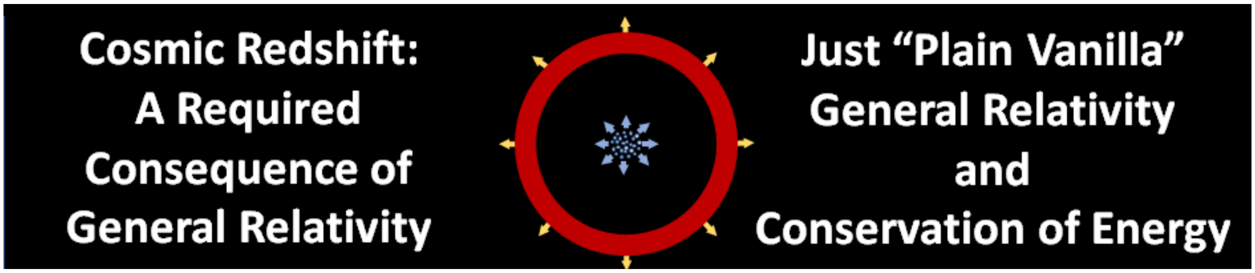

Cosmic Redshift: A Required Consequence of "Plain Vanilla" General Relativity

One sentence synopsis: While General Relativity demands conservation of energy in all its myriad forms, the speed of light limits how fast energy and gravity can travel – which then creates an asymmetry that presents itself to an observer as a redshift in every direction.

Abstract

One of the postulates of modern cosmology is a relatively stable Hubble Constant that quantifies how much light is stretched as a function of distance from our point of observation here on Earth. The current value for the Hubble Constant states that for every million parsecs[i] we look away, objects will appear to be accelerating away from us by another 70 km/sec.

According to the current interpretation of this phenomenon, the wavelengths of light are shifted to the red end of the spectrum (e.g., redshifted) due to the stretching of space itself and, yet, the source of energy responsible for the expansion of space is unknown. While a type of energy responsible for this expansion could eventually be identified, invoking an unknown energy is unsettling because the principle of conservation of energy is paramount in every branch of physics except, apparently, cosmology.

This paper hypothesizes whether there may be an alternative explanation for the redshift observation which is consistent with the conservation of energy, Einstein's Field Equations and with other aspects of physics.

The alternative hypothesis proposed here is that all the incoming photons of light that we observe will have passed by an innumerable number of other photons traveling in an opposite direction. When the photons traveling in their respective *future light cones*[ii] pass each other, their *past light cones* overlap and they will become "aware" of each other. Then these countervailing photons will elastically exchange a portion of their kinetic energy for an equal amount of gravitational potential energy once they become "aware" of each other. This exchange of energy appears to us as a redshift of the wavelengths of the light we observe. This effect is a result of asymmetries in the universe caused by the time it takes for information (e.g., light, energy, gravity etc.) to travel. Only when their *past light cones* overlap can the gravitational attraction of the oppositely traveling photons affect the curvature of space time in such a way that their paths are deflected in space time towards each other[iii].

In all appearances, this would present itself similar to the widely accepted hypothesis of the stretching of space itself. Specifically, this effect would be observed equally in all directions. Additionally, this

same effect would be experienced by any observer, anywhere in the universe although the magnitude may vary depending on the countervailing flux of the electromagnetic and gravitational waves encountered by the incoming photons.

Invoking the expansion of space, itself, to explain the Hubble Constant has had profound consequences for our understanding of the physics that affects the universe on large scales, the origin of the universe and its long-term destiny. If an alternative explanation of redshift is hypothesized, which is consistent with known physics, it should be of interest to anyone interested in astrophysics and cosmology.

1. Recession as Measured by Redshift

The recession of objects that emit or reflect electromagnetic waves can be determined by comparing the wavelength that we observe to the wavelength of the source. In the case of radar traffic control, this is done by reflecting an electromagnetic wave back from a moving vehicle and observing the change in wavelength received when compared to the source because the radar has an incrementally greater or lesser distance to travel (depending on the direction of travel).

In astronomy, this measurement is done by observing a spectrum of light where the wavelength of an identified electron transition can be compared to the wavelength of the same electron transition that occurs in a stationary laboratory. This change is quantified by observing spectral lines of easily identifiable transitions that have a distinct feature in a spectrum. Using observations, this approach can be used to make precise measurements quantifying the radial velocity away from us, or toward us. In astrophysics, this is typically quantified using the following equation.

$$z = (\lambda_{\text{observed}} - \lambda_{\text{laboratory}}) / \lambda_{\text{laboratory}} \qquad (1)$$

Wavelengths emitted by objects that are receding from us are stretched because the light has incrementally more distance to travel in the same time. Because of this effect, the wavelengths are shifted to the red end of the visible spectrum. Assuming a pure Doppler shift where the object is receding, the observed stretching of wavelengths is caused by the emitting or reflecting object continuously moving away through an incrementally greater amount of space. Given the constant speed of electromagnetic waves, the wavelengths appear stretched. These redshifted emission lines would produce a *z* value that is positive. If an object were to be approaching us, the wavelengths would be compressed compared to a laboratory spectrum and the light would be said to have been blue shifted toward the blue end of the visible spectrum. Blue shifted emission lines produce a *z* value that is negative.

Since about the time Edwin Hubble published his observed relationship of recession speed to distance, the observed redshift patterns have been attributed to the cosmological expansion of space, itself[iv]. A Belgian priest, Georges Lemaître, is given credit for being the first to propose the hypothesis that space itself was expanding[v]. According to the modern hypothesis, there are variations in redshift associated with stars and galaxies that are gravitationally attracted to the Milky Way and are moving closer to us. According to this framework, this is a local effect superimposed on the overall cosmological expansion of space.

Other effects that are associated with a distant object such as rotational velocities of one side of a galaxy as compared to the rotational velocities on the other side of the galaxy can also be observed by differences in wavelengths. These additional observations can be used to provide insights into various aspects of the object under observation. Again, these local effects are layered on top of the cosmological redshift.

2. The Space, Itself, is Expanding Hypothesis

The hypothesis that space, itself, is expanding was acknowledged by Edwin Hubble to explain the observation that objects appeared to be receding from us at similar accelerated velocities versus distances in all directions[vi]. This is frequently described using the analogy of raisins in raisin bread dough that is expanding before it is baked. In this analogy, the distance between raisins is expanding in all directions regardless of which raisin is selected as the reference. However, this raisin bread analogy also highlights the question of where the energy for such an expansion of the universe comes from. In the case of raisin bread, yeast converts low-volume sugar to high volume carbon dioxide that creates a pressure which fosters the observed expansion.

While Einstein's General Relativity postulates that nothing can travel through space faster than the speed of light, the Big Bang theory hypothesizes that space, itself, has expanded faster than the speed of light[vii]. Indeed, this is the fundamental explanation for the Cosmic Microwave Background (CMB) that will be discussed later.

This faster than the speed of light expansion is not considered a violation of Einstein's Special Relativity because space is the medium[viii] through which light would travel at its constrained characteristic velocity. However, Special Relativity is silent on both how fast space can expand, and even whether space can expand at all. Furthermore, since the 1970's, a theory known as "cosmic inflation" postulates a period of time in the first instant of the Big Bang where the cosmological expansion of space occurred at enormous multiples of the speed of light[ix].

While other theories have been proposed that attempt to impose a physical meaning for the observation of the redshift underlying the Hubble Constant using concepts such as a variable speed of light or Compton scattering, none have withstood scrutiny. The absence of any other working hypotheses has left the concept of space, itself, expanding the current best hypothesis.

Therefore, with great trepidation, a different hypothesis will be proposed here.

3. Effect of Gravity on the Path of Light

While the word "light" is used in much of the following discussion, the word "light" is intended to broadly incorporate all wavelengths of the electromagnetic spectrum because electromagnetic waves contain energy. This energy is inherent in light's time-varying electric and magnetic fields. The amount of energy in an electromagnetic wave decreases as the wavelength gets longer which is illustrated by gravitational redshift as light climbs away from a mass[x] such as a black-hole. The effect of energy in gravitational waves being comparable to the effect of energy in light will be discussed later.

It is a well-known feature of light that its electro-magnetic path can be altered by the presence of large massive objects due to gravitational attraction. This implies that the path of light traveling from a distant source in the universe will not travel in a straight line from its source to earth, but rather it will be pulled off-course in innumerable encounters with varying magnitudes and orientations of gravity and energy as it passes galaxies, galaxy clusters, stars and anything else that contains an equivalent to gravity.

The most frequently mentioned illustrations for the change in the direction of light due to encounters with large massive objects are Einstein Rings[xi]. These rings form when light emanating from a distant galaxy is bent by a massive object, usually a cluster of galaxies that is located directly along the line of sight between an observer on Earth and the distant object. In the more spectacular examples of this effect, the light from the distant object appears as a circular ring surrounding the massive object located at its center.

The phenomenon of mass affecting light has been observed locally within the solar system by interactions of light (and even radio waves) with objects in the solar system. The observation by Sir Arthur Eddington of the 1919 solar eclipse was the first demonstration of a mass attracting light and changing its direction[xii]. In subsequent years, radio communications with remote space probes have likewise been observed to have been affected by the mass of solar objects[xiii].

