Is there any evidence for a change in c? Implications for creationist cosmology

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Recent astronomical observations of spectral lines in starlight from distant quasars suggest that the fine structure constant was lower in the past. Astrophysicists have claimed that this means the speed of light (*c*) may have been higher in the early universe. Observations by Webb may be interpreted in this way back to redshift *z* = 3.5, assuming the usual long-age evolutionary cosmology. Creationist cosmologists, however, place a different interpretation on the timescales relating to these reported redshift values. As a result, a model is explored where c was enormously greater at Creation. From the moment of Creation on, *c* very rapidly decreased. By redshift *z* = 1 it had reached its current value except for very small residual changes. The model however doesn't provide an explanation to the starlight-travel-time issue in creationist cosmology. Nor does it provide a mechanism to explain rapid stellar aging in the early universe, which could account for the deficit of old dwarf stars in nearby galaxies in Humphreys' model. More significantly, the model clearly shows that no variable-speed-of-light model consistent with current observations on the fine structure constant can explain a young universe.

Creationists have been concerned about the issue of the time of flight of light across the vast distances of the visible universe in the 6,000 years since the Creation.[1,2] Specifically the Humphreys' model[1] attempts to answer this problem. It seems that one difficulty facing that model is the observation of apparently old stellar objects such as white dwarf stars in the halos of galaxies near our own. In Humphreys' model nearby stars would have aged very little compared to stars on the edge of the universe. Therefore we shouldn't see any 'old' stars nearby. This objection may be answered by rejecting models of stellar evolution that are all based on million-year time scales. But is there an alternative explanation?

In this paper I present the hypothesis that if the speed of light (c) was shown to decrease over cosmological time, then it is also possible that the speed of light was enormously greater at Creation. The decrease in the value of c may have resulted from changes in values of some parameters or 'constants' related to the fabric of space itself. In this model, the process causing the decrease ceased long ago but the effects may still be observed in astronomical data at cosmological distances. The process described here may have gone hand-in-hand with a very rapid expansion of space, something like the 'inflation' period invoked by the big-bang cosmologists. Note that these very same evolutionary cosmologists are abandoning inflation for a superluminal or variable-speed-of-light model with c as much as a billion times its current value. The question can then be asked: Does such a model explain the light travel time problem or explain the abundance of 'old' dwarf stars in galaxies that are in our local galactic neighbourhood? I will attempt to answer these questions.

The speed of light c, the limiting constant of the universe

The two-way speed of light, usually specified by the letter c, is the quantity measured in all tests of Relativity and is the quantity under consideration in this paper. It has been described as the limiting constant for all causally related events in the universe and is related to two important parameters by

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \tag{1}$$

where ε_0 and μ_0 are the permittivity and permeability of free space, respectively. The permittivity and permeability of free space really describe properties of the fabric of space that permit wave propagation, something analogous to the stiffness of a medium to sound propagation. Therefore, the constant c has been called Einstein's constant as it imposes a limit on all forms of energy propagation in the universe.

Drift in dimensionless constants

Since Dirac conjectured about the ratio of certain constants varying on the timescale of the age of the universe, the search has been on to measure variation in the three main contenders. They are the electron to proton mass ratio, (m_e/m_p), the fine structure constant, α, and the quantity $\alpha^2 g_p(m_e/m_p)$, where g_p is the proton gyromagnetic ratio. Generally the search has been for temporal variation in these constants[3–6] and can be divided into cosmological observations and modern atomic clock measurements. Variation of these non-gravitational constants is forbidden in General Relativity and other metric theories of gravitation.

In those theories gravitation is described as a result of the geometry of space-time. String theories, however, suppose that, as the universe expanded over time, compact (extra) dimensions have unraveled a little, causing 'constants' as seen in our 3-dimensional space to vary.[7]

Cosmological observations have set upper bounds on these ratios generally back to about a redshift, $z = 3$. Spectroscopic observations of molecular hydrogen in quasar absorption-line systems has set a limit on $m_e/m_p = y$ of $\delta y/y \leq 8 \times 10^{-5}$ at the 95% confidence limit, back to $z = 2.811$.[8] The ratio of the frequencies of the hyperfine 21 cm absorption transition of neutral hydrogen and an optical resonance transition is the dimensionless constant $\alpha^2 g_p(m_e/m_p) = x$. Lennox used absorption-line data from a system involving a quasar at a redshift $z = 1.77644$ to set an upper limit of $\delta x/x \leq 7 \times 10^{-6}$ at the 95% confidence limit.[4]

