8 CONTAINMENT AND THE COSMIC EDGE

To see a World in a grain of sand,
And a Heaven in a wild flower,
Hold Infinity in the palm of your hand,
And Eternity in an hour.
William Blake (1757–1827), Auguries of Innocence

THE CONTAINMENT PRINCIPLE

Much of cosmology in the past has been concerned with the center and edge of the universe (see Figure 8.1), and our attitude nowadays on these matters is expressed by the principles of location and containment. Broadly speaking, the location principle (previous chapter) involves issues concerning the cosmic center, and the containment principle (this chapter) involves issues concerning the cosmic edge. Both principles help us to avoid pitfalls that trapped earlier cosmologists.

The containment principle of the physical universe states: *the physical universe contains everything that is physical and nothing else.* It is the battle cry of the physical sciences (chemistry and physics). To some persons the principle seems so elementary and obvious that it hardly deserves mentioning, to others it is a declaration of an outrageous philosophy. Before condemning the principle as too elementary or too outrageous, we must look more fully at what it means.

Modern scientific cosmology explores a physical universe that includes all that is physical and excludes all that is nonphysical. The definition of physical is sweeping and at first sight exceeds what common sense deems proper. It includes all things that are measurable and are related by concepts that are vulnerable to disproof. Atoms and galaxies, cells and stars, organisms and planets are physical things that belong to the physical world. Particles and their corpuscular-wavelike duality, atoms and their choreography of electron waves, DNA and its genetic coding, fields and waves that propagate through space, the rich virtual worlds of the vacuum, the special relativity properties of spacetime, the general relativity properties of curved and dynamic spacetime, and the vast astronomical universe are all things of a physical nature.

But there is more. We, as physical creatures, possessing bodies and brains, are imprisoned in the physical universe. Space and time are not just voids into which the universe has been dropped; if they were, we could escape by searching out places in space and time not occupied by the universe. But spacetime, which is the four-dimensional physical combination of space and time, is not a mere receptacle; it is a physically real continuum. A continuum that is real in its own right. Space and time are active participants in the scheme of things, they belong to the physical universe, and do not extend beyond. *The universe contains space and time and does not exist in space and time.* If you believe in a nonphysical realm, such as heaven, you must endow it with its own space and time. You cannot extend our space and time to include heaven, for heaven would then be brought into the physical universe and its existence exposed to the critical methods of scientific inquiry.

The physical nature of space (or rather spacetime) is demonstrated by its dynamic properties. Empty regions of space act on and influence one another! This is the essence of general relativity. Gravitational

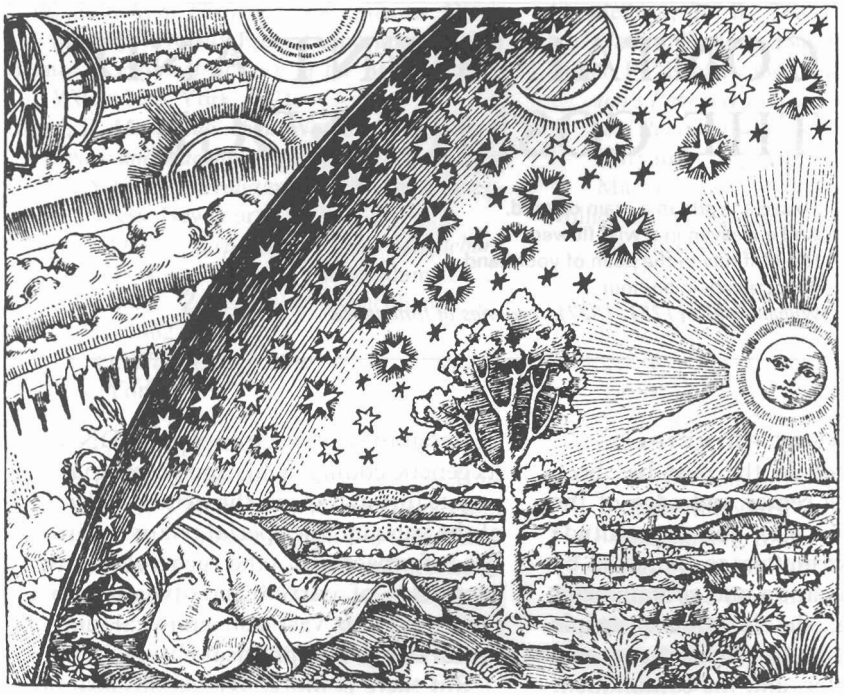

Figure 8.1. A nineteenth-century woodcut that supposedly presents the medieval view of the universe. Beyond the sphere of stars lies the celestial machinery and other heavenly wonders.

