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REACTING TO THE SIZE AND SHAPE OF THE UNIVERSE

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REACTING TO THE SIZE AND SHAPE OF THE UNIVERSE

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ABSTRACT

Our conception of the cosmos has been transformed since the early Greek philosophers talked about crystalline spheres wheeling over a stationary Earth. Starting with the Copernican revolution, humans have been revealed as insignificant players within a vast and inhospitable universe. The linear space and metronomic time of Newton has been replaced with the curved space-time of Einstein. In the big bang model, the size, expansion rate, and fate of the universe is linked to the curvature of space. If the idea of a rapid early phase of inflation is correct, the physical universe must be very much larger than the observable universe. Time and space emerged from an unfamiliar state of chaos and quantum fluctuations. The role of life in the universe is one of the most profound enigmas in cosmology. This article looks primarily at the poetic and literary responses to the physical nature of the universe — the subject of cosmology continues to inspire writers and leave its mark in the popular culture.

THE COZY UNIVERSE

"I don't pretend to understand the universe — it's a great deal bigger than I am." T. Carlyle

Go to a dark place far from city lights. The night sky is a velvet backdrop sprinkled with points of light. Modern city-dwellers are poorly acquainted with this sight, but to early hunter-gatherers the pattern of the stars must have been as familiar as the lines on their hands. Early cultures locked their lives to the waxing and waning of the Moon and the wheeling motions of the Sun and stars. The sky was a clock, a map, and a calendar.[1]

The ancient universe was a cozy universe. In those pre-industrial days, the stars must have seemed bright enough to pluck from the heavens. Egyptians saw the sky as a tented canopy, held up by mountain ranges at the corners of their desert kingdom. The sky was a proximate reflection of human existence, a repository of myth and legend.[2] We can see the utility of the heavens in the words of the poet Hesiod[3]:

> When great Orion rises, set your slaves
> To winnowing Demeter's holy grain
> Upon the windy, well-worn threshing floor...
> But when Orion and the Dog Star move
> Into the mid-sky, and Arcurus sees
> The rosy-fingered Dawn, then Perseus, pluck
> The clustered grapes, and bring your harvest home...
> When great Orion sinks, the time has come
> To plough; and fittingly, the old year dies.

However, about 2500 years ago a group of philosophers living on the rugged coast of Asia Minor started asking deep questions about the natural world. Their speculations about the size and shape of the universe were the first stirrings of science.[4]

The ancient Greeks had no telescopes or other advanced technology, but they brought a new element to the study of astronomy — the idea that the universe is governed by number. When Pythagoras experimented with the sounds made by a plucked string, it came as a revelation to him that harmonious sounds could only be made when the string was held in places that divided it into exact units of whole numbers. He extended this idea to the heavens and proposed that the planets and stars orbited the Earth on perfect spheres, with motions defined by integers and the ratios of integers. The 5th century B.C. marks the emergence of the belief that the universe and its contents are governed by natural mathematical laws. These early ideas were molded by Aristotle into cosmology that would endure for 2000 years.

Beyond the Pythagorean abstractions, just how did the Greek universe actually work? A spherical Earth sat motionless at the center of the spherical universe. The Earth was known to be a sphere from the observation of the curved shadow it casts on the Moon during a lunar eclipse. It was common sense that the Earth stood still, because no motion

was apparent, and the stars always maintain fixed positions from season to season. The celestial objects orbited on translucent crystalline sphere, nested like Russian dolls and each rotating on a different axis and at a different speed. Beyond the last sphere that carried the stars, the Supreme Deity kept the entire ensemble in constant motion. The source of light from the stars was unknown, but Empedocles speculated that nails driven into the celestial vault let light through. All terrestrial matter was derived from the elements of earth, fire, air, and water. The heavens were home to a fifth, ethereal element: quintescence.

By the 2nd century A.D., when Ptolemy published a 130-volume encyclopedia containing the sum of Greek astronomical knowledge, the geocentric model had acquired a complexity worthy of Rube Goldberg. Nature did not conform to the expectations of symmetry — the planets moved on elliptical rather than circular paths, and varied speed continuously throughout their orbits. A set of 55 concentric but offset spheres was required to match the planet motions. The distance to the outermost sphere that carried the stars was a distinctly uncozy 50 million miles, and to complete an orbit of the Earth once per day, the stellar sphere was whizzing round at over a million miles per hour. When Spain's Alfonso X watched his court astronomers laboriously calculate planetary positions, he commented that if he had been present at the creation, he would have suggested a simpler arrangement.

More radical ideas were squashed by the intellectual weight of Aristotle. Aristarchus used a series of clever geometric proofs to argue that the Sun was larger than the Earth. It made no sense to him for the larger body to orbit the smaller one. With the Earth orbiting the Sun, the stars had to be extremely distant to maintain their fixed patterns. The Aristarchan universe was a five billion miles across. Archimedes dusted off the long-forgotten heliocentric model to demonstrate his mastery of large numbers.[5] Filled with grains of sand, an Aristarchan universe would contain 10^{80} atoms, an incredible number.