Fine structure constant

There is experimental evidence[6] suggesting that the fine structure 'constant' (α) has increased over the lifetime of the observed universe by about 1 part in 100,000. It is related by

$$\alpha = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar c} \tag{2}$$

where e is the charge on the electron and $\hbar$ (pronounced 'h-bar') is Planck's constant divided by 2π. The current value of the fine structure 'constant' $\alpha_0 = 1/137.0359895$. This dimensionless 'constant' specifies the extent of the splitting of some spectral lines resulting from the fine structure of energy levels in atoms caused by spin-orbit coupling. The starlight from distant quasars intersects line-of-sight absorption systems and the spectral lines of certain elements are compared to laboratory spectra of specific ions. *New Scientist* recently reported Webb's work stating in regard to this discovery 'The ground is shifting under our feet. Fundamental properties of the universe are changing, and physicists can't explain how or why. Now researchers say an as yet undiscovered fifth force could be behind these mysterious changes'.[9] So it could be interpreted in two ways: either the universe has extra dimensions suggested by Kaluza-Klein and Superstring theories or 'if the universe is four dimensional then a fifth force is the only thing capable of triggering these changes'.[9] This new force would be repelling and about 100,000 fainter than gravity, it is claimed. They report that 'light may be slowing down'. In another article entitled 'Light may have slowed down', the on-line Newscientist.com quotes John Webb as saying 'If it holds up, it surely has to be one of the more important discoveries in fundamental physics'.[10]

Electronic transitions between excitation states in alkaline ions are the usual choice to measure the fine structure constant in cosmological sources. Ionized atoms of elements like Ni, Cr, Zn, Al, Si, Mg, Fe etc. are observed and identified in gas/dust clouds in the interstellar medium by their spectral characteristic lines. The separation between the wavelength λ_1 of the $^2S_{1/2} \rightarrow {}^2P_{3/2}$ transition and the wavelength λ_2 of the $^2S_{1/2} \rightarrow {}^2P_{1/2}$ transition is proportional to α^2 to lowest order in α. Therefore after defining the mean wavelength $\bar{\lambda} = \frac{2}{3}\lambda_1 + \lambda_2$ we can write

$$\frac{\lambda_1 - \lambda_2}{\bar{\lambda}} \equiv \frac{\Delta\lambda}{\bar{\lambda}} \sim \alpha^2 \Rightarrow \frac{\delta\alpha}{\alpha} = \frac{1}{2}\frac{\delta(\Delta\lambda)}{\Delta\lambda} \tag{3}$$

