Starlight and Time is the Big Bang

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ABSTRACT

*The physics of Dr. Russell Humphreys' new cosmological model presented in **Starlight and Time** is profoundly flawed and the conclusions drawn from this model are seriously mistaken. An accurate treatment of the physics indicates that this model is actually a trivial variant of the standard Big Bang model, with its attendant implications for the age of the Universe and the Earth time required for light to travel from distant galaxies to the Earth.*

1. INTRODUCTION

Dr D. Russell Humphreys' **Starlight and Time: Solving the Puzzle of Distant Starlight in a Young Universe**[1] purports to solve the light-travel-time problem in a way which is compatible with astronomical observations of the Universe and the General Theory of Relativity, the best present description of gravity and the structure of the Universe. Humphreys alleges that his alternative cosmology lifts from the neck of the young-Universe movement the doubly burdensome yoke of the light-travel problem and the movement's past denials of the validity of General Relativity, a very thoroughly tested and proven theory.

The arguments presented in **Starlight and Time** sound ingenious and are attractively presented, but they are flawed in ways which are so serious as to totally invalidate them. These flaws centre around a series of misunderstandings about the meaning of General Relativity concepts and the interpretation of cosmological models based on General Relativity. When these misunderstandings are corrected it is found that the approach to cosmology advocated in **Starlight and Time** leads to the same time-scale conclusions as standard Big Bang cosmology. The model of **Starlight and Time** is in fact a trivial variant of the Big Bang model.

The misunderstandings exhibited in **Starlight and Time** may be grouped into several clusters. The body of this paper is organised into sections correcting each of these sets of misunderstandings. The first set centres around the 'Cosmological Principle', or the 'Copernican Principle'. **Starlight and Time** affirms, wrongly, that the long-time-scale implications of Big Bang cosmology theory are crucially dependent on the global validity of this principle/assumption and that the relaxation of this assumption, through the introduction of a boundary to the matter of the Universe, produces dramatic differences in the gravitational properties of the Universe. In fact, the gravitational properties of the visible part of the Universe are identical for unbounded and spherical bounded models regardless of the validity of the Copernican Principle in more distant regions. A second cluster of misunderstandings centres around the nature of time in cosmological models. **Starlight and Time** affirms, wrongly, that the physical clock synchronisation properties which occur in the standard Big Bang model are due to the boundary conditions implied by the Copernican principle and that modification of these boundary conditions can change the way that physical clocks behave in the Universe. In fact, physical clocks located on Earth and on distant galaxies behave identically in bounded and unbounded Universes which have identical interior matter distributions. A third set of misunderstandings centres around the nature and effects of event horizons in the Universe. **Starlight and Time** affirms, wrongly, that observers who pass through event horizons observe dramatic changes in the rate of time passage in distant parts of the Universe. In fact, no such changes are observed; the distant-clock time phenomena observed in a bounded Universe are identical to those observed in an unbounded Universe. A fourth cluster of misunderstandings centres around the observable consequences of this model. **Starlight and Time** and other of Humphreys' writings affirm, wrongly, that this model can be adjusted to accurately predict observed phenomena while limiting the passage of time on Earth, since the beginning of the Universe, to only a few thousand years. In fact, the short-time-scale expansion proposal has profound and easily testable consequences which are not observed. Examination of a number of these phenomena demonstrates that the short-time-scale cosmic expansion and short-time light travel from distant galaxies proposed in **Starlight and Time** did not occur in the history of the real Universe.

The physical model of the Universe presented in **Starlight and Time**, a locally homogeneous and isotropic spherical matter distribution, is possible, and in fact was proposed more than 20 years prior to the unveiling of **Starlight and Time** in 1994.[2] The young-Universe interpretations which Humphreys derives from this model are, however, mistaken. The time-scale implications of the bounded cosmology of **Starlight and Time** are identical to the standard Big Bang model.

Before proceeding to the substance of our rebuttal of **Starlight and Time**, it is important to state the physical and mathematical assumptions on which this rebuttal depends. We assume that:

(1) General Relativity is an accurate description of gravity;
(2) gravity is the most important force acting over cosmologically large distances, so that the conventional application of General Relativity to cosmology theory is valid;
(3) the fundamental parameters of nature, such as the gravitational constant G and the speed of light c, are invariant over the observable history of the Universe;
(4) the visible region of the Universe is approximately homogeneous and isotropic on large distance scales; and
(5) the events which we witness by the light of distant galaxies and quasi-stellar objects are real events and not appearances impressed onto the Universe by the intention of the Creator.

Assumption (1) is an established fact,[3] there is excellent evidence for assumptions (2) through (4), and assumption (5) is a metaphysical postulate which is necessary if one is to 'do' cosmology at all. Humphreys agrees explicitly or implicitly with all five of these assumptions.[4] The assumption which may attract the most scepticism from readers of this journal is (3), in particular the invariance of c. The hypothesis that c was much larger in the past is a common view in the young-Universe movement and is, in fact, a competing solution to the light-travel-time problem. However, there is compelling evidence, overlooked by the originators and promoters of the declining-c hypothesis, that c has not varied significantly in the past on Earth, and persuasive evidence that it has not varied in the past at distant galaxies.[5]

Humphreys claims that it is possible to build cosmological models which satisfy these five assumptions and which are also compatible with the short time-scales required by young-Universe interpretations of the Bible. **Starlight and Time** purports to show how to build such models. As we shall show below, the approach to cosmology advocated in **Starlight and Time** fails and no plausible variation of it can succeed.

Readers not familiar with the concepts and the mathematical apparatus of General Relativity may find parts of the following discussion obscure. We have prepared a much more 'user-friendly' version of this paper titled 'The Big Bang Cosmology of **Starlight and Time**', but henceforth referred to simply as 'the Supplement'.[6] The Supplement is much longer than the present article, is less terse and is equipped with an extensive set of explanatory and supplementary appendices which will be helpful to readers not familiar with General Relativity and its application to cosmology theory. It also discusses numerous additional errors in **Starlight and Time** which cannot be mentioned in this paper due to lack of space. Readers interested in the Supplement should write to the address given in reference 6.

2. MISUNDERSTANDINGS ABOUT THE SIGNIFICANCE OF THE COSMOLOGICAL PRINCIPLE

The 'Copernican Principle' or 'Cosmological Principle' is an assumption which was adopted in the early years of General Relativity-based cosmology theory in order to render tractable the mathematical problem of applying General Relativity to the structure of the Universe.[7] The assumption is that the Universe is, on large scales, very smooth and that there are no preferred directions in the Universe — homogeneity and isotropy. One of the consequences of the Cosmological Principle is that, if it is valid globally (throughout the Universe) as opposed to locally (only in the region of the Universe visible from Earth), then the Universe is unbounded. The central contention of **Starlight and Time** is that the long-time-scale consequences of Big Bang cosmology are the fault of this unbounded feature of globally homogeneous and isotropic universes. The book lays considerable emphasis on the widespread acceptance of this assumption among cosmologists, and criticises professional cosmology theorists and popular science writers for uncritically adopting this hypothesis. Much of the remainder of the book is devoted to attempting to demonstrate that the relaxation of the global validity of the Cosmological Principle through the introduction of a spherical boundary to the matter of the Universe completely changes the gravitational properties of the Universe and overthrows the long time-scale implications of standard cosmology theory.

This argument of **Starlight and Time** is mistaken. The global validity of the Cosmological Principle is not necessary for standard cosmology theory to be valid as a description of the Universe visible from Earth. This has been recognised for decades and is especially prominent in recent work on inflationary cosmology. The imposition of a spherical boundary to the matter of the Universe has no effect on the gravitational and clock time-keeping properties in the interior of such a boundary.

2.1 Misunderstanding About Cosmologists' Acceptance of the Cosmological Principle

To begin with, **Starlight and Time** misrepresents professional cosmology theorists' views of the

Cosmological Principle. The fact of the matter is that theorists do not, in general, believe that it must apply to the entire Universe. Examples of this can be found in recent graduate-level textbooks on General Relativity and cosmology, for example,[8,9] and even in some popular writing.[10] It is true that not every text mentions this fact, and it is probably the case that some, perhaps many, of the authors of older textbooks who do not mention this fact believed that the Cosmological Principle was globally valid. The silence of these earlier works does not establish Humphreys' claims, however. Present-day cosmology theorists readily acknowledge the possibility that the Universe may be very inhomogeneous at very large distances or on very large distance scales. As a single example of this we cite an important recent paper on the very large-scale structure of the Universe:

> '*. . . one of the main principles of the big bang theory is the homogeneity of the Universe. The assertion of homogeneity seemed to be so important that it was called "the cosmological principle". Indeed, without using this principle one could not prove that the whole universe appeared* ***at a single moment of time****, which was associated with the big bang. So far, inflation remains the only theory which explains why the observable part of the Universe is almost homogeneous. However, almost all versions of inflationary cosmology predict that on a much larger scale the Universe should be extremely inhomogeneous, with energy density varying from the Planck density [$\approx 10^{94}$ g/cm^3] to almost zero.*'[11]
> (Emphasis in original)

Despite the global inhomogeneity discussed by this author, he affirms that the local, observable part of the Universe is well-described by standard Big Bang theory.[12] This citation and the other references show that **Starlight and Time** is mistaken in its assertions about cosmology theorists' reliance on the global validity of the Cosmological Principle. Modern cosmology theorists do not believe in the model of the Universe which Humphreys critiques. Despite this, these theorists still affirm, with good reason, that general relativistic cosmology theory implies that the Universe is very old.

The bounded cosmology proposed in **Starlight and Time** is not the innovation it has been represented to be.[13] It is nearly identical in its most important features to the model proposed in 1971 by Oskar Klein.[2] Klein's model, like Humphreys', is spherical, bounded and starts in a state of contraction. Also, like Humphreys' model, Klein's model is motivated by dissatisfaction with the Cosmological Principle. The principal differences are that Klein's model does not have an optically thick boundary, employs a different method for reversing the initial contraction, has a different explanation for the cosmic microwave background, and permits the Earth to be not at the centre. Regarding the differences between his bounded model and the standard unbounded Big Bang model, Klein writes:

> '*Although there is hardly any difference between a cosmological Friedmann* [that is, a standard unbounded Big Bang] *solution and a bounded one so long as observations are not approaching the border* [which would reveal a deficit of galaxies beyond the edge of the matter] *and the extrapolations backward in time do not approach the state of the so-called fireball, the difference becomes significant when these conditions are not satisfied; in fact, it is enormous at the early stage assumed for the fireball . . .*'[14]

The 'fireball' state Klein mentions is the hot, dense state in which primordial nucleosynthesis occurs in the standard Big Bang model, when the Universe is about 10^{10} times smaller than its present size, with densities of order 10^4 g/cm^3 and temperatures of order 10^{10} K. Klein's model does not resemble the Big Bang at this early stage because radiation can escape from the Universe through the boundary, resulting in greater cooling at the edge than at the centre, so that the Universe does not remain radially homogeneous. At late times ($Z < 1100$), when radiation plays an insignificant role in the dynamics of the Universe, there is, in Klein's words, *'hardly any difference'* between his bounded model and the standard unbounded model. Humphreys avoids the excessive early cooling which would occur in Klein's model, if extrapolated back to the fireball state, by postulating an optically thick boundary, which absorbs and re-emits into the interior the radiation which escapes from Klein's model. In such a case, there is hardly any difference between the observable behaviour and properties of the bounded and unbounded cases at any time.

The problem of **Starlight and Time** and the debate surrounding it can be summarised thus: either Humphreys is right that boundaries matter, in which case many past and present-day cosmology theorists have committed a colossal intellectual blunder in admitting global inhomogeneity but not recognising its implications for the time-scale of the visible Universe, or else the cosmology theorists are right and Humphreys is mistaken — non-local inhomogeneity is irrelevant. As we shall see, the answer to this problem is the second case; the boundary conditions do not matter. For this reason, cosmology theorists do not pay attention to them when studying the part of the Universe which we can observe from Earth. The visible Universe is very nearly homogeneous and isotropic on large scales,[6,15] and this is sufficient for the results of standard cosmology theory, applied to the visible part of the Universe, to be valid.

In sum, the Cosmological Principle is a mathematical convenience which does not have to be globally valid in order for the results of standard cosmology theory to apply to the part of the Universe we can see. Humphreys has misinterpreted the historical fact that this principle was invoked to simplify the mathematics of cosmology to imply that, without this assumption, the standard model falls apart, even when applied only to the visible portion of the

Universe. This is not so. Contemporary cosmology theorists do not implicitly believe that the Cosmological Principle is true throughout the Universe, but this does not affect their work since it is necessary only that it be valid locally.

2.2 Misunderstanding About the Gravitational Properties of Bounded and Unbounded Universes

The other side of the erroneous assertion that the global validity of the Cosmological Principle is essential to Big Bang models is the erroneous assertion that relaxing this principle produces profound changes in the gravitational properties of the Universe. In particular, **Starlight and Time** asserts, wrongly, that the supposition of a boundary to the matter of the Universe, beyond which there is only vacuum, completely changes the gravitational properties of the Universe and consequently the time-keeping properties of physical clocks in the Universe.