waves, ripples of space, travel at the speed of light. Gravitation, once a mysterious force that acted instantaneously across empty space, has become the dynamic curvature of space itself that propagates at the speed of light. It is possible, such are the bewildering properties of space, to have a universe containing only gravitational waves, and the dynamic behavior of this universe is governed by the gravitational attraction of the energy in the gravitational waves. A black hole need not contain matter; it may contain only rippling space-waves whose total energy has a mass that accounts for the strong gravity of the black hole.

Space and time in most universes of the past were the stage on which was enacted the cosmic drama. In the modern physical universe space and time are the leading actors. Who can doubt the physical reality of space (or spacetime) when it raises the tides, guides the Moon around the Earth, the Earth around the Sun, and will tear apart incautious astronauts and their spaceships in the vicinity of neutron stars and black holes?

Space may be finite and yet edgeless. The curved two-dimensional surface of a sphere is an easily visualized analogy. The surface is finite yet has no edge. An ant crawling in a straightforward direction on the surface of a spherical water melon returns to its starting point without encountering an edge. The cosmic explorer traveling in a straight line in a finite, homogeneous, and isotropic universe also returns to the starting point.

Some people will protest that the containment principle leaves out all that is most valuable. What about our souls, our minds, consciousness, and all the richness of the inner mental world, where do they fit in? The response that must be made is quite simple: they do not fit in anywhere. At best only their physical counterparts (such as chemical activities) fit in. All the

joys of life are no more than the biochemistry of neurons in the brain. In response to those who protest and want it all put together neatly in a spiritual–psychical–physical universe, we must answer: "You are confusing the Universe with universe. The unknown Universe is everything, including our minds; the known physical universe contains what is physical, including our brains. Mathematicians, physicists, biophysicists, and chemists have made the physical universe, and if you do not like it, despite its extraordinary success, you must make your own universe."

The science of modern cosmology deals only with a physical model of the Universe that is yet another mask on the face of the unknown. But what a fantastic mask it is! All the inventive genius of the greatest thinkers in the history of science has gone into its making. Can one wonder that many people, including scientists, when confronted with the majesty of the physical universe, have mistaken this latest mask for the real face, the physical universe for the Universe?

THE COSMIC EDGE

The cosmic-edge riddle

In the ancient Mediterranean world, the Atomists and Epicureans championed the idea of an infinite, centerless, and edgeless universe; the Aristotelians and Stoics championed the idea of a finite system having a center and an edge. Of primary importance in the long debate was the problem of the cosmic edge.

The cosmic-edge riddle – "what happens to a spear when it is hurled across the outer boundary of the universe?" – was posed in the fifth century BC by Archytas of Tarentum, a Pythagorean soldier-philosopher and friend of Plato. (See Figure 8.2.) "Does the spear rebound or vanish from this world?" he asked. The riddle exposed the logical inconsistency of believing that

