ON TIME DILATION IN COSMOLOGY

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Abstract

In recent years various authors have suggested that time dilation could solve the problem of seeing distant galaxies in a young universe. Time dilation which arises in both special and general relativity, could presumably slow earth clocks with respect to those on distant galaxies. This article examines how time dilation can arise within various relativistic cosmological models. It is found that in most cosmological models time dilation is either not significant or is in the wrong direction. Strong time dilation can occur in a static universe with pressure terms. However, in that case the predicted galactic red shifts would be much greater than those actually observed. It is concluded that the time dilation hypothesis thus faces a number of serious problems that must still be resolved.

1. Introduction

If the world is only a few thousand years old, how is it that we can see stars seemingly billions of light years away? Various possible solutions have been discussed in this journal, including mature creation (Akridge, 1979), curved space (Byl, 1988), a variable speed of light (Chaffin, 1990; Byl, 1990). In recent years several authors have proposed a new possibility: time dilation. In the theory of relativity the rate at which a clock ticks depends both on its motion and on the local gravitational field. Could it be that, in the past, time passed much more slowly on earth than in the distant parts of the galaxies, so that light from distant galaxies travelled billions of light years during, say, only a few earth years?

Although this view has received a considerable amount of publicity in the last few years, it has not yet been fully worked out. Both Roy Peacock (1990) and Gerald Schroeder (1990) appeal to time dilation to reconcile Genesis with modern cosmology. However, they provide no quantitative details and, as we shall see, their proposal is fatally flawed.

A more detailed scenario has been advanced by D. Russell Humphreys (1994). He has developed a rather elaborate cosmological model wherein the universe is considered to emerge from a "white hole" (i.e., the opposite of a collapse into a black hole). An earth-based observer, being near the center, would experience a greater gravitational field, resulting in a slower clock rate.

While this model looks promising, it is still incomplete and has not yet been proven able to provide sufficient time dilation. The scenario Humphreys describes is, as he himself acknowledges, highly speculative and is not yet backed up by definite quantitative calculations. All he offers is a possible outline of a solution. Hence, also this model, in its present unfinished state, does not convincingly solve the creationist problem.

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The purpose of this paper is to examine the nature of time dilation. What conditions must a cosmological model satisfy for significant time dilation to occur? To this end various relativistic cosmological models will be examined. We shall see that in most cosmological models time dilation is not significant, nor in the right direction. Although it is possible to construct a static model where time dilation does seem to work as desired, this model unfortunately predicts large galactic red shifts, which are not observed.

2. Time Dilation In Special Relativity

In modern physics there are two causes of time dilation: (1) relative motion and (2) gravitational fields. In special relativity gravitational field's are not taken into account, so that time dilation due only to relative motion is considered. Two clocks will tick at different rates if they are moving relative to each other.

The light from distant galaxies is observed to be generally shifted towards the red end of the spectrum, the amount of red shift roughly increasing proportional to the distance of the galaxy. This is sometimes interpreted as a Doppler shift, the change in frequency due to the motion of an object away from us through space.

A frequency change implies a corresponding change in clock rates; the outward motion of a galaxy causes a slowing down of a clock on the galaxy. According to special relativity (Shadowitz, 1968, p. 40), a time interval Δt, as measured on a galaxy receding from us at a relative speed v, will correspond to an earth time interval

$$\Delta t_{earth} = \Delta t_{galaxy} \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \qquad (1)$$

As the galactic speed v, with respect to the earth, approaches the speed of light c, the galactic clock will appear to slow down to a full stop.

Unfortunately, however, such time dilation is exactly opposite to what we need: The *earth* clock should be slowed down, not that of the distant galaxy. We need a long time interval on the distant galaxy during a short time interval on earth,. Equation (1), on the contrary, gives a long period of time on earth during a short period of time on the distant galaxy. Hence this type of time dilation will not help us. In fact, it makes the problem worse.

3. Time Dilation In General Relativity

Now examine time dilation in general relativity, where both motion and gravity effects are taken into account.

Peacock (1990, p. 111) and Schroeder (1990, p. 53) have both suggested that the six creation days are to be measared, not on earth, but on the divine clock. Due to motional and gravitational time dilation the divine clock could, presumably, be ticking much slower than an earth-based clock: Many billions of years could have passed in earth time during the corresponding six days of divine time.