Consequently, while the path of light may be traveling using the shortest distance in space-time, it may in-fact be a wobbly line as seen from a remote observer that has the ability to see both the source and destination of the light along its entire path. In fact, the light is following a straight line through its geodesic through curved space-time.

4. Einstein's Field Equations

Einstein's Field Equation for general relativity specifies the relationships between gravity, space-time, mass, energy and momentum where these relationships must be respected[xiv]. Consequently, Einstein's Field Theory demands a framework that is effectively a closed system, in which, for every action there is an equal and opposite reaction in space-time. While energy in its various forms is conserved within this closed system[xv], there is no requirement that all parts of this closed system need to be aware of all events, everywhere because of the constraints of time, distance, the speed of electromagnetic and gravity waves as well as their associated direction of propagation. These constraints will result in temporary asymmetries. However, these temporary asymmetries could last for an eternity.

Because most of the rest mass of an atom is believed to be due to kinetic energy of quarks circling each other in the nucleus[xvi], mass is effectively a confined energy system in which energy and mass are related by the famous Einstein equation:

$$E=mc^2 \quad (J) \tag{2}$$

Thus the attraction of light to mass is, equivalently, the attraction of light to energy. Extending this to its logical conclusion, all energy has an effect on all other energy via an attraction manifesting itself as gravity. In General Relativity, this creates a non-zero energy-momentum tensor[xvii] which does not decrease to zero at a finite distance. Because mass and energy are two different ways of describing a related property, if a physical system has energy it will act as a source of gravity[xviii] just like mass.

5. The Energy Component of Light

The energy of a photon of light is dependent on Planks Constant (h) and the frequency (v) at which the electromagnetic wave is associated. Higher frequency electromagnetic waves embody more energy than lower frequency electromagnetic waves. The energy (E) associated with a photon is given as:

$$E = h\text{v} \quad (J) \tag{3}$$

where:

$$h = 6.626\text{ e-}34 \text{ (J/Hz or kg m\^{}2 / sec)} \tag{4}$$

The most ubiquitous example today of light rays having energy is a photovoltaic power panel (e.g., solar cells)[xix]. Because a photon's energy, in the form of electromagnetic radiation, has a magnitude and a direction of propagation there must be an equal and opposite reaction when the photon is emitted. This recoil effect[xx] is shown in Figure 1 where an atom begins in an excited state (A) and then transitions to the ground state in (B). When the electron transitions, a photon is emitted with an energy, hv, that propagates in a specific direction. In accordance with the conservation of energy and conservation of momentum these vector components must be conserved. This is the source of the recoil energy, R.

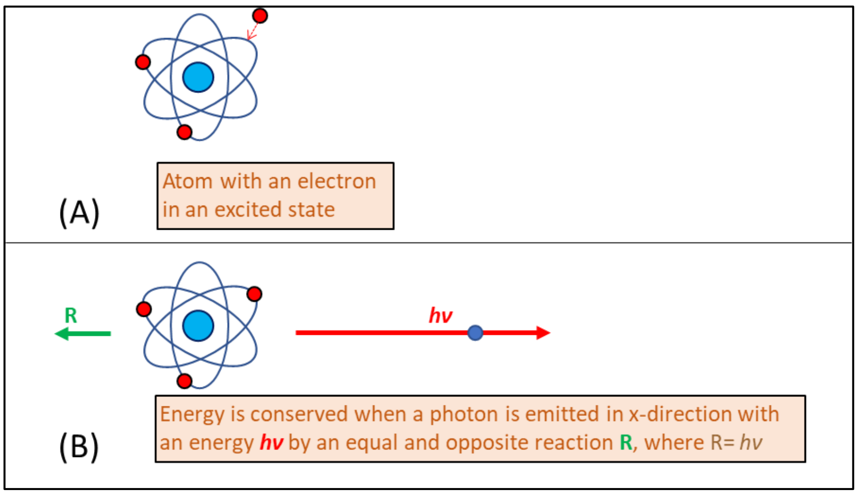

Figure 1: Conservation of energy requires the energy vector of the photon to be counteracted by an equal and opposite force

The key point is that the emitted photon will travel at the speed of light and anything that it encounters will only be affected by the energy in the photon – and only once it has passed by. Information about the recoil energy, R, may possibly be transmitted as a gravity wave. However, this will not have an effect because it can be assumed this gravitational effect would have been canceled out by the recoil energy from photons emitted in the opposite direction from another atom. Figure 2 (A) shows two atoms in an excited state. In (B), the atoms emit a photon in opposite directions. It is assumed that these oppositely directed photons arise from independent events and quantum entanglement does not play any role.

Assuming the two atoms represent a miniscule fraction of those from a significant source of energetic photons, such as a star, the photons will radiate outward in all directions while the recoil forces will push inward equally from all directions. Under these conditions, the gravitational effect of the recoil energy will effectively cancel out in aggregate.

There will be an asymmetry in energy as seen by photon *A* in (B). However, in the global sense, there is no asymmetry because a photon *A'* approaching from the opposite side will see a complementary asymmetry from its perspective when it encounters *hv'*. The effects will cancel out from a global perspective, but the local effects will appear as an asymmetry. The underlying source of this asymmetry is that each emitted photon will travel in its own light cone, as shown in (C), that limits where its energy can have an effect in the three dimensions of space and one dimension of time (e.g., space time).

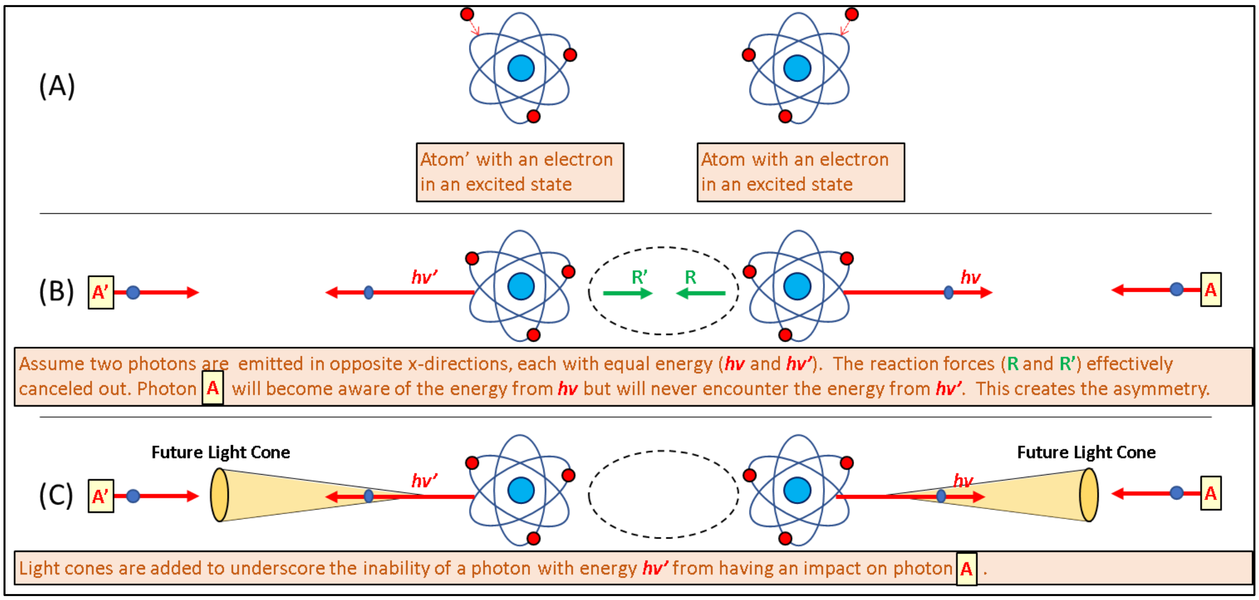

Figure 2: An asymmetry will occur when Photon A encounters the photon with energy hv, but it will never encounter the recoil energy or the energy in Photon hv' traveling in the opposite direction.

6. Gravitational Attraction of Photons

For purposes of this conceptual explanation, it will be assumed that Newton's constant of gravitation, G, links not just two masses, but two energetic objects including photons. Because the gravitational force decreases by the square of the distance, d, and the energy of individual photons are small, the mutual effect of gravitation will be small but not zero:

$$\text{Gravitational Attraction} = Gm_1m_2/d^2 \qquad (5)$$

Using equations (2) and (3) for explanatory purposes:

$$m = E/c^2 = h\nu/c^2 \qquad (6)$$

or:

$$\text{Gravitational Attraction} = G\,(h\nu_1/c^2) * (h\nu_2/c^2)/d^2 \qquad (7)$$

$$\text{Gravitational Attraction} = G\, \nu_1\, \nu_2\, (h/d)^2/c^4 \tag{8}$$

Gravitational attraction between photons has been discussed in the literature since the 1930[xxi]. Currently, the effect of the gravitational attraction of photons is of interest in the field of lasers[xxii] because this effect may become a detectible source of distortion in high speed laser communications at earth scale distances[xxiii].

At cosmological scale distances, the effect of gravitational attraction of photons may have already been observed as the redshift of light we observe from distant objects.

7. Gravitational Effects between Light Rays

Streams of photons, or light rays, may be emitted anywhere in the universe and travel across the universe interacting with other objects containing energy. Objects like our sun, our galaxy or clusters of galaxies can influence the path of a light ray.