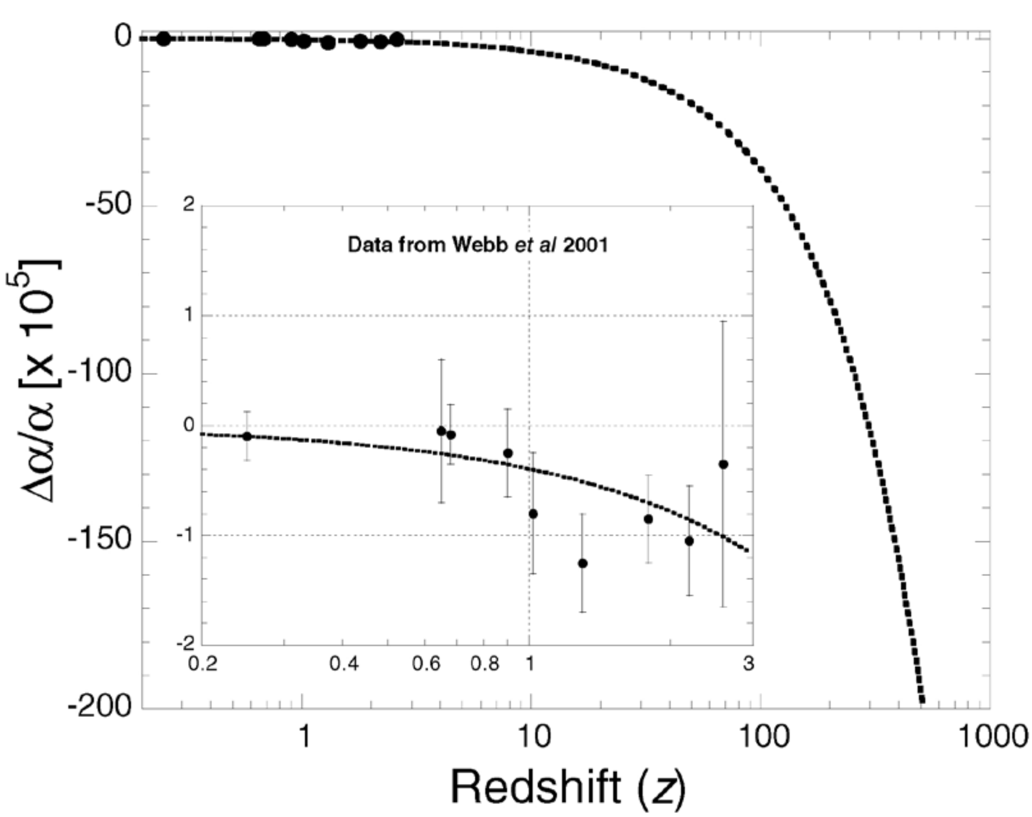

***Figure 1.** Fractional change in the fine structure 'constant' and error bars taken from Webb* et al.[6] *The curve fit is my exponential fit extrapolated to nearly z = 1000.*

Any change in α will result in a change in the mean separation of the doublets (pairs of spectral lines) in high-z quasar absorption systems. From Si IV doublets, observed with the Keck HIRES spectrograph, Lennox[4] (in 1995) was able to set a limit $\delta\alpha/\alpha < \pm 3.5 \times 10^{-4}$ at $z = 2.78$. The main uncertainty in the measurement comes from the uncertainty in the laboratory determination of the doublet separation. Webb (in 1999) was able to achieve greatly improved sensitivities by applying a multiplet[11] technique to the relativistic fine-structure splitting of certain doublets. He made further gain by comparing the wavelengths of different species. Still the limiting accuracy was due to an uncertainty in the laboratory reference. For example, the limit $\delta\alpha/\alpha \sim 10^{-5}$ results from uncertainty in the laboratory frequency of ~ 0.03 cm^{-1} (unit: 1 cm^{-1} = 30 GHz), which is typical for accurately known lines.[5] In Webb's 2001 paper, he combined three large data sets and two 21 cm and mm absorption systems, resulting in four independent samples producing 72 individual estimates of $\delta\alpha/\alpha$. Each sample showed α smaller in the past and the optical sample shows a 4σ deviation. Rigorous statistical analyses were applied to the data sets, resulting in $\delta\alpha/\alpha = -0.72 \pm 0.18 \times 10^{-5}$ over the redshift range $0.5 < z < 3.5$. The most recent analysis of the cosmic microwave background (CMB)[12] taken from BOOMERANG and MAXIMA data also suggest α may have been smaller in the past. However I would not apply too much weight to the interpretation placed on that data as it is much more open to alternative interpretation than the fine structure constant data described here.[13]

It is believed it may be possible to measure the current 'drift' in α with carefully constructed modern laboratory experiments. Prestage3 describes a test by comparisons of the rates of atomic clocks based on the hyperfine transitions in alkali atoms with different atomic number Z. Hydrogen-maser[14], cesium and Hg^+ ion clocks have different dependence on α via relativistic contributions of order $(Z\alpha)^2$. Prestage set a limit on the fractional temporal change[15] in α of $\alpha/\alpha \le 3.7 \times 10^{-14}$/yr using a comparison of H-maser and a Hg^+ ion clock. Further tests are planned using the world's best cesium and rubidium atomic fountain clocks[16] and another using monolithic crystal resonators.[17]

Effect on the speed of light

From (1) and (2) it follows that

$$\alpha \propto \frac{1}{\varepsilon_0 c} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{4}$$

The term on the right of (4) is called the impedance of free space and currently evaluates to approximately 377 ohms. It is something like a resistance to electromagnetic wave propagation. If the data for an increase of α over cosmological time proves to be true, it could imply that this parameter too has increased. The data from Webb[6] have been plotted in Figure 1. From (4) it can be seen that for an increase in α, the impedance of free space would decrease provided the electron charge and Planck's constant remained constant. By making assumptions of cosmological parameters and choosing a value for the Hubble constant H_0 = 68 km s^{-1} Mpc^{-1}, Webb claims that α has changed by 1 part in 10^5 over the past 12 billion years. However, the same data indicate the 'drift' now has become very small in our galactic neighborhood at least. From atomic clock experiments the local drift in α it is expected to be less than 1 part in 10^{16} per day. This is at the very limit of current experimental precision.

