Lambert: self-taught physicist

This year marks the bicentennial of the death of Johann Heinrich Lambert; although his contributions to photometry are better known, his ideas in cosmology are surprisingly modern, even hinting at black holes.

Stanley L. Jaki

He was a physicist (Lambert's cosine law in optics, for example); a mathematician; a cosmologist (Did he anticipate the black holes of today?); but above all Johann Heinrich Lambert was a logician. "He . . . examined with the same rules the most trivial incidents of domestic life as well as the problems and demonstrations of science. A hole in his stocking made him conjure up a syllogism . . . , the leg of a chair prompted him to construct a hypothesis . . . All things presented themselves to his mind in the garment of logic . . ." Thus one colleague portrayed Lambert, the bicentennial of whose death is being commemorated this month. Another contemporary described him as a "dissertation-machine"—and even Lambert himself once referred to his head as a machine.[1]

To the Berlin Academy—on thin ice

About logic it has been said that it is the art of going wrong with confidence. Indeed, Lambert's obsession with logic was coupled with a self-confidence that almost deprived him of obtaining membership in the Berlin Academy. On being presented to Frederick the Great, Lambert stated in a few curt phrases—so many replies to the king's inquiries—that he was an expert in all fields of knowledge, that he had needed no teacher except himself, and that he was therefore the equal of Blaise Pascal. (Historians of mathematics rate Lambert, the first to give a strict proof of the irrationality of π and e, not much below the Pascal of conic-sections fame.)

Even more than Pascal, Lambert was his own teacher. Because of the poverty of his parents, Lambert's formal education came to a close when he was nine, still in the elementary school of Mulhouse (Mülhausen), the Alsatian town in which he was born in 1728. In his mid teens he could have attended courses at the University of Basel, but by then he preferred to remain his own teacher. He spent his twenties as tutor in the family of Count von Salis in Chur, Switzerland, apparently with much spare time left to continue his self-education. That he did so with signal success is witnessed by his books in German, French and Latin; he also had a good command of Italian and Greek.

Swiss scholars visiting with the Count von Salis soon discovered their equal in the shy, odd-looking "Hofmeister," as Lambert liked to refer to himself. At their prompting Lambert began to write for the freshly launched *Acta helvetica*. Its second volume, published in 1755, contained Lambert's seventy-page essay on the "force by which heat expands bodies." The work showed him not only in full command of calculus and bent on geometrical rigor but also diligent in collecting experimental data.

Heat, to Lambert, was the impact of very small elastic particles acting together as a fluid; he defined thermal equilibrium as "the equality between the force of fire and the resistance of matter." Three of his essays, which made up one fourth of the third (1758) volume of the *Acta*, dealt respectively with the principles of mechanical balance, with the sum and convergence of series and with meteorological observations, the latter marshalling a wealth of data.

In the year 1758 Lambert began a period of feverish publishing activity. During his eight years of tutoring he obviously had prepared the material for the half dozen books that saw print in quick succession. First came, in 1758, a treatise in French "on the remarkable properties of the path of light." This was republished the following year in The Hague, a city Lambert visited on a grand tour with his charges. On lengthy stopovers in Göttingen, Utrecht and Paris the self-confident tutor made contact with such eminent scientists as Tobias Mayer, Petrus van Musschenbroek and Jean d'Alembert. There was a touch of his characteristic confidence in the way Lambert submitted, in his treatise on light, the law of the exponential decrease of its intensity in homogeneous media: Lambert only briefly referred (in the preface) to Pierre Bouguer, without mentioning that the latter had already formulated the law thirty years earlier.

First major publications

Originality was not lacking in either his *Freye Perspektive* (1759) or his *Photometria* (1760), although in both cases Lambert proved to be only a co-discoverer. In his *Leçons élémentaires d'optique* Nicolas Lacaille had already shown in 1750 that, in drawing a scene, the various objects constituting it can be sketched "freely," that is, independently, without first correlating their respective sizes in a general sketch. The method is based on projecting each object to a graduated line of the horizon. Lambert not only presented the method in far greater detail than Lacaille did but also included a history of the art of perspective.

The originality in *Photometria* lay in part in the precision by which Lambert enunciated and applied the law now known as Lambert's cosine law. According to it the intensity of light emanating from a bright surface is proportional to the product of the intensity in the normal direction and the cosine of the angle formed by the normal and the direction in question. In his 1729 work Bouguer had merely adumbrated that

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The title page of Lambert's cosmological treatise, in which he explains the visual appearance of the Milky Way and postulates "dark regents." Reproduced from a copy in the Crawford Library of the Royal Observatory, Edinburgh, by permission of the Astronomer Royal of Scotland.

law. When the *Photometria* was published, Lambert was not aware yet of the second greatly enlarged edition of Bouguer's work, published as *Traité d'optique* (1760), in which the law in question is clearly stated.

