JHA, xvi (1985)

STUKELEY'S COSMOLOGY AND THE NEWTONIAN ORIGINS OF OLBERS'S PARADOX

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INTRODUCTION

William Stukeley (1687-1765), the antiquary and founder of British field archaeology, is best known to historians of science for his memoirs of Isaac Newton and, to a lesser extent, for the part he played in the affairs of the Royal Society from the time of his election in 1718. His name brings to mind the story of Newton's apple, and the fanciful association of Stonehenge with Druids, and it is therefore not surprising if his manuscripts have not previously been examined by historians of astronomy. Nevertheless, Stukeley fills a 'gap' in the history of theories of the Milky Way, for he antedated Kant and Lambert by three decades in seeing the Milky Way as the counterpart among the stars of the ecliptic in the solar system. He discussed the Milky Way and the stellar universe with Newton in the latter's old age, and Newton's replies give us additional insights into Newton's own thinking. And Stukeley may well be the long-sought person who stimulated Halley into the first public discussion of what has developed into 'Olbers's Paradox'.

THE SOURCES

Stukeley was born in Holbeach, Lincolnshire, on 7 November 1687, and went to a local school. In 1703 he entered Corpus Christi College, Cambridge, where his contemporaries included Stephen Hales and Stephen Gray. After graduating in medicine early in 1708 he continued his medical studies in London, and himself practised medicine, first in the country and then, from 1717, in London. Stukeley suffered from gout, and in the hope of finding a cure he returned in 1726 to Lincolnshire. Three years later – to the consternation of friends – he gave up medicine to be ordained a clergyman of the Church of England, so giving institutional expression to the concern he and many contemporaries felt for integrating the religious and the scientific views of the world. For the rest of his life he held benefices, first in Lincolnshire and then, from 1747, in London, where he died on 3 March 1765.

Stukeley is famous for his lifelong passion for antiquities, and in addition to his many publications on Stonehenge and other sites he left behind a vast quantity of manuscripts now scattered among numerous public and private libraries of England and Wales. These have been listed, but not completely, by the archaeologist Stuart Pigott, who studied Stukeley while a graduate student at Oxford and published a biography, in which he naturally concentrates on Stukeley's activities as an antiquary.[1] Stukeley was a meticulous draughtsman and has preserved for us a record of ancient monuments as they appeared in his day. He also kept careful memoranda of conversations, although when using these later he often employs several words where one had originally sufficed.

The surviving manuscripts of major relevance to our story are (i) the draft in the Library of the Royal Society of Stukeley's "Memoirs of S^{r} Isaac Newton's Life",[2]

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which was not published until 1936;[3] (ii) the earlier draft of these Memoirs,[4] and a related document,[5] now in Grantham Public Library; and (iii) a tract on "Hades", now in Corpus Christi College, Cambridge,[6] which dates from 1757 and is close in spirit to the writings of Thomas Wright of Durham.

In the first part of this paper we shall be concerned with Stukeley's Memoirs of Newton. These are dated 1752 in both the Grantham and the Royal Society manuscripts, but were assembled piecemeal, as we shall see, from earlier materials, many of which were exactly dated and possibly composed at the time of the events reported. Stukeley's method of 'working up' his drafts into a publishable document is clear from examination of the Grantham and Royal Society manuscripts. In the first version (Version I) the Grantham text was written out on the right-hand pages of the manuscript, the facing pages being left blank. Alterations and additions were then placed on these facing pages, though the changes are so extensive that the facing pages are sometimes filled to capacity and any further additions must be placed elsewhere as space allows; the composite text we term Version II. The Royal Society draft, which is a modification of Version II that we term Version III, was written out afresh, again on right-hand pages only; and once more, extensive additions were made on the facing page to give the Version IV from which the 1936 printed edition was (somewhat carelessly) taken.

Often the additions are nothing more than 'padding': a Stukeley determined to use many words where few would suffice. In such cases Version I will usually be more faithful to the original memoranda than the enhanced Version IV of the modern edition. But some additions in Versions II and IV introduce completely new material that is of the greatest interest, as we shall see.

It may be that some of the original memoranda from which Version I was compiled survive unrecognised in libraries, but a search of the likely sources has brought nothing to light, except for the one short document at Grantham. Its title, "Memoirs of the life of S^r^ Isaac Newton", is a variant of the "Memoirs of S^r^ Isaac Newton" of the other Grantham manuscript; but it must represent a much earlier stage in the process by which Stukeley digested his memoranda into the Memoirs, for *without the slightest preamble* the text begins abruptly with "15 April 1726. I visited S^r^ Isaac Newton...". This was the famous occasion on which Newton explained to Stukeley how the fall of an apple had triggered off his thinking on dynamics. Although clearly not the actual sheet of paper on which Stukeley made a record of the meeting, since it has the heading "Memoirs..." that belongs to a later era, it may be an unrevised transcript of this record, and is probably as close as we can come to the famous conversation. The relevant passage is transcribed as Appendix 2.

Elsewhere in the Memoirs Stukeley explains how he came to be intimate with Newton: he was a regular attender at the Royal Society meetings from the time of his election in March 1718, and because he and Newton both came from Lincolnshire, "I was well receiv'd by him, and enjoy'd a good deal of his familiarity and friendship".[7] This happy state of affairs continued until Edmond Halley resigned as Secretary of the Society late in 1721. Stukeley dared to stand as candidate for the post in opposition to Newton's nominee, and was narrowly defeated.[8] This display of independence led to a coolness between them for two or three years, but eventually good relations were restored, and Stukeley was nominated by Newton to the Council of the Society and, interestingly, as one of the Visitors of Greenwich Observatory for 1726.[9] His fellow Visitors were Martin Folkes, Vice-President of the Royal Society, Brook Taylor the mathematician, and John Hadley and George Graham the instrument makers.[10] Stukeley is the only one of the party not to figure in the *Dictionary of scientific biography*, but he may perhaps win a place in the next edition.

The conversation between Stukeley and Newton with which we are chiefly concerned was on cosmology and cosmogony. Stukeley tells us that it occurred "toward the beginning of our acquaintance",[11] and so we can place it in the early part of the period from March 1718 to November 1721 (when the "coolness" began), and presumably it took place before 23 February 1721 when, as we shall see, Stukeley and Halley breakfasted with Newton. It is noteworthy that Stukeley does not date the conversation exactly, which might mean that he is writing later from memory. But the conversation made a big impression on Stukeley, for he tells us it led him to give serious thought to the implications for science of the Creation account in Genesis;[12] and his summary report of Newton's recorded comments, though not as precise as we would wish, makes surprisingly good sense in the light of what *we* know (but Stukeley probably did not) of his theorizing about the stellar universe. It is most unlikely that Stukeley could have carried such a convincing report in his head for thirty years.

The report of the conversation is very lengthy, and in the printed version occurs awkwardly near the end of the Memoirs.[13] The reason for this becomes clear from the Grantham manuscript; for Version I of the Memoirs contains no mention of their talk. But when revising the draft for Version II Stukeley either recalled the conversation or came across his memorandum of it, and decided it was so important that it must be inserted somewhere. Uniquely, he makes no attempt to fit the additional words onto the facing pages (his account was to be much too long for that), but instead writes them out on completely fresh sheets.[14] Unfortunately the later sheets (which physically formed the final pages of the compound manuscript) are lost, and for the concluding stages of the conversation we have only the text of Versions III and IV in the Royal Society manuscript. The incomplete Version II account is reproduced below in our next Section, and an edition of the account in Versions III and IV is given in Appendix 1.

The other section of the Memoirs that interests us is Stukeley's report, dated exactly to 23 February 1721,[15] of the breakfast conversation between himself, Newton and Halley. In the Memoirs Stukeley confines himself to what Newton said, but it is entirely possible that Stukeley repeated to Halley something of the ideas on cosmology he had expressed to Newton on the previous occasion. Only a fortnight later, Halley read a short but momentous paper to the Royal Society on whether the stars are infinite in number, in which he discusses an "Argument I have heard urged"[16] based on the darkness of the night sky. Historians have wondered from whom Halley heard the argument. It was probably Stukeley.

One later Stukeley document is of importance to us. This is the fifteenth of a number of short tracts and formal 'letters' written between 1729 and 1762, and now in the Library of Corpus Christi College, Cambridge.[17] It is on "Hades", and near the title carries the date "17. aug. 1757". As an interpolation near the end of the document[18] is dated 18 September 1757, we know with certainty when the pages before us were written. It could be that, as with the Memoirs, Stukeley has revised earlier material, but there is no evidence of this. The text occupies some 16 small pages, and in addition there is a drawing (see Figure 3). The tract is in the form of an imaginary letter (Thomas Wright of Durham's *An original theory* is in the form of nine such 'letters', and J. H. Lambert's *Cosmologische Briefe* in the form of twenty[19]), from "Chyndonax"[20] to "Miriam" – Chyndonax being a Druidic name used by Stukeley. It shows how Stukeley, like Wright, was striving to unify his scientific and his religious views of the universe; and how, in the process, he was able to offer novel (if speculative) insights into the universe of stars.

STUKELEY'S CONVERSATION WITH NEWTON ON COSMOLOGY AND COSMOGONY

It is in the Royal Society manuscript (Version III) that Stukeley assigns this important conversation to the period "toward the beginning of our acquaintance".[21] By contrast, in the account[22] of the conversation interpolated in the revised Grantham manuscript (Version II of the Memoirs), Stukeley makes no mention of date, but instead begins as follows:

> I remember further, that in some discourse I had with S^r Isaac, I proposed to him a thought I had entertained how to account for that great luminous circle incompassing us, which we call[e]d the Milky Way. We all readily suppose it to be owing to the suns of seperate systems there plac'd whose united rays cause that luminous appearance. We mortals said I are pleas[e]d with new works, new advances in our knowledg, more than in what we have already done, what we are now in poss[ess]ion of, like Alexander [the Great], who sigh[e]d for new worlds to conquer. & this is the constant entertainment of our lives as long as our facultys will permit us.
>
> This desire in us may be a divine particle derived from our maker, & seperated from its imperfection may give us some notion of the agency of the supreme mind. I suppose therefore God almighty tho' in the Mosaic cosmogony, he is said to rest from all his works wh[ich] he had created & made, spoke only in regard to our present system: yet why sh[oul]d we not suppose that God always created new worlds, new systems, to multiply the infinitude of his beneficiaries, not only in giving a power in all things partaking of any degree of life in his systems already made to continue their own kind in an endless chain: but that he still made new worlds for the living creatures thereof to do the like.[23]
>
> We may suppose therefore, continued I, that G[od] alm[ighty] who always practises order method & regularity & in all his works places these new worlds & systems of worlds in a certain great & broad line or belt as it were, not made of single systems in bredth, but of many, wh[ich] we call the milky way: not filling infinite space *quaquaversum* [on every side], but in a certain huge meridian, as we may call it, thus dividing infinite space into two great parts....

The rest of the Grantham manuscript is lost, and from here on we must be content with the revised manuscript in the Royal Society. If we compare the passage just quoted against Stukeley's revisions of it (see Appendix 1), we find that by the time we reach Version IV the changes have nearly trebled the length. But this extra material adds little of substance, except that after the second sentence quoted above Stukeley does enlarge helpfully on what he believes to be the received view of the stars. To quote Version III:

> We suppose with probability enough, that every star is a sun of a seperate system; some perhaps bigger, some lesser, some farther distant from others, some nearer. That they all have their concomitant planets, as our Sun. & in order to have a just idea of God's power, we may well conceive, every globe is perfectly different in its self, as to its inhabitants, and furniture, and attendants.
>
> But still the question remains, whence the origin of the milky way; notoriously a great circle including the whole of the creation to us visible?[24]

Stukeley's inspiration, we see, was religious, like that of Richard Bentley, William Whiston, William Derham, Thomas Wright and others (including Newton) who figure in the history of cosmology in England in this period.[25] The view that the universe is populated throughout with "inhabitants" is of course commonplace; but Stukeley is unusual in holding that creation did not end after the Sixth Day, and that any cosmology must allow God, like Alexander the Great, to conquer new worlds – or, rather, to create them. Creation did not stop after God made the solar system and the stars that are individually visible in the night sky; God continues, and will always continue, to create new stars with their attendant planets.

Further, Stukeley believes that God "always practises order method & regularity". He would have agreed with William Whiston, who had written, in his widely-read *Astronomical lectures* (to quote from the 1715 English edition):

> Phaenom. X. *The Fixed Stars seem to be dispos'd in the Heavenly Spaces in no certain Order, but as it were by Chance only.*
>
> *Solution.* Seeing that the System of our Sun now appears to be dispos'd in all its Parts, in a most beautiful Order, and with wonderful Skill; ...it is very rational to conclude, that some regular Order hath Place also amongst the Fixed Stars. There may be a certain orderly and harmonious Disposition of the Fixed Stars amongst themselves, when they are beheld from some other proper Place, altho' that Order appears not when they are seen from this Earth.[26]

Similarly, Rev. William Derham, in his immensely popular *Astro-theology* of 1715, had written of the "great Parity and Congruity observable among all the works of the Creation; which have a manifest harmony, and great agreement with one another". Modern telescopes, he says, have revealed many more stars than were formerly known,

> and all these far more orderly placed throughout the Heavens, and at more and due agreeable distances, and made to serve to much more noble and proper ends.... [The stars] are not set at random, like a Work of Chance, but placed regularly and in due order ... they look to us, who can have no regular prospect of their positions, as if placed without any Order: like as we should judge an Army of orderly, well disciplined Soldiers, at a distance, which would appear to us in a confused manner, until we came near and had a regular prospect of them, which we should then find to stand well in rank and file.[27]

Whiston and Derham were convinced there must be order among the stars to match the order in the planetary system; *Stukeley believes he has discovered wherein this order consists.* To quote Version III:

> but bec[ause] G[od] alm[ighty] always practises order, method, regularity in all his works; I suppose, he places these new worlds, & systems of worlds, in a certain great, and broad line [*del.*: , or belt, as it were]; not made of single systems in bredth, but of many, like a vast meridian, or plane of worlds; not filling infinite space *quaquaversum*, but dividing infinite space into two great parts, one on each side, this great mundane meridian. & that this is the occasion of the appearance, wh[ich] we call the milky way.
>
> for this notion we have a considerable confirmation, from considering our own world, that the plane of all the circles of the primary, & of the secondary planets, is nearly in one line. G[od] observes a great analogy in all his works. So that our System in that respect is but a sort of picture of the universe. & that meridional plane of our Solar System may be called our milky way. & hence the milky way in the heavens is the aggregate of what we can discern of this meridional plane of the macrocosm.[28]

Stukeley, then, draws the analogy between the ecliptic in the solar system and the Milky Way in the stellar system; the new stars, whose number will grow without limit, God places close to the plane of the Milky Way, and together they create the milky appearance of the Milky Way.

