An Alternative Explanation for 
Cosmological Redshift

David Schuster
Department of Physics, Colorado School of Mines

Abstract

The first and most compelling evidence of the universe's expansion was, 
and continues to be, the observed redshift of spectra from distant objects. This 
paper plays "devil's advocate" by providing an alternative explanation with elemen-
tary physics. I assume a steady-state universe that is infinite in both 
expanse and age, with the observed redshifts caused by particle interactions 
creating an overall index of refraction of the universe. The cumulative effects 
of these interactions over long distances cause not only the shifts that we ob-
serve, but also the monotonically increasing redshifts as more distant objects 
are observed. This is a novel explanation for the phenomenon known as "tired 
light" which has been discussed for decades.

1. Introduction

Hubble was the first to describe the relation between distance from Earth 
and radial velocity of extra-galactic targets in 1929 [1]. This ground-breaking 
discovery has served as a foundation on which to build all of modern Big Bang 
cosmology. Hubble's work is based on the apparent Doppler redshift of spectra 
obtained from these targets. As is widely known to any physics student, a 
Doppler redshift occurs when an emitter is moving away from an observer in 
the observer's frame. Redshift is given simply by:

\[ z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} \]  

Where \( U \ll c \) and is the velocity of the emitter. This concept is applied 
cosmologically to calculate objects' radial recession velocities as observed from 
Earth. It is the contention of this paper that an alternative explanation for this 
effect can be offered by examining a flaw in the basic assumptions made about 
the nature of the observations. The flaw is that the intervening space between 
the emitter and the observer is perfect vacuum, allowing the photons to travel 
at exactly \( c \). The ISM and IGM have some mass density and, while it may be 
 extremely low, it cannot be ignored when examining optical sources in space.

\[1\] dschuste@mines.edu
This mass density creates an index of refraction that slows the light down and causes an apparent redshift.

2. Putting the Brakes on Light

Einstein set the universal speed limit at $c$ with Relativity, he also claimed that light always traveled at $c$ in vacuum, regardless of reference frame. However, in materials, it is well established that light will slow down or even stop, depending on the conditions [2]. To a physics student, this is why the image of a drinking straw appears broken in a glass of water, the light from the image is being redirected as it slows down through the medium. The quantitative description of this is the index of refraction given by:

$$n = \frac{c}{v} \quad (2)$$

Where $v$ is velocity of light as it propagates through the material. In vacuum, $c$ is related to frequency and wavelength by $c = f\lambda$. In a material, however, the frequency stays constant, but the wavelength shifts according to the change in velocity implying that $n_1\lambda_1 = n_2\lambda_2$ when a light beam goes from a material with index $n_1$ to a material with index $n_2$. This effect is traditionally compared to a marching band that goes from marching on dry hard ground to soft wet mud; the lines of the band will remain oriented the same relative to one another within the two media, however the lines will be redirected as the marchers slow down in the mud.

3. The IGM as a Super-Low Density Fluid

Current models of the intergalactic medium contend that it has mass density on the order of $\rho_M \approx 10^{-27} \text{ kg m}^{-3}$. While it is true that this equates to approximately one atom of neutral Hydrogen per cubic meter, averaging over cosmological distances, it is reasonable to consider the IGM a super-low density fluid. Modeling the IGM in this manner does away with the idea that light propagates exactly at $c$ through intergalactic space. Instead the IGM now has an index of refraction:

$$n_{IM} = 1 + \epsilon \quad (3)$$

In this classical framework, light certainly has a wavelength shift that deviates from the wavelength of light in a perfect vacuum. Given that $n_1\lambda_1 = n_2\lambda_2$, if our reference wavelength $\lambda_c$ occurs when $n_2 = 1$, corresponding to a perfect vacuum, then:
\[(1 + \epsilon)\lambda_{\text{emitted}} = \lambda_c\]  

(4)

Which then implies that the redshift measured is given by:

\[z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} = \frac{\lambda_c - \frac{\lambda_c}{1+\epsilon}}{\lambda_c} = \epsilon\]  

(5)

So far we have played some games with elementary physics by coming up with an expected constant redshift. While these games may have been fun, the idea of a constant redshift has already been disproven by mountains of observational evidence showing that redshift gets larger and larger the farther away we look. To resolve this we must go further and examine the behavior of the photon as it travels to an observer from a distant target.

4. Variable Optical Travel Time

Let us perform a short thought experiment. Imagine two light-emitting objects an equal distance \(x\) away from an observer. They each emit a photon at the same time toward the observer, the difference is that the path between the first object and the observer is perfect vacuum with \(n = 1\) and the path between the second object and the observer has the particle density of the IGM with \(n = 1 + \epsilon\). Assuming that the observer and the sources share a common frame, then the travel time for the photon from object number one is \(t_1 = \frac{x}{c}\). The travel time for the second object’s photon will be delayed, however by an amount proportional to the number \(N\) of absorptions and reemissions experienced in the intervening medium. If the characteristic, average time delay from these reactions is \(t_0\) then the travel time for object two’s photon is:

\[t_2 = t_1 + Nt_0 = \frac{x}{c} + Nt_0\]  

(6)