Some bold thinkers were even willing to contemplate the fact that the universe might not have a boundary. Lucretius put it this way: "Let us assume for the moment that the universe is limited. If a man advances so that he is at the very edge of the extreme boundary and hurls a swift spear, do you prefer that this spear, hurled with great force, go where it was sent and fly far. Or do you think that something can stop it and stand in its way?"[6] Even though science went into a deep sleep for over 1000 years, Lucretius had planted an important seed with his thought that the universe might be infinite.

THE INFINITE UNIVERSE

"The center of the universe is everywhere, and the circumference is nowhere." G. Bruno

On the eve of the Copernican revolution, most people still viewed the universe in terms that Aristotle would have understood. Dante Alighieri represented the nested spheres of

celestial objects as counterparts to the layers encountered in the descent to hell.[7] There was widespread belief in the Chain of Being, a powerful idea where an immutable social order and the hierarchy of living things mirrored the static arrangement of the celestial spheres[8]. Even though his writing is suffused with Renaissance humanism, Shakespeare still subscribed to the medieval worldview[9], as seen in this passage from *Troilus and Cressida*:

> The heavens themselves, the planets, and this center
> Observe degree, priority, and place,
> Insisture, course, proportion, season, form,
> Office, and custom, in all line of order

Copernicus was the quiet revolutionary who pried the Earth loose from its traditional position at the center of creation. However, the real noise was made by Galileo, who traveled around Italy proclaiming the correctness of the heliocentric model[10]. Galileo obtained a version of the newly invented telescope and improved on it. He observed the phases of the planet Venus, which could only be explained if Venus and the Earth both orbited the Sun, with Venus on an interior orbit. He observed moons around Jupiter and mountains and valleys on the Moon. The demonstration that there were no crystalline spheres and that the planets were not perfect geometric forms was a decisive break with Arisotelian physics. Most spectacularly, he trained his telescope on the Milky Way and saw the filmy band break up into myriad points of light. To the limit of his simple telescope, there were perhaps 100,000 stars visible. If these points of light were glowing orbs like the Sun, they must be at vast distances from the Earth to appear so faint.

There was continued speculation that the universe might be infinite. Late in the 16th century, Thomas Digges presented a view of the stars scattered through unbounded space. The philosopher and mystic Giordano Bruno wrote[11] "There is a single general space, a single vast immensity which we may freely call Void: in it are innumerable globes like this on which we live and grow; this space we declare to be infinite, since neither reason, convenience, sense-perception nor nature assign it a limit." The intellectual climate for such thoughts was chilly. To dissuade him from espousing the Copernican view, Galileo was summoned before the Inquisition and shown the instruments of torture. Bruno paid the ultimate price for his more radical heresies, and was burned at the stake in 1600 in the Campo del Fiori in Rome.

Isaac Newton was the austere genius who dominated the next phase of cosmology. He unlocked the rainbow in his work on the nature of light. His laws of mechanics inspired the creation of the machines that would drive the Industrial Revolution. But his greatest achievement was the unification of terrestrial and celestial motions in a universal law of gravity. To the unschooled eye, Newton's insights seemed to have the power of divine revelation. The literary world was entranced by astronomy. John Donne visited Kepler in the remote Austrian town of Linz in 1619, and John Milton called on the Sun-blind Galileo during his house arrest at Arcetri near Florence. The poet Alexander Pope expressed what was a widespread awe of Newton in his epigrammatic couplet[12]:

Nature and Nature's laws lay hid in Night.
The God said: "Let Newton Be," and all was Light

If the Greeks shrank from the idea of a boundless universe, Newton embraced it. His force of gravity diminished with the inverse square of the distance from an object. Although gravity weakens with distance, it never loses its grip entirely. Newton knew that if the universe had an edge, the long arm of gravity would pull matter away from the edge and cause a collapse. To preserve a static situation, Newton imagined an infinite universe filled with stars. Yet, in an endless universe, the gravity at any point must be the sum of the gravity from all stars at larger and larger distances. The sum is infinite. Newton had no answer to this conundrum. Moreover, moving away from the Sun, the number of stars increases at just the same rate that the light received from each one diminishes. So the amount of light in an infinite universe is infinite. In other words, every sight line from the Earth must eventually intercept a star, just as a tree is seen in every direction in an endless forest. Yet the dark night sky mocks this expectation. And what is the nature of this mysterious force that acts instantly over enormous gulfs of space? To this question, Newton gave the gnomic response "I frame no hypotheses."[13]

How are space and time described in Newton's universe? His view of space was that "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable."[12] His equally uncompromising view of time was that "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external."[12] Newton's space and time were linear and immutable, and succeeding generations of thinkers tried to come to grips with these concepts. For many, the mere *existence* of time and space was noteworthy. The mathematician Karl Friedrich Gauss wrote "We must confess in all humility, while number is a product of our mind alone, space has a reality beyond the mind whose rules we cannot completely prescribe."[14] The nature of time was equally opaque, as the philosopher Henri Bergson noted "Time is invention or it is nothing at all."[15] Most people could agree with the early 19th century poet Charles Lamb "Nothing puzzles me more than time and space; and yet nothing troubles me less, as I never think about them."[16]

