GENESIS

THE STORY OF HOW EVERYTHING BEGAN

GUIDO TONELLI

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Farrar, Straus and Giroux
New York

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For little Jacopo

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We need poetry, desperately.

Anonymous (graffitied on a wall in an alleyway in central Palermo)

All sorrows can be borne if you put them into a story, or tell a story about them.

Isak Dinesen

To be rooted is perhaps the most important and least recognised of the needs of the human soul.

Simone Weil

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Introduction: The Grand Narrative of Origins

Forty thousand years ago, when the second wave of *Homo sapiens* arrived from Africa, many areas of Europe were already populated by Neanderthals. Organised into small clans, they lived in caves that today provide unequivocal proof of a complex symbolic universe: walls painted with symbols and drawings of animals, bodies buried in foetal positions, bones and large stalactites arranged in ritual circles; plentiful evidence, in other words, of a culture that had in all probability also developed a sophisticated spoken language.

It is possible, then, to imagine hearing a story of the origins of the world already resounding in those caves, the elders transmitting it to the young through the power of words and the magic of memory: the echo of an ancient narrative. It would be thousands of generations before Hesiod (or whomever we know by that name) left us, in his *Theogony,* a written account of how our universe came into being, woven from poetry and cosmology.

This ancient origin story continues to evolve to this day, thanks now to the language of science. Equations might lack the evocative power of poetry, but the concepts of modern cosmology – a universe that was born from a fluctuation in the quantum void, or from cosmic inflation – can still take our breath away.

All such stories spring from one simple, inescapable question: 'Where does *all this* come from?'

It's a question that still resonates in every part of the world, among people belonging to vastly different cultures. It's a point of commonality in otherwise distant civilisations; a question

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posed alike by children and executives, scientists and shamans, astronauts and those small, isolated populations of hunter-gatherers who survive in areas of Borneo, Africa and the Amazon. A question so primal that some have even imagined it must have been handed down to us by the species that came before.

Foundation Myths and Science

For the Kuba of the Congo, the universe was created by the great Mbombo, the lord of a dark world who vomited up the Sun, Moon and stars in order to free himself from a terrible stomach ache. According to the Fulani of the African Sahel, it was the hero Doondari who transformed an enormous drop of milk into earth, water, iron and fire. For the Pygmies of the forests of equatorial Africa, everything came into being when a huge turtle laid its eggs while swimming in the primordial water.

At the origin of mythological narratives of this kind, there always seems to be something indistinct that most troubles us: chaos, darkness, a liquid and formless expanse, a tremendous fog, a desolate Earth – until a supernatural being intervenes to shape things and bring order. This is where the great reptile comes in, the primeval egg, the hero or the creator who separates the heavens from the Earth, the Sun from the Moon, and gives life to animals and men.

The creation of order is necessary because it establishes the rules, providing the foundations of rhythms that mark the life of communities: the cycles of day and night, the changing seasons. Primitive chaos triggers an ancestral fear: the terror of falling prey to the forces unleashed by nature – from ferocious beasts and earthquakes to droughts and floods. But once nature is induced to follow the rules dictated by the hero who has brought order to the world, humankind is able to survive and reproduce. The natural order is reflected in the social one, in the combination of norms and taboos that define what is allowed and what is strictly forbidden. If the tribe behaves according to the rules established by that originary pact, then this stockade of rules will protect the community and prevent its disintegration.

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From such myths as this, other constructions follow. They morph into religion and philosophy, art and science – disciplines that will hybridise and fertilise each other, and allow enduring civilisations to flower. Yet their interweaving breaks down when science starts to develop out of all proportion to our other speculative activities. From that moment on, the sleepy rhythm of societies, unchanged for centuries, is ruptured by a succession of discoveries that will profoundly alter the existence of untold populations. Suddenly everything changes, and continues to change, at a vertiginous pace.

The emergence of science ushers in modernity. Societies become dynamic, subject to continuous transformations; social groups enter a period of ferment, dominant classes undergo profound changes, and in the course of just a few decades the centuries-old balance of power is disrupted.

