Issues on Barry Setterfield's Claims of a Recently Decaying Speed of Light

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August 22, 2001

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1 Introduction

The notion that fundamental physical constants have changed over cosmic history is not a new hypothesis - P.A.M. Dirac [Dirac] and others ([Dicke]) have suggested it on various grounds.

Along with the theoretical interest, there have been a number of experimental searches for evidence that some physical parameters which we consider as constant, might in fact vary over the history of the cosmos. [Taylor] used changes in the orbits of binary pulsars (due to gravitational radiation losses) to search for changes in G, placing a limit on $|\dot{G}/G| < (1.2 \pm 1.3) \times 10^{-11} yr^{-1}$. There have been reports of a possible variation in the Fine Structure constant, α, through observations of spectral lines in high-z quasars([Webb]). [Shlyakhter] used the fission reaction created in the Oklo uranium deposits to place limits on the variation of the Fine Structure constant ($|\dot{\alpha}/\alpha| < 10^{-17} yr^{-1}$), the weak nuclear coupling constant ($|\dot{g_w}/g_w| < 2 \times 10^{-12} yr^{-1}$) and the strong nuclear coupling constant ($|\dot{g}_s/g_s| < 5 \times 10^{-19} yr^{-1}$). A number of tests are described and summarized in [Sisterna].

Since one goal of this document is to provide a resource for teachers (particularly in physics, astronomy and perhaps mathematics), the treatment herein will be very pedagogical. Even problems are available at the end.

This document will be subject to periodic additions and revisions. The derivations within are my own work based on descriptions by others in the talk.origins newsgroup and other sources. I'd appreciate information on original work on some of these topics so they can be properly cited.

2 An Introduction to the Setterfield Hypothesis

Many rebuttals deal with Setterfield's interpretation of the measured values for the speed of light over the past 250 years. Many of these rebuttals are dealt with in other sources.

- Strahler [Strahler] summarizes and describes a number of problems with how Setterfield collected his data.
- Link to talk.origins c-decay article (`http://www.talkorigins.org/faqs/c-decay.html`)
- Lambert Dolphin (`http://www.ldolphin.org/constc.shtml`) has a web site which describes a number of components of the Setterfield hypothesis and it is the primary source used in this paper.

We can summarize the main points of Setterfield's hypothesis

- Accept the cosmic distance estimates as valid.
- The speed of light varies universally at the same time.
- Dynamical time (τ) synchronized to gravitational phenomena. Orbital periods are constant in this timescale. This is the 'true' timescale.
- Atomic time (t) synchronized to atomic phenomena. Atomic and nuclear processes keyed to this timescale.
- In the (not so distant) past, the atomic timescale was much faster than the dynamical timescale. This allows radioisotopes to appear to have taken millions to billions of years to decay when really only a few thousand years in dynamical time have passed.
- The ratio a unit of the atomic time to the dynamical time is $dt/d\tau \propto c$ or $dt/d\tau = \zeta(\tau)$.

- Today, a second of atomic time is indistinguishable from a second of gravitational time ($\zeta(\tau) = 1$ and ζ no longer changes, so $d\,\zeta/d\,\tau = 0.$).

- Other physical quantities are allowed to vary so that certain other quantities remain constant with time (e.g. $E = mc^2 = constant$, $Gm = constant$(this is strange because Setterfield initially claims that G is the constant), $hc = constant$). See Section 5.

I will address implications of Setterfield's claims that don't seem to get much treatment in the literature but which are just as, if not more, important, in determining if the value of the speed of light has changed substantially in historical times. Legitimate science *builds* on the work done before and there are strong observational arguments for why the speed of light has *not* undergone significant change (within a factor of 2?) in the past approximately 14 billion years of the Universe's history.

In addition to direct measurement of the speed of light (which Setterfield uses), there are numerous other predictions which can be made by this hypothesis alone. It is often complained by Creationists that quantities such as the speed of light are *assumed* constant over the history of the cosmos. However, just because it is an assumption does not mean that it is an *untested* assumption, as the number of references in Section 1 attest. This constancy is just the simplest assumption that fits the available data. This exercise also enables us to see just how science can actually test these assumptions.

3 Other Models with a Changing Speed of Light

Is Setterfield's c-decay the same as being advocated by Barrow, et al.[Barrow & Magueijo])? No.

- Barrow et al. have c changing rapidly as a mechanism of inflation in the very early stages ($< 10^{-30} seconds$) of the Big Bang and then holding a roughly constant value in the billions of years since then. Setterfield is claiming c has undergone significant change in the past few hundred years.

- Barrow et al. recognize the issues described below. They do not have the changing c responsible for the redshift of galaxies. Their large values for c take place before galaxies are formed, even before the Cosmic Microwave Background (CMB), nucleosynthesis, or baryogenesis.

4 Kinematic Implications of a Changing Speed of Light

While Setterfield goes into great detail on quantum mechanical issues with his claims, he fails to consider the fatal flaws in his arguments on *kinematic* considerations alone that can be addressed by anyone with a competent background in calculus-based physics, a course which is occasionally taught at the high-school level. These arguments are based on one of the oldest physical principles, that distance traveled is velocity multiplied by the travel time, or in calculus terms, that distance is the integral of velocity over time:

$$s = \int_{t_1}^{t_2} v(t)\, dt \tag{1}$$

or

$$v(t) = \frac{ds(t)}{dt} \tag{2}$$

This is one of the founding equations of kinematics to compute the distance, s, travelled by an object moving at a non-constant velocity $v(t)$ at time t during the interval t_1 to t_2. It is basically the *definition* of velocity. In this section, I'll address many predictions about c-decay based on this concept alone.

To start our analysis of this theory, lets establish a few conventions to ensure we develop the concepts in a self-consistent fashion. On the Lambert Dolphin web site([Dolphin]), the notion is established that there are two timescales: an atomic time scale that is synchronized to atomic interactions, and a dynamical time scale that is synchronized with gravitational phenomena. According to Setterfield's hypothesis, in our modern day, a second of atomic time is indistinguishable from a second of dynamical time, but just a few thousand years ago, a second of dynamical time could correspond to several months of atomic time. This allegedly enables radioisotopes to appear to have taken millions or billions of years to decay in modern measurements while only a few thousand years have passed in the dynamical time scale. It also lets the speed of light appear constant when measured against the atomic time scale but varies when measured against the gravitational time scale.