Another original aspect of the *Photometria* is its highly systematic character. In that respect it was very different not only from its two chief sources, Bouguer's *Essai d'optique* and Robert Smith's *A Compleat System of Optics* (1738), but also from Bouguer's *Traité d'optique*.

Lambert's *Photometria* was, however, soon forgotten and major further advances in photometry were not made until the middle part of the nineteenth century. A discussion of the brightness of stars brought the *Photometria* to a close as if to indicate the fields—astronomy and cosmology—in which Lambert the scientist was to make his most lasting and most original contributions.

The proposition that the time interval between any two points of a planetary orbit is given by the semimajor axis, the sum of radius vectors and the chord connecting the two points was first given in Lambert's work on the characteristics of cometary orbits (*Insigniores orbitae cometarum proprietates*, 1761). The study was the basis on which Wilhelm Olbers later worked out his own "more commodious" method of determining the orbit of comets. Interestingly enough, Lambert once more turned out to be a co-discoverer and elaborator. Working independently of Leonhard Euler, Lambert stated of elliptical and hyperbolic as well as of parabolic orbits what Euler had already found in connection with the latter.

The same feature is evident in the most enduring detail of Lambert's famed *Cosmologische Briefe über die Einrichtung des Weltbaues* of 1761. In the book (English title: Cosmological Letters on the Arrangement of the World-Edifice[2]), he explained the visual appearance of the Milky Way as the effect of the fusion of the light of stars confined within a space resembling a flat disk. Immanuel Kant had already submitted the explanation in 1755 in his *Allgemeine Naturgeschichte und Theorie des Himmels,* a work which saw but limited circulation. In fact, when Kant queried Lambert in 1765 about priority, Lambert could not obtain a copy of the work.

The academician

By 1765 Lambert was member of the Berlin Academy with the right to read papers in all its four classes, that is, not only in the exact sciences but also in philosophy, history and belles-lettres—he had proved himself not only as a mathematician and physicist–astronomer but also as a philosopher. His *Neues Organon* (1764), subtitled, "thoughts on the explanation and identification of truth and on its difference from error and appearance," was a major addition to Lambert's program to "purge logic of all scholasticism." The program was further implemented in his *Anlage zur Architectonic,* published in Riga in 1771. The subtitle of this two-volume work, "theory of the simple and primordial in mathematical and philosophical knowledge," intimates a major characteristic of Lambert's thought; in a letter[3] he gave the opinion that "no matter how much attention a metaphysician or philosopher gives to putting in order and connecting his abstract ideas, all will remain there in complete confusion until he develops them to the point where the mathematician can immediately apply the calculus, the ruler, and the compass."

It was in that reduction of the study of philosophy and history to mathematics that Lambert saw the indispensable basis for harmony among men in every respect, a vision that has befogged the eyes both of scientists and non-scientists. Philosophers aiming at the certainty of mathematics could but be impressed by the *Neues Organon,* the author of which was taken by Kant as the greatest intellect of his time. Jean Trembley, who translated the work into French, related in a note that Lambert brushed aside his request for clarification of some passages with the remark that such clarifications would not in any case help those who don't understand the passages themselves.[4] Lambert the philosopher was soon eclipsed by Kant (who originally planned to dedicate his *Critique of Pure Reason* to Lambert) and others who embraced his reductionist program.

It was Lambert the scientist who lived on. The significance of a three-volume collection of astronomical tables published under his direction in 1776 was recognized by Joseph Lalande[5] as "... the most extensive and most complete published so far. It contains all that is necessary for an astronomer for doing his computations and observations: tables of the Sun, Moon, planets, satellites." Some credit for all this went to Bode.

The name of Johann Elert Bode perhaps symbolizes the decisive influence Lambert exercised on late-eighteenth-century science. In 1772 Lambert spotted the talent in Bode, the author of a popular book on astronomy, brought him from Hamburg to Berlin and put him in charge of a yearly publication, the *Berliner Astronomisches Jahrbuch.* It served during the next two generations as a principal clearing house for astronomical information.

Two remarkable achievements

Lambert's non-astronomical scientific work dating from his period as member of the Berlin Academy is distinguished more by diligence than by ingenuity. Its main items are:

- a four-volume collection of essays on mathematical topics;
- a two-volume work, *Hygrometrie,* which contains some of his meteorological essays and prompted the famous precision instrument maker, Georg Brander, with whom Lambert corresponded for years, to construct a hygrometer according to Lambert's principles;
- a treatise on the derivation of all shades

of color from mixing white with the three fundamental colors, red, blue and yellow, a work that developed an idea of Euler even in its final diagram, a color pyramid;

- the *Pyrometrie*, a treatise "on the measure of heat and fire." Although more than three-hundred pages long, Lambert wrote the *Pyrometrie* in five months immediately preceding his death on 25 September 1777. The wealth of experimental data it contained witnessed, of course, a much longer period of research.