Confining our attention to universes which are spherically symmetric about Earth, there are two classes of bounded universes: those with a boundary within the Earth's particle horizon, and those for which the boundary is more distant than the particle horizon. The presence of a boundary is manifestly irrelevant in the latter case, since gravitational influences from the matter distribution beyond the boundary, travelling at the speed of light,[16] have not yet reached Earth. The observed interior properties of such a universe cannot depend in any way on the presence or absence of matter beyond the horizon. The standard Big Bang model is consequently an accurate description of what we are able to observe in such bounded universes, and it is for this reason that cosmology theorists do not worry about the very large-scale inhomogeneity of the Universe.

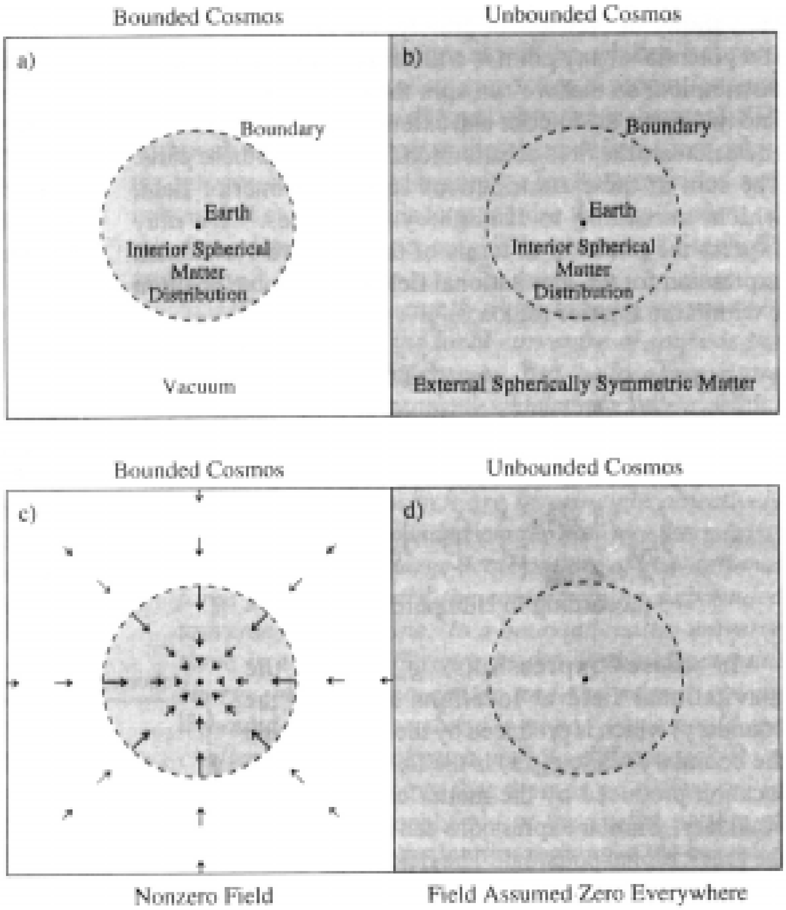

Figure 1. *(a) Bounded, and*
(b) Unbounded cosmos matter distributions.
(c) Gravitational field configuration for the bounded cosmos.
(d) Humphreys' claim of no fields in the unbounded cosmos.

Starlight and Time proposes that the boundary is within Earth's particle horizon. This can be seen from the low value of the comoving radius of the edge proposed in its example model[17] (which is actually too low, corresponding to a redshift of $Z_{edge} = 1.375$, well below the largest redshifts observed for discrete objects, around $Z_{max} \approx 5$),[6] and from its appeal to an optically thick boundary to preserve the thermal character of the observed cosmic microwave background radiation (this is not necessary if the boundary is beyond the particle horizon). Thus, in Humphreys' model, there is sufficient time for gravitational influences from the matter distribution (or lack thereof) beyond the boundary to produce detectible effects at Earth. What are these effects? It is easy to show that, in fact, there are none. The arguments of **Starlight and Time** on this score are basically Newtonian, so we will first disprove this thesis using Newtonian arguments and only then cite the corresponding results from General Relativity.

Starlight and Time claims that the interior gravitational properties of a spherical bounded universe are profoundly different from those of an unbounded universe, both of which are assumed to be locally homogeneous and isotropic within the matter-filled region. The two cases are illustrated in panels (a) and (b) of Figure 1. The two cases differ in that the unbounded case has a spherically symmetric matter distribution extending without limit outside the boundary which marks the edge of the bounded case. Any difference in the interior properties (that is, the properties within the actual boundary of the bounded case and the corresponding region of the unbounded case) of the two universes must be due to the additional exterior matter in the unbounded case.

Starlight and Time alleges that the bounded Universe has a large-scale pattern of gravitational potential and gravitational force which points toward the centre, but that the unbounded Universe does not.[18-20] This situation is illustrated in panels (c) and (d) of Figure 1. In the limit of the validity of Newtonian gravity, the gravitational field and potential at any point is a linear function of the matter distribution, so that we can split the unbounded Universe into two parts, the interior and exterior matter distributions, and calculate the field contribution from each of these parts. The sum of these contributions equals the interior field, which, according to Humphreys, vanishes. We may express the situation in terms of the standard Newtonian expression for the gravitational field ***g(x)*** at some position ***x*** within the interior region:

$$\begin{aligned} g(x) &= \int_{all\ space} d^3x'G\rho\frac{x'-x}{|x'-x|^3} \\ &= g_{int}(x)+g_{ext}(x) \\ &= \int_{allspace} d^3x'G\rho\frac{x'-x}{|x'-x|^3}+\int_{ext} d^3x'G\rho\frac{x'-x}{|x'-x|^3} \\ &= 0\ (according\ to\ Humpreys) \end{aligned}$$

In these expressions, $g_{int}(x)$ is the gravitational field at locations ***x*** (inside the boundary) which is produced by the matter within the boundary while $g_{ext}(x)$ is the field at the same location produced by the matter external to the boundary. Similar expressions can be written for the gravitational potential. The field contribution in the interior region of the unbounded matter distribution which is due to the interior matter distribution itself, $g_{int}(x)$, is the same for the bounded and unbounded cases, since the interior matter distribution is identical for the bounded and unbounded cases (see Figure 2, panel (a)). In order for the total field (that produced by the interior **and** exterior matter) to vanish in the interior region, it necessarily follows that the field contribution in the interior region due to the external spherical matter distribution must exactly cancel out the field contribution due to the interior matter distribution:

$$\begin{aligned} g_{ext}(x) &= \int_{ext} d^3x'G\rho\frac{x'-x}{|x'-x|^3} \\ &= -g_{int}(x) = -\int_{int} d^3x'G\rho\frac{x'-x}{|x'-x|^3} \end{aligned} \qquad (1)$$

The claim that the gravitational field vanishes in the interior region of the unbounded Universe requires that the field produced in the interior region by the external spherically symmetric matter distribution be exactly the opposite of the field of the bounded matter distribution, as illustrated in Figure 2, panel (b). This requirement is in conflict, however, with a well-known theorem of Newtonian gravity:

The gravitational field in the empty interior of a hollow spherically symmetric matter distribution vanishes. The gravitational potential in such a region is spatially non-varying.

In fact, the field due to the exterior matter distribution vanishes in the interior region, $g_{ext}(x) = 0$, so that the field in the interior region is due solely to the interior matter distribution:

$$g(x) = g_{int}(x) = \int_{int} d^3x'G\rho\frac{x'-x}{|x'-x|^3} \qquad (2)$$

as illustrated in panels (c) and (d) of Figure 2. This field is identical to the field of the bounded Universe. A similar argument leads to the conclusion that the pattern of Newtonian gravitational potential in the interior of the bounded and unbounded Universes is identical, with the possible exception of a spatially non-varying offset between the two cases. The gravitational effects on clocks which

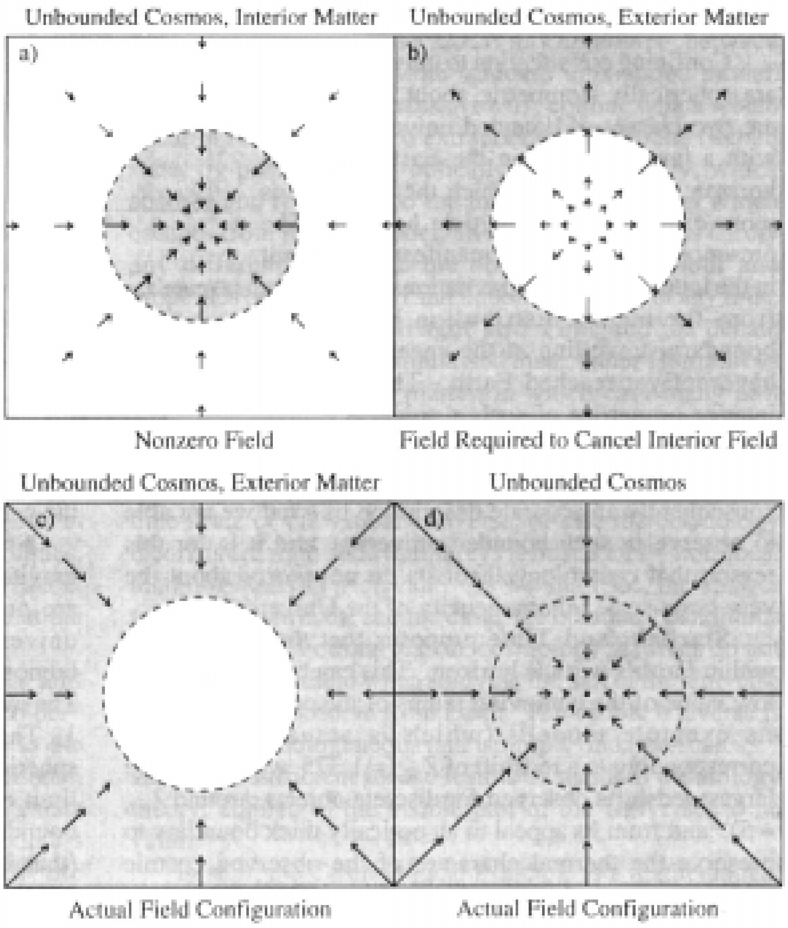

Figure 2. *(a) Actual field configuration due to the interior matter in the unbounded cosmos.*
(b) Field which the exterior matter must produce in order to cancel the field produced by the interior matter.
(c) Actual field configuration produced by the exterior matter.
(d) Actual field configuration in the unbounded cosmos.

Humphreys alleges to occur in the bounded Universe are, in the Newtonian limit, the result of differences in potential, and the pattern of potential differences in the interior of the bounded and unbounded cases is identical.

The identity of the gravitational field in the interior of the bounded and unbounded cases may be easily seen by consideration of the motion of galaxies in the interior region of both cases. If we consider a galaxy located at the same position in the two models and follow its motion as both models expand, we will find that the motion is identical for the two cases: radial recession (with identical speeds) from the centre, but with identical radial accelerations toward the centre which slow the recession as time passes. In the Newtonian description, the deceleration which slows the expansion of the Universe, whether bounded or unbounded, is due to the gravitational field of the Universe. This deceleration is identical for the two cases because the gravitational field is identical. Indeed, if Humphreys' claim of zero field in the unbounded Universe were correct, then in the Newtonian description of such a Universe, the Universe would expand without decelerating. In fact, however, an unbounded Universe decelerates in exactly the same way as a bounded Universe with the same interior properties.

This Newtonian counter-argument to Humphreys' erroneous Newtonian arguments may be readily extended to a truly relativistic Universe. The General Relativity result which corresponds to the Newtonian 'hollow sphere' theorem is a corollary of a famous General Relativity theorem called Birkhoff's theorem. This corollary has the consequence that

> *'the metric inside an empty spherical cavity at the center of a spherically symmetric system must be equivalent to the flat-space Minkowski metric* $\eta_{\alpha\beta}$ *. . . This corollary is analogous to another famous result of Newtonian theory, that the gravitational field of a spherical shell vanishes inside the shell . . . Its importance arises from the fact that the Birkhoff theorem is a local theorem, not depending on any conditions on the metric for* $\square \rightarrow \infty$ *(aside from spherical symmetry), so that space must be flat in a spherical cavity at the center of a spherically symmetric system, even if the system is infinite — even, in fact, if the system is the whole universe.'*[21]

The flat space-time described by the Minkowksi metric has no gravitational fields. In the general relativistic description as well as the Newtonian approximation, the external spherically symmetric matter produces no gravitational effects on the interior region, so that the interior gravitational properties are identical.

