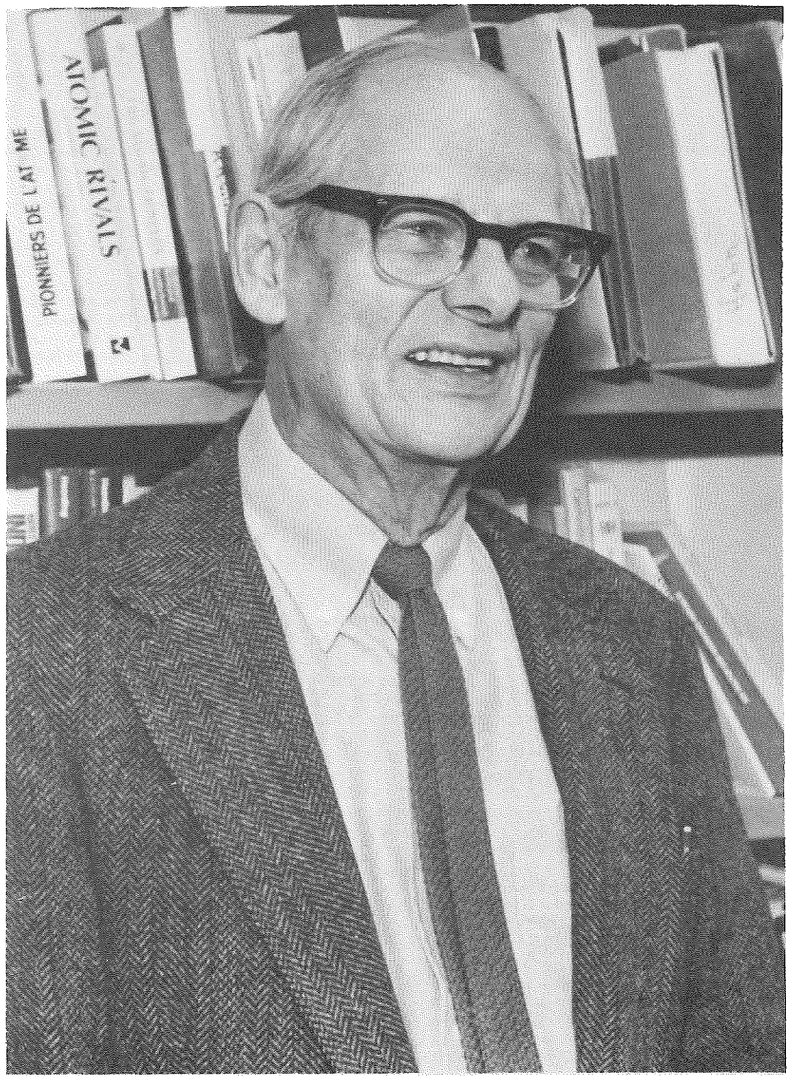

ERWIN N. HIEBERT

THE INVENTION OF PHYSICAL SCIENCE

Intersections of Mathematics, Theology and Natural Philosophy Since the Seventeenth Century

Essays in Honor of Erwin N. Hiebert

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SARA SCHECHNER GENUTH

DEVILS' HELLS AND ASTRONOMERS' HEAVENS: RELIGION, METHOD, AND POPULAR CULTURE IN SPECULATIONS ABOUT LIFE ON COMETS

According to eighteenth-century astronomical theory, comets were opaque, spherical, solid bodies shining by reflected light and revolving in elliptical orbits around the sun. The perceived similarities between them and the planets raised the question of their fitness for habitation. At the heart of this question was a tension among natural theology, scientific reasoning, and popular culture. Theology played a role in suggesting how the existence of extraterrestrial life was to God's credit, and its natural side sought to divine the Lord's purposes in populating the heavenly bodies. Scientific reasoning played a role in posing what that life might be like, given the material and biological conditions assumed to inhere on the heavenly bodies by analogy with the earth. And popular culture shaped the way that rules of reasoning and natural theology were applied to the case of comets. Before turning our attention to speculations about cometarians, let us examine the doctrine of the plurality of worlds with its religious and methodological underpinnings.

Though rooted in antiquity, the idea of the plurality of worlds was given new force in the seventeenth century by work in astronomy and natural history. Pointed skyward, telescopes revealed mountains standing on the moon and satellites orbiting around Jupiter and Saturn. The analogy between the earth and planets encouraged further comparison of the sun to the fixed stars, and stars soon became seen as other suns surrounded by their own planetary retinues. Pointed earthward, microscopes revealed that the smallest drops of water were crowded with minute creatures. This discovery led natural philosophers to ask why should the vast planets remain barren if nature was so fecund here. Were we not ascribing wastefulness to God if we thought he had squandered those opportunities to populate the celestial globes? Was it not more consistent with the doctrine of divine omnipotence and benevolence to maintain that God created innumerable worlds? These thoughts were expressed by Bernard le Bovier de Fontenelle in his lively and highly popular *Entretiens sur la pluralité des mondes* (1st edition, 1686). He endorsed the plurality of worlds for five reasons:

M. J. Nye et al. (eds.), The Invention of Physical Science, 3–26.

[1] The total resemblance of the planets to the earth which is inhabited; [2] the impossibility of imagining any other use for which they were made; [3] the fecundity and magnificence of nature; [4] the consideration she seems to have had for the needs of their inhabitants, as having given moons to planets remote from the sun, and more moons to those more remote; and [5] this which is very important, that everything is in its favor, and nothing is against it.[1]

Fontenelle's reasons were by no means original and to a great extent they hinged on what Arthur Lovejoy has termed the "principle of plenitude" – i.e., the doctrine that "no genuine potentiality of being can remain unfulfilled, that the extent and abundance of creation must be as great as the possibility of existence and commensurate with the productive capacity of a 'perfect' and inexhaustible Source, and that the world is the better, the more things it contains."[2] Tied to this principle of plenitude was a conception of teleology or final causes within the universe. All things were created for a purpose. Sacred texts such as Psalm 8 affirmed that the earth and its creatures existed for the sake of man, but were silent on the purpose of the stars, the planets, and their satellites. It was sheer hubris, however, to say that the dimmest of these, some visible only by means of a telescope, were created for man's benefit too, for that would imply that God did much in vain. If planets and stars were of no use to men, then, by parity of reason, they were created to serve their own inhabitants or those in their neighborhood.[3]

In making the case for pluralism, natural philosophers made much use of the methods that were codified by Isaac Newton in his "Rules of Reasoning in Philosophy." Newton's first rule was the principle of simplicity tinged with teleology: "We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances. To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve." His second rule expressed the uniformity of nature: "To the same natural effects we must, as far as possible, assign the same causes." Newton applied this rule "to respiration in a man and in a beast; the descent of stones in *Europe* and in *America*; the light of our culinary fire and of the sun; the reflection of light in the earth, and in the planets." By way of justification for the principle of uniformity, Newton referred to the "analogy of nature, which is wont to be simple, and always consonant to itself." This explanatory statement was attached to Newton's third rule, which concerned analogical reasoning and universal qualities.[4] Following these premises of simplicity, uniformity, and analogy, and guided by empiricism whenever possible, the natural philosopher in theory was to feel secure in applying the physical laws governing terrestrial events to celestial phenomena.

Since the nature of cometary life was not open to direct inspection, the authors to be discussed in this paper often relied on these simple rules to guide them in comparing comets to the earth. Their speculations highlight the degree of latitude afforded by the rules and the pitfalls in trying to apply them in a case where there were few empirical controls. Of the principles of simplicity, uniformity, and analogy, analogy generated the most controversy in its practical application. First, in comparing comets to the earth, natural philosophers had to weigh the relative importance of likenesses and differences. Everyone agreed that the earth's nearly circular orbit was quite unlike those of the comets, which traveled in elongated ellipses, parabolas, and sometimes hyperbolas that were angled every which way to the ecliptic, but they disagreed on whether this made any difference in terms of their habitability. Ideally, it would have been prudent to establish a firm foundation on agreed physical or metaphysical preconditions before ascending the ladder of analogy, but as our case study of comets will show, there was little consensus on the selection of dependent and independent variables, or on whether an appropriate goal of analogy was to reason from form to function, or from function to form.