Often Lambert failed to realize that it was not the quantity of data but their incisiveness that mattered. He wrote too much and too fast, which was one of the reasons why some of his works fell into quick oblivion. His posthumously published essays on philosophical and logical topics had no wide appeal.

It was not until long after their publication that two remarkable achievements of Lambert appeared in their proper importance. One was his inference that smaller periodicities of the irregularities in the motion of Saturn have their lowest common multiple in 1045½ years, which is also the period of a larger irregularity of Saturn's motion. From this Lambert concluded that the mutual perturbation of Saturn and Jupiter was periodic and therefore presented no threat to the stability of the solar system. In view of this he felt it proper to remark that the two planets "are not placed by sheer chance into the solar system but in such a manner that their mutual actions counterbalance one another in a way conform to the state of permanence."[6] A penchant for reductionism and a deep conviction as to the validity of teleological considerations were alike parts of Lambert's thought.

That Pierre Laplace failed to refer to Lambert's work on Saturn, published in French in the *Mémoires* of the Berlin Academy, was already a cause of sharp though private criticism soon after Laplace's death. Giovanni Plana, director of the Turin Observatory, was reported to be convinced[7] that "in his theory of Jupiter and Saturn Laplace had taken a thing or two from Lambert without mentioning him."

The other remarkable achievement was Lambert's essay on Euclid's parallel postulate. The essay was written by Lambert with no knowledge of Girolamo Saccheri's famed effort, published in 1733, to justify that postulate. Although Lambert, like Saccheri, failed to formulate a non-Euclidean geometry, he went farther toward that goal. Indeed he came so close to it as to recognize that if the sum of the third and fourth angles of a quadrangle with two right angles at its basis is less than 180 degrees, then there ought to exist "an absolute unit of the length of each line, of the content of each surface and of every bodily space." [8]

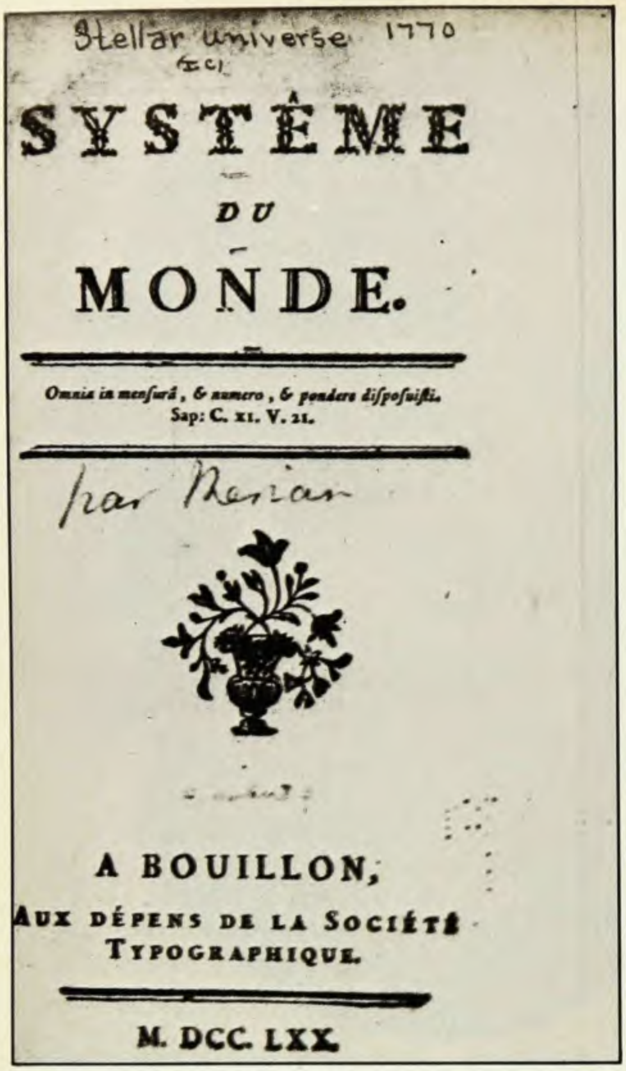
Lambert's essay, written in 1776, did not see publication until eight years after his death. His decision not to publish it was most likely due to his failure to advance from valuable insights to a consistently formulated non-Euclidean geometry. Only in the twentieth century, through Albert Einstein's general theory of relativity, did the esoteric topic of non-Euclidean geometries reveal its natural affinity with physical reality. These geometries secured for cosmology a consistency that could not be had in a static Euclidean framework without assuming a three-dimensional boundary for the Universe, an unwelcome option after the overthrow of the closed Aristotelian cosmos.

Johann Heinrich Lambert, 1728–1777, physicist and cosmologist. The drawing, by Pierre Roch Vigneron, is from *Johann Heinrich Lambert: Leistung und Leben*, Braun, Mulhausen (1943).