Another way of recognising the identity of the interior gravitational properties of the bounded and unbounded cases is to note that the space-time metric, $g_{\mu\nu}$, is identical in the interior of both kinds of Universe. The identical metric means that the two classes of Universe have identical geometrical properties, such as space-time curvature, in their interior. These identical properties result in identical gravitational behaviours (interested readers are referred to the Supplement for a discussion of the relation between the metric and more familiar gravitational properties such as the 'gravitational field' and 'gravitational potential'). Although Humphreys agrees that the metric is identical in the interior of the matter boundary for both bounded and unbounded cases, he fails to recognise the implications of this fact. Responding to our 1995 rebuttal of **Starlight and Time**,[22] he writes:

> *'. . . What they are actually trying to say is true: within the matter sphere, the local curvature of space is the same in both types of cosmos. But the local curvature of space is not the property which makes the essential difference. The distinguishing properties are the* ***gravitational field strength*** *and the* ***gravitational potential****, both of which are in principle objectively measurable. In a bounded-matter universe there exists a small but definite large-scale pattern of gravitational force pointing toward the center; in an unbounded universe there is none. In a bounded-matter universe there is a large difference in gravitational potential energy between the center and the edges; in an unbounded universe there is none. How could the challengers overlook such obvious differences?'*[20]

We have shown above that there is no difference in the pattern of gravitational field or the spatial pattern of potential differences in the interior regions of the bounded and unbounded cases. Humphreys fails to recognise that it is the curved geometry of space-time which **produces** all of the familiar gravitational properties such as the Newtonian field and potential, and less familiar phenomena such as gravitational time dilation. Identical interior space-time metric implies identical interior space-time geometry which implies identical interior gravitational properties. The failure to recognise this fact lies at the heart of the errors of **Starlight and Time**.

3. MISUNDERSTANDINGS ABOUT TIME IN COSMOLOGICAL MODELS

The metric in the interior of a locally homogeneous and isotropic space-time may be written, using coordinates which are at rest with respect to the matter of the Universe ('comoving coordinates'), in Robertson-Walker form:[23]

$$ds^2 = c^2 d\tau_c^2 - a^2(t_c)\left(\frac{d\eta^2}{1-k\eta^2} + \eta^2\left[d\theta^2 + \sin^2\theta d\varphi^2\right]\right) \quad (3)$$

where τ_C is the cosmic time coordinate, η a dimensionless radial coordinate, θ and φ the standard spherical angles, and $a(\tau_c)$ the time-dependent radius of curvature or scale factor of the Universe. The parameter k takes on the values -1, 0 and 1 for spaces of negative, zero and positive curvature, respectively. The example cosmological model employed in **Starlight and Time** uses $k = +1$. The metric tells how to compute the space or time distance between events at different locations in space-time. It thus must figure prominently in any discussion of time passage in the Universe. **Starlight and Time** and other of Humphreys' cosmological writings exhibit serious misunderstandings about what time measures are relevant in discussions of cosmology and how to use the metric to compute them. We will illustrate these misunderstandings by a number of quotes from Humphreys' writings. The first comes from the introductory part of the relativity appendix in **Starlight and Time**:

> *'The "cosmic" time* $\tau[\tau_c$ in equation (3)] *in the Robertson-Walker metric is same* [sic] *as the proper time or "natural" time in eq. (1). It is the time measured by a set of clocks throughout the universe, each one riding with a galaxy as it moves with the expansion of space. These clocks can all be synchronized with one another. Later on I will introduce a distinctly different time,* t, *often called* Schwarzschild time*, or "coordinate" time. The difference between these two types of time measurements constitutes the essence of this paper, so be alert for the distinctions.'*[24]

This statement, which is correct, clearly affirms that the time measured by a physical clock located in a galaxy (for example, a clock on Earth, in the Milky Way galaxy, or a clock located in some other galaxy) is the same as the cosmic time of standard cosmology theory. Thus, the amount of physical time elapsed on a physical clock located on Earth or in a distant galaxy is simply the elapsed cosmic time. This should settle the matter, since it tells us how to measure time intervals elapsing on real clocks in the Universe. Instead, Humphreys introduces a new time coordinate and prefers to make measurements in that coordinate. The reader should note that the difference between the real, physical, 'natural' time measured by real, physical clocks and Humphreys' preferred Schwarzschild time coordinate is, by his own declaration, the **essence** of his model. We shall see that this 'essential' difference is irrelevant to what really happens on real, physical clocks in the Universe.

The second quote comes from Humphreys' reply to our 1995 rebuttal[22] of **Starlight and Time**:

> *'. . . Conner and Page again spend much effort asserting another point I had already made. It is on page 114, the fact that the same "comoving" coordinate system equation can be used to describe that part of the bounded biblical cosmos which has matter in it. In it, clocks can similarly be synchronized. Next they say (section 2, end of first subsection):*
> *"As the universe expands from a certain size* a_1 *to a larger size* a_2*, exactly the same amount of* ['cosmic'] *time passes on every comoving clock."*
> *They imply that somehow this fact is damaging to my theory, but nowhere in their article do they say exactly why that should be. Therefore, I will spell out their implication for them. They are implying that right "now", all parts of the cosmos are the same age. If that implication were so, it would invalidate my theory'.*[25]

In this statement, Humphreys agrees with us that, as the Universe expands from small initial size a_1 to its present large size a_2, all comoving clocks (these are the clocks which 'ride along with each galaxy' as Humphreys puts it in his first quote) experience the same passage of proper or 'natural' time. This clearly means that the same amount of time, as measured by physical clocks, has elapsed in every part of the Universe as the Universe has expanded to its present size. Therefore, at the present moment in the history of the expansion of the Universe, that is, on space-like hypersurfaces for which the radius of curvature a is the same at all locations in the interior of the matter sphere (a definition of simultaneity which is also adopted by Humphreys),[26] it is inescapable that the same amount of physical time has elapsed in every part of the Universe. To borrow Humphreys' words,

> '*right "now",* [that is, on space-time surfaces of constant spatial curvature, which is clearly what Humphreys intends in his definition of cosmic simultaneity, demonstrated in his Figure 2[26]] *all parts of the cosmos are the same age'.*

The third quote comes from Humphreys' reply to Dr John Byl's rebuttal of **Starlight and Time** published in **Creation Research Society Quarterly**:[27]

> *'Byl's assertion, "All galactic clocks tick at the same rate", contains the loose ends of its own unravelling. To specify the "rate" of one type of clock, we need to have another type of clock in the same location for comparison. If I tell you your watch is running slow, you have the right to ask what clock I am saying is correct. To what other type of clock is Byl comparing his cosmic clocks? He does not say. That renders his claim of "same rate" meaningless. Furthermore, according to Schwarzschild clocks, his statement is wrong: in a bounded universe, Byl's clocks tick at different rates (relative to my clocks) in different places. Byl's clocks really should not be called "cosmic" at all. The name comes from applying his metric to an unbounded "Big Bang" cosmos, where a similar type of analysis would show that cosmic clocks and Schwarzschild clocks would indeed tick at the same rate everywhere* [this claim is false, as we show below]. *For the bounded, finite-mass, non-Big-Bang cosmos I propose, perhaps Byl's system should be called* ***local*** *clocks and* ***local*** *time'.*[28]

The reader should note that there is an evolution of Humphreys' ideas between the first (1994) and third (1997) quotes. In the first quote, Humphreys acknowledges that the cosmic time coordinate τ_c of the standard Robertson-Walker metric of cosmology **is** the time measured by a physical clock on Earth or accompanying a distant galaxy. In the second quote, he again acknowledges this fact but tries to avoid its force. In the third quote, he rejects the legitimacy of the cosmic time coordinate in a bounded Universe. Byl is saying that **as the Universe expands a given amount, all galactic clocks register the same passage of physical time**. Humphreys is wrong in saying that there is no time reference for Byl's statement. Byl is using the expansion of the Universe as his reference. **All galactic clocks tick at the same rate with respect to the expansion of the Universe**, a fact which Humphreys affirms in the second quote. Byl's statement is true and is virtually identical to the statement of ours which Humphreys quoted in his quote # 2 above, and which Humphreys agreed is a **fact**. Although Humphreys acknowledged in the first and second quote that cosmic time (or, if he prefers, "local" time) is indeed the time kept by physical clocks in real galaxies, he rejects this time measure because he prefers to use Schwarzschild time. It is true that Schwarzschild clocks do not keep the same time as galactic clocks (this difference is the essence of the model), but the question which must be answered is, 'Which clock actually tells how much time has elapsed at a particular galaxy or on the Earth'. By Humphreys' own admission (quote # 1), it is the cosmic, or "local", or "natural", or "galactic" (these terms are all interchangeable) clocks which tell how much time has elapsed on Earth or at distant galaxies.

3.1 The Metric Tells How to Measure Distance and Time in the Universe

From the third quote above, one might get the impression that Humphreys and his critics are engaged in a childish shouting match: 'My time is better than yours!' 'No! **My** time is better!' Is there no objective time measure to which appeal can be made in order to resolve this disagreement? In fact, there is. General Relativity provides a very specific method for calculating how much time passes on a physical clock travelling along a physical trajectory through space-time. By using this method, it is easy to unambiguously answer the question, 'Which time measure gives the true age of the cosmos in the bounded Universe model of **Starlight and Time'**? This book's errors stem in part from a failure to follow the mathematical rules of General Relativity for measuring physical time passage in the Universe.

Starlight and Time affirms, rightly, that the space-time metric tells us how to measure space-time intervals between space-time events which are separated by some infinitesimal coordinate differential dx^{μ}.[29] The square of the space-time interval, ds^2, is given by

$$ds^2 = \sum_{\mu=0}^{3} \sum_{\nu=0}^{3} g_{\mu\nu} dx^{\mu} dx^{\nu} \equiv g_{\mu\nu} dx^{\mu} dx^{\nu} \qquad (4)$$

In this expression, the dx^{α} are coordinate differentials between two events at slightly different coordinate locations in space-time, and $g_{\alpha\beta}$ are the components of the space-time metric, which gives the space-time interval in accordance with this equation. The Greek indices μ and ν are, in this equation, dummy indices which are summed over their range of 0 to 3. The right-most expression gives the definition of the 'Einstein summation convention' (repeated upper and lower indices are summed over their full range), a convenient shorthand notation which we will employ. The index 0 customarily refers to the time coordinate and the indices 1, 2, 3 refer to the space coordinates. An important fact which must be kept in mind in thinking about this equation is that ds^2 is the square of a **physical distance**, either in space or time, along the differential trajectory element dx^{μ}. With the sign convention adopted in **Starlight and Time**, $ds^2 > 0$ means that ds^2/c^2 is the square of the physical time elapsed on a physical clock traversing the coordinate trajectory $dx^{\mu}: ds^2 = c^2 d\tau^2_{proper}$. This physical time interval is called the **proper time interval**, $d\tau_{proper}$. Humphreys also refers to this as the 'natural' time interval.[30] If ds^2 is negative, then $-ds^2$ is the square of the physical distance interval between the two space-time events which would be measured by an observer for whom the two events are simultaneous: $-ds^2 = dl^2_{simult}$. The intermediate case, $ds^2 = 0$, corresponds to a trajectory dx^{μ} which is traversible only by particles moving with the speed of light. Humphreys affirms these facts.[30]

The quantity ds^2 is an 'indexless' quantity; it has no superscripts or subscripts. The expression used to compute ds^2, $ds^2 = g_{\mu\nu}dx^{\mu}dx^{\nu}$, has two sets of super- and subscripts, but these are summed over and so do not persist in the final result. The quantity ds^2 is known in tensor calculus, the mathematical language of relativity, as a **scalar invariant** — its value is independent of the coordinate system used to express or compute it. Thus, if one were to describe the coordinate differentials dx^{μ} in a new coordinate system, x', then when one computed the space-time interval in the new coordinate system, one would find

$$ds'^2 = g_{\alpha'\beta'} dx^{\alpha'} dx^{\beta'} = g_{\mu\nu} dx^{\mu} dx^{\nu} = ds^2 \qquad (5)$$

This is an elementary fact of tensor calculus which occurs because, in the new coordinate system, the metric takes on new values $g_{\alpha'\beta'}$ which are not the same as the old values $g_{\mu\nu}$ in the old coordinate system. The changes in the values of the metric coefficients exactly counteract the changes in the values of the coordinate differentials in such a way that the scalar (indexless) quantity ds^2 is conserved. This fact is shown in any elementary textbook of tensor analysis; a simple demonstration is also given in the Supplement. It is also eminently reasonable: the physical time elapsed on a clock cannot depend on the coordinate system used to describe the clock's trajectory.

The crucial fact to keep in mind is that the physical space-time distance along a trajectory is independent of the coordinate system used to describe that trajectory. So, for example, if one uses a particular coordinate system to calculate the physical time elapsed along a time-like (that is, $ds^2 > 0$ for each differential step dx^{μ}) trajectory, one will obtain the identical physical elapsed time along this physical trajectory **using any other coordinate system**. The time elapsed on a physical clock is determined by the clock's trajectory through space-time, not by the coordinate system used to describe the trajectory. This means that there is something incorrect in the appeal, in **Starlight and Time**, to a different coordinate system to argue against physical results which are derived from the standard comoving coordinate system of cosmology theory.

3.2 Time Measurements Using the Robertson-Walker and Klein Metrics

We can apply the principle that 'the physical time elapsed on a physical clock is determined by the clock's trajectory and not by the coordinate system' to the physical time elapsed on physical clocks in a bounded universe and compare the results with the claims of **Starlight and Time**. We will start with the standard coordinate system and metric of cosmology theory and derive the desired result in that simple coordinate system. Then we shall derive the same result in the coordinate system which Humphreys prefers.