But the most profound transformations do not concern the way in which we communicate or produce wealth, our medicine or mobility. The most radical alterations are in how we look at the world, and therefore our place within it. The origin story provided by modern science very quickly acquires an unrivalled consistency and complexity. No other discipline can provide explanations that are more convincing, verifiable, coherent or consistent with regard to the myriad observations supplied by scientists.

And yet, despite the notion that we have progressively lost something of the magic and mystery that had accompanied us for millennia, the vision of the world that we have gradually developed through science is actually more amazing than anything we could have imagined before. It retells the story of our origins more imaginatively and powerfully than any mythological narrative. In order to construct this story, scientists have had to scrutinise the most hidden and minute corners of reality, and have explored the remotest worlds, coming to terms with states of matter so different from anything previously known to us as to nearly blow our minds.

From science we derive the paradigm shifts that define our epochs, and that irreversibly modify our relationships. And it is the ceaseless pressure of scientific discoveries that sets the tempo of this subterranean development, like the forces exerted upon the Earth's crust by white-hot magma, sometimes

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breaking it apart and irreparably transforming the landscape above.

Our lives are conditioned by the story of the origins of the universe told by science: it profoundly shifts the foundations on which we will build new social arrangements, opening up vistas full of opportunities and risks, and shaping the future for coming generations.

This is why, just as in ancient Greece everyone had to know the foundation myths of the polis, the origin story that is provided by science ought to be familiar to everyone. But for this to happen, we must first overcome a considerable obstacle. We need to come to terms with the difficulty of scientific language.

A Complicated Language

It all begins with an apparently marginal episode that took place just over four hundred years ago, and which has as its protagonist a Pisan professor of geometry and mechanics at the University of Padua. When Galileo Galilei began to modify the strange tube manufactured by a Dutch optician, converting it into an instrument for examining celestial bodies, he could hardly have imagined the trouble it would get him into; much less could he have foreseen the turbulence that his observations would create across the entire planet.

What Galileo sees through his system of lenses astonishes him. The Moon is not, after all, the perfect celestial entity described by the most authoritative texts. It is not composed of incorruptible matter, but has mountains, craters with jagged edges, and plains similar to our own. The Sun has stains on its surface and rotates on its axis; the Milky Way is a vast accumulation of individual stars; the 'starlets' surrounding Jupiter are orbiting satellites that resemble the Moon.

When in 1610 he publishes all this in his *Sidereus Nuncius*, he provokes, perhaps unwittingly, an avalanche that will undermine the system of beliefs and values that had prevailed for more than a thousand years and that no one had ever dared to challenge.

Modernity begins with Galileo: humankind frees itself from all protection and faces the vastness of the universe alone,

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armed only with its own ingenuity. A scientist no longer looks for truth in books, no longer bows his head before the principle of authority, no longer repeats formulas handed down by tradition – but subjects everything to the fiercest scrutiny instead. Science becomes creative research into 'provisional truths', through 'sensory experiences' and 'necessary demonstrations'.

The power of the scientific method resides in conjectures verified by means of instruments that allow the observation, measurement and categorisation of the most diverse natural phenomena. It is the results of these experiments, what Galileo calls 'sensory experiences', that determine whether a conjecture works or should be discarded.

From his observations, irrefutable evidence is soon provided in support of the 'lunatic' theories of Copernicus and Kepler, and our view of the world changes so radically that nothing will ever seem the same again. Art, ethics, religion, philosophy, politics – everything will emerge transformed by this conceptual revolution which places humankind and its capacity for reasoning at the centre of everything. The disorientations that this new approach will produce, in a relatively brief period of time, are so profound that it is hard to think of anything remotely comparable.

Galilean science is truly revolutionary because it does not allow itself the right to hold back the truth, but instead relentlessly seeks the possibility of falsification even in its own predictions; it welcomes the prospect of all the certainties established up to that point crumbling if they turn out to be false, and it is self-correcting in the light of experimental verification. Finally, in order to stress-test the increasingly complex conjectures that are being elaborated in its name, it pushes towards the exploration of ever more mysterious aspects of matter and of the universe.

From this patient and self-critical approach, accounts are produced of elusive and apparently marginal phenomena. In the process of evolving a view of the world that is ever more sophisticated and complete, we end up mastering, down to the minutest detail, the most remote natural phenomena – and at the same time developing increasingly sophisticated new technologies.