But this will not do. The days of Genesis are clearly defined as periods of light and darkness as measured on the *earth.* The Genesis account refers to an earth-based clock, the same clock as that used by cosmologists.

In constructing various cosmological models we take note of the fact that, as seen from the earth, the uniyerse is roughly isotropic (i.e., it looks the same in all directions). Thus, assuming the universe to be spherically symmetric about the earth, we choose a reference frame with spherical coordinates, centred on the earth.

In standard cosmology the expansion of the universe is attributed, not to the motion of galaxies through space, but to the expansion of space itself, in which the galaxies are embedded. [Misner, Thorne, and Wheeler (1973, p. 777) refer to the expanding space as the "cosmological fluid".] The galaxies may have their own appreciable peculiar motions with respect to the local space of the universe. However, since we are in, terested primarily in general, averaged effects, we shall consider the galaxies to be locally at rest, any relative motion between them and the earth being due to the expansion of the universe as a whole.

According to general relativity, the basic equation governing the spacetime geometry is given by (Weinberg, 1972, p. 177)

$$d\tau^2 = g_{00}dt^2 - \frac{g_{rr}}{c^2}dr^2 - \frac{r^2}{c^2}(d\theta^2 + \sin^2\theta \; d\phi^2) \qquad (2)$$

This equation gives the change in τ, the "proper" time (i.e., the time as measured by the observer's clock) as the observer moves a small distance (measured in terms of changes in the radial coordinate r, and the angular coordinates θ and ϕ) during a small interval of t, the "coordinate" time (i.e., the ideal time in the absence of gravity). The terms g_{00} and g_{rr}, called "metric coefficients," measure the distortion due to gravity of time and space, respectively. For weak fields, where the distortions are small, both coefficients are close to 1.

Homogeneous Models

In standard big bang cosmology the earth is denied any special position; the universe is assumed to be isotropic from *any* position. This is known as the Cosmological Principle. It implies that the universe is everywhere the same (i.e., it is "homogeneous") and has no edges.

In a homogeneous universe the gravitational potential at any time is the same everywhere. Consequently, the metric coefficients will not vary with r and all clocks locally at rest will tick at the same rates. There is no gravitational time dilation in a homogeneous universe.

There will be some time dilation due to the expansion of the universe. As we shall see below, the expansion will generate a red shift that corresponds to a slowing down of clocks on distant galaxies by a fraction equal to the fractional change in the size of the universe during the transmission of light. The presently observed red shifts correspond to a time dilation effect that is both too small and in the wrong direction for the time dilation hypothesis which postulates that distant clocks should appear to be relatively faster, not slower.

Free-Fall Models

Perhaps non-homogeneous models are more conducive to time dilation. Following Humphreys (1994), we now consider a model where the universe is a sphere of radius R with uniform density ρ, centred about the earth. Recall that the galaxies are embedded in the universe: Their separations, measured as fractions of the radius of the universe, remain constant as the universe expands. It is thus most convenient to choose η as a "comoving" coordinate, which varies from 0, at the center, to 1 at the edge (i.e., η = r/R). Suppose that there is no pressure and the material is acted on by purely gravitational forces. Then the matter will be in "free-fall." If the material is given an initial outward velocity then we get Humphreys' white hole model, which is the reverse of a star collapsing into a black hole. Such a model has the following metric (Weinberg, 1972, pp. 344, 412; Humphreys, 1994, p. 91):

$$d\tau^2 = dt^2 - \frac{R^2(t)}{c^2}\left[\frac{d\eta^2}{1 - k\eta^2} + \eta^2(d\theta^2 + \sin^2\theta \; d\phi^2)\right] \qquad (3)$$

Here θ and ϕ denote the angular position and k is a constant depending on the curvature.

Note that for a galactic clock, embedded in the local space, the coordinates η, θ, and ϕ are constant. Hence dτ = dt (i.e., the proper time equals the coordinate time) and there is no gravitational time, dilation. All galactic clbcks tick at the same rate.