As is well known, in the mid-century the analogy between the ecliptic and the Milky Way was applied in their very different ways by Wright, Kant and Lambert, and in print; later it was introduced into scientific astronomy by William Herschel.[29] But as early as 1720 or thereabouts Stukeley was making the analogy the central concept of his discourse to Newton; so that (unless we regard the entire episode as a fiction created in 1752) he is by a whole generation the first person known to history to have had this fundamental insight into the stellar universe.

But in Version IV Stukeley goes on to draw a further analogy, this time with Saturn and its ring. He does this, first, by making two interpolations (which we here italicize) in the passage just quoted:

> ...& that this is the occasion of the appearance, wh[ich] we call the milky way *being a very distant view of that luminous plain, like the ring of Saturn, extending all around & beyond us.*
>
> for this notion we have considerable confirmation, from considering our own world, that the plane of all the circles of the primary, & of the secondary planets, is nearly in one line, *the plane of Saturns ring the same.*[30]

Secondly, after interrupting Version IV of his argument for an important digression (to which we return in the next Section), Stukeley introduces an extended exposition of the Saturn analogy:

> ...and this perhaps may give us some obscure notion of the reason of the odd formation of the planet Saturn: that it is as a miniature picture, or model of the το παν [lit.: "the all"; Halley uses the same term in the second of his 1721 papers to the Royal Society[31]]. for we must conceive that the plane of suns & systems of planets concomitant, wh[ich] make the lacteal circle, have a vast space left betw[een] it & the several stars wh[ich] we behold in a clear night. therefore these stars wh[ich] we behold in a clear night, we may liken taken altogether to the globe of Saturn: the plane of those stars beyond, wh[ich] appear to us like the lacteal circle, may be assimilated, taken all together, to the ring of Saturn.[32]

With his Saturn analogy, Stukeley distances himself from Wright, Kant and Lambert, for they all made the Sun one of the stars of the Milky Way. In Kant's conception, all the stars we can see – the Sun, the stars individually visible, and the stars of the Milky Way – are members of a disk-like Galaxy.[33] For Lambert, the Sun and the individually visible stars form a cluster that is one of many such clusters together making up a disk-like (but subdivided) Galaxy.[34] And although Wright's preferred model of our star system was quite different, he admitted the possibility that the Sun and all the stars known to astronomy occupy on terms of equality a space that has the shape of a flattened disk.[35]

By contrast, in his Saturn analogy Stukeley sees the Sun and the visible stars as surrounded first by empty space and then, at a distance, by the (increasingly numerous) stars of the Milky Way; and here Stukeley's conception is astonishingly close to a model popular in the mid-nineteenth century. Thus John Herschel, in *A treatise on astronomy* (London, 1833), says that a certain nebula "offers obvious analogies either with the structure of Saturn or with that of our own sidereal firmament and milky way" (p. 406). It is , however, noteworthy that the references to Saturn in Stukeley's Memoirs all enter in Version IV, and it is possible that this elaboration of the analogy belongs to 1752 rather than to c.1720. Indeed, in Versions II and III it is not entirely clear that Stukeley intends the Sun and the nearby stars to be distinct from the stars of the Milky Way, though Version II has God placing the new worlds in a "belt, as it were".[36] But in Version IV his grasp of the Saturn analogy is clear enough for him even to tackle the question of how the various distances involved compare: "I tryd it after a rude manner & found the interval [?between us and the nearest stars of the Milky Way] double the diamet[er] of the whole view of the fixt stars wh[ich] we behold." (See Figure 1.)

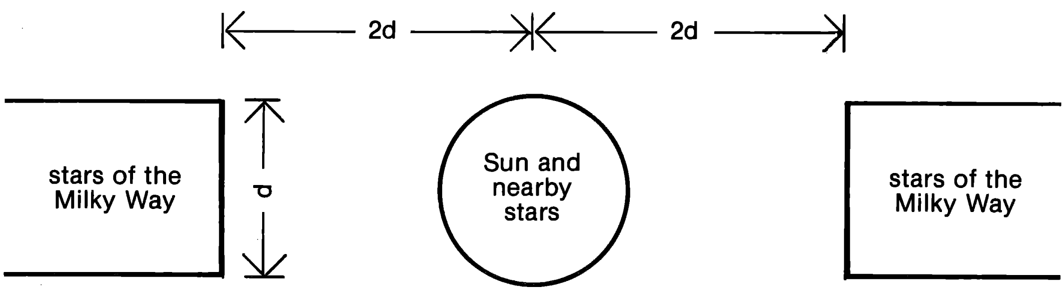


FIG. 1. A possible interpretation of Stukeley's account of the universe of stars as set out in Version IV of his Memoirs of Newton: "...the apparent bredth of the galaxy is generally about 23[?] degrees.... quaere supposing my hypothesis to be fact how far distant is it? I tryd it after a rude manner & found the interval double the diamet[er] of the whole view of the fixt stars wh[ich] we behold" (for text, including citation of different but similar angles, see Appendix 1). The figure as drawn represents a cross-section of the spherical cluster of nearby and individually visible stars, and of the surrounding layer of the stars of the Milky Way. The breadth of the layer is *d*, where *d* is the diameter of the spherical cluster, and the distance from the centre of the spherical cluster to the nearest stars of the layer is 2*d*. The apparent width of the layer as viewed from the centre of the cluster is then about 28°.

Stukeley is of course idiosyncratic in his speculations about the continuous creation of stars and planets; Newton, he tells us, conceded the notion was "agreable to philosophy", but wondered whether it was compatible with the account of the Creation in Genesis.[37] More importantly, despite his clear grasp of the analogy between the ecliptic and the Milky Way, Stukeley says nothing explicitly about the stars having an orbital motion about a central position. Instead, his interests are in explaining the appearances – in interpreting the information reaching us in the form of light – rather than in examining the implications for stellar astronomy of the universal law of gravitation attraction. How indeed could one discuss the effect of gravity in a universe where, at unspecified intervals, new matter in the form of new solar systems is repeatedly being created by God? This continuous creation no doubt explains why Stukeley sees the analogy between our solar system and the universe of stars as spatial and visual rather than dynamic, and why he does not discuss whether the stars are in orbit or at rest. But, as we shall now see, by asking from what possible arrangements of stars could the present appearance result, he may well have initiated the discussions that have led to the 'Olbers's Paradox' of modern cosmology, or the question "Why is the sky dark at night?"

To set Stukeley's contribution to this in its context, we must go back a generation in time, to events surrounding the publication of Newton's *Principia*, more than thirty years earlier: events in which Stukeley himself of course played no part.

STUKELEY, NEWTON AND THE ORIGINS OF OLBERS'S PARADOX

Introduction

In his conversation with Newton, Stukeley – probably unknowingly – confronted Newton with a compelling argument against the very world picture that Newton himself had devised a quarter-century before. Briefly: in order to reconcile the universal law of gravity with the observed absence of movement among the stars, Newton in the 1690s investigated a model of the stellar universe in which the stars are spread throughout infinite space with near uniformity, so that each star is balanced between roughly equal and opposite gravitational pulls. Newton explained this model to David Gregory in 1694, and Gregory touched briefly on it in 1702 in his *Elementa astronomiae*. Stukeley, in his c.1720 discourse to Newton on the Milky Way – which is the most obvious evidence against a symmetric universe – pointed out that if the stars were uniformly scattered, the whole sky (and not merely the Milky Way) would have a "luminous gloom". Newton himself was by that time no longer seriously involved in questions of the stellar universe, but there is circumstantial evidence that Stukeley may have repeated his comments to Halley and so provoked the first of Halley's famous 1721 papers on an infinite universe of stars; and it is also probable that Halley reread Gregory's account before giving the second paper a week later. To appreciate Stukeley's role in the history of Olbers's Paradox, therefore, it is necessary to know something of the earlier episode. In this Section, therefore, we outline what is already known about Newton's own investigation; and we examine more fully the two papers by Halley and the influence of Gregory and Stukeley in their composition.

Newton's Treatment of the Stars in Principia *(1687) and* De mundi systemate

In the account of his conversation with Newton on the structure of the universe of stars, Stukeley gives the impression that Newton remained aloof, merely deigning to offer gracious comment from time to time. In fact, though Stukeley is unlikely to have known it, Newton had given the question intensive thought when preparing a revision of the *Principia* in the 1690s.[38] For gravity, being a force, is a source of motion, and yet observations since Antiquity had confirmed that *without exception* the stars – the 'fixed stars', as the Greeks had termed them – were at rest, without motion. Therein lay for Newton a true paradox, but it was not one to which he addressed himself until after the publication of the *Principia* in 1687. In this first edition of the *Principia*, in fact, Newton makes only one mention of the stars, and that is merely to say that they are all very remote from the solar system: so remote that the planets in their orbits are for practical purposes always at the same distance from any given star, which therefore does not deform the orbits as it would if it were close at hand.[39] That is, the student of planetary orbits need not concern himself with the stars.

In *De mundi systemate* which in autumn 1685 had been intended as a conclusion to the *Principia* but which was not published until after Newton's death, Newton has more to say about the enormous distances of the stars.[40] The failure of astronomers to measure annual parallax showed (if one was a Copernican) that the stars were too remote for the parallax to be detected with the instrumental accuracy available, and this had led to estimates of the *minimum* distances at which the stars must lie. But Newton exploits a technique due to James Gregory,[41] and arrives at the first correct understanding of the scale of the *actual* distances that separate the Sun from the nearest stars. Gregory proposed that we assume the stars to be physically similar, so that faint stars look faint simply because they are more distant. Since light falls off with the square of the distance, this assumption allows us to convert ratios of apparent brightnesses into ratios of distances. But how to compare apparent brightnesses with the equipment available in the seventeenth century? In particular, how to compare the light of the nearest star, the Sun, with another star such as Sirius?

James Gregory hit on an ingenious technique that was to be exploited time and again into the early nineteenth century. This was to seize on a particular planet at a time when it is equal in brightness to Sirius, and then to forget about Sirius and calculate instead the ratio between the light that reaches us from the Sun directly and the light that comes to us from the Sun by bouncing off the planet. This ratio depends upon distances and other characteristics of the solar system, which we suppose to be known. This being so, we can calculate the ratio; and it is the same ratio as that of the apparent brightness of the Sun in comparison to that of Sirius. Now by the time Newton came to address himself to the problem, he had available a better value of the solar parallax than that used by Gregory, and this allowed him to become the first man in history to reach a correct appreciation of the distances that separate Earth from the stars (expressed as a multiple of the distance Earth-Sun): Sirius, he believes, is some one million times further from us than the Sun.[42] Since therefore even the brightest of the stars is unimaginably remote, and since gravity falls off with the *square* of the distance, little wonder that in *De systemate* Newton dismisses any worries over the gravitational pulls of stars on each other: "The fixed stars being, therefore, at such vast distances from one another, can neither attract each other perceptibly, nor be attracted by our Sun."[43]

But Newton here makes much too strong a claim. To begin with, he has not shown that the stars are very distant from one another, merely that they are very distant from one particular star, namely the Sun. More fundamentally, although the pull of one single star on another may be exceedingly small, the combined pulls of many – perhaps infinitely many – stars may be great, and perhaps even infinite. But, as we shall see, despite his pivotal role in the creation of the infinitesimal calculus, Newton does not think in terms of adding infinitely many pulls; and the grasp of David Gregory and Edmond Halley on the problem of infinitely many pulls is even less secure. For his part, Newton prefers to proceed by pairing off stars that lie in opposite directions from us, cancelling the pull of one star against the pull of a similarly placed star in the opposite part of the sky. Carrying this to a more sophisticated level, he will invoke Proposition LXX of Book I of the *Principia*, which tells us that a uniform shell of matter has no gravitational field inside it. If the stars at a given, large distance from us (or from anywhere else) are randomly scattered all round the sky, spread out on a geometrical sphere so to speak, then they will together approximate to a uniform shell and so have no collective gravitational effect on *any* of the stars within the sphere: as far as the stars inside the sphere are concerned, gravitationally it will be as though the stars on the sphere (and of course on any larger and concentric spheres) do not exist.

Newton's Correspondence with Bentley (1692-93)

We shall find Newton carrying these ideas to what is in effect their logical conclusion: once seriously and several times casually, he will compare the observed universe to a model suitably modified from one in which the stars are distributed throughout infinite space in perfectly regular fashion and each star is therefore poised between equal and opposite forces. This step was, it seems, forced upon him by the letters he received from the young theologian Richard Bentley in the winter of 1692/93. Bentley wished to publish the series of sermons he had recently preached under the will of Robert Boyle, in which his task had been to show that Christianity was fully compatible with the new science; and, anxious to find out what new light the forbidding *Principia* might shed on the universe, he decided to write directly to its author.[44] It did not occur to either Newton or Bentley to question whether the stars are indeed at rest. Lambert, in the 1760s, was to realise that since the stars are so enormously far away, their proper motions – if they have any – must be very small, so that even after a lapse of many centuries the rough agreement of modern and ancient star positions by no means proves that the stars are 'fixed'. Lambert knew no more of stellar distances and proper motions than did Newton; but Lambert's theory that the stars form a finite but stable system *required* the stars to be in orbit, and this led him to question whether the traditional evidence against this actually occurring was valid.[45] Newton remained under the influence of an earlier cosmology in which there had been no doubt but that the stars were at rest. Being at rest, they could not be finite in number in a universe ruled by a gravitational attraction, for a finite system would suffer gravitational collapse. (In any case, it is clear that many thinkers would not have regarded a finite system, alone in infinite space, as an intelligible concept.) Interestingly, when in 1718 Halley published the first three changes in stellar positions,[46] none of his contemporaries seems to have seen the implications, and neither did Halley himself: "But if the whole [universe of stars] be Infinite", he wrote in 1721, "all the parts of it would be nearly *in aequilibrio*, and consequently each fixt Star, being drawn by contrary Powers, would keep its place; or move, till such time, as, from such an *aequilibrium*, it found its resting place...".[47] He seems to have believed that the stars will oscillate about equilibrium positions provided only that the stellar system is infinite, and they will do so whether or not the stars are *regularly* distributed. In short, although to Newton it was puzzling that the stars did not move, neither he nor others who were aware that the stars are very remote had subjected their supposed 'fixity' to critical examination. No one had asked whether there had been time for the stars to alter position noticeably since Antiquity, and no one examined catalogues to see whether they had in fact done so – Halley's discovery was an unforeseen by-product of a study of the rate of precession, and its significance went unappreciated. The possibility of secular motion of stars was admitted into astronomy only when theory positively demanded it, and meanwhile for Newton the challenging paradox remained, that every star was at rest despite the gravitational pulls upon it.

