# ALPHA AND OMEGA

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TRANSWORLD
BOOKS

# About the Book

Since A BRIEF HISTORY OF TIME scientists have been in the midst of a revolution in cosmology. Gradually, astronomers and physicists are answering questions that have plagued mankind since prehistory: how was the universe born, how will it end? They are even now peering into the cradle of the universe – and into its grave. By the beginning of next year, scientists will have a clue to some of the answers. These will be among the greatest triumphs of science.

This book tells that story and will reveal results of the most advanced experiments in cosmology ever conducted. It’s a tale of men solving the insoluble, of the controversy and anger of rivals after the same goal. Even more thrillingly – it is a lucid explanation of new scientific ideas that stretch man’s powers of understanding to their highest levels.

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CHARLES SEIFE

# ALPHA AND ΩMEGA

THE SEARCH FOR THE BEGINNING AND THE END OF THE UNIVERSE

# Preface

> *I am Alpha and Omega, the beginning and the end, the first and the last.*
>
> —Revelation 22:13

TEN BILLION LIGHT-YEARS away, Nature screams. In a fraction of a second, a star explodes with more energy than ten billion billion billion hydrogen bombs. For a few weeks, the funeral pyre of the dying sun blazes and outshines the countless stars of its galaxy. When a star dies as a supernova, it is visible halfway across the universe.

The light from that supernova travels for ten billion years, attenuated and stretched along the way. By the time the light reaches Earth, it is far too dim to be spotted by the naked eye, but telescopes can see the supernova as a dim blotch in the sky. It is a message from the ends of the cosmos—a message whose receipt on Earth heralds the beginning of a revolution.

This revolution began in the late 1990s, when two teams of scientists began to decode the death throes of dying stars. Their observations showed that the universe was suffused with a mysterious “dark energy,” an invisible substance that stretches the very fabric of space and time. The discovery of dark energy baffled and delighted astronomers, who scrambled to confirm the observations and understand the enigma. What’s more, the stellar death rattles held the secret to the universe’s death—scientists merely had to decrypt the message from the dying stars and they would understand how the cosmos would end.

That message has now been deciphered. On June 25, 2001, *Time* magazine devoted its cover to the end of the universe. “Peering deep into space and time, scientists have just solved the biggest mystery in the cosmos,” it exclaimed. This is no overstatement. Cosmologists now know how the universe will end, and a new set of experiments, whose results have begun to trickle out, is removing the veil over the big bang, showing us how it began.

The revolution is being fought on many fronts, by astronomers, cosmologists, and physicists, high atop the Chilean mountains, deep underneath the Canadian soil, stranded in the middle of the Antarctic wasteland, and all across the globe. *Alpha and Omega* is the story of galaxy hunters and the microwave eavesdroppers, gravity theorists and particle physicists, quantum theorists and atom smashers, all of whom are on the brink of major discoveries. Each of their stories, taken alone, would be noteworthy. Together, they add up to a renaissance—a major shift in our understanding of the universe. This shift is happening right now, and it is far from finished.

*Alpha and Omega* is the story of the most exciting scientific discoveries in decades and the people behind them. It is also a guide to understanding the headlines that are erupting in *Time*, in the *New York Times*, in *Science*, and in newspapers and magazines all across the planet. This revolution in cosmology will be front-page news again and again over the next few years. Indeed, it will be one of the most important scientific stories of the twenty-first century. When it is over, we will have seen the moment of creation, and we will see the face of our own destruction.

# *Chapter* 1
# The First Cosmology

[THE GOLDEN AGE OF THE GODS]

> *Then All-father took Night and her son, Day, and gave them two horses and two chariots and put them up in the sky, so that they should ride round the world every twenty-four hours. Night rides first on a horse called Hrimfaxi, and every morning he bedews the earth with the foam from his bit. Day's horse is called Skinfaxi, and the whole earth and sky are illumined by his mane*.
>
> —Snorri Sturluson, *The Prose Edda*

PERHAPS IT HAPPENED on a midwinter's night thirty thousand years ago. A tribe of cavemen huddled close to the embers of a dying flame. A single hairy face gazed upward, bewildered. Against the innumerable, immutable pinpricks of light in the heavens, a star had moved. A human looked into the cosmos and saw the trail of a wandering god.

Even before the dawn of civilization, people gazed skyward and wondered. Who created the stars in the sky? How was the universe born? Will it end? If so, how? These are the most ancient questions of humanity. Yet, for millennia upon millennia, the only way to answer these mysteries was through mythology. Even today, the remnants of that mythology can be seen in the heavens. The tiny lights that meander slowly through the sky, better known as planets, bear the names of gods. Red Mars is gorged with the blood

of conquest; bright Venus glitters in the morning with the allure of the goddess of love. Each civilization invoked its own gods to explain the creation of the universe, the existence of stars in the night sky, and occasionally the ultimate destruction of the cosmos.