I explore in this paper a creationist model where the increase in the fine structure constant is related to a relaxation mechanism of the expansion of space. Hence the expected functional form for the fractional change in α is exponential and may be expressed

$$\frac{\delta\alpha(z)}{\alpha_0} = \frac{\alpha(z) - \alpha_0}{\alpha_0} = 1 - e^{az} \tag{5}$$

where z is the redshift due to the expansion of space. This was fit to Webb's data and is shown in Figure 1, where $a = 3.895 \pm 0.917 \times 10^{-6}$ was evaluated from the fit. This is a reasonable expectation for this model. The fit is consistent with an annual change less than 10^{-14} at the present epoch ($z \le 10^{-10}$) and is good back to when the universe was a quarter its current size. As space expanded, $\alpha(z)$ increased from a zero value (at large z) to its current value α_0 (at $z = 0$). A reduced spacing between spectral lines would be observed with increasing z. From (4), it follows that an increase in α as z decreases would also result in an increase in the impedance of free space and a decrease in c. Therefore these parameters respond also to the relaxation process, which could be described by String theorists as an unravelling of extra spatial dimensions.

Assuming the change in α is totally due to a change in c, then from (2) and (5) we can write

$$c(z) = \frac{c_0}{2 - e^{az}} \tag{6}$$

where c_0 is the current value of the speed of light at $z = 0$. The form of the dependence on z is plotted in Figure 2. Note the asymptote at approximately $z = 2 \times 10^5$. Due to the uncertainties arising from the small domain of the data this exercise is only meant to give us a functional form of this dependence.

The expansion redshift is the redshift that according to General Relativity results from the stretching of space itself and is usually defined by

$$\frac{R_0}{R} = 1 + z \tag{7}$$

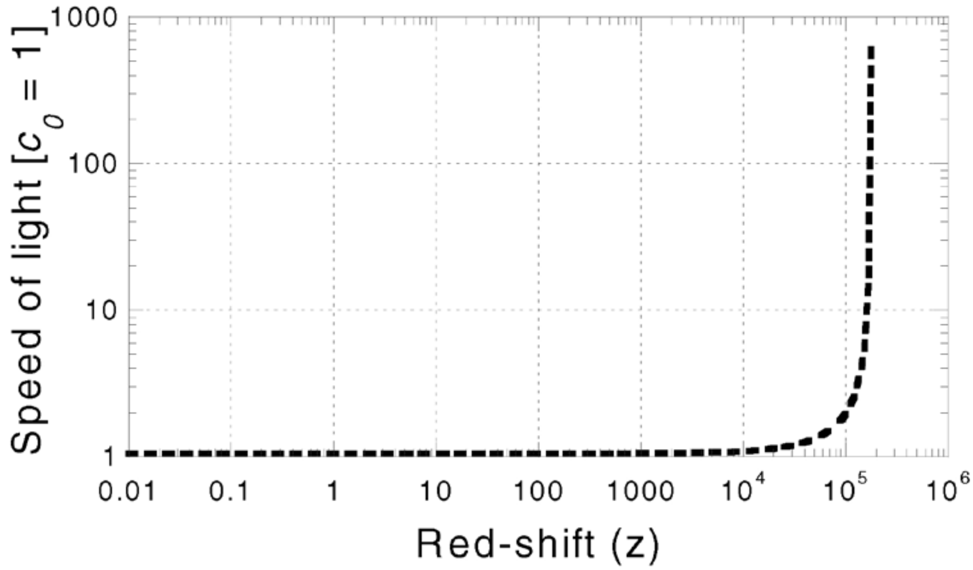

Figure 2. *Speed of light as a function of redshift (z), expressed as a fraction of the current value (c_0 = 1).*

where R_0 is the scale factor of the universe now, and R at some time in the past. According to the Friedmann-Lemaître solution of Einstein's field equations, the expansion redshift only depends on the scale factor of the universe at the time the light was emitted and the time it was received. The fabric of space itself stretches between emission and reception. This is what is usually referred to as Hubble flow. The expansion redshift doesn't depend on the rate of this expansion. Other types of redshift are Doppler shift, due to the absolute motion of the source itself with respect to space, and gravitational redshift, which results from the pull of the gravitational field on a photon at the moment of emission from the surface of a star. The latter two forms of redshift are not involved in these data, assuming careful measurements were made to separate out any such effects. Therefore the farther we look back in space the greater z and the further into the past. For example, if we look at light coming from a source, emitted at the time when the universe was half its current size, $1 + z = 2$, or $z = 1$. Because the speed of light is finite, the redshifts we observe on Earth have time delays built in. Therefore, z more correctly describes some convolution of distance with time.