Bentley in his first letter asked Newton what would be the effect of gravity on matter "eavenly scattered"[48] throughout infinite space. Newton was more pragmatic in outlook than is often thought, and he was loathe to take literally the hypothesis of complete uniformity of distribution. But eventually he had no option but to agree that if the matter were distributed with perfect and unbroken uniformity then every particle would remain at rest. He did so with reluctance:

> but that there should be a Central particle so accurately placed in ye middle as to be always equally attracted on all sides & thereby continue without motion, seems to me a supposition fully as hard as to make ye sharpest needle stand upright on its point upon a looking glass. For if ye very mathematical center of ye central particle be not accurately in ye very mathematical center of ye attractive power of ye whole mass, ye particle will not be attracted equally on all sides.
>
> And much harder it is to suppose that all ye particles in a infinite space should be so accurately poised one among another as to stand still in a perfect equilibrium. For I reccon this as hard as to make not one needle only but an infinite number of them (so many as there are particles in an infinite space) stand accurately poised upon their points.[49]

It did not take Bentley long to realise that it was just as difficult to have infinitely many *stars* without motion as it was particles:

> I acquiesce in your authority, yt in matter diffused in an infinite space, tis as hard to keep those infinite particles fixt at an equilibrium, as poise infinite needles on their points upon an infinite speculum. Instead of particles, let me assume Fixt starrs or great Fixt Masses of opake matter; is it not as hard, yt infinite such Masses in an infinite space should maintain an equilibrium, and not convene together? so yt though our System was infinite, it could not be preserved but by ye power of God.[50]

Providence and the Universe of Stars

Bentley had put his finger on the problem: how to reconcile universal gravity with the 'fixity' of the stars. In his reply[51] Newton ignores the challenge, yet within a few months he was telling David Gregory that "a continual miracle is needed to prevent the Sun and the fixt stars from rushing together through gravity".[52] But surely this "miracle" could not simply be the annihilation of gravity at large distances, for presumably gravity would then cease to be a universal law, and the stars would be at rest *whatever* their distribution in space. Had this been Newton's position, he would have been saved a great deal of anguish, as we shall see. Instead, it would seem, Newton believes there is a providential plan to ensure long-term stability and this plan is to be found in the structure of the system of the stars, just as we recognise the hand of Providence in the well-structured system of the planets and comets. As he writes in the 1706 edition of the *Opticks*: "... whence is it that planets move all one and the same way in orbs concentric, while comets move all manner of ways in orbs very eccentric, and what hinders the fix'd stars from falling upon one another?"[53] For the stars this providential plan consists in (a) a wide separation of the stars one from another, and (b) a high degree of regularity in their distribution; so that the individual gravitational pulls (a) are tiny, and (b) to a large extent cancel one another out.

But this is not the end of the story. In the system of planets and comets, Newton sees careful planning on the part of Providence that has ensured long-term stability; but the stability is not completely permanent, and in the end the system, as he puts it, "wants a reformation"[54] – Providence must intervene to prevent gravitational collapse, and will thereby demonstrate a continuing concern for the welfare of mankind. In short, Providence has what might be described as a regular servicing contract with the solar system. But these 'reformations' are not miracles in the conventional sense of the word; they are not 'one-off' interventions for a specific purpose. Rather, they were planned from the beginning, and are a consoling demonstration to mankind that God has not simply created his universe and then abandoned it to its fate.

If my understanding is correct, then Providence has a regular servicing contract with the stars too: David Gregory's "perpetual miracle". These provisions for the long-term stability of the system of the stars show the foresight of Providence when planning the creation; but as the stars are *not* arranged with *perfect* symmetry – they are not like infinitely-many needles balanced on their points – the stability is not permanent, and Providence must regularly intervene to restore order. Leibniz later objected that the products of a good clockmaker need no such repairs, and that the Newtonian conception of God was inadequate. But Samuel Clarke, on behalf of Newton, retorted: "The notion of the world's being a great machine, going on without the interposition of God, as a clock continues to go without the assistance of a clockmaker, is the notion of materialism and fate, and tends ... to exclude providence and God's government in reality out of the world."[55]

Newton several times in later years touched briefly on the divine involvement in the universe of stars.[56] Sometimes he emphasises the symmetry in the arrangement of the stars that permits the cancelling out of pairs of pulls in opposite directions, sometimes he emphasises the enormity of inter-stellar distances – the two aspects are closely linked in his mind since, as we shall see, man's knowledge of the distances between stars other than the Sun can only come indirectly, from knowing *both* the structure or shape of the stellar system, *and* its scale, which is given us by the distance from the Sun to the nearest stars. In drafts of the General Scholium to conclude the second edition of the *Principia* that eventually appeared under the editorship of Roger Cotes in 1713, Newton tries out such phrases as "by removing the fixed stars to suitable distances [*ad commodas distantias*] lest they fall in on themselves" and "the distances of the fixed stars from the Sun and from each other should be of the same size lest their systems [of stars with attendant planets] fall in on each other";[57] but these did not actually get into print. Instead, the same sentiment, shorn of the specific reference to God and more technically expressed, is contained in the brief sentence he added to Proposition XIV of Book III: "Not to mention that the fixed stars, everywhere promiscuously dispersed in the heavens, by their contrary actions destroy their mutual actions, by Prop. LXX, Book I."

It was only in the third edition of 1726, which appeared near the end of Newton's life, that he set out explicitly the role of God in planning the stellar universe: "...and lest the systems of the fixed stars should, by their gravity, fall on each other, he [God] hath placed those systems at immense distances from one another."[58] In his own copy of the second edition, with annotations intended for the third, Newton considered (but rejected) an even more revealing statement – one which, though brief, sums up the role of God in reforming the stellar universe: "...et fixarum systemata per gravitatem suam in se mutuo paulatim caderent nisi omnia consilio entis summi regerentur" – the stars would, through their gravity, gradually fall on each other, were they not all carried back [*regerentur*] by the divine plan.[59]

How did Newton justify his claim that the stars are arranged in such a way that their pulls largely cancel each other out? He had intended to do so by means of a new Proposition XV for Book III, which he had evidently drafted by the time of Gregory's visit in May 1694 and which was very probably provoked by Bentley's cross-examination. It was intended for a second edition of the *Principia* that was to have had extensive revisions; but the second edition that eventually appeared did so long after Newton had abandoned academic life, and all that remained of the Proposition with its very lengthy proof was the single sentence that we have just quoted and which was simply added to an existing corollary to Proposition XIV. But elaborate drafts to Proposition XV remain among Newton's manuscripts, and they contain Newton's attempts to justify his belief that the system of the stars is approximately symmetric. To these we now turn.

Newton's Investigations of the System of the Stars (c.1693)

Newton sets out to prove in Proposition XV that "The fixed stars are at rest in the heavens and are separated by enormous distances from our Sun and from each other".[60] The observational evidence against which Newton must compare his geometrical model consists of the star catalogues. These catalogues give positions of the stars in the sky (that is, directions from us to them) and their apparent magnitudes; and an enquirer like Newton, interested in stellar statistics rather than information about individual stars, can readily obtain from them the numbers of stars of first, second, ..., sixth magnitude. To use this information to test predictions of the numbers of stars at various distances in a geometrical model, Newton must have a means of relating magnitudes – apparent brightnesses – to distances, and this requires him to assume, approximately at least, that the stars are physically uniform and differ in brightness only because they lie at different distances. This assumption was, after all, familiar from James Gregory's method of determining distances of individual stars.

Although in Newton's universe the Sun is an ordinary star and in no way specially located, in practice he has no alternative to structuring his geometrical model around a quasi-central Sun; for this is how the observational evidence is presented to us by Nature, and a successful comparison of model with evidence is his goal. Newton therefore sets up a geometrical model of the universe in which the Sun is surrounded, in the first place, by a number of stars lying at 1 unit of distance (whatever that should be). These are the nearest of the geometrical stars, and so correspond by hypothesis to the real stars of first magnitude.

Newton asks how many of these geometrical stars, which lie on a sphere centred on the Sun and with radius 1, could be found such that no two of them are less than 1 unit from each other – for all stars must keep due distance from their neighbours. The answer, he knows from geometry, is either 12 or 13, the small uncertainty being of no consequence. And this is indeed the approximate number of stars of the first magnitude, so that the first test of prediction against evidence is encouraging.

The next nearest stars must lie at least 1 unit from those just discussed, and so they are assigned to the sphere centred on the Sun and radius 2 units. Such a sphere, having four times the surface area of the previous one, will have room for four times as many stars, where each is to be no less than 1 unit from its nearest neighbours: four times 12 or 13, say 50. And this is close to the number of second magnitude stars in the catalogues; so far so good.

In the early drafts of the theorem, Newton continues with geometrical spheres of radii 3, 4, 5, 6 units, containing respectively some 9, 16, 25, 36 times 12 or 13 geometrical stars; and he hopefully declares in the drafts that these are roughly the numbers of (real) stars of third, fourth, fifth and sixth magnitudes, leaving blank spaces in his manuscript for these numbers to be filled in from the star catalogues later. Only when he actually comes to fill in the blanks does he make the disconcerting discovery that the numbers of stars in the catalogues in fact grow altogether more rapidly than the predictions from the model.

Newton realises that he has assumed, without argument, that a star of the *n*th magnitude lies at *n* units of distance. But the system of stellar magnitudes inherited from the ancients is not derived from astronomical considerations but depends essentially upon the physiology of the human eye: on when the eye judges the difference between two stars to be significant. There is certainly no reason to expect that Ptolemy's magnitudes correspond directly to distances, number to number, nor do they in fact do so. Newton, by this pioneering exercise in stellar statistics, is the first to realise this. It also provides him with an escape from his dilemma: he concludes that third magnitude stars correspond not only to 3 units of distance, but that they extend out to $\sqrt{10}$ and $\sqrt{11}$ units. With this flexibility, and a remark that the catalogues are incomplete for the fifth and sixth magnitudes, Newton believes himself vindicated in his claim that the stars are spaced out at near-regular intervals.

It was Halley, in one of the papers he read to the Royal Society in 1721, who suggested that sixth-magnitude stars correspond to about 10 units of distance[61] – so anticipating the modern definition of magnitude, which is chosen to conform as far as possible to the ancient classification. How Halley arrived at this brilliant insight he does not say: it may have been the fruit of an extended analysis along the lines we have just seen.

Obviously the real universe is not as regular as that of the model, and Newton is prepared to have a larger-than-average space allocated to a larger-than-average star: "For in the measure that their bodies are greater, so they ought [*debent* – the word is highly significant] to lie at a greater distance, because of the greater force of gravity by which they attract other stars."[62] Indeed, on further investigation he finds there are 15 or 16 first magnitude stars surrounding the Sun, instead of the expected 12 or 13, and this he explains by supposing the Sun to be some 20% oversized and therefore surrounded by a larger-than-average geometrical sphere with more than the usual number of stars.

The flexibility that Newton allows himself is most clearly set out in a draft of an elementary exposition of astronomy, undated but from his Cambridge days and so prior to 1696. He explains his assumption that the stars are physically uniform and continues:

> Yet this is to be understood with some liberty of recconning. For we are not to account all the fixt starrs exactly equal to one another, nor placed at distances exactly equal nor all regions of the heavens equally replenished with them.
>
> For some parts of the heavens are more replenished with fixt stars yn others, as the Constellation of Orion w[i]th greater or nearer stars & the milky way with smaller or remoter ones. For ye milky way being viewed through a good Telescope appears very full of very small fixt stars & is nothing else then ye confused light of those stars. And so ye fixt clouds & cloudy stars [nebulae and clusters] are nothing else then heaps of stars so small & close together that without a Telescope they are not seen appart, but appear blended together like a cloud.[63]

This is the only document known to me where Newton recognises the extent of the contrast between his idealized symmetric model and the appearance of the real universe. The "fixt clouds & cloudy stars" he could perhaps have deemed to be numerous tiny stars gravitationally equivalent to a smaller number of normal stars, but the Milky Way seems an insuperable obstacle. All the greater the fascination, therefore, when we read of Stukeley, years later, putting to Newton an explanation of the Milky Way and demanding to know his opinion.

But these obstacles do not prevent Newton, in continuation of the same document, from embarking on yet another comparison between predictions from his model and data from the star catalogues – and breaking off once more when he finds the numbers hopelessly diverge.

In another elementary document, entitled "Phaenomena",[64] Newton is yet again perplexed to find the numbers do not tally; this time in explaining away the divergence he speaks of "the stars of the small magnitudes being distinguished by their light decreasing in a geometric proportion", so that each magnitude class contains three times as many stars as its predecessor – a remarkable approximation to the modern definition which implies an idealized proportion of 3.98.

David Gregory and the System of the Stars (1694/1702)

In view of what we have learned from the study of Newton's manuscripts, we can appreciate how accurate were the memoranda that David Gregory made of his conversations with Newton in May 1694 when Newton explained to him his conception of the universe of stars and of the role of Providence in planning and preserving that universe:

> To discover how many stars there are of first, second, third etc. magnitude, he considers how many spheres, nearest, second from them, third etc. surround a sphere in space of three dimensions [this geometry is equivalent to the model we have discussed]: there will be 13 of first magnitude, 4×13 of second, 9×4×13 [error for 9×13] of the third. But there are 15 stars of the first magnitude, 4×15 of the second, and so on, other inequalities can compensate here. James Gregory first thought of comparing a star with the Sun....[65]

> [Newton says] that a continual miracle is needed to prevent the Sun and the fixed stars from rushing together through gravity....[66]

> The fixed starrs not coming together is a constant Miracle.[67]

The task of transmitting Newton's conception, so to speak, now passes into the hands of David Gregory. Except for his textbook, of which more anon, our knowledge of his thinking is fragmentary. The Royal Society possesses Gregory's "Notae" on the *Principia*, and on Proposition XIV of Book III he comments: "But besides the huge distance, their [the stars'] location on all sides hampers the effects, by Book I, Prop. LXX",[68] which is close to the addition cited above that Newton eventually made in the second edition, and which did duty for the enormously long Proposition XV he had earlier drafted.