Obviously, as the density of the intervening medium increases, so does the number of interactions and, consequently, so does the travel time of the light. This is the effect seen in a dense material like calcite where there are so many interactions that the light slows down appreciably in a short distance. Thus, as the path \(x\) gets longer and more interactions occur, travel time increases. This gives the photon an effective velocity of:

\[v = \frac{x}{t_1 + Nt_0}\]  

(7)
With the index of refraction given by:

\[ n = 1 + \epsilon = \frac{c}{v} = \frac{c(t_1 + Nt_0)}{x} \]  \hspace{1cm} (8)

Recalling that \( \epsilon \) is our value for redshift, simple algebra will give us a variable value for redshift of the form:

\[ z = N \frac{t_0}{t_1} \]  \hspace{1cm} (9)

Obviously, as we increase the distance to a source, both \( N \) and \( t_1 \) will increase. The traditional model assumes a more-or-less linear relationship between distance (or photon travel time) and redshift. This model differs in that larger values of \( t_1 \) actually work to suppress redshift, whereas \( N \) works to increase redshift. Thus, to fit current observations, \( N \) must grow faster relative to \( t_1 \).

A "back-of-the-envelope" calculation for the mean free path of a photon at an average number density of \( n = \frac{\text{particles}}{m^3} \) gives:

\[ \ell = \frac{1}{n \sigma} \approx 37.6 \text{kly} \]  \hspace{1cm} (10)

Assuming the interaction cross-section to correspond to the Bohr radius. This means that a photon will, on average, have an interaction and, accordingly, a characteristic delay every 37600 light years. This is using the minimum particle density in intergalactic space, which can vary widely up to approximately 1000 \( \frac{\text{particles}}{m^3} \) in areas of particularly high density. This fact turns out to be very fortunate for our analysis, however. If the particle density remained constant at this minimum value for the duration of the photon’s journey, then the growth rate of the number of interactions \( N \) and the growth of the unperurbed travel-time \( t_1 \) would offset one another and we could expect a flat redshift curve everywhere we looked. This is clearly not the case observationally. This fact is why it is important to consider the total number of interactions, rather than attempting to average over large distances since, in our model, the universe is a fluid of continuously varying density. The effect must be considered cumulatively, allowing the interaction delays to increase multiplicatively through regions of high and low density. The regions of high density, relative to those of the low density, are what will work to increase \( Nt_0 \) compared to \( t_1 \) and, since photons from more distant objects will statistically travel through more "stuff" of varied density, observed redshifts for more distant objects will be higher.
5. Possible Criticism

There is ample opportunity to criticize this formulation and I’m sure the knowledgable reader can come up with many more criticisms (after all isn’t that what science is all about?), but for the sake of this paper, I will address three main concerns:

Why discount Doppler redshift altogether?

While the way in which the idea was formulated, it may appear that I re-ject the idea that cosmological objects can have any relative motion. This is not true, as I believe that galaxies do move relative to one another, sometimes blueshifted, sometimes redshifted. This formulation was done in a highly sim-plistic toy universe simply for the purpose of exploring the effect of intergalatic particles on photons as they propagate through space and how it might affect redshift. What I wanted to address was why we see redshift everywhere we look and it is my belief that the effect described in this paper overwhelms any actual relative motion between objects.

Why do we not see large redshifts for local stars known to be embedded in dust?

According to my argument, it would make sense that any light emitting object embedded in particles would automatically exhibit a high redshift. This is not necessarily true, however, since it is only the total number of particle interactions that correspond to redshift, not the density. While the density of the intervening material certainly plays a part, it is not the whole story. My idea changes the yardstick by which we measure cosmological distance and a high-redshift quasar could be a great deal further away than we currently believe it to be. This means that a photon emitted by that quasar could, in theory, have many orders of magnitude more interactions than a photon emitted from a local star embedded in a dense dust cloud.

Isn’t this just a retread of the Wolf Effect? [4]

While on the surface, my formulation may seem similar to that of Emil Wolf, I believe that the mechanism by which the redshift is realized is unique.
6. Conclusion

This model describes an alternate explanation for cosmological redshift and the supposed relationship between radial velocity and distance. The wavelength shifts observed are postulated to occur not from a Doppler effect, but rather from an overall, variable index of refraction for an infinite steady-state universe. The time delay from interactions with particles in the IGM account for the ”tired light” aspect of this model, as well as the redshift. The variability of the IGM’s particle density accounts for variability of the refractive index and, consequently, the increase of redshift value with respect to distance. The full consequences and additional ideas for such a ”steady-state revival” will be discussed at length in future papers.

7. References

[1] Hubble, Edwin, "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae", Proceedings of the National Academy of Sciences of the United States of America, Volume 15, Issue 3, pp. 168-173 (1929)

[2] Yanik M.F., Fan S., "Stopping Light All Optically", Physical Review Letters, vol. 92, Issue 8, id. 083901 (2004)

[3] Crawford, David F., "Curvature pressure in a cosmology with a tired-light redshift", Australian Journal of Physics, vol. 52, pp. 753-777 (1999)

[4] Wolf, Emil, "Noncosmological redshifts of spectral lines", Nature 326: pp. 363-365 (1987)