

Cosmological Redshift: Accelerating Expansion or Quantum Phenomenon

Colin Walker

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 a common objection to tired light. Observed supernova redshift, luminosity distance, and distant 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.

The big bang framework can accommodate tired light as a flat, pure energy cosmological model, so that light travel distance and comoving distance would be the same. It is comoving distance that is used in the determination of luminosity distance.

A resolution to the difficulty presented by tired light in the context of the big bang 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 both factors as would be needed classically.

On the other hand, in a stationary cosmology of tired light, luminosity distance requires two correction factors when based on distance traveled by light in order to approximate the supernova model, thus obviating the need to consider complementarity, so that both energy loss and distant time dilation affect received light intensity.

There is much that is intriguing about this inferred quantum aspect of light. A study of complementarity with a shared distance scale may facilitate the development of two quantum models in parallel, referred to as Pure Energy in the big bang and Tired Light in a stationary universe, where both assume the same energy loss from light, and the same distance scale.

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. This quantum of energy is equal to the product of Planck and Hubble constants, hH . Fritz Zwicky¹ was among the first to investigate the redshift as energy loss from light, but it was Walther Nernst² who saw the the significance of the quantum aspect of the phenomenon.

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 theory³ dictates that this phenomenon of quantization should be investigated in the context of Planck's hypothesis that the energy of an oscillator with natural frequency ν can only take values which are separated by integral

multiples of a quantum, $h\nu$. In a quantum mechanical harmonic oscillator, the energy of a photon would be quantized with the energy of the n 'th state ($n = 0, 1, \dots$) given by $E_n = hH(n + \frac{1}{2})$. 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 $1 + z = E_N/E_M$. The distance traveled is the sum of the wavelengths of all states from M to N , where the wavelength of state n is $\lambda_n = c/[H(n + \frac{1}{2})]$. Approximating the summation by integration gives the light travel distance as a function of redshift under the hypothesis of quantum energy loss as

$$s_T(z) = \frac{c}{H} \ln(1 + z). \quad (1)$$

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 one-dimensional 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 dilation⁴ that increases with redshift. This was taken to imply that energy loss from light cannot be valid since it makes no prediction about time dilation, so the duration a supernova is expected to be independent of the redshift. It was similarly argued that a theory⁵ based on time dilation is invalid because it makes no prediction about energy loss. The possibility of having both active in a static universe was not considered.

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 Hilgevoort and Uffink,⁶ 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 Bohr⁷ 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 Scattering of photons

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 $k^*N^{\frac{1}{2}}/2 \approx 2 \times 10^{16}$ 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 can be derived from a simple application of the inverse square law to the radiant flux received from a distant object with known luminosity. Luminosity distance does not compensate for time dilation or Doppler effect, processes that reduce received energy, and is thus greater than light travel distance.

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

$$s_L(z) = \frac{c}{H} (1+z) \ln(1+z). \quad (2)$$

Alternatively, a case can be made for a modification to the conventional model. There are several cosmological distance measures in big bang cosmology. The dimensionless Hubble parameter is defined as a function of redshift as

$$E(z) = \sqrt{\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda} \quad (3)$$

with matter density given by Ω_m , energy density by Ω_Λ and curvature by $\Omega_k = 1 - \Omega_m - \Omega_\Lambda$. Flat cosmological models have no curvature, so $\Omega_k = 0$. Radiation will be assumed to make a negligible contribution.

In a flat pure energy model with $\Omega_\Lambda = 1$ and $\Omega_m = 0$ so that $E(z) = 1$, light travel distance matches Tired Light (1) and is given by

$$d_T(z) = \frac{c}{H} \int_0^z \frac{dz}{(1+z)E(z)} = \frac{c}{H} \ln(1+z). \quad (4)$$

Luminosity distance is conventionally expressed in the flat big bang as

$$d_L(z) = \frac{c}{H} (1+z) \int_0^z \frac{dz}{E(z)}. \quad (5)$$

A comparison of (2) and (5) 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 $(1+z)^{\frac{1}{2}}$ for the Pure Energy model since only one correction factor is used due to complementarity, so for this case

$$d_L(z) = \frac{c}{H} z(1+z)^{1/2}. \quad (6)$$

6 Comparison with supernova model

The hypothesis of accelerating expansion has been inferred from supernova data, summarized here as a curve of luminosity distance *vs* redshift. The contribution of matter to the cosmos in a typical model⁸ is proportional to $\Omega_m \approx 0.31$ while dark energy causing acceleration amounts to $\Omega_\Lambda \approx 0.69$. Models are generally consistent with a flat cosmos having no curvature.

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, if time dilation and photon energy are complementary then only one factor, $(1+z)^{\frac{1}{2}}$, may be required.

By matching the distance traveled by tired light (1) with light travel distance in the big bang (4), it can be deduced that tired light must appear as a flat cosmological model comprised of pure energy only. Furthermore, because of complementarity, only one factor of $(1+z)^{\frac{1}{2}}$ 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 Tired Light model with two factors.

Both models imply distances smaller by roughly 10% at $z = 2$ compared to the conventional model of supernova luminosity distance *vs* redshift. The difference seems to be attributable to the distance scale which would be used to infer luminosity. In this case, source luminosity would need to be adjusted to account for the ratio of classically determined distance to comoving distance, corresponding to a 20% reduction in supernova luminosity at $z = 2$. The ratio approaches unity for small z .

