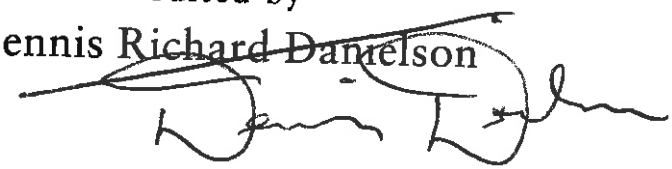
the Book of the Cosmos

Imagining the Universe from Heraclitus to Hawking

A Helix Anthology

edited by

Dennis Richard Danielson



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A Very Liquid Heaven

René Descartes

The ideas of René Descartes (1596–1650) figure prominently in histories of philosophy but in some histories of cosmology receive only a footnote. His notion of vortices, or whirlpools of matter that account for the origin and structure of planetary systems, was decisively displaced by Newtonian conceptions and was subsequently, by most, remembered no more. In the seventeenth century, however, it was an influential idea. To us it can perhaps seem somewhat ridiculous simply because our common conceptions of space and motion are themselves still doggedly Newtonian. Yet if we bracket the assumptions that motion is naturally rectilinear and that space is empty, absolute, and devoid of any structure of its own, then we can better enter into the process of thought which Descartes exhibits in the following selection from his Principles of Philosophy *(published in Latin in 1644, in French in 1647). Once Descartes has rejected vacuous space and made the fundamental assumption that the heavens are liquid, the analogy between celestial motions and the familiar phenomenon of whirlpools within a current of water becomes almost inevitable. In this way too he is able to offer a hypothesis that accounts for the dynamism of the heavens while avoiding (he says, somewhat equivocally) any imputation of motion to the earth.*

I will be more careful than Copernicus not to attribute motion to the earth, and will attempt to show how my thoughts on this subject might be truer than Tycho's: I will propose here a hypothesis that seems to me to be the simplest and most convenient of all, in order to explicate the planets as well as to research their natural causes. . . .

First, because we do not yet know for sure what the distance is between the earth and the fixed stars, and because we cannot imagine them so distant as to be at odds with experience, let us not be content merely to put them above Saturn, where all the astronomers acknowledge they are; but let us take the liberty of supposing them to be as distant from it as will be useful for our goal. If we wish to judge their height in comparison with the distances we see between objects on earth, our estimations of them will have as little credibility as the greatest distance we could imagine. On the other hand, if we consider the omnipotence of God, who created them, the greatest distance we can conceive is no less believable than the smallest. And . . . we can no better explain the appearance of comets or planets unless we suppose a very great space between Saturn's sphere and the fixed stars. . . .

Secondly, because the sun is similar both to a flame and to the fixed stars, in that light departs from it which is not borrowed from elsewhere, let us also imagine that its motion is similar to a flame and that its position is similar to the stars. . . . We may assume that the sun is composed of a very liquid material, the particles of which are so extremely agitated that they carry away heavenly particles which are their neighbors and which surround them. Moreover, the sun is likewise similar to the fixed stars in that it does not travel from one part of the heavens to another. . . .

Furthermore, it must be noted here that, if the sun and fixed stars resemble one another in their positions, we may not assume they are all on the surface of the same sphere (as several suppose them to be), since the sun is not able to be with them on the surface of this sphere. Instead, we must assume that, just as it is surrounded by a vast space in which there are no fixed stars, so too each fixed star is very remote from all the others, and some of these stars are more remote from us and from the sun than others are. . . .

Thirdly, let us assume that the material of the heavens, like that which composes the sun and fixed stars, is liquid. This is an opinion that is now commonly held by astronomers, because it is almost impossible to explain well the phenomena without it. . . .

But, wishing to grant that the heavens are liquid, some make the mistake of imagining them to be a totally empty space that not only does not resist the movements of other bodies, but also has no force to move them or carry them along. For one thing, there can be no such vacuum in nature. For another, all liquids share this property, namely that they do not resist the movement of other bodies—not because they have less agitation than particles of solid matter but because they have the same or more. For this reason their small particles can easily be made to move every which way. But when they do all move together in the same direction, they necessarily carry along any body which they embrace and surround (and which no external force pre-

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vents from being thus carried along)—even though such bodies are hard, solid, and completely at rest. . . .

Fourthly, since we see that the earth is neither supported by columns nor suspended in the air by cables, but rather surrounded on all sides by a very liquid heaven, let us assume that it is at rest and that it has no propensity to movement, for we observe no such thing. However, let us not assume that this stops it from being carried along by the heaven's current, just as a boat that is neither driven along by wind or oar nor held back by anchor remains at rest in the midst of the sea, though the ebb and flow of this great mass of water imperceptibly carries it along with itself. . . .

Just as the other planets resemble earth (opaque, and reflecting the sun's rays), so too we have reason to believe that they likewise resemble it in remaining at rest in the part of heaven where each is located, and that every change we observe in their positions arises from the fact of their submitting to the motion of the heaven which contains them. . . .

In this regard, let us recall . . . the nature of movement. *Properly speaking* it is the transference of a body from the vicinity of those bodies which are in immediate contact with it and which we think of as at rest. Yet *in common usage* "movement" is predicated of every action that makes a body pass from one place to another. In this sense one can say that the same thing at the same time both is and is not in motion, depending on the different ways of determining its position. However, neither in the earth nor in the planets is there any movement properly speaking. They are not transferred from the vicinity of the heavenly particles they are in contact with. And thus they are at rest. . . .

If we consider movement according to common usage, we may well say that all the other planets move, and so do the sun and fixed stars. But the same thing cannot be said of the earth except very improperly. We determine the positions of the stars according to what we take to be certain fixed places on earth, and we consider them to have moved when they deviate from the positions we have thus determined. . . . But if a philosopher, who makes a profession out of seeking truth, takes heed of the fact that the earth is a globe floating in a liquid heaven whose particles are extremely agitated, and that the fixed stars always keep the same positions among themselves—if a philosopher wishes to conceive of these stars as stable in order to determine the earth's position, and consequently intends to conclude that it moves, then he is making a mistake, and his discourse lacks rational support. For . . . in its true sense, position is necessarily determined by the bodies in direct contact with whatever is said to be in motion, not by those very distant, as are the fixed stars in relation to the earth. . . . Whoever considers God's grandeur and the fallibility of our senses will judge that . . . perhaps beyond all the vis-

ible stars there are still other bodies in relation to which . . . the earth is at rest and the stars are in motion. . . . Therefore, even if, in order to accommodate ourselves to custom, we attribute some movement to the earth, we must acknowledge we are speaking unphilosophically, just as when we sometimes say of those who are asleep on a boat that they nevertheless move from Calais to Dover because the boat is carrying them there.

Having by these arguments removed all our misgivings concerning the earth's movement, let us assume that the heavenly material in which the planets are located revolves incessantly like a vortex with the sun at its center, that its particles close to the sun move faster than those (to a certain limit) that are more distant, and that all the planets (among which we include the earth) remain continually suspended amid the same segments of this heavenly material. By this hypothesis alone, without the help of any other machinery, we will easily understand everything we observe in the heavens.

Picture the bend of a river, where the water coils itself, turning in circles, some major, some quite minor. Things floating in this current, we notice, are carried along by it and turned round and round, even heavy objects, some of which revolve about their own centers. Those objects nearer the center of the eddy containing them complete their revolution sooner than do those farther from the center. Finally, though these eddies always turn in a circle, they hardly ever describe a perfect circle . . . so that not all the particles on the circumference are equidistant from the center. Let us likewise imagine the same things happening to the planets. And this is all we need in order to explain all of their phenomena.

SOURCE: Adapted from René Descartes, *Principles of Philosophy*, trans. Blair Reynolds, *Studies in the History of Philosophy*, vol. 6, Lewiston, N.Y.: Edwin Mellen, 1988.

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The Eternal Silence of These Infinite Spaces

Blaise Pascal

Blaise Pascal (1623–1662) possessed a remarkable combination of talents. He invented what he called "a machine for making arithmetical calculations without pen or counters," considered by some to be the world's first digital calculator. Fittingly, then, his name reappears in computer programming languages as well as in laws and units of fluid pressure, in the physics of which he did groundbreaking experimental *work. Indeed, he said that geometry, arithmetic, music, physics, medicine, and architecture are all "sciences that are subject to experiment and reasoning"; and he criticized "the blindness of those who bring authority alone as proof in physical matters." When he wrote these words, Pascal particularly had in mind the age-old question regarding the possibility of a vacuum, which contemporaries such as Descartes denied for quite nonempirical reasons. Descartes and Pascal in fact met with each other for two days in September 1647 to discuss the issue, a meeting whose lack of harmonious outcome is attested by Descartes' snide remark to Huygens that Pascal "has too much vacuum in his head."*

Pascal was also a philosopher and a Christian apologist who engaged with imagination and meditative awe questions of humankind's place in the post-Copernican universe.

Let man then contemplate the whole of nature in her full and grand majesty, and turn his vision from the low objects which surround him. Let him gaze on that brilliant light, set like an eternal lamp to illumine the universe; let the earth appear to him a point in comparison with the vast circle described by

the sun; and let him wonder at the fact that this vast circle is itself but a very fine point in comparison with that described by the stars in their revolution round the firmament. But if our view be arrested there, let our imagination pass beyond; it will sooner exhaust the power of conception than nature that of supplying material for conception. The whole visible world is only an imperceptible atom in the ample bosom of nature. No idea approaches it. We may enlarge our conceptions beyond an imaginable space; we only produce atoms in comparison with the reality of things. It is an infinite sphere, the center of which is everywhere, the circumference nowhere. In short, it is the greatest sensible mark of the almighty power of God that imagination loses itself in that thought.

Returning to himself, let man consider what he is in comparison with all existence; let him regard himself as lost in this remote corner of nature; and from the little cell in which he finds himself lodged, I mean the universe, let him estimate at their true value the earth, kingdoms, cities, and himself. What is a man in the Infinite?

But to show him another prodigy equally astonishing, let him examine the most delicate things he knows. Let a mite be given him, with its minute body and parts incomparably more minute, limbs with their joints, veins in the limbs, blood in the veins, humors in the blood, drops in the humors, vapors in the drops. Dividing these last things again, let him exhaust his powers of conception, and let the last object at which he can arrive be now that of our discourse. Perhaps he will think that here is the smallest point in nature. I will let him see therein a new abyss. I will paint for him not only the visible universe, but all that he can conceive of nature's immensity in the womb of this abridged atom. Let him see therein an infinity of universes, each of which has its firmament, its planets, its earth, in the same proportion as in the visible world; in each earth animals, and in the last mites, in which he will find again all that the first had, finding still in these others the same thing without end and without cessation. Let him lose himself in wonders as amazing in their littleness as the others in their vastness. For who will not be astounded at the fact that our body, which a little while ago was imperceptible in the universe, itself imperceptible in the bosom of the whole, is now a colossus, a world, or rather a whole, in respect of the nothingness which we cannot reach? He who regards himself in this light will be afraid of himself, and observing himself sustained in the body given him by nature between those two abysses of the Infinite and Nothing, will tremble at the sight of these marvels; and I think that, as his curiosity changes into admiration, he will be more disposed to contemplate them in silence than to examine them with presumption.