Three revolutions separate modern cosmologists from the shamans and storytellers of the age of mythology. The first, which took place in the 1500s, was the most dangerous. Its enemies tried to stifle it with all the weapons in their arsenal: accusations of heresy and witchcraft. The second revolution, which began in the 1920s, was the most unsettling; the comforting concept of a clockwork universe was shattered, and humanity was suddenly alone in a vast, empty cosmos. For the first time, scientists saw evidence of the act of creation. These two revolutions take us to the present day, where we are in the midst of a third revolution, a revolution that is finally answering the eternal questions, revealing our origins and our ultimate fate.

**I**f you look upward on a sunny day and squint your eyes just right, you can imagine the vault of the heavens as an immaculate blue dome, arching high above the wispy clouds that float slowly across the sky. To ancient peoples, the dome of the sky was a real object; the Earth was enclosed by a beautiful sphere that shone blue in the daytime as the sun slowly traveled from east to west. In the evening, tiny, flickering points of light mocked the humans far below, and a faint shimmering ribbon stretched across the giant ball surrounding the Earth.

Who fashioned that sphere? Each culture had a different answer; every people had a story of creation, which told of how the gods came to be and how they created the universe. The Norse people, not surprisingly, thought that the universe was born from ice. As the frost encountered an enormous fire, it thawed and formed a giant named

Ymir. Odin, chief of the gods, and his brothers slew Ymir and used his skull as the dome of heaven. They then fashioned the Earth from Ymir's flesh, the oceans from his blood, and the clouds from his brains. They set the planets in the sky and made the glowing chariots of the sun and moon chase each other in the vault of the heavens—each eternally pursued by a wolf.[1] The Pawnee Indians of central North America saw corn as the mother of all things; Mother Corn gave life to humanity, which emerged from the ground like the crops that the Pawnee depended on. Some cultures thought the universe began as a vast ocean; others, as a shapeless chaos. There are dozens and dozens of vastly different tales of the creation of the universe, but most of them focus on the same events: the birth of the gods; the creation of the heavens, Earth, and stars; and the fashioning of man and woman. These elements are the foundation of any religion, as they answer the fundamental questions that humans have been asking since the dawn of time. Before the scientific revolution gave humanity another tool with which to examine the universe, people could only explore its history and nature by listening to the stories of shamans and the musings of philosophers. Religion and philosophy formed the cosmologies of the ancients.

Two of these numerous cosmologies dominated the Western world, from before the ascent of Rome until the time of William Shakespeare. Even though these two traditions are mutually contradictory, they fused, and fashioned a story of the universe that was almost unassailable until the advent of the scientific method. The combination of an Eastern, Semitic cosmology, encoded by the Bible, and a Western, Greco-Roman one, became a solid structure that stood for more than a millennium. It took a cosmological revolution to tear the edifice down.

**T**he word *cosmos* is the Greek word for “order,” and the cosmos—the universe as a whole—was the only order to be found in the chaos of Greek mythology. The sun traveled across the sky each day, guided by Helios, the solar charioteer.[2] The moon waxed and waned each month, growing pregnant and barren in turn. And in the night sky, the stars remained fixed, except for five wanderers—the planets—that moved across the unchanging backdrop of the heavens.[3] Even today, we know the planets by their Olympian names: Mercury, Venus, Mars, Jupiter, and Saturn are the Roman names of the Greek gods Hermes, Aphrodite, Ares, Zeus, and Cronus. The Greeks saw order in the clockwork motions of the heavenly bodies, and from early on in their civilization they began to work out the details of that clockwork. In 585 BC, the Greek mathematician Thales was the first to predict the coming of a solar eclipse. According to Herodotus, two warring peoples, the Medes and the Lydians, were astonished to see the day turn into night and decided that it would be a good time to put down their weapons.

By trying to understand how the heavens worked, Thales became the first starry-eyed cosmologist—to the amusement of his neighbors. “While he was studying the stars and looking upward, he fell into a pit, and a neat, witty Thracian servant girl jeered at him,” Socrates reportedly said, several centuries later. But Thales put all his concentration and observation to good use. He created an entire cosmos from the sheer power of his mind.

Perhaps because the Greek stories of creation were fragmentary and contradictory, Thales ignored them when building his cosmology. Though he believed that gods were everywhere in the universe, Thales took the act of creation out of the gods’ hands. In Thales’ universe, water was the source of all things; earth floated upon the water like a cork. Not everyone agreed with Thales that water was the primordial material from which the universe was made.

Others, like Anaxagoras and Diogenes, argued that air came before water. (After all, water destroys fire, so water could hardly have given birth to fire.) Yet others argued that fire was prime. Empedocles, who lived at around 450 BC, refused to pick a single primal essence and instead argued that earth, air, fire, and water were the four elements. In different combinations, he declared, these four essences made up everything in the universe.

