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An examination of time as featured in the General Theory of Relativity, which supercedes Einstein's Special Theory, serves to rekindle the issue of the existence of absolute time. In application to cosmology, Einstein's General Theory yields models of the universe featuring a worldwide time which is the same for all observers in the universe regardless of their relative motion. Such a cosmic time is a rough physical measure of Newton's absolute time, which is based ontologically in the duration of God's being and is more or less accurately recorded by physical clocks.

Introduction

Probably not too many physicists and philosophers of science would disagree with Wolfgang Rindler's judgment that with the development of the Special Theory of Relativity (STR) Einstein took the step "that would completely destroy the classical concept of time."[1] Such a verdict is on the face of it rather premature, not to say false. For by its very nature the Special Theory is a restricted theory, since it concerns only reference frames which are in a state of uniform motion. Although the Special Theory can be adapted so as to analyze the notion of non-inertial (that is, accelerating or decelerating) frames of reference, it does not serve to relativize the motion of such frames by rendering them equivalent to inertial frames.[2]

Troubled by the non-equivalence of inertial and non-inertial frames, Einstein labored for a decade on a General Theory of Relativity (GTR), which had as its aim the enunciation of a General Principle of Relativity which would serve to render physically equivalent all inertial and non-inertial frames alike. After completing his General Theory in 1915, he boasted that it "takes away from space and time the last remnant of physical objectivity."[3] It was supposed to be, in effect, the final destruction of Newton's absolute space and time.

In fact, however, Einstein was only partially successful in achieving his aims. He did not succeed in enunciating a tenable General Principle of Relativity after the pattern of the Special Principle, nor was he able to show the physical equivalence of all reference frames. He did succeed in drafting a revolutionary and complex theory of gravitation, which has been widely hailed as his greatest intellectual achievement. The so-called General Theory of Relativity is thus something of a misnomer: it is really a theory of gravitation and not an extension of the Special Theory of Relativity from inertial reference frames to all reference frames.[4]

The failure of Einstein's epistemological and physical arguments aimed at relativizing acceleration and rotation does not, however, entail the existence of Newtonian absolute space and time. For within the context of GTR these "absolute" motions are conceived to exist, not with respect to some absolute space and absolute time, but rather with respect to spacetime.[5] Spacetime itself becomes, as Einstein saw, a sort of relativistic ether which serves to define such motions, but is not itself a reference frame.[6] Thus, although "absolute" motions — "absolute" in the sense of "non-relativized"— still exist within Relativity Theory, they do not guarantee the existence of absolute space and time, as Newton thought.

Cosmic Time

It might appear, therefore, that GTR has nothing more to contribute to our understanding of time than STR. The theories differ simply over the presence of curvature in spacetime; if one adds a condition of flatness to GTR, then STR results. But such a conclusion would be hasty, indeed, for GTR serves to introduce into Relativity Theory a cosmic perspective, enabling one to draft cosmological models of the universe governed by the gravitational field equations of GTR. Within the context of such cosmological models, the issue of time resurfaces dramatically.

Einstein himself proposed the first GTR-based cosmological model in 1917.[7] The model describes a spatially finite universe which possesses at every time t the geometry of the surface of a sphere in three dimensions with a constant radius R. Time, which is decoupled from space, extends from $-\infty$ to $+\infty$. Thus, spacetime takes on the form of a sort of four-dimensional cylinder, temporal cross-sections of which are the 3-spheres. In order to bring such a model into conformity with his field equations, Einstein was compelled to adopt a term L, the so-called cosmological constant, which counteracted gravitation and so preserved the static three-dimensional space through time. By setting $L > 0$, one generates a weak repulsion between bodies, which keeps the universe equiposed between gravitational collapse and cosmological expansion. Kanitscheider draws our attention to the sort of time coordinate which shows up in the metric of Einstein's model:

> It represents in a certain sense the restoration of the universal time which was destroyed by STR. In the static world there is a global reference frame, relative to which the whole of cosmic matter finds itself at rest. All cosmological parameters are independent of time. In the rest frame of cosmic matter space and time are separated. For fundamental observers at rest, all clocks can be synchronized and a worldwide simultaneity can be defined in this cosmic frame.[8]

Thus, cosmological considerations prompted the conception of a cosmic time which measures the duration of the universe as a whole.

Nor was this cosmic time limited to Einstein's static model of the universe. Expansion models, which trace their origin to de Sitter's 1917 model of an empty universe,[9] may also involve a cosmic time. De Sitter showed that Einstein's field equations may be satisfied by a gravitational field in the absence of any matter whatsoever. The de Sitter universe appears to be static, but that is only because it is empty. If particles of matter are introduced into it, one discovers that de Sitter space is in fact expanding because the distance between any two arbitrary points increases with time due to the repulsive force of the cosmological constant L. Thus, in 1917 two GTR-based cosmological models had been drafted: one in which a material world exists, but is static, and another which is dynamic, but lacks a material world — a situation which inspired Eddington's crack: "Shall we put a little motion into Einstein's world of inert matter or shall we put a little matter into de Sitter's *primum mobile*?"[10]