Comets by the million

The shift of allegiance, among astronomers at least, from the closed to the infinite Universe was by Lambert's time characterized more by intimations of the infinity of the Universe than by a firm assertion of it. Lambert's insistence in the *Cosmologische Briefe* on a strictly finite Universe with a definite boundary[8] is therefore telling evidence of the independence and precision of his thinking. This confers on his cosmological work a special significance in this century of ours, which has seen the science of cosmology come into its own. The *Cosmologische Briefe* indeed more than any other work of Lambert's has a fresh appeal to the present-day reader. It, of all his works, has been most frequently recalled in our times, both because of the spectacular flourishing of scientific cosmology since Einstein and of the parallel rise of interest in its history.

Yet, the many brief references to Lambert's cosmology have hardly been really instructive, as almost invariably they were not based on a study of the original. It is revealing that for twenty years no one challenged the claim[10] that "the idea of a hierarchy of celestial systems culminating in a single infinite [!] Universe was worked out by Johann



Stellar universe 1770

SYSTÊME

DU

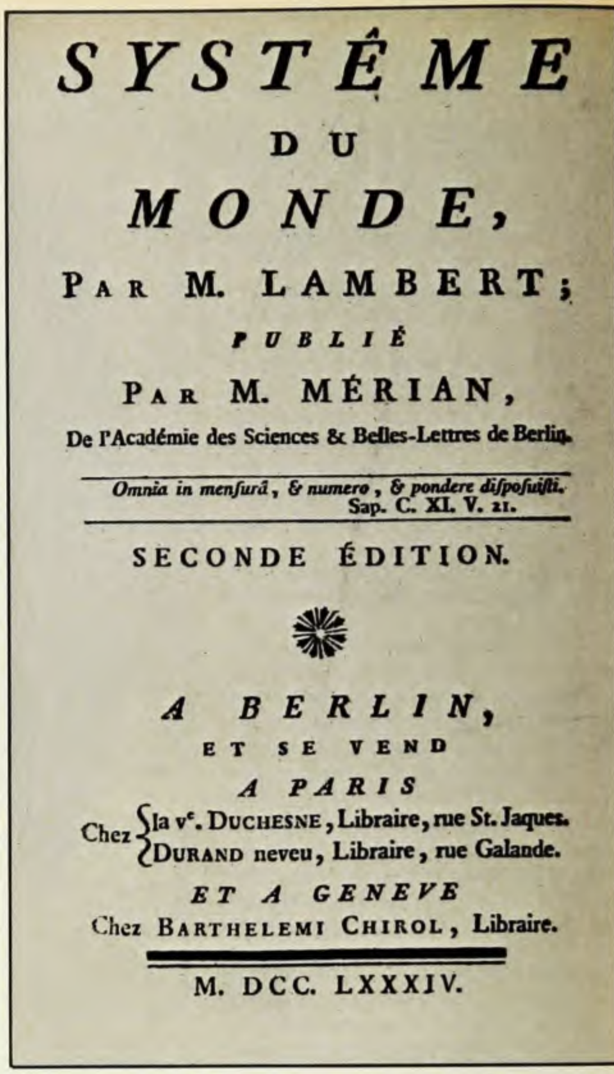
MONDE.

Omnia in mensurâ, & numero, & pondere disposuisti.
Sap: C. XI. V. 21.

par Merian

A BOUILLON,
AUX DÉPENS DE LA SOCIÉTÉ TYPOGRAPHIQUE.

M. DCC. LXX.



SYSTÊME

DU

MONDE,

PAR M. LAMBERT;

PUBLIÉ

PAR M. MÉRIAN,

De l'Académie des Sciences & Belles-Lettres de Berlin.

Omnia in mensurâ, & numero, & pondere disposuisti.
Sap. C. XI. V. 21.

SECONDE ÉDITION.

A BERLIN,
ET SE VEND
A PARIS
Chez la v^{e}. DUCHESNE, Libraire, rue St. Jaques.
DURAND neveu, Libraire, rue Galande.
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First and second editions of Bernard Merian's condensation of Lambert's *Cosmologische Briefe*. Merian, a leading fellow member of the Berlin Academy, left out much of the scientific contents. Worse yet, he left Lambert's name off the title page, an omission he remedied in the second edition. First-edition title page reproduced from a copy in the New York Public Library, second edition from the Crawford Library, Edinburgh.

Lambert . . ." Another stereotyped claim about Lambert's cosmology is its identity with that of Kant; actually, the differences between the two are considerable.

Finally, in most recent references to Lambert's cosmology, no mention is made of the contemporary scientific preoccupation with comets and of the widespread popular concern about a possible collision of the Earth with a comet, two factors that were very much in Lambert's mind when he suddenly composed the *Cosmologische Briefe* between June and October 1760.

Once more he wrote in haste. He chose the letter form to enliven his presentation, but as a result he continually repeated himself through his imaginary correspondent. Nor did it help that, during those months with his family in Mulhouse, he was away from his books—except, obviously, his chief source material, a table[11] of the characteristics of 21 cometary orbits published by Edmond Halley in 1705. One of the entries there was the comet known today as Halley's comet, the return of which Halley predicted for mid-1759. Although its failure to appear exactly on time prompted some to doubt the validity of Newtonian dynamics, its appearance around Christmas and its splendid visibility during the first months of 1760 was electrifying.