The philosophers also argued about the nature of the heavenly clockwork. They looked to the heavens and tried to figure out the order of the cosmos, and Earth's place within that order. They began by describing the Earth itself. Pythagoras, an eccentric philosopher who is best known for his theorem about right triangles, argued that the planets, including Earth, revolved around a central fire. Others argued that the Earth was flat, and still others that it was spherical, but at the center of the universe. By the fourth century BC, Aristotle became the philosopher who mattered. Born in Macedonia, and tutored by Socrates' student Plato, Aristotle, in turn, became the teacher of Alexander of Macedon—better known as Alexander the Great. And just as surely as Alexander conquered the West, so too did Aristotle's philosophy.

Aristotle's cosmos was exquisitely orderly. Everything had its place in the universe. Empedocles' four elements had their natural positions; earth, the heaviest element, sank to the center of the universe, so the Earth, quite naturally, must be at the very center of the cosmos. Water was slightly lighter, so it floated above earth, but below air and fire, which were lighter still. Aristotle added a fifth element—literally, the quintessence—that was purest of all. Earthly things were made of earth, air, fire, and water; the quintessence was only found in the heavens. To Aristotle, the pure, unchanging heavens were made of stuff entirely different from the ever mutable, but motionless, Earth at the center of the universe. The moon, sun, and planets each

revolved around the Earth in perfect, crystalline spheres, never ceasing in their motion, and filling the heavens with celestial harmony: the music of the spheres.

This cosmology was based upon pure logic. Aristotle made certain basic assumptions—that the universe had to be finite, that everything had a natural place, that circles and spheres were the most perfect geometric shapes—and deduced what he thought was the natural order of the cosmos. Aristotle's mentor, Plato, mocked the "light-minded men" who, "being students of the worlds above, suppose in their simplicity that the most solid proofs about such matters are obtained by the sense of sight," and Aristotle agreed. Observation was for fools.

Aristotle's cosmos was light on theology. It only required the existence of a "prime mover" to set the celestial spheres in motion—it did not specify the nature of that divine power. This, in part, is what gave Aristotle's cosmos such longevity even after an entirely different culture became the foundation for Western religion.

"In the beginning God created the heaven and the earth. And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters." The beginning of Genesis is the basis for Jewish—and, later, Christian—cosmology. Its roots lie in the hazy past of the first civilization, in the Fertile Crescent. Thousands of years later after the Hebrew Bible was set down in writing, Christ took this ancient tradition and bent it into a new form.

Unlike the Greek cosmology, which could easily accomodate a pantheon of petty, squabbling gods, the Jewish cosmology tells of an omnipotent, omniscient God who creates the heaven and Earth out of nothing. He alone fashions the vault of heavens and the Earth below; he alone set the sun, moon, and stars in their places in the sky. His act of creation took six days, but the universe, complete with the heavenly bodies, was finished by the fourth. God

created man on the sixth day—the culmination of his efforts.[4] The hierarchy is clear. Genesis sets it out quite neatly. God is above all, and then comes man, which God created in his image. Then comes woman. Then the beasts of the field, the fowl of the air, the fish of the sea, herbs and plants, and then the Earth itself. Man has dominion over all; everything else in the universe is meant to serve him. The sun and moon were meant to divide the night from the day for man's benefit; along with the innumerable stars, they were fashioned to provide him with light. Man is the center of the universe, both literally and figuratively.

When Rome conquered Greece, it absorbed Greek philosophy and culture—and its cosmology—and as the Roman Republic and Empire spread across the known world, so too did Aristotle's picture of the universe. But Rome, in turn, would be conquered by Christianity, a religion that branched off of Judaism. At the end of the first century AD, Christianity was a small sect. Less than three centuries later, the emperor Constantine, ruler of the most powerful nation on earth, converted to Christianity. The Greco-Roman and Christian cultures began to merge. Aristotle's ambiguous theology made it easy for the early Christians to absorb Aristotle, just as Rome had. (The New Testament was written in Greek, after all, so the early church had already absorbed a heavy dose of Greek culture.) Christianity, with Greek philosophical undertones, became the dominant cosmology in the Western world.

The Aristotelian component of Western cosmology had a very firm foundation—it was based upon observation of the natural world. In the second century AD, in Alexandria, the intellectual capital of the ancient world, the mathematician Ptolemy built an intricate, and incredibly complicated, model of the universe based upon Aristotle's cosmology. The Earth was at the center of the universe, and the stars and planets whirled in circular orbits around it. To explain the complicated motions of the planets (such as the

occasional backward, or *retrograde*, motion of Mars), Ptolemy proposed that the planets danced in tiny little circles called epicycles as they spun around the Earth.

Ptolemy's clockwork universe worked beautifully. It explained the motions of the planets to fairly high precision, providing seemingly unshakeable support for Aristotle's theory of the cosmos. By building upon Aristotle's geocentric universe, Ptolemy had fashioned a powerful cosmology, one that had predictive power. Its ability to describe the motion of the planets, along with its "prime mover" that seemed to describe the Christian God admirably well, made the Aristotelian-Ptolemaic universe unassailable until Elizabethan times.