A second Gregory fragment is in the form of a slip pasted into the "Notae", and here he briefly reviews the problem: "If all bodies truly have a gravitational attraction for each other, why do the fixed stars not move towards each other by gravity and come together? Is there need for a continual miracle to prevent this outcome? Or is gravity enfeebled [*languescit*] in the immense distance that separates them? Or do they revolve around various centres, turning after the manner of the planets?" He has later added: "If the world were finite this [latter] objection would hold good; but in the infinity that actually exists it has no force."[69]

In 1702 Gregory published his textbook of astronomy, *Astronomiae physicae et geometricae elementa*.[70] While drafting his manuscript, Gregory went to Oxford, in May 1701, "to talk with M^{r} Halley about the whole of my Astronomy", and it may well be that this topic came up. Certainly Newton himself had comments to make, for "Mr Newton's exceptions ag[ains]t my book" include the tantalizingly brief remark: "The fixt Starrs may move inter se by their mutual actions."[71] In the Preface to the book, as is well known, Gregory was allowed to print material supplied by Newton.[72] More immediately to our purpose is Proposition XXI of Book II, "To explain the several Orders of the Fix'd Stars, into which they are divided on account of their differing apparent Magnitude; and to give an account of this difference".

Gregory tells his readers that some would "make their [the stars'] different distance to be the cause of their different Magnitude".

> And this Opinion is very much favoured by the Number of the Fix'd Stars of the first and second Magnitude. For if every Fix'd Star did the Office of a Sun, to a Portion of the Mundane space nearly equal to this that our Sun commands, there will be as many Fix'd Stars of the first Magnitude, as there can be Systems of this sort touching and surrounding ours; that is, as many

equal Spheres as can touch an equal one in the middle of them. Now, 'tis certain from Geometry, that thirteen Spheres can touch and surround one in the middle equal to them, (for *Kepler* is wrong in asserting, in *B.* 1. *Epit*[*ome*] that there may be twelve such, according to the Number of the Angles of an *Icosaedrum*,) and just so many uncontroverted Stars of the first Magnitude are taken Notice of by Observation....

Again, if it be ask'd how many Spheres equal to the former can touch the first Order of Spheres,... the Number of these will be found to be 52, or 4x13 ... and nearly as many Fix'd Stars of the second Magnitude have been taken Notice of.... Nor will there be any great Difference from Observation in determining the Number of the Fix'd Stars of the other Magnitudes according to this Method. For the farther Consideration of this Matter, it only remains that we shew, that there is the same Order observed among the Fix'd Stars of the first Rank, as there is between the central Bodies of the Spheres touching and surrounding the inmost Sphere (near whose Center the Eye is placed;) and the same between the Fix'd Stars of the second Magnitude, as there is between the central Bodies of the Spheres second in order from these; and so on. And here indeed the Matter does not go on so well, (which made *Kepler* of another Opinion,) as is evident even from hence, that upon the first cast of our Eyes upon the Heavens, some Tracts of the Firmament appear fill'd with innumerable Fix'd Stars, whereas others are found to be almost empty and void of any.

But there is no great Error committed in the Order of the Stars of the first and second Magnitude, as will appear to any one that makes a Comparison: For there are six Stars of the first Magnitude in the Zodiac, three to the North, and four to the South, nearly, as it ought to be according to this Theory.[73]

We notice that Gregory goes further than Newton in confirming that the nearest stars really do fit a model of a symmetric universe, in that he examines the *distribution across the sky* of the first-magnitude stars and confirms that they are scattered with some approach to uniformity; and, importantly, he does so in print. But Gregory is unperturbed about the lack of uniformity in the large-scale structure of the universe, for he seems to think that the infinity of the stars is itself sufficient to insure against gravitational collapse: "The indefinite Number of those Systems, included in no [finite] Space, is the Reason why they don't run into one, but, being separated from one another, will for ever stand in the Universe, as Marks of the Power and Wisdom of their Almighty Creator."[74]

Stukeley and "The Present Sight of the Starry Firmament" (c.1720)

Gregory died a premature death in 1708, but his account of our neighbourhood in what was in fact the Newtonian model of the universe of stars lived on and received renewed circulation with the publication of an English translation of his textbook in 1715. Certainly Gregory's *Elements* would be very familiar to Halley (his copies of both the 1702 *Elementa* and the 1715 *Elements* survive[75]), and perhaps even to Stukeley. Whether or not Stukeley's explicit analogy between the stellar system and the Saturnian system is to be assigned to *c.*1720 or to 1752, Stukeley's theorising about the Milky Way grew out of his awareness of the contrast between the relatively uniform distribution of the brightest stars and the highly non-uniform distribution of the faint stars of the Milky Way.

In our earlier discussion of Stukeley's discourse to Newton, we reserved until now consideration of one episode of the conversation. This was where Stukeley poses the question – to himself and to Newton – as to whether it would not have been more fitting for God to have filled space in *every* direction with stars, rather than limiting the distant stars to the galactic plane. Stukeley's answer (see Figure 2) is to point out the disadvantages to mankind if the whole of space had indeed been filled with stars:

> What w[oul]d have been the consequence had infinite space *quaquaversum* been disseminated with worlds? We see every night, the inconvenience of it. *The whole hemisphere w[oul]d have had the appearance of that luminous gloom of the milky way* [emphasis supplied]. We sh[oul]d have lost the present sight of the beauty and the glory of the starry firmament....[76]

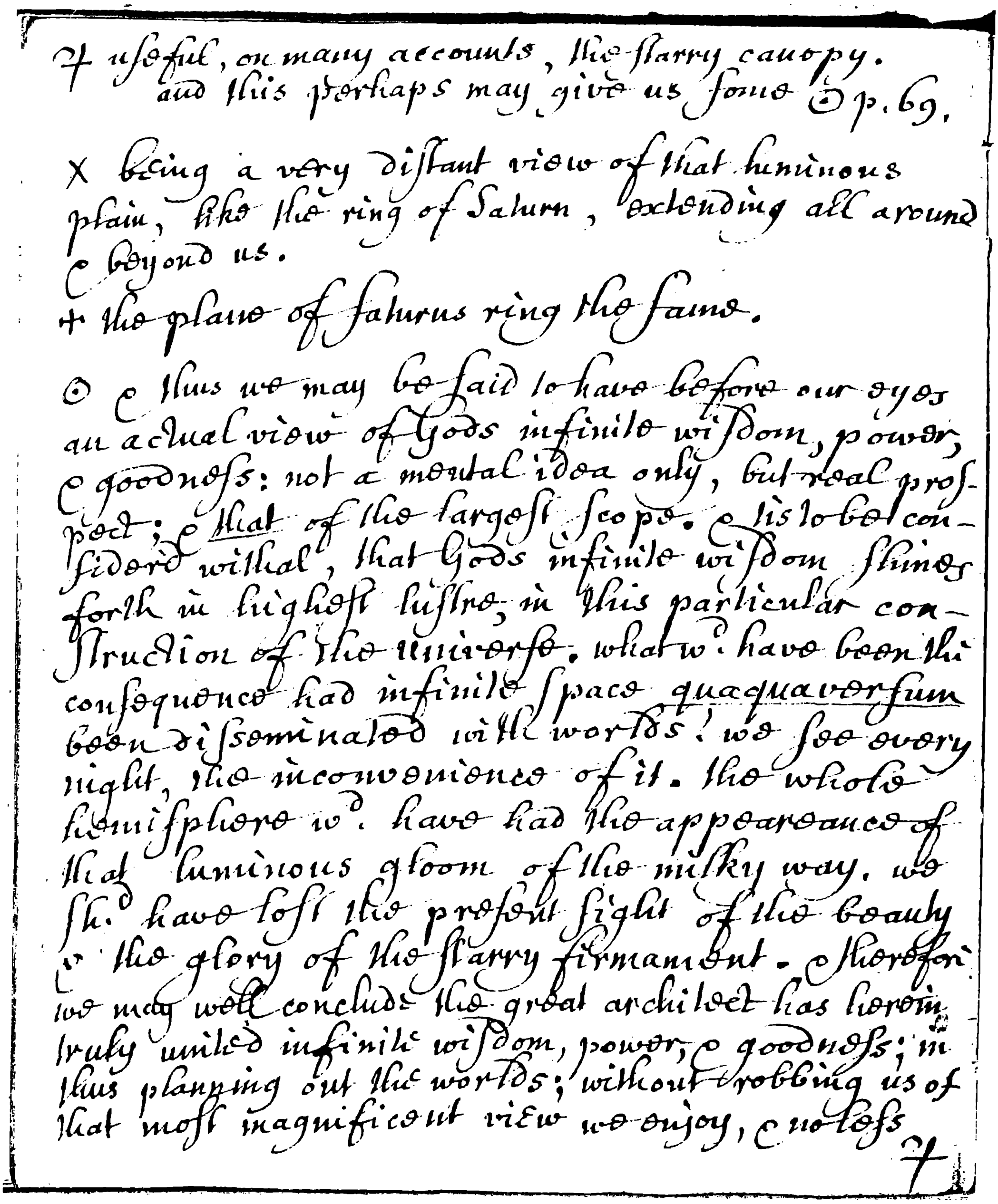
How did Newton react to this and to Stukeley's earlier disquisition on the Milky Way? – for so far Stukeley had done nearly all the talking.

> Sir Isaac seem'd to listen to this kind of discourse, with some approbation. & we discuss'd an objection or two. as 1. Whether tis not better to suppose the worlds infinitely extended *quaquaversum* than in a sort of plane. this w[oul]d provide better for th[e]ir stability; that mutal attraction acting on all sides, hinder'd the systems from falling together. this objection is overruled, by supposing the several systems set respectively, at such distances, as that attraction from any side, sh[oul]d be infinitely small; wh[ich] therefore w[oul]d operate nothing in the case.[77]

If Stukeley reports Newton faithfully, it would seem that Newton hinted at the world picture of a near-uniform system of stars that he had so elaborately developed in the *Principia* drafts; but that then – possibly because the counter-evidence of the Milky Way had just been brought so forcibly to his attention – he reverted to the casual and inadequate dismissal of the problem familiar to us both from the 1680s (when he had written in *De mundi systemate*: "The fixed stars being, therefore, at such vast distances from one another, can neither attract each other perceptibly, nor be attracted by our Sun"[78]), and from the third (1726) edition of the *Principia* (where he would add to the General Scholium: "...and lest the systems of the fixed stars should, by their gravity, fall on each other, he [God] hath placed those systems at immense distances from one another"[79]).

We notice that Stukeley is far from arguing that the entire sky would be ablaze with the equivalent of sunlight if the stars were disseminated in infinite space "*quaquaversum*" (as in modern statements of Olbers's Paradox). He is simply remarking that most of the sky is without the faint luminous glow of the Milky Way; with the implication that when we thus see the individual stars against a dark background, we know that our gaze has reached beyond the limits of the system of stars and into empty space. The (spherical?) system of the individually visible stars is not merely finite but small. For this reason it is not necessary to enquire whether those involved in this astronomical discussion believed the universe had existed long enough for the light of very distant stars yet to have reached us: the light from the stars of the Milky Way *has* reached us, and that is enough.

With Stukeley, the emphasis shifts still further from the dynamics of the system of the stars to their visual appearance: from gravity to light. After all, Stukeley could hardly investigate the effects of gravity on a system to which God was repeatedly adding stars and planets as he saw fit. Nor was the effect of gravity the serious problem for Gregory and Halley that it had been for Newton, for they held that *any* infinite system of stars is in equilibrium or nearly so. In the longer term, puzzlement about the effect of gravity on the system of the stars would diminish still further after the middle years of the century, when the stars ceased to be 'fixed'.


+ usefull, on many accounts, the starry canopy.
and this perhaps may give us some ⊙ p. 69.

x being a very distant view of that luminous
plain, like the ring of Saturn, extending all around
& beyond us.

+ the plane of Saturns ring the same.

⊙ & thus we may be said to have before our eyes
an actual view of Gods infinite wisdom, power,
& goodness: not a mental idea only, but real pros-
pect; & that of the largest scope. & tis to be con-
sidered withal, that Gods infinite wisdom shines
forth in highest lustre, in this particular con-
struction of the universe. what wd. have been the
consequence had infinite space quaquaversum
been disseminated with worlds? we see every
night, the inconvenience of it. the whole
hemisphere wd. have had the appearance of
that luminous gloom of the milky way. we
shd. have lost the present sight of the beauty
& the glory of the starry firmament. & therefore
we may well conclude the great architect has herein
truly united infinite wisdom, power, & goodness; in
thus planning out the worlds; without robbing us of
that most magnificent view we enjoy, & no less +

FIG. 2. RS MS, f.69v: a typical left-hand page of a Stukeley manuscript, with interpolations to be fitted into the text on the facing page. In these interpolations (for Version IV of the Memoirs) Stukeley draws the analogy between the stellar system and that of Saturn, and argues that if the stars had been scattered in every direction the whole sky would have had "that luminous gloom of the milky way". (Courtesy of the Librarian of the Royal Society.)

One further study of the Newtonian universe of stars was to come from the group around Newton. Slight and careless though they are, Halley's two short papers to the Royal Society were to be published in *Philosophical transactions*[80] and republished in the influential abridgement, and so a cosmological model hitherto discussed largely in private became internationally accessible.