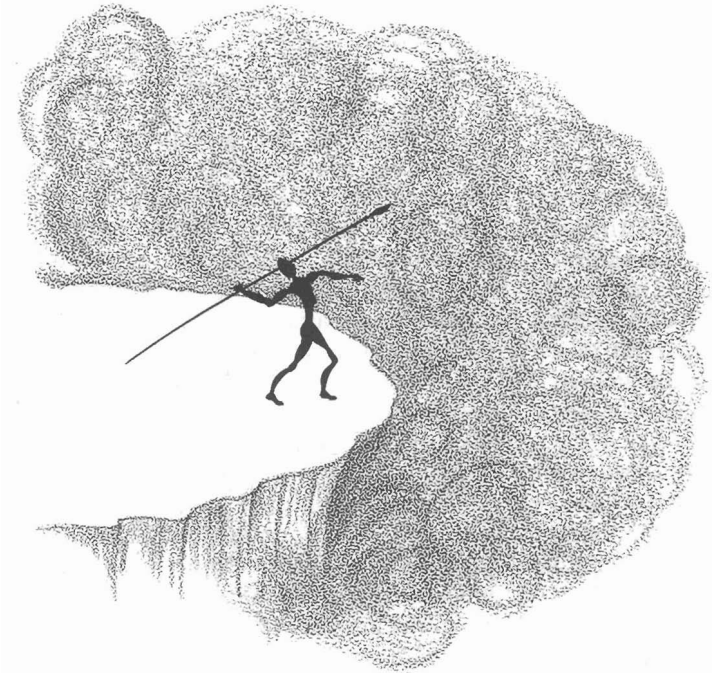

Figure 8.2. The cosmic edge riddle: What happens when a spear is thrown across the edge of the universe?

whatever bounds the universe is itself not part of the universe. For more than two thousand years the ablest minds wrestled with the riddle, and it is true to say that Archytas's riddle has shaped much of the history of cosmology.

Epicurus in the fourth century BC stated, "Democritus of Abdera said that there is no end to the universe, since it was not created by an outside power. Moreover, the universe is boundless. For that which is bounded has an extreme point, and the extreme point is seen against something else."

Lucretius the Epicurean, influenced by the riddle of Archytas, wrote in the first century BC in his magnificent poem *De Rerum Natura*: "It is a matter of observation that one thing is limited by another. The hills are demarcated by air, and air by the hills. Land sets bounds to seas, and the seas to every land. But the universe has nothing outside to limit it." Of those who believed in a bounded universe he asked: "Suppose for a moment that the whole of space were bounded and that someone made his way to its uttermost boundary and threw a flying dart. Do you choose to suppose that the missile, hurled with might and main, would speed along the course on which it was aimed? Or do you think something would block the way and stop it? You must assume one alternative or the other.... With this argument I will pursue you. Wherever you may place the ultimate limit of things, I will ask you: 'Well, then, what does happen to the dart?' " Lucretius then gave the Atomist answer: "Learn, therefore, that the universe is not bounded in any direction."

Simplicius in the sixth century AD quoted Archytas in his commentary on Aristotelian physics with the words: "If I am at the extremity of the heaven of fixed stars, can I stretch outwards my hand or staff? It is absurd to suppose that I could not; and if I can, what is outside must be either body or space. We may then in the same way get to the outside of that again, and so on; and if there is always a new place to which the staff may be held out, this clearly means extension without limit."

In the dialogue of *The Infinite Universe*, written by Bruno while he lived in England, he gave Burchio (an imaginary Aristotelian) this argument: "I think that one must reply to this fellow that if a person would stretch out his hand beyond the convex sphere of heaven, the hand would occupy no position in space, nor any space, and in consequence it would not exist." To which Philotheo (Bruno himself) replied that space inside and outside the universe must be continuous and the same; "thus, let the surface be what it will, I must always put the question: what is beyond? And if the reply is: nothing, then call that the void, or emptiness. And such a Void or Emptiness hath no measure nor outer limit, though it hath an inner; and this is harder to imagine than is an infinite or immense universe." The commentary by Simplicius (a Neoplatonist) on Aristotelian physics was little known until translated into Latin in the sixteenth century. The influential poem by Lucretius, after its discovery in 1417 in a monastery, was widely read, in particular by such scholars as Nicholas of Cusa, Giordano Bruno, Thomas Digges, and William Gilbert.

In a finite universe, everything had comprehensible relation to the cosmic center and edge, and this arrangement in which things have absolute location dominated pre-Copernican cosmology. Eventually, astronomical developments abolished the cosmic center and the riddle of Archytas abolished the cosmic edge.

Cosmic edges

Possibly the idea of an infinite universe emerged in response to the cosmic-edge riddle, either in the form posed by Archytas, or in an earlier unrecorded form. Both Atomists and Epicureans certainly had no difficulty with the riddle; they believed space was infinite in extent, endlessly populated with stars and with planetary systems that teemed with life, and the universe had no edge. As we shall later see, solving the cosmic-edge riddle in this way created the

riddle of a dark night-sky (Chapter 24), which also played a prominent role in the history of cosmology.