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The price to be paid for this course of development is the need to use increasingly complex instruments, and a language increasingly remote from common speech. No sooner have we departed from the realm of daily life than the instruments and conceptual apparatus that govern our ordinary activities become inadequate. When we explore the minuscule dimensions in which the secrets of matter tend to be hidden, or embark on an exploration of those cosmic spaces that tell of the origins of the universe, we find ourselves in need of very special equipment and years of preparation.

This should come as no surprise. Even actual journeys of exploration and adventure across the globe require a great deal of preparation, effort, and specialised equipment. Think of extreme sailing, or climbing in the Himalayas, or descending into the oceanic abyss. Why should scientific exploration be any easier?

Anyone wishing to thoroughly appreciate physics, therefore, will need to labour for years, to study group theory and differential calculus, and gain a command of relativity and quantum mechanics, as well as field theory. These are all abstruse subjects, involving concepts and language that are difficult even for those who have used them for years. But the barrier of specialised language which prevents most people from entering into the living heart of modern scientific research can also be surmounted more readily. We can still use ordinary language to explain the basic concepts, and to make the vision of the world that science is in the process of advancing accessible to everyone.

A Dangerous Voyage

In order to understand the origins of our universe, we must be prepared to undertake a risky journey. The danger comes from the fact that we need to push our minds into areas or environments so remote from those we are accustomed to that our usual conceptual categories are no longer of any use. We find ourselves obliged to say the unsayable, to depict the unimaginable, to experience the limits of our mind. Limits of a mind that for *Homo sapiens* has been a powerful tool for exploring and colonising our planet, but which turns out to be

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altogether inadequate for fully understanding what happens in such vastly distant places. Like the explorers of old, we have no other option but to point the prow of the ship towards a horizon, and to accept the risks and the unknowns that go with navigating in uncharted waters.

Similarly, in scientific research the voyage home and return to port is also very important. In this respect the modern researcher is a lot like Ulysses, for wherever his journey takes him he is always dreaming of the moment when he will reach Ithaca again. Coming home also means, even if no new territory has been discovered, or we have suffered a terrible shipwreck, that it is possible to warn other sailors about the routes not worth taking, and the dangerous passages that should be avoided.

We do this because modern science is also a great collective adventure. We have theories and charts to guide us, but chance often takes us to places that are completely unknown. We have 'ships' that are meticulously cared for, but we only need to neglect one small detail and disaster can befall us. Our crew is a colourful and lively community of thousands of passionate minds, patient and curious modern explorers, quick like Ulysses to invent new stratagems to overcome whatever unexpected events might be thrown at them.

Despite the objectives of our research raising almost philosophical questions (What is matter made of? How did the universe come into being? How will the world end?), the practice of experimental physics is one of the most concrete activities imaginable.

A particle physicist – one of the thousands of researchers in the world exploring the behaviour of the extremely small components of matter – does not spend his time sitting at a desk making calculations, meditating on theory and fantasising about new particles. A modern apparatus for high-energy physics is as tall as a five-storey building, weighs as much as a cruise ship, and contains tens of millions of detectors. To construct and make operable these miracles of technology, thousands of people are required, and painstaking, obsessively detailed work that can take decades needs to be done. To devise new instruments more sophisticated than the previous ones, to prepare 'ships' more agile and swift for our navigation, we

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spend years producing prototypes, in relentless efforts to make them work before going on to build them on a vast scale. And even when detectors are rigorously cared for and installed in the experiment, functioning quietly for months, we are always faced with the fear of catastrophe. An overlooked minor detail, a defective chip, a fragile connection, a cooling tube that has been hastily soldered can at any moment cause irreparable damage to the entire collective enterprise. The difference between an outstanding scientific success and the worst of all possible failures frequently lies hidden in some stupid, insignificant detail or other.

The Two Paths of Knowledge

How do we collect experimental information on the birth of space-time? How do scientists study the first cries of the infant universe? Two paths of knowledge come into play here, completely independent and different from each other.