For the purpose of our analysis and to ensure consistency throughout, we'll use t to designate measurements on the atomic time scale and τ to designate measurements made on the dynamical time scale. Setterfield claims the dynamical time scale is the 'true' or uniform time so we'll perform our analyses using this time tag and translate to the atomic time scale when necessary.

The key component of Setterfield's theory is that the aforementioned changing time scales are linked to changes in the speed of light (measured in a vacuum). To guarantee consistency, we'll separate our equation for the speed of light into a dimensional component, $\bar{c}$, which will be equal to the speed of light in the modern era ($2.99792458 \times 10^{10} cm/sec$), and a dimensionless component, ζ, which will contain all the time variability (measured in dynamical time, τ). This separation makes it easier to identify just how the time varying component affects other observables. Changing the c to $\bar{c}$ when we mean the constant speed of light helps keep track of which speed of light is being used in our equations. So our equation for the time variable speed of light becomes

$$c(\tau) = \bar{c}\, \zeta(\tau) \tag{3}$$

where τ is time from the instant of creation measured on the dynamical time scale. Therefore, Setterfield's hypothesis can be reduced to the idea that $\zeta(\tau)$ is much greater than one in the distant past and generally decreases towards a value of unity in the modern age. It also deals with just where else in the physics this factor may appear.

4.1 First-Order Implications on Periodic Phenomenon if c is Changing

The universe is full of convenient 'clocks', spectral lines, binary stars, pulsars and variable stars which provide ready methods for measuring cosmological changes.

Consider an object at some distance, s, that emits pulses of light at regular intervals, P (measured in dynamical time). In Figure 1 we use a binary star system. When the blue companion star emits a photon which we will label as 'A', at a time, τ_e, and travels the distance, s, then it will be

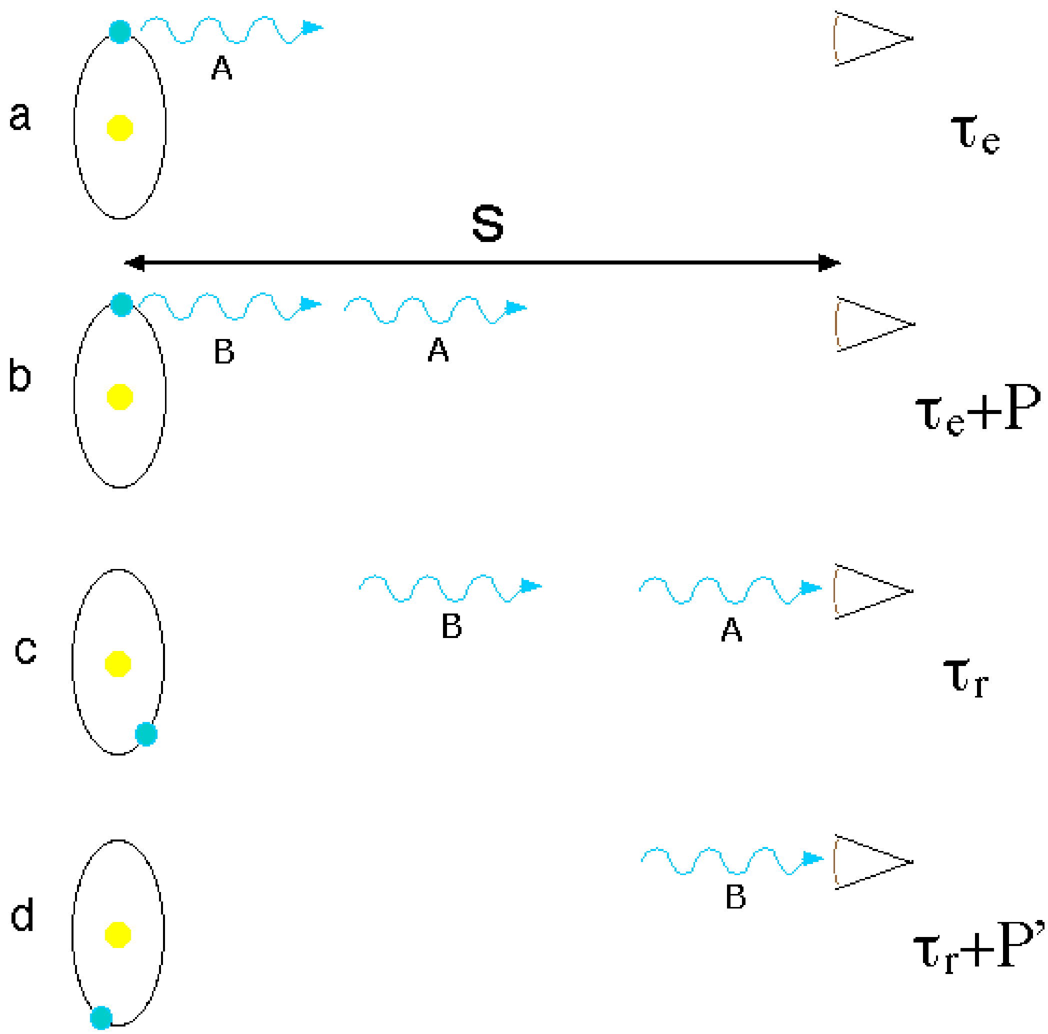

Figure 1: Analysis of light travel from a binary star. (a) At time τ_e a photon, A, is emitted from one companion of a binary star. (b) After the companion has completed one orbit, in a time P, a second photon, B, is emitted at time $\tau_e + P$. (c) Photon A arrives at the observer at time τ_r and (d) photon B arrives at the observer at a later time, $\tau_r + P'$.

received at a time τ_r (Figure 1c). Then, after the companion has completed one orbit with a period P, a photon which we will label 'B' is emitted at time, $\tau_e + P$ (Figure 1b), travels over that same distance, s, and arrives at the observer at the time $\tau_r + P'$ (Figure 1d), where P is not necessarily equal to P'. The simple answer is that photon B had a lower average speed to the observer than photon A. From the basic kinematics of Equation 1, we can write (assuming that the distance of the object is fixed between time τ_e and $\tau_e + P$)

$$s = \int_{\tau_e}^{\tau_r} c(\tau)\ d\tau \ = \ \int_{\tau_e+P}^{\tau_r+P'} c(\tau)\ d\tau \tag{4}$$

or, inserting our Equation 3 for $c(\tau)$, we get

$$s = \bar{c}\ \int_{\tau_e}^{\tau_r} \zeta(\tau)\ d\tau \ = \ \bar{c}\ \int_{\tau_e+P}^{\tau_r+P'} \zeta(\tau)\ d\tau \tag{5}$$