In 1922 the Russian physicist Alexander Friedman combined these features to produce a cosmological model of an expanding, material universe.[11] His model universe was characterized by ideal homogeneity and isotropy and set L = 0 (which was equivalent to omitting it, thus preserving the form of Einstein's original equation). The most startling implication of the Friedman model is that as one traces the expansion back in time the universe becomes increasingly dense until one arrives at a state of infinite density before which the universe did not exist. Indeed, this state represents a spacetime singularity at which all spatial and temporal dimensions become zero, so that it marks the boundary to physical time itself. Cosmic time could not exist at or prior to the singularity, so that cosmic time must be finite in the past, thereby implying a definite, finite age of the universe. It is difficult to exaggerate how amazing such a prediction was, for it revealed that, in the ideal case at least, the original GTR equations implied the finitude of the past and *creatio ex nihilo*.

In 1930, one year after Edwin Hubble's explanation of the observed redshift of galactic light as a Doppler effect due to a universal, isotropic galactic recession, Eddington demonstrated that the static Einstein model was radically unstable.[12] Even small changes in the density would upset the balance between gravitation and the cosmological constant, so that a cosmic expansion or collapse would result; moreover, so much as the mere transportation of matter from one part of the universe to another would cause the former region to expand and the latter to collapse. The following year Einstein recommended that the cosmological constant be dropped from the equations, later recalling it as "the greatest blunder of my life."[13] Thus, the Big Bang model of the universe—despite a later, temporary challenge from the Steady State model—came to be the controlling paradigm of GTR-based cosmological models.

The nature of the cosmic time which measures the duration of the universe in such models deserves our scrutiny. On a very large scale, galaxies and galactic clusters can be viewed as particles of a homogeneous and isotropic dust or gas filling the universe. We may even choose to ignore the particulate structure of this gas and treat it instead as an idealized, perfect fluid, characterized by a four-dimensional velocity u, a mass-energy density r, and a pressure p. The 4-velocity u has reference to a hypothetical observer who is at rest relative to the material substratum in his region and who therefore observes the immediately proximate galaxies to have no mean motion. Such an observer is frequently referred to, after the manner of E. A. Milne, as a "fundamental observer" and his associated galactic particle as a "fundamental particle." The mass-energy density r also has reference to such a fundamental observer, being the material density and radiation density of the cosmological fluid as observed by a fundamental observer in his reference frame. The pressure p is the kinetic pressure of the galaxies determined by both matter and radiation.

In the Friedman model, the cosmological fluid is homogeneous and isotropic. But how are these notions to be understood? Intuitively, something is homogeneous if it is everywhere the same at a given moment of time. But when we take a cosmological perspective, this notion necessitates the existence of a cosmic time. Such a universal time can be constructed by assigning a time parameter to spacelike hypersurfaces which are distinguished by natural symmetries in the spacetime. A spacelike hypersurface is a three-dimensional spatial slice of spacetime, the prefix "hyper-" serving to alert us to the fact that the surfaces which dissect spacetime are not the two-dimensional planes which appear in our diagrams, but three-dimensional spaces. By foliating spacetime into such slices we can construct a cosmic time by ordering these slices serially according to a time parameter. The cosmic time so constructed will bear a special relationship to the fundamental observers, whose local planes of simultaneity, calculated by the standard STR clock synchronization procedure, will fit together to coincide with the cosmic hypersurface.[14]

Several features of this cosmic time deserve comment. First, although one may slice spacetime into various hypersurfaces wholly arbitrarily, certain spacetimes have natural symmetries that guide the construction of cosmic time.[15] GTR does not itself lay down any formula for dissecting the spacetime manifold of points; it has no inherent "layering." Theoretically, then, one may slice it up at one's whim. Nevertheless, certain models of spacetime, like the Friedman model, have a dynamical, evolving physical geometry, a geometry that is tied to the boundary conditions of homogeneity and isotropy of the cosmological fluid, and in order to ensure a smooth development of this geometry, it will be necessary to construct a time parameter based on a preferred foliation of spacetime. For example, in 1935 H. P. Robertson and A. G. Walker independently showed that a homogeneous and isotropic universe requires that space be possessed of a constant curvature and be characterized by the metric:

$$\frac{dr^2 + r^2\,(d\theta^2 + \sin^2\theta d\phi^2)}{(1 + kr^2/4)^2}$$

In the metric for spacetime, the spatial geometry is dynamic over time:

$$ds^2 = -dt2 + R(t)\;\frac{dr^2 + r^2\,(d\theta^2 + \sin^2\theta d\phi^2)}{(1 + kr^2/4)^2}$$

In this equation, called the Robertson-Walker line element, *t* represents cosmic time, the proper time of a fundamental observer. It is detached from space and serves to render space dynamic. The geometry of space is thus time-dependent. The factor *R*(t) determines that all spatial structures of cosmic proportions, for example, a triangle demarcated by three galactic clusters or fundamental particles, will either shrink or stretch through the contraction or expansion of space, in this case into a similar smaller or larger triangle. The boundary condition of homogeneity precludes other geometrical changes such as shear, which would preserve the area but not the shape of the triangle. The condition of isotropy further precludes that the triangle should be altered in such a way as to preserve both its area and shape while nonetheless undergoing a rotational change of direction. Thus, in a Friedman universe there are certain natural symmetries related to the dynamic geometry which serve as markers for the foliation of spacetime and the assigning of a cosmic time parameter. Of course, there are other cosmological models which do not involve homogeneity and isotropy and so may lack a cosmic time altogether.[16] Cosmic time is thus not nomologically necessary, and its actual existence is an empirical question.