Aristotelian-Ptolemaic cosmology was embraced by the church, even though it sometimes contradicted the Bible. For instance, Psalm 148 exclaims, "Praise him, ye heavens of heavens, and ye waters that be above the heavens." Though having a water above the heavens seemed to explain both the blueness of the sky and the source of rain, this was forbidden in the Aristotelian universe. Water is a heavy element, so it did not belong above the heavens; it was only allowed to exist in the earthly sphere.

Though the church struggled internally with the contradictions between Aristotle and the Bible, it eventually used Aristotelian cosmology as the basis for its own theology. To attack Aristotle became tantamount to attacking the truths handed down by the pope himself. And when a revolution toppled Aristotle, the church found itself on the losing side. It has never recovered.

1. Unfortunately for the sun and moon, the wolves catch up in the end.
2. One legend tells of a single, disastrous aberration in the sun's daily course, when the son of Helios took the reins of the chariot. The son, Phaëthon, died due to his hubris and poor horsemanship.

3. The Greek word *planetos* means “wanderer.”
4. The two Genesis stories of the origin of man and woman are somewhat contradictory. Genesis 1 has both man and woman being created on the sixth day; Genesis 2 starts with Adam and tells of Eve being fashioned from Adam’s rib. For this reason, some Jewish mystics believed that Adam had a wife before Eve, Lilith, who now wanders the Earth as a demon.

# *Chapter* 2
# The First Cosmological Revolution

[THE COPERNICAN THEORY]

> *The indispensable catalyst is the word, the explanatory idea. More than petards or stilettos, therefore, words—uncontrolled words, circulating freely, underground, rebelliously, not gotten up in dress uniforms, uncertified—frighten tyrants.*
>
> —RYSZARD KAPUSCINSKI, *SHAH OF SHAHS*

HIGH UP ON a wall in the Vatican, there is a tiny yellow portrait, a relic of a four-hundred-year-old battle. Surrounded by flowers and laurels, and crested by the two keys to heaven, a bemused-looking bearded man gazes to his left. He would be unrecognizable but for a handy Latin inscription: "Galileus." Galileo Galilei, the most famous scientist of his day, was condemned to perpetual imprisonment by the Roman Inquisition. Now that he's back in favor with the church, his picture is adorned with the trappings and symbols of the pontiff. A few yards away, another bearded man on the wall stares to his right. His three-pointed hat reveals that he is a cardinal, a prince of the church. "Bellarminus," Cardinal Robert Bellarmine, the chief of the Roman Inquisition, was the man who first tried to subdue Galileo. His portrait is also surrounded by laurels, and he too is adorned by the keys to heaven. Galileo and Bellarmine, adversaries in life, are both honored by the church, and their portraits adorn the same

wall of the Vatican. Yet the two still look in opposite directions.

Four hundred years after the opening shots of the first cosmological revolution, the Roman Catholic Church is still struggling to come to terms with its past. When the discipline of science was born, the church tried to smash the scientists who trod carelessly across Christian theology. Unfortunately for some scientists, it was hard not to stray into forbidden territory, especially since the first major achievement of modern science was to shatter the ancient Aristotelian cosmos—to smash the cozy universe, as self-contained as a nutshell—into a thousand shards. For the first time, science provided genuine insight into the nature of the universe. A new breed of philosopher started telling a tale of how the cosmos was put together, contradicting the Aristotelian-Ptolemaic cosmology. The church, with its foundation perched upon that ancient nutshell, struck back.

The scientific cosmology eventually defeated the Aristotelian one, but this would not provide any consolation for Galileo, or for the other victims of that struggle. Centuries after the clash of theology with science, the church still suffers from losing the first cosmological revolution.

**T**he church had a love-hate relationship with Aristotle and Ptolemy, the ancient Greek architects of Western cosmology. The Greek cosmos made a great deal of sense to the medieval mind; the stars and planets had their own natural places. So did the elements that made up all the matter in the cosmos. Heavy earth sinks to the center of the universe, forming the ground we walk on. Water, which is lighter, sits on top of the earth, forming the oceans and rivers. Air, lighter still, forms the atmosphere we breathe. Fire is the lightest element—after all, flames try to leap into the sky. The sun, moon, planets, and stars, made from some light, fiery substance, inhabit the heavens, revolving in

crystal spheres about our planet. What made the cosmology even more attractive to the church was that Aristotle's universe required a prime mover. The Greek cosmology was inherently a proof of a divine existence.

Few philosophers or theologians in the West questioned the idea that the prime mover, the being who set the crystal spheres in motion, was the Christian God. The church embraced Aristotle's ideas, seeing the value of a proof of God's existence. But before long, theologians realized that the Aristotelian cosmology, in fact, contradicted the Bible. The ancient Greek wisdom denied the existence of an omnipotent God—a heretical idea. Cracks in Aristotle's nutshell universe began to appear very early in church history. Augustine of Hippo, the fifth-century scholar and saint, was one of the first to attack the ancient philosophy.