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SOURCE: Blaise Pascal, *Thoughts*

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For, in fact, what is man in nature? A Nothing in comparison with the Infinite, an All in comparison with the Nothing, a mean between nothing and everything. Since he is infinitely removed from comprehending the extremes, the end of things and their beginning are hopelessly hidden from him in an impenetrable secret; he is equally incapable of seeing the Nothing from which he was made, and the Infinite in which he is swallowed up.

What will he do then, but perceive the appearance of the middle of things, in an eternal despair of knowing either their beginning or their end. All things proceed from the Nothing, and are borne towards the Infinite. Who will follow these marvelous processes? The Author of these wonders understands them. None other can do so.

. . .

When I consider the short duration of my life, swallowed up in the eternity before and after, the little space which I fill, and even can see, engulfed in the infinite immensity of spaces of which I am ignorant, and which know me not, I am frightened, and am astonished at being here rather than there; for there is no reason why here rather than there, why now rather than then. Who has put me here? By whose order and direction have this place and time been allotted to me? . . .

The eternal silence of these infinite spaces frightens me.

SOURCE: Blaise Pascal, *Thoughts*, trans. W. F. Trotter, New York: Collier, 1910.

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This Pendent World

John Milton

John Milton (1608–1674) is best known not as a cosmologist but as a poet, and his great poem Paradise Lost *is most famous as a magnificent re-telling of the biblical story of the fall of humankind, packaged as a classical epic. It should not be surprising, however, that a work dealing with the grand themes of God and human destiny would engage in a serious way questions about what the world is like and how it came to be. Although Milton's universe is eclectic and not easy to categorize, we can see its relation to various developments in cosmological history by charting the experiences or responses of three different characters in* Paradise Lost, *a devil, a human, and an angel.*

Following the journey of Satan allows us to "zoom in" on earth in three distinct stages. First, Satan sets out on a voyage from Hell, which is located at one "end" or "side" of what seems to be a boundless, infinite uncreated realm called Chaos. Milton avoids dualism by saying that the substance of Chaos came originally from God, but the picture we are given of it has much in common with the state described by the early atomists. Satan, together with the personified figures of Sin and Death, looks out from the gates of Hell and views the disordered, precreational state of matter.

Before their eyes in sudden view appear
The secrets of the hoary deep—a dark
Illimitable ocean, without bound,
Without dimension, where length, breadth, and height,
And time, and place, are lost; where eldest Night
And Chaos, ancestors of Nature, hold
Eternal anarchy, amidst the noise

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Of endless wars, and by confusion stand.
For Hot, Cold, Moist, and Dry, four champions fierce,
Strive here for mastery, and to battle bring
Their embryon atoms; they around the flag
Of each his faction, in their several clans,
Light-armed or heavy, sharp, smooth, swift, or slow,
Swarm populous, unnumbered as the sands
Of Barca or Cyrene's torrid soil,
Levied to side with warring winds, and poise
Their lighter wings. To whom these most adhere
He rules a moment; Chaos umpire sits,
And by decision more embroils the fray
By which he reigns. Next him, high arbiter
Chance governs all. Into this wild abyss,
The womb of nature and perhaps her grave,
Of neither sea, nor shore, nor air, nor fire,
But all these in their pregnant causes mixed
Confusedly, and which thus must ever fight,
Unless the Almighty Maker them ordain
His dark materials to create more worlds—
Into this wild abyss the wary fiend
Stood on the brink of Hell and looked a while,
Pondering his voyage.

(2.890–919)

On the analogy of an explorer voyaging to discover the New World (and also to corrupt it!), Satan crosses the "ocean" of Chaos and approaches what we readers know is our place in the cosmos. It is a scene that causes us to reflect on the astonishing scale of the physical reality Milton presents. Ptolemy had inferred the enormous size of the sphere of the fixed stars when he realized that the earth was but a point by comparison with it. Copernicus's system demanded a further expansion of that sphere, because even the entire orbit of the earth around the sun was immeasurably small in relation to the sphere of the fixed stars. But in Milton, that immensely large sphere is itself rendered not much larger than a point by comparison with the size of Heaven and Chaos. Our spherical universe—not the earth, but the entire solar and stellar system—appears as small as a faint, sixth magnitude star symbolically hanging down from heaven.

But now at last the sacred influence
Of light appears, and from the walls of Heaven

Shoots far into the bosom of dim Night
A glimmering dawn. Here Nature first begins
Her farthest verge, and Chaos to retire,
As from her outmost works, a broken foe,
With tumult less and with less hostile din;
That Satan with less toil, and now with ease,
Wafts on the calmer wave by dubious light,
And, like a weather-beaten vessel, holds
Gladly the port, though shrouds and tackle torn;
Or in the emptier waste, resembling air,
Weighs his spread wings, at leisure to behold
Far off the empyreal Heaven, extended wide
In circuit, undetermined square or round,
With opal towers and battlements adorned
Of living sapphire, once his native seat;
And, fast by, hanging in a golden chain,
This pendent world, in bigness as a star
Of smallest magnitude close by the moon.
(2.1034–53)

Having landed on the outer surface of our universe and gaining entrance through a kind of hatch intended for the use of heavenly beings, Satan makes the second leg of his journey, this time to the sun. Although the geometry of Milton's universe is Ptolemaic in the sense that earth is at the center, virtually everything else about it is related to some aspect of the new astronomy. There are no crystalline spheres; the stars are not all carried, equidistant from the center, by a single sphere (their locomotion is instead "magnetic," an idea Milton may have borrowed from Kepler); space is homogeneous and permits "space travel," as Satan illustrates; the stars may be "other worlds"; and the earth itself is a "star" reflecting sunlight as do the moon and other planets. The following passage ironically refers to Satan, after his arrival on the sun, as a "spot" (i.e. blemish) unlike any sunspot seen by Galileo through his telescope.

Down right into the world's first region [Satan] throws
His flight precipitant, and winds with ease
Through the pure marble air his oblique way
Amongst innumerable stars, that shone
Stars distant, but nigh hand seemed other worlds;
Or other worlds they seemed, or happy isles,

Like those Hesp
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The golden sun,
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Like those Hesperian gardens famed of old,
Fortunate fields, and groves, and flowery vales,
Thrice happy isles; but who dwelt happy there
He staid not to inquire. Above them all
The golden sun, in splendor likest Heaven,
Allured his eye; thither his course he bends
Through the calm firmament (but up or down,
By center, or eccentric, hard to tell,
Or longitude) where the great luminary [i.e. the sun]
Aloof the vulgar constellations thick,
That from his lordly eye keep distance due,
Dispenses light from far; they, as they move
Their starry dance in numbers that compute
Days, months, and years, towards his all-cheering lamp
Turn swift their various motions, or are turned
By his magnetic beam, that gently warms
The universe, and to each inward part
With gentle penetration, though unseen,
Shoots invisible virtue even to the deep;
So wondrously was set his station bright.
There lands the fiend, a spot like which perhaps
Astronomer in the sun's lucent orb
Through his glazed optic tube yet never saw.
(3.562–90)

The last stage of Satan's journey is from the sun to the earth. However, the reason he stops on the sun is to request directions. It is not obvious to him which "orb" humans live on—a further indication of the homogeneity of the universe. Earth is not conspicuously unique, and Satan's question echoes other seventeenth-century speculation about interplanetary travel and settlement. He asks an angel named Uriel, "In which of all these shining orbs hath man / His fixed seat, or fixed seat hath none, / But all these shining orbs his choice to dwell[?]" Uriel's answer gives not only Satan but also the reader a glimpse of earth as seen from space.

Look downward on that globe, whose hither side
With light from hence, though but reflected, shines;
That place is earth, the seat of man; that light
His day, which else, as the other hemisphere,

Night would invade; but there the neighboring moon
(So call that opposite fair star) her aid
Timely interposes, and her monthly round
Still ending, still renewing, through mid heaven,
With borrowed light her countenance triform
Hence fills and empties to enlighten the earth,
And in her pale dominion checks the night.
That spot, to which I point, is Paradise,
Adam's abode; those lofty shades, his bower.
Thy way thou canst not miss.

(3.722–35)

The human perspective on the universe is given by Adam in conversation with the angel Raphael, who has been sent from heaven to instruct him on various items, particularly on the importance of watching out for temptation. But the conversation includes discussion of astronomy. Adam's view is essentially Ptolemaic, but not in any stereotypically naive sense. Like Oresme, for example, Adam recognizes the lack of "economy" in assuming that the immense heavens make a daily revolution around this tiny earth:

When I behold this goodly frame, this world,
Of heaven and earth consisting, and compute
Their magnitudes, this Earth a spot, a grain,
An atom, with the firmament compared
And all her numbered stars, that seem to roll
Spaces incomprehensible (for such
Their distance argues, and their swift return
Diurnal) merely to officiate light
Round this opacous earth, this punctual spot,
One day and night, in all her vast survey
Useless besides; reasoning I oft admire,
How Nature wise and frugal could commit
Such disproportions, with superfluous hand
So many nobler bodies to create,
Greater so manifold, to this one use,
For aught appears, and on their orbs impose
Such restless revolution day by day
Repeated; while the sedentary earth,
That better might with far less compass move,
Served by more noble than herself, attains

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As tribute such a sumless journey brought
Of incorporeal speed, her warmth and light;
Speed, to describe whose swiftness number fails.

(8.15–38)

Raphael's answer does not explicitly take sides in any simplistically Ptolemaic-versus-Copernican debate. Like Robert Burton's account of astronomy ("They hoist the earth up and down like a ball"), Raphael's takes the subject seriously but adopts a somewhat satirical posture towards human efforts to "wield" the universe according to various theories. Raphael's reply to Adam ranges across issues from geocentrism to heliocentrism, extraterrestrial life, the size and purpose of the heavens, and limits (or lack of limits) to the speed of space travel.