Secondly, cosmic time is fundamentally parameter time and only secondarily coordinate time.[17] Physical time can be related in two quite different ways to the manifold in which motion is represented. If it is part of that manifold, then it functions as a coordinate. If it is external to that manifold, then it functions as a parameter. In Newton's physics time functioned only as a parameter. Motion takes place in absolute space and is parameterized by absolute time. Similarly, in Einstein's original formulation of STR, relativistic time functions only as a parameter. The familiar spacetime formulation of STR used in virtually all contemporary expositions of the theory, according to which time is a co-ordinate (along with the three spatial coordinates) of an event in spacetime, derives later from Minkowski. In the spacetime formulation, time functions as both a co-ordinate (locating events in the manifold) and as a parameter (recording the lapse of proper time along an observer's inertial trajectory), the chief difference between the two theories being that in STR parameter time loses the universality it possesses in Newtonian spacetime (that is, simultaneity becomes relative). When it comes to GTR, Kroes observes that differences in coordinate time values generally have no direct physical significance because of the variable spacetime geometry or gravitational fields which distort the co-ordinate grids laid on them. But insofar as time functions as a parameter in GTR, it is a more fundamental notion of time because it does possess direct physical significance.[18] As a parameter, cosmic time can serve as a direct measure of the time elapsed between two events.[19]

Thirdly, cosmic time is intimately related to a class of fundamental observers whose individual planes of simultaneity mutually combine to align with the hypersurface demarcating the cosmic time.[20] These hypothetical observers are conceived to be moving along with the cosmological fluid so that, although space is expanding and they are therefore mutually receding from each other, each is in fact at rest with respect to space itself. As time goes on and the expansion of space proceeds, each fundamental observer remains in the same place — his spatial co-ordinates do not change — though his spatial separation from fellow fundamental observers increases. Because of this mutual recession, the class of fundamental observers do not serve to define a global inertial frame, technically speaking, though all of them are at rest. When each of them utilizes the light signal method of synchronization, interesting relativistic effects arise due to their relative recessional motion. Since the spatial distance between them grows with time, a light signal from fundamental observer *F* to another such observer *F′* will have farther to travel on its return leg of its journey than on its out-going leg (Fig. 1).

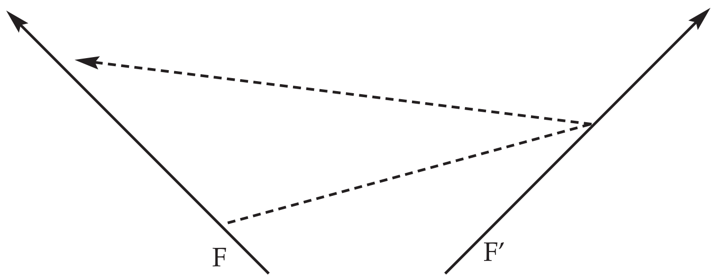

Fig. 1. Because of the distance between fundamental observers F and F′ increases with time, a light signal will have to travel a longer distance on its return trip than on its outbound trip in an exchange between F and F′.

F will therefore calculate that *F′*s clock is running slow; but, of course, the converse is also the case. Here we have "pure relativity" without absolute effects.[21] Because *F* and *F′* will draw their planes of simultaneity orthogonal to their world lines, their surfaces of simultaneity will not be aligned. But since each is at rest with respect to space, his plane of simultaneity will coincide locally with the hypersurface of cosmic time. Were he in motion with respect to the cosmological fluid, then his plane of simultaneity would be at an angle with the local hypersurface. But in virtue of being at rest, he can be guaranteed that local events which he judges to be simultaneous will lie on the hypersurface. Thus, the local regions of the planes of simultaneity of fundamental observers all blend together and coincide with the hypersurface, much as a circle is formed by the points of intersection of all the straight lines which are tangents of its circumference. This has two important implications: first, that the proper time of each fundamental observer coincides with cosmic time and, second, that all the fundamental observers will agree as to what time it is.

One is now prepared to construct a cosmic co-ordinate time.[22] The boundary conditions of homogeneity and isotropy in Friedman models enable fundamental observes to utilize a co-moving co-ordinate system, which serves to define a cosmic time in which a worldwide, absolute simultaneity exists. Deviations from this cosmic time are purely local effects to be explained due to velocity (STR) or to gravitation (GTR). Thus, on a cosmic scale, we have that universality of time and absolute simultaneity of events which the Special Theory had denied. Whitrow asserts, ". . . in a universe that is characterized by the existence of a cosmic time, relativity is reduced to a local phenomenon, since this time is world-wide and independent of the observer."[23] Based on a cosmological, rather than a local, perspective, cosmic time restores the classical notions of universal time and absolute simultaneity which STR denied.