Aristotelian cosmic edge

Often in ancient cosmology the universe ended abruptly with a wall-like edge. In mythology, the universe was an egg bounded by its shell, or a vast cavern bounded by dark walls. Later, in the Aristotelian universe, the edge became the sphere of fixed stars (Figure 8.3). Even Johannes Kepler believed that the universe was enclosed within a dark cosmic wall, and he was therefore able to explain why the sky at night is dark. Kepler argued that in an endless universe of stars the sky at night would not be dark but bright with starlight. We do not know if Kepler had an answer to the cosmic-edge riddle. In the case of a wall-like edge the spear must either rebound or pass through, and according to Epicurean critics, the first is impossible because what bounds space cannot itself be unbounded, and the second is proof that an edge does not exist.

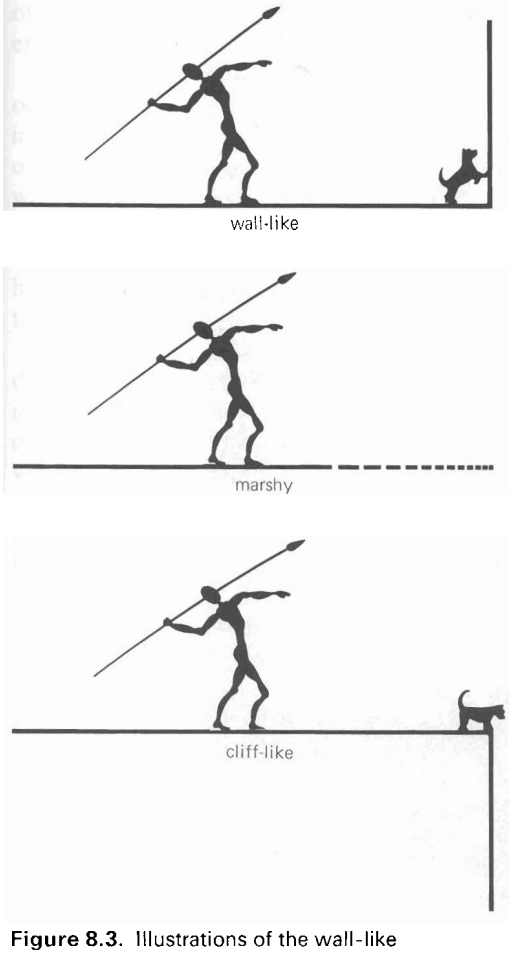

Figure 8.3. Illustrations of the wall-like (Aristotelian), marshy (medieval), and cliff-like (Stoic) cosmic edges.

Medieval cosmic edge

In later versions of the Aristotelian universe (Neoplatonic and medieval), space ended not sharply but gradually, beginning in the lunar sphere (Figure 8.3). As one moved outward away from Earth the physical realm slowly transformed into an etheric realm. In the medieval version, the outer etheric-celestial realm was surrounded by the empyrean, a realm occupied by God. To the question, "What happens to a physical body as it moves away from Earth?" two answers were possible. The body's earthly elements either remain unchanged and the body returns to Earth, as when a stone thrown in the air falls back to Earth, or the body transforms into etheric elements and its natural motion is then circular around the Earth and not up and down.

The medieval universe lacked an abrupt boundary and the force of "with this argument I shall pursue you" was lost because the pursuer was led into an etheric outer realm where physical arguments had no force. This kind of cosmic edge was like a gradual fading of firm ground into an infirm marshland. The medieval rebuttal of the riddle is now unacceptable. Observations show that the physical world does not fade into a nonphysical world at great distances.

Stoic cosmic edge

The Stoic universe consisted of a finite cosmos of stars surrounded by an infinite starless void. The Stoic edge was sharp like that of a cliff (Figure 8.3). It divided the universe into two parts: an inner starry cosmos and an outer starless and empty space that extended indefinitely. In this case the answer

to the cosmic-edge riddle was quite simple: The act of throwing the spear enlarged the cosmos and extended its outer edge. In early versions of the Stoic system, the infinite void was an addition tacked on to the Aristotelian sphere of stars, presumably in response to the riddle of Archytas.