The metric in the matter-filled portion of a locally homogeneous and isotropic space-time geometry is given by equation (3).[31] How can this equation be used to determine the age of the Universe? All that is needed is to choose an observer to measure the age of the Universe, determine what the coordinate trajectory of that observer is, and then 'turn the crank' of equation (3) to compute the time passage which this observer would measure at the Universe ages. The question which is most relevant to **Starlight and Time** is, 'how old is the Universe as measured by observers on Earth and by observers on distant galaxies?' The trajectories of such observers are simply the trajectories of their host galaxies.[32] These trajectories are extremely simple: $\eta_{com\ obs}(\tau_c) = constant$, $\theta_{com\ obs}(\tau_c) = constant$, $\varphi_{com\ obs}(\tau_c) = constant$. **Starlight and Time** affirms that this is so.[35] Such observers are often called 'comoving' because they move with or 'co-move' with the expansion of the matter of the Universe; the coordinates (η, θ, φ) are called 'comoving coordinates' for the same reason. For such observers, the differential coordinate trajectories are given by $d\eta_{com\ obs} = 0, d\theta_{com\ obs} = 0, d\varphi_{com\ obs} = 0$. Substitution of these coordinate trajectories into the metric gives us the proper time interval measured by such observers:

$$ds^2_{com\ obs} = c^2 d\tau^2_{com\ obs} = c^2 d\tau^2_c \qquad (6)$$

or

$$d\tau_{com\ obs} = d\tau_c \qquad (7)$$

This equation may be trivially integrated from the beginning of the expansion of the Universe to yield

$$\tau_{com\ obs} - \tau_{com\ obs,beginning} = \tau_c - \tau_{c,beginning} \qquad (8)$$

In other words, the physical time measured by a comoving observer's clock since the beginning of the Universe is identical to the cosmic time elapsed since the beginning of the Universe. It should be noted that the location (η, θ, φ) of the observer in the matter sphere does not enter into this equation — all observers measure the same dependence of their local physical clock time on the local radius of curvature a of the Universe. If one defines a surface of cosmic simultaneity as the space-time surface on which the radius of curvature a is everywhere the same (this is the standard definition of cosmic simultaneity in Big Bang theory and is the definition Humphreys adopts[26]), then all physical clocks associated with Earth and distant galaxies, regardless of their location on this surface, will read the same time elapsed since the beginning of the expansion. This equation does not tell us what that time passage is for any specific stage of the expansion of the Universe. To determine that, it is necessary to determine or adopt an equation of state for the matter of the Universe and solve the dynamical equations of cosmology.[36] In all cases, the elapsed dynamical time is a function only of the cosmic scale parameter a. That is, there is no dependence of the elapsed cosmic or comoving clock time on a comoving clock's location within the matter-filled region. For the matter-dominated, pressureless, positive curvature ($k = +1$ in equation (3)) case which is used for illustrative purposes in **Starlight and Time**, the cosmic time is given in differential form by

$$d\tau_{com\ obs} = d\tau_c = \pm \frac{da}{c}\sqrt{\frac{a}{a_{max} - a}} \qquad (9)$$

and in integral form by

$$\tau_{com\ obs}(a) = \tau_c(a) = \frac{a_{max}}{c}\left(sin^{-1}\sqrt{\frac{a}{a_{max}}} - \sqrt{\frac{a}{a_{max}} - \frac{a^2}{a^2_{max}}} \right) \qquad (10)$$

where a is the radius of curvature of the Universe, a_{max} being its value at the moment of maximum expansion (this expression is equivalent to Humphreys' equation (19)[37]), except that his equation is missing a factor of $\pi/2$.[6] It should be noted that equation (10) applies to both the bounded and unbounded $k = +1$ universes. This is so because the dynamical equations which govern the time behaviour of $a(\tau_c)$ depend only on the local properties of the Universe, and these are the same for the bounded and unbounded cases.

Equation (10) is the elapsed time on a comoving clock and hence is the age of the Universe as measured by a physical observer residing on Earth or on a distant galaxy. There is no hint in this expression of differential time passage on Earth and on distant galaxies — the elapsed comoving clock proper time is independent of the location (η, θ, φ) of the clock. There is no differential time passage for real, physical observers located on Earth and in distant galaxies in a locally homogeneous and isotropic universe.

Humphreys claims that consideration of time passage using his preferred Schwarzschild coordinate system indicates otherwise. We will now consider this. As we switch over to Schwarzschild coordinates, it is important to keep in mind the question we wish to answer using them: 'How much time is observed to pass on a physical clock located on Earth or in a distant galaxy as the Universe expands?' We are still thinking about the space-time trajectories of comoving clocks, since these clocks are the ones which tell how much time elapses on Earth and in distant galaxies. When we switch to Schwarzschild coordinates, the metric coefficients will be different from the Robertson-Walker metric, but the space-time trajectory description will also be different. Both effects must be taken into account when computing the elapsed proper time in the new coordinate system.

The transformation from comoving coordinates to the Schwarzschild-like coordinate system employed by Humphreys was derived by Klein:[38]

$$r = \eta a \tag{11}$$

$$t = \pm \frac{t_o}{1+b^2}\left[\frac{b^3}{1+b^2}\ln\left(\frac{\zeta+b}{\zeta-b}\right) + \frac{\zeta}{1+\zeta^2} + \frac{1+3b^2}{1+b^2}\left(\frac{\pi}{2} - \arctan\zeta\right)\right] \tag{12}$$

where

$$t_o \equiv \frac{a_{\max}}{c\sqrt{1-\eta_{edge}^2}}$$

$$\zeta \equiv \sqrt{\frac{a_{\max}}{a_{\max}-a}\sqrt{\frac{1-\eta_{edge}^2}{1-\eta^2}} - 1} \tag{13}$$

$$b \equiv \frac{\eta_{edge}}{\sqrt{1-\eta_{edge}^2}}$$

In these expressions, η_{edge} is the comoving radial coordinate of the edge of the matter sphere. The '+' sign is appropriate for a collapsing matter sphere and the '–' sign for an expanding one. It should be noted that there is an error in the corresponding expression in **Starlight and Time** for the coordinate time t (equation (20)[39]). That expression is missing the leading $(1 + b^2)^{-1}$ and has a spurious '–' sign in the denominator of the middle term. In this new coordinate system, the metric is

$$ds^2 = \beta(r,t)c^2dt^2 - \alpha(r,t)dr^2 - r^2d\Omega^2 \tag{14}$$

where

$$\alpha(r,t) = \frac{1}{1-\frac{a_{\max}r^2}{a^3}} \tag{15}$$

$$\beta(r,t) = \frac{\left[1-\frac{a_{\max}}{a}\left(1-\frac{\left(1-\eta_{edge}^2\right)^{3/2}}{\sqrt{1-\eta^2}}\right)\right]^2}{\left(1-\frac{a_{\max}}{a}\eta^2\right)\left[1-\frac{a_{\max}}{a}\left(1-\frac{\left(1-\eta_{edge}^2\right)}{\sqrt{1-\eta^2}}\right)\right]^3} \tag{15}$$

In order to use the transformed metric of equation (14) to compute the proper time elapsed on a comoving clock, it is necessary to transform the comoving clock trajectory from η, τ_c coordinates to r, t coordinates. Recall that the comoving coordinate trajectory of a comoving observer is given by the spatial coordinates fixed: $d\eta_{com\,obs} = d\theta_{com\,obs} = d\varphi_{com\,obs} = 0$. The θ and φ coordinates are the same for the comoving and Schwarzschild coordinate systems, so we will confine our attention to r and t. Differentiation of equation (11) subject to the constraint $d\eta_{com\,obs} = 0$ gives

$$dr_{com\,obs} = \eta_{com\,obs}da \tag{16}$$

As the Universe expands, comoving observers move outward from the coordinate origin. The Schwarzschild time coordinate is given in equation (13) as a function of a and η. For a comoving observer, a is variable (since the Universe expands) but η is fixed. Therefore, the differential element of Schwarzschild time elapsed along a comoving clock trajectory is

$$dt_{Schw,com\,obs} = da\left.\frac{\partial t(a,\eta)}{\partial a}\right|_{\eta=\eta_{com\,obs}} = -t_o\frac{\zeta^3}{\left(1+\zeta^2\right)^2\left(\zeta^2-b^2\right)}\left(\frac{1-\eta_{edge}^2}{1-\eta^2}\right)^{1/2}\frac{a_{max}}{\left(a_{max}-a\right)^2}da \tag{17}$$

Now we can substitute the comoving observer differential coordinate trajectories, equations (16) and (17) into the Klein metric, equation (14), to obtain the differential element of proper time elapsed along a comoving observer's trajectory:

$$ds^2 = c^2d\tau_{com\,obs}^2 = \beta\left(r_{com\,obs}, t_{com\,obs}\right)dt_{com\,obs}^2 - \alpha\left(r_{com\,obs}, t_{com\,obs}\right)dr_{com\,obs}^2 \tag{18}$$

(as before, $d\theta_{com\,obs} = d\varphi_{com\,obs} = 0$). The evaluation of this expression is straightforward but tedious. The reader may perform it for himself or refer to the Supplement, where we work it out step by step. The result is

$$d\tau_{com\,obs} = \pm\frac{da}{c}\sqrt{\frac{a}{a_{max}-a}} = d\tau_c \tag{19}$$

which is identical to the result (9) derived from the Robertson-Walker metric and the dynamical equations of cosmology.

Appeal to Schwarzschild coordinates cannot change the amount of time which passes on a physical clock; that is determined by the trajectory of the clock and not by the coordinate system. This exercise is an illustration of the fact that the proper time elapsed along a space-time trajectory is a scalar invariant. When one uses either the Klein form of the metric or the Robertson-Walker form of the metric (or any other form, for that matter, of the metric of this space-time geometry) to answer the question, 'How much time elapses on Earth clocks (or distant galaxy clocks) as the Universe expands?' one finds that the elapsed time is equal to the cosmic time and is the same, regardless of the location of the clock inside the matter sphere.

Before moving on to consideration of what Schwarzschild time is, it is worth noting that Oskar Klein, who devised[38] the Schwarzschild-like coordinate system employed by Humphreys in **Starlight and Time**, does not use the coordinate time t as the time coordinate in his own bounded cosmological model.[2] There, to the extent that he discusses time at all, he employs the conventional cosmic time/comoving clock proper time of standard cosmology theory. He adopts an age of 13 billion years as a reasonable estimate of the age of his bounded model, based on the data available in 1971.[14]

3.3 What is Schwarzschild Time and Why is Appeal to It Made in *Starlight and Time*?

Humphreys acknowledges that Schwarzschild time does not correspond to the time kept by comoving clocks, that is, physical clocks on Earth and on distant galaxies.[24] He also acknowledges, as the reader may verify by inspection of equation (12), that for certain values of η and a the Schwarzschild time has an imaginary component. What kind of clocks would keep Schwarzschild time? What are the space-time trajectories of hypothetical clocks which keep Schwarzschild time? It is easy to show that the space-time trajectories of such hypothetical clocks are, for much of the history of the Universe, physically impossible trajectories, moving faster than the speed of light.

3.3.1 The Space-time Structure of Constant $t_{Schwarzschild}$ Hypersurfaces and Schwarzschild Clock Trajectories

In order to visualize constant $t_{Schwarzschild}$ surfaces and Schwarzschild clock trajectories in a way which makes their physical absurdity manifest, it is desirable to recast the coordinate description of a bounded cosmos into a form which makes the trajectories of light and of physical observers obvious. We do this by appealing to the ψ, χ coordinate system. The angle χ is an alternate comoving radial coordinate defined by $\eta = \sin\chi$.[40] The radius of curvature a and cosmic time τ_c of the bounded sphere may be expressed in terms of the parametric equations

$$\tau_c(\psi) = \frac{a_{\max}}{2c}(\psi - \sin\psi)$$
$$a(\psi)\frac{a_{\max}}{2}(1-\cos\psi) = a_{\max}\sin^2\frac{\psi}{2} \qquad (20)$$

where ψ is an angle which ranges from 0 at the beginning of the expansion to 2π at the end of the recollapse.[6] Substitution of these into the $k = +1$ Robertson-Walker metric yields the simple form

$$ds^2 = a^2\left(d\psi^2 - d\chi^2 - \sin^2\chi d\Omega^2\right) \qquad (21)$$

The χ, ψ coordinate system yields a simple space-time diagram (see Figure 3) which closely resembles the Minkowski diagrams of Special Relativity. In this coordinate system, horizontal lines are hypersurfaces of constant spatial curvature a and constant comoving clock proper time $\tau_{com\,obs}$ and cosmic time τ_c. These lines terminate at $\chi_{edge} = \sin^{-1}\eta_{edge}$, which is $\pi/6$ for the example used in **Starlight and Time**;[6,17] vertical lines are the trajectories of comoving particles. Successive horizontal lines thus represent the Universe at successive moments in its expansion. Radial light trajectories, $ds^2 = 0$, $d\varphi^2 = d\theta^2 = 0$, manifestly obey the relation $d\chi = \pm d\psi$, so radially propagating light rays travel on trajectories tilted at 45° to the vertical, as shown in Figure 3.