The question, then, becomes an empirical one: does cosmic time exist? The answer to that question comes from the evidence for large scale (scales of ~10^8 light years or larger) isotropy in the universe. The observational evidence for cosmic isotropy, particularly for the isotropy of the cosmic microwave background radiation, which has been measured by the COBE satellite to an accuracy of one part in 100,000, makes it very likely that our actual universe does approximate a Friedman universe. Martin Rees concludes, "The most remarkable outcome of fifty years of observational cosmology has been the realization that the universe is more isotropic and uniform than the pioneer theorists of the 1920's would ever have suspected."[24] Consequently, "we have strong evidence that the universe as a whole is predominantly homogeneous and isotropic," states Whitrow, "and this conclusion . . . is a strong argument for the existence of cosmic time."[25] Thus, far from "taking away from space and time the last remnant of physical objectivity," as Einstein thought at first, GTR through its cosmological applications gives back what STR had purportedly removed. Relativity theory thus gives back with its right hand what it had taken away with its left.

God and Cosmic Time

In Newton's view, as he explains in the Definitions and General Scholium to his *Principia*, physical time is a relative measure of absolute time, which Newton regarded as God's time. It is plausible that since the inception of the universe and the beginning of physical time, cosmic time fills the role which Newton would assign to a relative measure of absolute time. As such it registers the true time, in contrast to the multiplicity of local times registered by clocks in motion relative to the cosmological substratum. Already in 1920, on the basis of Einstein and de Sitter's cosmological models, Eddington hinted at a theological interpretation of cosmic time:

> In the first place, absolute space and time are restored for phenomena on a cosmical scale . . . . The world taken as a whole has one direction in which it is not curved; that direction gives a kind of absolute time distinct from space. Relativity is reduced to a local phenomenon; and although this is quite sufficient for the theory hitherto described, we are inclined to look on the limitation rather grudgingly. But we have already urged that the relativity theory is not concerned to deny the possibility of an absolute time, but to deny that it is concerned in any experimental knowledge yet found; and it need not perturb us if the conception of absolute time turns up in a new form in a theory of phenomena on a cosmical scale, as to which no experimental knowl-

> edge is yet available. Just as each limited observer has his own particular separation of space and time, so a being co-extensive with the world might well have a special separation of space and time natural to him. It is the time for this being that is here dignified by the title 'absolute.'[26]

A couple of items in this remarkable paragraph deserve comment. First, Eddington rather charitably interprets STR as positing merely an epistemic limitation on our temporal notions rather than an ontological limitation on time and space. But as friend and foe alike have emphasized, Einsteinian STR requires metaphysical, not merely epistemological, commitments concerning the non-existence of absolute space and time. Otherwise, one winds up with the Lorentz-Poincaré interpretation of the theory, which is, in truth, the position which Eddington is describing. Second, Eddington is quite willing to call cosmic time "absolute" in view of its independence from space, that is to say, its status as a parameter. Relativistic time is, as Lorentz and Poincaré maintained, only a local time, whereas cosmic time, being non-local, gives the true time. Third, although in 1920 there was no empirical evidence for cosmic time, within a few short years astronomical evidence confirmed the prediction of the Friedman model of a universal expansion and, hence, of cosmic time. The veil of epistemic limitation had been torn away by empirical science. Finally, this cosmic time would be the time of an omnipresent being whose reference frame is the hypersurface of homogeneity itself. Cosmic time is not merely the "fusion" of all the proper times recorded by the separate fundamental observers, but, even *more* fundamentally, it is the time which measures the duration of the omnipresent being which co-exists with the universe. As the measure of the proper time of the universe, cosmic time also measures the duration of and lapse of time for a temporal being co-extensive with the world. For Eddington, it is the time of this being that deserves to be called "absolute."

The theological application is obvious. If God is temporal, as Newton believed, then it makes perfectly good sense to interpret the lapse of cosmic time as measuring the lapse of God's time. God's absolute time cannot be said to be identical with cosmic time, since absolute time could, as Newton believed, precede physical time (imagine God's counting down to creation). Nevertheless, since the inception of cosmic time, the moments of cosmic time would seem to coincide with the moments of God's time. Since God is causally related to the cosmos, sustaining it in being moment by moment, it seems natural to think that the duration measured by cosmic time is also the duration of God's being. If the duration of the universe measured in cosmic time is 15 billion years since the singularity, then is not the duration of God's creatorial activity in absolute time also 15 billion years? In God's "now" the universe has (present tense) certain specific and unique properties, for example, a certain radius, a certain density, a certain temperature background, and so forth; but in the cosmic "now" it has all the identical properties, and so it is with every successive "now." Is it not obvious that these "now's" coincide and designate one and the same present?