Comets are indeed the exclusive topics of the first eight of the twenty letters comprising Lambert's work (and are dealt with extensively in the other twelve). In those eight letters Lambert aimed to show that the collision of a comet with the Earth was most unlikely and that the number of comets around the Sun was very great. A collision-free world full of comets—so many abodes of life—appeared to be a perfect support of that contention. Both points were needed on behalf of Lambert's claim that, insofar as the Universe was a purposeful whole, it had to be full of intelligent beings everywhere.

One of the proofs Lambert offered as to the absence of collisions among celestial bodies was based on an analysis of Halley's table. It showed that the greatest angles of inclination were displayed by those comets that had their perihelion within the orbit of Mercury. But did it follow from this that their orbits had been set for the purpose of greatly reducing the possibility of their collision with the planets? If one pictured with Lambert the comets as bodies similar in density to planets but with an atmosphere much denser than that of Earth, their repeated return in their orbits could not be questioned. It was only a hundred years later that the opposite conclusion began to be drawn, precisely because of the very fragile composition of the bodies of comets. A body mainly composed of particles of ice and dust must disintegrate after repeated approaches to the Sun and exposure to the gravitational pull of the major planets. This is why today, after the recording of many thousands of comets, only a hundred or so are found to have periodic orbits.

In discussing the orderly arrangement of comets around the Sun, Lambert repeatedly referred to spokes in a wheel, an important analogy in his construction of the Universe. The analogy implied that the immense host of comets around the Sun were confined to a space resembling a disk which was, however, not as flat as the space within which the planets were confined. The disk was the basic pattern Lambert saw realized in ever higher units of the Universe. The spokes-in-the-wheel model also prompted Lambert to give preference to the increase of the number of comets with the square of distance instead of with its cube. On this Lambert was later criticized by Dominique-François-Jean Arago,[12] who argued that increase with the cube of distance was correct. At any rate, Lambert was a pioneer in insisting that the number of comets within a given radius from the Sun justified an inference to their number within a much larger radius.

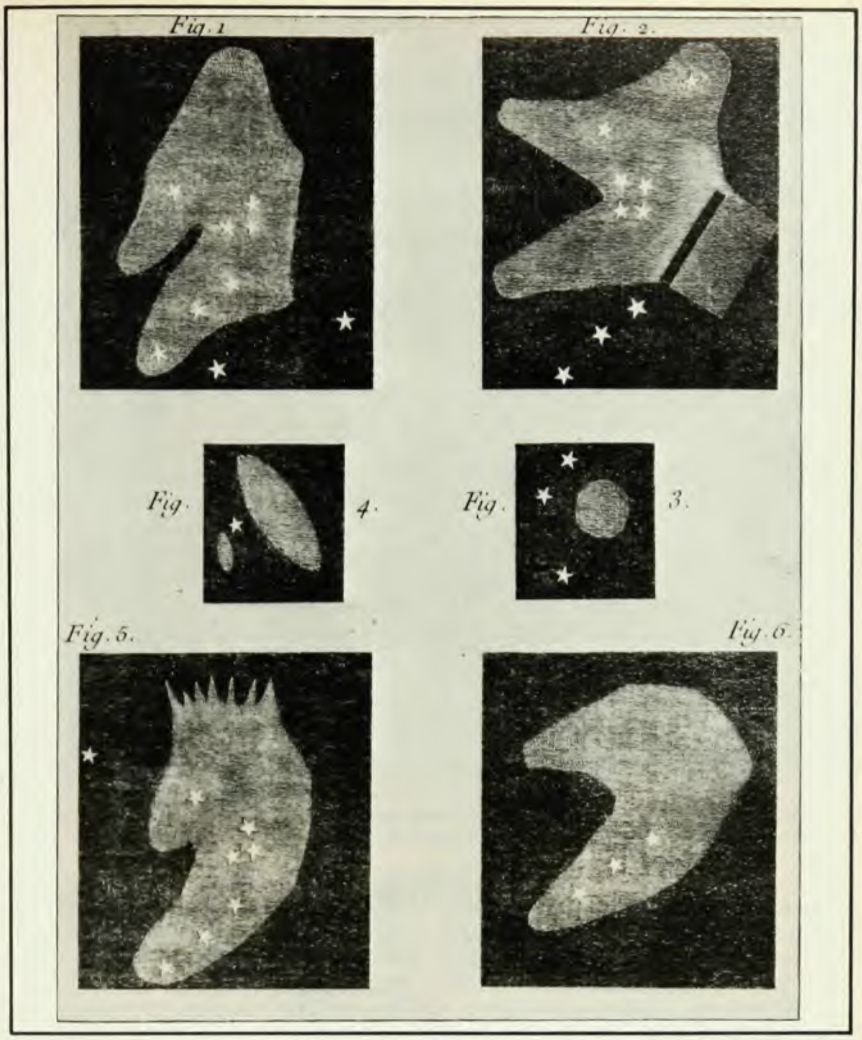
That number, as estimated by Lambert, ran into the millions even within the radius of Saturn's orbit. His estimate was based on Newton's estimate of the perihelion distance of the comet of 1680 as only one-sixtieth of the mean distance of Mercury from the Sun. When in the ninth letter Lambert offered another similar estimate of the number of comets, he had already spoken at length of the ability of life to exist under the most extreme conditions, referring as a proof to the ability of asbestos to resist fire. He considered those comets that spent much of their journey in incredibly cold interstellar spaces populated with "superior astronomers."