Surfaces of constant $t_{Schwarzschild}$ are defined by ζ constant, or equivalently, ζ^2 constant. The relation $\eta = \sin\chi$ along with equation (20) may be substituted into the expression for ζ (equation (13)) to yield the equation of constant $t_{Schwarzschild}$ surfaces in the ψ, χ plane. With a little simplification, the result is

$$\cos\chi\cos^2\frac{\psi}{2} = \frac{\sqrt{1-\eta_{edge}^2}}{\zeta^2+1} \qquad (22)$$

A sample of representative constant $t_{Schwarzschild}$ surfaces is plotted as the dashed curves in Figure 4. Constant $t_{Schwarzschild}$ surfaces are not horizontal and so do not coincide with constant τ_c or $\tau_{com\,obs}$ or constant a surfaces. It is also clear from this diagram that surfaces of constant $t_{Schwarzschild}$ are not space-like for all a and η, since parts of them lie inside the future light cone (less than 45° to the vertical). The slope of the constant t surfaces is given by

$$\left.\frac{d\chi}{d\psi}\right)_{const\ t_{Schw}} = -\frac{\tan\frac{\psi}{2}}{\tan\chi} \qquad (23)$$

When this slope is steeper than –1, the surfaces are time-like. The boundary between the time-like and space-like parts of the constant $t_{Schwarzschild}$ surfaces is plotted as the dotted line in Figure 4. In the regions of space-time below this curve, the constant $t_{Schwarzschild}$ surfaces are time-like — there is an unambiguous future-past relationship between adjacent points on these parts of the constant $t_{Schwarzschild}$

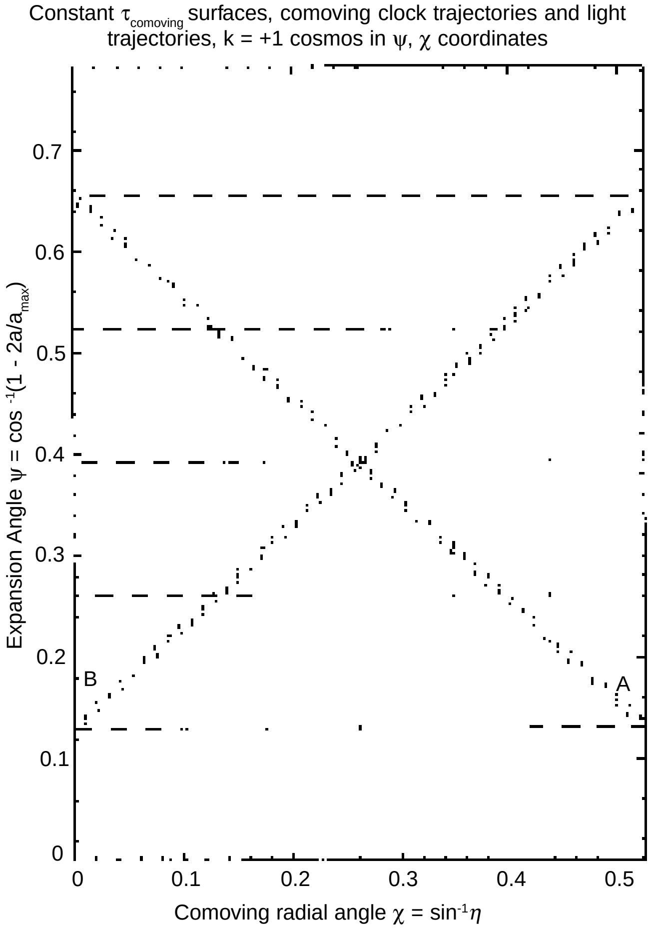

Figure 3. *Space-time diagram in ψ, χ coordinates for the bounded cosmos discussed in **Starlight and Time** (k = +1, η_{edge} = 0.5). The ψ coordinate parametrises the expansion and comoving time/cosmic time passage via equations (20). ψ ranges from 0 to 2π; the range 0 to π/4 is shown here. Surfaces of constant spatial curvature* a *and constant comoving clock time and cosmic time are horizontal lines (shown dashed). Comoving clock trajectories are vertical lines (shown solid). Radial light trajectories travel at ± 45° to the vertical. An inward (A) and outward (B) propagating light ray is shown by the labelled wavy lines.*

surfaces. This means that these surfaces cannot be simultaneous surfaces for any physical clocks (this is discussed more fully in the Supplement).

The succession of constant $t_{Schwarzschild}$ hypersurfaces defines the constant time surfaces in the Schwarzschild coordinate system. The space-time trajectories orthogonal to these surfaces are the trajectories of the Schwarzschild clocks. These clock trajectories can be determined by finding the radial trajectories $dT^{\mu} = (d\psi_{Schw\,cl}, d\chi_{Schw\,cl})$ which are orthogonal to the tangents $dS^{\mu} = (d\psi_{const\,t\,Schw}, d\chi_{const\,t\,Schw})$ of the constant $t_{Schwarzschild}$ surfaces. The orthogonality criterion is given by the metric: $g_{\mu\nu}dT^{\mu}dS^{\nu} = 0$. Using the metric appropriate to the (ψ, χ) coordinate system, we have

$$0 = d\psi_{Schw\,cl}\,d\psi_{const\,t_{Schw}} - d\chi_{Schw\,cl}\,d\chi_{const\,t_{Schw}} \qquad (24)$$

or

$$\left.\frac{d\chi}{d\psi}\right)_{Schw\,cl} = \left.\frac{d\chi}{d\psi}\right)_{const\,t_{Schw}} = -\frac{\tan\chi}{\tan\frac{\psi}{2}} \qquad (25)$$

This equation may be integrated to yield the equation which defines the Schwarzschild clock trajectories:

$$\sin\chi_{Schw\,cl}\sin^2\frac{\psi_{Schwcl}}{2} = \eta_{Schw\,cl}\frac{a}{a_{max}} = \frac{r_{Schw\,cl}}{a_{max}} = constant \qquad (26)$$

This leads to the unsurprising result that Schwarzschild clocks are stationary with respect to the Schwarzschild radius coordinate *r*. Since $\eta = r/a$, Schwarzschild clocks

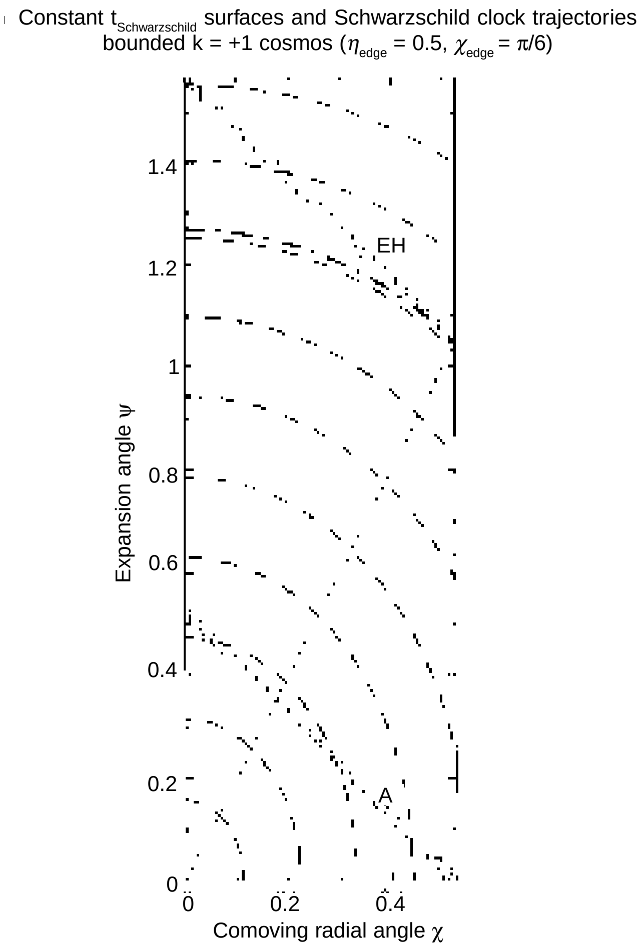

Figure 4. *ψ, χ spacetime diagram of the **Starlight and Time** bounded cosmos showing surfaces of constant Schwardschild coordinate time (dashed lines) and the trajectories of Schwarzschild clocks (solid lines). The dotted line is the boundary below which the constant $t_{Schwarzschild}$ surfaces and Schwarzschild clocks are physically impossible. The heavy dash-dot line is the β = 0 surface, which clearly does not coincide with the event horizon (wavy line labelled 'EH'). The wavy line 'A' is a radial inward light trajectory which leaves the surface at the beginning of the expansion, arriving at Earth long before the event horizon.*

are not stationary with respect to the matter of the Universe. Representative Schwarzschild clock trajectories are plotted as the thin solid lines in Figure 4. The unphysical character of Schwarzschild clocks is seen by the fact that part of the trajectory (the part below the dotted line) of such clocks involves the clocks moving faster than the speed of light with respect to the matter of the Universe, something impossible for real, physical clocks. From this diagram, it is obvious that Schwarzschild clocks travel inward with respect to the matter of the Universe (which travels on vertical trajectories in this coordinate system) and that, in the lower right part of the diagram, Schwarzschild clocks travel faster than the speed of light. In the same portion of space-time in which the constant $t_{Schwarzschild}$ surfaces are time-like, the Schwarzschild clock trajectories are space-like.

The properties of time-like constant t surfaces and space-like clock trajectories are impossible for any physical timekeeping system. Physical clocks are constrained to travel along time-like trajectories (within 45° of the vertical in the ψ, χ plane) and physically possible surfaces of simultaneity must be space-like (within 45° of the horizontal in the ψ, χ plane).[6] The time-like constant $t_{Schwarzschild}$ surfaces and space-like Schwarzschild clock trajectories imply clocks which travel, with respect to the matter of the Universe, faster than the speed of light. This is a physical impossibility, and Schwarzschild clocks are consequently physically impossible. If one confines one's attention to the space-time region above the dotted line in Figure 4, the Schwarzschild clock trajectories and constant $t_{Schwarzschild}$ surfaces are physically possible, but they are irrelevant, because they do not correspond to the real, physical clocks we are interested in, which are clocks on Earth and clocks associated with distant galaxies.

With this understanding of Schwarzschild time, we are in a position to evaluate Humphreys' reliance on Schwarzschild time as the correct time measure in a bounded Universe. Humphreys rightly notes that comoving clocks and Schwarzschild clocks do not keep the same time. It is obvious that this must be the case since Schwarzschild clocks move with respect to comoving clocks. Which of these clocks is more suitable as a measure of how much time has passed in the Universe since the beginning of the expansion? During the early part of the expansion of the Universe, Humphreys' favoured Schwarzschild clocks travel faster than the speed of light and thus do not correspond to physically possible clocks. Comoving clocks, on the other hand, travel along with the matter of the Universe. Schwarzschild clocks measure the time elapsed along space-time trajectories which, early in the expansion, are physically impossible and which at all times do not coincide with the trajectories of matter particles in the Universe. Comoving clocks measure the proper time elapsed along the trajectories which matter particles actually follow in the Universe. It is clear that comoving clocks are the correct answer to the question, 'Which clock tells how much time an observer on Earth or on a distant galaxy measures to elapse from the beginning of the expansion of the Universe to some later moment in the expansion?'

Finally, we consider the claim (quote # 3 above) that, in an unbounded Universe, the Schwarzschild time would match the cosmic time or comoving clock proper time. The unbounded $k = +1$ Universe occurs when we take the edge of the bounded Universe to be $\chi_{edge} = \pi$.[41] The trajectories of Schwarzschild clocks are still given by $r_{Schw\,cl} = a\eta_{Schw\,cl} = constant$, so relation (26) still gives the trajectories of Schwarzschild clocks. The constant $t_{Schwarzschild}$ surfaces are still orthogonal to the Schwarzschild clock trajectories, so it follows that these are given by

$$\pm cos\left(\chi_{const\ t_{Schw}}\right)cos^2\left(\psi_{const\ t_{Schw}}/2\right) = constant$$

('+' for $\chi < \pi/2$, '-' for $\chi > \pi/2$). Schwarzschild clock trajectories and constant $t_{Schwarzschild}$ surfaces for the unbounded case are shown in Figure 5. The shapes of these surfaces and trajectories are identical to the bounded Universe surfaces and trajectories except that they extend all the way to $\chi = \pi$, whereas the bounded case stopped at $\chi = \pi/6$ (or $\chi_{edge} = \sin^{-1} \eta_{edge}$ if a different choice of η_{edge} is made). It is obvious from this figure that constant $t_{Schwarzschild}$ surfaces do not correspond to constant τ_c surfaces (which are horizontal) and that the trajectories of Schwarzschild

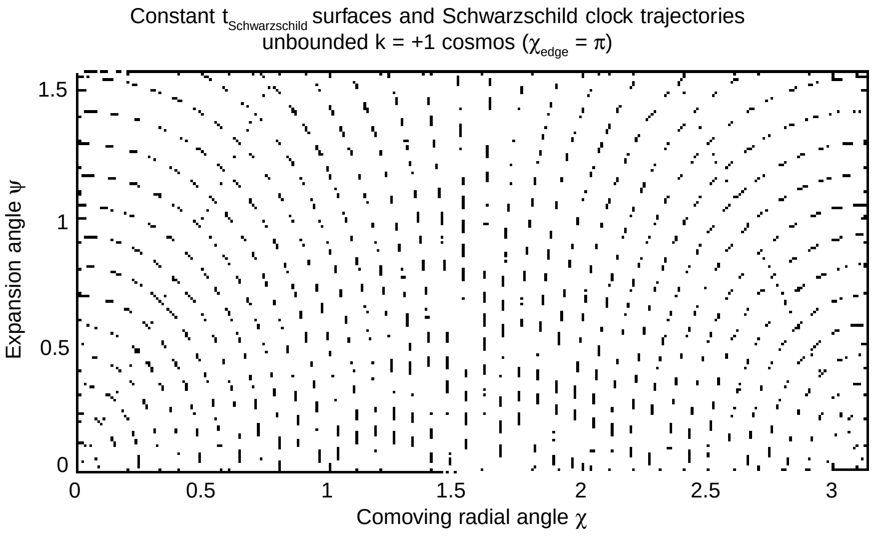

Figure 5. *ψ, χ space-time diagram of an unbounded ($\chi_{edge} = \pi$) k = +1 cosmos, showing surfaces of constant Schwarzschild time and the trajectories of Schwarzschild clocks. Schwarzschild clock trajectories are physically impossible in the region between the dotted lines.*

clocks do not correspond to the trajectories of physical comoving clocks (which are vertical). Thus, contrary to Humphreys' claim, it is not the case that the Schwarzschild time coincides with the cosmic time in the unbounded Big Bang cosmos.