Augustine saw a problem with Aristotle's ideas about the origin of motion, which comes from the prime mover. That idea in itself was not so troublesome to Augustine, but the devil was in the details. Aristotle's prime mover twists the outermost crystal sphere, causing the motion of all things in the universe, be it the eternal spinning of the planets in the heavens or the motion of the flames on a burning piece of flax. Therefore, argued the ancient philosophers, if God decided to stop the motion of the heavens, then all motion on Earth and the very passage of time should cease. Water should abruptly stop flowing over a waterfall, and birds should freeze motionless in midflight. Since God doesn't stop the motions of the heavens very often, this doesn't seem like a theory that would get tested. But, in fact, it did, in a medieval sort of way. God did stop the motion of the heavens once, at least according to the Bible. And biblical history does not match up with Aristotle's predictions.

Chapter 10 of the Book of Joshua tells of a battle between the Israelites and the inhabitants of the land of Canaan: "And the sun stood still, and the moon stayed, until the people had avenged themselves upon their enemies."

The men of Israel were happily smiting and slaying, even though the heavenly bodies had stopped in their tracks. This biblical passage directly contradicts Aristotle, whose theory implies that the Israelites should have been as motionless as the sun and moon.

Realizing the contradiction between the Bible and Greek philosophy, Augustine argued that the passage of time was independent of the motion of the heavenly bodies; if the sun and moon stood still in the heavens, a potter's wheel would still whirl around unabated. If Aristotelian philosophy and the Bible clashed, then Aristotle had to give way.

The friction between Aristotle and the Bible was inevitable. The Bible is based on Eastern philosophy, while medieval cosmology was built upon the Western philosophy of Aristotle and his successors. The two cultures had very different views about how the universe works, yet the two were forced into an uneasy marriage within church theology. The inherent contradictions led to centuries of conflict, which reached a peak in the 1200s.

Theologians argued, in the tradition of Augustine, that an omnipotent God can do whatever he wants to do; if he so desires, he can stop the planets and maintain the flow of time. He can create a void or a vacuum, an act absolutely forbidden by Aristotle's philosophy. (This abhorrence of the void forced Aristotelian scholars to conclude, rather absurdly, that all motion had to be circular—moving in a straight line was impossible. Motion in a straight line would create a vacuum behind the moving object. With circular motion, on the other hand, everything simply swapped positions without creating a vacuum.) However, Aristotle's no-vacuum declaration directly contradicts the Bible. Genesis says that the universe was born from void, a concept that Aristotle would have found to be ridiculous. Aristotle's rules were shackles on the hands of a God who is too powerful to be shackled. Therefore, some clerics

concluded, Aristotle must be wrong. In the first half of the thirteenth century, one cardinal banned Aristotle's *Physics* as well as his *Metaphysics*. Shortly thereafter, in 1277, the bishop of Paris, Étienne Tempier, called a council together to refute elements of Aristotelian cosmology, such as "God cannot move the heavens in a straight line, because that would leave behind a vacuum." If God wants to move the heavens in a straight line, argued Tempier, who could stop him? Certainly not Aristotle. The council condemned the "errors" that led adherents of Greek philosophy into heresy.

The pro-Aristotle camp fought back, particularly Thomas Aquinas, a noble-born hermit who found the philosophy of the ancients aesthetically—and theologically—pleasing. He argued for a deeper integration of Aristotelian cosmology within church theology. Aquinas died in 1274, after many years of serious research into such things as how many angels can dance on the head of a pin.[1] Three years later, some of his statements were condemned by Tempier as heresy. But in 1323, Aquinas got a promotion. *Saint* Thomas Aquinas could hardly be a heretic, so Tempier's condemnations fell by the wayside. Nonetheless, the question of Aristotle's role in the church was far from settled. The battle raged back and forth. For a time, even those at the very center of the church were espousing radical anti-Aristotelian ideas.

In the fifteenth century, Nicholas of Cusa, a cardinal, argued that the glittering stars in the sky were like our own sun; perhaps each point of light in the firmament was a distant solar system of its own, complete with alien Earths. Perhaps those alien Earths even had their own moons. This was a direct challenge to Aristotle, to the very idea that every element in the universe has its natural place. In Aristotle's cosmology, Earth must be unique, because there can be only one repository of earth, the heaviest element. All heavy objects, like rocks, goats, trees, and people, try to sink to the center of the universe and are held up only by

the elemental earth that forms the ground beneath our feet. Only things made out of lighter elements, like air and fire, can float in the sky. So, in Aristotelian cosmology, the very idea of other Earths is absurd. Any dirt in the sky would instantly crash down on our heads as it assumed its natural place at the center of the universe. Cusa, on the other hand, stated that other worlds—bits of rock and soil—float in the heavens. It was an absurd theory to any Aristotelian.

Cusa did not stop there. He boldly declared that all of these alien worlds had inhabitants. There were infinite worlds in the cosmos, teeming with infinite alien beings. Maybe those aliens gaze up in the sky at night and look at a point of light, our Earth, and wonder whether the tiny gleaming pinprick could harbor life. If so, how could the Vatican be the seat of the One True Church? How could alien beings obey the pope if they had never heard of Rome? Cusa's doctrine was very dangerous to the church, but it escaped notice, even after 1543 when a Polish clergyman, Nicolaus Copernicus, gave scientific support for Cusa's bold statement: the Earth is not the center of the universe. The church did not realize at the time that the first cosmological revolution had begun.