This result, which is similar to that for the homogeneous case, is not surprising, for equation (3) is identical to the Robertson-Walker metric for a homogeneous universe (Humphreys, p. 114; Weinberg, p. 344). In the free-fall model one can expect gravitational time dilation to be absent (g_{00} = 1) because the equivalence principle — the basis of general relativity — states that clocks in free-fall are not affected by gravity. It follows that this model yields the same time dilation effects as the previous case.

Why, then, does Humphreys get an apparent dilation? Humphreys follows the calculations of Weinberg (pp. 342-349) and Klein (1961), for the collapse of a star. Both of these authors arrive at equation (3) for comoving observers inside the star. On the other hand, for an observer at rest outside the star they obtain the static Schwarzschild metric, wherein time dilation does occur. It is only when one rewrites the interior coordinates in terms of the exterior, static Schwarzschild coordinates that the apparent time dilation arises, since then there is a singularity at the Schwarzschild radius. Such a transformation is needed to describe the collapse of the star in terms of a stationary human observer outside the star. However, when applied to Humphreys' model of the universe such a transformation serves no purpose, since all observers are, of course, inside the universe. In particular, as viewed by an earth-based observer, in terms of time measured by his earth clock, the metric of equation (3) is the pertinent one. Much the same point has been made by Conner and Page (1995) in their critique of this model.

This conclusion regarding the absence of time dilation in free-fall models is consistent with other papers on spherically symmetric non-homogeneous free-fall models. For example, G. C. Omer (1965) examined arbitrary spherically symmetric distributions (of which Humphreys' model is presumably a special case). Although such models clearly have a center and a gravitational potential gradient, Omer's metric in co-moving coordinates has no time dilation (i.e., the dt^2 term has a constant coefficient). Even more instructive is the work of Oscar Klein, whose (1961) analysis of a collapsing star forms a basis for Humphreys' calculations. In a later paper Klein (1971) himself studied a cosmological model identical to that of Humphreys: a bounded, finite universe of constant density which has a definite center and a gravtational potential gradient. There Klein did apply a continuity condition at the boundary to limit the maximum density of the university (he believed that the universe cannot collapse past the Schwarzschild radius). Yet he analyzed all observations using the interior metric (equation 3). For example, Klein finds that the frequency shift we should observe from a distant source within the universe depends only on the fractional change in the scale factor R during the light travel time. There is no ftirther change due to differences in gravitational potential, implying that there is no time dilation.

Static Models

Next consider some static models. Again, we assume the universe to be a sphere of uniform density ρ and radius R. To apply equation (2) we must first calculate the metric coefficients. A spherically symmetric mass distribution yields (Schutz, p. 259)

$$g_{rr} = \frac{1}{1-\frac{2Gm}{c^2 r}} \tag{4}$$

Here G is the gravitational constant and m is mass within a radius r, given by

$$m = \frac{4}{3}\pi \rho r^3 \tag{5}$$

The g_{00} term is more difficult to determine, as it depends also on the pressure. We first define a new variable Φ as follows

$$g_{00} = e^{2\Phi} \tag{6}$$

To keep the universe static in the gravitational field requires Φ to obey the equation (Schutz, 1990, p. 256)

$$(\rho + p)\frac{d\Phi}{dr} = -\frac{dp}{dr} \tag{7}$$

where p is the pressure. Furthermore, it follows (Schutz, p. 257; Misner, p. 608) that

$$\frac{d\Phi}{dr} = \frac{4\pi G(\rho + 3p)r}{3c^2 - 8\pi G \rho r^2} \tag{8}$$

The Static Zero Pressure Case

Consider first the static case with no pressure. This is, of course, physically unrealistic, since with no pressure to counterbalance gravity the universe cannot remain static but will collapse. However, this may serve to isolate the effect of the mass distribution alone on time dilation. If p = 0 and integrating the last equation, we find

$$\Phi = -\frac{1}{4} \ln \left(1 - \frac{8\pi G \rho r^2}{3c^2}\right) + K \tag{9}$$

where K is an integration constant. This yields

$$g_{00} = e^{2\Phi} = \frac{C}{\sqrt{1 - \frac{8\pi G\rho r^2}{3c^2}}} \tag{10}$$

where C = e^K. What is C? For r > R, it is found (Misner, et al., p. 607) that

$$g_{00} = 1 - \frac{2GM}{rc^2} \tag{11}$$

where M is the total mass of the universe, given by $(4/3)\pi\rho R^3$. At r = R equations (10) and (11) must match, giving