Figure 3 shows several light rays approaching the earth and traveling in various directions. For this discussion, light ray *A* will be the primary path of focus. Light ray *A* originates on a trajectory that was not originally directed toward Earth. However, as it approaches a cluster of galaxies, its trajectory is influenced by the mass (e.g., energy) of the cluster. Because of this, its path is bent toward Earth. The blue light ray is traveling parallel to *A* and its presence may influence the path of the light ray laterally based on their mutual attraction. It may be assumed that the blue light ray photons are very close to *A* and the interactions may have an effect. However, because the trajectories are parallel, the impact would predominately be lateral as they each warp space-time around them. Because they are all traveling at the same velocity, they will have no impact on the energy of the photons in light ray "A" as quantified by $h\nu$. They are all traveling in a straight line through their geodesic that would be influenced by their companion photons.

The green light ray is also shown to be deflected by a large gravity source. While this light ray intersects the path of light ray *A* the effect will be mostly orthogonal and the only impact that this could have is to impart a lateral shift. This would only make the apparent position of the source of *A* to shift a little in our night sky.

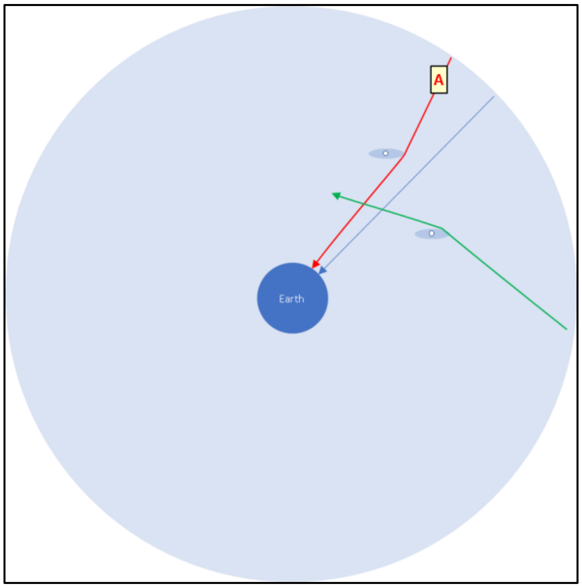

Figure 3: Light Rays Approaching Earth from the First Quadrant

8. Encountering Photons with Opposite Momentum

Using the illustration in Figure 3 with light ray *A* moving in the direction of the Earth, we can investigate the impact of light rays originating on the opposite side of the Earth and passing by the Earth as shown in Figure 4.

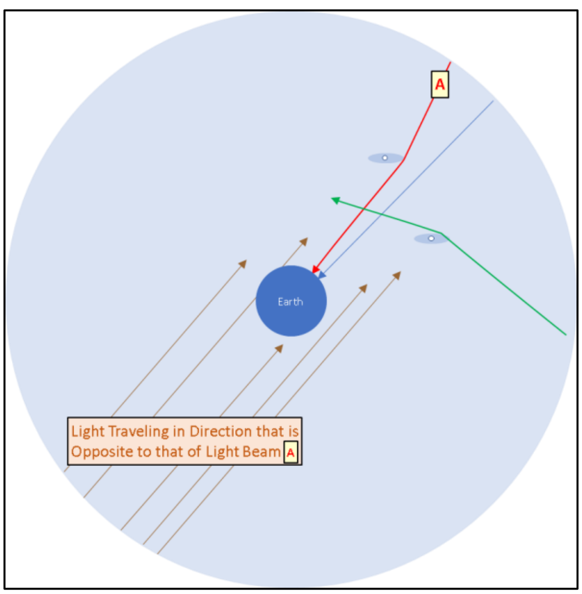

Figure 4: Light Rays Originating from the Third Quadrant Interacting With Light Approaching the Earth from the First Quadrant

Application of Einstein's Field equations can quantify the gravitational attraction of the photons in light ray *A* to the oncoming photons that pass in close proximity.

The key assumption is that the approaching photons in light ray *A* may, or may not, be aware of all matter and energy in the universe, however, the photons in light ray *A* cannot be aware of the energy in the photons approaching from the third quadrant before their *past light cones* overlap. This is because information communicating the electron transition shown in Figure 2 (A) cannot travel faster than the photon. Additionally, the resulting recoil "R" in Figure 2 (B) can be assumed to have been canceled out.

Consequently, the photons in light ray *A* will only learn about the energy in the photons approaching from the third quadrant once they pass by each other. This is because each photon will affect the curvature of space time only after they have passed by the other photon and their *past light cones* overlap. Only then will a photon be affected by the other's energy. Once the photon becomes aware of the energy that has just passed it by, it will become gravitationally attracted to it. This new gravitational attraction will then absorb kinetic energy from both photons as they exchange it for the gravitational potential energy that will increase between them as they continue moving apart. This reduced kinetic energy would stretch the wavelength of both photons and both would be redshifted.

The colloquial use of the word 'attracted,' as used here, is meant to convey the presence of a gravitational field that can do work and not the Newtonian concept of source acting at a distance. The value of the gravitational field between two photons is zero until they pass by each other and their *past light cones* overlap. Once they overlap, the energy in their mutual gravitational field begins to increase which is described as an increase in the curvature of space.

Because the speed and energy of the passing photons exceeds each other's "escape velocity," the two photons will continue in their original directions. Because of the wave properties of photons, the waves will pass through without scattering and will only be affected by their newly established gravitational field that causes them to lose kinetic energy as they move apart.

Figure 5 shows one photon in light ray *A* approaching a spherical front of photons emitted from a distant source similar to that shown in Figure 1 as it passes by the Earth. Because of the uniformity of this spherical front from the perspective of the photon in light ray *A,* its trajectory will remain unaffected. However, it will now be gravitationally attracted to all the photons in the passing spherical front. In this illustration, photons further away from the centerline of light ray *A* will be redshifted less because of an increase in distance, d, in Equation 8 as they pass by.

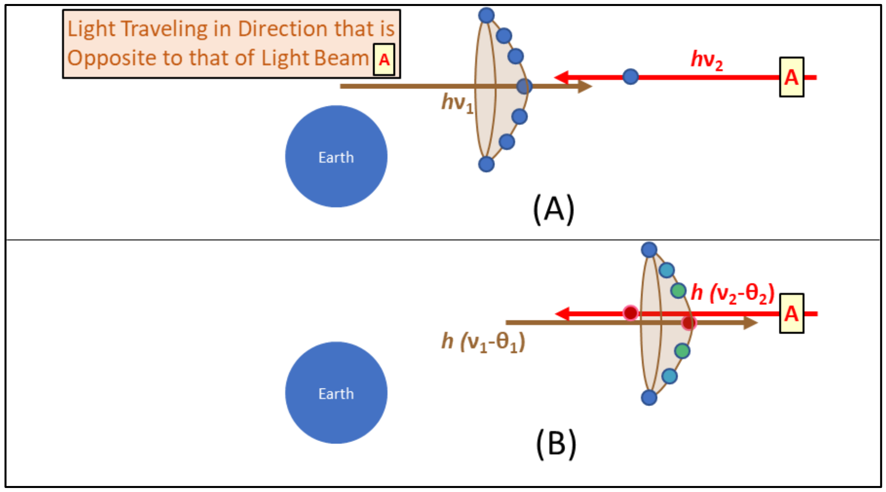

Figure 5: Redshifting of two passing photons by gravitational attraction

Figure 6 shows the initial (A) and final (B) symmetry of two spherical fronts of photons passing by each other. Distortions are nonexistent as the electromagnetic waves of the photons pass through each other with only the addition of gravitational attraction that absorbs energy from the photons and adds to the gravitational potential energy in the universe. Both spherical fronts of photons begin the encounter as "blue dots" in (A) and become redshifted "red dots" in (B).

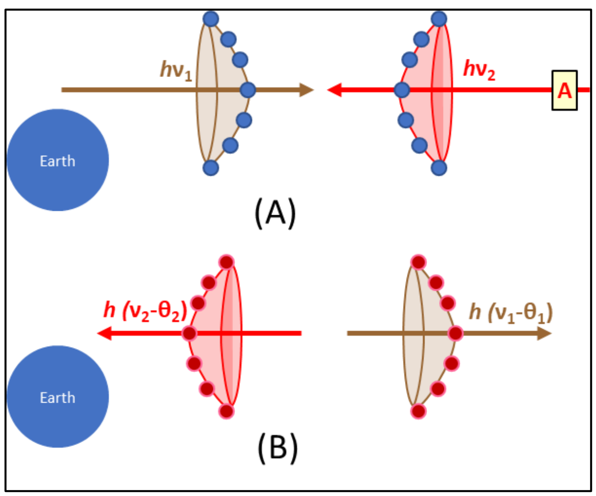

Figure 6: Two spherical fronts of photons approach and then pass through each other with gravitational attraction reducing energy in the photons equal to the additional gravitational potential between the photons

9. Edwin Hubble and the Expansion of Space

The expansion of space itself is a central concept in modern astronomy. About a century ago, Vesto Slipher[xxiv] noted that the radial movement of stars and galaxies could be quantified by the light they emitted. He studied the absorption and emission lines in the spectrum of light and converted these differences to radial velocities. His first observations included the relatively nearby Andromeda galaxy in which the spectral lines were both shifted to shorter and longer wavelengths relative to each other on either side of the galactic center. This meant that the Andromeda galaxy was rotating and this rotation caused a Doppler shift of the light due to the physical movements of the stars.