To ask or search, I blame thee not; for heaven
Is as the book of God before thee set,
Wherein to read his wondrous works, and learn
His seasons, hours, or days, or months, or years:
This to attain, whether heaven move or earth,
Imports not, if thou reckon right; the rest
From man or angel the great Architect
Did wisely to conceal, and not divulge
His secrets to be scanned by them who ought
Rather admire; or, if they list to try
Conjecture, he his fabric of the heavens
Hath left to their disputes, perhaps to move
His laughter at their quaint opinions wide
Hereafter, when they come to model heaven
And calculate the stars, how they will wield
The mighty frame, how build, unbuild, contrive
To save appearances, how gird the sphere
With centric and eccentric scribbled o'er,
Cycle and epicycle, orb in orb:
Already by thy reasoning this I guess,
Who art to lead thy offspring, and supposest
That bodies bright and greater should not serve
The less not bright, nor heaven such journeys run,
Earth sitting still, when she alone receives
The benefit. Consider, first, that great

Or bright infers not excellence: the earth,
Though in comparison of heaven so small,
Nor glistering, may of solid good contain
More plenty than the sun that barren shines,
Whose virtue on itself works no effect,
But in the fruitful earth; there first received,
His beams, unactive else, their vigor find.
Yet not to earth are those bright luminaries
Officious, but to thee, Earth's habitant.
And for the heaven's wide circuit, let it speak
The Maker's high magnificence, who built
So spacious, and his line stretched out so far;
That man may know he dwells not in his own;
An edifice too large for him to fill,
Lodged in a small partition, and the rest
Ordained for uses to his Lord best known.
The swiftness of those circles attribute,
Though numberless, to his omnipotence,
That to corporeal substances could add
Speed almost spiritual; me thou thinkest not slow,
Who since the morning hour set out from heaven
Where God resides, and ere mid-day arrived
In Eden, distance inexpressible
By numbers that have name. But this I urge,
Admitting motion in the heavens, to show
Invalid that which thee to doubt it moved;
Not that I so affirm, though so it seem
To thee who hast thy dwelling here on earth.
God, to remove his ways from human sense,
Placed heaven from earth so far, that earthly sight,
If it presume, might err in things too high,
And no advantage gain. What if the sun
Be center to the world, and other stars,
By his attractive virtue and their own
Incited, dance about him various rounds?
Their wandering course now high, now low, then hid,
Progressive, retrograde, or standing still,
In six thou seest; and what if seventh to these
The planet earth, so stedfast though she seem,
Insensibly three different motions move?
Which else to several spheres thou must ascribe,

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SOURCE: John Milton, *Paradise L*
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Moved contrary with thwart obliquities,
Or save the sun his labor, and that swift
Nocturnal and diurnal rhomb supposed,
Invisible else above all stars, the wheel
Of day and night; which needs not thy belief,
If earth industrious of herself fetch day
Travelling east, and with her part averse
From the sun's beam meet night, her other part
Still luminous by his ray. What if that light
Sent from her through the wide transpicuous air
To the terrestrial moon be as a star,
Enlightening her by day, as she by night
This earth? reciprocal, if land be there,
Fields and inhabitants: her spots thou seest
As clouds, and clouds may rain, and rain produce
Fruits in her softened soil for some to eat
Allotted there; and other suns perhaps,
With their attendant moons thou wilt descry
Communicating male and female light,
Which two great sexes animate the world,
Stored in each orb perhaps with some that live.
For such vast room in nature unpossessed
By living soul, desert and desolate,
Only to shine, yet scarce to contribute
Each orb a glimpse of light, conveyed so far
Down to this habitable, which returns
Light back to them, is obvious to dispute.
But whether thus these things, or whether not;
Whether the sun, predominant in Heaven,
Rise on the earth, or earth rise on the sun,
He from the east his flaming road begin;
Or she from west her silent course advance,
With inoffensive pace that spinning sleeps
On her soft axle, while she paces even,
And bears thee soft with the smooth air along;
Solicit not thy thoughts with matters hid;
Leave them to God above; him serve, and fear!

(8.66–168)

SOURCE: John Milton, *Paradise Lost: A Poem in Twelve Books* (2nd. ed.), London, 1674.

33

But One Little Family of the Universe

Bernard le Bouvier de Fontenelle and Aphra Behn

A highly engaging and imaginative encapsulation of ideas about the universe and "other worlds" in the late seventeenth century—one influenced both by Descartes and by John Wilkins—appears in the writings of Bernard le Bouvier de Fontenelle (1657–1757). His dialogue A Discovery of New Worlds *was translated into English by (in the words of Sam Briscoe, one of her later publishers) "the Sappho of our nation, the incomparable Mrs. [Aphra] Behn" (1640–1689). Thus the first professional female author in the English language became party to the popular dissemination of Copernican ideas.*

Behn's own preface to Fontenelle's dialogue is interesting for its engagement of the two issues just alluded to: the role of women in scientific discourse, and the desirability and danger of popularizing science. Behn admits she was motivated to translate the work by "the novelty of the subject in vulgar [i.e., vernacular] languages," and by "the author's introducing a woman as one of the speakers." At the same time, she is openly doubtful about whether Fontenelle succeeds—either in popularizing scientific ideas with appropriate dignity, or in creating a female character with sufficient credibility:

The design of the author is to treat of this part of natural philosophy in a more familiar way than any other hath done, and to make everybody understand him. For this end he introduceth a woman of quality . . . whom he

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feigns never to have heard of any such thing as philosophy before. How well he hath performed his undertaking you will best judge when you have perused the book. But if you would know beforehand my thoughts, I must tell you freely, he hath failed in his design; for endeavoring to render this part of natural philosophy familiar, he hath turned it into ridicule. He hath pushed his wild notion of the plurality of worlds to that height of extravagancy that he most certainly will confound those readers who have not judgment and wit to distinguish between what is truly solid (or at least probable) and what is trifling and airy. . . .

And for his Lady Marquiese, he makes her say a great many very silly things, though sometimes she makes observations so learned that the greatest philosophers in Europe could make no better. . . .

[The author] endeavors chiefly two things. One is that there are thousands of worlds inhabited by animals, besides our earth, and hath urged this fancy too far. I shall not presume to defend his opinion, but one may make a very good use of many things he hath expressed very finely, in endeavoring to assist his wild fancy. For he gives a magnificent idea of the vastness of the universe, and of the almighty and infinite power of the Creator, to be comprehended by the meanest capacity. This he proves judiciously by the appearances and distances of the planets and fixed stars. And if he had let alone his learned men, philosophical transactions, and telescopes in the planet Jupiter and his inhabitants not only there but in all the fixed stars, and even in the Milky Way, and only stuck to the greatness of the universe, he had deserved much more praise.

The other thing he endeavors to defend and assert is the system of Copernicus. As to this, I cannot but take his part as far as a woman's reasoning can go.

In the dialogue itself, the reader is to imagine five successive nights' conversation between the author and a beautiful noblewoman, a marchioness. Fontenelle sets the scene:

We went one evening after supper to walk in the park. The air was cool and refreshing. . . . The moon was about an hour high, which shining through the boughs of the trees made a most agreeable mixture, and checkered the paths beneath with a most resplendent white upon the green, which appeared to be black by that light. There was no cloud to be seen that could hide from us or obscure the smallest of the stars, which looked all like pure polished gold, whose lustre was extremely heightened by the deep azure field on which they were placed. These pleasant objects set me a-thinking, and had it not been for Madam the Marchioness, I might have continued longer in that silent contem-

plation. But the presence of a person of her wit and beauty hindered me from giving up my thoughts entirely to the moon and stars.

After a brief exchange in which the glories of the night are compared favorably to those of the day, the author summarizes his complaint regarding sunlight:

"The scene of the universe by day-light appears too uniform, we beholding but one great luminary in an arched vault of azure, of a vast extent, while all the stars appear confusedly dispersed, and disposed as it were by chance in a thousand different figures, which assists our roving fancies to fall agreeably into silent thoughts."

"Sir," replied Madam the Marchioness, "I have always felt those effects of night you tell me of. I love the stars, and could be heartily angry with the sun for taking them from my sight."

"Ah," cried I, "I cannot forgive his taking from me the sight of all those worlds that are there."

"Worlds!" said she. "What worlds?" And looking earnestly upon me, asked me again what I meant.

"I ask your pardon, Madam," said I. "I was insensibly led to this fond discovery of my weakness."

"What weakness?" said she, more earnestly than before.

"Alas," said I, "I am sorry that I must confess I have imagined to myself that every star may perchance be another world, yet I would not swear that it is so. But I will believe it to be true, because that opinion is so pleasant to me, and gives me very diverting ideas, which have fixed themselves delightfully in my imaginations. And 'tis necessary that every solid truth should have its agreeableness."

"Well," said she, "Since your folly is so pleasing to you, give me a share of it. I will believe whatever you please concerning the stars, if I find it pleasant."

"Ah, Madam," said I, hastily, "'Tis not such a pleasure as you find in one of Molière's plays. 'Tis a pleasure that is—I know not where, in our reason, and which only transports the mind."

"What?" replied she, "Do you think me then incapable of all those pleasures which entertain our reason, and only treat the mind? I will instantly show you the contrary, at least as soon as you have told me what you know of your stars."

"Ah, Madam," cried I, "I shall never endure to be reproached with that neglect of my one happiness, that in a grove, at ten o'clock of the night, I talked of nothing but philosophy to the greatest beauty in the world. No, Madam, search for philosophy somewhere else."

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In a subtly ironic reversal, the author describes the marchioness's persuasion as a kind of seduction to which he, in the end, cannot help but submit—on the condition that she be "secret for the saving of my honor." He then begins his discourse on celestial mechanics by way of analogy with an opera played out in a theater.

"Pray, Madam, imagine to yourself the ancient philosophers beholding one of our operas, such a one as Pythagoras, Plato, Aristotle, and many more, whose names and reputations make so great a noise in the world. And suppose they were to behold the flying of Phaeton [the chariot driver], who is carried aloft by the winds, and that they could not discern the ropes and pulleys, but were altogether ignorant of the contrivance of the machine behind the scenes. One of them would be apt to say, 'It is a certain secret virtue that carries up Phaeton.' Another, that 'Phaeton is composed of certain numbers, which make him mount upwards.' The third, that 'Phaeton has a certain kindness [or natural inclination] for the highest part of the theater, and is uneasy when he is not there.' And a fourth, that 'Phaeton was not made for flying, but he had rather fly than leave the upper part of the stage void.' Besides a hundred other notions which I wonder have not entirely ruined the reputation of the ancients.

"In our age Descartes and some other moderns would say that 'Phaeton's flight upwards is because he is hoisted by ropes, and while he ascends, a greater weight than he descends.' And now men do not believe that any corporeal being moves itself, unless it be set in motion, or pushed by another body, or drawn by ropes, nor that any heavy thing ascends or descends, without a counterpoise equal with it in weight to balance it, or that it is guided by springs. And could we see nature as it is, we should see nothing but the hinder part of the theater at the opera."

"By what you say," said Madam the Marchioness, "philosophy is become very mechanical."

"So very mechanical," said I, "that I am afraid men will quickly be ashamed of it. For some would have the universe no other thing in great, than a watch is in little; and that all things in it are ordered by regular motion, which depends upon the just and equal disposal of its parts. Confess the truth, Madam, have not you had heretofore a more sublime idea of the universe, and have not you honored it with a better opinion than it deserved? I have known several esteem it less since they believed they knew it better."

"And for my part," said she, "I esteem it more since I knew it is so like a watch. And 'tis most surprising to me, that the course and order of nature, however admirable it appears to be, moves upon principles and things that are so very easy and simple."

"I know not," replied I, "who has given you so just ideas of it, but 'tis not ordinary to have such. Most people retain in their minds some false principle or other of admiration, wrapped up in obscurity, which they adore. They admire nature only because they look on it as a kind of miracle which they do not understand; and 'tis certain that those sort of people never despise anything but from the moment they begin to understand it. But, Madam, I find you so well disposed to comprehend all I have to say to you that, without further preface, I need only draw the curtain and show you the world."