On the one hand there is particle physics, exploring the infinitely small. Its starting point is the matter that surrounds us – what rocks and planets, flowers and stars are made of, along with everything else besides, including ourselves. This matter has very special properties which may appear ordinary to us, but that are in reality very peculiar and in a way linked to the fact that the universe is a structure that is both very old and currently very cold. The most recent data tells us that our 'home' was built almost 14 billion years ago, and that we are talking about an extremely cold environment, reaching what seem like impossibly freezing temperatures. For us, isolated on the planet Earth, everything seems comfortably warm; but as soon as we leave the protective shell of our atmosphere, the thermometer plunges. If we measure the temperature at any point in the vast empty spaces that separate stars, or in intergalactic space, the thermometer registers just a few degrees above absolute zero, which is to say minus 270 degrees Celsius. The matter of the current universe – rarefied, extremely ancient and extremely cold – behaves in a very different way than when it was recently born and existed as an incandescent object of tremendously high density.

In order to understand what happened in those very first

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instants of life we need to be ingenious, to find a way of returning the elementary vestiges of current matter to the extremely high temperatures of those original conditions. We have to make a kind of journey back in time.

This is precisely what happens in particle accelerators. By making protons or electrons collide at very high energy, we exploit Einstein's equation: energy equals mass times the speed of light squared. The higher the energy of the collision, the higher the local temperature that will be obtained and the greater the mass of particles that we are able to produce and study. To reach the maximum energies possible we need truly gigantic equipment, such as the Large Hadron Collider at CERN that stretches for some 27 kilometres beneath the ground near Geneva.

Here we find that by heating extremely small portions of space to temperatures comparable to those of the primeval universe, extinct particles revive: those ultramassive particles that used to populate it and that vanished aeons ago. Thanks to the accelerators, they re-emerge for an instant from their icy tomb, as if from hibernation, and may be scrutinised in great detail. This is how we discovered the Higgs boson. We brought back to life several handfuls after they had slumbered for 13.8 billion years. Naturally, of course, the much sought-after bosons then immediately disintegrated into lighter particles, but they had left behind tell-tale traces in our detectors. The images of these special kinds of decay accumulated, and when the moment came when we were certain that the signal was well differentiated from the background, and that the other possible causes of error were under control, we announced the discovery to the world.

The exploration of the infinitesimally small, the reconstruction of extinct particles, the study of the exotic states of matter that everything was made up of at first; these constitute one of the two paths available for understanding the very first moment in the life of space-time. The other requires super-telescopes, huge instruments for exploring the infinitely *large*, and it studies stars, galaxies and clusters of galaxies, in an attempt to encompass the entire universe. Here too we resort to Einstein's equation in which the speed of light is fixed at approximately 300,000 kilometres per second: an extremely

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high but not infinite speed. Hence when we observe a very distant object, galaxies that are distant from us by billions of light years appear not as they are now (and it is quite difficult to define what 'now' means), but as they were billions of years ago, when they actually emitted the light that has only just reached us.

Looking with super-telescopes at very large and very distant objects, it is possible to watch all the principal phases of the formation of the universe 'live', and to collect valuable data about our history. In this way, by observing the first faint signals emitted from the heart of enormous gas clouds, we can understand how stars are born: we observe the thickening of gas and dust in the rings of material that orbit around some new celestial body, indicating protoplanetary systems in formation. This is how our Sun was born, and how the planets that orbit around it were formed – and it is truly amazing to see it actually happening.

Pushing a little further, we can witness the formation of the first galaxies, turbulent objects that sometimes emit enormous quantities of radiation of all wavelengths, an unequivocal sign of traumatic birth. Through the super-telescopes we can ultimately both observe the wonders of the universe and measure some of its properties with unbelievable accuracy. The local distribution of temperature throughout the universe is like a kind of incredible memory containing eloquent traces of what happened at the very beginning: extremely small fluctuations in temperature speak of our most remote history, in a language that we have managed with time to decode and interpret.

But the most awe-inspiring thing of all is that these two paths of knowledge, based on methods so different from each other that they are almost entirely distinct – undertaken and developed by two wholly independent scientific communities – are nevertheless completely coherent with each other: the data gathered from the world of infinitely small elementary particles, and that which pertains to enormous cosmic distances, converge implacably towards the same story of origins.

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Abandon All Prejudice, Ye Who Enter Here

Scientific discourse requires, above all else, the abandonment of every kind of prejudice. Genuine explorers do not fear the unexpected. Far from it, they cannot wait to find themselves faced with utterly unforeseen phenomena. Like the Argonauts setting sail in search of the golden fleece, they are inspired more by curiosity than by the prospect of reward. They are not looking for safety, they are deliberately embracing risk.