The location of the source in space is determined by the expansion redshift (z) measured by a comparison of the absolute shift of a group of spectral lines as compared to a laboratory reference. The separation between or the splitting of certain spectral lines as compared to the laboratory reference determines the value of α at that value of z. Then using (2) the value for c locally at redshift z is determined. Now at any time in the past, or at a specific value of z the fractional scale factor is $1/(1+z)$. In other words, the greater the value of z, the smaller the size of the universe. This means the distance between two points was smaller in the past. In young universe creationist cosmology, it is assumed the larger z is, the closer the epoch is to Creation week and the beginning of time. For example in the Humphreys' model, the universe started as a ball of the size of about a light-year in radius. Now if the universe is 10^{10} light-years in radius, the origin was at about $z = 10^{10}$.

In understanding this data it is best to divorce the redshift values from any universal time scale. The Hubble parameter (H_0), the space curvature parameter ($k = -1,0$ or $+1$) and the universal deceleration parameter (q_0) predetermine the distance scale of the universe. These parameters, however, are not well known and even less is known about their dependence on z. The type of cosmological model assumed in turn determines the timescale based on constant c, or in other words, how R evolves with time. The chosen model includes the form of the space-time metric and values for the cosmological constant (Λ), the amount of dark matter or dark energy (Ω_Λ) and the baryonic mass (Ω_M), which can only be assumed (see Hartnett[13]).

For small z, the Hubble relation is usually written for a flat space ($k = 0$) cosmology

$$v = cz = H_0 r \tag{8}$$

where v is the light source recession velocity and r the radial distance to the source. This is the relation Edwin Hubble originally fitted to his data. The value of H_0 is the asymptotic value of the normalised rate of change of the expansion of the universe, or $H(z) = \dot{R}/R$ at any value of z. For all cosmologies, $H(z)$ approaches H_0 for $z \leq 0.2$ (see Hoyle *et al*[18]). The Hubble relation (8) has been extremely well established by observational evidence out to $z = 0.2$. It follows from (8) that we would measure a recession velocity (v) for a galaxy at $z = 1$ equal to the speed of light. Therefore any creationist model must account for (8) valid to $z = 0.2$ at least. Creationist models need to solve the issue of the correct time calibration with z, which obviously cannot be the billion year scale that evolutionist determine from (8), because from a simple reading of Genesis the beginning was about 6 thousand years ago as measured by Earth clocks. The only creationist model, to my knowledge, which has attempted to do this, is Humphreys' model.

In order to evaluate if (6) could explain the light-travel-time problem in a recent-Creation cosmology, it is important to calculate the time for a photon to travel across the universe as measured by Earth clocks. Assuming the

Hubble relation to be a correct conversion for distance, it follows from (8) and constant c that the time of flight of a photon emitted with redshift z, is

$$t_{photon} = \frac{r}{c} = \frac{z}{H_0} = 1.438 \times 10^{10} z[years] \quad (9)$$

for small z. For all z, the general form of this equation must be used. For simplicity, and for a comparison with evolutionary cosmology, I have chosen the Hubble distance relation in a flat universe,

$$r(z) = \frac{2c_0}{H_0}\left(1 - \frac{1}{\sqrt{1+z}}\right) \quad (10)$$

which approximates to (8) for small z. Now, after dividing r by $c(z)$ from (6) and integrating out to redshift z, the look-back time to z is

$$t(z) = 1.438 \times 10^{10} \int_0^z \frac{2 - e^{az}}{(1+z)^{\frac{3}{2}}} dz \quad (11)$$

The result of (11) has been expressed as a percentage of the look-back time with constant c (see Figure 3). *It is obvious that this doesn't explain the light travel time problem.*[19] Though the increase in c is very great near $z = 10^5$ it does not reduce the transit times of light across the universe to six thousand years. In fact, any creationist cosmology based on a higher value of the two-way speed of light cannot, except by fantasizing about incredibly higher values of c in the very recent past. Such ideas are not based on observational evidence.