The author, thus continuing in his role as impresario, now briefly reviews the scenes of ancient astronomy from the Chaldeans and Egyptians to Ptolemy, at last arriving at an admission of difficulties in the stagecraft of the Ptolemaic system.

"Madam," said I without vanity, "I have very much softened and explained this system. Should I expose it to you such as it was first invented by its author Ptolemy, or by those that have followed his principles, it would frighten you. The motion of the planets being irregular, they move sometimes fast, sometimes slow; sometimes towards one side, sometimes to another; at one time near the earth, at another far from it. The ancients did imagine I know not how many circles, differently interwoven one with another, by which they fancied to themselves they understood all the irregular phenomena or appearances in nature. And the confusion of these circles was so great that at that time, when men knew no better, a King of Arragon, a great mathematician (not over devout), said that if God had called him to his council, when he formed the universe, he could have given him good advice. The thought was impious, yet 'tis odd to reflect that the confusion of Ptolemy's system gave occasion for the sin of that King. The good advice he would have given was, no doubt, for surpassing these different circles, which had so embarrassed the celestial motions, and it may be also with regard to the two or three superfluous spheres which they had placed above the fixed stars. The philosophers, to explain one kind of motion of the heavenly bodies, did fancy a sphere of crystal above that heaven which we see, which set the inferior heaven on motion; and if anyone made a new discovery of any other motion, they immediately made a new sphere of crystal. In short, these crystalline heavens cost them nothing."

"But why spheres of crystal?" said Madam the Marchioness. "Would no other substance serve?"

"No," said I. "For there was a necessity of their being transparent, that the light might penetrate, as it was requisite for them to be solid beams. Aristotle had found out that solidity was inherent in the excellency of their nature. And because he said it, nobody would adventure to question the

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truth of it. But there have appeared comets, which we know to have been vastly higher from the earth than was believed by the ancients. These in their course would have broken all those crystal spheres, and indeed must have ruined the universe; so that there was an absolute necessity to believe the heavens to be made of fluid substance. At least 'tis not to be doubted from the observation of this and the last age, that Venus and Mercury move round the sun and not round the earth. So that the ancient system is not to be defended as to this particular. But I will propose one to you which solves all objections, and which will put the King of Arragon out of a condition of advising; and which is so surprisingly simple and easy that that good quality alone ought to make it preferable to all others."

"Methinks," said Madam the Marchioness, "that your philosophy is a kind of sale, or farm, where those that offer to do the affair at the smallest expense are preferred."

"'Tis very true," said I, "and 'tis only by that that we are able to guess at the scheme upon which Nature hath framed her work. She is very saving, and will take the shortest and cheapest way. Yet notwithstanding, this frugality is accompanied with a most surprising magnificence which shines in all she has done. But the magnificence is in the design, and the economy in the execution. And indeed there is nothing finer than a great design carried on with a little expense. But we are very apt to overturn all these operations of nature by contrary ideas. We put economy in the design, and magnificence in the execution. . . ."

"I shall be very glad," said she, "that this system you are to speak of will imitate nature so exactly. For this good husbandry will turn to the advantage of my understanding, since by it I shall have less trouble to comprehend what you have to say."

"There is in this system no more unnecessary difficulties. Know then that a certain German [sic] named Copernicus does at one blow cut off all these different circles and crystalline spheres invented by the ancients, destroying the one and breaking the other in pieces; and being inspired with a noble astronomical fury, takes the earth and hangs it at a vast distance from the center of the world, and sets the sun in its place, to whom that honor does more properly belong. The planets do no longer turn round the earth, nor do they any longer contain it in the circle they describe. And if they enlighten us, it is by chance, and because they find us in their way. All things now turn round the sun, among which the globe itself, to punish it for the long rest so falsely attributed to it before. And Copernicus has loaded the earth with all those motions formerly attributed to the other planets, having left this little globe none of all the celestial train, save only the moon, whose natural course it is to turn round the earth."

"Soft and fair!" said Madam the Marchioness. "You are in so great a rapture, and express yourself with so much pomp and eloquence, I hardly understand what you mean. You place the sun unmovable in the center of the universe. Pray, what follows next?"

In his reply the author sketches the solar system according to Copernicus. Moreover—contrary to most medieval interpretations but in keeping with the popular modern notion—he interprets Copernicus's displacement of the earth as if rejection of geocentrism implied rejection of anthropocentrism.

"Ah, but," said Madam the Marchioness, interrupting me, "you forget the moon."

"Do not fear," said I. "Madam, I shall soon find her again. The moon turns round the earth and never leaves it. And as the earth moves in the circle it describes round the sun, the moon follows the earth in turning round it. And if the moon do move round the sun, it is only because she will not abandon the earth."

"I understand you," said she. "I love the moon for staying with us when all the other planets have left us. And you must confess that your German, Copernicus, would have taken her from us too, had it been in his power. For I perceive by his procedure, he had no great kindness for the earth."

"I am extremely pleased with him," said I, "for having humbled the vanity of mankind, who had usurped the first and best situation in the universe. And I am glad to see the earth under the same circumstances with the other planets."

"That's very fine," said Madam the Marchioness. "Do you believe that the vanity of man places itself in astronomy, or that I am any way humbled, because you tell me the earth turns round the sun? I'll swear, I do not esteem myself one whit the less."

"Good Lord, Madam!" said I. "Do you think I can imagine you can be as zealous for a precedency in the universe as you would be for that in a chamber? No, Madam. The rank of places between two planets will never make such a bustle in the world as that of two ambassadors. Nevertheless, the same inclination that makes us endeavor to have the first place in a ceremony prevails with a philosopher, in composing his system, to place himself in the center of the world if he can. He is proud to fancy all things made for himself, and without reflection flatters his senses with this opinion, which consists purely in speculation."

"Oh," said Madam the Marchioness, "this is a calumny of your own invention against mankind, which ought never to have received Copernicus's opinion, since so easy and so humble."

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"Copernicus, Madam" said I, "himself was the most diffident of his own system, so that it was a long time before he would venture to publish it, and at last resolved to do it at the earnest entreaty of people of the first quality. But do you know what he did, the day they brought him the first printed copy of his book? That he might not be troubled to answer all the objections and contradictions he was sure to meet with, he wisely left the world, and died."

The author explains the usual objections concerning the imperceptibility of the movement of the earth by recourse to the usual analogy of a ship whose inhabitants do not perceive its absolute movement from place to place. His next task is to explain how the earth moves both around the sun and around its own axis.

"Pray, sir," said she, ". . . I understand very well how we imagine the sun describes that circle which indeed we ourselves describe. But this requires a whole year's time, when one would think the sun passes over our heads every day. How comes that to pass?"

"Have you not observed," said I, "that a bowl thrown on the earth has two different motions. It runs toward the jack to which it is thrown. And at the same time it turns over and over several times before it comes that length, so that you will see the mark that is on the bowl sometimes above, sometimes below. 'Tis just so with the earth. In the time it advances on the circle it makes round the sun in its yearly course, it turns over once every four and twenty hours upon its own axis; so that in space of time, which is one natural day, every point of the earth (which is not near the South or North Poles) loses and recovers the sight of the sun. And as we turn towards the sun we imagine the sun is rising upon us, so when we turn from it we believe she is setting."

"This is very pleasant," said Madam the Marchioness. "You make the circle to do all, and the sun to stand idle. And when we see the moon, planets, and fixed stars turn round us in four and twenty hours, all is but bare imagination."

"Nothing else," said I, "but pure fancy."

In the second night of conversation, the author moves very quickly to speculation concerning the moon. Building on the likeness of the moon to the earth, and upon their reciprocity as concerns reflected light, he unfolds the idea that the moon too is inhabited.

"Well," said I, "since the sun . . . is now immoveable, and no longer a planet, and that the earth that moves round the Sun is now one, be not surprised if I tell you, the moon is another earth, and is by all appearances inhabited."

Said she, "I never heard of the moon's being inhabited but as a fable."

"So it may be still," said I. ". . . I will tell you my reasons that make me take part with the inhabitants of the moon. Suppose, then, there had never been any commerce between Paris and St. Denis, and that a citizen of Paris, who had never been out of that city, should go up to the top of the steeple of Our Lady and should view St. Denis at a distance, and one should ask him if he believed St. Denis to be inhabited. He would answer boldly, 'Not at all, for I see the inhabitants of Paris, but I do not see those of St. Denis, nor ever heard of 'em.' It may be somebody standing by would represent to him that it was true, one could not see the inhabitants of St. Denis from Our Lady's church, but that the distance was the cause of it; yet that all we could see of St. Denis was very like to Paris. For St. Denis had steeples, houses, and walls; and that it might resemble Paris in everything else, and be inhabited as well as it. All these arguments would not prevail upon my citizen, who would continue still obstinate in maintaining that St. Denis was not inhabited, because he saw none of the people. The moon is our St. Denis and we the citizens of Paris that never went out of our town."

"Ah," interrupted Madam the Marchioness, "you do us wrong. We are not so foolish as your citizen of Paris. Since he sees that St. Denis is so like to Paris in everything, he must have lost his reason if he did not think it was inhabited. But for the moon, that's nothing like the earth."

"Have a care, Madam," said I, "what you say. For if I make it appear that the moon is in everything like the earth, you are obliged to believe that the moon is inhabited."

"I acknowledge," said she, "if you do that, I must yield. And your looks are so assured that you frighten me already. The two different motions of the earth, which would never have entered into my thoughts, make me very apprehensive of all you say. But is it possible that the earth can be an enlightened body as the moon is? For to resemble it, it must be so."

"Alas, Madam," said I, "to be enlightened is not so great a matter as you imagine, and the sun only is remarkable for that quality: 'Tis he alone that is enlightened of himself by virtue of his particular essence. But the other planets shine only as being enlightened by the sun. The sun communicates his light to the moon, which reflects it upon the earth, as the earth, without doubt, reflects it back again to the moon, since the distance from the moon to the earth is the same as from the earth to the moon."

What does mark a difference between the earth and the moon is the fact that the rotation of the moon is exactly coincident with the period of its revolution about the earth. This is why from earth we see but one side of the moon.

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"I shall never be satisfied," said Madam the Marchioness, "with the injury we do the earth in being too favorably engaged for the inhabitants of the moon unless you can assure me that they are as ignorant of their advantages as we are of ours, and that they take our earth for a star, without knowing that the globe they inhabit is one also."