To keep our initial results as general as possible, we'll avoid setting a specific functional form for $\zeta(\tau)$. At present, lets just say that the indefinite integral of $\zeta(\tau))$ is some function $Z(\tau))$ or:

$$Z(\tau) \ = \ \int \zeta(\tau)\ d\tau + C \tag{6}$$

With this redefinition, Equation 5 becomes

$$s \ = \ \bar{c}\ \left(Z\left(\tau_r\right)\ -\ Z\left(\tau_e\right)\right) \ = \ \bar{c}\ \left(Z\left(\tau_r + P'\right)\ -\ Z\left(\tau_r + P\right)\right) \tag{7}$$

In most of our cases of interest, P and P' will correspond to time intervals on the order of radio and gamma-ray oscillations, binary star orbits and pulsar periods. These intervals are much smaller than the time intervals on the dynamical scale, τ, which will generally be the total travel time of the light across the cosmos. Therefore, we can expand $Z\left(\tau_r + P'\right)$ and $Z\left(\tau_r + P\right)$ in a Taylor expansion:

$$\begin{aligned} Z\left(\tau_e + P\right) \ &\approx \ Z\left(\tau_e\right) \ + \ P\ \frac{dZ\left(\tau_e\right)}{d\ \tau_e} && (8)\\ &\approx \ Z\left(\tau_e\right) \ + \ P\ \zeta\left(\tau_e\right) && (9)\\ Z\left(\tau_r + P'\right) \ &\approx \ Z\left(\tau_r\right) \ + \ P'\ \frac{dZ\left(\tau_r\right)}{d\ \tau_r} && (10)\\ &\approx \ Z\left(\tau_r\right) \ + \ P'\ \zeta\left(\tau_r\right) && (11) \end{aligned}$$

We can then incorporate these expansions into Equation 7. Cancelling the common $Z(\tau)$ components, we get the relationship:

$$P\,\zeta\,(\tau_e) \;=\; P'\,\zeta\,(\tau_r) \tag{12}$$

which can be manipulated to

$$P' \;=\; P\,\frac{\zeta\,(\tau_e)}{\zeta\,(\tau_r)} \tag{13}$$

Since $\zeta(\tau_e)$ is greater than $\zeta(\tau_r)$ in Setterfield's model, then a phenomenon that has a constant period, P at some location where the speed of light is $\bar{c}\,\zeta(\tau_e)$ will appear to have a period of P' at the time of reception of the signal when the speed of light is $\bar{c}\,\zeta(\tau_r)$ which will be greater than the period at the time of emission. Bear in mind that this effect is only noticeable if you know the period at the point of emission, $P = P(\tau_e)$. In the case of the orbital periods of binary stars and the spin rates of pulsars, this is determined from observations, which would tell us $P' = P(\tau_r)$, but not P. However, there is a second-order effect, which will be covered in Section 4.2.

Also note that this effect depends only on the speed of light at the point of emission and the point of reception. So long as the speed of light is piecewise-continuous along it's path (this even includes sudden 'jumps' in the speed), the speed at the endpoints will be the only factor determining the change in the observed periods.

While this may not seem that significant at first glance, consider that Setterfield's model claims that the speed of light has varied significantly in the past 250 years.

One might argue that the period, P, could change relative to the dynamical time scale in such a way that this effect vanishes. Yet Setterfield has already claimed that orbital motion is a periodic phenomena which is constant on a dynamical time scale.

Setterfield wants to keep orbital periods constant. The Julian calender, adopted in 45 BC by Julius Caesar[CalendarFAQ], is based on 365.25 days per year, only slightly different than our current year, therefore one should assume orbital periods have not changed significantly over this time period.

4.2 Second-Order Implications on Periodic Phenomenon if c is Changing

In Section 4.1 we saw how a changing speed of light will impact the observations of periodic phenomena. This is fine when we can make a statement about the period of the phenomena at the point of emission, but what about when we don't know this period? Would there be any other observations which might be usable for determining if the speed of light is undergoing a rapid change?

Yes, there is.

Consider that as the speed of light changes, the travel time of photons from the source to the observer changes. In the case of a monotonically decreasing speed of light, each photon will take a longer time to reach the observer so $\tau_r - \tau_e$ will steadily increase. Therefore the ratio $\zeta(\tau_e)/\zeta(\tau_r)$ will change. Let's take a closer look.

Recast Equation 13 to keep the time-dependencies apparent:

$$P(\tau_r) \;=\; P(\tau_e)\,\frac{\zeta(\tau_e)}{\zeta(\tau_r)} \tag{14}$$

Now let's examine how the period at the location of the observer appears to change at that observer's location. With a couple of applications of the Chain Rule from calculus, we find

$$\frac{d\,P(\tau_r)}{d\,\tau_r} \;=\; P(\tau_e)\,\frac{d}{d\,\tau_r}\left[\frac{\zeta(\tau_e)}{\zeta(\tau_r)}\right] \;+\; \frac{\zeta(\tau_e)}{\zeta(\tau_r)}\,\frac{d\,P(\tau_e)}{d\,\tau_e}\,\frac{d\,\tau_e}{d\,\tau_r} \tag{15}$$

$$= \frac{P(\tau_e)}{\zeta^2(\tau_r)}\left[\zeta(\tau_r)\,\frac{d\zeta(\tau_e)}{d\,\tau_e}\,\frac{d\tau_e}{d\,\tau_r} - \zeta(\tau_e)\,\frac{d\zeta(\tau_r)}{d\,\tau_r}\right] \tag{16}$$

$$+\frac{\zeta(\tau_e)}{\zeta(\tau_r)}\,\frac{dP(\tau_e)}{d\,\tau_e}\,\frac{d\tau_e}{d\tau_r} \tag{17}$$