From (2) and Webb's data, it is possible to envisage an early universe where the speed of light decreased enormously to its present value. I suggest that the data present *the possibility*, that early in the Creation week, enormous changes occurred that are now only seen as a very small residual 'drift' in dimensionless constants. I am not suggesting any connection to the work of Setterfield and Norman (c-decay). The astronomical measurements of the fine structure constant show that any significant changes to the value of c occurred in the very early universe and if any 'drift' remains today it is extremely small, well below the resolution of all early measurements of the speed of light. Only in the last few years have atomic clocks achieved the precision and accuracy to make such measurements.

The 'light-year' in this paper is a fixed length based on approximately 3×10^8 meter/second × 365.25 days × 24 hours × 60 minutes × 60 seconds, where meters and seconds are defined in the Earth frame of reference. In fact, on 20 October 1983, the General Conference (CGPM), as recommended by the International Committee on Weights and Measures (CIPM), formally redefined the meter so as to make the speed of light an exact unmeasurable quantity, determined by convention. The value of c therefore has been defined to be 2.99792458×10^8 ms^{-1}. As a result, now it all depends on the 'second'. The second in turn is determined from a certain frequency of light from a specific transition in an excited cesium atom. This brings it back to the fine structure constant and the energy of hyperfine transitions.

A more rapid star formation rate?

The product $\varepsilon_0 \cdot \mu_0$ more correctly relates matter and energy in Einstein's famous equation

$$e = mc^2 = \frac{m}{\varepsilon_0 \mu_0} \quad (12)$$

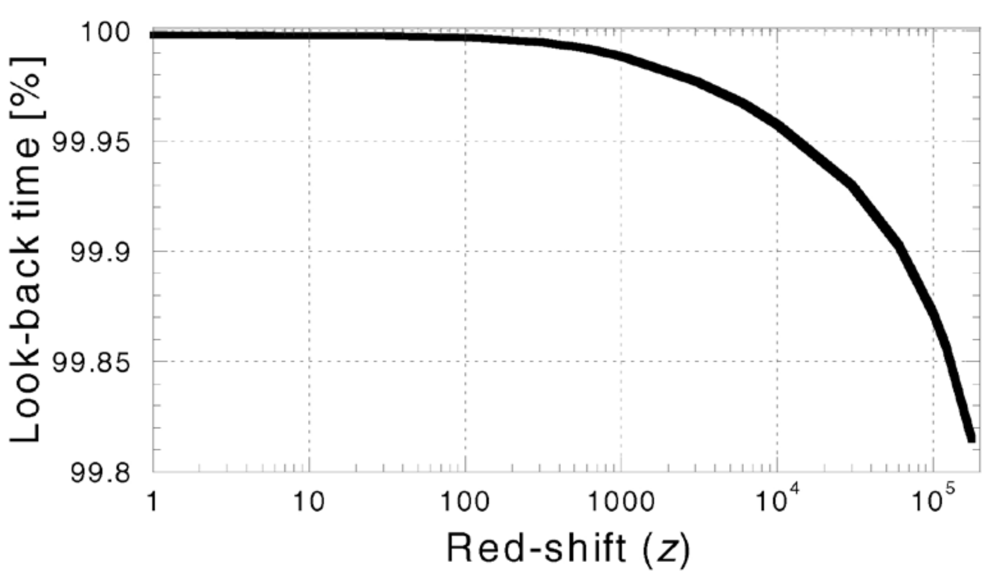

***Figure 3.** The look-back time due to the flight of a photon from z to the current epoch (z = 0). This is expressed as a percentage of the value calculated from a simple Hubble model.*

If we suppose total energy (E) is conserved, then the total energy of all matter is described by (12). As a consequence of (12), the mass of any body of matter would rapidly increase with decreasing c. This meant a rapid 'switching on' of stars as they gained mass and as the accompanying nuclear 'fires' started from increasing gravitational compression. By the time c slowed to the current value the mass of the stars would be approximately as we currently observe. Because luminosity and hence age is directly related to the mass of a star, *the model does not provide a rapid aging mechanism for stars in any region of the universe and as a result does not provide an answer for the abundance of white dwarfs stars nearby in a Humphreys' type cosmology.*

The light-travel-time problem explained?