When we undertake to journey towards the origin of the universe, as we are about to do, the concepts that guide our everyday lives, such as the persistence of things, the reassurance we feel when witnessing the harmony around us, must be left behind immediately and for good. We will no longer be able to refer to the universe with the word *cosmos*, as when everything seemed to belong to a well-regulated and orderly system that we were used to contrasting with *chaos*, the disorder relegated to remote and insignificant corners.

We are so conditioned by our everyday life, by what we see and experience habitually in the thin spherical shell we inhabit, that it is natural to imagine that the laws determining our existence are the same as those which prevail in every other corner of the universe. Spellbound by the regularity with which night follows day, by the recurrence of lunar cycles and the rhythm of the seasons, by the persistence of the stars that light up the heavens, we have assumed that a similar kind of balance must obtain everywhere. But this is far from being true. In fact, something like the opposite is the case.

We have only been here for a few million years, living lives of infinitesimal duration compared to the cycles of any relevant cosmic process. We live on a tepid, rocky planet, rich in water and surrounded and protected by an accommodating atmosphere and by a benevolent magnetic field which, like some kind of magic blanket, can absorb ultraviolet rays and screen us from the devastating impact of cosmic rays and swarms of particles. Our mother star, the Sun, is a medium-sized star located in a very calm and rather peripheral region of the galaxy which harbours us. The whole of the solar system orbits slowly, in a manner of speaking, at a distance of 26,000 light years from the centre of the Milky Way. A safe distance, because hidden within it there is a monstrous black hole,

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Sagittarius-A*, an object weighing 4 million times more than the Sun and capable of destroying thousands of stars in its vicinity.

If we now carefully observe further the phenomena that affect the celestial bodies, such as stars that seem to be stationary and inactive, we stumble across incredible objects and discover that immense quantities of matter may behave in a very strange manner.

This is the case with pulsars, dark and dense objects that concentrate in a radius of around 10 kilometres the mass of one or two Suns. Myriads of neutrons are held captive by the gravity of pulsars, which compresses and seeks to crush them while the star itself revolves in a vortex producing tremendous magnetic fields.

Even worse than pulsars are quasars and blazars, ultramassive bodies that roar at the centre of some galaxies. Disproportionately massive black holes – over a billion times more massive than our Sun – they are capable of swallowing the ill-fated stars that end up trapped in their gargantuan gravitational fields. This *danse macabre* has developed over millions of years, and we can observe it from Earth because the matter that is precipitated, spiralling, contorting into the abyss and disintegrating, ends up emitting high-energy jets and gamma rays that our detectors are able to identify.

These strange celestial bodies, neutron stars and black holes, are the cause of enormous catastrophes that occur regularly throughout the 'cosmos'. Today they can be studied with a great deal of precision, to the extent that we have even witnessed collisions between them that have distorted space-time, producing gravitational waves that have reached us from billions of light years away.

But we do not need to look as far as this in order to understand how beneath the appearance of the cosmos, there is a chaos concealed. We only need to look closely at the surface of the Sun. What seems to be a quiet star that calmly illuminates our days, when seen close up becomes a complex and chaotic system made of innumerable thermonuclear explosions, convection currents and periodic oscillations of awesome masses, with flows of plasma projected all around it by powerful magnetic fields. Within our mother star there is a clash

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occurring between titanic forces, a battle that has lasted for countless years, with only one winner: gravity. And in a few billion years, with the exhaustion of its nuclear fuel, it will finally succeed in crushing and shattering its own internal structure, causing it to collapse. The central nucleus will become compressed, while the external strata will begin to expand until they reach Mercury, Venus and Earth, causing them to instantly evaporate.

This is because systems that are markedly chaotic may appear orderly and uniform when seen from a great distance. The same thing happens at the other extreme of our observations, in the world of the infinitely small.