Based on our model, all the quantities are known but for $d\,\tau_e/d\,\tau_r$, but we can determine it by applying the constraint that the distance between source and observer, s, is a constant (to examine the case of relative motion between source and observer, see the problem sets in Section 8). Starting with Equation 7

$$s \;=\; \bar{c}\;\left(Z(\tau_r) \;-\; Z(\tau_e)\right) \tag{18}$$

we take derivatives with respect to the time the light is received

$$\frac{d}{d\,\tau_r}\left(\frac{s}{\bar{c}}\right) \;=\; \frac{d\,Z(\tau_r)}{d\,\tau_r} \;-\; \frac{d\,Z(\tau_e)}{d\,\tau_e}\,\frac{d\,\tau_e}{d\,\tau_r} \tag{19}$$

which, since s is assumed constant, and $dZ/d\tau = \zeta$, yields

$$0 = \zeta(\tau_r) - \zeta(\tau_e) \frac{d\tau_e}{d\tau_r} \tag{20}$$

and reduces to

$$\frac{d\tau_e}{d\tau_r} = \frac{\zeta(\tau_r)}{\zeta(\tau_e)} \tag{21}$$

This expression is basically the equation for the "slowing-down" effect. Processes in distant space would appear to run slower than the same process near Earth. Installing this result into Equation 17 and performing some cancellation, we obtain:

$$\frac{d\,P(\tau_r)}{d\,\tau_r} = P(\tau_e) \left[\frac{1}{\zeta(\tau_e)} \frac{d\zeta(\tau_e)}{d\,\tau_e} - \frac{\zeta(\tau_e)}{\zeta^2(\tau_r)} \frac{d\zeta(\tau_r)}{d\,\tau_r} \right] + \frac{dP(\tau_e)}{d\,\tau_e} \tag{22}$$

We now have an expression for $dP(\tau_r)/d\tau_r$, which we see has two components. One, $dP(\tau_e)/d\tau_e$, is the intrinsic change in the period of the source, measured at the time of emission, τ_e. The other term is the apparent change in the period of the source due to the change in speed of the signal travelling to the observer.

4.3 The Setterfield Hypothesis and Pulsar Observations

Pulsars provide some of the highest precision timing observations available in astronomy. A listing of the known pulsars and their timing information is available in dataset 7156 at the Astronomical Data Center. A direct link is `http://adc.gsfc.nasa.gov/cgi-bin/adc/cat.pl?/catalogs/7/7156A/`.

For our model of the change in the speed of light, we'll use the function for the past 250 years specified at [Dolphin2]

$$c(\tau) = 299792 + 0.031(1967.5 - \tau)^2 \tag{23}$$

where τ is the Gregorian year. This equation applies for times prior to 1967, after which Setterfield assumes c reaches it's presently measured constant value. While the original document uses the symbol t to specify the time in this equation, it's unclear whether Setterfield means the dynamical time

Designation	Distance (light years)	P (s) P_{adj}	$-\dot{P}$ $-\dot{P}_{Setterfield}$
PSR J0953+0755	358.6–456.4	0.253065 0.250332–0.248504	2.2915×10^{-16} $1.66 \times 10^{-5} - 2.12 \times 10^{-5}$
PSR J0826+2637	978.0–1467.0	0.530661 0.488059–0.446540	1.7094×10^{-15} $8.52 \times 10^{-5} - 1.04 \times 10^{-4}$
PSR J1456-6843	1271.4–1662.6	0.263377 0.230131–0.213065	9.8780×10^{-17} $4.91 \times 10^{-5} - 5.38 \times 10^{-5}$
PSR J0835-4510	1304.0–1956.0	0.089309 0.077559–0.067988	1.2484×10^{-13} $1.68 \times 10^{-5} - 1.86 \times 10^{-5}$
PSR J0358+5413	2282.0–10106.0	0.156382 0.111228–0.041113	4.3975×10^{-15} $3.24 \times 10^{-5} - 1.16 \times 10^{-5}$
PSR J1857+0943	2282.0–4238.0	0.005362 0.003814–0.002656	1.7836×10^{-20} $1.11 \times 10^{-6} - 8.53 \times 10^{-7}$
PSR J1713+0747	2608.0–5216.0	0.004570 0.003041–0.001960	8.5200×10^{-21} $9.22 \times 10^{-7} - 6.23 \times 10^{-7}$

Table 1: Pulsar Period Changes with a Varying Speed of Light

or the atomic time. We'll assume that the time specified is the dynamical τ since that is the timescale where the speed of light is non-constant. We can rework the problem with the alternate interpretation in a future version of this paper. Also, so our equation for $\zeta(\tau)$ stays greater than or equal to unity, for this analysis, we adopt $\bar{c} = 299792 km/sec$.

In the ADC data table, we find seven pulsars with distance estimates less than a kiloparsec. We'll use these for the analysis.

Using the distance estimates (upper and lower limits), we can compute the time when the pulses originally left the pulsar τ_e and therefore, $\zeta(\tau_e)$. We assume all pulses were received after 1967 so $\zeta(\tau_r) = 1$. From this, we can use the observed pulsar period, P, to compute the pulse period at the time of emission, P_{adj} using Equation 14.

Pulsars are observed to slow down, and that is listed as $-\dot{P} = dP(\tau_r)/d\tau_r$ in Table 1. We use the minus sign since $\dot{P}$ decreases the spin period, P. We can also compute the period slowdown, $-\dot{P}_{Setterfield}$, using Equation 22. We generate this table assuming $dP(\tau_e)/d\ \tau_e = 0$, there is no intrinsic pulsar spindown.

If we compare the observations of $-\dot{P}$ to those predicted by Setterfield's hypothesis, $-\dot{P}_{Setterfield}$, we see that Setterfield's hypothesis over-estimates the observed slowdown by factors of 10^9 and sometimes larger. This is a serious discrepancy with observation and is a major blow to the Setterfield hypothesis.

To view this graphically, we can plot the observational quantity $\dot{P}/P$ at the position of the receiver (assuming no intrinsic change in the pulsar period) as a function of pulsar distance. First, let's compute $\dot{P}/P$ using Equations 14 and 22 with the assumption that $dP(\tau_e)/d\ \tau_e = 0$

$$\frac{d\ P(\tau_r)/d\ \tau_r}{P(\tau_r)} = \frac{P(\tau_e)\ \left[\frac{1}{\zeta(\tau_e)}\ \frac{d\zeta(\tau_e)}{d\ \tau_e} - \frac{\zeta(\tau_e)}{\zeta^2(\tau_r)}\frac{d\zeta(\tau_r)}{d\ \tau_r}\right]}{P(\tau_e)\ \frac{\zeta(\tau_e)}{\zeta(\tau_r)}} \tag{24}$$

which after some cancellation, yields

$$\frac{\dot{P}}{P} = \frac{\zeta\,(\tau_{\rm r})}{\zeta^2\,(\tau_{\rm e})}\ \frac{d\zeta\,(\tau_{\rm e})}{{\rm d}\ \tau_{\rm e}} - \frac{1}{\zeta\,(\tau_r)}\frac{d\zeta\,(\tau_{\rm r})}{{\rm d}\ \tau_{\rm r}} \tag{25}$$

Since our data tables include information on the uncertainties in the measurements of P (σ_P) and $\dot{P}$ ($\sigma_{\dot{P}}$), we should use quadrature to properly compute the error bars for $\dot{P}/P$ ($\sigma_{\dot{P}/P}$).