3.3.2 'Earth Standard Time' and Schwarzschild Time

The appeal to Schwarzschild time is puzzling in view of the fact that in several places in **Starlight and Time**, it is explicitly affirmed that the relevant time measure is Earth proper time (which is also called 'Earth Standard Time').[42] Further, **Starlight and Time** shows a plot of the expansion of its example bounded sphere model[37] which clearly indicates that this bounded model requires the same billions of years (of order a_{max}/c, where $a_{max} = 4 \times 10^{10}$ light years) of proper time to expand as an unbounded model of identical interior matter density. Thus, in spite of the extensive appeal to Schwarzschild coordinate time, it is explicitly demonstrated within the pages of **Starlight and Time** that the introduction of a boundary does **not** modify the Earth proper time required for the Universe to expand to its present size.

3.4 Conclusion

Schwarzschild time, appealed to so extensively in **Starlight and Time**, is an irrevelant time coordinate which corresponds to the time kept by a set of hypothetical clocks which move with respect to the matter of the Universe at all times, and at faster than light-speed at early times. This time coordinate tells us nothing about the time which is measured by real, physical clocks in the Universe. Despite the fact that Humphreys asserts in a number of places that the relevant time quantity in the Universe is the time kept by real, physical, comoving clocks, when the need arises to compute time passage on such real, physical clocks, he veers away from physical reality and focusses instead on the physically irrelevant Schwarzschild coordinate time. It is true that, if one fails to notice that Schwarzschild clocks are not real, physical clocks on Earth and on distant galaxies, this focus on Schwarzschild time can make it appear that the centre of the Universe is 'younger' than the edge, but when one returns to reality and asks the question, 'how much time has elapsed on Earth clocks and on clocks located in distant galaxies', one must drop Schwarzschild time and compute the proper time elapsed on these clocks. This is a trivially easy calculation — the metric tells us that $\tau_{comoving} = \tau_{cosmic}$. Real, physical clocks on Earth and in galaxies located in different parts of a bounded Universe all keep the same time, cosmic time, and all remain synchronised with each other throughout the expansion of the Universe (this permanent synchronisation is readily verified by inspection of Figure 3). The dynamical equations which govern the expansion of a bounded Universe are identical to those which govern an unbounded Universe with identical interior properties, so that the expansion time-scales are identical for the two cases.

It follows from this that, if a young-Universe bounded cosmos model could be devised, an unbounded Universe with the same interior matter properties would also yield a young-Universe time-scale. However, as we show below, realistic young-Universe relativistic cosmological models are impossible.

4. MISUNDERSTANDINGS ABOUT THE NATURE AND EFFECTS OF EVENT HORIZONS IN THE UNIVERSE

The alleged effects of an event horizon in an expanding bounded Universe occupy a prominent place in the physics sections of **Starlight and Time**. These argue that the arrival of a shrinking event horizon at Earth would allow distant regions of the Universe to age billions of years during the passage of a single day of Earth time.[43] However, the discussion of event horizons is as flawed as the rest of the book. The mistakes include: event horizons occur where the 'time-time' metric component, g_{tt}, vanishes,[17,37] the reason for the absence of an event horizon in an unbounded cosmos is the absence of a large-scale pattern of gravitational force,[44] an event horizon stops the passage of time on physical clocks traversing it,[37] and matter and light cannot travel inward inside a past event horizon.[45]

4.1 What Event Horizons Are

In cosmology theory, the term **horizon** refers to a space-time boundary, typically between regions of space-time which are accessible to an observer and those which are not. An **event horizon**, in particular, a **future event horizon**, is a space-time boundary between regions from which light can propagate to great distances and regions from which it cannot. Space-time events within the boundary cannot be observed by observers far away because light signals conveying information about these events cannot propagate to the distant regions. Because an event horizon is the boundary between light trajectories which can and cannot propagate to great distance, it follows that the event horizon, considered through time, is itself a light-like three-surface, which is one in which at each point there is one light-like direction ($g_{\mu\nu}dx^\mu dx^\nu = 0$) within the surface, and all other directions within the surface are space-like ($g_{\mu\nu}dx^\mu dx^\nu < 0$). Thus, a necessary though not sufficient condition that a space-time trajectory $x^\mu(\lambda)$ (where λ is a quantity which parametrises the trajectory) coincide with an event horizon is that $g_{\mu\nu}dx^\mu dx^\nu = 0$ for all λ.

How can one locate the event horizon of a spherically symmetric geometry? In a static geometry, such as the Schwarzschild geometry, the event horizon will be stationary. In such a case, and adopting coordinates such that the metric is diagonal, it follows that $g_{tt} = 0$ and $dx^i_{eh} = 0$ (i = 1, 2, 3) satisfies the null requirement $g_{\mu\nu}dx^\mu_{eh}dx^\nu_{eh} = 0$. In a dynamic geometry, the event horizon may not be stationary — this is the case in the bounded cosmos proposed in **Starlight and Time**. In that case, the fact that $dx^i_{eh} \neq 0$ implies that $g_{tt} = 0$ cannot define the location of the event horizon, since those two conditions are incompatible with the null requirement $g_{\mu\nu}x^{\mu}_{eh}x^{\nu}_{eh} = 0$ (unless g_{rr} fortuitously vanishes wherever g_{tt} vanishes, which it does not in the model in question).

4.2 Why There is an Event Horizon in the Bounded Cosmos But Not in the Unbounded Cosmos

Starlight and Time is correct in affirming that there is an event horizon in the bounded cosmos which is absent in the unbounded cosmos, but the reason offered in explanation of this is mistaken. It is claimed, falsely, that the reason is that there is a radial pattern of gravitational force in the bounded matter sphere which is absent from the corresponding region of an unbounded Universe. We showed in section 2 that the gravitational field is identical for the interior regions of the bounded and unbounded Universe. The correct reason is that event horizons are global properties of the geometry which depend on the existence of distant observers — recall that the horizon is the boundary between space-time regions which can and cannot be seen by distant observers. In the bounded cosmos, there is an external asymptotically flat space-time in which distant observers can reside, and from which a distinction can be made between space-time regions in the interior of the matter sphere from which light can or cannot escape to the exterior. In the unbounded cosmos, on the other hand, there is no 'outside' for light to escape to and consequently no event horizon.[6]

4.3 The Location and Effects of the Past Event Horizon of an Expanding Bounded Universe

It will be easier to think about the past event horizon out of which an expanding bounded cosmos emerges after first considering the future event horizon into which a collapsing bounded cosmos would fall. This event horizon appears, at some value of the expansion parameter a, at the centre of the matter sphere and thereafter expands outward, eventually arriving at the surface as the surface falls inside its own Schwarzschild radius.[6] To determine the trajectory of the expanding event horizon inside the matter sphere, we need only keep in mind the meaning of the event horizon: the boundary between light rays which can and cannot escape to great distance. Clearly, any radially outward-travelling light ray which arrives at the surface before the surface falls within the event horizon will escape, and any light ray which arrives at the surface after the surface falls inside the horizon will not escape. The boundary between these two cases is the outward-travelling radial light trajectory which arrives at the surface exactly at the moment the surface falls inside its Schwarzschild radius. This defines the event horizon in the interior of the matter sphere.

If, in our Minkowski-like coordinate system (ψ, χ) we label the moment the future event horizon arrives at the surface by ψ_{surf}, χ_{surf}, the trajectory of the event horizon inside the matter is simply given by the outward radial light trajectory ($d\chi = d\psi$) which intersects this point: $\chi_{eh}(\psi) = \psi + \chi_{surf} - \psi_{surf}$, where the range of ψ during which the horizon propagates to the surface is ($\psi_{surf} - \chi_{surf} < \psi < \psi_{surf}$).

The inward-travelling past event horizon which occurs during the expansion of a bounded cosmos is simply the time-reversal of the future event horizon: it is the set of all radially-inward-travelling light trajectories which depart from the surface at the moment the surface arrives at the Schwarzschild radius. The equation of the past event horizon in the interior of the matter sphere is given by $\chi_{eh}(\psi) = \chi_{surf} - \psi + \psi_{surf}$. We show in the Supplement that, for the sample bounded cosmology employed in **Starlight and Time** ($a_{max} = 4 \times 10^{10}$ light years, $\eta_{edge} = 0.5$, $\chi_{edge} = \pi/6$), the event horizon reaches the surface at $\psi_{surf} = \pi/3$, $a = 0.25a_{max}$. Figure 4 shows the past event horizon (the wavy line which heads inward from the surface at $\psi = \pi/3$). The locus on which β, the g_{tt} component of the Klein metric, vanishes is shown as the heavy dash-dot line. The $\beta = 0$ curve is clearly not coincident with the event horizon, illustrating the point made previously that $g_{tt} = 0$ does not define the event horizon in a dynamic geometry.

4.4 What Effects Does the Event Horizon Have on Observers Traversing It?

Is it true, as claimed in **Starlight and Time**, that the event horizon has radical effects on the passage of time for an observer traversing it or that, as the past event horizon reaches Earth, distant regions of the Universe age enormously during the passage of a brief period of time on Earth? It is easy to see, by examination of Figure 4, that neither of these claims is true.

From the previous discussion, it is clear that the past event horizon of an expanding bounded Universe is simply a particular light-like surface: that generated by the family of inward-travelling radial light trajectories which leave each point of the surface of the matter at the moment the surface expands to its Schwarzschild radius. Each point in the interior of the matter lies on one of these trajectories, and the arrival of the event horizon at the position of a particular comoving observer in the interior of the matter simply corresponds to the arrival of one of these radial light rays at his location. The light ray arrives at the comoving observer and passes on toward the centre. That is the event horizon, as seen by such an observer. This light trajectory manifestly has no effect on the passage of time for this observer. His comoving clock continues to tick in concert with the expansion of the Universe and in synchrony with every other comoving clock on his constant a surface.

