Cosmological Redshift: Accelerating Expansion or Quantum Phenomenon

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Abstract

The postulate of tired light can be cast in terms of an elementary quantum of energy lost from a photon during each cycle. The uncertainty in time associated with the quantum of energy is the Hubble time. Given uncertainty at this cosmological scale, it is argued that complementarity between received photon energy and observed distant time dilation at the source overcomes the primary objection to tired light. Observed supernova redshift, luminosity and time dilation tend to support two possibilities for a quantum interpretation of the redshift.

1 Introduction

Tired light is attractive because exponential decay is familiar and well known. It seems far simpler than the recession hypothesis, but the finding of time dilation in distant supernova, in combination with reduced energy observed in received light energy, has been supposed to invalidate such theories, while supporting the big bang model.

Tired light is also attractive because it has been known practically since the discovery of the redshift that exponential decay of light energy would result if all photons lost the same, universal quantum of energy per cycle, which implies quantum structure. Given the conceptual foundations of quantum theory, it would seem unwise to regard this implication as meaningless coincidence.

A resolution to the difficulty faced by tired light may come from considering temporal uncertainty of the quantum energy, and inferred complementarity between received photon energy and distant time dilation. Because of complementarity, luminosity distance would require a single correction factor for time dilation or energy contraction, instead of two.

The big bang framework can accomodate tired light as a flat, pure energy cosmological model, so that light travel distance and comoving distance are the same. In the big bang, comoving distance plays the role of actual distance when calculating luminosity distance. On the other hand, in a stationary cosmology of quantum tired light, luminosity distance would require two correction factors when based on distance traveled by light in order to approximately match the supernova model.

There is much that is intriguing about this inferred quantum aspect of light. A study of complementarity with a shared distance scale, accomplished by considering a pure energy model, could facilitate the development of two quantum models in parallel.

2 A universal quantum of energy

Consider Hubble's law in terms of photon energy loss, and ask a crucial question: How much energy would be lost by a photon in traveling one wavelength? It turns out that every photon would lose the same amount of energy per cycle, independent of the wavelength.[1] The quantum of energy is equal to the product of Planck and Hubble constants, hH.

The energy lost per cycle from a photon can be found from Hubble's law, $c\Delta\lambda/\lambda_0 = Hs$. Given the initial wavelength, λ_0, the change in wavelength can be found to be $\Delta\lambda = H\lambda_0^2/(c - H\lambda_0)$ after traveling a distance of one wavelength given by $s = \lambda_0 + \Delta\lambda$. The energy of the photon at the source is hc/λ_0. In traveling its own wavelength, the photon loses an amount of energy, ΔE, as it falls to $hc/(\lambda_0 + \Delta\lambda)$. The energy lost in one cycle would be $\Delta E = hH$ independent of the wavelength.

Quantum theory dictates that the phenomenon of quantization should be investigated in the context of Planck's hypothesis.[2] In a quantum mechanical harmonic oscillator, the energy of a photon would be quantized with the energy of the n'th state ($n = 0, 1, \ldots$) given by $E_n = hH(n + 1/2)$. A photon would undergo exponential decay by reducing its energy state by one quantum from one cycle to the next. Suppose that a photon at the source starts off in state N, and after traveling a distance s, while losing a quantum of energy in each cycle, ends up in state M, where $M < N$. It follows that the redshift is given by $1 + z = E_{\mathrm{N}}/E_{\mathrm{M}}$. The distance traveled is the sum of the wavelengths of all states from M to N, where the wavelength of state n is $\lambda_n = c/[H(n + 1/2)]$. Approximating the summation by integration gives the distance traveled as a function of redshift under the hypothesis of quantum energy loss as

$$s(z) = \frac{c}{H} \ln(1 + z). \tag{1}$$

A point to notice is that a photon with zero-point energy would have a wavelength spanning a "universe" (as yet unspecified) in which electromagnetic radiation takes the form of a quantum harmonic oscillator with zero-point energy, $E_0 = hH/2$. Quantum energy loss has an associated time interval through the uncertainty principle, $\Delta E\,\Delta t = h$. Energy and time are a complementary pair by virtue of this uncertainty relation. For $\Delta E = hH$, the uncertainty in the time interval, $\Delta t = 1/H$, is the Hubble time. Similarly for quantum momentum loss, the uncertainty in distance is the Hubble length. This is uncertainty at cosmological scale.