Halley's Papers to the Royal Society (1721)

On 23 February 1721, Stukeley tells us in his Memoirs, he and Halley breakfasted with Newton.[81] They had an extensive discussion of astronomical topics including the state of the lunar theory, with Newton complaining that John Flamstead, the Astronomer Royal, "would not communicate his observations to him", and the two guests inspected a lens by Huygens of 170ft focal length that Newton had acquired. Stukeley does not record any topic that he himself contributed to the discussion, but his Diary records that "Halley mention[e]d a Calumny Flamstead rais[e]d ag[ains]t him for stealing 110 stars from him".[82] It was just two weeks later, on 9 March,[83] that Halley read his paper to the Royal Society "On the infinity of the sphere of fix'd stars", in which he mentions that among objections to the system of stars being infinite, "Another Argument I have heard urged, that if the number of Fixt Stars were more than finite, *the whole superficies of their apparent Sphere would be luminous...*" (emphasis supplied). Stukeley, as we have seen, had put to Newton: "What w[oul]d have been the consequence had infinite space *quaquaversum* been disseminated with worlds?... *The whole hemisphere w[oul]d have had the appearance of that luminous gloom of the milky way*" (emphasis supplied). Historians have long wondered from whom Halley "heard" the argument, and the circumstantial evidence now makes Stukeley the prime candidate. The sentences just quoted in italics are remarkably similar; and can we believe that Halley could have had it in mind to address the Royal Society in two weeks time on the universe of stars and never mentioned this in his long discussion with Newton on astronomy? And if Halley did not already have it in mind, might not the topic have been raised by Stukeley?[84]

Halley begins the paper as published by remarking that the universe of stars is taken as being "actually infinite", and that this is confirmed as powerful new telescopes bring still fainter stars into view. Furthermore, "were the whole System finite; it, though never so extended, would still occupy no part of the *infinitum* of Space...; whence the whole would be surrounded on all sides with an infinite *inane*". In addition, a finite system would collapse gravitationally – Halley fails to see in his own recent discovery of three proper motions evidence that the stars are not 'fixed'. "But if the whole be Infinite, all the parts of it would be nearly [interestingly, this word is interpolated in the manuscript] *in aequilibrio*, and consequently each fixt Star, being drawn by contrary Powers, would keep its place; or move, till such time, as, from such an *aequilibrium*, it found its resting place...." Or, in the more succinct account of the meeting in the Royal Society Journal Book, a star remains at rest "because it has not any tendency to move one way rather than another".

After these proofs that the system cannot be finite, Halley turns to two arguments against its being infinite; though he does so with misgivings, since both are "rather of a Metaphysical than Physical Nature". The first revolves around the meaning of the word 'infinite' and need not detain us. The second is that quoted above, that "the whole superficies of their apparent Sphere would be luminous". However, his justification is poorly expressed: "those shining Bodies would be more in number than there are Seconds of a Degree in the *area* of the whole Spherical Surface, which I think cannot be denied." This has made little sense to commentators familiar with the modern statement of Olbers's Paradox (according to which in the Newtonian model of the universe the whole of the sky would be as bright as the Sun), and determined to read this into Halley's words. But if Halley meant by "luminous" nothing more than Stukeley's "luminous gloom", his justification makes more sense. Halley's purpose would then be merely to demonstrate that in this supposed (Newtonian) universe there would be no direction in which the observer's gaze would quickly penetrate beyond the nearby stars into perfectly empty space; whereas in the real universe most of the sky outside of the Milky Way seems void of anything more than isolated stars which we see against a black background. And Halley can easily confirm this feature of the Newtonian model by remarking that in it, every square second of sky would have its star; which is essentially what he does.

Halley's solutions to the objection are two-fold, geometrical and physical. The geometrical solution is flawed, and no commentator has made complete sense of its confused language. We can however see where Halley went wrong. Reasoning, like Newton, in terms of spheres concentric on the solar system, he says of the stars on the successive spheres, that "at a greater distance their Disks and Light will be diminish'd in the proportion of Squares, and the Space to contain them will be increased in the same proportion; so that in each Spherical Surface the number of Stars it might contain, will be as the Biquadrate [fourth power] of their distances". For an accomplished mathematician Halley has made a simple error. At (say) twice the distance, the *apparent* surface area or disk of a star is reduced to one-quarter, while the apparent surface area of the heavenly sphere of course remains the same. Or, alternatively, at twice the distance the *actual* size of the star in cross-section of course remains the same, while the actual surface area of the sphere is multiplied by four. Both calculations naturally lead to the same conclusion, that at twice the distance you can fit four times as many stars onto the heavenly sphere. Halley, however, because he reckons with apparent areas in one case and actual areas in the other, ends up with the 'biquadrate' or sixteen times.

He continues: "Put then the distances immensely great, as we are well assured they cannot but be, and from thence by an obvious *calculus*, it will be found, that as the Light of the Fix'd Stars diminishes, the intervals between them decrease in a less proportion, the one being as the Distances, and the other as the Squares thereof, reciprocally." He seems to be saying that the apparent brightness falls off with the square of the distance (correct), and that for large distances the observed angular separation between two neighbouring stars falls off with the distance (correct). How all this helps, no commentator has yet discovered; but at all events, one basic confusion is evidently present in the earlier part of the argument.

The writer in the Royal Society Journal Book may have been similarly baffled, for he passes at once to Halley's second, and physical, solution to the objection, which he summarises as follows:

> The other objection against an infinite number of stars is from the small quantity of light which they all give whereas if there were an infinite number there should seem to be much more. To this Dr Halley replies that light is not

divisible in infinitum and consequently when the stars are at very remote distances their light diminishes in a greater proportion than according to the common rule and at last becomes intirely insensible even to the largest telescopes.

This formulation, if it be faithful to Halley's intention, adds significantly to the simple claim of the published text:

> ...the more remote Stars, and those far short of the remotest, vanish even in the nicest Telescopes, by reason of their extream minuteness; so that, tho' it were true, that some such Stars are in such a place, yet their Beams, aided by any help yet known, are not sufficient to move our Sense; after the same manner as a small Telescopical fixt Star is by no means perceivable to the naked Eye.

In this version Halley seems to say no more than that after a certain distance, stars make no impression on the eye and so are invisible. Commentators have seen it as their duty to criticise Halley yet again, on the grounds that he was well aware that a cluster of stars may be visible although the individual stars of the cluster cannot be seen; and that he should have realised that in the uniform distribution likewise, faint stars may have an effect in aggregate even though individually they cannot be seen. But the analogy is not obvious, since in a cluster the stars appear close together in the sky and their light seems to merge, whereas in the uniform distribution they appear as far apart as their numbers permit.

In the Journal Book, however, we have the further suggestion that because at great distances light is not divisible *in infinitum*, therefore the inverse square law no longer applies beyond a certain stage. There is a further clue at the end of the second paper (to which we come shortly), where Halley says of the light of a star at one hundred times the distance of the nearest stars: "This is so small a pulse of Light, that it may well be questioned, whether the Eye, assisted with any artificial help, can be made sensible thereof."[85] In the 1690s Halley had made a close study of the nature of light, and by 1700 had adopted a corpuscular theory, holding that "...the pure white light which we perceive is made up of corpuscles of every sort of colour...".[86] The number of corpuscles emanating from a star would be large but finite. Halley therefore accepts that for the nearer stars the simple formulation applies; and that at twice, four times, eight times ... the distance, a star sends us one-quarter, one-sixteenth, one-sixtyfourth ... the light. But eventually we reach a stage where the physical nature of light allows us no more to subdivide the emitted light in accordance with "the common rule", and therefore this objection to an infinite universe of stars is unsound.

The following week Halley had reflected further on this problem, and he read a second and equally short paper, "Of the number, order, and light of the fix'd stars".[87] If on the previous occasion his interest had been triggered off by Stukeley's remarks on the Milky Way, this time he had probably studied Gregory's sketchy remarks about the geometry of a symmetric star system, for what he has to say seems to develop naturally from Gregory's discussion. Indeed his very title echoes Gregory's examination of the *number* of the stars and their *order* or distribution across the sky. Halley may also have had further conversation with Newton who, as President, was in the Chair at the previous meeting.[88]

He begins by reminding his audience that at the last meeting "I adventured to propose some Arguments, that seemed to me to evince the Infinity of the Sphere of Fixt Stars, as occupying the whole Abyss of Space, or the τὸ πᾶν.... Since then, I have attentively examined what might be the consequence of an Hypothesis, that the Sun being one of the Fixt Stars, all the rest were as far distant from one another, as they are from us" – in other words, exactly the model that Newton had studied at such length and which Gregory had briefly touched on. Halley believes (correctly) that on the sphere of radius 1 there is room for only 12 points with mutual distances of at least 1 unit, and he feels it necessary to argue at length that there cannot be thirteen (as Gregory had asserted) – a further indication that he was writing with Gregory's book before him. Having made this minor correction, Halley, like Gregory, draws the general inference that "it is no very improbable Conjecture, that the number of the Fixt Stars of the first magnitude is so small, because this superior appearance of Light arises from their nearness; those that are less shewing themselves so small by reason of their great distance".

It was at this stage that Gregory had confirmed that the first-magnitude stars are widely scattered across the sky: "For there are six Stars of the first Magnitude in the Zodiac, three to the North, and four to the South, nearly, as it ought to be according to this Theory."[89] Halley, who was one of the very few European astronomers to have observed the whole of the southern skies, gives a detailed list, naming each star; but he too groups them as in the Zodiac, or to the north or the south: four in the Zodiac, four to the north, and eight to the south. Here there is some slight loss of symmetry, but this is of no concern to Halley, whose belief in the equilibrium of any infinite star system makes him free to abandon symmetry when the evidence requires it: "But that they exceed the number Thirteen, may easily be accounted for from the different magnitudes that may be in the Stars themselves; and perhaps some of them may be much nearer to one another, than they are to us." Gregory and Halley believed the universe of stars is *not* symmetric in the large, but they were struck by the close match between the predictions from (Newton's) model and the actual numbers of the brightest stars, and they believed that the match came about because the brightest stars are indeed fairly regular in distribution.

Halley then goes on to the next stages. He is aware that the 12 points on the unit sphere are actually spaced apart at somewhat wider intervals than the specified 1 unit, and so he works instead with the factor 13, getting 4×13, 9×13, ..., 100×13, at which stage, as we remarked above, he perceptively locates stars of the sixth magnitude. He then jumps in thought to the 100th stage, with 130,000 stars each with 1/10000th the light of a first-magnitude star. Interestingly, in his drafts of Proposition XV, Newton had written of the 'stars' on the sphere of radius 2 being four times more numerous than those on the sphere of radius 1, and four times fainter; those on the next sphere, nine times more numerous and nine times fainter; those on the next sphere, sixteen times more numerous and sixteen times fainter....[90] On reading what is so close to a modern exposition of Olbers's Paradox, one wonders why Newton did not draw the conclusion that to us is so obvious: that at each stage the *combined* stars make the same total contribution to the light of the sky, which therefore fills completely with light as we take more and more distant stars into account. But perhaps Newton would have thought in physical terms about the more remote stars much as Halley does. Of the stars at the 100th stage Halley makes his comment: "This is so small a pulse of Light, that it may well be questioned, whether the Eye, assisted with any artificial help, can be made sensible thereof" – in other words, as far as their light is concerned, for us they do not exist.

Retrospect

Almost all problems in the history of science have a prehistory as well as a history, and the problems of dynamics and light in an infinite universe of stars are no exception.[91] Newton himself believed that the ancients, in their wisdom, had attained a profound insight into the dynamics of an infinite universe, as they had in so many other fields.[92] In one surviving manuscript, he understands Lucretius, *De rerum natura*, I, 984-91, to hold – like Gregory and Halley – that infinite matter is exempt from gravitational collapse because it is in equilibrium.[93] But for us the history proper begins with Newton. For it is only when the *Principia* demonstrates that gravity – a force, and therefore a cause of motion – is a universal law in an infinite universe, and therefore poses a threat to the stability of the system of the stars and to the handiwork of the divine clockmaker, that the problem is clearly defined. Even then it took the religious purposes of Bentley, and the answering response of the equally religious Newton, for the problem to attract attention.

Newton, Gregory and Halley accepted that the stars are at rest (or nearly so) and their system therefore infinite. For Gregory and Halley an infinite system of stars was *necessarily* stable, and so they could investigate with an open mind the extent to which the system is symmetric. Both concluded that the nearest stars are spread out with approximate symmetry, but Gregory (at least) accepted that in the large the system of stars is highly unsymmetric.

Newton justified the required stability among the stars only with great difficulty. Believing – unlike Gregory and Halley – that *complete* stability (equivalent to infinitely many needles balanced on their points) was not a property of the existing universe, he claimed that gravitational collapse had been postponed through the skill of the divine clockmaker in fashioning the universe so that the stars are widely spaced (and their gravitation pulls correspondingly small) and the system roughly symmetric (so that pulls for the most part cancel each other out). This symmetry – dynamically important to him as it was not to be for Gregory and Halley – he justified as far as the nearest stars were concerned, though he neglected to consider the universe in the large and especially the great counter-example of the Milky Way. But in any case, in the long term gravitational collapse would be averted only through the intervention of Providence, by whom the stars with their attendants would be "carried back" ("*regerentur*") to their proper places from time to time.