The love affair of humanists with Isaac Newton was bound to end in tears. As the limits of science as a guide for behavior became clear, celebrations of the power of Newton's theories turned into an artistic revolt against rationalism and materialism. Blake described Newton as a devil and science as the Tree of Death, and Keats continued the attack in *Lamia*. Some of this reaction was based on a misunderstanding of the physics. For example, the equation of gravity can only be solved exactly in the artificial case of two objects. For any realistic situation, Newton knew that the theory was not deterministic. Nevertheless, Newtonian cosmology represents the culmination of the medieval metaphor of the Clockwork Universe. Disillusioned, Pope wrote[12]:

Go, wondrous creature! Mount where science guides
Go, measure earth, weigh air, and state the tides;
Instruct the planets in what orbs to run,
Correct old Time, regulate the Sun...

Go, teach Eternal Wisdom how to rule—
Then drop into thyself, and be a fool!

Meanwhile, astronomers built larger and larger telescopes with which to map the skies. Friedrich Bessel made a breakthrough in 1838 when he used trigonometry to measure the distance to a star for the first time. The nearest stars were trillions of miles away — a distance that light takes several years to travel. The faintest stars were hundreds, even thousands, of times more distant. In Thomas Hardy's *Two on a Tower*, astronomer Swithin St. Cleeve tries to explain to a visitor to his observatory the size of the universe: "There is a size at which dignity begins; further on there is a size at which grandeur begins; further on there is a size at which solemnity begins; further on, a size at which awfulness begins; further on, a size at which ghastliness begins. That size faintly approaches the size of the stellar universe. So am I not right in saying that those who exert their imaginative powers to bury themselves in the depths of that universe merely strain their faculties to gain a new horror?"[17]

THE CURVED UNIVERSE

"Because all reasoning is in a circle. At least, that's why the world is round." R. Frost

Early in the 20th century, the landscape of space and time was transformed by Albert Einstein. Even as a teenager, Einstein had thought deeply about nature, wondering how the world would look if he rode on a beam of light. Light defined nature's ultimate speed limit at a prodigious level of 300,000 kilometers per second. As consequence, a fast-moving object is contracted along its length and a fast-moving clock has its time slowed down. Moreover, he proposed that mass and energy are freely convertible, by the famous equation $E = mc^2$. Matter is "frozen" energy. The energy of motion of a fast-moving object goes into its mass, which is what prevents it from exceeding the speed of light. All these effects are imperceptible in the everyday world of cars and jets and walks in the park. However, physicists measure them routinely in the microscopic world of high-energy particles. The bizarre manifestations of relativity — time slowing down, objects squashed, and masses growing with increased speed — are not optical illusions, they are real descriptions of nature.[18]

Einstein then turned his attention to gravity. If light has mass, then light too must respond to the force of gravity and bend in the presence of a massive object. The slight deflection of starlight as it grazes the edge of the Sun was a key prediction of general relativity, confirmed by an eclipse expedition in 1916. While Einstein was wandering Europe with his thoughts of space and time, another intellectual exile, James Joyce, was gestating a novel that would transform space and time in literature. In *Ulysses*, Leopold Bloom performs a personal act of divination as he eclipses the Sun "He faced about and, standing between the awnings, held out his right hand at arm's length towards the Sun. Wanted to try that often. Yes: completely. The tip of his little finger blotted out the Sun's disk. Must be the focus where the rays cross."[19] Mass curves space, and light simply

follows the undulations of curved space. We can imagine the Sun as a weight deflecting a rubber sheet. Particles rolling near the Sun are deviated by the depression in the sheet.

In the sonnet *Any Size We Please*, Robert Frost contrasts the infinite and linear space of Newton with the curved space of Einstein[20]:

> No one was looking at his lonely case;
> So, like a half-mad outpost sentinel,
> Indulging in an absurd dramatic spell,
> Albeit not without some shame of face,
> He stretched his arms out to the dark of space
> And held them absolutely parallel
> In infinite appeal. Then saying "Hell,"
> He drew them in for warmth of self-embrace.
> He thought if he could have his space all curved,
> Wrapped in around itself and self-befriended,
> His science needn't get him so unnerved.
> He had been too all out, too much extended.
> He slapped his breast to verify his purse
> And hugged himself for all his universe.

By the end of his life, Einstein had become a cultural icon.[21] His brilliance, his passionate opposition to nuclear weapons, his quirky old-world appearance — all these were instantly recognizable. The playful spirit that he used to illuminate the clockwork of nature never left him. His monument is all around us, as this excerpt of a poem by R.H.W. Dillard implies, in the corrugations of space and time.[22]

> "Oh, Albert," she said,
> Shaking her head
> And falling back
> On the rumpled and unmade bed,
> "You make everything
> So dizzy." And he did.
>
> It was Albert and his equations —
> This equals that,
> And it's all the same
> Knocked it all out of line,
> Curved space, bent time,
> Cosmos like a wrinkled sheet.