**S**cience would never have come into conflict with the church if the scientific revolution had dealt with a discipline that was largely devoid of spiritual implications, like botany or chemistry. But scientists ventured into cosmology, a very touchy subject because it was traditionally the territory of theologians and philosophers, not scientists.[2] The scientific approach spurned a millennium-old tradition and was fraught with danger. When scientists sought answers in the heavens rather than in the writings of the ancients, they wandered into dangerous territory. In the church's eyes, the greatest affront was when the first scientific cosmologists stated

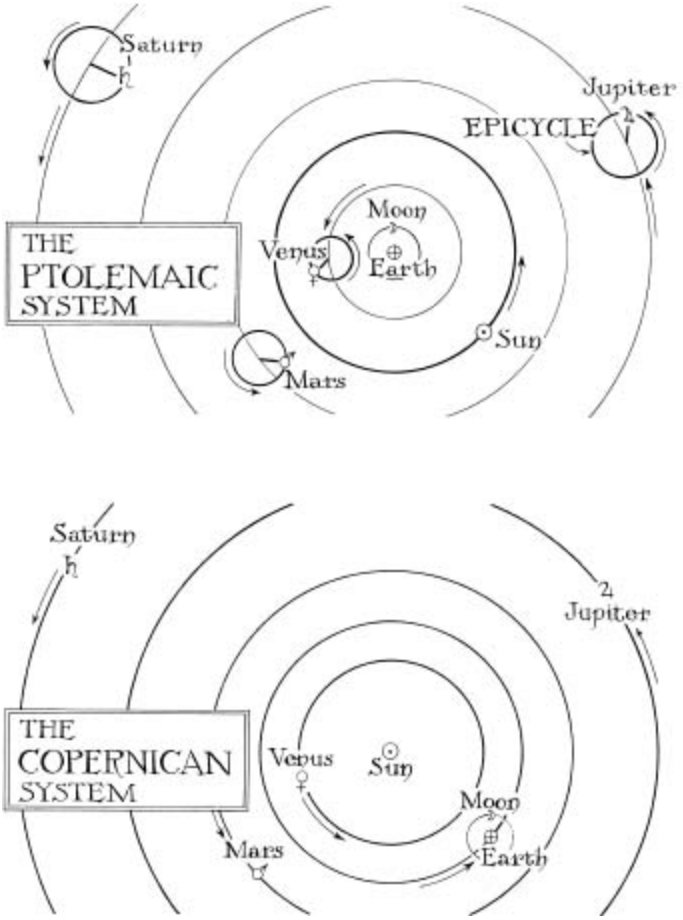
that observation and calculation, rather than divine revelation, could reveal the workings of the heavens. Scientists posed a direct threat to the shepherds of the Christian flock. Ironically, the first shot of this first cosmological revolution began with Copernicus, a devout clergyman.

Copernicus was not an astronomer by trade; he was a doctor. Doctors of the day had to be skilled in astrology, the better to deduce ailments and rebalance the body's humors. (Medieval medicine was another descendant of ancient Greek wisdom.) However, when Copernicus used Ptolemy's clockworks to prepare his astrological charts, he found that Ptolemy's cosmos seemed complicated, cumbersome, and unsatisfying. The skilled doctor spent much of his life trying to come up with a cleaner, simpler explanation of the motions of the planets.

Most of that effort was wasted. For a long time, Copernicus was convinced that the five known planets (Mercury, Venus, Mars, Jupiter, and Saturn) were mystically tied to the five Platonic solids (the four-sided tetrahedron, six-sided cube, eight-sided octahedron, twelve-sided dodecahedron, and twenty-sided icosahedron). For years, Copernicus tried unsuccessfully to build a cosmology based upon interlocked solids rather than crystal spheres. He failed.

Luckily, Copernicus came up with a better solution. He eventually realized that the Ptolemaic system was exceedingly complicated because it stuffed Earth into the center of the universe where it does not belong. By putting the sun at the center instead, and by allowing the planets to move around the sun rather than the Earth, Copernicus reduced the number of epicycles, the wild gyrations of the planets, from about eighty to about thirty. Copernicus's sun-centered system was cleaner and simpler, but it was not perfect. Actually, the Ptolemaic, Earth-centered system was more accurate at predicting the motions of the planets.

If scientists had had to choose a single system based solely upon the quality of its predictions, they would have chosen Ptolemy's, even though the ancient Greek's clockworks were so much more complex than the Polish doctor's.