Perhaps we can state this consideration a bit more formally by means of the following proposed principle:

> *P*: For any constantly and non-recurrently changing universe *U* and temporal intervals *x*, *y* large enough to permit change, if the physical description of *U* at *x* is the same as the physical description of *U* at *y*, then *x* and *y* coincide.

Given that in absolute time there is a temporal interval or duration during which a certain physical description of the universe is true and that in cosmic time a similar interval exists, then it follows from *P* that those intervals of absolute and cosmic time coincide. It seems to me, therefore, that if God is temporal, God's time and cosmic time ought naturally to be regarded as coincident since the inception of cosmic time. I do not mean to say that there are in fact two times rather than one; rather I mean simply to reaffirm Newton's distinction between absolute (or metaphysical) time and relative (or physical) time. The latter is merely a sensible measure of the former, and my suggestion is that cosmic time is a sensible measure of God's time since creation.

Such an affirmation will be typically met with passionate disclamations. Such protestations strike me, however, as being for the most part misconceived. In our weighing this issue, two questions need to be kept distinct: (i) Does cosmic time provide a sensible measure of God's time? (ii) Is cosmic time in some sense absolute?

Cosmic Time as a Measure of God's Time

The first question is scarcely ever addressed directly by theorists. But very frequently assertions are made about the nature of cosmic time which would seem to imply that cosmic time enjoys no special status that would warrant us in identifying it as a sensible measure of God's time, any more than we should be warranted in picking out some arbitrary inertial frame and identifying the time associated with it as privileged. The choice of cosmic time as a measure of God's time could be said to be arbitrary because nothing in GTR requires that we slice up spacetime in one way rather than another. The theory allows one's three-dimensional hyper-surfaces to dissect spacetime in any arbitrary way, so that the selection of one foliation over another is a conventional choice.[27] Eddington graphically expressed this point in drawing our attention to the difference between a pile of sheets of paper and a solid paper block. "The solid block is the true analogy for the four-dimensional combination of spacetime; it does not separate naturally into a particular set of three-dimensional spaces piled in time order. It can be redivided into such a pile; *but it can be redivided in any direction we please*."[28] The implication would seem to be that the identification of our cosmic time as the sensible measure of God's time is wholly conventional.

But the shortcoming of this answer to our question is that such a response is not based on the whole story. It is true that the General Theory itself does not mandate a specific foliation of spacetime; but this is only to consider the theory *in abstracto*, apart from any *de facto* boundary conditions arising from the nature of material reality. The answer explicitly ignores the notion of the evolution of the universe and considers just a manifold of points. Once we introduce, however, considerations concerning the *de facto* distribution of matter and energy in the universe, then certain natural symmetries emerge which disclose to us the preferential foliation of spacetime and the real cosmic time in distinction from artificial foliations and contrived times.[29] To return to Eddington's analogy of the paper block, suppose that only by foliating the block into a stack of sheets do we discover that on each sheet is a drawing of a cartoon figure and that by flipping through the sheets successively, we can see this figure, thus animated, proceed to pursue some action. Any other slicing of the block would result merely in a scrambled series of ink marks. In such a case, it would be silly to insist that any arbitrary foliation is just as good as the foliation which regards the block as a stack of sheets. But analogously, the Robertson-Walker metric discloses to us the natural foliation of spacetime for our universe. It would be disingenuous to insist that the universe is not *really* expanding homogeneously and isotropically in approximation of the Friedman model, that it does not *really* have a certain spacetime curvature, density, and pressure, that it has not *really* been about 15 billion years since the singularity, but that any arbitrary foliation and contrived time will yield equally appropriate descriptions of the way the universe actually is and evolves. Eddington realized this, of course, and we have seen that he recognized the privileged status of our cosmic time, though he emphasized that no experimental knowledge of it was as yet available. Today, however, the situation has considerably changed. Not only do we know that a privileged cosmic time in which the universe evolves exists, but because the earth is approximately at rest with respect to our galactic fundamental particle, we also have a fair idea of what time it is!

It seems to me, therefore, that we have quite convincing grounds for holding that cosmic time is, indeed, a privileged time. Its privileged status is implied by the existence of a fundamental reference frame for light propagation in line with modern cosmology and by the existence of the microwave background radiation, which serves to demarcate a preferential reference frame. Cosmic time is *the* time of the duration of the universe. The lapse of cosmic time thus plausibly measures the lapse of God's time, and the "now" of God's time coincides with the "now" of cosmic time. Therefore, I conclude, in answer to our first question, that God's time does coincide with cosmic time.

The Absoluteness of Cosmic Time

That leads us on to our second question: is cosmic time in some sense absolute? We have already had occasion to say something about this in our answer to the previous question. Since cosmic time coincides with God's time since the moment of creation, it records, in effect, Newton's absolute time.[30]

But the suggestion that cosmic time is comparable to Newton's absolute time is likely to be met with heated resistance. Unfortunately, much of the disagreement seems due simply to the failure to keep clearly in mind Newton's distinction between absolute and relative time. Virtually all the objections involve showing that cosmic time is in some way relative time and then concluding that it cannot therefore be absolute time — as if

Newton had not himself distinguished the two! Of course, no physical time *is* absolute time; that is true by definition. The pertinent question is whether the relative time kept by the ideal clock of a fundamental observer provides a measure of absolute time and so in that derivative sense can be said to share its absoluteness. Most critics have failed to keep clear the sense in which cosmic time can be said to be "absolute," and have compounded that failure by failing to appreciate the notion of the coincidence of cosmic time with absolute time.