Starlight and Time asserts the contrary, but this is due to a misunderstanding. The r, t part of the metric in Schwarzschild coordinates is

$$ds^2 = c^2 d\tau^2 = \beta c^2 dt^2 - \alpha dr^2 \quad (27)$$

Humphreys wrongly alleges that the vanishing of β (mistakenly identified with the event horizon) will cause $d\tau$ to vanish, resulting in the momentary stopping of 'natural clocks'[37] during which, it is claimed, exterior parts of the Universe rapidly age. This claim is in error: this equation gives $d\tau = 0$ for finite dt only if $dr = 0$ simultaneously. However, comoving clocks do not, in general, have $dr = 0$. As we showed in section 3, comoving clocks have fixed η, so that $dr = \eta da = \sin\chi da$. In addition, at the moment $\beta = 0$, the coordinate time diverges to $-\infty$,[6,17,39] so that dt at this moment is arbitrarily large. Thus, the arrival of the $\beta = 0$ surface at any finite comoving radius χ will not stop comoving clocks at that radius: $d\tau_{comoving} \neq 0$. As we showed previously, throughout the expansion of the Universe, the elapsed proper time on comoving clocks is given by

$$d\tau_{comoving} = \sqrt{\frac{a}{a_{\max} - a}}\frac{da}{c}$$

The vanishing of β is due to a singularity in Klein's coordinate system. The coordinate time $t_{Schwarzschild}$ diverges to $-\infty$ along a certain surface in the interior (wrongly identified with the event horizon in **Starlight and Time**) and the g_{tt} metric component must vanish on this surface to keep the proper time interval finite. One could redefine the time coordinate in the interior of the matter sphere to remove this singularity or even move the singularity so that it coincides with the true event horizon.[6] However, due to the scalar invariant nature of the proper time, whatever modification of the coordinate system employed, it would still be the case that the time elapsed on physical, comoving clocks would be

$$d\tau_{comoving} = \sqrt{\frac{a}{a_{\max} - a}}\frac{da}{c}$$

Are any unusual aging effects in the distant Universe observed by an Earthbound observer as the event horizon arrives at Earth? To determine this, we need to consider how Earth-based observers receive information about the passage of time at distant comoving clocks in a bounded Universe. This information obviously arrives by means of light signals. As shown in Figure 6, two signals emitted from some comoving radius χ_{em} at different values of the expansion parameter ψ, ψ_{em} and $\psi_{em} + d\psi_{em}$, will arrive at Earth at ψ_{rec} and $\psi_{rec} + d\psi_{rec}$, respectively. Since an inward-travelling ray obeys the relation $d\chi = -d\psi$ and the two rays have to travel the same $\Delta\chi$ to arrive at Earth, it is clear that the $d\psi_{rec} = d\psi_{em}$. Recalling the coordinate transformation between τ_c and ψ,

$$d\tau_c = \frac{a_{\max}}{2c}(1 - \cos\psi)d\psi = a(\psi)d\psi$$

gives $d\tau_{c,em} = a(\psi_{em})d\psi_{em}$ and $d\tau_{c,rec} = a(\psi_{rec})d\psi_{rec}$. Since $d\psi_{rec} = d\psi_{em}$, it follows that

Ingoing light trajectories in a bounded k = +1 cosmos

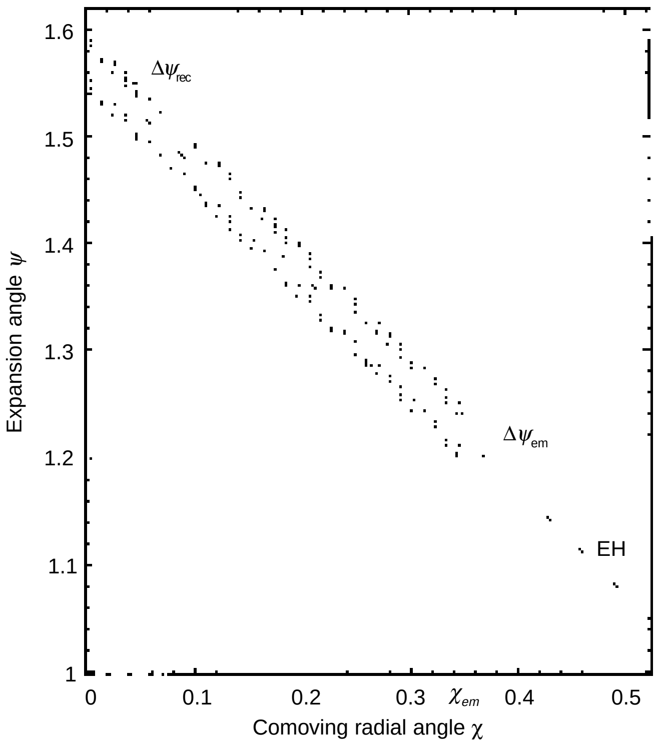

Figure 6. *Earth observations of distant clock behaviour are unaffected by the event horizon of the bounded cosmos. The time interval at a distant galaxy between the emission of two signals leads to a time interval at Earth between the reception of the two signals.* ***Starlight and Time*** *claims that the reception time interval shrinks to zero for signals arriving near the arrival of the event horizon, resulting in an apparent speed-up of distant clocks when the event horizon arrives at Earth. As shown in the text, this is not so. Earth observers observe distant clocks to run slower than Earth clocks throughout the expansion of the bounded cosmos.*

$$d\tau_{c,em} = d\tau_{c,em}\frac{a(\psi_{rec})}{a(\psi_{em})} \quad (28)$$

This means that the proper time interval separating the reception of the two signals $d\tau_{c,rec}$ will differ from the proper time interval separating the emission of the two signals, $d\tau_{c,em}$ by the factor $a(\psi_{rec})/a(\psi_{em})$, the ratio of the size of the Universe when the signals arrive at Earth to the size of the Universe when the signals were emitted. In other words, distant clocks will be seen by an Earth-based observer to run slow (since the Universe is expanding, $a(\psi_{em}) < a(\psi_{rec})$). Distant comoving observers would likewise observe Earth clocks to run slow. This is just the well-known redshift effect. The same thing is true for signals arriving at Earth as the event horizon arrives: they will simply be redshifted (the two signals shown in Figure 6 have been chosen to bracket the event horizon, shown as the dash-dots line). Contrary to **Starlight and Time**, Earth observers will not witness any rapid aging of the distant Universe as the event horizon arrives at Earth.

4.5 Is It Impossible for Light to Travel Inward Inside the Matter Sphere Until the Event Horizon Has Shrunk to the Centre?

Humphreys claims that light cannot travel inward in the interior of the past event horizon of a 'white hole', which is what he calls the expanding bounded matter distribution discussed in **Starlight and Time**.[46] This assertion, coupled with the claim that the event horizon did not arrive at Earth until Day Four of Genesis 1, plays a minor role in the correlation of his cosmological proposal to the Genesis 1 narrative: it accounts for the absence of visible starlight from distant galaxies on Earth prior to Day Four.

Examination of the space-time diagrams we have been using demonstrates that this assertion is untrue. Figure 4 shows the past event horizon (labelled 'EH') and an inward radial light ray emitted from the edge of the matter sphere at the beginning of the expansion (labelled 'A'). Clearly, light rays from the edge of the matter as well as from regions in the interior can and do travel inward and reach Earth long before the event horizon arrives at Earth. The light ray 'A' arrives at Earth at $\psi = \pi/6$, or $\tau_{comoving} = 0.47 \times 10^9$ yr, while the event horizon does not arrive at Earth until $\psi = \pi/2$, or $\tau_{comoving} = 11.4 \times 10^9$ yr (where we have adopted Humphreys' choice of $a_{max} = 4 \times 10^{10}$ light years).

4.6 Conclusion: Event Horizons

The physics of event horizons plays a prominent role in the new cosmological model proposed in **Starlight and Time**. There it is claimed that the shrinking event horizon of an expanding bounded Universe stops clocks as it passes them, producing differential aging from centre to edge of the matter distribution. This effect is so powerful, it is claimed, that the distant Universe ages billions of years during the course of a single Earth day as the event horizon arrives at Earth. In addition, it is claimed that light cannot travel inward to Earth until after the event horizon arrives at Earth.

These assertions are false. Humphreys' understanding of the meaning and effects of event horizons is mistaken. **Starlight and Time** gets the location and consequences of the past event horizon of its model cosmology all wrong. The past event horizon is simply a particular inward-travelling light-like surface. It has no consequences at all for the passage of time on physical clocks in the interior of a bounded Universe and no effect on the ability of light to travel inward in the interior of a 'white hole'. Time passes on physical clocks in a bounded Universe in exactly the same way as it does in an unbounded Universe, and light trajectories are likewise identical for the two cases.

5. OBSERVATIONAL REFUTATION OF *STARLIGHT AND TIME*

In response to earlier analysis[22] which pointed out incompatibilities between the model proposed in **Starlight and Time** and the observed properties of the Universe, Humphreys has pleaded lack of time to develop this model fully.[20] In this section we show that no amount of development can fix this model's problems. Observations which thoroughly rule out young-Universe relativistic cosmologies are already available.

5.1 The Observed Invariance of Extragalactic Redshifts is Incompatible With Expansion as Rapid as That Required by Young-Universe Theory

It is easy to show that, in a Robertson-Walker cosmology, a galaxy or QSO with cosmological redshift Z will exhibit a present rate of change in its redshift of[6,47]

$$\frac{dZ}{d\tau_o} = (1+Z)H_o - H\left(\tau_{em}\left(\tau_o\right)\right) \tag{29}$$

where τ_0 is the present cosmic time, H_0 is the present value of the Hubble parameter, $\tau_{em}(\tau_0)$ is the emission time for light now arriving at Earth with redshift Z, and $H(\tau_{em})$ is the value of the Hubble parameter at that emission time. The value of H_0 has been measured to be close to 10^{-10} yr^{-1}. Any young-Universe cosmology which accepts cosmic expansion as the cause of redshifts will require that the past value of $H(\tau)$ be large in order to expand the Universe to its present size in a few thousand years or less. Humphreys' model, for example, expands the Universe much of the way to its present size in a period of six days or less.[48,49] Other proposals have been made,[50] and the common feature of all these proposals is that $H(\tau)$ is very large in the past.

The simplest physical model which can produce rapid past expansion is the supposition of a large value of the cosmological constant (this is proposed in **Starlight and Time**, for example) or an equation of state with slowly varying energy density (cosmic inflation[51]). In this case, the Hubble parameter is constant, H_{large}, and the cosmic scale factor varies as $a(\tau_c) \propto \exp(\tau_c H_{large})$. We may obtain a lower estimate for the value of H_{large} from the fact that the largest redshift observed for discrete objects is at present about $Z_{max} = 5$, implying that the Universe has expanded by a factor of $1 + Z_{max} = 6$ since the light from these objects was emitted. If we assume that the rapid expansion of the Universe from one sixth its present size to its present size took place during some Earth time period $\Delta\tau_{rapid}$, we can obtain an expression for the value of the Hubble parameter during this period

$$H_{large} = \frac{ln\left(1+Z_{max}\right)}{\Delta\tau_{rapid}} \approx \frac{1.8}{\Delta\tau_{rapid}} \tag{30}$$

The length of the rapid expansion period, $\Delta\tau_{rapid}$, is a free parameter of the theory. A lower limit on the value of H_{large} may be obtained from the fact that $\Delta\tau_{rapid}$ cannot exceed the age of the Universe. For a young Universe model with $\Delta\tau_{rapid} < 6000$yr, $H_{large} > 3 \times 10^{-4}$yr^{-1} so that distant galaxies and QSOs should now exhibit redshift change rates with magnitudes in excess of 3 x 10^{-4} per year:

$$\frac{dZ}{d\tau_o} < -3\times10^{-4}\,yr^{-1} \qquad (31)$$

This is just a lower limit on the magnitude of the predicted present redshift change rate. **Starlight and Time** calls for a much larger expansion factor (about 10^{10} from the primordial nucleosynthesis state[52] in a much shorter time (six days or less), which would imply a present $dZ/d\tau$ of ≈ $-1400 yr^{-1}$, a manifestly absurd prediction.

Astronomical observations (see the discussion in the Supplement) rule out any changes as large as those of equation (31), which in turn implies that the Universe cannot have expanded to its present size as rapidly as required by young-Universe theology. Figure 7 shows a series of measurements of $dZ/d\tau$ for a number of objects with different redshifts. The measurements are all consistent with zero observed change (the changes implied by the standard model, ≈ $-10^{-10} yr^{-1}$, are undetectibly small) and are all incompatible with the large rates of change required by any young-Universe model based on relativity.

It might appear possible, in principle, to wriggle out of this argument by claiming, 'the Universe did not expand in a smooth fashion. Rather, it expanded in a series of jerks, between which it was static. The observations which show $\Delta Z/\Delta\tau \approx 0$ only show that the Universe was not expanding during the time period between the emission times of those observations'. In such a case, $a(\tau)$ would have the form of a series of 'steps' or 'ramps' and $H(\tau)$ would be a series of Dirac delta functions or 'top-hat' functions at the times corresponding to the 'steps/ramps'. This is an unsatisfactory response, however. The redshift change rate of equation (29) can be integrated to yield the observed redshift of a source at arbitrary Earth time:

$$Z_{(\tau_2)} = Z_{(\tau_1)} + \int_{\tau_1}^{\tau_2} d\tau' \left[\left(1+Z(\tau')\right)H(\tau') - H\left(\tau_{em}(\tau')\right)\right] \qquad (32)$$

where the integration variable τ' is the Earth observer time between two measurements of the redshift of an object (made at Earth times τ_1 and τ_2) and $\tau_{em}(\tau')$ is the emission time for a signal which arrives at Earth at Earth time τ'. Noting that the present Hubble parameter, $H(\tau')$, is essentially zero and assuming that $H(\tau_{em}(\tau'))$ is zero everywhere except during the 'steps/ramps', the integral simplifies to

$$Z_{(\tau_2)} = Z_{(\tau_1)} - \sum_{i=1}^{N} \Delta\tau_{em,i} H_{large,i} \qquad (33)$$

where $\Delta\tau_{em,i}$ is the length of the ith period of expansion (of N total) which occurs between $\tau_{em}(\tau_1)$ and $\tau_{em}(\tau_2)$, and $H_{large,i}$ is the value of the Hubble parameter during that period. If the expansion is confined to a set of discrete steps or ramps, the values of $H_{large,i}$ must be correspondingly larger than the smooth value H_{large} in order to expand the Universe to its present size. If any of these brief, but very rapid,