Among those who disregarded orbital characteristics, some were prompted by perceptions of similar physical forms (e.g., of comparable atmospheres) to advocate an analogy of function (e.g., to sustain life); conversely, others were led by their metaphysical belief in the uniformity of function (e.g., to sustain life) to posit the existence of analogous physical forms (e.g., atmospheres) on comets. Among those who factored in the stresses that orbits of different shape would introduce (e.g., by exposure to extremes of hot and cold), some concluded that though comets might be composed of matter similar to the earth, their functions could not be the same; others were led by their belief in analogous functions to conclude that the physical composition or life-forms had to be different in order to survive the stresses caused by the orbits. Here we have four possible arguments backed up by little or no tangible evidence. One consequence of such methodological ambiguity was the disagreement over whether comets were places of torment or delight. As this paper will suggest, the choice between hell and heaven was influenced by religious tenets and vestiges of folk beliefs.

WANDERING HELLS

The plurality-of-worlds view gained momentum during the course of the seventeenth century. After Fontenelle, the view was forthrightly advanced by Christiaan Huygens, quietly intimated by Isaac Newton, and propounded by Richard Bentley and John Ray.[5] In the *Astro-Theology* of William Derham, F.R.S., chaplain to the future king, George II, and Boyle Lecturer, the hypothesis was touted highly. Derham supported the "New Systeme" of the world, which "supposeth [that] there are many other Systemes of *Suns* and *Planets*, besides that in which we have our residence: namely, that every Fixt Star is a Sun, and encompassed with

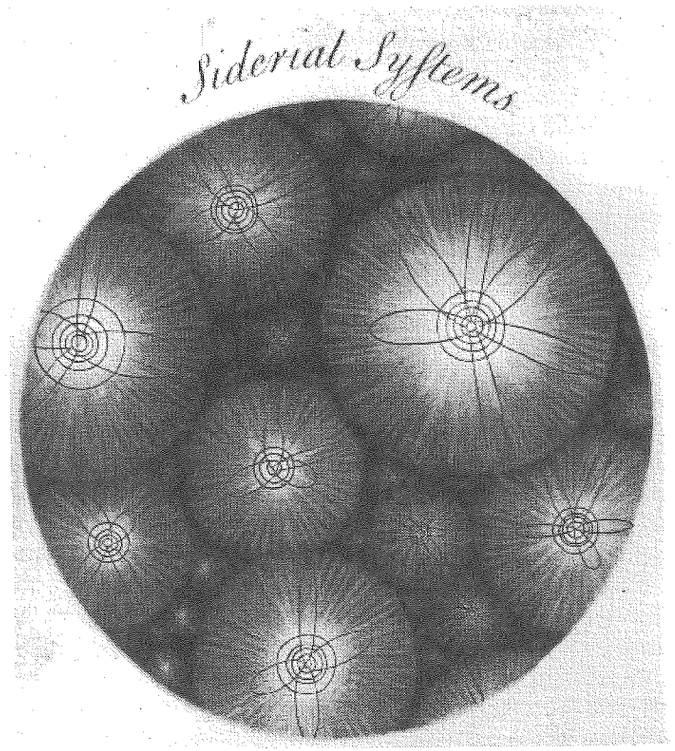

Fig. 1. Newtonian plurality of worlds. James Ferguson, *An Idea of the Material Universe* (London: 1754). [By permission of the Houghton Library, Harvard University.]

a Systeme of Planets, both Primary and Secondary, as well as ours." All planets, Derham judged, were "places as accommodated for Habitation, so stocked with proper Inhabitants" because myriads of systems befitted an infinite, glorious Creator.[6] It was perhaps due to the credentials of Derham that his pluralistic view became sanctioned and adopted by the majority of eighteenth-century natural philosophers.

Comets were a challenge to the pluralists. Once Newton and Edmond Halley had convinced natural philosophers that comets were members of the solar system, it was logical to compare their sizes, material composition, and atmospheres with the planets, and by extension, their habitability. But as Derham observed, their elliptical orbits differed greatly from those of the planets, indicating that their uses might differ as well.[7] Scorched and frozen in turns, they seemed unlikely abodes of happy creatures. Therefore, Derham thought that God appointed "such noxious Globes for the Executioners of his Justice, to affright and chastize sinful men at their approaches to the Earth, (and as some have imagined) to be the place of their Habitation and Torment after death."[8]

Here Derham, I suspect, alluded to the thought of Dr. George Cheyne. In a work on natural religion, Cheyne had noted that atmospheric conditions of comets created environments hostile to life as we know it on earth:

> These *Comets* sometimes come so near the *Sun*, as to be heated to such a Degree that they cannot become cool again, in many Thousands of Years. This with its violent Motion in a *Curve*, which comes near to a streight Line, after it has pass'd its *Perihelium*, and the irregular Disposition of the confuss'd Mass of its *Atmosphere*, makes it an unfit Habitation for Animals, that are not in a state of Punishment, so far as we can conceive of the Nature of Animals.[9]

William Whiston concurred, writing:

> The external Regions of Comets, which by passing through such immense Heat when nearest, and such prodigious Cold when farthest off the Sun; and by the confused and Chaotick State of their Atmospheres, do evidentally appear incapable of affording convenient Habitations for any Beings that have Bodies, or Corporeal Vehicles, whether visible or invisible to us.[10]

With respect to habitability, comets were "design'd for very different Purposes from the Planets," Whiston and Cheyne concluded.[11] Unable or unwilling to imagine new forms of life suited to hostile cometary climates, they seized on comets as the sites of hell.

The theory had much to recommend it. Cheyne noted that it accommodated the philosophical rule of simplicity, for nothing in nature was

wasted, nothing was in vain. From comets "we may learn that the *Divine Vengeance* may find a seat for the punishment of his Disobedient Creatures, without being put to the Expense of a new Creation."[12] It was economical and resourceful for God to use comets as hell. Whiston delighted in the theory's compatibility will both science and scripture:

> I observe, that the Sacred Accounts of *Hell*, or of the Place and State of Punishment for wicked Men after the general Resurrection, is agreeable not only to the Remains of ancient profane Tradition, but to the true System of the World also. This sad State is in Scripture describ'd as a State of *Darkness*, of *outward Darkness*, of *blackness of Darkness*, of *Torment* and *Punishment for Ages, or for Ages of Ages, by Flame*, or *by Fire*, or *by Fire and Brimstone, with Weeping and Gnashing of Teeth*; where *the Smoak of the* Ungodly's *Torment ascends up for ever and ever*; where they are Tormented *in the Presence of the Holy Angels, and in the Presence of the Lamb*; *when the Holy Angels shall have separated the Wicked from among the Just, and have cast them into a Furnace of Fire.* Now this Description does in every Circumstance, so exactly agree with the Nature of a Comet, ascending from the Hot Regions near the Sun, and going into the Cold Regions beyond *Saturn*, with its long smoaking Tail arising up from it, through its several Ages or Periods of revolving, and this in the Sight of all the Inhabitants of our Air, and of the rest of the System; that I cannot but think the Surface or Atmosphere of such a Comet to be that *Place of Torment* so terribly described in Scripture.[13]

The blazing comet would be a "most useful Spectacle," a reminder to the blessed to preserve their obedience to the Lord.