3 Time dilation or energy loss – but not both

Light curves from supernova as they brighten and fade exhibit time dilation[3] that increases with redshift. This is taken to imply that energy loss from light cannot be valid since it makes no prediction about time dilation, so the width of a supernova light curve is expected to be independent of the redshift. It is similarly argued that a theory[4] based on time dilation is invalid because it makes no prediction about energy loss. This argument can be turned around and used against the conventional model. Since it is not predicted, accelerating expansion can be taken as a sign that an underlying assumption in the big bang is faulty.

The argument against tired light overlooks the possibility that received photon energy and time dilation may be complementary descriptions of a quantum phenomenon. This possibility can satisfy the objection in a way which is not founded on the classical notion of causality. As discussed by Hilgevoorg and Uffink,[5] it may be that "a causal description of the process cannot be attained; we have to content ourselves with complementary descriptions. *'The viewpoint of complementarity may be regarded'*, according to Bohr, *'as a rational generalization of the very ideal of causality'*." While not common sense, it does not necessarily indicate a lapse in reasoning to consider two independent classical explanations for a quantum phenomenon.

Quantum uncertainty would appear to be necessary for complementarity. Complementary explanations for quantum processes in terms of wave-particle duality, for example, are useful in different situations. As Bohr[6] put it, quantum mechanics *"forces us to adopt a new mode of description designated as complementary in the sense that any given application of classical concepts precludes the simultaneous use of other classical concepts which in a different connection are equally necessary for the elucidation of the phenomena."* Occam's razor cannot help in determining which of two possible classical explanations for a quantum process might be correct because they both may have validity in describing the process independently.

4 Effect of scattering would be unobservable

If the redshift is due to the loss of energy from light, then smearing of the images of distant objects should occur as a result of the scattering of photons as they lose momentum. The momentum of the photon is given by $p = E/c = h/\lambda$. The change of momentum in each cycle is $\Delta p = \Delta E/c = hH/c$, so that the scattering angle is at most $\theta = \Delta p/p = H\lambda/c$. A demonstration of the expected smearing is provided by the following example. Consider a photon with wavelength, $\lambda = 10^{-7}$ m, emitted from a distant object with redshift $z = \Delta\lambda/\lambda \approx 0.1$, corresponding nearly to a number of cycles, $N = 10^{32}$. For this wavelength, the maximum scattering angle is $\theta = 10^{-33}$ radian per cycle. The worst-case estimate of the total scattering angle, $N\theta = 0.1$ radian, would occur if all deflections were in one direction.

A photon has two degrees of freedom, meaning that changes can only occur in a plane perpendicular to its path. A much smaller estimate of the total scattering angle is obtained by assuming that deflections to the left occur with the same probability as deflections to the right. The natural analogy here is to decide which direction is taken on the basis of flipping a coin in the manner of Bernoulli trials. Let k be the number of heads which occur in N tosses of the coin. The variable $k^* = 2(k - N/2)/N^{1/2}$ is standardized normal – i.e., k^* has zero mean and unit variance, and is from the normal distribution. This enables statements to be made concerning the probability of deviations of k from its mean, $N/2$. For instance, $k^* = 3.88$ corresponds to $1 - F(k^*) = 0.0001$ from the cumulative normal distribution. This means that 99.98% of sequences of N tosses are expected to yield less than $k^*N^{1/2}/2 \approx 2 \times 10^{16}$ surplus heads. The total angle of deflection corresponding to this surplus is $2 \times 10^{16}\,\theta = 2 \times 10^{-17}$ radian. At $z = 0.1$ the distance subtended by this angle is 2×10^{8} m, or about one third the radius of the Sun. It can be concluded that smearing due to scattering associated with quantum energy loss would likely be unobservable.

5 Distance measures

Luminosity distance is derived from a simple application of the inverse square law to the measured brightness of an object with known luminosity and distance. Luminosity distance is calculated without correcting for time dilation and Doppler effect, processes that reduce received energy, and is thus greater than light travel distance.