If we look closely at the most apparently smooth and polished surfaces, we are immediately struck by the chaotic dance of the elementary components of matter which fluctuate, oscillate, interact and change nature at a frenetic pace. The quarks and gluons that make up protons and neutrons are constantly changing condition, interacting among themselves and with millions of virtual particles around them. At a microscopic level, matter relentlessly follows the laws of quantum mechanics, dominated by chance and the principle of uncertainty. Nothing stays still. Everything seethes in an extraordinary, constantly changing variety of states and possibilities.

But when we observe great numbers of these particles, when the structures become macroscopic, the mechanisms that regulate this dynamic almost magically acquire regularity, persistence, order and equilibrium. The superposition of a sufficiently large number of random microscopic phenomena, developing in all possible directions, produces macroscopic states that are orderly and that endure.

Perhaps the time has come to introduce a new concept to describe this fact, which seems to be truly structural. *Cosmic chaos* might be the right oxymoron to capture the relation between the two entities that in the universe chase each other and play at hide-and-seek. It is a game that we observe when we probe the tiniest recesses in the world of elementary particles, but that also occurs when we observe what happens at the heart of stars or of gigantic structures such as galaxies or clusters of galaxies.

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To understand the birth of the universe, we will need to abandon the prejudice of order, among many others. We will face a voyage guided only by imagination, and we will have resort to concepts so bold as to make the most fantastic science fiction seem banal by comparison. On this journey we will get to know about theories that are changing forever our view of the world. And at the end of it, perhaps, discover that we ourselves have become different from what we were at the beginning.

So fasten your seat belts. We are about to take off.

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In the Beginning Was the Void

In the beginning was the void. There, we have done it, we have right away given an answer to the most difficult of questions: what was there before the Big Bang?

Strictly speaking it's a badly put question. As we shall soon see, space-time makes its entry together with mass-energy; hence there is no *before*, there is no clock that ticks *beyond* the universe that is still waiting to be born. Nevertheless, for the sake of the narrative we can ignore this logical difficulty and go straight to the substance of the matter.

Let us accept the paradox of asking ourselves what existed *before* time came into being and let us imagine ourselves in that *no-place* from which all space would unfurl. Let us fantasise, we material beings who need air to breathe and light to see, that we are already present there, where there is still no trace of matter or energy, waiting to assist at the birth of everything, and to see it with our own eyes.

Before us extends the void, a very peculiar physical system that despite its frankly misconceived name is anything but empty. The laws of physics fill it with virtual particles that appear and vanish in frenzied rhythm, packing it with fields of energy whose values fluctuate continuously around zero. Anyone can borrow energy from the great bank of the void and live an existence the more ephemeral the greater the debt acquired.

From this system, from these fluctuations, a material universe may emerge that in reality is still only a void, but a void that has undergone a marvellous metamorphosis.

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A Gigantic Expanding Universe

Today it is hard not to smile a superior smile when confronted by the naive imaginings that the best scientists from previous eras relied upon, produced without the benefit of modern telescopes. The word 'universe' contains the Latin roots *unus*, 'one', and *versus*, the past participle of *vertere*, 'revolving'. We use it as a synonym for 'everything', even if its literal meaning should be 'that which is turned wholly in the same direction', containing therefore a residue of all the ancient beliefs that invariably involve a stable and ordered system of rotating bodies. This prejudice is shared by both the ancient conceptions of Aristotle and Ptolemy and the more modern models of Copernicus and Kepler.

From a conceptual point of view, the geocentric and heliocentric universes are completely different. For almost two thousand years' some of the world's most learned men engaged in calculations and endless disputes concerning the movements of the wonderful concentric spheres in which the Moon, Sun, planets and stars were fixed. Then, suddenly, this vision of the world collapsed.

Removing the Earth from the centre of creation was no trivial matter. For sixteenth-century society it brought with it a terrible cultural, philosophical and religious shock. From that moment onwards the world would never be the same again. Nevertheless, if we look at things from a certain distance, the two systems which appear to be so irreconcilable that blood was spilt over the gulf between them, are actually in possession of similar structures. Both describe an immutable, stationary universe; a perfect machine that guarantees perennial, harmonious rotation. Whether it is made to work by 'the love that moves the Sun and stars', or by the gravitational force of Galileo and Newton, the basic substance of what is involved does not change.