$$C = (1 - \frac{2GM}{Rc^2})^{\frac{3}{2}} \tag{12}$$

To slow the earth clock, equation (2) requires that g_{00} approach zero at the earth. According to equations (10) and (12), this can happen only when R approaches $2GM/c^2$. This critical value of R is known as the Schwarzschild radius, which we shall denote S. In terms of S we can rewrite g_{00} and g_{rr} as,follows

$$g_{00} = \frac{(1 - \frac{S}{R})^{\frac{3}{2}}}{\sqrt{1 - \frac{Sr^2}{R^3}}} \tag{13}$$

$$g_{rr} = \frac{1}{1 - \frac{Sr^2}{R^3}} \tag{14}$$

Note that for S/R << 1 we obtain the approximation:

$$g_{00} \cong 1 - \frac{3S}{2R}(1 - \frac{r^2}{3R^2}) \tag{15}$$

This corresponds to the static Newtonian potential, referred to by Humphreys (1994, p. 100).

Equation (13) indicates that, as R approaches S, the term g_{00} approaches zero for all values of r and all clocks will slow down. Will this fulfill the time dilation hypothesis?

The crucial question is how long will it take a photon to travel from a distant galaxy to the earth. To calculate this we return to equation (2). Since the earth is at the center of our coordinate system, the photon will be traveling along a radial line, so that dθ = dϕ = 0. Furthermore, since photons travel at the speed of light, equation (1) with v = c tells us that its clock is effectively stopped. Hence, for photons, dτ = 0, in equation (2). Solving equation (2) for dt/dr, we find that the photon travel time from r to 0 is thus given by

$$\Delta t = \int_0^r \frac{dt}{dr}\, dr = \frac{1}{c}\int_0^r \frac{\sqrt{g_{rr}(r)}}{\sqrt{g_{00}(r)}}\, dr \tag{16}$$

At the earth, which is fixed at r = 0 during this time, we have dr = dθ = dϕ = 0, and equation (2) gives the proper time interval elapsed as (see Misner, et al., p. 1107)

$$\Delta\tau = \sqrt{g_{00}(0)}\;\Delta t = \frac{\sqrt{g_{00}(0)}}{c}\int_0^r \frac{\sqrt{g_{rr}(r)}}{\sqrt{g_{00}(r)}}\, dr \tag{17}$$

In terms of the travel time in the absence of gravity (i.e., r/c), the fractional travel time, $\Delta\tau_{rel}$, is

$$\Delta\tau_{rel} = \frac{\sqrt{g_{00}(0)}}{r}\int_0^r \frac{\sqrt{g_{rr}(r)}}{\sqrt{g_{00}(r)}}\, dr \tag{18}$$

For this particular model, using the metric coefficients given by equations (13) and (14), the relative photon flight time is thus

$$\Delta\tau_{rel} = \frac{1}{r}\int_0^r \frac{1}{(1 - \frac{Sr^2}{R^3})^{\frac{1}{4}}}\, dr > 1 \tag{19}$$

If the photon comes from the edge of the universe (i.e., r = R) then this equation holds only for R > S. Since the integrand is always larger than 1, the integral is greater than r, so that $\Delta\tau_{rel} > 1$ (in fact, $\Delta\tau_{rel}$ increases from 1, at R = ∞ to 1.2, at R = S). Hence, also here, time dilation does not decrease the photon flight time.

For R < S this equation can still be used, but only for r < $(R^3/S)^{1/2}$. In this case, too, the relative flight time is greater than that in flat space. Thus this static model provides no time dilation for earth clocks.