*The Ptolemaic and Copernican cosmologies*

Nonetheless, the Copernican system was the first rumble of an approaching storm. By putting the sun rather than the Earth at the center of the universe, Copernicus challenged the very foundation of Aristotelian cosmology, just as Nicholas of Cusa had. In Copernicus's universe, the Earth was in the heavens, just as all the other planets were; the whole idea of earth and water sinking to the center of

the cosmos could not be true if the Earth were floating up in the sky. Perhaps even Cusa's wildest idea was true, that each star in the sky was home to alien worlds. But in Copernicus's day, the case for the heliocentric system was not yet airtight, and the church had not caught scent of the danger it posed. Indeed, when Copernicus in 1543 published his great work, *On the Revolutions of the Heavenly Spheres*, he dedicated it to Pope Paul III. But Copernicus was a prudent man. He took the precaution of publishing it while on his deathbed.

By the time Copernicus died, another upheaval—this one theological—was well under way. In 1517, Martin Luther nailed ninety-five theses to the door of the castle church at Wittenberg. His hammer blows resounded throughout Christendom as more and more people, angry with the corruption of the church, renounced their allegiance to the pope. The Protestant Reformation was born, and it quickly gained strength. To counter the threat, the church trained an elite corps of intellectual clerics, the Jesuits, who would be ideal ground troops for the war on Protestantism. Jesuit theology was strongly dependent on Aristotelian ideas; they used the ancient Greek wisdom to explain the motion of the planets in the sky and the transmutation of bread into Christ's body during the sacrament of Communion. Aristotle became a potent weapon in the church's intellectual arsenal. To attack Aristotelianism became tantamount to challenging the word of the Bible and the holiness of the Communion.

The church, under attack, was less and less able to allow challenges to Aristotle. Yet it was more than half a century before the church banned Copernicus. (Luther saw the problem before the Catholic Church did and rushed to denounce Copernicus as a fame-seeker. "People give ear to an upstart astrologer who strove to show that the earth revolves, not the heavens or the firmament, the sun and the moon," he wrote. "This fool wishes to reverse the entire

science of astrology; but sacred Scripture tells us that Joshua commanded the sun to stand still, not the earth." That passage in Joshua caused no end of trouble.)

As the Protestant Reformation grew, the church became harsher and harsher with its critics, including those who took up the cause of a sun-centered cosmology. Giordano Bruno learned this the hard way. On February 17, 1600, after Bruno had endured a long imprisonment, the church burned him at the stake for his heretical ideas. Bruno had embraced Copernicus's heliocentric model of the solar system, and like Nicholas of Cusa he declared that the Earth was only one of an infinite number of worlds.

Nobody knows what role Bruno's cosmology played in his condemnation. The records of Bruno's trial at the hands of the Roman Inquisition are lost to history, so it is unclear whether he was burned for his cosmology, his personal conduct, or both. But the crackdown on heresy was getting ever stronger, even as a noseless noble (with a pet midget) and a German astrologer-mathematician turned the Copernican system into an instrument with clockwork precision.

The noble, Tycho Brahe, was a sybaritic Dane. Born in 1546, he was a glutton. (Overeating led to his death half a century later.) For his amusement, Brahe kept a dwarf whom he fed with table scraps, but this was not nearly as unusual as Brahe's physical appearance. Brahe lost much of his nose in a duel—he was a better astronomer than fencer—and had a silver prosthesis. Yet this comical character would strike blow after blow to Aristotle's perfect universe.

On a chilly November night in 1572, Brahe spotted a new star in the constellation Cassiopeia. We now know that he had seen a supernova, the spectacular death throes of a doomed star, but to Brahe it was an incredible paradox. The Aristotelian heavens were supposed to be perfect and immutable, yet they had changed before his eyes. Within a

year or so, Brahe had enough data to show that the new star was quite distant, farther out than even the moon, so it was clearly not an atmospheric phenomenon. The new star —the imperfection—was part of the supposedly unchanging heavens.

Then Brahe set up the best astronomical observatory of his day, Uraniborg, located off the coast of Copenhagen. It was an enormous undertaking; the sextants, quadrants, and other instruments (telescopes had not yet been invented) cost the Danish government about a third of its national income. It was worth every penny. In 1577, Brahe showed that comets, the irregular fuzzy bodies that appeared in the sky from time to time, were also more distant than the moon, so they were heavenly bodies rather than luminous clouds in the atmosphere. He also detected a slight periodic variation in the speed of the moon's orbit around the Earth. It was blazingly clear: the heavens were fickle and imperfect.

However, Brahe's lasting legacy came from his reams of observations. In 1600, he convinced a young astrologer and mathematician named Johannes Kepler to join him in Prague as an assistant. (Brahe had moved from Uraniborg after arguing with the king of Denmark.) Kepler used Brahe's data to show that the planets didn't move in perfect circles.

Unlike Brahe, Kepler believed in Copernicus's sun-centered theory, having learned it from his mathematical mentor in school. Kepler seemed to be attracted to the simplicity of the heliocentric universe, even though it was still less accurate than the ancient Ptolemaic, geocentric cosmology. Kepler fixed this defect in 1609 when he announced that the planets move in ellipses rather than circles. After years of tedious labor, Kepler broke out of the circular universe imposed by Ptolemy and by Copernicus. Everything fell into place, and the heliocentric universe, freed from all the philosophic preconceptions that held it

back, described the motions of the planets more accurately than did the Ptolemaic system. Heliocentrism was simpler, more accurate, and more elegant than geocentrism. It was the death knell for Ptolemy and Aristotle, and for the cosmology that underpinned the theology of the church.