Although Newton and Gregory had both studied the near-symmetry in the distribution of the nearest stars, and although Gregory had accepted the lack of symmetry among the distant stars, it is not until the conversation c. 1720 between Newton and Stukeley that we encounter an explicit discussion of the appearance of the sky if the stars are spread out on every side ("*quaquaversum*"). Stukeley, if his report is accurate, pointed out that the "luminous gloom" of the Milky Way would then be present throughout the whole sky; so that not only is the existing system not extended infinitely *quaquaversum*, but away from the Milky Way its extent is small. Similarly, Halley, while explicitly examining the objections against an infinite system of stars, remarks that he has heard the objection that the sky would then be "luminous", for every square second of the sky would have its star. This is a far cry from the Olbers's Paradox of modern astronomy, which has the entire sky filled with the brilliance of sunlight. But Halley's papers were published in *Philosophical transactions* and republished in the abridgement in 1734, and must surely be the source of the first fully-fledged statement of the Paradox, by the young Jean-Philippe Loys de Chéseaux in an appendix to his 1744 treatise on the recent comet.[94] Cheseaux treads the path now so familiar to us, in examining the geometry of stars on concentric spheres ('*couches*' in French); but he studies their contribution to the light of the night sky with a precision and clarity unknown to Halley, and concludes that the stars of each sphere would together send us the same amount of light: "...cette quantité de lumière toûjours la même pour toutes les couches...."[95] The whole sky would then be as bright as the Sun: "...chaque point du Ciel nous paroitroit aussi lumineux qu'un point du Soleil de même grandeur apparente...."[96] Chéseaux concludes that either the stars are finite and of very limited extent, or physical causes prevent their light from reaching us; and he points out that if the transparency of space is only slightly imperfect, this will be enough to resolve the problem.[96] For Chéseaux, as for the numerous nineteenth-century students of the problem, the Paradox was no paradox.[97]

To Newton, then, we owe the first dynamical studies of the effects of gravity in an infinite universe of stars. Stukeley, it seems, was the first to insist on the implications that follow from the "luminous gloom" in the night sky being confined to the Milky Way. Halley, in two brief, confused, but widely distributed papers, brought these problems into the public domain and with them the techniques developed by Newton and his circle for their solution.[98]

STUKELEY'S 1757 TRACT ON "HADES"

Nearly forty years elapsed between Stukeley's conversation with Newton and his writing of the Corpus Christi College tract on "Hades". Like Whiston and Wright – the two Englishmen with whom he had so much in common – Stukeley was profoundly interested in the locations in the universe of Heaven and Hell;[99] and, for that matter, of where Christ went when (in the words of the Apostles' Creed) he "descended into Hell" between his death and resurrection. It is with this latter problem that the tract is concerned, but in writing it Stukeley reveals an interesting development in his thinking about the Milky Way. The tract is illustrated by a drawing (Figure 3), which Stukeley explains as follows:

> The drawing, I call TO ΠAN, being my conception of the Universe. I need not be tedious in a description; having before open'd my notion about it, to you [his imagined correspondent, Miriam] who have so lively an apprehension of these and the abstrusest matters. *A.B.* represents a section, of what we call the *Via Lactea*; I mean by it, that plane of worlds extended all around; indefinitely, thro' the immense space. Every one of the circles that compose it, is such an appearance, as we behold in a bright, starry night; made up of an orb, or globular *congeries* of solar systems; every star being a central

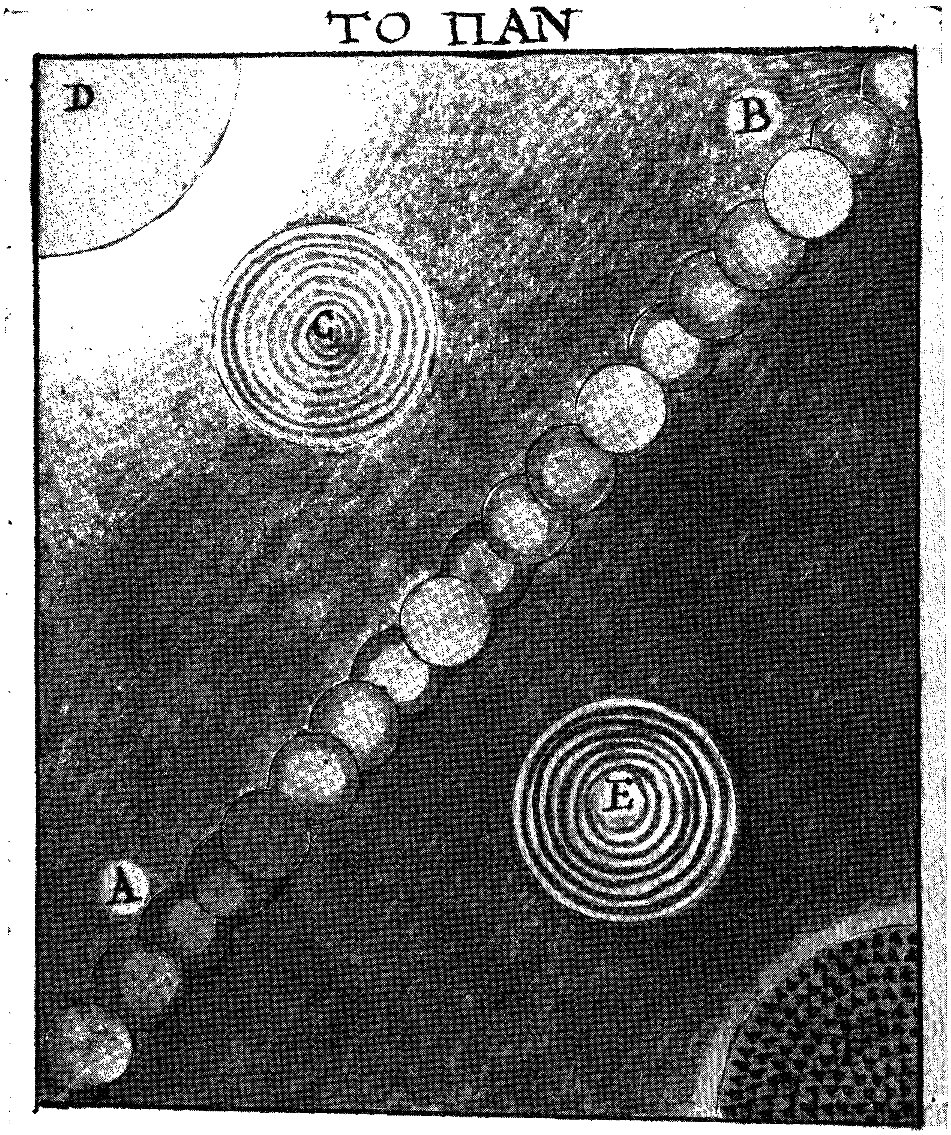


FIG. 3. The diagram from Corpus Christi College, Cambridge, MS 615, XV. The layer of the Milky Way (shown in cross-section *AB*) is formed of innumerable spherical clusters, of which one comprises the Sun and the individually visible stars. Heaven is marked *D*, Hell *F*, and *C*, *E* are the two Hades that are staging-posts, respectively, to Heaven and Hell. (Courtesy of the Librarian of Corpus Christi College.)

sun of a system like ours; bec[ause] of comets moving in long *parabolas* [ellipses?], far beyond the circles of their planets; & not infringing upon any neighbouring system.

If then we consider only one of those systems, much more, if we consider a whole, globular *congeries* of them, (like what we see in a starry night) it must give us a most dilated idea of the Creator, that made them; & sowed (as it were) boundless space with worlds, call[e]d the *Via lactea*; (a part, or section of wh[ich] is on our drawing) what a stretch is this for the human mind to conceive! an infinity of globular *congeries*'s, each like what we see in a starry night, but farther still, tis my firm belief, that the great Creator adds to the verge of this plane, all around; not only new worlds, or solar systems, but new globular *congeries*'s of worlds, continually; at such times, & periods, as he thinks best.

This is undoubtedly the greatest idea of the Supreme Being, that ever was hitherto presented to our imagination. Yet it must be just & true; bec[ause] not only fit, but necessary. For the same motive that urged God to begin creation, vizt his *goodness*, must for ever induce him to continue it....

In the picture of the universe, wh[ich] I have drawn, we are to suppose infinite space, as divided into two parts, by the plane of creation, *A.B.* On one side of infinite space, wh[ich] we may call the upper side, is *D.* wh[ich] we call heaven, the throne of the Supreme, the seat of angels.

On the opposite half of infinite space, wh[ich] we may call the lowest side, is the region of hell, properly, the seat of the devil, & his angels. *F.* Therefore I conceive, there are two distinct places, which we call *Hades*; one for the good spirits, the other for the evil: wh[ich] we may call hell, tho' not properly. The former I have marked by the [let]ter *C.* the delectable recess of the souls of those, who have behav'd well in life....

The other is the doleful prison of those who have merited nothing, from the hand of a bountiful creator; and are now under the horrible dread, of changing their situation, bad enough, for one of real and endless misery. marked *E.*[100]

Stukeley, then, sees the Sun and the other stars of creation as lying in or close to a plane that divides the universe into two halves. On one side of the plane is Heaven, and the Hades that is "Abraham's bosom", a staging post on the way to Heaven. On the other side is Hell and its staging post, the second Hades.

What concerns us is the remarkable modification in his picture of the stellar creation. When talking to Newton (or at any rate when revising his Memoirs of Newton in 1752), Stukeley had seen the Sun and the individual stars in the night sky as forming a spherical cluster analogous to Saturn, with the stars that make up the Milky Way occupying space in the form of a hollow, flattened disk that surrounds the spherical cluster and is analogous to Saturn's ring. As in this model our Sun is at (or, at least, near) the centre of the cluster, the solar system is exactly (or at least roughly) central to creation. But much of this is now changed. Our Sun and the nearby stars continue to form a spherical cluster, but now it is only one of innumerable such spherical clusters or "globular congeries's" that make up the uninterrupted and ever-expanding layer of the Milky Way. That is, the Sun belongs to a *typical* spherical cluster of the Milky Way. These clusters, though loosely described as "infinite", are finitely many at any one time, but their number increases without limit as God's act of creation continues. As in c. 1720, this continuous creation no doubt precludes Stukeley from addressing himself to the problem of gravitational stability, though his purpose is in any case religious rather than scientific.

Stukeley's conception has much in common with that of Lambert, who would shortly publish a theory[101] according to which the Milky Way is a fragmented disk of stars made up of a fixed number of subordinate clusters, one of them containing the Sun. But Lambert took the dynamics of a stable, 'clockwork' universe seriously. As we saw in the last Section, he realised that there was no good evidence that the stars are at rest; and, to preserve each cluster from gravitational collapse, he taught that the component stars are in orbit about the centre of the cluster – as are the clusters themselves about the centre of the Milky Way.[102]

Stukeley's conception of the Milky Way is nevertheless remarkable, and shows that Thomas Wright of Durham is more representative of his time than has been supposed. Wright and Stukeley were kindred spirits, each striving to unite his theory of the stellar universe with his theological world view, and each making our Sun no more than a typical star of a typical system. Did either influence the other? This is possible but not, I think, probable. They were contemporaries with interests in common, and we know they corresponded about antiquities;[103] they may have met, or Stukeley may have read Wright's *An original theory of the universe* (1750), though he is not listed among the (prepublication) subscribers. But the central theme of *An original theory* and of Wright's earlier attempt to reconcile his scientific and religious views of the universe is that the Sun and the other stars of our system surround, at a distance, a supernatural centre, about which they orbit.[104] Our system forms either a sphere, hollow except for the supernatural centre, in which case the Milky Way defines the tangent plane to the sphere at our position; or a flattened disk, similarly hollow, in which case the Milky Way defines the plane of the disk. In either case Heaven lies in our midst, quite unlike the conception in Stukeley's tract. In short, Wright and Stukeley asked themselves where Heaven and Hell are in the universe, and they saw the Milky Way as offering the fundamental clue to the answer; but their answers are so different that we require further evidence before seeing either as influencing the other.

APPENDIX I: STUKELEY'S DISCOURSE TO NEWTON c. 1720

Stukeley's notable "discourse" appears first in the Grantham draft of the Memoirs as an interpolation (now incomplete) in Version II, and this text has been reproduced in our discussion above. Version III (the original Royal Society draft) is reproduced below in roman type, and the interpolations that make up Version IV are printed in italics. Latin words underlined by Stukeley are printed in roman with single quotation marks, and English words underlined are indicated by 'word emphasized'.

Royal Society MS App. XXXVI, ff. 66v-71r.

I cannot better conclude this article, than in reciting the subject of a conversation, I once had with him, toward the beginning of our acquaintance.

I proposed to him a thought I had entertain'd, how to account for that great luminous circle incompassing us, wh[ich] we look upon with so much wonder, in a clear, starry night, called the milky way. We all readily suppose it to be owing to the suns of seperate systems there plac'd, one beyond another, *one by the side of another, in the boundless extent of space*, whose united rays cause that luminous appearance, *for light is the only thing that do[e]s not diminish in proportion to its distance.* we suppose with probability enough, that every star is a sun of a separate system; some perhaps bigger, some lesser, *some having more some fewer concomitant planets*, some farther distant from others, some nearer, *but that those wh[ich] compose the milky way are still incomparably further distant from* *us, & all the other stars within our ken.* that they all have their concomitant planets, as our sun. & in order to have a just idea of God's power, we may well conceive, every globe is perfectly different in its self as to its inhabitants, & furniture, & attendants, *as we discern here an infinite diversity & variation, as well as number, in every thing around us, the amazing product of his forming hand.*

But still the question remains, whence the origin of the milky way; notoriously a great circle including the whole of the creation to us visible? my thought concerning it is this. we mortals, said I, are pleas[e]d with new works, new advances in our knowledg[e], *new acquisitions of any sort,* new writing, wh[ich] is a sort of creation, new building, new plantation, wh[ich] too is a kind of creation. *we are fonder of what we are in pursuit of than of what we possess: of what we intend to do, than of what we have done.* tho' like the alm[ighty] architect, we look with pleasure on what we have already done, wh[ich] we approve of; yet we are more eager in pursuing somewhat further, than in surveying what we have already done, what we are now in poss[ess]ion of; like Alexander, sighing for new worlds to conquer. & this is the constant bent of our minds as long as our facultys will permit us.