Using the new 100 inch telescope at the Mount Wilson Observatory, Edwin Hubble was able to quantify the distances to distant stars by using a technique based on the luminosity cycles of Cephid variable stars[xxv]. Combining this information with the technique pioneered by Vesto Slipher, Hubble discovered that other stars and galaxies were moving away from him, as an earth-based observer, at greater and greater velocities as their distance increased. The observed relationship of increasing recessional velocity and distance was seen to be linear and extended into the universe as far as distances to the remote stars could be quantified[xxvi]. The coefficient of this linear relationship became known as the Hubble Constant, H_0 with the subscript "0"denoting its value today[xxvii].

The current value for the increase in velocity vs. distance, the Hubble Constant, is approximately:

$$H_0 = 70 \text{ km/s/Mpc or } 7\text{x}10^4 \text{ m/s/Mpc} \tag{9}$$

Where:

$$\text{Mpc} = 3.086\text{x}10^{22} \text{ m} \tag{10}$$

Therefore:

$$H_0 = 7\text{x}10^4 \text{ m/s/Mpc x } (1 \text{ Mpc} / 3.086\text{x}10^{22} \text{ m}) \tag{11}$$

$$H_0 = 2.268\text{x}10^{-18} \text{ m/s /m} \tag{12}$$

In the units presented in equation (12) the Hubble constant is shown to be a small but non-negligible increase in recession velocity per meter. This acceleration can be put in more conventional terms by multiplying by the speed of light so that the Hubble Constant can be expressed as acceleration in the more recognizable terms of meters per second squared.

Where:

$$c = 3.0\text{x}10^8 \text{ m/s} \tag{13}$$

$$H_0 = 2.268\text{x}10^{-18} \text{ m/s /m} * (3.0\text{x}10^8 \text{ m/s}) \tag{14}$$

$$H_0 = 6.80\text{x}10^{-10} \text{ m/s/s} \tag{15}$$

10. Kinetic Energy – Gravitational Energy Exchange

Assuming that the redshift phenomenon discovered by Hubble is caused by the loss of kinetic energy of the incoming photon *A* in exchange for an increase in gravitational energy, this effect would be a function of the total amount of flux that photon *A* encounters along its journey.

Under this hypothesis, the uniform stretching of the earth-bound wavelengths characterized by the Hubble Constant would be a result of all the electromagnetic and gravitational waves permeating the universe. In accordance with the assumption that the universe is homogeneous and isotropic, this would create the same magnitude of redshift in every direction. This effect would be indistinguishable from the scale factor *a(t)* that it used to describes space, itself, expanding[xxviii].

A greater total flux encountered would amplify the redshift while a lower total flux encountered would create a smaller redshift. Variations in the prevailing energy in the flux in the universe over time could create the variation in the observed Hubble Constant over time. Local effects along a line-of-sight, whether recent or in the distant past, could create local anisotropies in the redshift.

It is quite possible that variations in the prevailing electromagnetic and gravitational flux along a specific line of sight to a distant object could affect the resulting observed redshift. For example, a powerful gamma ray burst may have been emitted by an object a billion years ago along a specific line of sight where the source could have either migrated out of the line of sight or become undetectable.

11. Reformulating the Hubble Constant

Because nobody can see and measure the universe with a meter stick, the accepted standard for astronomical observations is the distance that light can travel in a specific time period. For our convenience, Earth is typically taken as the center of our inertial frame.

The observed redshift has been attributed to the expansion of space which is hypothesized to be expanding at approximately 70 km/s per Mpc as shown in Equation (9). Figure 7 shows a linear application of the Hubble Constant as recessional velocity vs. distance. In this range, the linear approximation is a close approximation to a relativistic approach[xxix].

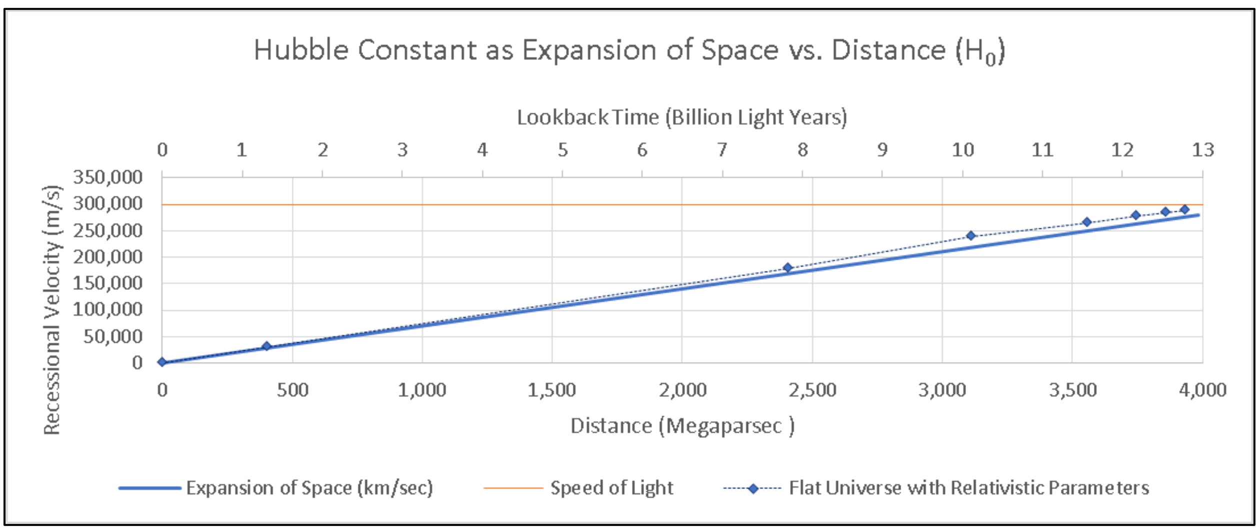

Figure 7: If the Hubble Constant reflects a Doppler Effect caused by the expansion of space, it is expected that eventually objects will recede with such a velocity that electromagnetic waves will never reach Earth.

The hypothesis presented in this paper is that the redshift is not caused by (or at least not entirely caused by) the expansion of space, itself, but rather the loss of kinetic energy of the photons which is exchanged for gravitational potential energy between those countervailing photons. This exchange in energy does not change the speed of light, but rather, it decreases the frequency of the light.

Consequently, the Hubble Constant can be transformed into different units that are more appropriate for this framework. The notation H_{0w}, will be used where the subscript "w" denotes that the Hubble Constant is being expressed in terms of increasing wavelength with distance. The notation H_{0f}, will be used where the subscript “f” denotes that the Hubble Constant is being expressed in terms of decreasing frequency.

For each Mpc further away we look, the wavelength will be stretched by H_{0w}.

$$H_0 = 7x10^4 \text{ m/s/Mpc} \quad \text{(an increase in velocity per Mpc)} \tag{16}$$

Where:

$$c = 3.0x10^8 \text{ m/s} \tag{17}$$

A recast definition of the Hubble Constant would be expressed as an increase in wavelength per Mpc (H_{0w}):

$$H_{0w} = [1 + (7x10^4 / 3.0x10^8)] \text{ (increase in wavelength per Mpc)} \tag{18}$$

$$H_{0w} = 1.0002333 \text{ (increase in wavelength per Mpc)} \tag{19}$$

Figure 8 shows the Hubble Constant as an increase in wavelength with distance. At a distance of about 4,000 Mpc the wavelengths would be stretched by a factor of about 2.5 times. At distances beyond 4,000 Mpc, the phenomenon of increasing wavelengths will continue ad infinitum and will only be affected by the total flux of electromagnetic and gravitational energy encountered[xxx].

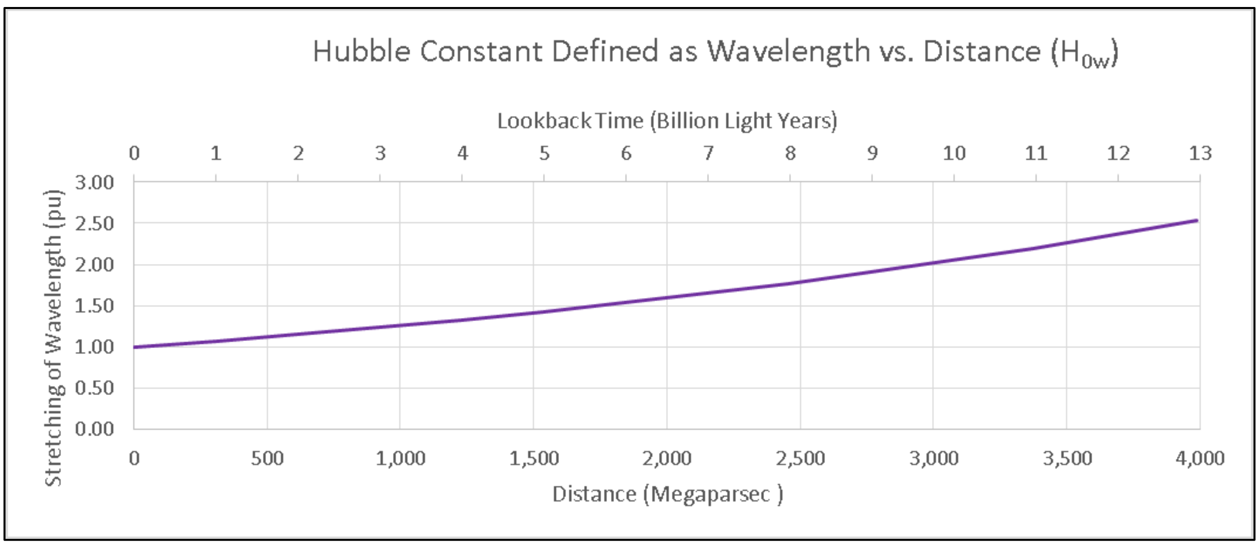

Figure 8: Increase in observed wavelength of approaching light as a function of distance to the emitting source.