Cotton Mather likewise advised "serious Christians" to take note of those hellish stars. In colonial New England, he preached that God directed noxious comet steams towards sinful planets capable of reform, but set incorrigible worlds ablaze and hurled these hells into cometary orbits.[14] Every comet, he declared, was a "wicked World *made a fiery Oven in the Time of the Anger of GOD!*"[15]

Mather's statement that comets were punished worlds raised the question of whether our earth could be transformed into a cometary hell. In an essay published as an appendix to Tobias Swinden's *Enquiry into the Nature and Place of Hell* (1714), William Wall lent indirect support to that idea. He suggested that there were thousands of planets beyond Saturn. When destroyed by divine decree, these fell towards the sun. At the Second Coming, once the righteous were gathered to meet the Lord in the air, the earth too would drop as a comet into the sun:

> in which descent . . . not only the wicked Men, with all that is on the Surface, will be burnt up; but also the Heavens, i.e. the Sky about the Earth, will be dissolv'd, and the Elements (of Air, Water, &c.) be evaporated, or melt with fervent Heat, and the Body of the Earth burnt to a Coal.[16]

That was not the end of things, however. The scorched planet would "(like a Nut-shell let fall into a great Flame) be tossed out again, and carried to a new and better Place in the Firmament, and become a new Earth in a new Heaven or Sky, and there be the Scene of the millennial State."[17] Although Wall saw the sun as the ultimate prison for the damned, Whiston situated hell on the old earth, which would after the millennium be forced to travel through the heavens in a terrible blaze, leaving the blessed behind to watch the fearful spectacle from the vantage point of the earth's former orbit.[18] The cometary fate of the earth also impressed Mather Byles, a nephew of Cotton Mather. In vivid couplets inspired by the 1744 comet, he described the Day of Judgement when our guilty globe would be transformed into a fiery hell in cometary orbit.[19]

Implicit in these statements was an insistence on the uniformity and analogy of nature; or to put it more specifically, on the thesis that the material composition and life-forms of comets were essentially like the planets'. By presupposing the analogy and uniformity of material and biological structures, Derham, Whiston, Cheyne, and others were led to conclude that cometarians had a tortured existence. Were it not for the comets' eccentric orbits, these "Worlds in Confusion" would be in an orderly state fit for the domicile of happy creatures.[20] Whiston had first made this point in *The New Theory of the Earth* (1696), where he claimed that the earth had once been a comet and after the millennium would be transformed into a comet again.[21] Cheyne apparently subscribed to a similar view, describing comets as "the first *Rudiments* of *Planets*, not as yet brought into our *System*, or rather the *Ruins* of some banish'd thence."[22] The motif of comets as ruined, punished planets appears again and again in early eighteenth century texts. It was one basis for analogical arguments that established hell on comets.

The role of natural religion in the construction of these theories is worthy of comment, too. In hunting for a physical site of hell, the authors were motivated by a desire to provide a naturalistic interpretation of scriptural accounts of hell. In selecting comets, they adopted a view of divine power that emphasized both purpose and economy. God was magnificent in all his designs but frugal in the execution of them. Purposeful yet parsimonious, God was apparently unwilling to create life-forms happily suited to cometary climates.

The gruesome view that comets were penal worlds created to torment guilty creatures was widely adopted at the turn of the eighteenth century.

Nonetheless by the century's end, it had gone out of style, supplanted by the view that comets were populated not by sinners, but by the luckiest beings, blessed with the opportunity to explore the farthest reaches of the universe. In espousing this upbeat theory, natural philosophers emphasized different religious and physical premises, drawing inspiration from both the principle of plenitude and the latest theories of heat.

OTHER WORLDS

In the foregoing theories of comets as ruined planets, we may detect a bit of Cartesianism. René Descartes had kept silent on the possibility of other worlds and intellectual life among the stars, but his vortex cosmology was conducive to this opinion, for he had viewed both comets and planets to originate as darkened suns that no longer could sustain their own vortices and were consequently swept into neighboring ones.[23] Followers of Descartes extended his hypothesis to include as comets the old star's "lost" planets, which also left the ruined vortex and migrated into others.[24] The tails of these wayward planets were only optical illusions, and the cometary planets were otherwise the same as any other planet. If one assumed that normal planets were inhabited, then why not those that had lost their moorings? This was the point wittily considered by the Cartesian pluralist, Fontenelle, in his *Entretiens sur la pluralité des mondes*. In that work, the narrator chats with a Countess about cometarians, observing how sad it must be for them to see their own sun extinguished, but how diverting it must be to change vortices. Travelling through the heavens, cometarians would eagerly await the sighting of a new solar system. When one was spied, they would cry out, "*A new Sun, a new Sun*, as Sailors use to cry, *Land, Land.*"[25]

Early Newtonians had a less sanguine view of cometary life, believing it to be a tortured existence at best, but by the mid-eighteenth century, we find natural philosophers embracing attitudes more in keeping with Fontenelle's pluralism. The first thing that distinguished these later scholars from the earlier hell-finders was the focus of their natural theology. In their opinion, the hellacious-comet hypothesis offered a limited and irreverent grasp of divine omnipotence and providence. God was a font of goodness, an inexhaustible source of life. It was more in keeping with his wisdom and benevolence that he should populate cometary worlds with creatures suited to their weather. These views were expressed in 1754 by James Ferguson, who wrote:

> The extreme Heat, the dense Atmosphere, the gross Vapours, the chaotic-like State of Comets, seem to indicate them unfit for the Purposes of animal Life, and a most uncomfortable Habitation for rational Beings. Nevertheless, when we consider on the other Hand the infinite Power and Goodness of the Deity, the latter inclining, and the former enabling him to make Creatures suited to all States and Circumstances; that Matter exists only for the Sake of Intelligence, and wherever we find it, we find it always pregnant with Life, or necessarily subservient thereto; . . . when we reflect moreover, that some Centuries ago, 'till Experience undeceived us, a great Part of our Earth was judged uninhabitable; the torrid Zone by reason of excessive Heat, and the frigid Zones on account of exces-

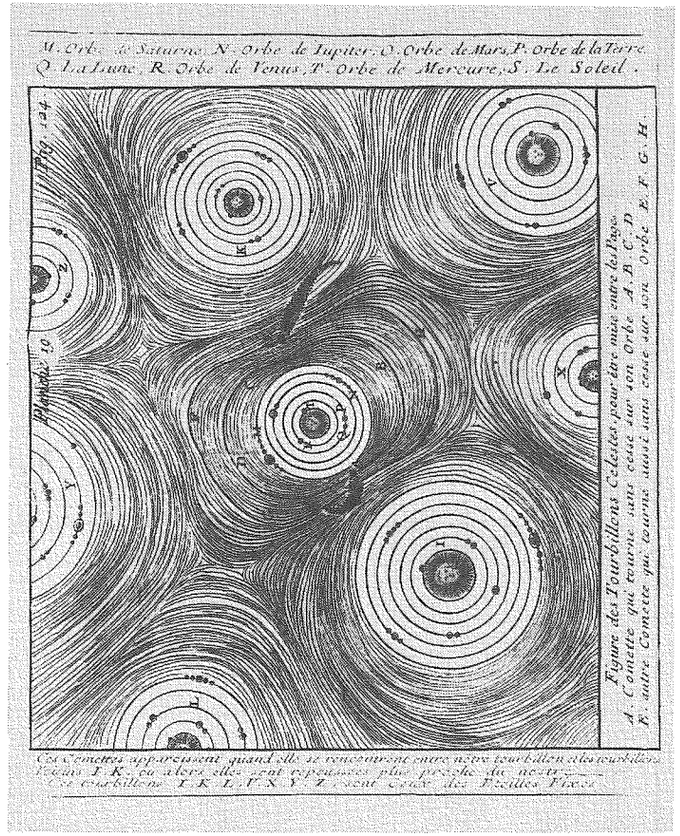

Fig. 2. Cartesian plurality of worlds showing comets within vortices. Nicolas Bion, *L'usage des globes celeste et terrestre, et des spheres suivant les differens systemes du monde* (Paris: 1744). [Courtesy of the Adler Planetarium, History of Astronomy Collection, Chicago.]

sive Cold: From these Considerations, it seems highly probable that such numerous and large Masses of durable Matter as the Comets, the most considerable Part of our System, however unlike they are to our Earth, are not destitute of Beings capable of contemplating with Wonder, and acknowledging with Gratitude, the Beauty, Wisdom, and Symmetry of the Creation; which is more plainly to be observed in their extensive Tour through the Heavens, than in our more confined Circuit. If farther Conjecture is permitted, may not one suppose they are peopled with guilty Creatures reclaimable by Sufferings, as we are on the Earth.[26]