Regents of star systems

Lambert's explanation of the visual appearance of the Milky Way in the ninth letter signalled a turning point in his cosmological speculations. In his explanation,[13] first conceived in 1749, he saw a major observational evidence that the disk was indeed the pattern on which the world was built, even on levels far surpassing the level of satellites and planets. Lambert illustrated his explanation of the Milky Way with a model, a huge room filled with lamps. He pictured the Milky Way as a disk composed of a large number of stellar systems, with an empty space in its central region.

Although he first gave an optical reason for advocating this ring-like model of the Milky Way, his real reason had to do with gravitation. Just as satellites were kept in their orbits by planets, and planets and comets by the Sun, so the suns of the Milky Way also needed a central gravitational fulcrum.

To secure the stability of systems of stars Lambert postulated at their center a body that ruled the system gravitationally, which he called a regent. The body had to be very massive to match the total mass of all suns, each with a huge



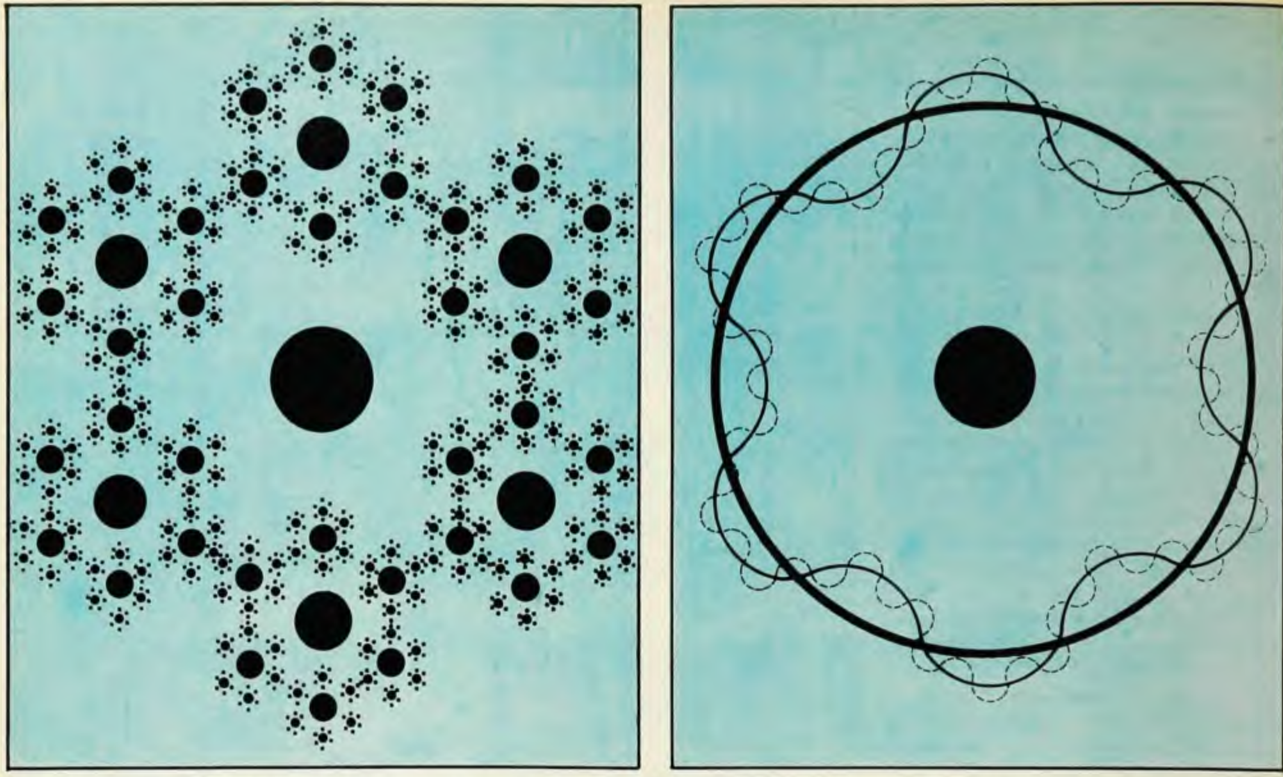
The Orion nebula, shown in the four corner drawings, was thought by Lambert to be in the direction of the center of our local system and hence of the site of a dark regent. He urged the study of drawings such as these for possible variations in appearance. Figure 1 in the illustration is by Christian Huygens, figures 2 and 6 are by Guillaume Le Gentil and figure 5 is by Jean Picard. This copper engraving, published by Le Gentil in the 1759 volume of the *Mémoires de l'Académie des Sciences*, is reproduced here by permission of the Universiteits-Bibliotheek, Amsterdam.