"Be assured of that, Madam," said I, "that the earth appears to them to perform all the functions of a star. 'Tis true, they do not see the earth describe a circle round 'em, but that's all one. I'll explain to you what it is. That side of the moon which was turned towards the earth at the beginning of the world has continued towards the earth ever since, which still represents to us these same eyes, nose, and mouth, which our imaginations fancy we see composed of these spots, lights, and shadows which are the surface of the moon. Could we see the other half of the moon, 'tis possible our fancy would represent to us some other figure. This does not argue, but the moon turns however upon her own axis, and takes as much time to perform that revolution as she does to go round the earth in a month. But then, when the moon performs a part of her revolutions on her own axis, and that she ought to hide from us (for example) one cheek of this imaginary face, and appear to us in another position, she does at the same time perform as much of the circle she describes in turning round the earth. And though she is in a new point of sight or opposition as to us, yet she represents to us still the same cheek. So that the moon, in regard to the sun and the other planets, turns upon her own axis, but does not so as to the earth. The inhabitants of the moon see all the other planets rise and set in the space of fifteen days, but they see our earth always hanging in the same point of the heavens. This seeming immovability does not very well agree with a body that ought to pass for a planet. But the truth is, the earth is not in such perfection. Besides, the moon has a certain trembling quality which does sometimes hide a little of her imaginary face, and at other times shows a little of her opposite side. And no doubt but the inhabitants of the moon attribute this shaking to the earth, and believe we make a certain swinging in the heavens, like the pendulum of a clock."

"All these planets," said Madam the Marchioness, "are like us mortals, who always cast our own faults upon others: Says the earth, 'It is not I that turn round, 'tis the sun.' Says the moon, 'It is not I that tremble, 'tis the earth.' There are errors and mistakes everywhere."

Having learned to speak familiarly about the inhabitants of the moon, the author and the marchioness find it but a small step farther to imagine inhabitants of the other planets. In this way the by-now familiar speculations of extraterrestrial science fiction beckon.

"We, the inhabitants of the earth, are but one little family of the universe; we resemble one another. The inhabitants of another planet are another family, whose faces have another air peculiar to themselves. By all appearance, the difference increases with the distance, for could one see an inhabitant of the earth and one of the moon together, he would perceive less difference between them than between an inhabitant of the earth and an inhabitant of Saturn. Here (for example) we have the use of the tongue and voice, and in another planet it may be they only speak by signs. In another the inhabitants speak not at all. Here our reason is formed and made perfect by experience. In another place experience adds little or nothing to reason. Further off, the old know no more than the young. Here we trouble ourselves more to know what's to come than to know what's past. In another planet, they neither afflict themselves with the one nor the other; and 'tis likely they are not the less happy for that. Some say we want a sixth sense by which we should know a great many things we are now ignorant of. It may be the inhabitants of some other planet have this advantage, but want some of those other five we enjoy. It may be also that there are a great many more natural senses in other worlds, but we are satisfied with the five that are fallen to our share, because we know no better. . . ."

"Truly," said she, "I find not so much difficulty to comprehend these differences of worlds. My imagination is working upon the model you have given me. And I am representing to my own mind odd characters and customs for these inhabitants of the other planets. Nay more, I am forming extravagant shapes and figures for 'em."

By the fifth night, speculation has indeed taken wings, and the conversation between the author and the beautiful marchioness soars from the moon and the planets to the stars themselves. As with so much science fiction, this dialogue has a gentle undercurrent of satire directed at the inhabitants of our planet. And at the same time it registers in the respective responses of the marchioness and the author the two contrary emotions one may feel upon contemplating the immensity of the universe: a sense of philosophical humility at the smallness of oneself and of earthly things, and exhilaration at the grandeur of the cosmic prospect. Neither of these emotions eclipses the other emotion that has energized the author's efforts: love.

My lady Marchioness was very impatient to know what should become of the fixed stars.

"Can they be inhabited as the planets are?" said she to me. "Or are they not inhabited? What shall we make of 'em?"

"If you would take the pains, you could not fail to guess," said I. "Madam, the fixed stars cannot be less distant from the earth than fifty mil-

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"Do not I deceive myself?" cried out the Marchioness. "Do not I see whither you are going to lead me? Are you not about to tell me the fixed stars are so many suns, and that our sun is the center of a great *tourbillion* [or vortex], which turns round him? What hinders but a fixed star may be the center of a *tourbillion*, whirling or turning round it? Our sun has planets, which he enlightens. Why may not every fixed star have planets also?"

"I have nothing to answer, but what Phaedra said to Oenone, 'Tis you that have hit it.'"

"But," said she, "I see the universe to be so vast that I lose myself. I know not where I am, and having conceived nothing all this while. What is the universe thus divided into *tourbillions*, confusedly cast together? Is every fixed star the center of a *tourbillion*, and it may be full as big as our sun? Is it possible that all this immense space wherein our sun and planets have their revolution is nothing but an inconsiderable part of the universe? And that every fixed star must comprehend and govern an equal space with our sun? This confounds, afflicts, and frightens me."

"And for my part," said I, "it pleases and rejoices me. When I believed the universe to be nothing but this great azure vault of the heavens wherein the stars are placed, as it were so many golden nails or studs, the universe seemed to me too little and straight. I fancied myself to be confined and oppressed. But now when I am persuaded that this azure vault has a greater depth and vaster extent, and that 'tis divided into a thousand and a thousand different *tourbillions* or whirlings, I imagine I am at more liberty, and breathe a freer air; and the universe appears to me to be infinitely more magnificent. Nature has spared nothing in her production, and hath profusely bestowed her treasures upon a glorious work worthy of her. You can represent nothing so august to yourself as this prodigious number of *tourbillions*,

whose center is possessed by a sun, and that makes the planets turn round him. The inhabitants of the planets of any of these infinite *tourbillions* see from all sides the enlightened center of the *tourbillion* with which they are environed, but cannot discover the planets of another, who enjoy but a faint light, borrowed from their own sun, which it does not dart further than its own sphere or activity."

"You show me," said Madam the Marchioness, "so vast a prospect that my sight cannot reach to the end of it. I see clearly the inhabitants of our world. And you have plainly presented to my reason the inhabitants of the moon, and other planets of our *tourbillion* or whirlings. After this you tell me of the inhabitants of the planets of all the other *tourbillions*. I confess they seem to me to be sunk in so boundless a depth that whatever force I put upon my fancy, I cannot comprehend 'em by the expressions you made use of in speaking of 'em and their inhabitants. You must certainly call 'em the inhabitants of one of the planets of one of these infinite *tourbillions*. And what shall become of us in the middle of so many worlds, since the title you give to the rest agrees to this of ours? And for my part, I see the earth so dreadfully little that hereafter I shall scorn to be concerned for any part of it. And I admire why mankind are so very fond of power, so earnest after grandeur, laying design upon design, circumventing, betraying, flattering, and poorly lying, and are at all this mighty pains to grasp a part of the world they neither know nor understand, nor anything of these mighty *tourbillions*. For me, I'll lazily contemn it, and my carelessness shall have this advantage by my knowledge, that when anybody shall reproach me with my poverty, I will with vanity reply, 'Oh! You do not know what the fixed stars are.'" . . .

"As for me who know 'em," [said I,] "I am very sorry I can draw no advantage from that knowledge, which can cure nothing but ambition and disquiet—and none of these diseases trouble me. I confess a kind of weakness in love, a kind of frailty for what is delicate and handsome. This is my distemper, wherein the *tourbillions* are not concerned at all. The infinite multitude of other worlds may render this little in your esteem, but they do not spoil fine eyes, a pretty mouth, or make the charms of wit ever the less. These will still have their true value, still are a price in spite of all the worlds in the universe."

Thus love conquers all, even in a possibly infinite universe. Although the author goes on to discourse on the Milky Way—"an infinity of little fixed stars," an "ant-hill of stars, . . . seeds of worlds"—the dialogue concludes by returning (as befits its participants) to the gentle analogy between astronomical instruction and the persuasions of a lover.

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SOURCE: Bernard le Bouvier c
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"It is a strange thing," said Madam the Marchioness, laughing, "that love saves himself from all dangers, and there is no system or opinion can hurt him." . . .

"Madam," said I, "since we are always in the humor of mixing some little gallantries with our most serious discourses, give me leave to tell you that mathematical reasoning is in some things near akin to love. And you cannot allow the smallest favor to a lover, but he will soon persuade you to yield another, and after that a little more; and in the end [he] prevails entirely. So if you grant the least principle to a mathematician, he will instantly draw a consequence from it which you must yield also, and from that another, and then a third; and maugre your resistance, in a short time he will lead you so far that you cannot retreat. These two sorts of men, the lover and philosopher, always take more than is given 'em."

. . .

"Let us return yet more," said I, "and, if you please, make this subject no longer that of our discourse. Besides, you are arrived at the utmost bounds of heaven. . . . 'Tis sufficient for me to have carried your understanding as far as your sight can penetrate."

"What," cried out Madam the Marchioness, "have I the systems of all the universe in my head? Am I become so learned?"

"Yes, Madam, you know enough, and with this advantage, that you may believe all or nothing of what I have said, as you please. I only beg this as a recompense for my pains: that you will never look on the heavens, sun, moon, or stars, without thinking of me."

SOURCE: Bernard le Bouvier de Fontenelle, *A Discovery of New Worlds*, trans. Aphra Behn, London, 1688.

34

Into the Celestial Spaces

Isaac Newton

Isaac Newton (1642–1727) ranks with Copernicus and Einstein among principal shapers of our physical worldview. However, whereas we can appreciate Copernicus against the backdrop of Ptolemy, and Einstein against the backdrop of Newton, Newton himself may strike the average educated non-scientist as somewhat unremarkable. For our everyday physical conceptions are themselves so thoroughly Newtonian that, to us, Newton may sound merely as if he is expounding common sense. Today perhaps only a small proportion of people are aware, when they use terms such as inertia, mass, gravity, and centripetal or centrifugal force, that it was Newton who either coined these terms or else worked them into the definitions they still generally retain.

Newton indeed begins his Mathematical Principles of Natural Philosophy*—his* Principia*—with definitions, and in them we may glimpse something both of the spirit of the whole work, whose essence is mathematical and quantitative, and of its magisterial lucidity. It is precisely the abstract character of mathematics that allows Newton to move so deftly, almost imperceptibly, from air, snow, and dust, to planets; and from a bullet fired from a mountaintop, to the critical orbit of the moon.*

Definition I

The quantity of matter is the measure of the same, arising from its density and bulk conjointly.

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Thus air of a double density, in a double space, is quadruple in quantity; in a triple space, sextuple in quantity. The same thing is to be understood of snow, and fine dust or powders, that are condensed by compression or liquefaction, and of all bodies that are by any causes whatever differently condensed. I have no regard in this place to a medium, if any such there is, that freely pervades the interstices between the parts of bodies. It is this quantity that I mean hereafter everywhere under the name of body or mass. And the same is known by the weight of each body, for it is proportional to the weight, as I have found by experiments on pendulums, very accurately made. . . .

Definition II

The quantity of motion is the measure of the same, arising from the velocity and quantity of matter conjointly.

The motion of the whole is the sum of the motions of all the parts; and therefore in a body double in quantity, with equal velocity, the motion is double; with twice the velocity, it is quadruple.

Definition III

The* vis insita, *or innate force of matter, is a power of resisting, by which every body, as much as in it lies, continues in its present state, whether it be of rest, or of moving uniformly in a right line.