Recent astronomical evidence suggests that the speed of light *c* may have changed over cosmological time. Though variation in the value of *c* would violate General and Special Relativity, modern experimental evidence as yet cannot decisively exclude the possibility. A 'drift' may be observed in some dimensionless 'constants' of physics that contain *c*, because *c* itself, as a result of the way it was conveniently defined in 1983, is truly a constant. I have proposed a model with *c* enormously greater in the past, particularly during Creation week, yet consistent with recent observational data. Such a model, however, cannot provide an explanation for the light-travel-time problem in creationist cosmology. In fact, a significant point is made that no variable-speed-of-light model consistent with current observations can explain a young universe.

References

1. Humphreys, D.R., *Starlight and time*, Master Books, Colorado Springs, 1994.
2. Newton, R., Distant starlight and Genesis: conventions of time measurement, *TJ* **15**(1):80–85, 2001.
3. Prestage, J.D., Tjoelker, R.L. and Maleki, L., Atomic clocks and variation of the fine structure constant, *Phys. Rev. Lett.* **74**(18):3511–3514, 1995.
4. Lennox, L.C. and Songaila, A., Astrophysical limits on the evolution of dimensionless physical constants over cosmological time, *Astrophys. J.* **453**:596–598, 1995.
5. Webb, J.K., Flambaum, V.V., Churchill, C.W., Drinkwater, M.J. and Barrow, J.D., Search for time variation of the fine structure constant, *Phys. Rev. Lett.* **82**(5):884–887, 1999.
6. Webb, J.K., Murphy, M.T., Flambaum, V.V., Dzuba, V.A., Barrow, J.D., Churchill, C.W., Prochaska, J.X. and Wolfe, A.M., Further evidence for cosmological evolution of the fine structure constant, *Phys. Rev. Lett.* **87**(9):091301, 2001.
7. Dzuba, V.A., Flambaum, V.V., Murphy, M.T. and Webb, J.K., Relativistic effects in Ni II and the search for variation of the fine structure constant, *Phys. Rev. A* **63**:042509, 2001.
8. Varshalovich, D.A. and Levshakov, S.A., J. *Exp. Theor. Phys. Lett.* **58**: 231, 1993.
9. Choi, C., And then there were five, *New Scientist*, 2 March, p. 7, 2002.
10. Cho, A., Light may have slowed down, Newscientist.com, <www.newscientist.com/news/print.jsp?id=ns99991158>, 2001.
11. A multiplet technique compares a number of doublet lines in an atomic species. The technique significantly reduces systematic errors.
12. Avelino, P.P., Martins, C.J.A.P., Rocha, G. and Viana, P., Looking for a varying α in the cosmic microwave background, *Phys. Rev. D* **62**(123508), 2000.
13. Hartnett, J.G., Recent cosmic microwave background data supports creationist cosmologies, ***TJ*** **15**(1):8–12, 2001.
14. A maser is a microwave frequency laser. MASER means microwave amplification by stimulated emission of radiation. A hydrogen maser is built around a resonant cavity filled with hydrogen gas. When stimulated at about 1.4 GHz maser activity is observed. Once atoms enter the resonant cavity, they find other atoms radiating and they fall in step with each other. They 'start to talk to each other' and echo what they hear. This produces a highly coherent oscillation. Because the frequency of this oscillation is determined by the atomic transition (the 21 cm line) it is called an atomic clock.
15. Time rate of change of the fine structure constant $\dot{\alpha} = \frac{\partial \alpha}{\partial t}$
16. Sortais, Y., Bize, S., Nicolas, C., Mandache, C., Santarelli, G., Clairon, A. and Salomon, C., Rubidium and cesium in one fountain: A new tool for the search of the time variation of the fine structure constant, in *2001 IEEE International Frequency Control Symposium*, Seattle, pp. 22–24, 2001.
17. Braxmaier, C., Pradl, O., Muller, H., Peters, A. and Mlynek, J., Proposed test of the time independence of the fundamental constants α and me/mpusing monolithic resonators, *Phys. Rev. D* **64**:042001, 2001.
18. Hoyle, F., Burbidge, G. and Narlikar, J. V., A different approach to cosmology: *From a static universe through the big bang towards reality* Cambridge University Press, Cambridge, UK, 2000.
19. If the fractional change of $1/\varepsilon_0$ in (4) was not small in comparison to the change in the impedance of free space then an additional exponent may be added to (6). That is if $\varepsilon_0/\varepsilon_0(z)$ ~ ebz, then the value of c was even greater in the past. For comparison, if b = 10, the value of c would be 20,000 times greater at $z = 1$and the look back time reduced to 15%. Still this is a billion years and does not solve the problem.

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