S^{r} Isaac thought the notion to be very just, & agreeable to his own experience. I continued my discourse. this desire in us of new creations of any sort in our little way, *of what is within the scope of our power, or of what we fancy, may be, is undoubtedly,* [*del.*: may be] a divine particle deriv'd from our maker. with wisdom is it implanted in us, for good purposes: that we may be active, & busy. *'tis a species of ambition, & is as the salt of life.* this same principle seperated from all imperfection *incompatible with the divine n*[*atu*]*re* may give us some notion of the agency of the supreme mind, and solve our problem. *the antients had some notion of this sort, for Democritus affirmed infinite worlds.* I suppose, therefore, God alm[ighty] tho' in the Mosaic cosmogony, he is said to "rest from all his works, wh[ich] he had created & made"; yet this I take to be spoken only in regard to our present system. for yet why sh^{d} we not think, that God always created new worlds, *always creates new worlds, always will create new worlds,* new systems, to multiply the infinitude of his beneficiaries & *extend all happiness beyond all compass & imagination. I must needs affirm, this is exactly consonant to the idea we ought to have of God.* I mean, since he thought fit to begin creation; for that [word emphasized] creation certainly & necessarily must commence in time, *is a truth the most certain in the world for by the definition, tis bringing that in to being wh*[*ich*] *was not in being before. therefore there was a time before it. therefore an eternal creation 'a parte ante' is the greatest absurdity. but the continuing it 'a parte post' is the greatest glory of the divine n*[*atu*]*re.*

We see here, God has given a power, in all things partaking of any degree of life, to continue their own kind, in an endless chain. it suits the notion we have of Gods goodness, that he still made new worlds, for the creatures thereof to do the like, *that the fountain of his bounty may flow for ever; & all the streams of it, may not only flow, but increase eternally, both in no. & quantity.*

when we indevor to form in our minds an apt idea of God alm. we are to stretch our imagination to the utmost pitch, that we may view somewhat of the largest scope of infinite wisdom, power, & goodness, wh[*ich*] *we can possibly reach to.*

but bec[ause] G[od] alm[ighty] always practises order, method, regularity in all his works; I suppose, he places these new worlds, & systems of worlds, in a certain great, & broad line [*del.*: , or belt, as it were]; not made of single systems in bredth, but of many, like a vast meridian, or plane of worlds; not filling infinite space 'quaquaversum' [on every side], but dividing infinite space into two great parts, one on each side, the great mundane meridian. & that this is the occasion of the appearance, wh[ich] we call the milky way *being a very distant view of that luminous plain, like the ring of Saturn, extending all around & beyond us.*

for this notion we have a considerable confirmation, from considering our own world, that the plane of all the circles of the primary, & of the secondary planets, is nearly in one line, *the plane of Saturns ring the same.* G[od] observes a great analogy in all his works. So that our System in that respect is but a sort of picture of the universe. & that meridional plane of our Solar System may be called our milky way. & hence the milky way in the heavens is the aggregate of what we can discern of this meridional plane of the macrocosm. *& thus we may be said to have before our eyes an actual view of Gods infinite wisdom, power, & goodness: not a mental idea only, but real prospect; & that* [word emphasized] *of the largest scope. & tis to be consider'd withal, that Gods infinite wisdom shines forth in highest lustre, in this particular construction of the universe. What w[oul]d have been the consequence had infinite space 'quaquaversum' been disseminated with worlds? We see every night, the inconvenience of it. the whole hemisphere w[oul]d have had the appearance of that luminous gloom of the milky way. we sh[oul]d have lost the present sight of the beauty & the glory of the starry firmament. & therefore we may well conclude the great architect has herein truly united infinite wisdom, power & goodness; in thus planning out the worlds; without robbing us of that most magnificent view we enjoy, & no less useful, on many accounts, the starry canopy. and this perhaps may give us some obscure notion of the reason of the odd formation of the planet Saturn: that it is as a miniature picture, or model of the τo παν. for we must conceive that the plane of the suns & systems of planets concomitant, wh[ich] make the lacteal circle, have a vast space left betw[ee] it & the several stars wh[ich] we behold in a clear night. therefore these stars wh[ich] we behold in a clear night, we may liken taken altogether to the globe of Saturn: the plane of those stars beyond, wh[ich] appear to us like the lacteal circle, may be assimilated, taken all together, to the ring of Saturn.*

S^r^ Isaac seem'd to listen to this kind of discourse, with some approbation. & we discussed an objection or two. as 1. whether tis not better to suppose the worlds infinitely extended 'quaquaversum' than in a sort of plane. this w[oul]d provide better for th[e]ir stability; that mutual attraction acting on all sides, hinder'd the systems from falling together. this objection is overruled, by supposing the several systems set respectively, at such distances, as that attraction from any side, sh[oul]d be infinitely small; wh[ich] therefore w[oul]d operate nothing in the case. a second objection is merely theological. Some are inclined to think our religion not founded sufficiently on philosophy. bec[ause] it supposes the globe of our earth to be the whole world. that it is unworthy, that a divine Mediation sh[oul]d be allotted to so small, so inconsiderable a portion, in comparison of the whole.

but this objection is as easily vacated by the single consideration of the nature, & the value of our Souls. an immortal principle that cannot cease to be. therefore in a few words, it must be asserted, to be of infinitely more value, than the whole material globe, wh[ich] must perish: than the whole mundane system.

in conclusion S^r^ Isaac intimated, that the thought was worthy of Gods power, &

goodness; that it solv'd the appearance of the galaxy; if it was fact. *the bredth of the angle, wh*[*ich*] *the galaxy makes, shows its inconceivable distance, in this view: & that beyond all number*. that it was not easy to say, whether is the greater idea of G[od] alm[ighty] that he creates infinite worlds now, *& that* [word emphasized] *to all eternity,* to multiply the objects of his benignity: or that he created them all at once. I mean, says he, in the "hexaemeron". For I take it to be agre[e]able to philosophy.

but as to Sr Isaac's problem proposed, whether it be more consentaneous to the n[*atu*]*re & the glory of the deity, that he sh*[*oul*]*d create new worlds infinitely, in succession: or have done it all in the "hexaemeron", we may leave it to be solv'd, when we are in his* [word emphasized] *present scituation.*

I shall only propose another problem, wh[*ich*] *tho' the numbers can scarcely reach the solution, yet they may possibly give us some little idea of the matter: the apparent bredth of the galaxy is generally about 23*[?] *degrees, sometime it is nearly double. about 21½ on Mr Senex's planispheres* [phrase replacing "about 23½ equal to our obliquity of the ecliptic"]. *quaere supposing my hypothesis to be fact how far distant is it? I tryd it after a rude manner & found the interval double the diamet*[*er*] *of the whole view of the fixt stars wh*[*ich*] *we behold.* [See Figure 1.] *thus as in pa. 57.*[105]

however this discourse put me upon studying the Mosaic cosmogony seriously...

APPENDIX 2: STUKELEY'S ACCOUNT OF NEWTON AND THE APPLE

No historian believes that the fall of an apple was a decisive incident in the development of Newton's thinking in dynamics, but, in the words of Newton's recent biographer, the story "is too well attested to be thrown out of court".[106] A prime source for the story has been the modern printed version of Stukeley's *Memoirs*, 19-20, but (as mentioned above) the Grantham manuscript is accompanied by a document from which the accounts in Version I and, eventually, in the printed *Memoirs*, derive.[107] The document reads as follows:

> 15 April 1726. I visited S^{r} Isaac Newton, at his lodgings in Orbels buildings Kensington. I was well acquainted with him, being of the same country: & I spent the whole day with him, & alone. After dinner, being a fine day, we sat in the garden, under the apple trees, & drank thea there. He told me among other discourse it was in such a scituation, that he first took the notion of the gravitation of matter: from an apple dropping off the tree. Why sh^{d} this apple, always, & invariably fall to the earth, in a perpendicular line: why should it not fall upwards, sideways, or obliquely? The perpendicular line leads only to the central point of the earth. Why sh^{d} it seek to gain that point, & not any other quarter of the globe?
>
> These, & such like were the questions, wh[ich] S^{r} Isaac revolv'd in his mind, upon that occasion. When he discerned, the reason, to be an attraction of the earth: & that the sum of the power of attraction, in all its parts, must needs reside there. That this apple must attract the earth; as well, as the earth the apple; tho' infinitely little, & in proportion to the quantity of matter in each.
>
> Thence he began to consider, & discover, the mode, propertys, measure, &

laws of this universal power in matter & apply them to the motion of the heavenly bodys, to the cohesion of matter; & to unfold the true philosophy of the universe....

ACKNOWLEDGEMENTS

My interest in the cosmology in Stukeley's *Memoirs* was first aroused by a letter from Dr S. Wagner of Bielefeld University, and the 1757 tract on Hades was generously drawn to my attention by Dr D. W. Dewhirst. I am grateful to Dr Dewhirst, Dr J. A. Bennett and Dr Simon Schaffer for commenting on an early version of this paper. For permission to reproduce material in their care I am indebted to the Librarians of Corpus Christi College, Cambridge, of Grantham Library, and of the Royal Society. For assistance in the study of Stukeley manuscripts I wish to thank Mr F. K. Annable of the Museum of the Wiltshire Archaeological and Natural History Society, Mr A. S. Wood of Grantham Library and Museum, the Librarian of King's College, Cambridge, Miss Janet Dudley of the Royal Greenwich Observatory, and Mr Ross MacLean of Wolfson College, Oxford. Mr F. W. Manders of the Central Library, Newcastle upon Tyne, kindly supplied a photocopy of a document by Thomas Wright.

REFERENCES

1. Stuart Piggott, *William Stukeley: An eighteenth-century antiquary* (Oxford, 1950). His list of extant manuscripts (Appendix A) runs to 13 pages.
2. Royal Society MS App. XXXVI (hereafter: RS MS). This comprises some 10pp of partly numbered 'prelims', followed by the main text in which the right-hand pages are numbered 1 to 81, together with an allegorical sketch of Newton, an engraving of Colsterworth Church, and a sketch of the manor house at Woolsthorpe.
3. William Stukeley, *Memoirs of Sir Isaac Newton's life*, edited by A. Hastings White (London, 1936). Hereafter: Stukeley, *Memoirs*.
4. Hereafter: Grantham MS. The draft comprises a title page and the main text in which the right-hand pages are numbered 1-54, followed by four pages of which the first is numbered 49a.
5. Consisting of eight pages larger in size than the draft Memoirs.
6. Corpus Christi College, Cambridge, MS 615, XV. There is a title page, a figure (our Figure 3), and 32 pages of which the right-hand ones are numbered 1-16. As usual the text is on the right-hand pages and the left-hand are reserved for possible changes.
7. *Cf.* Stukeley, *Memoirs*, 12.
8. *Ibid.*, 17.
9. *Ibid.*, 21.
10. Stukeley himself has a modest place in the history of astronomical instruments, for in 1747 he devised a "*Lunaesolarium* or machine which I invented for shewing by rackwork the apparent motions of the moon and sun round the globe of the earth, with the course of the tides &c, the rising and setting of the sun and moon & southing, the passage of the light and darkness over the globe of the earth: the reason of high and neap tides, of equinoctial & solstitial tides: the time of day when the sun shines". See John R. Millburn, "William Stukeley and the early history of the orrery", *Annals of science*, xxxi (1974), 511-28, p. 523. I owe this reference to Dr Simon Schaffer.

    Stukeley (*Memoirs*, 21) says John Machin was a Visitor and Hadley not, but his memory is at fault (RGO 6/21, p. 14; I owe this reference to Miss Janet Dudley of Royal Greenwich Observatory).
11. This dating is introduced in Version III (RS MS f.67r), and is not in Version II where the conversation is first described.

12. "...this discourse put me upon studying the Mosaic cosmogony seriously, wh[ich] I did, when I lived in Ormon street, and wrote a large tract upon it..." (RS MS, ff. 71r-72r). Stukeley lived in Great Ormond Street from 1717 (Piggott, *Stukeley*, 38) until his move to Grantham in 1726.
13. Stukeley, *Memoirs*, 71-78.
14. The first being numbered 49a.
15. We have an early source for this conversation in the letter from Stukeley to Richard Mead, 15 July 1727 (King's College, Cambridge, Keynes MS 136, f. 10). The account there does not differ in substance from that in the published *Memoirs* (pp. 14-15). For Halley's contribution to the conversation, see Stukeley's Diary entry (below, and ref. 81).
16. E. Halley, "Of the infinity of the sphere of fix'd stars", *Philosophical transactions*, xxxi (1720), 22-24, p. 23. The date, 1720, is nominal only.
17. See ref. 6 above.
18. On f. 16.
19. Thomas Wright of Durham, *An original theory or new hypothesis of the universe* (London, 1750; reprinted with an introduction by Michael Hoskin, London, 1971). J. H. Lambert, *Cosmologische Briefe* (Augsburg, 1761), trans. by Stanley L. Jaki as *Cosmological letters* (Edinburgh, 1976).
20. 'Chyndonax' was the name, supposedly of a Druid priest, engraved on an archaeological find allegedly made in 1598. In 1722 Stukeley and some friends formed an antiquarian club for the study of Roman Britain. This club they termed the "Society of Roman Knights", and each member adopted a suitable Celtic or similar name; Stukeley was known as Chyndonax. See Piggott, *Stukeley*, 53-55.
21. See ref. 11 above.
22. Grantham MS, f. 49a seq.
23. In somewhat similar vein, Edmond Halley "adventured to make the Earth hollow and to place another Globe within it" ("An account of the cause of the change of the variation of the magnetical needle; with an hypothesis of the structure of the internal parts of the Earth", *Philosophical transactions*, xvi (1686-87), 563-78, p. 572). This interior globe was to permit a physical explanation of the variation in magnetic north; but in addition Halley saw it as offering the Creator further scope for the creation of living creatures, for "no Man can doubt but the Wisdom of the Creator has provided for the Macrocosm by many more ways than I can either imagine or express" (p. 573). In addition to these extensions of the creation in space, some thinkers wished to extend it backwards as well as forwards in time. Halley writes of "those Changes which might have happen'd to the Earth in Times before the Creation, and which might possibly have reduc'd a former World to a *Chaos*, out of whose Ruins the present might be formed, than of the Deluge whereby Mankind was in a manner extinguished about 4000 Years since" ("Some farther thoughts...", *Philosophical transactions*, xxxiii (1724-25), 123-5, p. 123 (but read to the Royal Society in December 1694)). I owe these references to Dr Simon Schaffer.

    It should be noted that such public speculations, proposed openly at a meeting of the Royal Society, offer easy disproof of the persistent legend that the universe as a whole was thought by everyone to be no more than six thousand years old. An example of speculations about future 'creations' is in David Gregory's memorandum of what Newton told him in May 1694, that "The Satellites of Jupiter and Saturn can take the places of the Earth, Venus, Mars if they are destroyed, and be held in reserve for a new Creation" ("...et ad novam Creationem reservari", Memoranda by Gregory (Royal Society Library), 5-7 May 1694, available in *The correspondence of Isaac Newton* [hereafter: Newton, *Correspondence*], iii, ed. by H. W. Turnbull (Cambridge, 1961), 334/336).
24. RS MS, 67r-68r.
25. On this see my "The English background to the cosmology of Wright and Herschel", in *Cosmology, history, and theology*, ed. by W. Yourgrau and A. D. Breck (New York, 1977), 219-31.
26. William Whiston, *Praelectiones astronomicae* (Cambridge, 1707), Lectio IV; transl. from the English edn, *Astronomical lectures* (London, 1715), 41-42.
27. William Derham, *Astro-theology*, 3rd edn (London, 1719), pp. xvi, 40, 52, 57-58.
28. RS MS, ff. 69r-70r.
29. Michael Hoskin, *Stellar astronomy: Historical essays* (Chalfont St Giles, 1982), chapters B3, B4, C1 and C2.
30. The interpolations are on f. 69v.
31. E. Halley, "Of the number, order, and light of the fix't stars", *Philosophical transactions*, xxxi (1720), 24-26, p. 24. (As remarked above, the date, 1720, is nominal only.) Stukeley uses the term again in the Corpus Christi MS, as we shall see.