For example, it is frequently said that cosmic time does not represent a return to Newtonian absolute time because cosmic time would not exist independently of all physical events as would absolute time.[31] But such an objection only reminds us that cosmic time is physical time rather than metaphysical time. One can reject cosmic time's absoluteness in the sense of "non-relational" without repudiating the absoluteness of cosmic time in the sense that cosmic time represents the true time (in the Lorentz-Poincaré sense) as opposed to the merely local time. The objection is impotent against the claim that cosmic time and absolute time are presently *coincident*, though not *identical*. Because these times are not identical, cosmic time need not share all the properties of absolute time, such as its allegedly non-relational character, and yet its moments still coincide with the moments of absolute time. In virtue of that coincidence, cosmic time may be quite properly said to be absolute in the sense that it gives the true time.

Or again, it is frequently objected that cosmic time is contingent and therefore cannot be regarded as absolute.[32] But all that follows from the existence of models lacking a cosmic time is that cosmic time *contingently* coincides with absolute time. In virtue of that coincidence, it records the true time in this world. Our world is characterized by cosmic time, and its absence in other cosmological models is wholly irrelevant to whether it coincides with God's time in the actual world. The contingency of cosmic time thus says nothing against its privileged status in this world; in fact, a relationalist can consistently maintain that even metaphysical time exists contingently, for if God had chosen to exist absolutely changelessly permanently and never created a world, there would be no events at all and, hence, not even metaphysical time. The existence of both metaphysical and physical, cosmic time is thus a contingent fact dependent upon God's will.

Finally, it is sometimes objected that cosmic time cannot be the basis for the construction of an absolute Newtonian time because cosmic time is observer-dependent in that it is defined in terms of hypothetical fundamental observers and is, hence, relativistic.[33] But this objection merely trades on the ambiguity of the expression "observer-dependent." Co-ordinate cosmic time does rely on the use of certain fundamental observers to establish origins of the co-moving co-ordinate system and in that sense can be said to be observer-dependent. But the time so constructed is the same for all observers, in whatever inertial frame they find themselves, and so is observer-independent. Every observer, whatever his state of motion, will measure events as occurring at the same values of cosmic time. Therefore, the fundamental observers are a *privileged* group of observers. The fact that cosmic time is relative to a reference frame, namely, the fundamental frame, is not incompatible with its coincidence with absolute time. Otherwise one might as well charge that the time of nineteenth century physics was not absolute either, since it was relative to the aether rest frame! The point is that in both cases, the reference frame in question is preferred and therefore the time kept with respect to it measures absolute time.

One of the most intriguing indications that cosmic time is the physical equivalent of Newtonian absolute time is the surprising demonstration by E. A. Milne and W. H. McCrea that all the results of GTR-based, Friedman cosmology can be recovered by Newtonian physics and in a way that is simpler than Einstein's cumbersome tensor calculus! Milne and McCrea were able to reproduce all the results of Big Bang cosmology by means of a material universe expanding in empty, classical space through classical time.[34] In particular the concept of cosmic time in GTR-based models corresponds to absolute time in the Newtonian model.[35] The history of the universe described by the variation of the scale factor $R(t)$ in the Robertson-Walker line element is identical in the two theories, even though in the one the scale factor $R(t)$ is determined by Einstein's gravitational field equations, while in the other only Newtonian absolute time and Euclidean geometry come into play.[36] The equivalence of Milne-McCrea Newtonian cosmology with GTR-based, Friedman cosmology is a convincing demonstration that cosmic time is, indeed, the physical equivalent of Newtonian absolute time.[37] Kerszberg concludes, "On the whole, the equivalence between Newtonian and relativistic cosmology only reinforces the conviction that cosmic time is indeed a necessary ingredient in the formalisation of a relativistic cosmology, however alien to general relativity and congenial to Newton's theory the notion of universal synchronisation might seem."[38]

Conclusion

In conclusion, then, we have seen that when one moves from STR into GTR, the application of the latter theory to cosmology yields a cosmic time, which is plausibly regarded as being the physical time which measures God's absolute time and therefore registers to a good degree of approximation the true time.