General relativity contains an intimate connection between the shape of space and the motion of objects in the universe. As physicist John Archibald Wheeler puts it "Space tells matter how to move...and matter tells space how to curve."[23] Space and time are linked. The suppleness of space and time was a liberating idea for artists and writers.[21] A second set of influential ideas about nature came from the quantum theory. The early 20th

century saw the granularity of nature revealed — subatomic particles and tiny bullets of light called photons. Heisenberg showed that our knowledge of the microscopic world must always be incomplete. Indeterminacy is built into nature. The placid surfaces of everyday objects conceal both structure and chaos. The structures are the arrays of atoms, often arranged in grids and lattices, and the discrete energy levels of the electrons. The chaos is the fact that matter and energy can be freely interchanged, and the fact that perfect knowledge of one physical quantity might mean complete ignorance of another one. The quantum theory also implies a strong connection between the act of observation and the result of the observation.

Inspired by relativity, 20th century literature saw many experiments in time. Here is Lawrence Durrell in the preface to the second volume in the *Alexandria Quartet*, "I am not suggesting that modern poetry is constructed to illustrate the quantum theory, but I do suggest that it unconsciously reproduces something like the space-time continuum in the way that it uses words and phrases: and the way in which its forms are cyclic rather than extended. Time, both in the novel and in the poem, has taken on a different aspect."[24] In Vladimir Nabokov's *Ada*, the hero develops a complex theory of time "The texture of space is not that of Time, and the piebald four-dimensional sport bred by relativists is a quadruped with one leg replaced by the ghost of a leg."[25] Here is Peter Hoeg, in the novel *Borderliners* "Time refuse to be simplified or reduced. You cannot say that it is only found in the mind or only in the universe, that it runs only in one direction, or in every one imaginable. That it exists only in biological substructure, or is only a social convention... It is all of these things."[26] The liberation from old rules of time and space, and the confusion it engendered, are conveyed by the following limerick by Bennett Cerf (although it has been attributed to Einstein himself)[27]:

In a notable family called Stein,
There were Gertrude, and Ep, and then Ein.
Gert's writing was hazy,
Ep's statues were crazy,
And nobody understood Ein.

The ultimate expression of space curvature is a black hole. The density of matter in a black hole is so large that light cannot escape and the space beyond the event horizon is pinched off from the rest of the universe. In the novel *Night Train*, Martin Amis sees a black hole as a proxy for mortality "Why was it Hawking who cracked black holes? I mean, in the *Sixties* everyone was going at black holes hammer and tongs. But it was Stephen who gave us some answers. She said: Why him? And I gave the physicist's answer: Because he's the smartest guy around. But Jennifer wanted me to consider a notion that was more — romantic. She said: Hawking understood black holes because he could *stare* at them. Black holes mean oblivion. Mean death. And Hawking has been staring at death all his adult life. Hawking could see."[28]

A less conventional meditation on Einstein's universe comes from E.E. Cummings. In a dazzling leap, he connects curved space with the bent finger of Man in the creation

tableau on the ceiling of the Sistine Chapel that fires the gun that kills elephants on Earth.[29]

Space being(don't forget to remember)Curved
(and that reminds me who said o yes Frost
Something there is which isn't fond of walls)
an electromagnetic(now I've lost
the)Einstein expanded Newton's law preserved
conTinuum(but we read that beFore)
of Course life being just a Reflex you
know since Everything is Relative or
to sum it All Up god being Dead(not to
mention inTerred)
LONG LIVE that Upwardlooking
Serene Illustrious and Beatific
Lord of Creation,Man:
At a least crooking
of Whose compassionate digit,earth's most terrific
quadruped swoons into billiardBalls!

Einstein knew that his theory had implications for the size and shape of the universe. When he visited the Mount Wilson Observatory, astronomers there told him that the universe was static — a vast collection of stars in the Milky Way spread over tens of thousands of light year. In their simplest form, the equations of general relativity take flight, indicating that the universe is either expanding or contracting. To conform to the existing observations, Einstein added a repulsive term to the equations; he later called the addition of the cosmological constant "the greatest blunder of my life."[30] As a result, he missed predicting the expansion and the mathematicians Freidmann and Lemaître were the first to show that we might live in a dynamic universe. Edwin Hubble provided the evidence in 1929 when he measured the recession of galaxies beyond the Milky Way.

THE KINETIC UNIVERSE

"The world, the race, the soul — space and time, the universes — all surely going somewhere." W. Whitman

Hubble made the discoveries that would once again humble people as they considered their place in the universe. First, he showed that many of the diffuse nebulae in the sky were "island universes" — systems of stars remote from the Milky Way. At a stroke, the size of the known universe became a hundred times larger. Then he notice that no only were virtually all galaxies moving away from the Milky Way, but the recession velocity was larger for the more distant galaxies. The Hubble law is most easily interpreted as a universal expansion. Imagine the expansion reversed, like a movie played backwards, and it points to a time when all matter was crushed to a hot and dense state. The big bang was

a derogatory appellation provided by the astronomer Fred Hoyle, who favored a rival theory.[31] But it is a catchy moniker, and it has stuck.