This prejudice or fixed idea of an eternal and immutable universe that's perfect in every respect, identical to itself *ab initio*, from its very beginning, is a legacy that reaches down almost to our own time. It is astonishing to come across it at the start of the twentieth century, even in the first formulations of relativistic cosmology.

In 1917 Albert Einstein, developing the consequences of his

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general theory of relativity, postulated a homogeneous, static, spatially curved universe. Mass and energy warp space-time, and would tend to make it collapse into a point – but if you add to the equation a positive term that compensates for this tendency towards contraction, the system remains in equilibrium. The beginning of modern cosmology is ushered in with this manoeuvre. To avoid the catastrophic ending of the universe – the inevitable result if only gravity were present – an arbitrary term was invented. Wanting to maintain the prejudice regarding the stability and persistence of the universe that had lasted for millennia and still evidently held Einstein captive, he forcefully introduced the 'cosmological constant', a kind of vacuum energy which is positive and tends to push everything outwards, thus contrasting with and counterbalancing the gravitational pull and guaranteeing the stability of the whole.

Today, now we know that the universe is made up of 100 billion galaxies, it is shocking to realise that scientists in the first two decades of the last century, among them some of the most brilliant minds of all time, were still convinced that it consisted solely of the Milky Way. It was the slow concentric movement of the bodies belonging to this galaxy that gave the idea of a universe that was like a stationary, harmonious and ordered system. Soon afterwards this was brought into question by new kinds of observation, but a radical break with the old conceptions was also anticipated by the brilliant intuition of a young Belgian scientist.

In 1927 Georges Lemaître was a thirty-three-year-old Catholic priest with a degree in astronomy from the University of Cambridge, and in the process of completing his PhD at the Massachusetts Institute of Technology. He is among the first to grasp that Einstein's equations can also describe a dynamic universe, a system of constant mass but one that is expanding – with a radius, that is, which gets bigger with the passage of time. When he presents this idea to his older and much more established colleague, Einstein's response is shockingly negative: 'Your calculations are correct, but your physics is abominable.' So deeply rooted is the prejudice which for millennia had conceived of the universe as a stationary system that even the most elastic and imaginative mind of the period rejects the idea that it can be expanding, and that as a

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consequence of this expansion it must have had a beginning.

It would take years of discussion and fierce argument before this extraordinarily novel idea was generally accepted by scientists, and a great deal more time would have to pass before it became public knowledge.

The key to its success is suggested by Lemaître himself, in an article in which he proposed his new theory, backed up with measurements of the radial speed of extra-galactic nebulae.

At the time, the attention of astronomers was concentrated on those peculiar objects resembling clouds which they conceived of as being groups of stars aggregated together with agglomerations of dust or gas. Today we know that they are in fact galaxies, each containing thousands of stars, but the telescopes of the time were not sufficiently developed to show them in much detail.

In order to calculate the speed at which a star or any other luminous body moved, astronomers had long known how to use the *Doppler effect*. The same phenomenon that we notice with sound waves from an ambulance siren can be observed with light waves. When the source recedes, the frequency of the waves that we receive is reduced: the sound of the siren gets fainter the further away it is. In the same way, the colour of visible light shifts towards red with distance. By analysing the spectrum of luminous frequencies emitted by various celestial bodies, we can measure for each one this shift towards red, precisely the so-called *red shift*, and work out from this the radial speed with which they are receding from us.

But it was not easy to measure how far away these formations were, or consequently to determine whether they were situated within our galaxy or not. The solution was discovered by Edwin Hubble, a young astronomer working at the Mount Wilson Observatory in California, equipped with what at the time was the world's most powerful telescope.

The technique employed was based on the study of Cepheids, pulsating stars of variable luminosity or brightness. Hubble begins his work just a few years after the death of Henrietta Swan Leavitt, one of the first American astronomers, a young scientist who had contributed enormously to this field and received, as is often the case, no appropriate recognition. In fact, at the beginning of the twentieth century it was

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Farrar, Straus and Giroux
120 Broadway, New York 10271

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Originally published in Italian in 2019 by Giangiacomo Feltrinelli Editore, Milano, Italy, as *Genesi*
English translation originally published in 2021 by Profile Books Ltd, Great Britain
Published in the United States by Farrar, Straus and Giroux
First American edition, 2021

Ebook ISBN: 978-0-374-60049-5

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