Talbot School of Theology

NOTES

1. W. Rindler, "Einstein's Priority in Recognizing Time Dilation Physically," *American Journal of Physics* 38 (1970): 112.
2. A. Einstein, "The Foundations of General Relativity Theory," in *General Theory of Relativity*, ed. C. W. Kilmister, Selected Readings in Physics (Oxford: Pergamon Press, 1973), pp. 141-72. The original paper appeared in *Annalen der Physik* 49 (1916): 769.
3. Ibid., p. 148.
4. See the very frank discussion by Herman Bondi, "Is 'General Relativity' Necessary for Einstein's Theory of Gravitation?" in *Relativity, Quanta, and Cosmology in the Development of the Scientific Thought of Albert Einstein*, ed. Francesco De Finis, 2 vols. (New York: Johnson Reprint Corp., 1979), pp. 179-

86. According to Bondi, any notion of equivalence between inertial and accelerated observers is "physically meaningless," which goes to show "how void of significance any general principle of relativity must be." But because "a physically sound formulation of Einstein's theory of gravitation exists not involving the physically empty concept of general relativity," one may admire and embrace Einstein's theory of gravitation while rejecting his route to it. "It is perhaps rather late to change the name of Einstein's theory of gravitation, but general relativity is a physically meaningless phrase that can only be viewed as a historical momento of a curious philosophical observation."

5. Michael Friedman, *Foundations of Spacetime Theories* (Princeton: Princeton University Press, 1983), p. 17.

6. A. Einstein, "Ether and the Theory of Relativity," in *Sidelights on Relativity* (New York: Dover Publications, 1903), pp. 16-17.

7. A. Einstein, "Cosmological Considerations on the General Theory of Relativity," in *The Principle of Relativity*, by Albert Einstein, *et. al.*, with Notes by A. Sommerfeld, trans. W. Perrett and J.B. Jeffery (rep. ed.: New York: Dover Publications, 1952), pp. 177-88.

8. Bernulf Kanitscheider, *Kosmologie* (Stuttgart: Philipp Reclam. jun., 1984), p. 155. See also G.J. Whitrow, *The Natural Philosophy of Time*, 2d ed. (Oxford: Clarendon Press, 1980), pp. 283-84.

9. Willem de Sitter, "On the Relativity of Inertia," in *Koninglijke Nederlandse Akademie van Wetenschappen Amsterdam. Afdeling Wis- en Natuurkundige Wetenschappen. Proceedings of the Section of Science* 19 (1917): 1217-25.

10. Arthur S. Eddington, *The Expanding Universe* (Cambridge: Cambridge University Press, 1952), p. 46.

11. A. Friedman, "Über die Krümmung des Raumes," *Zeitschrift für Physik* 10 (1922): 377-86.

12. A.S. Eddington, "On the Instability of Einstein's Spherical World," *Monthly Notices of the Royal Astronomical Society* 19 (1930): 668-78.

13. Albert Einstein, quoted in George Gamow, *My World Line* (New York: Viking Press, 1970), p. 44.

14. Misner, Thorne, and Wheeler explain, "In Newtonian theory there is no ambiguity about the concept 'a given moment of time.' In special relativity there is some ambiguity because of the nonuniversality of simultaneity, but once an inertial frame has been specified, the concept becomes precise. In general relativity there are no global inertial frames (unless spacetime is flat); so the concept of 'a given moment of time' is completely ambiguous. However, another, more general concept replaces it: the concept of a three-dimensional spacelike hypersurface. This hypersurface may impose itself on one's attention by reason of natural symmetries in the spacetime. Or it may be selected at the whim or convenience of the investigator . . . . At each event on a spacelike hypersurface, there is a local Lorentz frame whose surface of simultaneity coincides locally with the hypersurface. Of course, this Lorentz frame is the one whose 4-velocity is orthogonal to the hypersurface. These Lorentz frames at the various events on the hypersurface do not mesh to form a global inertial frame, but their surfaces of simultaneity do mesh to form the spacelike hypersurface itself.

The intuitive phrase 'at a given moment of time' translates, in general relativity, into the precise phrase 'on a given spacelike hypersurface.' The investigator can go further. He can 'slice up' the entire spacetime geometry by means of a one-parameter family of such spacelike surfaces. He can give the parameter that distinguishes one such slice from the next the name of 'time'. . . . The successive slices of 'moments of time' may shine with simplicity or may only do a tortured legalistic bookkeeping for the dynamics [of the geometry of the universe]. Which is the case depends on whether the typical spacelike hypersurface is distinguished by natural symmetries or, instead, is drawn arbitrarily" (Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler, *Gravitation* (San Francisco: W.H. Freeman, 1973), pp. 713-14).

15. See Kanitscheider, *Kosmologie*, pp. 182-97.

16. Kanitscheider comments,

"On the other hand it should also be emphasized concerning the geometric side of this world model that the simple, form-preserving (dynamic), physical geometry can be traced back to the boundary conditions which have been laid down and by no means possess either a logically *a priori* or physically necessary character. If one eases the boundary conditions, one obtains world models with shear and rotation, and they, too, . . . can be brought into harmony with the Einsteinian gravitational theory" (Ibid., p. 188).

17. See Peter Kroes, *Time: Its Structure and Role in Physical Theories*, Synthese Library 179 (Dordrecht: D. Reidel, 1985), pp. 60-96.