This force is always proportional to the body whose force it is and differs nothing from the inactivity of the mass, but in our manner of conceiving it. A body, from the inert nature of matter, is not without difficulty put out of its state of rest or motion. Upon which account, this *vis insita* may, by a most significant name, be called inertia *(vis inertiae)* or force of inactivity. But a body only exerts this force when another force, impressed upon it, endeavors to change its condition; and the exercise of this force may be considered as both resistance and impulse; it is resistance so far as the body, for maintaining its present state, opposes the force impressed; it is impulse so far as the body, by not easily giving way to the impressed force of another, endeavors to change the state of that other. Resistance is usually ascribed to bodies at rest, and impulse to those in motion; but motion and rest, as commonly con-

ceived, are only relatively distinguished; nor are those bodies always truly at rest, which commonly are taken to be so.

Definition IV

An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of uniform motion in a right line.

This force consists in the action only, and remains no longer in the body when the action is over. For a body maintains every new state it acquires, by its inertia only. But impressed forces are of different origins, as from percussion, from pressure, from centripetal force.

Definition V

A centripetal force is that by which bodies are drawn or impelled, or any way tend, towards a point as to a center.

Of this sort is gravity, by which bodies tend to the center of the earth; magnetism, by which iron tends to the loadstone; and that force, whatever it is, by which the planets are continually drawn aside from the rectilinear motions, which otherwise they would pursue, and made to revolve in curvilinear orbits. A stone, whirled about in a sling, endeavors to recede from the hand that turns it; and by that endeavor, distends the sling, and that with so much the greater force, as it is revolved with the greater velocity, and as soon as it is let go, flies away. That force which opposes itself to this endeavor, and by which the sling continually draws back the stone towards the hand, and retains it in its orbit, because it is directed to the hand as the center of the orbit, I call the centripetal force. And the same thing is to be understood of all bodies, revolved in any orbits. They all endeavor to recede from the centers of their orbits; and were it not for the opposition of a contrary force which restrains them to, and detains them in their orbits, which I therefore call centripetal, would fly off in right lines, with a uniform motion.

A projectile, if it was not for the force of gravity, would not deviate towards the earth, but would go off from it in a right line, and that with a uniform motion, if the resistance of the air was taken away. It is by its gravity that it is drawn aside continually from its rectilinear course, and made to deviate towards the earth, more or less, according to the force of its gravity,

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and the velocity of its motion. The less its gravity is, or the quantity of its matter, or the greater the velocity with which it is projected, the less will it deviate from a rectilinear course, and the farther it will go. If a leaden ball, projected from the top of a mountain by the force of gunpowder, with a given velocity, and in a direction parallel to the horizon, is carried in a curved line to the distance of two miles before it falls to the ground; the same, if the resistance of the air were taken away, with a double or decuple velocity, would fly twice or ten times as far. And by increasing the velocity, we may at pleasure increase the distance to which it might be projected, and diminish the curvature of the line which it might describe, till at last it should fall at the distance of 10, 30, or 90 degrees, or even might go quite round the whole earth before it falls; or lastly, so that it might never fall to the earth, but go forwards into the celestial spaces, and proceed in its motion in infinitum.

And after the same manner that a projectile, by the force of gravity, may be made to revolve in an orbit, and go round the whole earth, the moon also, either by the force of gravity, if it is endued with gravity, or by any other force that impels it towards the earth, may be continually drawn aside towards the earth, out of the rectilinear way which by its innate force it would pursue; and would be made to revolve in the orbit which it now describes; nor could the moon without some such force be retained in its orbit. If this force was too small, it would not sufficiently turn the moon out of a rectilinear course; if it was too great, it would turn it too much, and draw down the moon from its orbit towards the earth.

In a scholium (explanatory discussion) following his opening definitions, Newton lays out assumptions concerning the absoluteness of time and space that stood for more than two centuries, until Einstein undermined them with his theories of relativity.

Hitherto I have laid down the definitions of such words as are less known and explained the sense in which I would have them to be understood in the following discourse. I do not define time, space, place, and motion, as being well known to all. Only I must observe that the common people conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common.

1. Absolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external, and by another name is called duration. Relative, apparent, and common time

is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time, such as an hour, a day, a month, a year.

2. Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces, which our senses determine by its position to bodies and which is commonly taken for immovable space; such is the dimension of a subterraneous, an aerial, or celestial space, determined by its position in respect of the earth. Absolute and relative space are the same in figure and magnitude, but they do not remain always numerically the same. For if the earth, for instance, moves, a space of our air, which relatively and in respect of the earth remains always the same, will at one time be one part of the absolute space into which the air passes; at another time it will be another part of the same, and so, absolutely understood, it will be continually changed.
3. Place is a part of space which a body takes up and is, according to the space, either absolute or relative. I say a part of space, not the situation nor the external surface of the body. For the places of equal solids are always equal; but their surfaces, by reason of their dissimilar figures, are often unequal. . . .
4. Absolute motion is the translation of a body from one absolute place into another, and relative motion the translation from one relative place into another. Thus in a ship under sail, the relative place of a body is that part of the ship which the body possesses, or that part of the cavity which the body fills, and which therefore moves together with the ship; and relative rest is the continuance of the body in the same part of the ship, or of its cavity. But real, absolute rest is the continuance of the body in the same part of that immovable space in which the ship itself, its cavity, and all that it contains is moved. Wherefore, if the earth is really at rest, the body, which relatively rests in the ship, will really and absolutely move with the same velocity which the ship has on the earth. But if the earth also moves, the true and absolute motion of the body will arise partly from the true motion of the earth in immovable space, partly from the relative motion of the ship on the earth; and if the body moves also relatively in the ship, its true motion will arise partly from the true motion of the earth in immovable space, and partly from the relative motions as well of the ship on the earth as of the body in the ship; and from these relative motions will arise the relative motion of the body on the earth. . . .

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Newton crucially concedes that there may be no accessible criteria for determining time and space absolutely, but asserts that a true philosophical treatment of these topics requires a careful distinction between the absolute and the relative.

Absolute time, in astronomy, is distinguished from relative by the equation or correction of the apparent time. For the natural days are truly unequal, though they are commonly considered as equal and used for the measure of time. Astronomers correct this inequality that they may measure the celestial motions by a more accurate time. It may be that there is no such thing as an equable motion whereby time may be accurately measured. All motions may be accelerated and retarded, but the flowing of absolute time is not liable to any change. . . .

As the order of the parts of time is immutable, so also is the order of the parts of space. . . . But because the parts of space cannot be seen or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from the positions and distances of things from any body considered as immovable we define all places; and then, with respect to such places, we estimate all motions, considering bodies as transferred from some of those places into others. And so, instead of absolute places and motions, we use relative ones, and that without any inconvenience in common affairs. But in philosophical disquisitions we ought to abstract from our senses and consider things themselves, distinct from what are only sensible measures of them. For it may be that there is no body really at rest to which the places and motions of others may be referred.

And yet Newton does not entirely bend under the difficulty of determining absolute motion. The one criterion he considers reliable is that of centrifugal force. To take a modern (actual) example, an astronaut skilled in gymnastics conducts a perceptual experiment while on a space mission. Floating in a state of weightlessness, he tucks himself into a slow backwards somersault and, having done so, closes his eyes and imagines himself in a state of rest. When after a minute he opens his eyes, what he perceives *is the space capsule in a slow forward rotation about his stationary body. According to Newton, however, anything other than a very slow rotation would indicate which body is rotating absolutely, the astronaut or the capsule; for the parts of a body truly in motion about an axis will tend away from that axis. (See Feynman's discussion, Chapter 59.) Newton's own experiment demonstrating this principle is terrestrial, but it does not take him long to move from a bucket of water hanging by a rope to the planets in their orbits.*

The effects which distinguish absolute from relative motion are the forces of receding from the axis of circular motion. For there are no such forces in a circular motion purely relative; but in a true and absolute circular motion, they are greater or less according to the quantity of the motion.

If a vessel hung by a long cord is so often turned about that the cord is strongly twisted, then filled with water and held at rest together with the water, thereupon by the sudden action of another force it is whirled about the contrary way, and while the cord is untwisting itself the vessel continues for some time in this motion, the surface of the water will at first be plain, as before the vessel began to move. But after that the vessel, by gradually communicating its motion to the water, will make it begin sensibly to revolve and recede by little and little from the middle, and ascend to the sides of the vessel, forming itself into a concave figure (as I have experienced). And the swifter the motion becomes, the higher will the water rise, till at last, performing its revolutions in the same times with the vessel, it becomes relatively at rest in it. This ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water, which is here directly contrary to the relative, becomes known and may be measured by this endeavor. At first, when the relative motion of the water in the vessel was greatest, it produced no endeavor to recede from the axis; the water showed no tendency to the circumference, nor any ascent towards the sides of the vessel, but remained of a plain surface, and therefore its true circular motion had not yet begun. But afterwards, when the relative motion of the water had decreased, the ascent thereof towards the sides of the vessel proved its endeavor to recede from the axis; and this endeavor showed the real circular motion of the water continually increasing, till it had acquired its greatest quantity, when the water rested relatively in the vessel. And therefore this endeavor does not depend upon any translation of the water in respect of the ambient bodies, nor can true circular motion be defined by such translation.

There is only one real circular motion of any one revolving body, corresponding to only one power of endeavoring to recede from its axis of motion, as its proper and adequate effect. But relative motions in one and the same body are innumerable, according to the various relations it bears to external bodies, and, like other relations, are altogether destitute of any real effect, any otherwise than they may perhaps partake of that one only true motion. And therefore, in their system who suppose that our heavens, revolving below the sphere of the fixed stars, carry the planets along with them; the several parts of those heavens and the planets, which are indeed relatively at rest in their heavens, do yet really move. For they change their position one to another (which never happens to bodies truly at rest) and, being carried

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In 1692, Newton corresponded with the young classicist and clergyman Richard Bentley, who was preparing his Boyle lectures, later published as A Confutation of Atheism. *Bentley was collecting evidence for design in the universe as part of the theistic apologetic indicated by his title, and Newton lent his support. The following extracts from a letter dated December 10, 1692 are notable both for Newton's acceptance of an argument from design—which reappears in more recent discussions of the "fine-tuning" of the universe—and for clarifications he makes regarding the behavior of matter, given gravity, across space either finite or infinite. (Clearly, the prospect of a "big crunch" is the main thing standing behind his preference for infinite space.) Newton even glances briefly in the direction of issues related to cosmic evolution and "lumpiness" in the universe.*

As to your first query, it seems to me that if the matter of our sun and planets and all the matter of the universe were evenly scattered throughout all the heavens, and every particle had an innate gravity towards all the rest, and the whole space throughout which this matter was scattered was but finite, the matter on the outside of this space would, by its gravity, tend toward all the matter on the inside and, by consequence, fall down into the middle of the whole space and there compose one great spherical mass. But if the matter was evenly disposed throughout an infinite space, it could never convene into one mass; but some of it would convene into one mass and some into another, so as to make an infinite number of great masses, scattered at great distances from one to another throughout all that infinite space. And thus might the sun and fixed stars be formed, supposing the matter were of a lucid nature. But how the matter should divide itself into two sorts, and that part of it which is fit to compose a shining body should fall down into one mass and make a sun and the rest, which is fit to compose an opaque body, should coalesce, not into one great body, like the shining matter, but into many little ones; or if the sun at first were an opaque body like the planets, or the planets lucid bodies like the sun, how he alone should be changed into a shining body whilst all they continue opaque, or all they be changed into opaque ones whilst he remains unchanged, I do not think explicable by mere natural causes, but am forced to ascribe it to the counsel and contrivance of a voluntary Agent. . . .