Pierre Maupertuis, John Winthrop, Johann Lambert, and others joined Ferguson in finding extraterrestrial cometary life consistent with the inexhaustible variety of the works of God.[27] As Ferguson pointed out, God had created an "astonishing Diversity of Animals in Earth, Air, Water, and even on other Animals." Every blade of grass, every drop of water teemed with living things who enjoyed "such Gratifications as their Nature and State require[d]." If the earth teemed with life, then comets, like the planets and satellites revolving around every sun, could be commodious habitations for beings capable of knowing, obeying, and adoring God.[28]

In embracing the principle of plenitude, however, Lambert went one step further. Not only could comets be inhabited, but God had made them expressly for the purpose of packing the universe with as many creatures as possible. Angled every which way to the ecliptic, cometary orbits were suited to maximize habitability in every solar system. Lambert estimated that there were as many as five million comets around the sun alone, making them "much more necessary and useful for the habitability of the solar system than are the planets," he wrote, "and therefore contribut[ing] the most not only to the completeness but also to the perfection of the solar system."[29]

Believing it quite vain for men to suppose that a hundred or so comets had been created for the sake of punishing the solar system's sinners, Ferguson and Lambert emphasized the privileged state of cometarians who got to admire more of God's handiwork in their wide-ranging orbits. Some comets travelled in hyperbolic orbits, Lambert jealously noted, and therefore, were destined to visit one star after another. Far from peopling them with luckless sinners, Lambert "made astronomers of all of them, created for the purpose of viewing the edifice of the heavens, the position of each sun, the plane and course of their planets, satellites, and comets in their whole interconnectedness."[30]

Although the motif of ruined planets is frequently met within the works of those who thought comets to be hells, it seldom appears in the

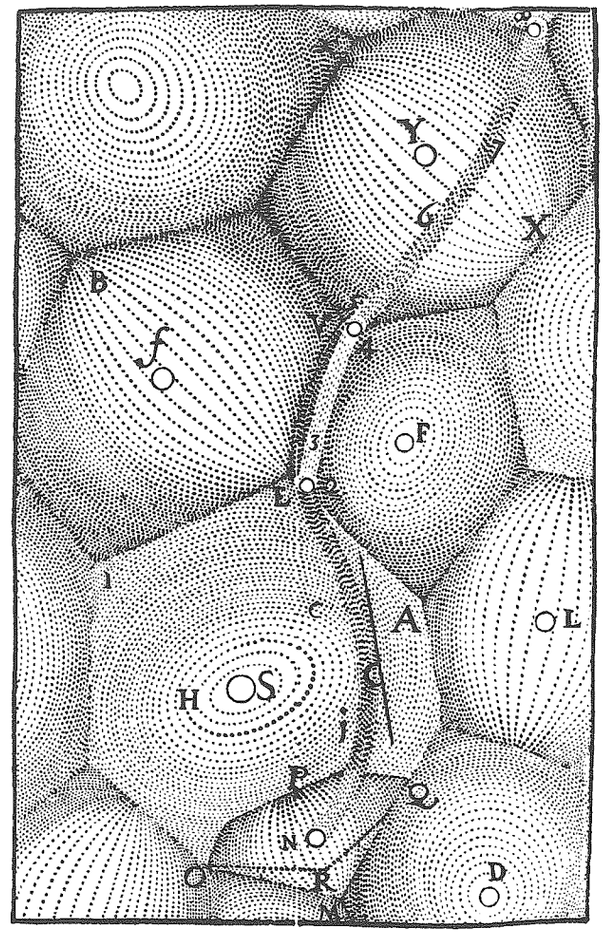

Fig. 3. Comet traveling from vortex to vortex. Descartes, *Principia philosophiae* (Amsterdam: 1644). [Courtesy of Department of Special Collections, University of Chicago Library.]

writings of those who thought them to be happy abodes. Those committed to cometary life tended to emphasize the permanence of celestial bodies. Judge Andrew Oliver, for example, rejected the possibility that comets and planets shared electrical atmospheres because this would

be dangerous to world order. Planets with smaller atmospheres than comets would have less electrical fluid, and so would attract electrical tails. The discharge would result in an "instantaneous cataract of fire" between the two worlds, and an "explosion, which nothing could equal, short of the final voice of an archangel; and, if it were not sufficient to rouse the ashes of the dead, might reduce the living to their primitive dust." This was too frightening to contemplate, and Oliver hastened to reassure his readers:

> But such a catastrophe, we have not the least reason to dread, from the neighborhood of a Comet, unless we can suppose, that infinite wisdom and goodness would create one world, merely for the destruction of another; as we cannot conceive of any other ends, to which such huge electrical atmospheres could be adapted. Indeed the discharge would be equally fatal to both worlds; as it is certain from electrical experiments, that the effects of a stroke of lightning are the same, whether the flash proceeds from the cloud to the Earth, or is discharged from the Earth into the cloud, both of which have happened during the same thunder-gust.[31]

Serendipitous destruction of planetary worlds was not in keeping with God's benevolence or design. Whiston's theory, Oliver retorted, did not hold water.[32] Lambert thoroughly agreed, decrying theories in which planets became comets and comets became planets because, he said, "I do not at all think that a celestial body can make itself inhabited, or that, should the earth become a comet, the seed for industrious creatures could lie hidden in it and sprout up afterwards."[33] The region of comets was not a "storehouse of underdeveloped planets;"[34] every celestial body was to remain what it always had been. God saw that there was no need to transform one into another or repopulate it since "the preservation of celestial bodies and of their inhabitants is such an aim of the creation which allows no such exception that would include a complete destruction."[35]

The premises of permanence and preservation were fostered in part by the dedication of these natural philosophers to the principle of plenitude and their belief in the primacy of life, for it seemed unacceptable that God would go to the trouble of populating a comet only to destroy it. Again we see the role of natural religion in shaping scientific theory, and how the religious tenets at work differed from those held earlier by Whiston and others who had sought the site of hell. We may also here observe a distinction between the later pluralists and the earlier hell-finders in their applications of scientific method. Like the hell-finders, the pluralists agreed that nature was uniform, but they emphasized

uniformity of function rather than of material and biological form. Or to put it more specifically, they accepted that the primary purpose of comets, like the planets, was to support life, and made their physical theories come in line with this assumption.

Late eighteenth-century physical speculations are noteworthy in showing how the commitment to the plurality of worlds was a driving force behind studies of the atmospheric and material conditions of comets that would make life possible. A common thread in these speculations was the view that the comas and tails of comets existed to protect the occupants. How this was accomplished varied from theory to theory. Lambert, for example, compared the tails and comas to the atmospheres of the planets, arguing that their distinctive appearance was an incidental by-product of the variation in solar heat experienced by a comet in its elongated orbit.[36] Composed of great vapory layers and mists, the comet's atmosphere expanded into a thick, enveloping fog as the comet approached perihelion and served to shield cometarians from the excessive heat of the sun.[37] The tail was formed from pieces of the atmosphere that were torn off when atmospheric heat rushed into the colder regions beyond the comet. Since tail matter was dispersed bit by bit through the aether, the comet lost a part of its atmosphere on each perihelion passage. In a twist on Newton's theory of comets' replenishing vital matter to the planets, Lambert proposed that comets were able to replenish their own stores of protective atmospheric matter by picking up fresh supplies as they travelled through the aether.[38]