The big bang model makes a remarkable connection between the evolution of the universe and the shape of space. The universe began as a fiery cauldron of infinite temperature and density with all matter and space squeezed into a point. After about a billion years, the thinning gas had cooled enough for stars and galaxies to form. Now, some twelve billion years after the big bang, galaxies recede from one another separated by enormous regions almost devoid of matter. It sounds like the aftermath of an explosion, but it is not. Galaxies do not fly through space like shrapnel. They are carried apart by the expanding fabric of space itself. The big bang is the origin of time, as Plato intuited: "Time, then, and the heaven came into being at the same instant in order that, having been created together, if there was ever to be a dissolution of them, they might be dissolved together."[32] Matter and space unfold in the big bang, like a flower.

Here is the big bang as described by John Updike in *Roger's Version* "Space-time. Three spatial dimensions, plus time. It knots. It freezes. The seed of the universe has come into being. Out of nothing. Out of nothing and brute geometry, laws that cannot be otherwise, nobody handed them to Moses, nobody had to. Once you've got that seed, that little itty-bitty mustard seed — ka-boom! Big Bang is right around the corner."[33] Diane Ackerman put it this way[34], in an excerpt from *The Planets: A Cosmic Pastoral*:

> Fifteen billion years ago, when the Universe
> let rip, and in disciplined panic
> Creation
> spewed
> mazy star-treacle and resin,
> shrinking balls of debut fire smoldered
> and
> glitched.

In general relativity, the entire universe can be curved by the matter it contains. The gravity between galaxies retards the expansion; the universe decelerates with gravity as the foot on the brake. If the mean density of the universe is high enough, gravity will overcome the expansion and the universe will collapse. At some maximum size, in a kind of cosmic sigh, all galaxies will start moving toward each other as they head to a return engagement with infinite temperature and density. The two-dimensional analogy for this positive space curvature is the surface of a sphere. Here is the answer to the question of Lucretius: the universe can be finite yet have no boundary. Imagine an expanding balloon with beads glued on it to represent galaxies. By analogy with the sphere, no galaxy can claim to be the center of the expansion, and every galaxy sees all other galaxies rushing away. The universe can have a finite size, yet no traveler would ever reach an edge.

The idea that a light beam might return to its origin in a curved universe inspired William Faulkner in the *Sound and the Fury* "As the clock chimes, Quentin muses, 'It was a while before the last stroke ceased vibrating. It stayed in the air, more felt than heard, for a long

time. Like all the bells that ever rang still ringing down the long-dying light rays...Like Father said down the long and lonely light rays you might see Jesus walking.' "[21,35] Alternatively, if the mean density of matter is low and the universe is open, the expansion will decelerate but will never be overcome. The geometry of an endlessly expanding universe has negative curvature, analogous to a saddle-shape in two dimensions. Only the special boundary between closed and open cases has the flat and familiar geometry of Euclid.

Within the universe, we see a bewildering array of motions. The Earth spins just over 1000 mph at the equator, and we orbit the Sun at 65,000 mph. As the poet Archibald MacLeish realized[21,36], the dead are not laid to rest since their bones describe a lazy helix through space:

His chronicle is endless — the great curve
Inscribed in nothing by a point upon
The spinning surface of a circling sphere.
Dead bones roll on.

The Sun moves in an enormous orbit of the disk of the Milky Way, taking 225 million years to complete the grand tour. The Milky Way is tugged in the direction of the Andromeda galaxy, and both are tumbling toward the Virgo cluster, some 60 million light years away. Virgo galaxies are all streaming toward an even more massive concentration of galaxies in the direction of the Hydra and Centaurus constellations. We vainly try to find a fixed horizon on our heaving ship, but even the distant seas are tilting and sliding. See it expressed by A.R. Ammons[37] in the poem *Cascadilla Falls*:

I went down to Cascadilla
Falls this
evening, the
stream below the falls,
and picked up a
handsized stone
kidney-shaped, testicular, and

thought all its motions into it,
the 800 mph earth spin,
the 190-million-mile yearly
displacement around the sun,
and the overriding
grand haul

of the galaxy with the 30,000
mph of where
the sun's going:
thought of all the interweaving
motions

into myself: dropped

the stone to dead rest:
the stream from other motions
broke
rushing over it;
shelterless,
I turned

to the sky and stood still:
oh
I do
not know where I am going
that I can live my life
by this single creek.

The framework for all these motions is the cosmic microwave background. Discovered in 1965, this diffuse radiation is the relic of the early hot phase of the universe. Some 300,000 years after the big bang, the high-energy radiation and matter in the universe stopped interacting. Since then, gravity has been free to sculpt the structures of planets and stars and galaxies, while the radiation has had its wavelength stretched by the expansion of space. In our large and old universe, the radiation has been redshifted to low energy microwaves. The radiation is perfectly smooth; its largest fluctuations are no bigger than tiny ripples on a large pond. The microwaves define the rest frame of the universe. If we search out to distances of several hundred million light years, we can find a large set of galaxies that have no net motion with respect to the microwave background.

The big bang is all around us. There are about 100 million microwave photons for every particle in the universe, 100,000 in every breath we take. Tune a TV between stations and 1% of the specks you see are interactions with the microwave background. This is the radio "hiss" of the universe, an echo of the big bang 12 billion years ago.