In a stationary cosmology of tired light, the only feasible possibility is to include the combined effect of energy loss and time dilation in the model, each contributing a factor of $(1+z)^{1/2}$ to a product of two factors. In this case, luminosity distance would be given by

$$s_{\mathrm{L}}(z) = \frac{c}{H}\,(1+z)\,\ln(1+z). \tag{2}$$

There are several cosmological distance measures[7] in big bang cosmology. The dimensionless Hubble parameter is defined as a function of redshift as

$$E(z) = \sqrt{\Omega_{\mathrm{m}}(1+z)^3 + \Omega_{\mathrm{k}}(1+z)^2 + \Omega_\Lambda} \tag{3}$$

with matter density given by Ω_{m}, dark energy density by Ω_Λ and curvature by $\Omega_{\mathrm{k}} = 1 - \Omega_{\mathrm{m}} - \Omega_\Lambda$. Flat cosmological models have no curvature, so $\Omega_{\mathrm{k}} = 0$. Radiation will be assumed to make a negligible contribution.

Luminosity distance is conventionally expressed in the flat big bang as

$$d_{\mathrm{L}}(z) = \frac{c}{H}(1+z)\int_0^z \frac{\mathrm{d}z}{E(z)}. \tag{4}$$

A comparison of (2) and (4) shows that luminosity distance in tired light is based on light travel distance (1) instead of comoving distance in the big bang. This needs to be divided by $(1+z)^{1/2}$ for the pure energy model, since only one correction factor is necessary, so for this case

$$d_{\mathrm{L}}(z) = \frac{c}{H}\,z(1+z)^{1/2}. \tag{5}$$

In a flat pure dark energy model with $\Omega_\Lambda = 1$ and $\Omega_{\mathrm{m}} = 0$ so that $E(z) = 1$, light travel distance matches tired light (1) and is given by

$$d_{\mathrm{T}}(z) = \frac{c}{H}\int_0^z \frac{\mathrm{d}z}{(1+z)E(z)} = \frac{c}{H}\ln(1+z). \tag{6}$$

6 Comparison with supernova model

The hypothesis of accelerating expansion is inferred from a cosmological model which best fits the basic supernova data consisting of luminosity and redshift. Models are generally consistent with a flat cosmos having no curvature. The contribution of matter to the cosmos in a typical model[8] is proportional to $\Omega_{\mathrm{m}} \approx 0.31$ while dark energy causing acceleration amounts to $\Omega_\Lambda \approx 0.69$.

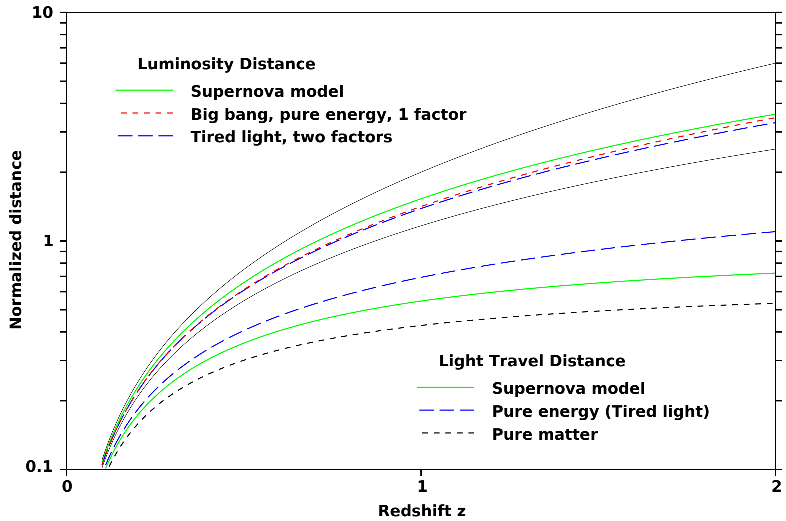

Figure 1: *Luminosity distance:* Supernova data are conventionally modeled by a combination of matter and dark energy shown as the solid green line. Pure dark energy model with complementarity is shown as red dots. Tired light model is shown as blue dashes. Black bounding lines indicate conventional pure energy, and pure matter models. *Light travel distance:* Conventional supernova model is shown as solid green, with pure energy and pure matter models displayed as blue dashes and black dots respectively.

Comoving distance in big bang cosmology is transformed into luminosity distance by two equal factors at the source: time dilation and Doppler effect. In combination these factors amount to multiplying comoving distance by a factor, $1+z$. However, tired light proposes energy loss instead of Doppler effect. If time dilation and photon energy are complementary then only one factor, $(1+z)^{1/2}$, may be required.