18. There are three choices of time parameter available in GTR, according to Misner, Thorne, and Wheeler: (i) the original time variable *t*. "This quantity gives directly proper time elapsed since the start of the expansion. It is the time available for the formation of galaxies. It is also the time during which radioactive decay and other physical processes have been taken place" (*Gravitation*, p. 730). (ii) the expansion factor *R(t)*. Since this factor grows with time, it serves to distinguish one phase of the expansion from another, thus serving as a parametric measure of time in its own right. The ratio of *R(t)* at two different times gives the ratio of the dimensions of the universe at those two times. (iii) the arc-parameter measure of time h(*t*). During the time interval *dt*, a photon traveling on hypersphere of radius *R(t)* covers an arc in radians equal to *d*h=*dt*/*R(t)*. (In a model where the curvature constant *k*=0 or -1, the words "hypersphere" and "arc" should be replaced with their appropriate analogues.) Small values of the arc parameter indicate early times in the universe, large values later times.

19. Kroes, *Time*, p. 96.

20. See S.J. Prokhovnik, *Light in Einstein's Universe* (Dordrecht: D. Reidel, 1985), chaps. 4, 5, 6.

21. Named for so-called pure relativists like Bergson and Dingle, who misinterpreted Einstein's theory in terms of mere appearances.

22. See Misner, Thorne, and Wheeler, *Gravitation*, pp. 715-16.

23. Whitrow, *Natural Philosophy of Time*, p. 371.

24. Martin J. Rees, "The Size and Shape of the Universe," in *Some Strangeness in the Proportion*, ed. Harry Wolf (Reading, Mass.: Addison-Wesley Publishing Co., 1980), p. 301. See also now Martin Rees, *Before the Beginning: Our Universe and Others,* with a Foreword by Stephen Hawking (Reading, Mass.: Addison-Wesley, 1997), p. 34: "The simple 'model universes' turn out, more than 60 years later, to fit extraordinarily well—they are more relevant to our real universe than Friedmann and other the pioneers would have dared to hope."

25. Whitrow, *Natural Philosophy of Time*, p. 307.

26. Arthur Eddington, *Space, Time and Gravitation,* Cambridge Science Classics (Cambridge: Cambridge University Press, 1920; rep.ed.: 1987), p. 168.

27. Kroes, *Time*, pp. 15-16.

28. Eddington, *Space, Time and Gravitation*, p. 34. Cf. Graves's comment that it makes no difference to the validity of the (tensor) initial value equations how we define a hypersurface or what sort of coordinates we use on it. The choice of an initial hypersurface is "wholly arbitrary" (John Cowperthwaite

Graves, *The Conceptual Foundations of Contemporary Relativity Theory*, with a Foreword by John Archibald Wheeler [Cambridge, Mass.: MIT Press, 1971], pp. 250-52). So also Vesslin Petkov, "Simultaneity, Conventionality, and Existence," *British Journal for the Philosophy of Science* 40 (1989):75, who argues that all events are therefore equally real.

29. Michael Shallis, "Time and Cosmology," in *The Nature of Time*, ed. Raymond Flood and Michael Lockwood (Oxford: Basil Blackwell, 1986), pp. 68-69; see also Kroes, *Time*, pp. 16-17.

30. See John Barrow, *The World within the World* (Oxford: Oxford University Press, 1988) p. 234. Barrow's further discussion of which is the fundamental cosmic time has to do more with cosmic timekeeping and, despite his disclaimers, treats cosmic time on the pattern of Zeno's paradoxes. See also Evandro Agazzi, "The Universe as a Scientific and Philosophical Problem," in *Philosophy and the Origin and Evolution of the Universe*, ed. Evandro Agazzi and Alberto Cordero, Synthese Library 217 (Dordrecht: Kluwer Academic Publishers, 1991), p. 29; Prokhovnik, *Light in Einstein's Universe*, p. 127; Shallis, "Time and Cosmology," p. 71.

31. Whitrow, *Natural Philosophy of Time*, pp. 34-36, 283-302.

32. Paul Fitzgerald, "The Truth about Tomorrow's Sea Fight," *Journal of Philosophy* 66 (1969): p. 326; see also Alan Padgett, *God, Eternity and the Nature of Time*, (New York: St. Martin's, 1992), pp. 128-29.

33. Kroes, *Time*, pp. 17-18.

34. E. A. Milne, *Relativity, Gravitation and World Structure* (Oxford: Clarendon Press, 1935); idem, "A Newtonian Expanding Universe," *Quarterly Journal of Mathematics* 5 (1934): 64-72; W. H. McCrea, "On the Significance of Newtonian Cosmology," *Astronomical Journal* 60 (1955): 271-274.

35. See Pierre Kerszberg, "On the Alleged Equivalence between Newtonian and Relativistic Cosmology," *British Journal for the Philosophy of Science* 38 (1987): 349; E. L. Schücking, "Newtonian Cosmology," *Texas Quarterly* 10 (1967): 274.

36. H. Bondi, *Cosmology*, 2d ed. (Cambridge: Cambridge University Press, 1960), p. 105; Kerszberg, "Equivalence," p. 349.

37. Bondi, *Cosmology*, pp. 70-71.

38. Kerszberg, "Equivalence," p. 376.