Whereas Lambert had stressed the shielding nature of the comet's atmosphere, Dr. Hugh Williamson of Philadelphia turned his attention to temperature and pressure changes. Although many imagined that the surfaces of comets were alternately subjected to scalding heat and icy cold, Williamson thought that temperature fluctuations aboard a comet were less drastic and posed no obstacle to their habitation by beings of superior intelligence. He believed heat to be derived from a tremulous motion within bodies, and asserted that the heat of a comet depended both on its distance from the sun and its fitness to retain, propagate, and dissipate the vibrations that were communicated to its particles by light rays. The key was its atmosphere, which Williamson thought consisted of particles more subtle, elastic, tiny, and easily warmed than those in our air. He also reckoned the atmosphere on a comet to vary from eight to ten thousand miles in depth as compared to a depth of sixty to seventy miles on the earth. "Why should they have such a weight of

atmosphere more than us? This is doubtless subservient to some very extraordinary purpose," he observed. Now where the earth's atmospheric pressure was greatest, as at sea level, the air was much heated by the sun; but where pressure was low, like that found on mountain tops, the air was cooler. The same should be true for comets, he claimed. At aphelion the comet's great atmosphere was highly compressed and responsive to the sun's feeble rays; the cometarians kept warm. Near perihelion the atmosphere was rarefied and rendered less fit for generating and retaining heat. The tail also helped to wick away excess heat. Thus, "we may easily see how they [cometarians] may be tolerably cool at noonday, on their nearest approach to the Sun."[39]

In Salem in 1772, Judge Oliver was so enthusiastic about Williamson's account of cometarians, that he penned a complete discourse on the origin and physical nature of comet atmospheres and tails, and their ameliorating effects on the abodes of cometarians. Oliver discussed meteorological conditions experienced by denizens of comets, and drawing on Halley's experiments with a diving bell, he considered how the cometarians' respiratory and optical organs might be adapted to an atmosphere whose density greatly fluctuated.[40] A distinguishing feature of Oliver's thesis was that all heavenly bodies including the sun had aerial atmospheres identical to the earth's. Formed from a highly elastic, transparent fluid, these atmospheres were mutually repellent. Their power of repulsion varied inversely as the distance, and Oliver believed that as celestial bodies gravitated towards each other, their respective atmospheres would endeavor to recede, while remaining gravitationally attracted to the bodies. As the solar atmosphere repelled a comet's, a tail was formed.[41]

Oliver illustrated this repulsion by means of electrical experiments using pith balls covered with threads, and an "artifical Comet, consisting of a small, gilt cork ball, with a tail of leaf-gold" suspended near a gilt sphere mounted on the stem of a Leyden jar. The electrical analogy had its limitations, however. Since electric sparks were self-luminous, Oliver was quick to assert that electric fluid was not responsible for comet tails, which shone by reflected light.[42] Electrified tails, moreover, would be dangerous to world order, and so were unacceptable on philosophical grounds. No matter how awful and portentous tails appeared, they were "designed for, and are wisely adapted to, the truly god-like purposes, of rendering habitable a vast variety of Worlds."[43] "Does it not redound more to his [God's] honour," Oliver asked, "to consider these bodies as

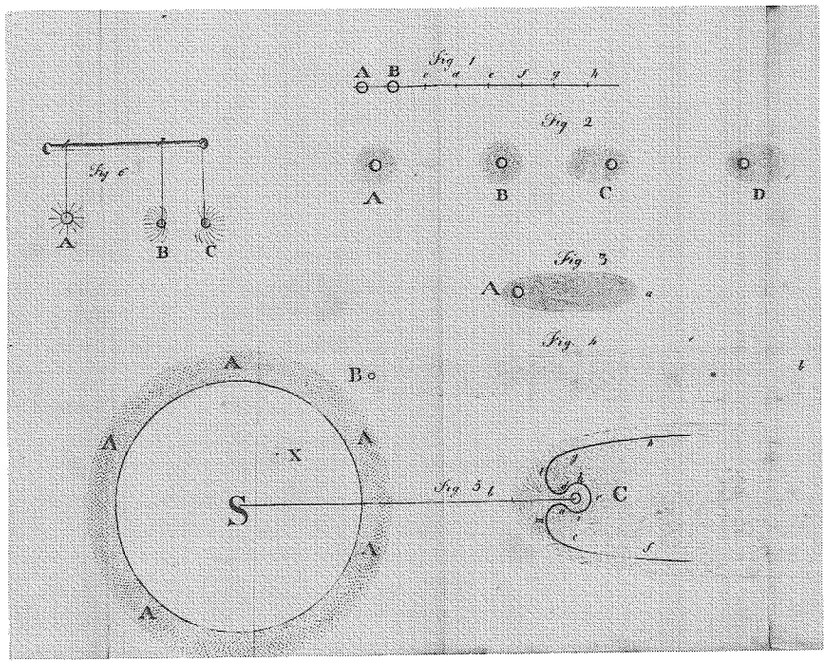

Fig. 4. Electric theory of mutually repellent cometary atmospheres. *Upper left*, electrified pith balls covered with strings that represent the atmospheres of comets at aphelion (*A*) and perihelion (*B*); *below*, the repulsion of a comet's atmosphere (*C*) by the sun (*S*). Andrew Oliver, *An Essay on Comets* (Salem: 1772). [Courtesy of the Adler Planetarium, History of Astronomy Collection, Chicago.]

so many inhabited Worlds, provided with every[thing] necessary for the comfortable subsistence of innumerable inhabitants, rational and irrational, like the Earth?"[44]

Oliver dedicated his essay to his former Harvard professor, Winthrop, who made the guarded comment that it was "really curious and uncommon."[45] Yet, it is a testimony to the temperament of the times that, like Williamson's paper, the tract was well received at home and abroad. Williamson was elected to a Dutch scientific society on the strength of his thesis, whereas Oliver's book was translated into French, reprinted in 1811, and treated seriously by Joseph Priestley. Priestley read the essay "with attention and pleasure," but urged Oliver to reconsider his

rejection of any role for electrical fluids and to support Priestley's own theory that electrical atmospheres surrounded each heavenly body and interacted with aerial atmospheres at great distances.[46]

Oliver's, Lambert's, and Williamson's propositions concerning heat transfer within comet atmospheres were rather unsophisticated compared to the analysis of Pierre-Simon Laplace. In 1783 Laplace had made careful experiments with Antoine Laurent Lavoisier on latent and specific heats, and he incorporated this research into the treatment of the nebulosity of comets in his *Exposition du système du monde*.[47] Comet nebulosity was due to vapors raised from the comet's surface by the action of solar heat.[48] He suggested that near perihelion, the process of vaporization of cometary fluids would absorb heat, and so might temper the scorching temperatures a comet would otherwise experience near the sun, whereas near aphelion, the condensation of the same fluids might restore in part the loss of heat experienced as the comet traveled away from the sun into icy space. Therefore, the latent heat associated with changes of state would offset the temperature extremes encountered by comets, such that a thermometer placed on a comet would register little variation.[49]

Subscribers to Oliver's and Williamson's point of view were cheered by Laplace's work, which they thought reinforced the thesis of comet habitability.[50] It is not clear whether Laplace himself intended this discussion as a tentative preamble to statements of the possible habitability of comets. He embraced pluralism as a logical consequence of his nebular hypothesis. If the solar system evolved from the rotation and condensation of a primordial fluid, then planets and stars evolved together. When Laplace looked at the night sky, he saw "innumerable suns, which may be the foci of as many planetary systems,"[51] and he was disposed to populate these celestial bodies. He reasoned by analogy. Since terrestrial matter was so fertile, it was not natural for planetary matter to be sterile.

> Man, formed for the temperature which he enjoys upon the Earth, could not, according to all appearance, live upon the other planets; but ought there not to be a diversity of organization suited to the various temperatures of the globes of this universe? If the difference of elements and climates alone, causes such variety in the productions of the Earth, how infinitely diversified must be the productions of the planets and their satellites? The most active imagination cannot form any just idea of them, but still their existence is extremely probable.[52]

By this logic, comets too might be inhabited by creatures suited to their climates. If Laplace believed this, however, he kept it to himself.

SECULARIZATION AND POPULAR CULTURE

In the example before us, we observe a chronological movement from abodes of the damned to realms of the blessed, and from scripturally dependent arguments to more naturalistic ones. It remains to ask what factors may have caused natural philosophers to give up their gloomy determination to locate hell in favor of their more optimistic search for an astronomer's heaven.