Inevitably the medieval universe evolved into a Stoic cosmos of stars, and the infinite void became the extramundane realm of God. This cosmic picture subsequently enjoyed considerable popularity. It was Isaac Newton's view of the universe in his early years at Cambridge; it was the Milky Way cosmos of William Herschel in the late eighteenth century; it was the Victorian universe of the nineteenth century; and it survived until the early decades of the twentieth century. One could in principle travel – in imagination at least – outside the Milky Way, look back, and have a magnificent grandstand view of the whole material

Figure 8.4. *The Empyrean* by Gustav Doré. This picture shows Dante and Beatrice standing at the rim of the world and gazing at the angelic spheres on the other side of the universe.

content of the universe. Alas! observations have shown that the material universe extends to vast distances beyond the Milky Way with no sign of an abrupt edge.

Amateur cosmology

Often, on first taking an interest in cosmology, a person has in mind the Stoic cosmic picture. The universe is visualized as a spherical cloud of galaxies that expands in space and has a center and an edge. This simple picture, unfortunately, is quite wrong and violates the containment principle. Space is not a nonphysical receptacle in which the universe expands; space is physical, and expands with the universe. We must think of space as an essential part of the universe and realize that it cannot extend outside the universe.

As an illustration, the big bang did not occur somewhere in space, as seems natural in the Stoic picture, but occupied the whole of space. If space is infinite, the big bang was also infinite. An infinite universe remains always infinite and cannot change and become finite. Wherever we stand, we have only to stay still and travel back in time to find ourselves in the big bang.

A centerless and edgeless infinite three-dimensional space is not too difficult to imagine. Trying to imagine a centerless and edgeless finite three-dimensional space is very difficult. Instead, we think of a two-dimensional surface that is centerless, edgeless, and finite. A spherical surface is finite in extent, and in itself has no center and no edge.

Cosmic edges in space do not exist. We cannot travel to the edge, like Dante and Beatrice in *The Divine Comedy*, and have a grandstand view of the universe (Figure 8.4). In an expanding universe, the galaxies are not rushing away from us through space, but sit in space, and space itself expands in the same way as the surface of an expanding balloon that is slowly inflated. As we later show (Chapter 14), the space between galaxies expands, and the galaxies are carried apart by the expansion of space.

CONTAINMENT OF SPACE AND TIME

Time, like space, is physical and is therefore contained in the universe. It cannot extend outside the universe across a timelike cosmic edge. We must not ask what the universe looks like from outside space and similarly we must not ask what the universe looks like before time begins and after time ends. Such questions violate the containment principle and imply that the physical universe does not contain everything physical.

Cosmogony (the word means the begetting of cosmic progeny) is the subject that deals with the origin of astronomical structures such as planets, stars, and galaxies. It embraces the origin of the elements and even the origin of life. The constraints set on cosmogony by containment are elementary. All things must have sizes smaller than or equal to the size of the universe. The following is a possible cosmogonic space sequence:

size of atom
<size of cell
<size of multicellular organism
<size of planet
<size of planetary system
<size of galaxy
<size of galaxy cluster
<size of supercluster
<visible universe

where the symbol < means "less than." Also, all things must have ages shorter than or equal to the age of the universe. The following is a possible cosmogonic time sequence for human beings:

age of *Homo sapiens*
<age of mammals
<age of life on Earth
<age of Earth
≤age of Sun
<age of Galaxy
<age of helium produced in early universe
<age of universe

where the symbol ≤ means "less than or equal to."

Figure 8.5. "If we don't know how big the whole universe is, then I don't see how we could be sure how big anything in it is either, like the whole thing might not be any bigger than maybe an orange would be if it weren't in the universe, I mean, so I don't think we ought to get too uptight about any of it because it might be really sort of small and unimportant after all, and until we find out that everything isn't just some kind of specks and things, why maybe who needs it?" – John Milligan. (With permission from John Milligan, whose cartoon first appeared in *Saturday Review*, 1971.)

Nucleochronology (the study of the origin and history of the elements) consists of various dating techniques. The light elements, mostly deuterium and helium, were made from protons and neutrons in the big bang while the universe was still young, dense, and very hot. Most other chemical elements were made much later in stars and ejected into space in supernova outbursts. The elements composing the Earth were produced in stars that died before the birth of the Solar System. Most heavy elements when formed are radioactive and decay into daughter elements. Uranium-235, for example, has a half life of 4.5 billion years and decays into lead. By finding how fast radioactive elements decay, and measuring their present relative abundances, it becomes possible to determine the age of the Earth, the Solar System, and the Galaxy. From these studies we find that the Solar System has an age of 4.6 billion years and the Galaxy an age of roughly 15 billion years.