A Static Model with Pressure

Finally, consider a static model with a pressure term. This is more realistic than the previous case, since the gravitational field is now somehow balanced. The case is then identical to that of a static star of uniform density, which is well-known (e.g., Schutz, p. 262; Weinberg, p. 331; Misner, et al., p. 610). The g_{rr} term is the same as before, but g_{00} is now given by

$$\sqrt{g_{00}} = \frac{3}{2}\sqrt{1 - \frac{S}{R}} - \frac{1}{2}\sqrt{1 - \frac{Sr^2}{R^3}} \tag{20}$$

Equation (18) yields a relative flight time of

$$\Delta\tau_{rel} = \frac{3\sqrt{1-\frac{S}{R}}-1}{r}\int_0^r \frac{dr}{[3\sqrt{1-\frac{S}{R}}-\sqrt{1-\frac{Sr^2}{R^3}}]\sqrt{1-\frac{Sr^2}{R^3}}} \qquad (21)$$

Note that there are two singularities, one at R = S and another when

$$3\sqrt{1-\frac{S}{R}} = \sqrt{1-\frac{Sr^2}{R^3}} \qquad (22)$$

This corresponds to R = 9S/8. To avoid both singularities, we constrain equation (21) to cases where R > 9S/8, or S/R < 8/9.

Now calculate the relative photon flight time from the edge of the universe (i.e., r = R) as a function of H, which is defined as H = 8/9 - S/R. Numerical integration of equation (21) shows that $\Delta\tau_{rel}$ approaches 0 as H approaches 0 (see Table I). In particular, for small values of H, $\Delta\tau_{rel} = 5\sqrt{H}$.

Table 1. The relative photon travel time as a function of H=8/9-S/R.

H	0	.000	.001	.01	.1	.2	.4	.6	.8
$\Delta\tau_{rel}$	0	0.04	0.15	0.47	0.89	0.98	1.02	1.02	1.0

For example, a reduction of the flight time from, say 1 billion years to 1000 years (i.e., $\Delta\tau_{rel} = 10^{-6}$) requires R/S to be within about H = 0.2 x 10^{-12} of 9/8. Hence, if the universe is poised at precisely the proper radius, time dilation becomes highly significant.

What is the value of the critical radius R_{crit} = 9S/8? Humphreys (p. 105) estimates the mass of the universe, M, as about 3 x 10^{51} kg, based on a radius of 20 billion light years and a density of 10^{-28} kg/m^3. Taking c, the speed of light, as 3 x 10^8 m/s and one light year as 9.5 x 10^{15} m, we get R_{crit} = 8 x 10^8 light years. This is about 1/25th of the current assumed radius of the universe.

The time-dilation hypothesis thus requires the following scenario. The universe remained fixed at the critical radius for billions of years of coordinate time, which was just a few earth years. This was followed by a very rapid expansion from R_{crit} to almost the present radius (a factor of about 25) in at most a few thousand earth years. During this phase, the radius no longer being near the critical value, time dilation was greatly diminished: Earth time and coordinate time differed by at most a small percentage. If the universe were presently still in a state of such rapid expansion one would expect the brightness of the galaxies to fade appreciably over an interval of, say, 80 years. Since this has not been observed, one must postulate that, after a brief period of rapid expansion, the expansion rate was greatly reduced.

Note that the rapid expansion of the universe of a few billion lightyears during a few thousand years implies that the most distant galaxies receded from us at speeds greater than that of light. Such faster than light speeds do not contradict special relativity, for that limits speeds only with respect to the local space. Relativity theory places no constraint on the expansion rate of space itself. Faster than light stretching of space occurs also in inflationary cosmology (Linde, 1994).

4. Red Shifts

If significant time dilation has taken place then there should be further observational consequences. For example, since measurements of the frequency of light depend on the local clock rate, time dilation will alter the frequency, and thus also the wavelength of light. Let us calculate how the wavelength of light is altered in its journey from emission at observer 1 to reception by observer 2.

The wavelength of light can be altered by: (1) a Doppler effect due to motion of emitter or receiver relative to the local cosmological fluid, (2) local gravitational time dilation at the emitter or receiver, and (3) an expansion of the universe during transmission.

Assume, as before, that both observers are at rest with respect to the local matter of the universe. Local Doppler effects will thus be neglected. Further, in order to have strong time dilation effects, assume that at emission the universe was static (with pressure) and at the critical radius. After emission assume, for simplicity, that the universe reverted to the uniform density, free-fall case, so that the Robertson-Walker metric (i.e., equation (3)) applies.

Changes in the wavelength of light emitted from observer 1 and later received by observer 2 then depend on three steps:

(1) At emission, gravitational time dilation will cause the wavelength λ, as measured by observer 1 at $r = r_1$ to be stretched by a factor $g_{00}^{-1/2}(r_1)$, the ratio of the local proper time and the (flat) coordinate time.