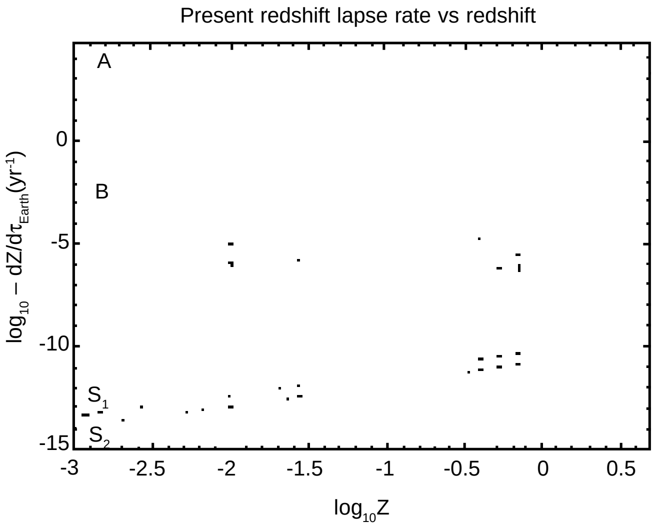

Figure 7. *Observed and predicted redshift change rates for young-Universe cosmologies and the standard model. Curve A is the prediction of* ***Starlight and Time****, assuming 10^{10}-fold expansion in six days. Curve B is the lower limit possible in a 6000-year expansion, given observed redshifts as large as* Z = 5*. Curves* S_1 *and* S_2 *are the precitions of standard Big Bang models with* k = 0, Ω_0 = 1 *and* H_0 = *100 and 40 km/s/Mpc, respectively. The data points show 2σ upper liits on the observed* dZ/dτ *for very high precision measurements of several distant galaxies and quasars.*[6] *The observed limits on* dZ/dτ *are 100 to 1000 times too small to be compatible with the young-Universe scenario.*

expansions occurs between the emission times of the first and second light ray, there will be a difference in the observed redshifts of the two rays. In order to expand the Universe six-fold, since the emission of light from Z = 5 quasars, it is necessary that the sum $\Sigma\Delta\tau_i H_{large,i}$ over all the discrete expansions occuring between the emission time of Z = 5 light and the present must be at least 1.79. Thus, it is not possible to 'hide' the expansion in a limited number of very large jerks if there are many pairs of observations Z_1, Z_2 for different objects at different redshifts which indicate no redshift change.

In the astronomical literature there are thousands of pairs of redshift observations of nearby and distant galaxies and quasars separated by Earth time intervals of years to decades. The emission time intervals corresponding to the observation dates of these measurements would densely blanket a 6,000-year expansion history. No statistically significant redshift variation has been detected in the 80+ years of such measurements, ruling out the 'jerky' 6,000-year expansion scenario. Most of these observations are not sufficiently precise to rule out smooth expansion spread over 6,000 years, but there are a few which can be used to test for this. Figure 7 shows the highest quality (that is, smallest uncertainty in $dZ/d\tau$) data the authors have found in the literature.[6] These rule out the rapid expansion scenario proposed by Humphreys and any smooth expansion scenario for which the expansion time is less than about 10^6 years.

The measured upper limit on $dZ/d\tau$ sets an upper limit on the value of H_{large} (assuming expansion spread out over 6,000 years, which makes H_{large} as small as it can be in the young-Universe scenario):

$$H_{large} < 10^{-6}\, yr^{-1} \tag{34}$$

This limit on H_{large} in turn sets a lower limit on how long it has taken the Universe to expand from one sixth its present size, (that is, from the size it was when the light from $Z = 5$ QSOs was emitted) to its present size:

$$H_{large} \Delta\tau_{6-fold\ expansion} = ln 6 = 1.79 \tag{35}$$

implies that

$$\Delta\tau_{6-fold\ expansion} > 1.8 \times 10^{6}\, yr \tag{36}$$

The quantity $\Delta\tau_{6\text{-}fold\ expansion}$ is also the light travel time from a $Z = 5$ object. Thus, the tiny upper limits on observed redshift changes imply long expansion times and long light travel times.

5.2 The Light Travel Time from Distant Galaxies Places a Firm Upper Limit on the Distance to Those Galaxies

The whole premise of **Starlight and Time** is that it is possible to construct a locally homogeneous and isotropic cosmological model in which light travels great distances during the passage of short periods of time on Earth clocks. It is straightforward to show that this is impossible — the Earth time elapsed during the light travel gives a hard upper bound on the distance to the object from which the light is travelling. Conversely, the distance to a distant object places a hard lower bound on the amount of Earth time which elapses as light travels from that object to Earth. This fact can be shown by a short mathematical proof. We present a terse form of the proof below. Readers interested in more elaboration are referred to our supplementary paper.

5.2.1 The Dyer-Roeder Equation

In a Universe which is homogeneous and isotropic in the mean, and in which a fraction α of the total matter (assumed to be non-relativistic, an excellent approximation) is distributed smoothly (a fraction $(1 - \alpha)$ is clumped into galaxies, clusters, etc.), the angular diameter distance[53] D_A obeys the differential equation

$$\frac{d^2 D_A}{d\lambda^2} = -\frac{3}{2}\alpha\Omega_o (1+Z)^5 D_A \tag{37}$$

where λ is the affine parameter along the light trajectory from the source to Earth[54] ($\lambda = 0$ at the beginning of the light trajectory at the source at redshift Z and is $\lambda_{Earth}(Z)$ at the end of the trajectory when it reaches Earth) and Ω_0 is the present value of the cosmic density parameter.[55] The terminal conditions on equation 37 are $D_A(\lambda_{Earth}(Z)) = 0$ and $dD_A/d\lambda\,|_{\lambda_{Earth}(Z)} = -c/H_0$.[6]

The angular diameter distance of any object may be determined by integrating equation (37) backwards from $\lambda_{Earth}(Z)$ to $\lambda = 0$ twice with respect to λ. Short of doing this for all Z, α, and Ω_0, we can derive a general relation between D_A and $\lambda_{Earth}(Z)$ as follows. From equation (37), it is obvious that $D_A(\lambda)$ curves toward the λ axis and from the terminal conditions, $D_A(\lambda)$ intersects the λ axis with slope $-c/H_0$ (see Figure 8). By definition, D_A is a positive quantity, so it follows that the angular diameter distance of an object at redshift Z must obey the inequality

$$0 \le D_A(Z) \le \frac{c}{H_0}\lambda_{Earth}(Z) \tag{38}$$

The affine parameter λ is related to cosmic time τ_c by[54]

$$\frac{d\tau_c}{d\lambda} = \frac{a_0}{H_0 a(\tau_c)} \ge \frac{1}{H_0} \tag{39}$$

where the the inequality follows since the past scale factor of the Universe $a(\tau_c)$ is smaller than the present scale factor a_0 in an expanding Universe. Given that $a(\tau_c) < a_0$ for cosmic times earlier than the present, it is obvious that

$$\lambda_{Earth}(Z)\frac{c}{H_0 a(\tau_c)} \le c\Delta\tau_c(Z) \tag{40}$$

where $\Delta\tau_c(Z)$ is the cosmic time elapsed during light travel from an object with redshift Z. Inequalities (38) and (40) together imply that

$$\frac{D_A(Z)}{c} \le \Delta\tau_c(Z) \tag{41}$$

We have already shown that the elapsed cosmic time $\Delta\tau_c$ is identical, to within a few parts in 10^6, to the elapsed

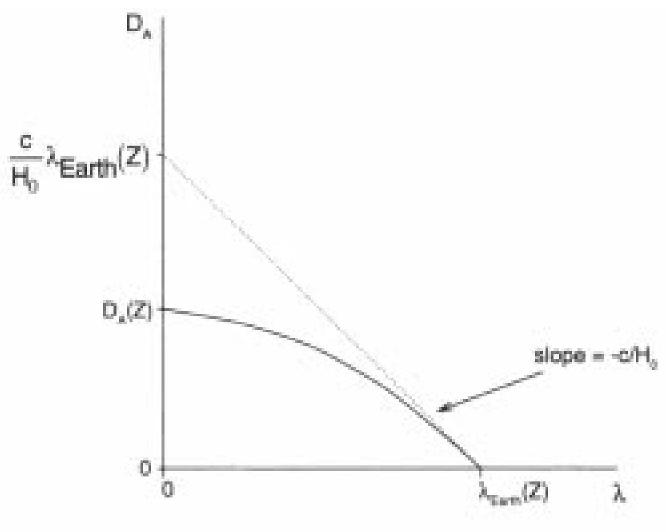

Figure 8. *Diagram illustrating how the Dyer-Roeder equation (equation (37)) provides an upper limit on the angular diameter distance in terms of the affine parameter* λ. *From the diagram, it is obvious that* $D_A(Z) \le \lambda_{Earth}(Z)c/H_0$.

Earth time, so that without loss of accuracy we may rewrite this as

$$\frac{D_A(Z)}{c} \le \Delta\tau_{Earth}(Z) \qquad (42)$$

where $\Delta\tau_{Earth}(Z)$ is the Earth proper time elapsed during light travel from an object with redshift Z. Thus, in an arbitrary on-average locally homogeneous and isotropic expanding Universe, the angular diameter distance provides an absolute lower bound to the light travel time as measured by physical clocks on Earth.

Angular diameter distances are difficult to measure, but are related by $D_A(Z) = D_L(Z)/(1+Z)^2$ to a more easily measured distance quantity called the luminosity distance, D_L.[56] Based on large numbers of measured luminosity distances and confirmed with a much smaller number of measured angular diameter distances, it is found that the angular diameter distance to objects with redshifts much less than unity is

$$D_A(Z) = Z\frac{c}{H_0} = 15Z \times 10^9 \textit{ light years} \qquad (43)$$

where we have taken H_0 = 64 km/s/Mpc.[57,58] The light travel time from low redshifts objects is consequently

$$\Delta\tau_{Earth}(Z) \ge 15Z \times 10^9 \textit{ years} \qquad (44)$$

So, for example, the light travel time of an object with redshift $Z = 0.1$ must exceed 1.5 billion years.

The converse of this theorem is that, if the light-travel time from an object must be small, the angular diameter distance of that object cannot be large: $D_A(Z) < c\Delta\tau_{Earth}(Z)$. This is an observable consequence of the **Starlight and Time** model: there should be no visible objects in the Universe with an angular diameter distance of greater than 6,000 light years. This is a preposterous proposition, and one which Humphreys himself rejects.[59]

This argument is strictly valid only if the visible Universe is homogeneous and isotropic in the mean, one of the key assumptions of standard cosmology theory and one shared by **Starlight and Time**. However, it is possible to generalise this argument to an arbitrary inhomogeneous Universe (provided only that the Universe undergoes expansion in the past). A proof of this is presented in the Supplement.

5.3 Conclusion: Observable Implications of *Starlight and Time*

The recent-creation, rapid expansion approach to cosmology of **Starlight and Time** has two profound observable implications not recognised in that book. The first of these is that extragalactic objects should exhibit large annual changes in redshift. The second is that no visible object in the Universe should have an angular diameter distance greater than 6,000 light years. Both of these predictions are found to be false. No significant changes in redshift of extragalactic objects have been observed in the almost 100 years of such measurements. The most precise measured upper limits on redshift changes imply that the Universe has been expanding for at least one million years of Earth time, not the 6,000 or less required by **Starlight and Time**. No extragalactic angular diameter distances as small as 6,000 light years have ever been observed. Indeed, the centre of the Milky Way galaxy is about four times this distance from Earth.[60] These results apply, regardless of the details of the expansion. Thus, no adjustment of the expansion history can avoid the force of these consequences. These two phenomena rule out all possible variations of young-Earth relativistic cosmology which possess the properties of past expansion and large present size, properties which Humphreys concedes do apply to the real Universe.

6. CONCLUSION

The arguments of **Starlight and Time** are profoundly flawed and by no means offer a solution to the light-travel-time problem. The central premise of the book, that the long time-scale implications of standard cosmology theory are a consequence of the historically unbounded character of the standard model, is mistaken; in fact, the presence or absence of boundaries is irrelevant to the standard model, provided that the observable Universe is approximately homogeneous and isotropic. The appeal to Schwarzschild coordinate time is ill-conceived and avoids the central question of which clocks are relevant and how much time elapses on them as the Universe expands; the relevant clocks in a bounded Universe, as in an unbounded one, are comoving clocks, which remain synchronised to cosmic time throughout the expansion of the Universe. The claim of profound time distortions accompanying the passage of a past event horizon in an expanding bounded cosmos is mistaken; in fact, the past event horizon of an expanding bounded Universe produces no effects detectible by observers inside the Universe. The rapid-expansion hypothesis required to bring the Universe to its present size in only a few thousand years leads to observable consequences, such as rapid changes in redshift and a very low upper limit on the observed distance to extragalactic objects, which clearly do not occur in the real universe; conversely, the observed staticity of redshifts and the observed large distances of extragalactic objects imply that the Universe has been expanding and light from distant galaxies has been travelling toward Earth for spans of time far longer than the brief time-scale permitted by young-Universe interpretation of the Bible.

The bounded cosmology approach of **Starlight and Time** leads to cosmological models which are identical to the standard Big Bang model in their time-scale implications. It should not be promoted in the Church as a scientifically sound young-Universe alternative to Big Bang cosmology.

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