This increase in wavelength per Mpc can also be expressed as a reduction in frequency per Mpc (H_{0f}) based on the reciprocal of H_{0w}:

$$H_{0f} = 0.999766721 \text{ /Mpc (frequency multiplier per Mpc)} \tag{20}$$

Figure 9 shows the Hubble Constant as a decrease in frequency with distance. At a distance of about 4,000 Mpc the frequency would be decreased by a factor of 60 percent. At distances beyond 4,000 Mpc, the phenomenon of decreasing frequency will continue ad infinitum and will only be affected by the total flux of electromagnetic and gravitational energy encountered.

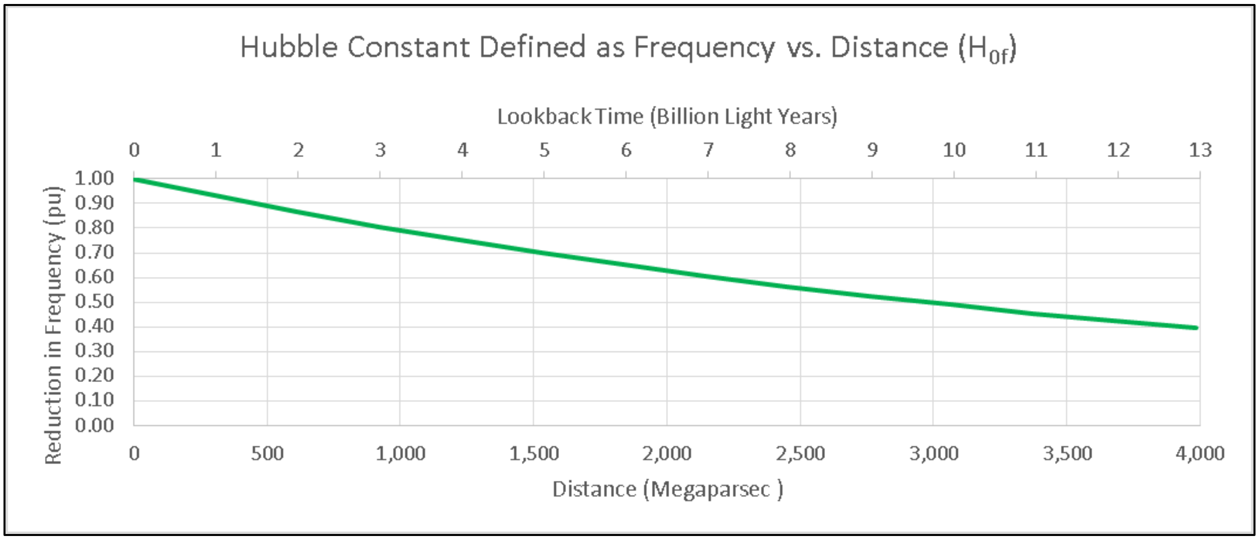

Figure 9: Decrease in observed frequency of approaching light as a function of distance to the emitting source.

12. Redshift Due to Gravity Wave Flux

In addition to the asymmetric energy coupling of electromagnetic waves and countervailing photons, gravity waves can also provide an asymmetric source of energy that would add to the redshifting. Several observatories such as the Laser Interferometer Gravitational-Wave Observatory (LIGO)[xxxi] have detected the presence of, and analyzed some characteristics of, these gravity waves. The detection of these gravitational waves by LIGO and other similar observatories[xxxii] demonstrates that there is a significant amount of energy in gravitational waves. Similar to electromagnetic waves, the sudden passing by of the energy in these gravitational waves should also foster an exchange of a portion of the kinetic energy in the photons for a reduction in the gravitational energy of the gravity wave.

In the same manner that the origin of an electromagnetic wave in Figure 2 can create an asymmetry, the energy source behind a gravitational wave can also create an asymmetry as seen by an incoming photon traveling toward Earth. The incoming photon would suddenly encounter the gravitational wave as it passes by.

As with the electromagnetic wave, the asymmetry would be due to the vector property of the *future gravity cone* traveling at the speed of light with a magnitude and direction. This would ensure that some of the gravitation wave energy (denoted as *f(v)*) would be directed toward the incoming photon *A* as shown in Figure 10 while, based on symmetry, a portion of the gravitational energy would be directed in an opposite trajectory (denoted as *f(v')*). Because gravity waves travel at the speed of light, this energy would not have been known to the incoming photon *A* until it passed by and the photon's *past light cone* and the *past gravity cone* overlap. This effect is consistent with Einstein's Field Equations which is premised on a photon being gravitationally attracted to the energy of the wave. In this case it is attracted to the energy in a gravitational wave.

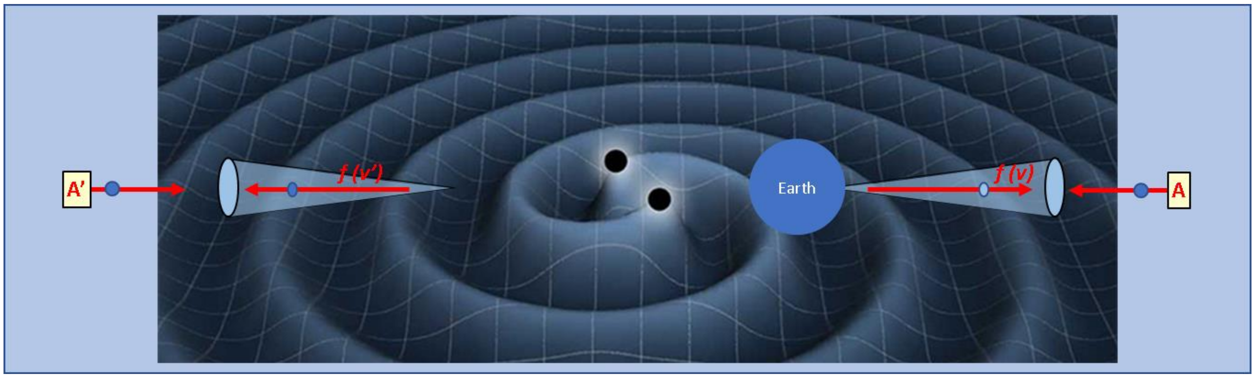

Figure 10: Computer simulation of gravitational waves generated by 2 closely-orbiting black holes. The energy is transmitted outward in all directions characterized by a magnitude and a direction, denoted as f(v) (Image credit: NASA)

The recoil effect shown in Figure 1 is replaced by the continuous outward radiation of the gravity waves in all directions. Upon the merger of the circling objects, all of the decrease in mass/energy caused by the merger of these massive objects will have been dispersed as gravity waves with some portion of the energy dispersed as electromagnetic waves at the time of the final cataclysm.

Gravitational waves could also lose energy and be "redshifted" by the asymmetry associated with passing photons. Unfortunately, there is no known phenomenon within a gravity wave spectrum that would function like an electron transition to enable the measurement of such a redshift. Therefore, it is not possible to calculate how much energy has been lost by using a redshift type analysis of a gravity wave.

13. Co-occurring Gravity and Electromagnetic Waves

In recent years, a nearly simultaneous detection of electromagnetic waves and gravitational waves has been captured from the merger of two neutron stars[xxxiii]. An analysis of the 2017 observation, GW170817, showed that gravity waves and light waves both travel through space at, effectively, the same velocities.

According to the researchers, approximately 130 million years ago, two neutron stars were in their final moments of orbiting each other. The combined system was losing energy as gravity waves radiated their energy away. The loss of energy brought them closer together which increased their orbital velocities – a phenomenon like water rotating faster at the bottom of a vortex in a draining sink. As the objects spiraled faster and closer together, they stretched and distorted the surrounding space-time more violently, giving off energy in the form of ever higher magnitude gravitational waves. Upon merging, an electromagnetic burst of gamma rays was also emitted along with a maximum gravity wave emission spike.

The Gamma-rays were detected first, followed by the identification of a gravity wave event at approximately the same time. Then optical astronomers around the world searched the approximate location of this event and succeeded in spotting an object in the target area of the sky that was changing. The object was identified as originating in galaxy NGC4993. The optical signal then faded away.[xxxiv]

The amount of energy emanating from a merger in the form of gravity waves is substantial. The energy estimated to have been radiated by a 2015 observation identified as GW150914 was 3.0 ± 0.5 solar masses in only a matter of seconds[xxxv]. With an estimated distance of 1.4 billion light years, the effect of the gravity waves stretching the LIGO detector was detectable.