(2) During transmission the wavelength will be affected by the expansion of the universe. If the density is to remain uniform all portions of the universe must expand at the same rate. The expansion of space stretches the wavelength by $R(t_2)/R(t_1)$, the fraction by which the universe has stretched during transmission. It is important to note that only the end values of R are important, not how R actually varied with time: it is not affected by rapid acceleration or deceleration (Misner, et al., p. 778; Weinberg, p. 416).

Humphreys (1994, p. 121) notes that the amount of red shift depends not on the expansion rate but only on the amount by which space has been stretched. He then asserts that it does not matter whether the expansion took place in

20 billion years or in six days. Yet one must be careful. Suppose that galaxy A is 1 million light years distant and galaxy B is 1 billion light years distant. For a slow, uniform expansion, the light we now receive from A will have been emitted much later than that of B. Hence the light from A will have undergone a much smaller stretching while in transit, corresponding to a smaller red shift. In this case z should be proportional to distance (i.e., the Hubble relation), as is observed. On the other hand, if the expansion occurs in a very rapid burst (as is postulated above) after the light from A was emitted, then the light from both A and B will be stretched by the same amount. In that case A and B (and other distant galaxies) will have the same red shift due to the expansion of space.

(3) At reception by another observer at r_2, another gravitational time dilation effect will change the wavelength by a factor $g_{00}^{1/2}(r_2)$, to bring it into observer 2's proper time.

Combining all three effects, we calculate z, the fractional change in wavelength to be

$$z = \frac{\lambda_2 - \lambda_1}{\lambda_1} = \frac{\lambda_2}{\lambda_1} - 1 = \frac{R(t_2)}{R(t_1)}\sqrt{\frac{g_{00}(r_2)}{g_{00}(r_1)}} - 1 \tag{23}$$

Let us now use this equation to calculate the red shift we should presently be observing for light from distant galaxies. If the light has been time-dilated it must have been emitted at the critical radius, so that $R(t_1) = 9S/8$ and, applying equation (20),

$$\sqrt{g_{00}(r_1)} = \frac{1 - \sqrt{1 - \frac{8r^2}{9R^2}}}{2} \tag{24}$$

The critical radius was about 8 x 10^8 light years, 25 times smaller than the current estimated radius, yielding $R(t_2)/R(t_1) = 25$. All significantly time-dilated light now received from distant galaxies must have been emitted while (or possibly before) the universe was very near the critical radius. Hence, for all such distant galaxies, the stretching factor of 25 applies.

At reception at the earth, $r_2 = 0$. Assuming that the free-fall model now applies, $g_{00}(0)$ has a value of 1 [actually, this differs very little from that of the static model with pressure: equation (20) with R at the current radius yields a value of 0.95]. Equation (23) then gives

$$z = \frac{50}{1 - \sqrt{1 - \frac{8r^2}{9R^2}}} - 1 \tag{25}$$

Note that z varies from 74 for the furthest galaxies at r = R, to infinity for the nearest ones. For r << R we have z = $112/(r/R)^2$. This is quite different from the observed situation, where z is roughly proportional to r, increasing to a maximum of about 3.5 (see figure 1).

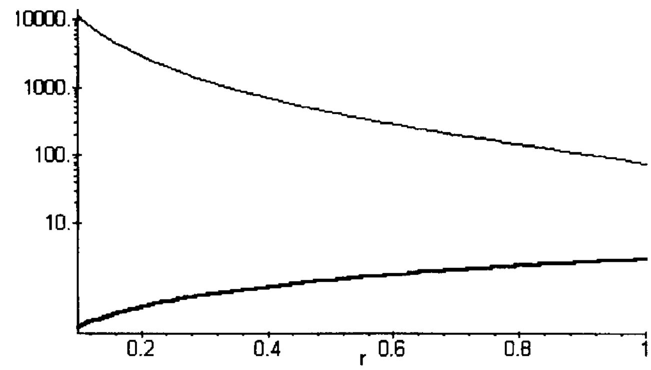

Figure 1. Redshift versus distance. The thin line represents equation (25), the thick line the observed relationship.