THE CULINARY UNIVERSE

"The universe may be the ultimate free lunch." A. Guth

Surveys of galaxies reveal the architecture of the cosmos, patterns on the largest scales that have been sculpted by gravity over billions of years. Astronomers have used colorful language to describe the structures they see. Historically, it was thought that the rich clusters were set in a uniform sea of galaxies, like meatballs. The discovery of strings and filaments of galaxies added a component of spaghetti. The first slices of the universe showed that the galaxies form large connecting structures around empty voids, like Swiss cheese. The most recent research indicates a single analogy that cleans up these various terms. The general emptiness of space — where galaxies are distributed in sheets and

filaments and clusters are found at the junctions of the sheets — is like a network of soap bubbles.

Astronomers have also used mathematics to describe large-scale structure. What is the shape, or topology, of the way galaxies cluster in space? A point has no dimensions, and in three-dimensional space this would correspond to galaxies that were scattered with no clustering at all. A line has one dimension, so this would be the appropriate description of galaxies in stringy structures. A plane has two dimensions, so this would describe galaxies that are all contained in sheet-like structures. We live in a universe where the large-scale structure has a dimension of about 1.7, which is partway between 1 and 2. In geometry terms, a dimension of 1.7 corresponds to structures that are somewhat string-like and somewhat sheet-like. Overextended pizza dough.

Astronomers have cataloged an amazing smorgasbord of structures in the universe. There are galaxy groups about a million light years across that contain dozens of galaxies. There are galaxy clusters 10 to 20 million light years across that contain hundreds or thousands of galaxies. These are all part of superclusters of size up to 200 million light years that contain tens of thousands of galaxies. The situation is like a landscape with many small foothills and far fewer mighty peaks. The universe on the largest scales we can measure is isotropic — with a similar Hubble law and similar types of structures in every direction we look. It is also homogeneous. Imagine that you are looking down on a beach from a mile high. The grains of sand and pebbles would not be visible and the beach would appear smooth and featureless. Similarly, a mountain range would appear smooth as viewed from a high Earth orbit. Gravity has obviously formed lumps that range in size from planets and stars to clusters and superclusters of galaxies. But the universe is smooth on scales larger than about a billion light years. The universe contains about 10^{20} stars in about 10^{11} galaxies — here are the astronomical numbers that describe cosmology:

Age of the universe in years: 10^{10}
Number of stars in the universe: 10^{20}
Time to walk across universe in years: 10^{26}
Size of the observable universe in meters: 10^{33}
Growth factor of the universe since big bang: 10^{48}
Number of particles of all kinds in the universe: 10^{80}
Number of photons of radiation in the universe: 10^{89}
Time before the universe decays in years: 10^{100}

Note that Archimedes estimated the correct material content of the universe but got the density wrong. Literary reactions to these fantastic numbers have varied. However, cosmology has often been used as a vehicle for existential angst, analogous to the banana skin in slapstick. For a flippant tone, we can look to Woody Allen "Can we actually "know" the universe? My God, it's hard enough finding your way around Chinatown."[38] Or here is a character in John Updike's *Trust Me* contemplating his true position in space as he watches a movie "Fulham would be visited by terror: the walls of the theatre would fall away, the sticky floor became a chasm beneath his feet. His true situation in time and

space would be revealed to him: a speck of consciousness now into its seventh decade, a mortal body poised to rejoin the minerals, a member of a lost civilization that once existed on a sliding continent. The curvature of the immense Earth beneath his feet and solidity of the piece of earth that would cover Fulham's grave would become suffocatingly real to him, all in an instant, he would begin to sweat. There was a *seriousness* to human existence, an absolute irreversibility, from which all our social arrangements and entertainments attempt to divert us."[39] The poem *Prologue* by Edward Field inverts the Copernican revolution to see the universe through the lens of a single person[40]:

> Look, friend, at this universe
> with its spiral clusters of stars
> flying out all over space
> like bedsprings suddenly busting free,
> and in this galaxy, the sun,
> fissioning itself away,
> surrounded by planets, prominent in their dignity,
> and bits and pieces running wild,
> and this middling planet
> with a lone moon circling around it.
>
> Look, friend, through the fog of gases at this world
> with its skin of earth and rock, water and ice,
> with various creatures and rooted things,
> and up from the bulging waistline
> to this land of concrete towers,
> its roads swarming like a hive cut open,
> offshore to this island, long and fishshaped,
> its mouth to a metropolis,
> and in its belly, this village,
> a gathering of families at a crossways,
> and in this house, upstairs and through the wide open door
> of the front bedroom and with a window on the world
> look, friend, at me.