Figure 11 shows the observed wave trace of the gravitational waves from GW150914. The dramatic increase in magnitude of these gravity waves when they peaked was followed by a very quick reversion to the steady state. This demonstrates both, the elasticity of space during detection as well as the stiffness of space as it returned to its preferred stable state. The stable state is at the zero point between the maximum and minimum excursions of the wave trace as well as after the end of the trace. The difference between the zero point and maximum / minimum excursions is an indication of the energy needed to stretch space[xxxvi].

By inspection, the sum of the positive excursions and negative excursions appear to be equal, suggesting that there was no net expansion of space from this event[xxxvii]. If space were as easily expandable as suggested by the current interpretation of the scale factor, *a(t)* then a significant net expansion of space might have been an observable outcome.

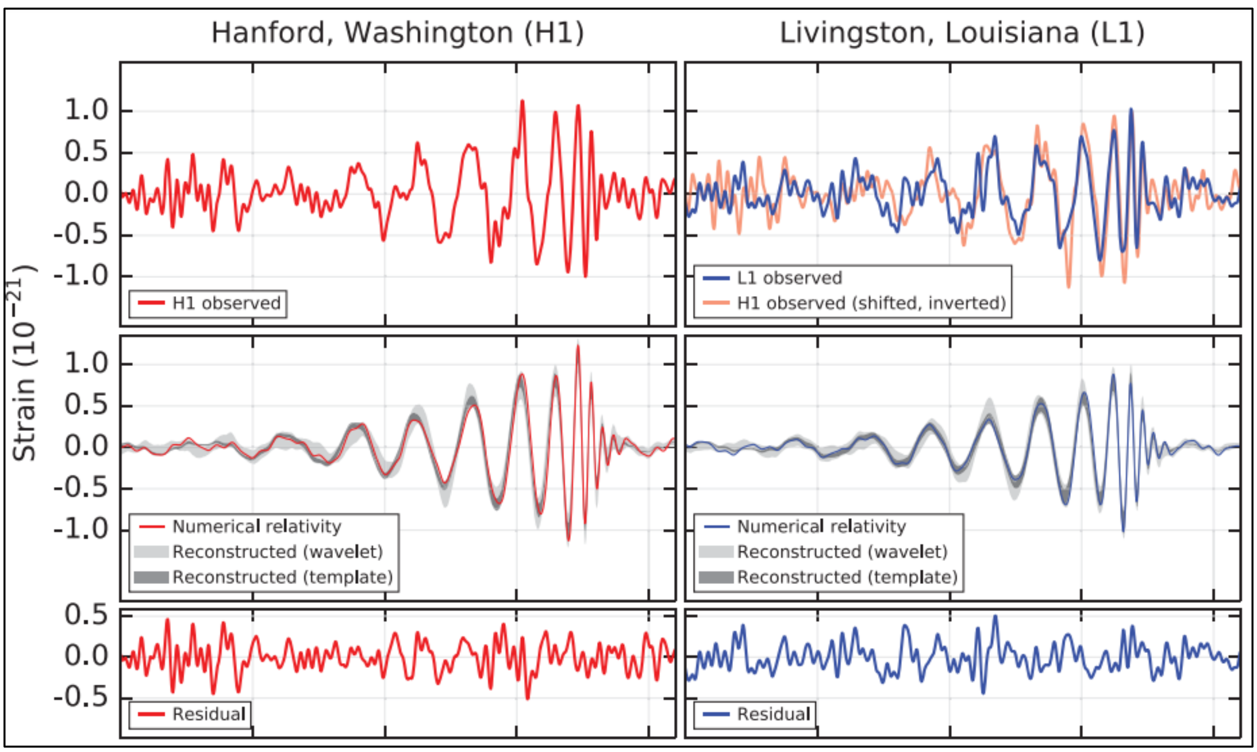

Figure 11: First observation of gravitational waves by LIGO (signal GW150914). Shows the gravitational wave signals received by the LIGO instruments at Hanford, Washington (left) and Livingston, Louisiana (right). Source: (Creative Commons Attribution 3.0 Unported license Wikipedia)[xxxviii]

14. Energy in Gravitational Waves and the Expansion of Space, Itself

A gravitational wave passing through the universe creates a time-varying strain in space that periodically changes the distances between all objects. Gravity waves can be thought of as a compression and rarefaction of space that occurs in a direction perpendicular to the direction of wave propagation[xxxix]. While the wavelengths and energies observed in LIGO may be small, that does not mean gravitational waves are weak in the sense that they transmit small amounts of energy. It is estimated that a supernova in a nearby galaxy will fill every square meter here on Earth with kilowatts of gravitational radiation. The resulting length changes are small because space time is a stiff elastic medium, so that it takes extremely large energies to produce even minute distortions.[xl]

The stiffness of space demonstrated by gravity waves suggests a lot of energy is needed to make small distortions in space. Therefore, the amount of energy needed to create the expansion of space described by the cosmic scale factor, *a(t),* must be unimaginably huge – even by astrophysical standards.

Figure 12 provides an analogy for acoustic waves in (A) and gravitational waves in (B) showing that both types of waves transmit energy that can then be detected and turned into an audio signal for observation. In both cases, the medium is compressed to create peaks and then pulled apart to create a rarefaction between peaks. In (A), the medium is air at a specific temperature and pressure, while in (B) the medium is space. The amplitude in both (A) and (B) are determined by the horizontal oscillating movement of the driver. When the driver stops oscillating, the amplitude drops to zero (assuming the wall and endcap of these example cylinders are perfectly absorbing to prevent resonance and standing waves). In both cases, the waves self-propagate through either air or space by compression followed by rarefaction of a transmitting medium due to a perturbation from the steady state property.

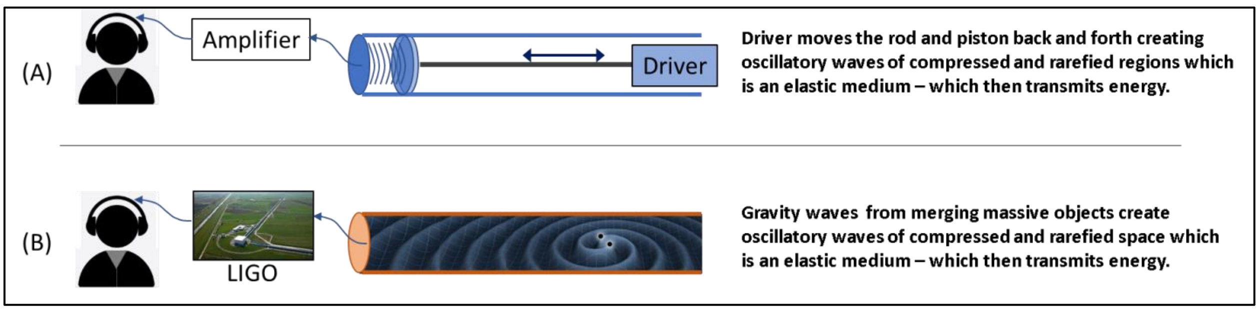

Figure 12: Analogy for acoustic and gravitational waves showing that both waves transmit energy that can then be detected and turned into an audio signal.

Figure 13 illustrates the effect of a steady-state rarefaction of the air as the piston is pulled slowly outward from the cylinder. The required force to create the rarefaction is dependent upon the difference in pressure outside minus the pressure inside multiplied by the area of the piston. These pressure differences are affected by the properties of the air that had transmitted the sound waves in Figure 12 (A).

Extending the analogy to illustrate the steady state rarefaction as space is expanded; Figure 13 (B) shows that a force F would be required to create this rarefaction. The force would be related to the energy observed in the compression and rarefaction of gravity waves (maximum and minimums in the wave trace) imparted by the merging massive objects.

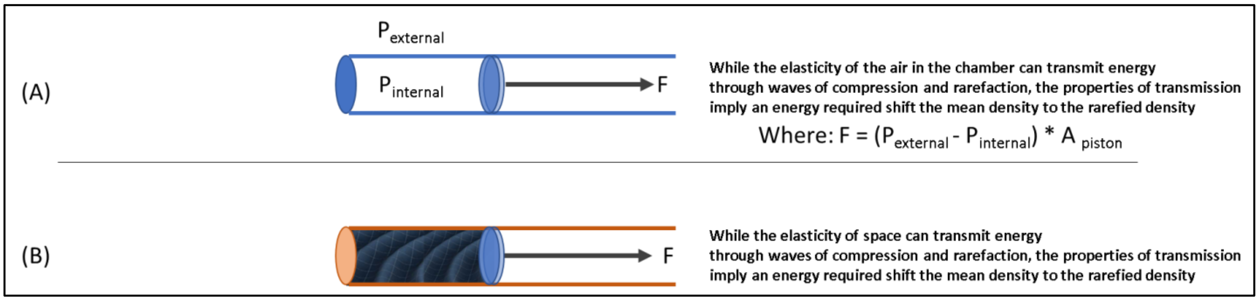

Figure 13: Analogy showing forces, F, required to expand the wave-supporting medium of air (A) and space (B) assuming the energy to create a steady-state rarefaction is related to the properties of compression and rarefaction of the associated wave type.