The results are plotted in Figure 2. The extrapolation of Equation 23 is performed because the functional form claimed for this time frame is somewhat unclear.

Is there a way around this problem? Certainly. Perhaps every pulsar we observe is indeed spinning-*up* instead of spinning-down and in just such a way that the net change we observe is a very small spin-down. However, this would require *extreme* fine-tuning of each observed pulsar. In addition, the question arises of where the energy and angular momentum for this process would be coming from. It also creates a problem for the notion popular in "Creation Science" that the Universe is "winding down". There is more to see in this issue in Sections 5.2 and 5.3 and the Problems (Section 8).

Tikkanen[Tikkanen] has performed a similar analysis which includes binary star observations and is available online.

4.4 Placing Limits on the Rate of Change of c

We can take our pulsar results from section 4.3 and use them to place an upper limit on the variability of the speed of light over the past few thousand years.

(This section still under development)

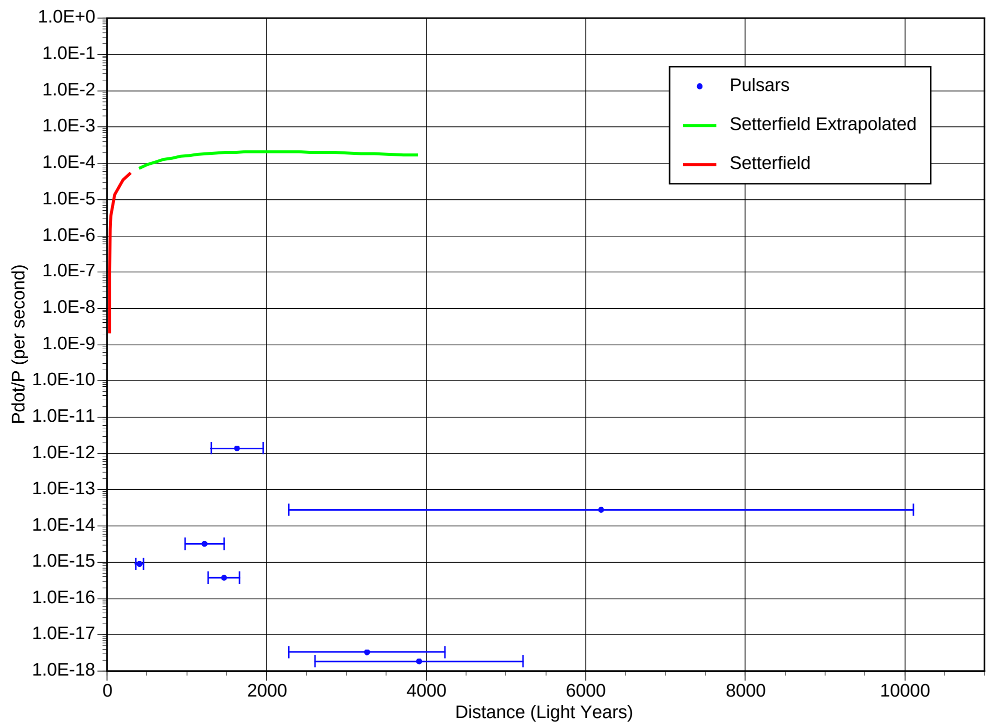

Figure 2: Setterfield Model Comparison to Pulsar Timing Data. The error bars in the $\dot{P}/P$ axis are too small to be visible on this scale. The red 'Setterfield' line represents Equation 23 for the 250 years of claimed validity. The green 'Setterfield Extrapolated' line extrapolates this function. See the text for details.

4.5 Why Supernovae Reflections are Bad Diagnostics for the Value of c at Distant Locations

Recently, the light from SN 1987A was observed after it excited gases near the remnant. Knowing the angular distance on the sky and the time since the explosion, it is possible to obtain a distance estimate to the supernova which turned out to be close to the result obtained by other methods([Panagia],[Gould]). In this calculation, the speed of light is used and one might be tempted to regard this as additional evidence that the speed of light was the current value 100,000 years ago when the star originally exploded. Unfortunately, this is not the case.

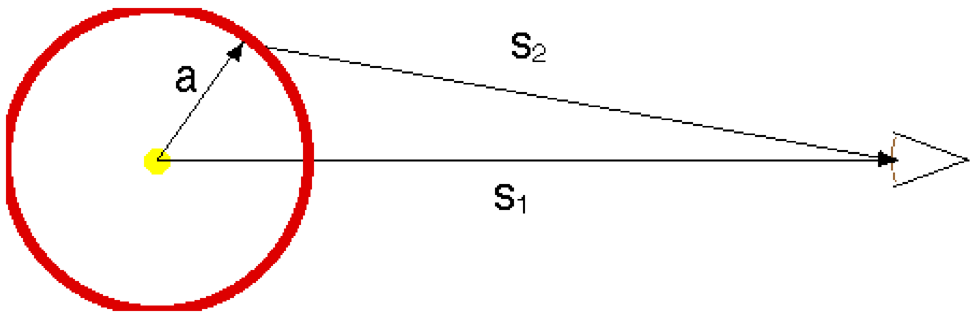

Figure 3: Geometry for the supernova reflection analysis. Some photons emitted from the supernova (yellow) travel a distance, s_1 directly to the observer, while others are absorbed and re-emitted at the ring of material from the stellar wind (red) before traveling to the observer, travelling a total distance $a + s_2$.

Consider Figure 3. Photons travel from from the original point of the supernova (the yellow dot on the left) a distance s_1 to the observer (the eye on the right). Other photons travel from the initial point of the explosion to a ring of material around the supernova (the red ring) at a distance a around the remnant. From there, they excite atoms to radiate (for this analysis we'll assume this to be instantaneous) which sends their photons to the observer a distance s_2 from the ring. By comparing the time it takes for different points on the ring to fluoresce, one can obtain both the size and orientation of the ring. Knowing the angular size of the ring on the sky, one can then deduce the distance to the supernova. One would think that the assumption that the speed of light is the present day value at the location of the supernova would be key in this calculation.