The church finally was fully awake to the danger posed by the new philosophy, and everyone who threatened Aristotle's framework was, himself, in mortal peril. Even Galileo Galilei, friend of Pope Urban VIII, was in danger of being burned at the stake. In 1609, the same year that Kepler published his *New Astronomy*, Galileo heard that a Dutch lens-maker, Hans Lippershey, had created a device to make distant objects look nearer. Galileo immediately built himself one of these new instruments—the telescope—and turned it to the heavens. Everywhere he looked, like Brahe before him, he saw evidence that Aristotelian cosmology was wrong. His discoveries were systematically destroying what was left of the Aristotelian universe.

When Galileo looked at the moon, he saw mountains and craters. A heavenly body, which, according to Aristotle, was made of purer stuff than the Earth, was just as pitted and scarred as the craggiest parts of our own planet. When he looked at the sun, he saw blotches—sunspots—that belied the orb's perfection. Turning the telescope to Jupiter, Galileo found four bodies that orbited the giant planet; here was incontrovertible proof that not everything orbits the Earth. If these distant moons circled Jupiter, ignoring Earth, it was hard to imagine that the Earth was truly the center of the cosmos. Looking at Venus, Galileo noticed that the planet went through phases, waxing and waning like the moon. This was predicted by the Copernican system (indeed, Copernicus realized that the apparent lack of phases was a problem for his theory) but nearly impossible to explain within Aristotelian-Ptolemaic cosmology.

The telescope was the big gun of the first cosmological revolution, and Galileo wielded it with skill, shooting down one Aristotelian conceit after another. Galileo's observations convinced him that Aristotle was wrong, and Copernicus was right. Unfortunately, this made his scientific investigations a theological matter.

In 1613, Galileo wrote to a student of his, a priest, arguing that if the Bible seemed to contradict scientists' observations of the workings of nature, then the interpretations of the Bible must be mistaken. To Galileo, science was stronger than theology; if the two contradicted each other, then theology must give way, not science. This was heresy. From the church's point of view, Galileo was trying to reshape Christian theology, replacing the Aristotelian philosophy at its center with a new and uncertified doctrine. Galileo was no Saint Thomas Aquinas—he had no right to dictate theology to the church. Galileo was on the edge of becoming a heretic.

In 1616, Cardinal Bellarmine, head of the Roman Inquisition, called Galileo into his office. The cardinal warned Galileo that Copernicanism was heresy and, according to one account, told Galileo not "to defend or hold" Copernican theory. Galileo took the warning seriously because the church was becoming more and more brutal in persecuting heretics. On December 21, 1624, three years after the death of Bellarmine, a crowd gathered in Rome to watch the immolation of the body of a heretic who had died three months earlier. Even the dead were not safe from the flames of the righteous.

Unfortunately for Galileo and fortunately for posterity, the scientist in Galileo could not stay away from the new cosmology despite the increasing danger. He was irresistibly drawn to it by his own observations, and he continued to write about the new science of the heavens. In 1633, the Inquisition condemned Galileo as a heretic.

“We say, sentence and declare that you, Galileo …,” the condemnation reads, “[have] believed and held the doctrine, false and contrary to sacred and divine Scripture, that the Sun is the center of the world and does not move from east to west and that the earth moves and is not the center of the world; and that an opinion may be held and defended as probable after it has been declared and defined to be contrary to Holy Scripture.” In other words, Galileo had claimed that science could force theologians to change their views, rather than vice versa. Heretics who confessed and recanted could escape with their lives; those who stuck to their incorrect ideas were burned. Galileo prudently recanted and was imprisoned rather than burned. As a favor to his old friend, Pope Urban VIII allowed Galileo to spend his perpetual imprisonment at his own home, rather than in a dank cell in the Vatican.

The church was provably, criminally wrong. The church had condemned an innocent man. It punished Galileo for the revolution that destroyed its wrongheaded cosmology. But it held its ground for centuries. In 1930, Pope Pius XI canonized Bellarmine.

Even today, the Catholic Church is struggling with its past—not very successfully. In 1992, Pope John Paul II expressed regret that the Galileo incident came to represent the “myth of … the Church’s supposed rejection of scientific progress,” even though it was merely a case of “tragic mutual incomprehension” between Galileo and the church. Mistakes were made. But the church was not alone in its error, according to the Vatican. Cardinal Paul Poupard defended the inquisitors, stating that Galileo’s arguments were not airtight. “In fact, Galileo had not succeeded in proving in an irrefutable fashion the … motion of the Earth,” he said in 1992. “It took more than 150 additional years to find the optical and mechanical proofs of the Earth’s motion.” Galileo too was at fault, for not making the case sufficiently, according to the Vatican.