In the rising energy of the second part of his letter to Bentley, signalled by the hypotaxis of his style, Newton conveys his awe and his enthusiasm regarding the engineering feats of his geometer God.

To your second query, I answer that the motions which the planets now have could not spring from any natural cause alone but were impressed by an intelligent Agent. For since comets descend into the region of our planets and here move all manner of ways, going sometimes the same way with the planets, sometimes the contrary way, and sometimes crossways, in planes inclined to the plane of the ecliptic and at all kinds of angles, it is plain that there is no natural cause which could determine all the planets, both primary and secondary, to move the same way and in the same plane, without considerable variation; this must have been the effect of counsel. Nor is there any natural cause which could give the planets those just degrees of velocity, in proportion to their distances from the sun and other central bodies, which were requisite to make them move in such concentric orbs about those bodies. Had the planets been as swift as comets, in proportion to their distances from the sun (as they would have been had their motion been caused by their gravity, whereby the matter, at the first formation of the planets, might fall from the remotest regions towards the sun), they would not move in concentric orbs, but in such eccentric ones as the comets move in. Were all the planets as swift as Mercury or as slow as Saturn or his satellites, or were their several velocities otherwise much greater or less than they are, as they might have been had they arose from any other cause than their gravities, or had the distances from the centers about which they move been greater or less than they are, with the same velocities, or had the quantity of matter in the sun or in Saturn, Jupiter, and the earth, and by consequence their gravitating power, been greater or less than it is, the primary planets could not have revolved about the sun nor the secondary ones about Saturn, Jupiter, and the earth, in concentric circles, as they do, but would have moved in hyperbolas or parabolas or in ellipses very eccentric. To make this system, therefore, with all its motions, required a cause which understood and compared together the quantities of matter in the several bodies of the sun and planets and the gravitating powers resulting from thence, the several distances of the primary planets from the sun and of the secondary ones from Saturn, Jupiter, and the earth, and the velocities with which these planets could revolve about those quantities of matter in the central bodies; and to compare and adjust all these things together, in so great a variety of bodies, argues that cause to be, not blind and fortuitous, but very well skilled in mechanics and geometry.

SOURCES: Isaac Newton, *Mathematical Principles of Natural Philosophy and His System of the World*, translated by Andrew Mott, revised by Florian Cajori, Berkeley: U of California P, 1934; *Four Letters from Sir Isaac Newton to Doctor Bentley*, London, 1756.

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Discernible Ends and Final Causes

Richard Bentley

The advent of Newtonian mechanics marked a sea change not only in physics itself but also in how physics was conceived in relation to religious issues such as belief in God and in divine providence. Late in 1692, Newton's correspondent Richard Bentley (1662–1742) delivered his Boyle lectures, A Confutation of Atheism from the Origin and Frame of the World. *In them he re-paints the "argument from design"—the traditional "proof" for the existence of God based on the order and fitness of the creation—on a Newtonian canvas. Facing the impediment both of ingrained Aristotelianism and of Cartesian rationalism, which deny the existence of empty space, Bentley finds himself defending a notion that for two millennia has been associated with the atomism of Democritus and Epicurus—not the sort of philosophical company he would normally mix in. Yet, for Newtonian gravity to work, there must be space between bodies.*

Since gravity is found proportional to the quantity of matter, there is a manifest necessity of admitting a vacuum, another principal doctrine of the Atomical philosophy. Because if there were everywhere an absolute plenitude and density without any empty pores and interstices between the particles of bodies, then all bodies of equal dimensions would contain an equal quantity of matter. . . .

From the point of view of modern cosmology, one of the most fascinating parts of Bentley's discussion is his attempt to grapple with the issue of the

density and distribution of matter in space. That average density *is today estimated at very roughly 10^{-30} grams/cm²; and that* distribution *is now discussed by cosmologists under headings such as cosmic "smoothness" and "lumpiness" (see Chapter 76). Bentley's calculations deal with size rather than mass, but his question concerning how a smooth, thin distribution of matter might have been transformed into a complex and lumpy universe has not disappeared from the cosmological scene.*

The sum of empty spaces within the concave of the firmament is 6860 million million million [6.86×10^{21}] times bigger than all the matter contained in it.

Now from hence we are enabled to form a right conception and imagination of the supposed [original] chaos; and then we may proceed to determine the controversy with more certainty and satisfaction, whether a world like the present could possibly without a divine influence be formed in it or no. . . .

As to the state or condition of matter before the world was a-making, which is compendiously expressed by the word "chaos," [our adversaries] must suppose that either all the matter of our system was evenly or well-nigh evenly diffused through the region of the sun (this would represent a particular chaos), or all matter universally so spread through the whole mundane space (which would truly exhibit a general chaos), no part of the universe being rarer or denser than another. Which is agreeable to the ancient description of it, that the heavens and earth had one form, one texture and constitution, which could not be unless all the mundane matter were uniformly and evenly diffused. It is indifferent to our dispute whether they suppose it to have continued a long time or very little in the state of diffusion. For if there was but one single moment in all past eternity when matter was so diffused, we shall plainly and fully prove that it could never have convened afterwards into the present frame and order of things.

Even if Bentley does not in fact prove the impossibility of chaos bringing forth cosmos, he does skeptically put the question of how it might do so, satirizing the materialistic alternative to his own view that God himself designed and carried out the ordering of things. A specific target of Bentley's scorn is the Cartesian notion of vortices or "whirlpools" (French: tourbillions*) of matter.*

We have now represented the true scheme and condition of the chaos: how all the particles would be disunited, and what vast intervals of empty space would lie between each. To form a system, therefore, it is necessary that these squandered atoms should convene and unite into great and compact masses

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like the bodies of the earth and planets. Without such a coalition the diffused chaos must have continued and reigned to all eternity. But how could particles so widely dispersed combine into that closeness of texture?

Our adversaries can have only these two ways of accounting for it. Either by the common motion of matter proceeding from external impulse and conflict (without attraction) by which every body moves uniformly in a direct line according to the determination of the impelling force. For, they may say, the atoms of the chaos being variously moved according to this catholic law, must needs knock and interfere, by which means some that have convenient figures for mutual coherence might chance to stick together, and others might join to those, and so by degrees such huge masses might be formed as afterwards became suns and planets. Or there might arise some vertiginous motions or whirlpools in the matter of chaos, whereby the atoms might be thrust and crowded to the middle of those whirlpools, and there constipate one another into great solid globes, such as now appear in the world.

In part 2 of his sermon, Bentley summarizes the design argument and considers the ends for which creation was brought into being. In attempting to defend his position against possible charges of anthropocentrism, he speculates about rational life elsewhere in the universe.

The order and beauty of the systematical parts of the world, the discernible ends and final causes of them, the meliority above what was necessary to be, do evince by a reflex argument that it could not be produced by mechanism or chance, but by an intelligent and benign agent that by his excellent wisdom made the heavens.

But . . . we must offer one necessary caution: that we need not nor do not confine and determine the purposes of God in creating all mundane bodies merely to human ends and uses. Not that we believe it laborious and painful to Omnipotence to create a world out of nothing, or more laborious to create a great world than a small one, so as we might think it disagreeable to the majesty and tranquility of the Divine Nature to take so much pains for our sakes. Nor do we count it any absurdity that such a vast and immense universe should be made for the sole use of such mean and unworthy creatures as the children of men. For if we consider the dignity of an intelligent being and put that in the scales against brute inanimate matter, we may affirm without overvaluing human nature that the soul of one virtuous and religious man is of greater worth and excellency than the sun and his planets and all the stars in the world. . . . If all the heavenly bodies were thus serviceable to us, we should not be backward to assign their usefulness to mankind as the sole end of their creation. But we dare not undertake to show what advantage is brought to us by those innumerable stars in the galaxy and other parts of the

firmament not discernible by naked eyes, and yet each many thousand times bigger than the whole body of the earth. If you say, they beget in us a great idea and veneration of the mighty Author and Governor of such stupendous bodies, and excite and elevate our minds to his adoration and praise, you say very truly and well. But would it not raise in us a higher apprehension of the infinite majesty and boundless beneficence of God to suppose that those remote and vast bodies were formed not merely upon our account to be peeped at through an optic glass, but for different ends and nobler purposes?

And yet who will deny but that there are great multitudes of lucid stars even beyond the reach of the best telescopes, and that every visible star may have opaque planets revolve about them, which we cannot discover? Now if they were not created for our sakes, it is certain and evident that they were not made for their own. For matter has no life nor perception, is not conscious of its own existence, nor capable of happiness, nor gives the sacrifice of praise and worship to the Author of its being. It remains, therefore, that all bodies were formed for the sake of intelligent minds. And as the earth was principally designed for the being and service and contemplation of men, why may not all other planets be created for the like uses, each for their own inhabitants which have life and understanding?

If any man will indulge himself in this speculation, . . . the Holy Scriptures do not forbid him to suppose as great a multitude of systems and as much inhabited as he pleases. . . . [We need not] be solicitous about the condition of those planetary people, nor raise frivolous disputes, how far they may participate in the miseries of Adam's fall, or in the benefits of Christ's incarnation. As if, because they are supposed to be rational they must needs be concluded to be men. For what is man? . . . God almighty by the inexhausted fecundity of his creative power may have made innumerable orders and classes of rational minds, some higher in natural perfections, others inferior to human souls. . . . God . . . may have joined immaterial souls, even of the same class and capacities in their separate state, to other kinds of bodies and in other laws of union . . . . So that we ought not upon any account to conclude that if there be rational inhabitants in the moon or Mars or any unknown planets of other systems, they must therefore have human nature, or be involved in the circumstances of our world. And thus much was necessary to be here inculcated (which will obviate and preclude the most considerable objections of our adversaries) that we do not determine the final causes and usefulness of the systematical parts of the world merely as they have respect to the exigencies or conveniences of human life.

SOURCE: Richard Bentley, *A Confutation of Atheism from the Origin and Frame of the World*, London, 1693.