Part of the answer lies in the secularization trend of the eighteenth century. It is not the aim of this paper to examine the causes of the trend, but only to say that this case study exemplifies it. Whereas earlier astronomers had looked to comets in the heavens for astrological or divine messages pertaining to local affairs, those of the eighteenth century studied the skies primarily for practical or scientific ends. Insofar as religion was concerned, their aim was not to urge sinners to awake or repent, but to admire God's wise design of the cosmos. Their theories emphasized natural causes over the immediate hand of God.[53]

In the case before us, the secularization trend is reflected in the diverse role played by natural theology in speculations about cometary life. Those who endorsed comets as hells seemed motivated by a desire to find a physical site for hell that agreed with a rather literalist interpretation of scripture. Their God was an economizing master of vengeance. By contrast, those who populated comets with blessed individuals focused their attention on God as an inexhaustible source whose goodness, generosity, and providence inclined him to create life-forms suitable for cometary environments. Having said this, however, many of the latter pluralists concentrated on the physical and biological conditions that would be needed to sustain cometary life. In drawing on contemporary studies of heat and atmospheric science, they offered a view of the world-edifice in which God was a great architect, but otherwise seemed remote. The God of the earlier hell-finders, on the other hand, was an active executioner of justice who sent comets to chasten sinners and aggressively punished planets when their inhabitants refused to mend their ways.

Popular culture may provide another key to understanding the shift

in outlook. On a folk level, comets were widely viewed with horror, as divine signs of impending judgement and harbingers of death, but by the end of the seventeenth century, the learned elite had dismissed the crudest folk beliefs as vulgar.[54] I say the crudest, because it can be shown that the elite never fully withdrew from the popular culture they had long shared with the masses. Although they rejected as vulgar the traditional view that comets imported famine, plague, and revolution, they continued to see them as seeds of destruction and renewal, as signs of the world's end or its reformation.[55] The authors discussed in this paper make this evident when they considered the viability of life on comets.

It is easy to see the connection in the thought of Derham, Cheyne, Whiston, and Mather. As hells, comets remained God's tools to punish the wicked and their apparitions served to remind sinners of future judgements. In the writings of Ferguson, Lambert, Williamson, and Oliver, the connection is more remote. As homes to happy beings, comets were assumed to be composed of life-sustaining materials. This assumption was related indirectly to a hypothesis of Newton that all life would cease were it not for comets circulating vital spirits and aqueous fluids throughout the heavens, including fuel to the stars.[56] As I have demonstrated elsewhere, the Newtonian view was derived from an older folk belief that comets influenced agriculture, health, and the weather.[57] We see that the views of early eighteenth-century hell-finders were closer in spirit to the old folk beliefs than views of the later pluralists were. But perhaps it comes as no surprise that vestiges of the old beliefs remained more clearly in the thought of Whiston, Cheyne and the others, for they grew up during the transition period when the learned were consciously withdrawing their support from the traditional belief system. By contrast, Ferguson, Lambert, and the other pluralists were children of the enlightenment. In so far as vestiges of folk beliefs remained in their philosophies, they were stripped of their religious veneer and highly naturalized.[58]

If the loosening grip of traditional beliefs and the secularization trend shed some light on the chronological transition from earlier to later conjectures, we may yet be startled by their antithetical nature. There was, after all, a world of difference between the hells of devils and the heavenly abodes of astronomically-minded creatures. The different conclusions reached about the fitness of comets to sustain life reveal how much latitude there was in the application of scientific method in cases such as this where empirical inspection was impossible. All the authors

treated in this essay paid homage to the principles of analogy, uniformity, and simplicity, but it was up to each individual to decide where analogical reasoning was appropriate, when similarity of effects implied uniformity of causes, and how true causes could be distinguished from superfluous ones. In making these decisions, the natural philosophers were guided by their own metaphysical commitments to doctrines such as the principle of plenitude and purposefulness of nature. On the one hand, Derham, Cheyne, Wall, Whiston, and Mather saw God as purposeful and economizing in transforming planets into comets; hence, they chose to emphasize the similarity of material components and forms of life. Comets had atmospheres like the earth's, but their eccentric orbits caused the atmospheres to be "chaotic" and "confused," first scalding, then freezing. Insofar as cometarians resembled earthly creatures, they would find the conditions to be hell. Fontenelle, Ferguson, Lambert, Williamson, and Oliver, on the other hand, saw God as an inexhaustible creative power, and therefore emphasized analogy of purpose. Comets like the earth were designed for habitation, and their elliptical and hyperbolic orbits enabled cometarians to see more of the creation than earth-bound animals could. If comets were fit to be happy domiciles, it was likely that either their material conditions or forms of life must not be analogous to those on the earth. Williamson, for example, emphasized the different composition of the comets' protective atmospheres, whereas Ferguson and Oliver stressed the adaptation of cometarians to their environment. The historical question of life on comets is thus instructive for it reveals a dynamic interplay of natural theology, scientific method, and popular culture.

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NOTES

[1] Bernard le Bovier de Fontenelle, *Entretiens sur la pluralité des mondes*, critical edition, ed. Alexandre Calame (Paris: Librairie Marcel Didier, 1966), p. 161, my translation.
[2] Arthur O. Lovejoy, *The Great Chain of Being* (Cambridge: Harvard University Press, 1964), p. 52.
[3] Such arguments were made, for example, in the *Encyclopaedia Britannica*, 3 vols. (Edinburgh: 1771), 1: 444–445.
[4] Isaac Newton, *Philosophiae naturalis principia mathematica* (London: 1687), Book 3, 'Hypotheses,' which were renamed 'Regulae philosophandi' in subsequent editions.

Translation taken from Newton, *Mathematical Principles of Natural Philosophy*, Motte-Cajori edition (Berkeley: University of California Press, 1962), pp. 398–399. Similar statements appeared in Book 1, Part 1, Prop. 6, and Query 31 of the *Opticks*; see Newton, *Opticks*, 4th ed. (London: 1730; reprint, New York: Dover, 1952), pp. 76, 397.

5 Christiaan Huygens, ΚΟΣΜΟΘΕΩΡΟΣ [Cosmotheoros], sive de terris coelestibus earumque ornatu conjecturae (The Hague: 1698); *Idem, The Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets* (London: 1698). Newton, *Mathematical Principles* (ref. 4), General Scholium, p. 544; Conduitt Memorandum, March 1724/5, printed in Edmund Turnor, *Collections for the History of the Town and Soke of Grantham* (London: 1806), pp. 172–173. John Ray, *The Wisdom of God Manifested in the Works of the Creation* (London: 1691), pp. 1–2, 49. Richard Bentley's seventh and eighth Boyle Lectures, printed in Bentley, *A Confutation of Atheism from the Origin and Frame of the World* (London: 1693), part 2, pp. 14–15, 37, part 3, pp. 4–6; reprinted in I. Bernard Cohen, ed., *Isaac Newton's Papers and Letters on Natural Philosophy* (Cambridge: Harvard University Press, 1958), pp. 326–327, 349, 356–358. For detailed discussion of these and other authors, see Lovejoy, *Great Chain* (ref. 2), chapter 4; Michael J. Crowe, *The Extraterrestrial Life Debate, 1750–1900: The Idea of a Plurality of Worlds from Kant to Lowell* (Cambridge: Cambridge University Press, 1986), esp. pp. 9–26; and Steven J. Dick, *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant* (Cambridge: Cambridge University Press, 1982), esp. chapters 5 and 6.

6 William Derham, *Astro-Theology: Or a Demonstration of the Being and Attributes of God, from a Survey of the Heavens*, 1st ed. (London: 1715), 'A Preliminary Discourse Concerning the Systemes of the Heavens, the Habitability of the Planets, and a Plurality of Worlds,' pp. xl–lvi.