Because the quick reversion to a steady state after the gravity waves subsides implies the stiffness of space, and the large amount of energy required to perturb space, there appears to be an inconsistency with the concept that the expansion of space, implied by the scale factor, is simply a property of space. The energy associated with space, itself expanding is indicated by the magnitude of the forces required to rarefy space as shown in Figure 12 (B). Because of this inconsistency, an alternative explanation that does not invoke space, itself expanding, is worth considering.

15. Cosmic Microwave Background

A phenomenon known as the Cosmic Microwave Background (CMB) is considered by many astrophysicists to be the strongest corroborating evidence for space, itself, expanding. The CMB is hypothesized to be the presence of "left-over" fossil radiation from the birth of the universe. This fossil radiation is theorized to have originated in hot plasma when energetic photons of the Big Bang were trapped in a mixture of electrons and their associated hydrogen, helium and lithium nuclei.

At the moment of the Big Bang, it is estimated that the singularity had an initial temperature of a nonillion K[xli] which then expanded and cooled. It is hypothesized that the building blocks of our Milky Way galaxy were located squarely within the interior of the hot plasma of this proto universe.

Approximately 380,000 years after the Big Bang, the plasma is assumed to have expanded and cooled to approximately 3,000 K. At this temperature, electrons could permanently recombine with the hydrogen, helium and lithium nuclei to form stable atoms instead of being constantly ionized by a bombardment of very energetic photons. Once this occurred, the less energetic photons could travel unimpeded in all directions – outward, laterally as well as inward toward the embryonic Milky Way. These photons are assumed to have had a distribution of energies associated with a perfect back body radiator of 3,000 K. Curiously, this black body radiation is devoid of absorption or emission lines either from its origin or its travels through the evolving universe toward the Milky Way where we now observe a stretched, greatly red-shifted, version of an assumed perfect black body radiator.

According to current theory, the expansion of space has stretched the wavelength of the CMB photons by a factor of approximately 1,100. Due to this expansion, the initial black body radiation of 3,000 K that was present when electrons permanently recombined is now observed as radiation associated with a perfect 2.7 K black body[xlii]. Because space has expanded so much after the era of recombination, the CMB black-body radiation has been traveling inward, through the evolving universe toward our Milky Way, for the last 13.7 billion years.

Because the Milky Way was squarely within the interior of the plasma, we are seeing the inner layer of a sphere of energetic photons finally reaching us equally from all directions 13.7 billion years later. It has taken the original CMB radiation that long to reach us because of the interplay between electromagnetic waves approaching us at the speed of light and space expanding so that it takes longer for the light to travel to us. This is similar to standing at the top of a descending escalator and watching someone run up the escalator and finally reach the top—noting that this person's ascension took many times longer than if the same person ascended with the escalator turned off (e.g., the stair case was not expanding).

These photons were hypothesized to be the source of the microwave radiation observed by Penzias and Wilson in 1965. Satellites such as COBE and other terrestrial and atmospheric observations have confirmed the presence of a black-body emission spectrum (the monopole) of 2.7K from the perspective of the Earth that is remarkably uniform.

However, the 2.7 K CMB monopole has only been measured in the vicinity of Earth and has not been reported by the Planck Satellite from its orbit at the earth-sun L2 point (or any other significantly remote observation away from the Earth). Additionally, the error bars on the COBE measurements are frequently scaled-up by a factor of 400 so that they would be visible. Such a high signal-to-noise ratio suggests a proximal source for the observation. A source originating 13.7 billion years ago when electrons permanently recombined would have encountered non-trivial amounts of hydrogen, helium and lithium atoms with various levels of electron states during their travels. These travels, beginning during the era of recombination, would have left their mark on the hypothesized black body spectrum.

For purposes of this paper, the CMB will be assumed to be either a proximal source associated with the Earth or originating from another possible mechanism that is yet to be determined. Until the CMB is measured and reported at a distance remote from the earth, the CMB will not be viewed as contradictory evidence against this hypothesis. It will, however, remain as a troubling and unresolved curiosity.

16. Testing the Hypothesis

To measure directly the effect of a gravitational attraction of photons in laboratories we would need to measure light 19 orders of magnitude finer than the current best measurement. Interferometry techniques[xliii] such as those used in LIGO and other types of telescopes may be useful to perform an insightful experiment.

For example, it may be possible to leverage the interferometry capabilities of two telescopes of a Very Large Telescope Array[xliv] as shown in Figure 14 in conjunction with a laser. In this experiment, a strong laser pulse is sent toward a distant object that being observed by VLT #1 and VLT #2 (A).

If the hypothesis whereby gravitational attraction of countervailing photons cause redshift is valid[xlv], the interferometry should show a detectable change associated with the light from the observed object when the Earth rotates such that VLT #1 receives light that would have been slightly redshifted by the outward-bound laser pulse as compared to the light seen by VLT#2 (B).

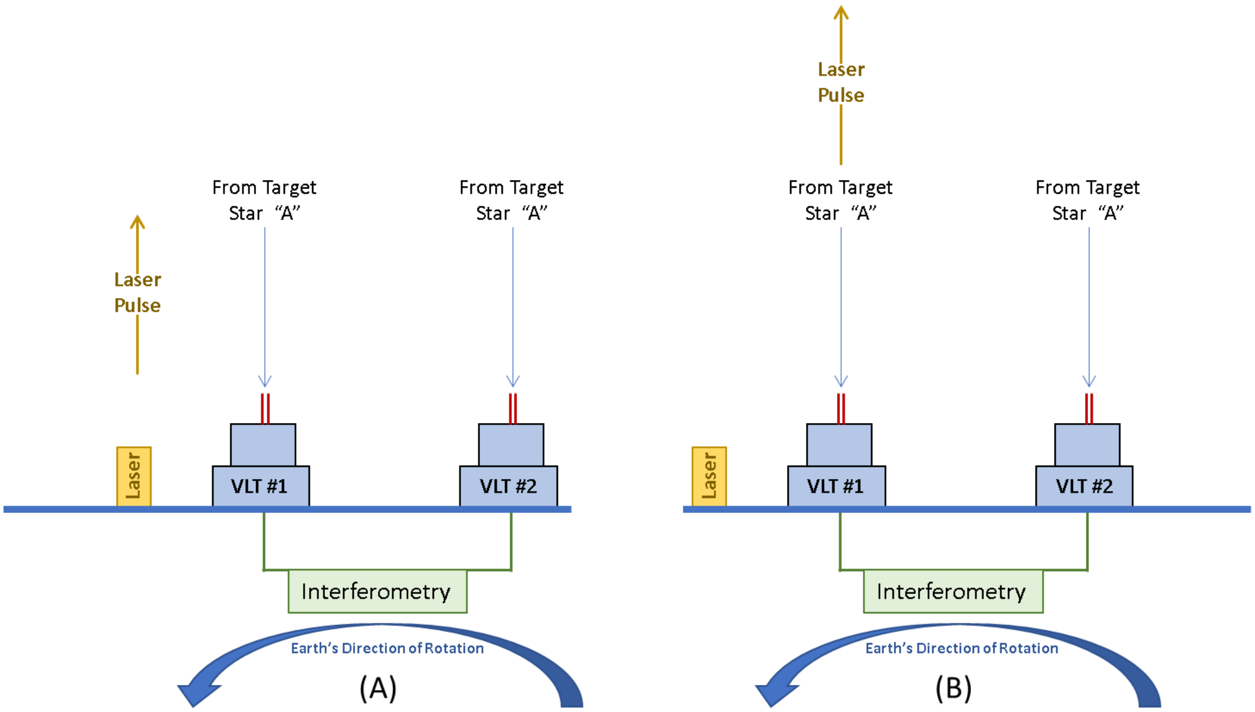

Figure 14: VLT with laser probe in (A) emits a known source of light toward Star "A" which, as the Earth rotates VLT #1 into position on (B), interferometry will identify a momentary redshift in VT#1 as compared to VLT #2.

If the laser pulse lasted for 1 second and remained aligned with the incoming light stream of target star "A" as seen by VLT#1, then the experimental column of photons affected by the laser would be 300,000 km long – or approximately 40,000 times longer than would be possible at LIGO.

This experiment can be varied to better quantify the effect by using lasers with different amplitudes to create different magnitudes of countervailing photon fluxes to see the effect. Additionally, the effect of different frequencies could also be investigated to quantify the sensitivity to countervailing photon energies.

Due to the need for precise alignment of the outgoing laser, it would be a challenge to construct an experiment as described above. However, with the astronomical community's widespread use of adaptive optics and the selection of a powerful laser with a wavelength that would have minimal atmospheric absorption, this may be a meaningful experiment that can be performed rather quickly.

A second possible test of the hypothesis would be if a target star could be identified that had been catalogued with a well measured redshift, that then had a supernova explode approximately in the line of sight, the incoming photons of the target star could now be redshifted by an incremental amount due to the interaction with the countervailing photons from the supernova. Figure 15 shows three steps in such a validation. In (A), the measured redshift of the "Distant Galaxy" was observed before the supernova event. In (B), an unremarkable star goes supernova and provides a perturbation by emitting many energetic photons. Some of these photons will pass by the photons from the "Distant Galaxy." In

(C), the light from the supernova and the photons from the "Distant Galaxy" encounter each other. When their *past light cones* overlap, they exchange some kinetic energy for gravitational energy. This increases the redshift of the photons from the "Distant Galaxy."