These, results depend somewhat on our estimates of the density and radius of the universe, quantities that are not known with a high degree of accuracy. However, changes in the radius or density do not greatly alter the general nature of the predicted red shift curve. If the density were 10 times greater than estimated, this would increase the critical radius by a factor of 10, reducing the red shift in equation (25) by a corresponding factor of 10. Figure 1 indicates that this still results in much too high red shifts for most galaxies.

Could it be that the actual density is so high that the critical radius is R = 9S/8 and that the static model with pressure still applies? In that case, $R(t_2)/R(t_1) = 1$. For observer 2 at the earth, $r_2 = 0$, and equation (20) gives $g_{00}^{1/2}(r,) = 0$. Thus the light, as received at the earth, is shifted infinitely far to the blue (i.e., $\lambda_2 = 0$); significant time dilation in a static universe causes light from distant galaxies to be strongly blue shifted, which is not presently observed to be the case.

5. Conclusions

In summary, neither special nor general relativity appear to lend much support to the time dilation hypothesis. Although special relativity predicts time dilation due to motion, this is in the wrong direction. In the most natural general relativistic cosmological models (e.g., homogeneous or free-fall) gravitational time dilation does not apply and time dilation due to expansion is in the wrong direction.

Sufficiently large time dilation in the desired sense was found only in a static model with pressure. Unfortunately, this model has a number of serious problems that must still be overcome. The most important deficiency concerns the predicted red shifts, which differ drastically from the observed values. It is not clear how this can be resolved without the introduction of rather elaborate, artificial ad hoc modifications. Other difficulties include those of accounting for the pressure in the static phase and finding a physical cause for the brief burst of rapid expansion. There seems to be no obvious natural explanation as to why the universe should behave in such an eccentric manner.

Furthermore, it should be noted, that this model does not eliminate the need for "mature" creation of stars. Although, presumably, time dilation might allow distant stars sufficient time to develop via natural means, this is not the case for nearby stars. Certainly not for the Sun, where the cosmic gravitational potential - and hence the clock rate - is essentially the same as at the earth.

Of course, a cosmological model is not disproved by a mere inability to provide complete naturalistic explanations for all its details. Such shortcomings may merely reflect current human ignorance; further research might find viable remedies. On the other hand, it could be that naturalistic explanations fall short because of the existence of supernatural causes. In that case no scientific cosmological model will be adequate. Let us thus build our cosmological models with caution, testing them where possible with what God has revealed to us, and staying fully aware of their severe limitations.

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LETTERS TO THE EDITOR

It's Just a Matter of Time

Before I get to the delightful chore of quibbling with John Byl over his article "On Time Dilation in Cosmology" (1997), let me mention several important points of agreement. First, we agree that young-earth creationism has not had, and needs, a good cosmology. Second, we agree that creationists can and should try to use general relativity to meet that need. If my book *Starlight and Time (1994)* is remembered for nothing else, it would please me greatly to see it remembered for breaking the ice in those two areas.

I also want to commend Dr. Byl for introducing and discussing some models of his own. I do not have space to discuss those models here, but I find them interesting. As I remarked in my book, if we have a *multiplicity* of young-earth cosmologies to choose from, we are much more likely to arrive at the truth.

Byl's Coordinates Conceal Time Dilation

Now, let's quibble! The essence of Byl's criticism of my model is in his section "Free-fall Models." After introducing the Robertson-Walker system of coordinates in his (metric) equation (3), he then asserts that "... there is no gravitational time dilation. All galactic clocks tick at the same rate."

Here Byl, perhaps unwittingly, has swept time dilation under the rug of a definition. The time coordinate he has chosen is *cosmic time* or "proper" time, which I explain on pages 89 and 92 of my book. I symbolize cosmic time by the Greek letter τ, but Byl symbolizes it by the Roman letter t (which will confuse readers wanting to compare the two papers). Cosmic time is the time registered by an ordinary clock *affected by gravity*.

Imagine a set of clocks which God synchronizes at the instant of creation, when everything is close together. Assign one clock to ride along with each newly-forming galaxy. As space and the galaxies expand outward away from each other, the clocks also move away from one another. Each one ticks at a rate determined by its position in the gravitational potential "well" Cosmic time defines two events in separate places as being "simultaneous" if the cosmic