Cosmologists estimate that the universe, from its rate of expansion, has an age of between 10 and 20 billion years. But from the late 1920s until the middle 1950s the estimated age was little more than 1 billion years. A universe younger than the Earth violated containment, and for a quarter of a century this age paradox dominated cosmology. Attempts were made to evade the paradox, as in the hesitation universe (according to which expansion was very slow for a long period in the past) and in the steady-state universe (which had an infinite past).

Cosmologists who favored a big bang universe, such as Georges Lemaître and George Gamow, thought most elements were made in the big bang. This idea proved wrong but had one great virtue: it started Gamow and his colleagues Ralph Alpher and Robert Herman thinking about a hot early universe and led them to the prediction of the cosmic background radiation almost 20 years ahead of its discovery. The

steady-state idea proved wrong but also had one great virtue: the steady-state cosmologists could not accept big bang nucleosynthesis and therefore had to show that all heavy elements are made in stars. The pioneers in the successful theory of stellar nucleosynthesis were Alistair Cameron, Margaret and Geoffrey Burbidge, William Fowler, and Fred Hoyle.

Revised estimates of extragalactic distances made by Walter Baade and Allan Sandage in the 1950s, and by others since, have increased the size and age of the universe and it now seems possible to accommodate the ages of the chemical elements, the Earth, Solar System, stars, and galaxies within the lifetime of a big bang type of universe.

DESIGN ARGUMENT

Why is our universe so favorable in numerous ways to the existence of life? Throughout history, mythology and theology have urged the idea of a designed universe. The belief that the universe is intentionally designed to be a fit place for human habitation is as old as the creation myths (Chapter 25).

The design argument claims that we see everywhere evidence of cosmic design, and all the wonders of nature prove the existence of a supreme designer. The design argument emerged in a new and definitive form known as deism in the eighteenth century after the rise of the Cartesian and Newtonian world systems.

Theism is the ancient belief that a supreme being creates and runs the universe. Deism is the new belief that a supreme being creates a universe so perfect in design that supernatural maintenance is unnecessary. Thomas Burnet, a clergyman, wrote in 1687 in *Theory of the Earth*, "We think him a better Artist that makes a clock that strikes regularly every hour from the springs and wheels he puts in the work, than he that hath so made his clock that he must put his finger in it every hour to make it strike." Deists in the eighteenth century often used the clock analogy in support of the design argument. Archdeacon William Paley in 1802, in his book *Natural Theology*, subtitled *Evidence of the Existence and Attributes of the Deity Collected from the Appearances of Nature*, argued that the intricacies of the eye and hand could never have arisen by themselves in response to the blind forces of nature. Suppose, he wrote, that while walking on the heath "I found a watch on the ground;" a natural conclusion would be that "the watch must have a maker; that there must have existed at some time and at some place or other an artificer or artificers who formed it for the common purpose, which we find it actually to answer, who completely comprehended its construction and designed its use." But in the years ahead, the advance of science made it increasingly apparent that the forces of nature are not so blind as Paley believed.

In the *Bridgewater Treatise*, written by eight distinguished authors and dedicated to demonstrating the "Power, Wisdom and Goodness of God, as Manifest in the Creation," the chemist William Prout in 1834 wrote, "the anomalous properties of the expansion of water and its consequences have always struck us as presenting the most remarkable instance of design in the whole order of nature – an instance of something done expressly, and almost (could we indeed conceive such a thing of the Deity) at second thought, to accomplish a particular object." If water did not expand on freezing and ice did not float, as observed, said Prout, the oceans would freeze solid and life on Earth be impossible.

Science progressively revealed a world of astonishing intricacy governed by forces of extraordinary potency. Natural selection (which states those individual differences favoring survival and reproduction are shared increasingly among the members of an interbreeding population) accounts for the excellence of the eye and hand. The miracles of the physical universe are not its structures, such as eyes and hands, but its fundamental properties at the atomic and subatomic levels that miraculously contrive a universe fit for inhabitation by life.