Next consider photons emitted from the explosion at (dynamical) time τ_e and arrive at the observer at time τ_{r1} after travelling the distance, s_1. Doing the math:

$$s_1 \;=\; \bar{c} \int_{\tau_e}^{\tau_{r1}} \zeta(\tau)\; d\tau \tag{26}$$

Other photons strike the ring at some intermediate time, τ_r, (having travelled the distance a) and are "reflected" towards the observer to arrive at time τ_{r2}. Doing the math:

$$\begin{aligned} a + s_2 \;&=\; \bar{c} \int_{\tau_e}^{\tau_r} \zeta(\tau)\; d\tau \;+\; \bar{c} \int_{\tau_r}^{\tau_{r2}} \zeta(\tau)\; d\tau &(27)\\ &=\; \bar{c} \int_{\tau_e}^{\tau_{r2}} \zeta(\tau)\; d\tau &(28)\end{aligned}$$

What is the time difference between the arrival of the direct and reflected photons? Let's compute the differences in the distances that the two sets of photons must travel, $a + s_2 \;-\; s_1$:

$$a + s_2 \;- s_1 = \;\bar{c} \int_{\tau_e}^{\tau_{r2}} \zeta(\tau)\; d\tau \;-\; \bar{c} \int_{\tau_e}^{\tau_{r1}} \zeta(\tau)\; d\tau \tag{29}$$

Again, using some basic rules for manipulating the limits in integral equations, we see:

$$\begin{aligned} a + s_2 \;- s_1 \;&=\; \bar{c} \int_{\tau_e}^{\tau_{r2}} \zeta(\tau)\; d\tau \;+\; \bar{c} \int_{\tau_{r1}}^{\tau_e} \zeta(\tau)\; d\tau &(30)\\ &=\; \bar{c} \int_{\tau_{r1}}^{\tau_{r2}} \zeta(\tau)\; d\tau &(31)\end{aligned}$$

Here we see the (somewhat) counterintuitive result that the differences in arrival times of the photons will depend only on the value of the speed of light at the observer between the two times in question. Therefore, if, as Setterfield claims, the speed of light has been constant since about 1967, any direct and reflected photons received after that time will only indicate that the speed of light is at it's present day value.

We can see this result in an intuitive way, but we must consider the entire travel path of the photons. The photons which travel directly to the observer travel a distance s_1 in some time τ_d. The photons along the other path will travel the same distance in the same time so at time τ_d, they will be a distance $a + s_2 - s_1$ from the observer. How long will these photons take to cross this last distance to the observer? It will be based on the speed of the photons after the time τ_d which, in the case where the speed of light has dropped to a constant value in recent decades, will take a time $(a+s_2-s_1)/\bar{c}$ - the same amount of time if the speed of light had been constant the entire time.

4.6 How a Decaying Speed-of-Light Can Create a Redshift

Now let's examine computing a redshift in the Setterfield hypothesis. We start with Equation 14. Let's let the periods, P, be the time between successive wavecrests in an electromagnetic wave (so $P = 1/\nu$, where ν is the frequency). The fundamental relation for waves between frequency, wavelength, and wavespeed is

$$c = \lambda\nu \tag{32}$$

Using the speed of light at the points of emission and reception, respectively, we compute the wavelengths at these two locations:

$$\lambda_e \;=\; P(\tau_e)\;\bar{c}\;\zeta(\tau_e) \tag{33}$$

$$\lambda_r \;=\; P(\tau_r)\;\bar{c}\;\zeta(\tau_r) \tag{34}$$

Now let's compute the received wavelength, λ_r, in terms of the emitted wavelength, λ_e:

$$\begin{aligned}
\lambda_r &= P(\tau_r)\;\bar{c}\;\zeta(\tau_r) && (35)\\
&= \left[P(\tau_e)\;\frac{\zeta(\tau_e)}{\zeta(\tau_r)}\right]\;\bar{c}\;\zeta(\tau_r) && (36)\\
&= \left[\frac{\lambda_e}{\bar{c}\;\zeta(\tau_e)}\;\frac{\zeta(\tau_e)}{\zeta(\tau_r)}\right]\;\bar{c}\;\zeta(\tau_r) && (37)
\end{aligned}$$

which, after some cancellation, generates the interesting result:

$$\lambda_r \;=\; \lambda_e \tag{38}$$

Opps!! The received wavelength is the same as the emitted wavelength! There is *no* redshift!

Unfortunately, Setterfield does not provide a specific recipe for computing this important quantity and this is a serious shortcoming for a scientific paper. It is definitely sufficient for a peer reviewer to reject for publication.

Let's try another possibility. The above analysis assumed that the redshift is defined in terms of wavelength, the conventional use by astronomers. Since we know that there is a change in period between the emission and reception, let's remap the definition in terms of frequency. First, we must return to the fundamental definition of the redshift, z

$$z = \frac{\lambda_r - \lambda_e}{\lambda_e} \tag{39}$$

If we substitute in the definition of wavelength in terms of frequency (Equation 32) using the speed of light today, $\bar{c}$, this becomes

$$\begin{aligned} z &= \frac{\bar{c}/\nu_r - \bar{c}/\nu_e}{\bar{c}/\nu_e} && (40) \\ &= \frac{\nu_e}{\nu_r} - 1 && (41) \\ &= \frac{P(\tau_r)}{P(\tau_e)} - 1 && (42) \\ &= \frac{\zeta(\tau_e)}{\zeta(\tau_r)} - 1 && (43) \\ & && (44) \end{aligned}$$

where we use the defintion that frequency is the inverse of the period, $\nu = 1/P$.

With this equation, we can see that if the photons are emitted from a location where the speed of light is, say, 10^4 of it's present day value, then $z = 9,999$. If we compare this result to Setterfield's graph at `http://www.ldolphin.org/cdkrate.gif`, we immediately see a discrepancy. The right side of the graph displays z values less than unity and the corresponding values of light-speed on the left side are measured in the millions of times the current value. How did Setterfield get this result? Again, there is no clear answer to this crucial part of his model.

We should note that at the time of this writing (August 22, 2001), the highest reported redshift is just over 5 ([HighZ-need citation]) and the cosmic microwave background radiation corresponds to a redshift of $z \approx 1100$ ([Kolb & Turner]).