retinue of planets and comets. (Curiously, Lambert did not think of the need of increasing the Sun's mass to match the mass of millions of solid comets, each large enough to serve as the abode of life around it.) The regent had to be dark; a self-luminous regent would have been conspicuous in the sky.

The gravitational control of stars by a regent was needed not only for securing stable orbits but also for ensuring sufficiently fast motion in their orbits. With no regent in their midst their orbital velocities would have been much slower—and forever undetectable, a prospect not to Lambert's liking. He wanted to secure for his arrangement of the world edifice features that could eventually be verified by observation. Lambert hoped for verification of the systematic motion of stars around their regent through a comparison of old and new star catalogues, such as the comparison being carried out at that time by Mayer of Göttingen University.

Another observable feature of a stellar system concerned its regent, pictured by Lambert as a dark body illumined by stars close to it. Because these stars moved around it with various periods, the light reflected by the surface of the regent in a given direction was not always of the same intensity. Lambert, who saw the center of our local system in the direction of Orion, hoped that a part of the dark nebula there might be the surface of a regent, pointing out that previous drawings of it might show a variation of its brightness. He also hoped to obtain evidence about the regent of our star system from the analysis of planetary perturbations. These, Lambert contended, could be due in part to the cycloidal pattern imposed on the orbit of planets by their orbiting not only around the Sun but together with the Sun around its regent.

Being aware of the imperfections of the



Schematic generalization of Lambert's hierarchical universe as pivoted on dark regents. The latter's coordination is shown on the left, and the increasingly complex superposition of their cycloidal orbits on the right. Drawings by David Juchniewicz, Department of Fine Arts, Seton Hall.

telescopes of his day Lambert was not particularly concerned with observational evidence about systems higher than the Milky Way. He emphasized that if the existence of our local system were demonstrated, inference to more inclusive systems could be legitimately made on the basis of the principle of analogy.

These inferences were, however, occasionally inconsistent. A case in point is his presentation of a system composed of six stellar systems similar to our local system of stars. He thought that six circles (disks) placed contiguously around a circle of similar size secured the kind of plenitude that was no threat to an orderly arrangement of celestial systems all in gravitational interaction. But he did not apply this composition by six units to the Milky Way or to higher systems.

Lambert's cosmos

Lambert was not explicit about that major, all-pervading single plane of the Universe implied in his reliance on the disk pattern and of a pattern of disks lying in the plane of a more inclusive disk. It was only the local star system and the Milky Way that he considered as resembling a very flat disk. He had, however, explicitly rejected the possibility that in systems of stars like our local system stars could move at steep angles to the main orbital plane.

Assigning the shape of a disk to the Universe was certainly consonant with Lambert's repeated emphasis on its finiteness. That finiteness was demanded, according to him, by its purposeful nature, which called for its hierarchical organization. Lambert advocated the finiteness of the Universe with an assurance that could but make his reader feel that the growing popularity of the opposite view was no major challenge. Tellingly enough, it was not in the *Briefe* but in *Photometria* that he took up the optical paradox of an infinite number of stars. Although he recalled J. P. Loys de Chéseaux's solution to it, his point was that the paradox rested on a disregard of the inhomogeneous distribution of stars evidenced by the Milky Way.[14]

An interesting though not essential aspect of Lambert's cosmology was his assigning ranks to celestial bodies in ascending order from satellites to the centralmost regent. A satellite was a body of rank 1; a planet, of rank 2; a sun, of rank 3; the regent of the local stellar system, of rank 4; the regent of the Milky Way, of rank 5, and so forth. He gave rank 1000 to the centralmost regent, a number merely suggestive of the enormity he attributed to the finite Universe. In reverse order he ranked as number one the orbits of regents moving around the centralmost regent, the only purely elliptical orbits in the Lambertian universe. The orbit of the Earth was of the 998th order. This indicated the superimposition of as many orbits in the path they were actually tracing out, with each superimposition resulting in an additional cycloid. His illustration of this was the wobbling of a small canoe on a large wave.