By matching the distance traveled by tired light with light travel distance in the big bang, it can be deduced that tired light must appear as a flat cosmological model comprised of pure dark energy only. Furthermore, because of complementarity, only one factor of $(1+z)^{1/2}$ is used to calculate luminosity distance as a function of redshift, instead of the usual product of two factors. Fig. 1 shows the result of adjusting luminosity distance in the pure energy cosmological model by applying only one factor, as well as luminosity distance for the stationary tired light model with two factors. The resulting curves lines up reasonably well with a conventional model of supernova luminosity distance *vs* redshift.

A photon emitted from a supernova arrives at a photosensor after a time, t. Suppose received photon energy, E, and source time base, τ, form a complementary pair, so that $E\tau = h$. Since the reduction in photon energy due to tired light is known, complementary time dilation at the source follows. Let the energy of a photon generated locally by a known process be E_0, where the local time base is the period of oscillation, $\tau_0 = h/E_0$. After exponential decay, the energy of a photon from a distant supernova would be reduced to $E = E_0 \mathrm{e}^{-Ht}$. The time base at the supernova would then satisfy $\tau = \tau_0 \mathrm{e}^{Ht}$. Time dilation as a function of redshift at the photon's point of emission can be confirmed from (1) to be $\tau/\tau_0 = 1 + z$.

7 Nernst-MacMillan stationary cosmology

An alternative to dark energy in the big bang is quantum tired light in a universe that is stationary, or statistically isotropic in time, which implies non-expansion. William Thomson (Lord Kelvin) originated the concept of thermodynamic heat death as the state where all potential energy is exhausted. According to Thomson, the final state of the universe would arrive after the transformation of all potential energy into motion and then into heat.

Prior to the discovery of the redshift and the development of quantum mechanics, William MacMillan put forward the idea that stellar radiation would be gradually absorbed into the ether, and used to create matter. The aim of Nernst-MacMillan cosmology is to produce a universe in which entropy does not increase to produce heat death.

The idea that the redshift involves quantum energy, hH, originated around 1930 with Walther Nernst who was also troubled by heat death of the universe from accumulated radiant energy. He saw the discovery of the redshift as something he had been actively seeking to avoid this fate – evidence of energy dissipation – and realized quantum energy loss would be associated with exponential decay of photon energy.

Nernst, who had been awarded a Nobel a decade earlier for his work on low temperature physics and the third law of thermodynamics, avoids heat death by recycling the energy lost from light as it is redshifted, in order to replenish a reservoir (like a Bose-Einstein condensate) of incoherent zero-point potential energy. Matter is hypothesized to be created from coherent configurations of zero-point energy in order to maintain the low temperature of the reservoir ($T_{\mathrm{ZP}} < 10^{-28}\,\mathrm{K}$) and keep entropy from increasing.

If the idea of an eternal universe seems fantastic, it would be possible to consider instead a less imaginative, non-recycling alternative leading to heat death. See Ref. 1 for an introduction, as well as a bibliography of original publications on cosmology by Nernst. A historical perspective is presented in Ref. 9.

8 Discussion

Contrary to the conclusion of Ref. 3, it is argued that observed redshift, luminosity, and distant time dilation may indicate a quantum interpretation of the redshift as as a variant of a pure energy model in the big bang. Furthermore, it would seem prudent to consider also the stationary tired light model with distant time dilation, which is based on simpler assumptions.

The viability of these models remains to be seen. There is much that would be different in this quantum cosmology, notably the distance traveled by light inferred from redshift. Conceptually, the Hubble constant would correspond to the fundamental frequency of a quantum mechanical harmonic oscillator. Observational evidence like the cosmic microwave background would need further investigation in this context.

It is not clear what connections might be found between the quantum, and dark matter or gravitation. Although the quantum would be the ultimate wave, and quite unlike a particle, one can imagine a photon as a ship with a pair of cannons firing cannonballs symmetrically, allowing the ship to lose momentum without changing the path of the ship. This would be the case even if the cannons were firing fore and aft, as long as they were firing symmetrically. One tantalizing speculation has an emitted quantum reverting to zero-point energy as a combination of slow dark matter with spin 0, and a fast graviton with spin 2. In this scenario, half the energy lost from light would be available to accumulate around radiating objects as dark matter.

Accelerating expansion is an enigmatic feature of big bang cosmology. As part of a thorough study of the phenomenon, the cosmological redshift needs to be examined using quantum theory.

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