7 *Ibid.*, pp. 52–53; William Derham, *Astro-Theology*, 2nd ed., corrected (London: 1715), pp. 54–55. Cf. William Whiston, *Astronomical Principles of Religion, Natural and Reveal'd* (London: 1717), pp. 22–23.

8 Derham, *Astro-Theology*, 1st ed. (ref. 6), pp. 53, 218–219; Derham, *Astro-Theology*, 2nd ed. (ref. 7), pp. 55, 228–229.

9 George Cheyne, *Philosophical Principles of Natural Religion* (London: 1705), pp. 119–120, see also p. 122.

10 Whiston, *Astronomical Principles* (ref. 7), p. 92. Whiston wrote of "external regions" because he remained open to the possibility that the "internal regions" – i.e. cavities – within comets could be inhabited. See pp. 94–96.

11 *Ibid.*, p. 23.

12 Cheyne, *Philosophical Principles* (ref. 9), p. 151.

13 Whiston, *Astronomical Principles* (ref. 7), pp. 155–156.

14 [Cotton Mather], *A Voice from Heaven. An Account of a Late Uncommon Appearance in the Heavens* (Boston: 1719), pp. 8–11, 13–16, quotation on p. 11.

15 [Cotton Mather], *An Essay on Comets, their Nature, the Laws of their Motions, the Cause and Magnitude of their Atmosphere, and Tails; With a Conjecture of their Use and Design* (Boston: 1744), p. 7.

16 William Wall, 'Advertisement,' appended to Tobias Swinden, *An Enquiry into the Nature and Place of Hell* (London: 1714), pp. 287–292, see p. 291 for quotation.

17 *Ibid.*, pp. 289, 291–292. Final Judgement followed the millennium; the righteous would go to an even better place, while the damned would be imprisoned in the sun, which Swinden agreed was the site of hell.

18 William Whiston, *The Eternity of Hell-Torments Considered* [1740], 2nd ed. (London: 1752), p. 105; Whiston, *Astronomical Principles* (ref. 7), pp. 154–155; D. P. Walker, *The Decline of Hell* (Chicago: University of Chicago Press, 1964), pp. 100–101.

19 Mather Byles, *The Comet: A Poem* (Boston: 1744).

20 Whiston, *Astronomical Principles* (ref. 7), p. 23: "[Comets are] Worlds in Confusion, but capable of a change to Orbits nearer Circular, and then of settling into a State of Order, and of becoming fit for Habitation like the Planets." See also William Whiston, *A New Theory of the Earth* (London: 1696), pp. 48, and 74–75: "A *Planet* is a *Comet* form'd into a regular and lasting constitution, and plac'd at a proper distance from the Sun in a Circular Orbit, or one very little Eccentrical; and a *Comet* is a *Chaos*, i.e. a *Planet* unform'd, or in its primaeval state, plac'd in a very Eccentrical one."

21 Whiston, *New Theory of the Earth* (ref. 20) pp. 69, 378; Whiston, *Astronomical Principles* (ref. 7), pp. 153–154.

22 Cheyne, *Philosophical Principles* (ref. 9), p. 151.

23 René Descartes, *Principia philosophiae* (Amsterdam: 1644), part 3, sections 115, 119–120, 126–129, 133–139; recently published in translation as Descartes, *Principles of Philosophy*, trans. V. R. Miller and R. P. Miller (Dordrecht: D. Reidel Publishing Company, 1983), pp. 147, 150–151, 155–159, 163–168. Also see René Descartes, *Le monde, ou le traité de la lumière* [1st edition: 1664], French text of the 1677 edition, with translation by Michael S. Mahoney (New York: Abaris Books, 1979), pp. 44–45, 92–107.

24 See, for example, the remark made by John Flamsteed in a letter to Edmond Halley, 17 February 1680/1, that a "Comet . . . may have beene some planet belonging formerly to another Vortex now ruined;" reprinted in *The Correspondence of Isaac Newton*, ed. H. W. Turnbull *et al.*, 7 vols (Cambridge: Cambridge University Press, 1959–1977), **2**: 338.

25 Fontenelle, *Entretiens* (ref. 1), pp. 145–149; translation taken from [Fontenelle], *A Plurality of Worlds*, trans. J. Glanvill (London: 1702), 'Fifth Evening,' pp. 144–148, quotation, p. 148.

26 James Ferguson, *An Idea of the Material Universe, Deduced from a Survey of the Solar System* (London: 1754), pp. 25–27.

27 Maupertuis, *Lettre sur la comète* ([Amsterdam?]: 1742), p. 38; John Winthrop, *Two Lectures on Comets* (Boston: 1759), p. 40.; Bartholomew Burges, *A Short Account of the Solar System, and of Comets in General* (Boston: 1789), pp. 9, 15–16; J. H. Lambert, *Cosmologische Briefe über die Einrichtung des Weltbaues* (Augsburg: 1761); trans. and reprinted in *Idem, Cosmological Letters on the Arrangement of the World-Edifice*, trans. Stanley L. Jaki (New York: Science History Publications, 1976).

28 Ferguson, *Idea of the Material Universe* (ref. 26), pp. 9, 15–16, 23, 25–27, 29–30.

29 Lambert, *Cosmological Letters* (ref. 27), pp. 48–49, 55, 70–72, 87, 96, 103; quotation on p. 49. See also M. A. Hoskin, 'Lambert's Cosmology,' and 'Lambert and Herschel,' *Journal for the History of Astronomy* **9** (1978), 134–139 and 140–142.

30 Lambert, *Cosmological Letters* (ref. 27), pp. 83–84, and quotation, p. 73.

31 Andrew Oliver, *An Essay on Comets* (Salem: 1772), p. 48.

32 *Ibid.*, pp. 34–35.

[33] Lambert, *Cosmological Letters* (ref. 27), p. 99.
[34] *Ibid.*, pp. 48–49, 64–65, 84.
[35] *Ibid.*, pp. 58–59, 62, 67–68, 99, 104–105, 129, quotation, p. 68.
[36] *Ibid.*, pp. 55, 62, 84, 94, 103–104, 148. Like Kant, Lambert argued that the world of comets bordered on and fused with the world of planets. Cf. Immanuel Kant, *Allgemeine Naturgeschichte und Theorie des Himmels* [Leipzig: 1755].
[37] Lambert, *Cosmological Letters* (ref. 27), pp. 83–84, 93, 100–101.
[38] *Ibid.*, pp. 93–94.
[39] Hugh Williamson, 'An Essay on the Use of Comets, and an Account of their Luminous Appearance; together with some Conjectures concerning the Origin of Heat,' *Transactions of the American Philosophical Society* **1** (1771), appendix, pp. 27–36; and in the second edition of the *Transactions* **1** (1789), 133–143.
[40] Oliver, *Essay on Comets* (ref. 31), pp. 51–87.
[41] *Ibid.*, pp. v–vi, 11–32.
[42] *Ibid.*, pp. 40–49, quotation p. 46.
[43] *Ibid.*, pp. 49–50.
[44] *Ibid.*, p. iii.
[45] John Langdon Sibley and Clifford Kenyon Shipton, *Sibley's Harvard Graduates*, 17 vols. (Cambridge and Boston: 1873–1975), **12**: 457.
[46] Priestley to Oliver, 12 February 1775, *Proceedings of the Massachusetts Historical Society*, 2nd series, **3** (1886–1887), 13–14; letter reprinted in Robert E. Schofield, *A Scientific Autobiography of Joseph Priestley, 1733–1804* (Cambridge: M.I.T. Press, 1966), pp. 148–149. John Davis compared Oliver's theory to one of J. A. De Luc published in the *Journal de physique* (1802) and commented on its reception; see John Davis, ed., *Two Lectures on Comets, by Professor Winthrop, also An Essay on Comets, by A. Oliver, Jun. Esq. With Sketches of the Lives of Professor Winthrop and Mr. Oliver. Likewise, a Supplement, Relative to the Present Comet of 1811* (Boston: 1811), p. xxv. On Williamson's reputation, see Brooke Hindle, *The Pursuit of Science in Revolutionary America 1735–1789* (Chapel Hill: University of North Carolina Press, 1956), p. 172.
[47] See Antoine Laurent Lavoisier and Pierre-Simon Laplace, *Mémoire sur la chaleur lû à l'Académie Royale des Sciences, le 28 juin 1783* (Paris: 1783); facsimile reprinted with translation in *Memoir on Heat Read to the Royal Academy of Sciences, 28 June 1783 by Messrs. Lavoisier & de la Place of the same Academy*, trans. Henry Guerlac (New York: Neale Watson Academic Publications, 1982).
[48] Pierre-Simon Laplace, *Exposition du système du monde*, 1st ed., 2 vols. (Paris: 1796), **1**: 222.
[49] This discourse on latent heat appeared in only the third and fourth editions. Pierre-Simon Laplace, *Exposition du système du monde*, 3rd ed., 2 vols. (Paris: 1808), **1**: 224–228; Laplace, *Exposition du système du monde*, 4th ed. (Paris: 1813), pp. 130–132.
[50] Davis, *Two Lectures* (ref. 46), p. 187.
[51] Laplace, *Systême du monde*, 1st ed. (ref. 48), **2**: 304; translation taken from Laplace, *The System of the World*, trans. J. Pond [from the 2nd ed., 1799], 2 vols. (London: 1809), **2**: 366.
[52] Laplace, *Systême du monde*, 1st ed. (ref. 48), **2**: 294–295; translation taken from Laplace, *System of the World* (ref. 51), **2**: 355–356.
[53] On the secularization of the study of comets, see Sara Schechner Genuth, 'From Heaven's Alarm to Public Appeal: Comets and the Rise of Astronomy at Harvard,' in Clark A. Elliott and Margaret W. Rossiter, eds., *Science at Harvard University: Historical Perspectives* (Bethlehem: Lehigh University Press, 1992), pp. 28–54.