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The Planetarians, and This Small Speck of Dirt

Christiaan Huygens

Christiaan Huygens (1629–1695), an acquaintance of Descartes, Pascal, Leibniz, and (briefly) Newton, lived for many years in Paris and, though a Dutchman, became a founding member of the French Academy of Sciences. Huygens's contribution to descriptive astronomy is based largely on practical improvements he himself pioneered in the construction of telescopes. In 1659, Huygens published Systema Saturnium, *in which he described the shape of the rings of Saturn; he is also credited with founding the wave theory of light and discovering the usefulness of the pendulum as a regulator of clocks.*

Huygens's posthumous Cosmotheoros, *published in Latin in 1698 and translated into English the same year under the title* The Celestial Worlds Discovered, *is a retrospective and speculative work addressed familiarly to Huygens's brother Constantine.*

A man that is of Copernicus's opinion, that this earth of ours is a planet carried round and enlightened by the sun like the rest of them, cannot but sometimes have a fancy that it's not improbable that the rest of the planets have their dress and furniture, nay and their inhabitants too as well as this earth of ours: especially if he considers the later discoveries made since Copernicus's time of the attendants of Jupiter and Saturn, and the champaign and hilly countries in the moon, which are an argument of a relation and kin between our earth and them, as well as a proof of the truth of that system.

This has often been our talk, I remember, good brother, over a large telescope, when we have been viewing those bodies . . . . But we were always apt to conclude that 'twas in vain to enquire after what nature had been pleased to do there, seeing there was no likelihood of ever coming to an end of the enquiry. Nor could I ever find that any philosophers, those bold heroes either ancient or modern, ventured so far. At the very birth of astronomy, when the earth was first asserted to be spherical and to be surrounded with air, even then there were some men so bold as to affirm there were an innumerable company of worlds in the stars. But later authors such as Cardinal Cusanus, Brunus, Kepler (and if we may believe him, Tycho was of that opinion too) have furnished the planets with inhabitants. . . . Some of them have coined some pretty fairy stories of the men in the moon, just as probable as Lucian's true history; among which I must count Kepler's, which he has diverted us with in his Astronomical Dream.

But a while ago, thinking somewhat seriously of this matter . . . methought the enquiry was not so impracticable, nor the way so stopped up with difficulties, but that there was very good room left for probable conjectures. As they came into my head I clapped them down into commonplaces and shall now try to digest them into some tolerable method for your better conception of them, and add somewhat of the sun and fixed stars, and the extent of that universe of which our earth is but an inconsiderable point.

In Huygens's musings we see the confluence of important themes both of mature Copernicanism and of what would come to be called Enlightenment thought. The isotropic world of Galileo—in which there are mountains on the moon just as there are on the earth, and in which earthshine brightens the dark side of the moon even as moonshine brightens our night—is one that invites us to extrapolate from what we know on earth to other worlds. Huygens refers explicitly to such analogies as the basis of "our method in this treatise, wherein, from the nature and circumstances of that planet which we see before our eyes, we may guess at those that are farther distant from us." The result, perhaps predictably, is cosmological speculation that is often stunningly anthropocentric or geocentric, though of course no longer in any narrowly geometrical sense. This central paradox of self-professing Copernicanism—the simultaneous reduction of the earth to a mere peripheral point and *its elevation as the measure of all things—is in Huygens complicated and complemented by Leibnizian themes such as the principle of plenitude and the (logical) plurality of worlds.*

In offering what at first appears a standard declaration that astronomical study does not conflict with scriptural teaching, Huygens lays the foundation

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[The critics] have been answered so often that I am almost ashamed to repeat it: that it's evident God had no design to make a particular enumeration in the Holy Scriptures of all the works of his creation. When therefore it is plain that under the general name of *stars* and *earth* are comprehended all the heavenly bodies, even the little gentlemen round Jupiter and Saturn, why must all that multitude of beings which the almighty creator has been pleased to place upon them be excluded the privilege, and not suffered to have a share in the expression? And these men themselves can't but know in what sense it is that all things are said to be made for the use of man, not certainly for us to stare or peep through a telescope at, for that's little better than nonsense. Since then the greatest part of God's creation, that innumerable multitude of stars, is placed out of the reach of any man's eye, and many of them, it's likely, of the best glasses, so that they don't seem to belong to us; is it such an unreasonable opinion that there are some reasonable creatures who see and admire those glorious bodies at a nearer distance?

The more speculative Huygens's enquiry becomes, the more pronounced and careful is his defense of its utility and piety.

I must acknowledge still that what I here intend to treat of is not of that nature as to admit of a certain knowledge. I can't pretend to assert anything as positively true (for that would be madness) but only to advance a probable guess, the truth of which every one is at his own liberty to examine. If any one therefore shall gravely tell me, that I have spent my time idly in a vain and fruitless enquiry after what by my own acknowledgment I can never come to be sure of, the answer is that at this rate he would put down all natural philosophy as far as it concerns itself in searching into the nature of things. In such noble and sublime studies as these, 'tis a glory to arrive at probability, and the search itself rewards the pains. But there are many degrees of probable, some nearer truth than others, in the determining of which lies the chief exercise of our judgement.

But besides the nobleness and pleasure of the studies, may not we be so bold as to say, they are no small help to the advancement of wisdom and morality? So far are they from being of no use at all. For here we may mount from this dull earth and, viewing it from on high, consider whether Nature has laid out all her cost and finery upon this small speck of dirt. So, like travellers into other distant countries, we shall be better able to judge of what's

done at home, know how to make a true estimate of, and set its own value upon everything. We shall be less apt to admire what this world calls great, shall nobly despise those trifles the generality of men set their affections on, when we know that there are a multitude of such earths inhabited and adorned as well as our own. And we shall worship and reverence that God, the maker of all these things; we shall admire and adore his providence and wonderful wisdom which is displayed and manifested all over the universe, to the confusion of those who would have the earth and all things formed by the shuffling concourse of atoms.

After a long discussion supporting the claim that the planets are provided with water, plants, animals, and other "furniture" such as the earth is fitted out with, Huygens addresses the issue of "spectators," and, surprisingly, appears to declare unanimity among those who have addressed it. Again the premises of the argument seem utterly torn between anthropocentrism and an impulse to reject it.

But still the main and most diverting point . . . is the placing some spectators in these new discoveries, to enjoy these creatures we have planted them with, and to admire their beauty and variety. And among all that have never so slightly meddled with these matters I don't find any that have scrupled to allow them their inhabitants: not men perhaps like ours, but some creatures or other endued with reason. For all this furniture and beauty the planets are stocked with seem to have been made in vain, without design or end, unless there were some in them that might at the same time enjoy the fruits and adore the wise Creator of them.

But this alone would be no prevailing argument with me to allow them such creatures. For what if we should say, that God made them for no other design but that he himself might see . . . and delight himself in the contemplation of them? . . . That which makes me of this opinion, that those worlds are not without such a creature endued with reason, is that otherwise our earth would have too much the advantage of them, in being the only part of the universe that could boast of such a creature so far above not only plants and trees but all animals whatsoever: a creature that has a divine somewhat within him, that knows, and understands, and remembers such an innumerable number of things; that deliberates, weighs and judges the truth; a creature upon whose account and for whose use whatsoever the earth brings forth seems to be provided. . . . If we should allow Jupiter a greater variety of other creatures, more trees, herbs and metals, all these would not advantage or dignify that planet so much as that one animal doth ours by the admirable productions of his penetrating wit.

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Whereas previous ages may have posited that nonhuman rational creatures, angels in particular, dwell in or preside over the heavenly spheres—humankind, a little lower than the angels but lower nonetheless, being quarantined in the fallen realm, within the sublunary sphere—Huygens postulates extraterrestrials possessing even human vices. Moreover, armed with Leibnizian "optimism," including an instrumental view of evil as component of a greater good, he minimizes the seriousness of such moral evil within the scheme of the universe as a whole.

Nor let anyone say here that there's so much villainy and wickedness in this man that we have thus magnified, that it's a reasonable doubt whether he would not be so far from being the glory and ornament of the planet that enjoys his company that he would be rather its shame and disgrace. For first, the vices that most men are tainted with are no hindrance, but that those that follow the dictates of true reason and obey the rules of a rigid virtue are still a beauty and ornament to the place that has the happiness to harbor them. Besides, the vices of men themselves are of excellent use, and are not permitted and allowed in the world without wise design. . . . Virtues themselves . . . would be of no use if there were no dangers, no adversity, no afflictions for their exercise and trial.

If we should therefore imagine in the planets some such reasonable animal as man is, adorned with the same virtues and infected with the same vices, it would be so far from degrading or vilifying them that, while they want such a one, I must think them inferior to our earth.

Well, but allowing these planetarians some sort of reason, must it needs be the same with ours? Why, truly I think 'tis, and must be so, whether we consider it as applied to justice and morality, or exercised in the principles and foundations of science. For reason with us is that which gives us a true sense of justice and honesty, praise, kindness, and gratitude; 'tis that that teaches us to distinguish universally between good and bad, and renders us capable of knowledge and experience in it. And can there be anywhere a reason contrary to this, or can what we call just and generous in Jupiter on Mars be thought unjust villainy? This is not at all, I don't say probable, but possible.

Near the end of his little book, Huygens returns from speculation to retrospective reflection upon the early history of Copernicanism; and to a degree he criticizes, while trying to explain the motivations for, some of his predecessors' opinions. One may be tempted to adapt his concluding comment on Kepler as an appropriate appraisal of some aspects of Huygens's own work.

Before the invention of telescopes it seemed to contradict Copernicus's opinion to make the sun one of the fixed stars. For the stars of the first magnitude being esteemed to be about three minutes diameter, and Copernicus (observing that though the earth changed its place, they always kept the same distance from us) having ventured to say that the *magnus orbis* [the "great circle"] was but a point in respect of the sphere in which they were placed, it was a plain consequence that every one of them that appeared anything bright must be larger than the path or orbit of the earth, which is very absurd. This is the topping argument that Tycho Brahe set up against Copernicus. But when the telescopes shaved them of their fictitious rays, and showed them to us bare and naked (which they do best when the eye-glass is blacked with smoke) just like little shining points, then that difficulty vanished, and the stars might still be suns. Which is the more probable, because their light is certainly their own: for it's impossible that ever the sun should send or they reflect it at such a vast distance.

This is the opinion that commonly goes along with Copernicus's system. And the patrons of it do also with reason suppose that all these stars are not in the same sphere, as well because there's no argument for it, as that the sun, which is one of them, cannot be brought to this rule. But it's more likely they are scattered and dispersed all over the immense spaces of the heaven, and are as far distant perhaps from one another as the nearest of them are from the sun.

Here again too I know Kepler is of another opinion. . . . For though he agrees with us that the stars are diffused through all the vast profundity, yet he cannot allow that they have as large an empty space about them as our sun has. . . . But Kepler had a private design in making the sun thus superior to all the other stars, and planting it in the middle of the world, attended with planets, a favor that he did not desire to grant the rest. For his aim was by it to strengthen his Cosmographical Mystery, that the distances of the planets from the sun are in a certain proportion to the diameters of the spheres that are inscribed within, and circumscribed about Euclid's polyhedrical bodies. Which could never be so much as probable except there were but one chorus of planets moving round the sun, and so the sun were the only one of his kind.

But the whole Mystery is nothing but an idle dream taken from Pythagoras or Plato's philosophy . . . a mere fancy without any shadow of reason. I cannot but wonder how such things as these could fall from so ingenious a man, and so great an astronomer.

SOURCE: Christiaan Huygens, *The Celestial Worlds Discovered*, London, 1698.