32. RS MS, ff. 69v, 68v.
33. I. Kant, *Allgemeine Naturgeschichte und Theorie des Himmels* (Königsberg and Leipzig, 1755), Part I. English transl. by Stanley L. Jaki as *Universal natural history and theory of the heavens* (Edinburgh, 1981).
34. Lambert, *Cosmologische Briefe* (ref. 19). See Michael Hoskin, "The cosmology of J. H. Lambert", in *Stellar astronomy* (ref. 29), 117-21.
35. Wright, *An original theory* (ref. 19). See Michael Hoskin, "The cosmology of Thomas Wright of Durham", *Journal for the history of astronomy*, i (1970), 44-52, reprinted in Hoskin, *Stellar astronomy*, 101-16.
36. Version II is quoted above. The phrase is crossed out in Version III (RS MS, f. 69r).
37. RS MS, f. 71r.
38. Newton's investigations are examined in detail, with an edition of the principal text, in my "Newton, Providence and the universe of stars" [hereafter: "Newton, Providence"], *Journal for the history of astronomy*, viii (1977), 77-101, reprinted in Hoskin, *Stellar astronomy* (ref. 29), 71-95.
39. Isaac Newton, *Philosophiae naturalis principia mathematica* (London, 1687), Book III, Prop. XIV.
40. In the familiar Motte-Cajori translation of Newton's *Principia* (Berkeley & Los Angeles, 1934; hereafter: *Principia*, ed. Motte-Cajori), 596-7.
41. J. Gregory, *Geometriae pars universalis* (Padua, 1668), 148.
42. In *De mundi systemate* (*Principia*, ed. Motte-Cajori, 596), and in the *Principia* drafts c.1693 (Hoskin, "Newton, Providence" (ref. 38), 96, and see below).
43. Newton, *Principia*, ed. Motte-Cajori, 597.
44. See "Bentley and Newton" by Perry Miller, in *Isaac Newton's papers and letters on natural philosophy*, ed. by I. Bernard Cohen (Cambridge, 1958), 271-8. This volume contains a reprint of the 1756 edition of Newton's four letters to Bentley, and of the relevant sermons by Bentley. A more accurate edition of Newton's letters to Bentley, and the text of the surviving letter from Bentley to Newton, are in Newton, *Correspondence* (ref. 23), iii.
45. See Lambert, *Cosmologische Briefe* (ref. 19), and Hoskin, *op. cit.* (ref. 34).
46. E. Halley, "Considerations on the change of the latitudes of some of the principal fixt stars", *Philosophical transactions*, xxx (1717-19), 736-8.
47. Halley, "Of the infinity of the sphere of fix'd stars" (ref. 16), 23.
48. As quoted in Newton's reply of 10 December 1692, Newton, *Correspondence*, iii, 233-6, p. 234.
49. Newton to Bentley, 17 January 1692/3, *ibid.*, 238-40, p. 238.
50. Bentley to Newton, 18 February 1692/3, *ibid.*, 246-52, pp. 250-1.
51. Newton to Bentley, 25 February 1692/3, *ibid.*, 253-6.
52. "Continuo opus esse miraculo ne Sol et fixae per gravitatem coeant", Memoranda by Gregory, 5-7 May 1694; Newton, *Correspondence*, iii, 334/6.
53. I. Newton, *Optice* (London, 1706), Qu. 20: "...Et Quidnam est quod impedit, quominus Sol & Stellae fixae in se mutuo irruant?"
54. *Ibid.*, Qu. 23: "Nam cum Cometae moventur in Orbibus valde eccentricis, undique & quoquoversum in omnes coeli partes; utique nullo modo fieri potuit, ut caeco fato tribuendum sit, quod Planetae in orbibus concentricis Motu consimili ferantur eodem omnes; exceptis nimirum irregularitatibus quibusdam vix notatu dignis, quae ex mutuis Cometarum & Planetarum in se invicem actionibus oriri potuerint, quaeque verisimile est fore ut longinquitate temporis majores usque evadunt, donec haec Naturae Compages manum emendatricem tandem sit desideratura." The Latin is more tentative than the (later) English translation.
55. H. G. Alexander (ed.), *The Leibniz-Clarke correspondence* (Manchester, 1956), 14.
56. See Hoskin, "Newton, Providence" (ref. 38), espec. p. 93.
57. ULC (=University Library, Cambridge) Add. MS 3965, f. 152v. *Ibid.*, f. 362r; text edited in A. R. Hall and M. B. Hall, *Unpublished scientific papers of Isaac Newton* (Cambridge, 1962), 355-9, p. 358.
58. Newton, *Principia*, 3rd edn (London, 1726), 527; ed. Motte-Cajori, 544: "Et ne fixarum systemata per gravitatem suam in se mutuo cadant, hic eandem immensam ab invicem distantiam posuerit."
59. Newton's annotated copy of the second edition of the *Principia* is in the library of Trinity College, Cambridge. His annotations are published in the variorum edition of the *Principia* edited by A. Koyré and I. B. Cohen (Cambridge, 1971).
60. The drafts are scattered throughout ULC Add. MS 3965. For details, see Hoskin, "Newton,

Providence" (ref. 38).

61. Halley, *op. cit.* (ref. 31), 26.
62. ULC Add. MS 3965, f. 74r, reproduced in Hoskin, "Newton, Providence" (ref. 38), Fig. 2.
63. ULC Add. MS 4005, ff. 21r-22r; Hall & Hall, *Unpublished papers of Newton* (ref. 58), 374-6, pp. 375-6.
64. ULC Add. MS 4005, ff. 45r-49r; Hall & Hall, *Unpublished papers of Newton*, 378-85.
65. Memoranda by Gregory, 4 May 1694; Newton, *Correspondence*, iii, 312/317.
66. Memoranda by Gregory, 5-7 May 1694; Newton, *Correspondence*, iii, 334/336.
67. Memoranda by Gregory, 16 May 1694; Newton, *Correspondence*, iii, 355.
68. "Sed et praeter immensam distantiam earum positio circum circa effectus impedit ex prop: LXX lib:1."
69. David Gregory's "Notae" on the *Principia*, Royal Society MS 210, f. 47: "Verum si corpora omnia in omnia sint gravia, Quidni Stellae fixae ex gravitate coeant et concurrant? An continuo opus est miraculo ad hunc effectum impediendum? an in immensa quae intercedit inter eas distantia, languescit gravitas? an potius circa diversa centra rotata planetarum more revolvuntur." Later added: "Si mundus esset finitus obtineret haec obiectio: existente vero infinito vim nullam obtinet." I owe this reference to Miss Christina Eagles.
70. David Gregory, *Astronomiae physicae et geometricae elementa* (Oxford, 1702). The translations cited are from the second English edn, *The elements of physical and geometrical astronomy* (London, 1726).
71. Royal Society MS 247, ff. 74r, 76r.
72. See the Introduction by I. Bernard Cohen to the modern reprint of the second English edn of Gregory's *Elements* (New York, 1972).
73. Gregory, *Elementa*, 159-60; second English edn, 288-90.
74. Gregory, *Elementa*, 483; second English edn, 856.
75. Halley's copy of the 1702 *Elementa* is in the University Library, Cambridge, and contains at the back the autograph of Halley's famous *Astronomiae cometicae synopsis*, signed and dated 8 June 1705. (On this see "The first predicted return of Comet Halley" by Peter Broughton elsewhere in this issue of *JHA*.) A copy of the 1715 *Elements*, with a marginal note said to be by Halley on p. 116 of vol. i and with his name on the title page, was offered for sale in February 1983 by the book dealers Jay Books (D. & J. Brayford) of Edinburgh.
76. RS MS, f. 69v.
77. RS MS, f. 70r.
78. See ref. 43 above.
79. See ref. 58 above.
80. *Op. cit.* (refs 16, 31).
81. Grantham MS, f. 5v; Stukeley, *Memoirs*, 14-15; Stukeley, Diary, printed in *The family memoirs of the Rev. William Stukeley, M.D.*, ed. by W. C. Lukis for the Surtees Society (3 vols, London, 1882-87), i, 63.
82. Stukeley, Diary (ref. 81).
83. The date is given in the relevant Journal Book of the Royal Society.
84. In what follows I have borrowed some sentences from "Halley and 'Olbers's Paradox'", in Hoskin, *Stellar astronomy* (ref. 29), 95-100.
85. *Op. cit.* (ref. 31), 26.
86. E. Halley, "De iride", *Philosophical transactions*, xxii (1700), 714-25, p. 720: "...*Lucem* albam puramque quam conspicimus, ex omnigenarum Colorum corpusculis...." Translation by W. R. Albury, "Halley and the *Traité de la lumière* of Huygens", *Isis*, lxii (1971), 445-68, p. 464. Albury discusses Halley's pre-1700 views on the nature of light. I owe this reference to Dr Simon Schaffer.
87. Again, the date is given in the Journal Book.
88. This is stated in the Journal Book.
89. See ref. 73 above.
90. See ref. 62 above: "Deinde quae his undique proxima sunt ob distantias duplo majores erunt quadruplo obscuriora et quadruplo plura, et tot circiter sunt stellae fixae magnitudinis secundae, nimirum sexaginta. Quae vero tertio loco circumponuntur ob triplam dist. erunt noncuplo obscuriora et noncuplo plura...."
91. On this see Stanley L. Jaki, *The paradox of Olbers' Paradox* (New York, 1969).
92. Much of the Preface to Gregory's *Elementa* is on this theme, and was actually written by Newton (Cohen, *op. cit.* (ref. 72), pp. xiv-xvi). Newton writes of Lucretius: "His Argument runs thus; If

the Nature of things were bounded any where, then the outmost Bodies, since they have no other beyond them, towards which they may be made to tend by the force of Gravity, would not stand in an Equilibrio, but make towards the inner and lower Bodies, being necessarily inclin'd that way by their Gravity; and therefore having made towards one another, during an infinite space of time, would have long ago met, and lye in the middle of the whole, as in the lowest Place" (2nd English edn, pp. viii-ix). On the subject of Newton's belief in an ancient wisdom, see J. E. McGuire and P. M. Rattansi, "Newton and the 'pipes of Pan'"; *Notes and records of the Royal Society*, xxi (1966), 108-43.

93. ULC Add. MS 3965, f. 278r: "...in materiam omnem circum circa positam et per gravitatem mundi infiniti in aequilibrio sustinentur ne se mutuo ruant."

94. J.-P. L. de Chéseaux, *Traité de la comète qui a paru en décembre 1743 et en janvier, février et mars 1744* (Lausanne, 1744), 223-9: Appendix, "Sur la force de la lumière, sa propagation dans l'éther, et sur la distance des étoiles fixes"; reprinted in Jaki, *op. cit.* (ref. 91), 253-5. In his discussion (chap. 5) of Chéseaux, Jaki draws attention to infelicities in Chéseaux's exposition, but these are minor.

95. Chéseaux, *Traité*, 224.

96. *Ibid.*, 225.

97. *Ibid.*, 225-6.

98. On the later history of the Paradox, see Jaki, *op. cit.* (ref. 91), and M. A. Hoskin, "Dark skies and fixed stars", *Journal of the British Astronomical Association*, lxxxiii (1973), 254-62.

99. Wright, *An original theory* (ref. 19), discussed in Hoskin, *op. cit.* (ref. 35). W. Whiston, *Astronomical principles of religion, natural and reveal'd* (2nd edn, London, 1725), 25, 131-2, 154 seq. Whiston holds that the evil will one day be transferred to a comet, there to be tormented in the sight of the Blessed.

100. Corpus Christi College, Cambridge, MS 615, XV, ff. 1-3, 5, 6.

101. Lambert, *Cosmologische Briefe* (ref. 19).

102. J. H. Lambert, *Photometria* (Augsburg, 1760), 505-6; *idem*, *Cosmologische Briefe*, discussed in Hoskin, "The cosmology of J. H. Lambert" (ref. 34). Lambert's conception of our star system is virtually the same as Stukeley's: "We find ourselves in one such system [of fixed stars] and I count into it all stars that are visible to us and lie outside the Milky Way as well as the larger ones that cover that arch of sky" (Letter 10, trans. Jaki (ref. 19), 111).

103. In the Surtees Society edition of Stukeley's Diary and other materials (ref. 81), Thomas Wright features three times: i, 433-4, where there is a letter dated 25 February 1742 from Wright to an unknown correspondent about the recent comet; iii, 442, Diary entry for 9 November 1758, "Mr Thomas Wright sent a letter with a description of a sepulchral monument at Morgan, in Wales..."; and iii, 443, Diary entry for 23 March 1748-9, "Mr Wright, the astronomer, tells me that in Ireland, near Dundalk, is a Druid temple...". Though Thomas Wright was a common name, there is little doubt that the entries relate to Thomas Wright of Durham. He is known to have made a special study of the comet of 1742, submitting related material (now in Durham University Library) to the Royal Society, and publishing some of it in *The gentleman's magazine* (xii (1742), 106, 132, 183); and the 1742 letter is written from St James', London, whereas we know from Wright's Journal (Edward Hughes, "The early journal of Thomas Wright of Durham", *Annals of science*, vii (1851), 1-24, p. 16) that he was then in London and moving in high society. He also made an extensive study of antiquities, especially of Ireland; the results of his several months' study in 1746 of those of the county of Louth were published as *Louthiana* (London, 1748, 1758), and a sequel and a volume on the antiquities of England remain in manuscript. Indeed, the similarity between the interests of the two men is very remarkable.

We know for certain that from Wright's point of view, Stukeley was not a principal correspondent, for in vol. vii of the Wright MSS in the Central Library, Newcastle upon Tyne there is a list drawn up by Wright in 1766 of some 1107 letters in his "Cabinet of letters" (the contents of which are no longer extant). Wright lists his principal correspondents with the number of letters from them, but Stukeley is not mentioned, and if Wright held any of his letters they were simply included under "Miscellanies". (Mr F. W. Manders, the Local Studies Librarian, kindly made available a photocopy of this document.)

104. Hoskin, *op. cit.* (ref. 35).

105. This reference is obscure. It is simply omitted by the editor of the printed *Memoirs*.

106. Richard S. Westfall, *Never at rest: A biography of Isaac Newton* (Cambridge, 1980), 154. Westfall gives references to earlier treatments of the apple story. See also Gale E. Christianson, *In the presence of the Creator: Isaac Newton and his times* (New York and London, 1984), 77-78, 82-83.

107. The account in the printed *Memoirs* is essentially the same as in Version I, except that the sentence beginning "That there is a power..." is an interpolation in Version IV (RS MS, f. 14v).