[54] On folk beliefs about comets, see Stith Thompson, *Motif-Index of Folk-Literature: A Classification of Narrative Elements in Folktales, Ballads, Myths, Fables, Mediaeval Romances, Exempla, Fabliaux, Jest-Books, and Local Legends*, rev. and enlarged ed., 6 vols. (Bloomington: Indiana University Press, 1955–1958), A124.5, A780, A786, A1002.2, A1050, D1812.5.1, F493.5, F797, F960–969, T525.2, V211.1.2.1; *Standard Dictionary of Folklore, Mythology and Legend*, ed. Maria Leach, 2 vols. (New York: Funk & Wagnalls, 1949–1950), s.v. 'comet.' More direct information on folk beliefs is obtained through the study of ephemeral texts such as ballads, broadsides, chapbooks, and almanacs, which often contained crude woodcuts depicting comets, through first-hand reports in diaries and letters, and through visual representations in folk art and artifacts. The texts and images that I have consulted are far too numerous to mention here, but many are discussed in my other works (see refs. 53, 55, 57, 58). Good illustrations of this genre can be found in J. Classen, *15 Kometenflugblätter des 17. und 18. Jahrhunderts*, Veröffentlichungen der Sternwarte Pulsnitz, 11 (Leipzig: Verlag Johann Ambrosius Barth, 1977); Gerhard Bott, ed., *Zeichen am Himmel: Flugblätter des 16. Jahrhunderts* (Nuremberg: Germanisches Nationalmuseum Nürnberg, 1982); Jean-Pierre Séguin, *L'information en France avant le périodique: 517 canards imprimés entre 1529 et 1631* (Paris: Éditions G.-P. Maisonneuve et Larose, 1964), pp. 95–100, and plates 3, 6, 18, 19; Roberta J. M. Olson, *Fire and Ice: A History of Comets in Art* (New York: Walker and Company for the National Air and Space Museum, Smithsonian Institution, 1985).
On the denigration of folk beliefs and customs by the elite in the 17th and 18th centuries, see Peter Burke, *Popular Culture in Early Modern Europe* (New York: New York University Press, 1978), chaps. 2, 8, 9; Roger Chartier, 'Culture as Appropriation: Popular Cultural Uses in Early Modern France,' and Jacques Revel, 'Forms of Expertise: Intellectuals and 'Popular' Culture in France (1650–1800),' both in Steven L. Kaplan, ed., *Understanding Popular Culture: Europe from the Middle Ages to the Nineteenth Century* (Berlin, New York, Amsterdam: Mouton Publishers, 1984), pp. 229–273; Harry C. Payne, 'Elite versus Popular Mentality in the Eighteenth Century,' *Studies in Eighteenth-Century Culture* **8** (1979): 3–32; Natalie Zemon Davis, *Society and Culture in Early Modern France* (Stanford: Stanford University Press, 1975), chaps. 7, 8; Keith Thomas, *Religion and the Decline of Magic* (New York: Charles Scribner's Sons, 1971); Patrick Curry, *Prophecy and Power: Astrology in Early Modern England* (Princeton: Princeton University Press, 1989); Robert W. Malcolmson, *Popular Recreations in English Society, 1700–1850* (Cambridge: Cambridge University Press, 1973).
[55] See Sara Schechner Genuth, 'Newton and the Ongoing Teleological Role of Comets,' in Norman J. W. Thrower, ed., *Standing on the Shoulders of Giants: A Longer View of Newton and Halley* (Berkeley: University of California Press, 1990), pp. 299–311.
[56] Newton, *Principia*, 1st ed. (ref. 4), p. 506; Isaac Newton, *Philosophiae naturalis principia mathematica*, 2nd ed. (Cambridge: 1713), pp. 480–481; for both passages in the Motte-Cajori edition (ref. 4), see pp. 529–530, 541.
[57] Sara Schechner Genuth, 'Comets, Teleology, and the Relationship of Chemistry to

Cosmology in Newton's Thought,' *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* **10**, fascicolo 2 (1985), 31–65.

[58] The vestiges are better seen in theories about comets careening into planets than in those concerning comet habitability. See Genuth, 'Newton and the Ongoing Teleological Role of Comets' (ref. 55); and Sara Schechner Genuth, 'From Monstrous Signs to Natural Causes: The Assimilation of Comet Lore into Natural Philosophy' (Ph.D. Dissertation, Harvard University, 1988).

LORRAINE J. DASTON*

THE DOCTRINE OF CHANCES WITHOUT CHANCE: DETERMINISM, MATHEMATICAL PROBABILITY, AND QUANTIFICATION IN THE SEVENTEENTH CENTURY

INTRODUCTION

In 1814 the French mathematician Pierre Simon Laplace wrote:

> All events, even those which on account of their insignificance do not seem to follow the great laws of nature, are a result of it just as necessarily as the revolutions of the sun . . . Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it – an intelligence sufficiently vast to submit these data to analysis – it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes.[1]

Despite the astronomical references, this classic statement of determinism occurs in Laplace's work on probabilities, not celestial mechanics.[2] Nor was this combination of probability theory and thoroughgoing determinism anomalous: Laplace is in fact echoing the words of Jakob Bernoulli, published a century earlier, right down to the astronomical standard of prediction. Between Bernoulli's *Ars conjectandi* (1713) and Laplace's *Théorie analytique des probabilités* (1812) a multitude of lesser probabilists insisted that chance was a mere sound signifying nothing; that every event in at least the natural world was a link in an unbroken chain of causes. They were not simply voicing a fashionable position obtained secondhand, for theirs were among the strongest and most influential proclamations of determinism. Nor was it a metaphysics free of consequences: their determinism committed them to an interpretation of probability as a degree of subjective certainty, rather than as a measure of objective variability. Far from signalling a new openness toward chance in the world, the advent of mathematical probability banished chance altogether.[3]

Why were the architects of the mathematical "doctrine of chances" so unanimously hostile toward chance itself? I shall argue that the paradoxical alliance between mathematical probability and determinism was the result of seventeenth- and eighteenth-century views about the pre-

M. J. Nye et al. (eds.), The Invention of Physical Science, 27–50.