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

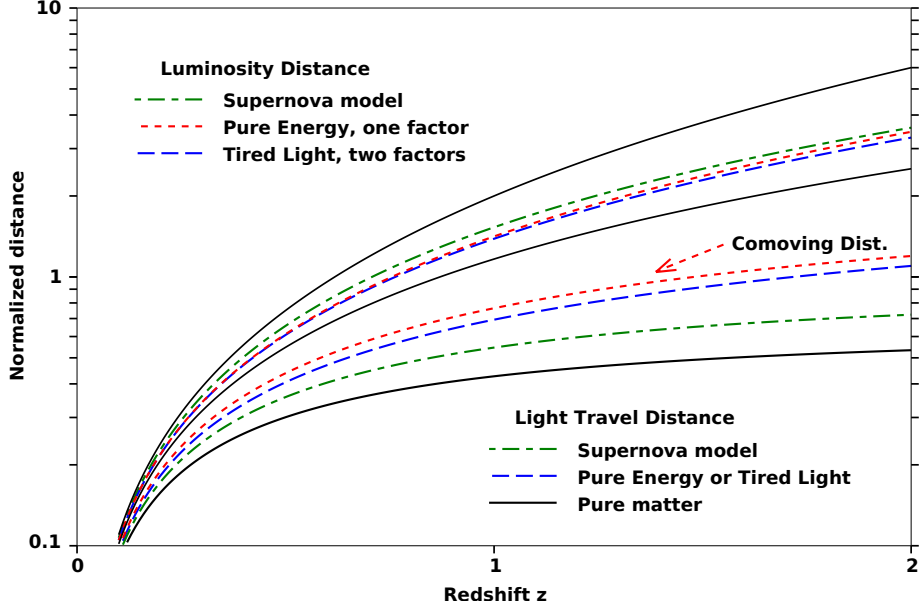


Figure 1: *Luminosity distance*: Supernova data are conventionally modeled by a combination of matter and energy shown as alternating dots and dashes. Pure Energy model with complementarity is shown as dots. Tired Light model is shown as dashes. Solid bounding lines indicate conventional pure energy, and pure matter models. *Comoving distance*: Comoving distance for supernova model shown as dots. *Light travel distance*: Light travel distance is the same for both quantum models, displayed as dashes. Supernova curve is shown as dot-dash line. Conventional pure matter model is solid. All distances normalized by c/H .

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 $E = E_0 e^{-Ht}$. The time base at the supernova would then satisfy $\tau = \tau_0 e^{Ht}$. Time dilation as a function of redshift at the photon's point of emission can be confirmed from (1) to be $\tau/\tau_0 = 1 + z$, in agreement with observation.

7 Nernst-MacMillan stationary cosmology

An alternative to dark energy in the big bang is tired light in a universe that is stationary, or statistically isotropic in time, and finite in extent. 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 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 ($T \approx k_{\text{Boltzmann}}hH \approx 10^{-28}$ 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. See⁹ for an introduction, as well as a bibliography of original publications in German by Nernst. A historical perspective is presented in.¹⁰

8 Conclusion

Observed redshift, radiant flux, and distant time dilation may indicate a quantum interpretation of the redshift as a variant of a pure energy model in the big bang, in which the notion of recession velocity is abandoned, replaced by considerations of energy and time. In this model, it is argued that only one of

these factors affects received flux, since energy loss and distant time dilation are presumed to be complementary at the scale of the interaction.

Alternatively, a stationary tired light model with combined energy loss and distant time dilation affecting received flux is also considered. No special assumptions are necessary.

While these models of tired light vary somewhat from the reported luminosity distance, it appears that the disparity may be resolved by a recalibration of supernova luminosity to account for the difference between light travel distance in tired light, and comoving distance in the conventional model, but this requires further study.

Accelerating expansion is an enigmatic feature of big bang cosmology which is not predicted in the conventional theory. There is much that would be different in a quantum cosmology, notably the distance traveled by light inferred from redshift. Conceptually, the Hubble constant would correspond to the natural frequency of a quantum mechanical harmonic oscillator. Observational evidence like the cosmic microwave background would need to be examined in this context.

References

- [1] Zwicky, F., On the red shift of spectral lines through interstellar space, *Proceedings of the National Academy of Sciences*, **15**, p. 773 –779 (1929).
- [2] Nernst W., Einige weitere Anwendungen der Physik auf die Sternentwicklung, *Sitzungsberichte der Preußischen Akademie der Wissenschaften* **28**, p. 473-479 (1935)
- [3] Bohm D., *Quantum Theory* (Prentice-Hall, New York 1951).
- [4] Leibundgut B., *et al.*, Time Dilation in the Light Curve of the Distant Type IA Supernova SN 1995K, *Ap.J.* **466**, L21 (1996).
- [5] Narlikar J. and Arp, H., Flat spacetime cosmology: a unified framework for extragalactic redshifts, *Ap.J.* **405**, 51 (1993).
- [6] Hilgevoord J. and Uffink J., The Uncertainty Principle, *The Stanford Encyclopedia of Philosophy* (Summer 2012 Edition), ed. Edward N. Zalta (2012).
- [7] Bohr N., *Atomic Theory and the Description of Nature*, (Cambridge University Press, Cambridge 1934).

- [8] Choudhury T. and Padmanabhan T., Cosmological parameters from supernova observations: A critical comparison of three data sets, *Astron. Astrophys.* **429**, p. 807 (2005).
- [9] Huber P. and Jaakkola T., The Static Universe of Walther Nernst, *Apeiron* **2**, 3, p. 53 (1995).
- [10] Kragh, H., Cosmology between the wars: the Nernst-MacMillan alternative, *Journal for the History of Astronomy*, **26**, 2, p. 93 (1995).