In addition, we should examine whether the redshift would be observed to undergo changes over time. By analogy with our analysis in Section 4.2, we compute $d\ z(\tau_r)/d\ tau_r$

$$\frac{d\ z(\tau_r)}{d\ \tau_r} = \frac{d}{d\tau_r}\left[\frac{\zeta(\tau_e)}{\zeta(\tau_r)} - 1\right] \tag{45}$$

$$= \frac{1}{\zeta^2(\tau_r)}\left[\zeta(\tau_r)\frac{d\zeta(\tau_e)}{d\ \tau_e}\frac{d\tau_e}{d\ \tau_r} - \zeta(\tau_e)\frac{d\zeta(\tau_r)}{d\ \tau_r}\right] \tag{46}$$

$$= \frac{1}{\zeta(\tau_e)}\frac{d(\tau_e)}{d\ \tau_e} - \frac{\zeta(\tau_e)}{\zeta^2(\tau_r)}\frac{d\zeta(\tau_r)}{d\ \tau_r} \tag{47}$$

where we've made use of Equation 21.

Up to this point, the analyses performed in Sections 4.1, 4.2, and 4.5 have yielded results that are independent of our choice of the functional form of $\zeta(\tau)$. If we want to proceed further into making specific predictions, we must add more detail in specifying our model.

4.7 Analysis of a Simple c-Decay Model

This section still under development.

4.8 Effects of an "Oscillating" Speed of Light

This section still under development.

4.9 Does 'Quantization' Fix the Problems?

Setterfield also attempts to use some of the work of [Tifft] who claims to have measured 'quantization' of extragalactic redshifts, to propose that the changes in the speed of light are somehow 'quantized'. One could spend considerable time on the topic of errors in Tifft's analysis[TifftErrors] and how the effect has vanished in subsequent analysis with larger galaxy surveys[TifftErrors2], but for now we will assume that such a quantization is possible and examine what this implies for the issues raised in the previous sections. One reason Setterfield may have installed this in his model an attempt to 'fix' or hide the issues described in Sections 4.2 and 4.3. As with other proposals in his model, the "fixes" create even more and larger problems.

By quantizing the changes in the speed of light so that the value of $c(\tau)$ changes only at discrete steps, you can set the value of the derivative, $d\zeta/d\tau$, to zero between the steps. At first glance, this would appear to eliminate the problem posed by Equation 22. This is the case only if the remote object does not pass through one of these c-changing 'transitions' either in the course of a continuous observation or even between two or more observations at different times. In the former case, we would directly see the derivatives in Equation 22 go non-zero, and in the latter case we would measure an even more dramatic change in the orbital or spin period of the object. We have over thirty years of pulsar observations, over eighty years of extragalactic redshift observations, and ?? years of binary star observations. The idea that with all these observations of distant objects, some of which have been subjected to intense, relatively continuous study for decades, and we've not observed a clear signature of one of these transistions stretches credibility.

Setterfield [Dolphin2] claims that due to this quantization, the redshift due to a decaying speed of light would not be visible for objects closer than 126,000 light years. There are two possibilities here

1. The redshift value is controlled by some other parameter than just the speed of light, in contradiction to Setterfield's claims that the redshift is controlled by the changing speed of light but consistent with the observations made in Section 4.6

2. The speed of light has not changed in the past 126,000 years.

In the case of first possibility:

1. What is this other parameter controlling the measured redshift?

2. While one might claim that the redshift has this other influence (perhaps through atomic processes?), it would still not impact the light travel time issues raised in Sections 4.1 and 4.2 of this paper for the periods of binary stars and pulsars.

In the case of option two, there are numerous other problems that contradict assumptions Setterfield has established earlier:

1. If the speed of light hasn't changed in the past 126,000 years, how is Setterfield using observations from the past 250 years claiming a measured change?

2. The universe must be at least 126,000 years old (in contradiction to Setterfield's claims of about 6,000).

4.10 Analysis of a Simple Quantized c-Decay Model

This section still under development.

4.11 c-Decay and Supernovae Light Curves

This section still under development.

5 Dealing with Changing 'Constants'

The speed of light is not an isolated physical constant, but is interlinked with many other physical phenomena. Setterfield's attempts to solve these problems lead him into even larger problems.

One of the initial arguments against such a radical change in the speed of light was that through Einstein's mass-energy equivalence, $E = mc^2$, if c were extremely large in the not-so-distant past, the energy released by the nuclear isotopes in the Earth interior would be sufficient to keep the planet molten even thousands of years ago ([need citation]). Setterfield tries to address this by claiming that masses change such that $E = mc^2 = constant$ over cosmic history. In our notation, this means

$$m(\tau) = \bar{m}/\zeta(\tau)^2 \tag{48}$$

where the $\bar{m}$ on the right-hand side of the equation is the mass measured today. So in the past, masses were much lower than their present value.

However, this generates another problem. For a circular orbit, the orbital period is easily shown from Newtonian gravity, to be

$$P_{orbital} = 2\,\pi\sqrt{\frac{r^3}{G\ m}} \tag{49}$$

which Setterfield claims is basically a constant over cosmic history (assuming no tidal braking, etc.). Assuming that the orbital radius remains constant, if m changes, the orbital period is no longer constant, so Setterfield revises his hypothesis to claim that actually $G\ m$ is constant which fixes the orbital period problem. With this change, it means everywhere we see G, we must replace it with

$$G(\tau) = \bar{G}\ \zeta(\tau)^2 \tag{50}$$

where the $\bar{G}$ on the right hand side of the equation is the gravitational G measured today.

The final 'changing constant' we will consider is Planck's Constant, h. If c alone is changing, then the Fine Structure Constant, $\alpha = e^2/hc$ will vary and this would create a shift in the spectral lines of some elements. A *very small* possible variation in α has been reported ([Webb]) in distant quasars, but this is as yet inconclusive. However, if c changes as dramatically as Setterfield claims, α would be subject to considerably larger variation. To alleviate this, he proposes that the electric charge, e, is constant, and that Planck's constant, h, varies such that $hc = constant$. This means we must perform the replacement

$$h(\tau) = \bar{h}/\zeta(\tau) \tag{51}$$

Setterfield goes on to propose other alterations to the underlying physics, but these are sufficient to demonstrate additional fundamental problems with Setterfield's hypothesis.

5.1 Problems with Conservation of Momentum

Consider the energy equation for a particle of mass, m, moving with (vector) velocity $\vec{v}$. It's linear momentum, another conserved quantity, is

$$\vec{P} \; = \; m\,\vec{v} \tag{52}$$

Replacing m with it's corresponding Equation 48, we obtain

$$\vec{P}\,(\tau) \; = \; \frac{1}{\zeta\,(\tau)^2}\,(\bar{m}\;\vec{v}) \tag{53}$$

and we see that now momentum is increasing with time.