The world beyond science rarely questions the validity of the insights of cosmology. Rather, the dizzying progression since the Copernican revolution has prepared us to accept our miniscule role in an ancient and forbidding universe. The wonder of life is a result of stellar ejecta, concentrated in puddles on a rocky cinder, bathed by the light of a middle rank star. When our comfort analogies from the kitchen fail us, we are left with the implacable nature of the physical universe. Listen to Martin Amis in *Night Train* "There's something in that. Knowing the mind of God, and so on. You're certainly affected by the incredible grandeur and complexity of revealed creation. But don't lose sight of the fact that it's *reality* we're investigating here. These things we're studying are very strange and very distant, but they're as real as the ground beneath your feet. The

universe is everything religions are supposed to be, and then some, weird, beautiful, terrifying, but the universe *is the case*."[28]

THE CHAOTIC UNIVERSE

"Listen, there's a hell of a good universe next door: let's go!" e e cummings

The big bang is a mature scientific theory. It explains the universal recession of galaxies and the relic radiation of the microwave background. It accounts precisely for the amount of helium in the universe — an amount too large to have been produced in all the generations of stars. The early universe was hot enough to behave like the interior of a star. Helium and other light elements were fused within the first few minutes after the big bang. However, the big bang leaves some basic features of the universe unexplained. Why is the universe so smooth? The early universe was expanding so fast that different regions were moving apart faster than the speed of light, yet the microwave radiation is perfectly uniform. This perfect regulation of temperature appears to violate causality. Why is the universe so flat? The curvature of the universe is subtle and space is close to flat, yet the universe could have started with any set of conditions. The similarity of the energy from expansion and the attractive energy from gravity is left as a coincidence.

These enigmas were answered with the idea of inflation, with important consequences for the size and shape of the universe. Astronomers speculate that inflation occurred the merest iota after the big bang — 10^{-35} second after, in fact — caused by the energy released when the different forces of nature became distinct. In this instant, the universe expanded exponentially from subatomic size to the size of a grapefruit. Thereafter, the more leisurely expansion of the big bang continued. The early surge in size had two consequences. First, a tiny patch of the pre-inflation universe expanded to become the observable universe. This allows all regions of our now-immense universe to have the same temperature. Also, the enormous expansion factor reduced any space curvature, as if a small balloon expanded so much that any small piece of it would appear nearly flat.

Inflation implies that the physical universe — everything that there is — is far larger than the observable universe — everything that we can see. We are limited to view the region of space from which light has had time to reach us in the 12 billion-year-history since the big bang. We may live in a bubble within a far larger region of space, as in the line from Shakespeare, in *Hamlet, Prince of Denmark*, "...I could be bounded in a nutshell and count myself the king of infinite space."[41] Inflation also implies that quantum fluctuations were magnified into the seeds that eventually grew into galaxies. The microscopic world has been writ large into the tapestry of gently wheeling spirals and stately ellipticals. As for the cause of the big bang, science cannot venture an answer. To paraphrase Saint Augustine "What did God before He made heaven and earth? He was preparing hell for pryers into such mysteries."[42]

The very early universe was a seething space-time foam, where gravity and the force that binds the atoms were on an equal footing. In a variation on cosmology called chaotic inflation, our universe emerged from one fluctuation in this roiling stew of particles and radiation. Other fluctuations may have led to other universes with different properties, some short-lived or stillborn, others as magnificent as our own. The ultimate theory of nature still eludes us, but it will have to incorporate both gravity and the quantum. It may involve more dimensions than the three of space and one of time that we are familiar with. The physicist Howard Georgi wrote this limerick to honor a colleague who has been a pioneer in the unification of the forces of nature[43]:

Steven Weinberg, returning from Texas
Brings dimensions galore to perplex us.
But the extra ones all
Are rolled up in a ball
So tiny it never affects us.

The early Greeks used the word cosmos to mean more than the catalog of the universe; it also implied order and harmony, a universe governed by rational laws. Its warring opposite is chaos: disorder and the absence of structure. Just as humans are made of stardust and return to dust, the universe was born from chaos and will return to chaos. If the universe is closed, a heat death awaits as the galaxies converge in a time-reversed replay of the big bang. If the universe is open, as appears more likely, galaxies will continue to flee from each other and the stars within them will exhaust their nuclear fuel. Eventually, matter will decay, even black holes will evaporate, and the universe will become an undifferentiated soup of neutrinos and low energy radiation. Either result marks the victory of entropy — the universal tendency toward disorder. Listen to John Updike[44] in his *Ode to Entropy*:

All change distributes energy
spills what cannot be gathered again.
Each meal, each smile,
each foot-race to the well by Jack and Jill
scatters treasure, lets fall
gold straws once woven from the resurgent dust.
The night sky blazes with Byzantine waste.
The bird's throbbing is expenditure,
and the tide's soughing,
and the tungsten filament illumining my hand.

A ramp has been built into probability
the universe cannot re-ascend.
For our small span,
the sun has fuel, the moon lifts the lulling sea,
the highway shudders with stolen hydrocarbons.

Microscopic processes care little about time — particle interactions can flow equally well forward or backward. However, the large-scale trend to increasing disorder is what gives time its arrow. In *Time's Arrow*, Martin Amis tells a story in strictly reverse chronology, where not only does the overall narrative unfold in flashbacks but each event also unfolds as if in a mirror of time.[45]

THE PARTICIPATORY UNIVERSE

" 'Any coincidence,' said Miss Marple to herself, 'is always worth noticing.' " A. Christie

There are many ways to react to modern knowledge of the size and shape of the universe: awe, bland acceptance, numbed disbelief, rejection.[22] Perhaps it is remarkable that the universe *is* understandable. Blaise Pascal wrote in *Pensées* "The spaces of the universe enfold me and swallow me up like a speck; but I, by the power of thought, may comprehend the universe."[46] We are insignificant players in a large cosmos, but it is unclear how much significance we should attach to the fact that we are sentient observers. The last act of the Copernican revolution would be the demonstration of life beyond the Earth, and in particular, intelligent life beyond the solar system.