Such a theory was free of the gravitational paradox of an infinite Euclidean homogeneous universe, and had for its support the explanation of the Milky Way as a disk and the presence of disk-type systems at the level of satellites, planets and stars in the Milky Way. The theory was rich in predictive details: the motion of stars in fairly circular orbits, the cycloidal pattern of their motion, the dark regents, and the solidity, periodicity and number of comets. Lambert listed in the concluding letter the existing proofs, principal predictions and expected verifications of his theory. This methodical procedure was not repeated in cosmological writing until the twentieth century, an indication of the genuinely scientific status Lambert meant to secure for his cosmology.

The modernity of Lambert's cosmology

The publication of the *Cosmologische Briefe* did not produce the echo Lambert hoped for. Bernard Merian, a colleague of Lambert in the Berlin Academy, did not help much by publishing, in 1770, a French résumé of it: He changed the title and put Lambert's name on the title page only in the second (1784) edition. Merian eliminated not only the letter form but also much of the science contained in the *Cosmologische Briefe*. He largely ignored Lambert's advocacy of the finiteness of the Universe.

One possible cause for the erstwhile lack of popularity for Lambert's cosmology appears to derive from his advocacy of the finiteness of the mass of the Universe. But that feature, which could hardly appeal in times when the infinity of the Universe was generally accepted as an incontestable verity, should appear attractive today when finiteness is endorsed by the most plausible relativistic cosmological models. That finiteness is endorsed today partly with a view toward the gravitational paradox that besets the infinite, homogeneous distribution of stars. Indeed, the gravitational paradox of a homogeneous Euclidean universe was the background against which Einstein presented his non-technical account of general relativity.[15]

Another reason for the timeliness of Lambert's cosmology may be found in the possible historical anticipation of black holes, bodies so massive as to trap even photons in their gravitational fields. A witness to that interest is the facsimile reproduction of a passage in Laplace's *Exposition du système du monde* (1796) in *Gravitation* by Charles Misner, Kip Thorne, and John Wheeler,[16] which is undoubtedly one of the major recent publications in scientific cosmology. In that passage Laplace claims as most likely the existence of as many opaque as of bright or visible stars and attributes their opaqueness to the gravitational field produced by their enormous mass.

The passage, in which Laplace asserts that a luminous star with a diameter exceeding 250 times that of the Sun and with a density equal to that of the Earth would prevent the outward flow of its light, did not go unnoticed. At the urging of Franz von Zach, Laplace worked out in mathematical detail his assertion in a paper that saw print in 1799 in the *Allgemeine geographische Ephemeriden* edited by Zach. That the English translation of the short paper was published in a recent major publication in the field of scientific cosmology[17] indicates the interest in the historical antecedents of the notion of black holes. Possibly these two recent references to Laplace's opaque stars were prompted by a reference to them in Sir Arthur Eddington's *The Internal Constitution of the Stars.*[18] In these references to Laplace's opaque stars, however, it went unnoticed that the passage in question failed to occur in the *Exposition* from its third edition (1808) on. Did Laplace sense that there was something wrong with his reasoning? Although he still spoke of opaque stars it was only in connection with highly variable stars.[19]

In view of Laplace's well known reluctance to give proper credit to his sources (his silence on Lambert's work on the periodic irregularities of the motion of Saturn is a case in point), it is possible that through Merian's work, widely available in France in Laplace's time, Laplace was led to his notion of opaque stars through Lambert's dark regents. Of course, Lambert did not speak of stars made opaque by their gravitational field. But the size of the opaque star assumed by Laplace was not very different from the one taken by Lambert for the size of the dark regent of the local star system. Lambert was more boldly modern than Laplace in suggesting a stellar density in comparison with which gold was mere sponge.

The house in which Lambert was born, photographed by the author. It is in the city of Mulhouse, Alsace, France, the site this month of a bicentennial meeting held in Lambert's honor.

But the real modernity of Lambert's dark regents and of his hierarchical (a word he never used) Universe goes beyond mere quantitative, technical details. A hierarchical cosmological system anchored in a centralmost dark regent of enormous mass and density shows the Universe in its stark singularity. Much the same view is evoked by black holes—especially that black hole into which all the matter in the Universe may eventually be confined should its present expansion turn into contraction. While it is not beyond the realm of possibility that eventually a way beyond the state in which matter exists in a black hole may be found, in all likelihood this will appear even more singular than the hole itself. Such at least is the prospect that presents itself from so many past failures to derive from generic considerations the singular, large-scale features of the Universe.

For all the *a priori* bent of his philosophizing, Lambert the scientist—always intent on experimental verification, on the improvement of scientific instruments, on amassing observational data—would have welcomed such a prospect. It is that respect for facts and that care for mathematical exactness that are in part the key to the lasting value of his scientific work, and to which his readiness to systematize was undoubtedly a threat. When the many aspects of his scientific and philosophical genius are discussed by a large international gathering of scholars in Mulhouse this month, his fondness for teleological considerations and his preoccupation with comets will also be set forth. It will be noted there that his cosmology was unsuccessful in his time not only because of a spreading infatuation with an infinite Euclidean, that is, a least singular, Universe, but also because of the sudden demise of interest in comets.

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