You might point out, and correctly so, that these quantities scale together, that the ζ factors will exactly cancel in any interaction and even in the distant past, a collision of billiard balls will behave exactly the same then as now.

5.2 Problems with Conservation of Angular Momentum

Consider the definition of angular momentum for a particle of mass, m, moving with (vector) velocity $\vec{v}$ and position $\vec{r}$ with respect to some reference point. It's angular momentum, another conserved quantity, is

$$\vec{L} \;=\; m\,\vec{v}\;\times\;\vec{\mathrm{r}} \tag{54}$$

and if we install the Setterfield hypothesis, this becomes

$$\vec{L} \;=\; \frac{1}{\zeta\left(\tau\right)^{2}}\left[\overline{m}\,\vec{v}\;\times\;\vec{\mathrm{r}}\right] \tag{55}$$

Again, we have the angular momentum varying with time the same as the linear momentum, but there's an added complication.

Equation 51 gives the variation of Planck's constant with time. But Planck's constant, in the form of $h/2\pi$ is also the quantum unit of angular momentum. Therefore, the total angular momentum of a system with orbital and spin angular momentum would be

$$\vec{L} \;=\; \frac{1}{\zeta\left(\tau\right)^{2}}\left[\overline{m}\,\vec{v}\;\times\;\vec{\mathrm{r}}\right]\;+\;\frac{1}{\zeta\left(\tau\right)}\frac{\overline{h}}{2\,\pi}\;s \tag{56}$$

where s is the spin quantum number. The total angular momentum, $\vec{L}$ no longer scales in a simple form with τ, unless $\zeta(\tau) = 1$, i.e. the speed of light is unchanging. This suggests that orbital angular momentum may have some additional interactions with the electron spin and that these vary with cosmic age. We could expect shifts in atomic energy levels in multi-electron atoms due to the interactions between the spin and orbital magnetic moments. This issue would require further study to determine it's full implications.

5.3 Problems with Conservation of Energy

Consider the energy equation for a particle of mass, m, moving with velocity v, in a gravitational field of a body of mass, M, at a distance, r. It has a total energy of

$$E \;=\; \frac{1}{2}\,m\,v^{2}\;-\;\frac{G\;M\;m}{r} \tag{57}$$

If we install the Setterfield hypothesis, we must replace the value of G with Equation 50 and M and m with the corresponding Equation 48 we find

$$E\left(\tau\right)\;=\frac{1}{\zeta\left(\tau\right)^{2}}\left[\frac{1}{2}\;\bar{m}\;v^{2}\;-\;\frac{\bar{G}\;\bar{M}\;\bar{m}}{r}\right] \tag{58}$$

and discover that the total energy of the system is no longer constant, but, since ζ was larger in the past, must now be *increasing*.

Where is this energy coming from?

In addition, consider a system such as a star where the gravitational force is balanced by pressure from nuclear reactions. The gravitational binding energy of such a system was lower in the past based on the relation of Equation 58. If the nuclear reaction rates are assumed identical and the nuclear energy release is constant (per Setterfield's claim represented in Equation 48), how did these distant stars hold together when the gravitational binding energy is much lower? At the least, we would expect these stars to find a very different equilibrium point. This would require a detailed examination and solution of the equations of stellar structure (such as described in Chapter 6 of [Clayton 1968]).

6 Summary & Conclusions

Probably one of the most frustrating issues with Setterfield's work is his failure to map his results into a consistent mathematical form. This is most frustrating when dealing with how he defines his time, t. He fails to clearly synchronize the dynamical and atomic time scale from some common zero point which is crucial for doing more sophisticated analysis of his claims.

In this work, it is assumed that most of his analysis is performed in the dynamical time scale and that references in his work to 'years BC' are also on that scale, but this is far from clear. The close synchronization of the dynamical and atomic times in the recent era means that the pulsar analysis (section 4.3) will experience only slight changes in the numerical values if this identification is incorrect. However, this is more of an issue when computing cosmic redshift. These are the types of oversights that really irk conscientious peer reviewers.

These analyses depend only on the definitions of velocity, distance, and time (Equations 1 and 2) and the relation between wavespeed, wavelength, and frequency (Equation 32), equations which are fundamental in the past 300 years of physics. However, Setterfield's model makes numerous claims in blatant contradiction to the predictions made by use of these relations. What is Setterfield *not* saying? If the Setterfield hypothesis is correct, we must basically re-write the past 300 years of basic physics.

Setterfield seems to add new assumptions into his model partway through the analysis without ever going back and reworking the entire model with the new assumption to ensure internal consistency. This is apparently the cause of the problems in Sections 5 & 4.6.

The Creationist search for a 'Magic Scale Factor' that enables the universe to appear billions of years old while actually being less than ten thousand years old *and* staying consistent with current observational data, remains unfulfilled.

7 Acknowledgements

Thanks to those who pointed out errors in the text and suggested additional material to include: Todd S. Greene and Sverker Johansson.

8 Problem Set

1. Rederive Equations 13 and 22 for the case where the source and receiver may be moving relative to one another (i.e. s is not constant). This would be the equivalent of the Doppler effect in a universe where c is changing.

2. From Equation 22, demonstrate that one way to eliminate the light travel time shift in the period (i.e. get $dP(\tau_r)/d\tau_r = dP(\tau_e)/d\tau_e$) is to have $\zeta(\tau) = 1$ for all τ. That is, the speed of light is constant. Is there another functional form for $\zeta(\tau)$ that can achieve this?

3. There is another way to get $dP(\tau_r)/d\tau_r = 0$ in Equation 22 and that is to define $dP(\tau_e)/d\tau_e$ so that it exactly cancels the light speed decay term. What type of constraint would this place on the emitting object and why? Would an observer at a different location see $dP(\tau_r)/d\tau_r = 0$ (note that τ_r would be measured at their location)?

4. In Section 5.2 we point out that having masses change with time creates a problem with angular momentum conservation. Consider the case for a spinning object where angular momentum *is* conserved and the object will spin up with dynamical time. Consider the two cases outlined in Section 5.2 by testing the problem when the moment of inertia varies as ζ^{-1} and as ζ^{-2} so that the spin frequency varies as ζ

and ζ^2, respectively. Can this yield cancellation of the c-decay term in Equation 22? What would this imply for planetary rotation and orbital periods?

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