Buckminster Fuller once said, "Sometimes I think we're alone. Sometimes I think we're not. In either case, the thought is staggering."[47] The universe is a large and bountiful place. There are an enormous number of potential sites for life, and the chemical constituents of life are distributed widely across space. At first sight it appears unlikely that we should be alone. If intelligent life exists beyond the solar system, our world might well be influenced by it, for better or worse. At the very least, as anthropologist D.K. Stern has pointed out, the discovery of alien life "would irreversibly destroy our self-image as the pinnacle of creation."[48] The alternative is equally profound. If we are the only intelligent creatures in the universe, it would imply a universe of incredible grandeur with us as the only spectators.

The debate over life in the universe has always been tinged by anthropocentric thinking. Logically, we have to admit the possibility that only once among 10^{20} stars did the right conditions occur for intelligent life. While it is likely that planets are common, and the chemical ingredients for life are widely dispersed through the universe, evolution towards intelligence and technology may be highly contingent. The fate of 99.99% of all species on Earth is extinction, and only one species has attained the ability to interrogate the universe in 4.5 billion years of adaptive experimentation. Yet optimism has ruled in the debate over life in the universe. The popular culture of television and films has primed us for cosmic companionship — even if most of these stories are no more than thinly veiled allegories of salvation and destruction[49]. As described by Diane Ackerman, we are listening[50]:

As our metal eyes wake
to absolute night
where whispers fly
from the beginning of time
we cup our ears to the heavens.
We are listening

on the volcanic rim of Flagstaff
and in the fields beyond Boston,
in a great array that blooms
like coral from the desert floor,
on highwire webs patrolled
by computer spiders in Peurto Rico.

We are listening for a sound
beyond us, beyond sound,

searching for a lighthouse
in the breakwaters of our uncertainty
an electronic murmer,
a bright, fragile *I am*

Small as tree frogs
staking out one end
of an endless swamp,
we are listening
through the longest night
we imagine, which dawns
between the life and times of stars.

Given present understanding, the universe is more likely to be filled with anaerobic bacteria than with interstellar travelers. Unless life is very common, we may be isolated in time and space. If the distances between civilizations are large, then we would be limited to decoding the runes of long-dead civilizations. In the novel *Ratner's Star*, Don DeLillo put a twist on this idea when an ancient Earth civilization uses the curvature of space to beam their message back to its point of origin "In the untold past on this planet a group of humans transmitted a radio message into space. We don't know whether these people were directing their signal to a particular solar system, towards a huge cluster of nearby stars, toward the center of our galaxy, toward another galaxy; or whether they were perfectly aware that their message would return to planet Earth at a specific time in the future — a message, moreover, that was more likely to be preserved and detected, when we consider earthquakes, erosion and continental drift, in the form of a radio transmission than in a time capsule or other kind of sealed device."[51] We have sent several messages in a bottle into the cosmic ocean: the plaque on the Pioneer spacecraft, the disk on the Voyager spacecraft, a radio message beamed toward the globular cluster

M 13. These quixotic attempts at interstellar communication seem to be designed to speak to us rather than to an alien of unknown form and function.

Those who want to give cosmic significance to the presence of intelligent life on Earth have embraced an idea called the Anthropic Principle. Many of the constants of nature do not have values that emerge from any physical theory, but they do have values that are finely tuned to allow the possibility of carbon-based life forms. For example, if the force that binds the atomic nucleus were much stronger, the big bang would have created so much helium that there would be no water and no long-lived stars. If the nuclear force were much weaker, early universe neutrons would not have decayed into protons and there would be no hydrogen. If the electromagnetic force were slightly stronger, stars would not create elements heavier than iron and they would be too cold to nurture life. If the electromagnetic force were slightly weaker, stars would burn too fast for life to evolve around them. In other words, a universe with slightly different properties would be physically plausible but would be unlikely to support complex biochemistry or life.

A provocative idea called the Anthropic Principle reconnects us with the larger universe.[52] In its "weak" form, the Anthropic Principle says that people can only observe a universe that is capable of allowing observers to exist. This is self-evident, but uninteresting — a tautology. In other words, we should not be surprised that the universe is as old and big as it is. If the mass density were much lower, gravity could not have formed stars and galaxies in the expanding gas, and we would not exist. If the mass density were much higher, the universe would have collapsed before generations of stars could make heavy elements, and we would not exist. The strong form of the Anthropic Principle holds that the universe was built for life — a truly audacious claim. Unfortunately, the Anthropic Principle is post hoc and it makes no clear predictions in the manner of a scientific theory. It is too soon to claim that we can explain the cosmic coincidences that led to our existence. In the words of Stephen Crane "A man said to the universe: 'Sir, I exist!' 'However,' replied the universe, 'The fact has not created in me a sense of obligation.' "[53]

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