,' without which, 'one wanders in vain through a dark labyrinth.' The key to the universe, said Galileo, lay with mathematical decryption, a sentiment

echoed three centuries later by the astronomer Sir James Jeans, who declared ‘The universe appears to have been designed by a pure mathematician!’ Galileo himself began the task of unlocking nature’s hidden mathematical order, but it was a generation later, especially with the work of Isaac Newton and Gottfried Leibniz, that everything came together. Theirs wasn’t a grand and highly organized cultural enterprise, as scientific research is today. The founders of what we now call science were more like members of an exclusive cult, almost a secret society, unconventionally religious, fractious and egotistical, still steeped in the mystical traditions of antiquity.

Galileo pioneered the use of the newly invented telescope to study the heavens. This enabled more accurate measurements to be made of the movement of planets and the shapes of their orbits. Like Galileo, Newton set his sights on the solar system, seeking to uncover mathematical laws of motion that applied equally on Earth and in space, and which could be tested by observation and measurement. To achieve this, he needed to find the correct mathematical key, but it was nowhere to be found in the great corpus of Greek arithmetic and geometry, nor in their Medieval refinements. So, he fashioned it himself, calling it the theory of fluxions – what is today termed differential calculus. Starting in his early twenties, and no doubt assisted by the need to self-isolate at home in Lincolnshire during the great plague of 1665–6, Newton applied fluxions to the laws of motion, and discovered how gravity, that enigmatic force that reaches across space, weakens in a precise arithmetical way, in inverse proportion to the square of the distance between objects.

Suddenly, humanity possessed a new window on the

heavens. The swooping parabolas of comets, the graceful ellipses of planets, the scalloped gyrations of the moon – all the delicate tracery of celestial orbits – fell into place, linked to each other by the immutable logic of fixed mathematical relationships. I'll never forget the thrill I felt as a student when I first applied Newton's laws to the motion of a planet going around the sun and out popped the formula for an ellipse! It was like magic. Imagine the sense of awe that Newton himself must have experienced when his own hand-crafted equations produced the very geometrical patterns so assiduously catalogued by astronomers from years of observations.

Spectacular though such an advance was, Newton had a grander vision. Having explained the solar system, he set about applying his law of gravity to the entire cosmos. Since Galileo had turned his telescope on the Milky Way it was obvious that the universe is teeming with stars. But how were they arranged? Were they clustered in a huge but finite cloud, or scattered endlessly through infinite space? Newton envisaged the cosmos as a gigantic clockwork, with gravity shaping its structure, literally holding it together, a universal force of attraction tugging tenaciously on every object in space. Where gravity is opposed by motion along a curved path, as it is for the Earth going around the sun, stability is attained: our planet is pulled by the sun but doesn't fall into it. But what about the universe as a whole? With nothing to prop it up, why, wondered Newton, doesn't the entire assemblage of stars fall together into one great mass?

The solution he proposed was that the universe must be infinite. With no boundary and no centre of gravity, the cosmos lacks any privileged place to collapse towards. A given