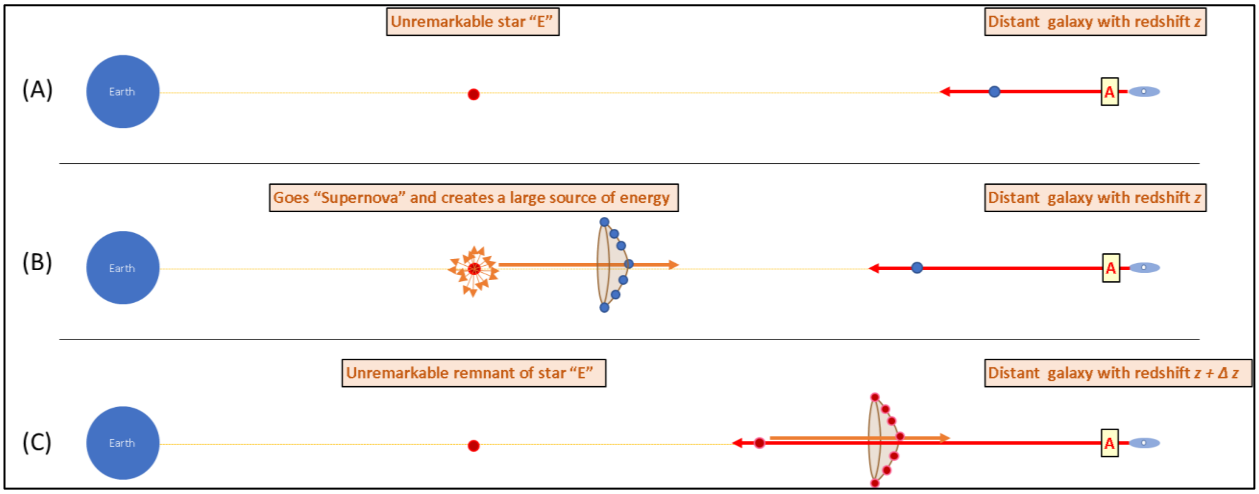

Figure 15: Possible technique for measuring the impact of countervailing photon flow on the observed redshift of a distant galaxy

The ability to detect a sufficiently large change in the redshift at an appropriate confidence level using this later approach is questionable. However, the mechanism described in this experiment may be useful in explaining differences in redshift between stars that should be at the same distance based on received flux from a standard candle.

It is hard to imagine differences in distances between nearby objects under an expanding space hypothesis, whereas it would be reasonable to expect some amount of non-uniform light flux anisotropies due to events shown in Figure 15.

17. Conclusion

This paper reframes the observed redshift associated with the Hubble Constant from an expansion of space itself into a natural outcome of the conservation of energy as passing photons exchange a portion of their kinetic energy for gravitational potential energy once their *past light cones* overlap and they become "aware" of each other. The physics underlying this exchange of energy is consistent with the principle of conservation of energy and Einstein's Field Equations. While energy is conserved, the effect is caused by a temporary asymmetry caused by the time it takes for light, gravity and energy to travel. This temporary asymmetry is allowed and can last for an eternity.

As allowed by General Relativity, the gravitational attraction of photons to each other has been acknowledged since the 1930's because the energy of photons creates a non-zero energy-momentum tensor. In recent years gravitational attraction of photons has become an area of study in high-speed lasers because of it is potential to cause detectable distortions in laser pulses.

Under the proposed hypothesis, objects in the universe are not moving away from the Earth at ever increasing velocities in all directions as the scale factor *a(t)* paradigm posits. Rather the photons in electromagnetic radiation from distant objects lose energy as they approach Earth because they encounter photons in electromagnetic flux from a countervailing direction.

The Hubble constant is reframed into different units that are more appropriate for this energy exchange hypothesis. The notation H_{0w}, is used where the subscript "w" denotes that the Hubble Constant is being expressed in terms of increasing wavelength with distance. The notation H_{0f}, is used where the subscript "f" denotes that the Hubble Constant is being expressed in terms of decreasing frequency.

Gravity waves are also examined as part of this hypothesis because they appear to have several important properties. First, because gravity waves contain energy, they too will contribute to the redshift of light incoming to Earth because of the same asymmetry and principles that applied to electromagnetic radiation. Secondly, they provide a qualitative basis for demonstrating the amount of energy needed for space, itself, to expand. The energy required to compress space followed by the rarefaction of space and the eventual return of space to a state of quiescence suggests an amount of energy needed to drive the expansion of space would be unimaginably large. This missing energy suggests an alternative hypothesis that is based on the conservation of energy should be considered.

Finally, two tests are proposed that could demonstrate the effect of an asymmetry associated with a powerful countervailing photon flow. The first would be based on a laser that could be detected using interferometry while the second could investigate the effect of a supernova on the redshift of a distant star of galaxy.

18. Epilogue

This reframing of the Hubble constant does not rule out the "space, itself, is expanding" hypothesis, but rather suggests an alternative explanation. The two effects could possibly be complimentary, and additive. If the proposed hypothesis can explain the majority of the observed redshift, then the need for the expansion of space, itself, hypothesis will have been greatly muted – if not ruled out.

In reflecting on the title of this paper, if the hypothesis that space, itself, is expanding is set aside as a result of this reframing, what is the meaning of the word biggest? The Lemaitre hypothesis and subsequent extensions suggests a Universe that will expand and approach an infinite size (e.g., it gets really big). However, if the Universe is not expanding, is it infinite already? Hopefully, the James Webb Telescope and the further efforts of the astrophysics community will increase our understanding of the cosmos.

This hypothesis, the Coste Conjecture, may provide a better frame to understand the Hubble Constant, but as the march of science has shown over the last millennia, theories evolve and possibly other explanations will fit the observations better.

END

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[i] One megaparsec (Mpc) is approximately 3.26 million light years.

[ii] Light cone, Wikipedia, https://en.wikipedia.org/wiki/Light_cone

[iii] Einstein's equation tells us that a light beam contains energy and momentum which curves (deflects) space-time around it. This is referred to as gravitational attraction., https://arxiv.org/pdf/1902.07287.pdf

[iv] Hubble's Law and the expanding universe, Neta A. Bahcall, Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, https://www.pnas.org/doi/epdf/10.1073/pnas.1424299112

[v] *"Georges Henri Joseph Édouard Lemaître was the first to theorize that the recession of nearby galaxies can be explained by an expanding universe, which was observationally confirmed soon afterwards by Edwin Hubble. He first derived "Hubble's law" and published the first estimation of the Hubble constant in 1927, two years before Hubble's article. Lemaître also proposed the "Big Bang theory" of the origin of the universe, calling it the "hypothesis of the primeval atom", and later calling it 'the beginning of the world'.,"* Georges Lemaître, Wikipedia, https://en.wikipedia.org/wiki/Georges_Lemaître

[vi] Who Really Discovered The Expanding Universe?, Ethan Siegel, https://www.forbes.com/sites/startswithabang/2018/11/13/who-really-discovered-the-expanding-universe/

[vii] *"The increase in size [of the universe in the aftermath of the Big Bang] does not contradict relativity, however, because it is accomplished by the stretching of space itself, and Einstein's theory of relativity places no limit on how fast space can stretch. Rather, the speed limit applies only to the motion of matter and information through space, so the theory implies that two objects cannot pass each other at speeds exceeding light.,"* Pasachoff, J. M., & Filippenko, A. (2019, 5th Edition). The Cosmos: Astronomy in the New Millennium. Cambridge University Press. p 609.

[viii] The use of the word "medium" here implies empty space and does not refer to the luminiferous aether that was the subject of the Michelson–Morley experiment.

[ix] Inflation (cosmology), Wikipedia, https://en.wikipedia.org/wiki/Inflation_(cosmology)

[x] Gravitational redshift, Wikipedia, https://en.wikipedia.org/wiki/Gravitational_redshift

[xi] Einstein ring, Wikipedia, https://en.wikipedia.org/wiki/Einstein_ring

[xii] Eddington experiment, Wikipedia, https://en.wikipedia.org/wiki/Eddington_experiment

[xiii] https://solarsystem.nasa.gov/news/12249/saturn-bound-spacecraft-tests-einsteins-theory/

[xiv] *"But in a relativistic theory of gravity, mass cannot be the only source of gravity. Relativity links mass with energy, and energy with momentum. The equivalence between mass and energy, as expressed by the formula $E = mc^2$, is the most famous consequence of special relativity. In relativity, mass and energy are two different ways of describing one physical quantity. If a physical system has energy, it also has the corresponding mass, and vice versa. In particular, all properties of a body that are associated with energy, such as its temperature or the binding energy of systems such as nuclei or molecules, contribute to that body's mass, and hence act as sources of gravity.,"* https://en.wikipedia.org/wiki/Introduction_to_general_relativity

[xv] Macleod, A. (2005). Do redshifted cosmological photons really violate the principle of energy conservation?, arXiv preprint physics/0511178 https://arxiv.org/ftp/physics/papers/0511/0511178.pdf

[xvi] Much of a proton's mass comes from the energy of the particles inside it, Science News Explores, https://www.snexplores.org/article/much-protons-mass-comes-from-energy-of-particles-inside

[xvii] [TBD] Light has energy, momentum, and puts a pressure in the direction of motion. All of these things contribute to the stress-energy tensor. Therefore, according to the Einstein field equation, the conclusion that light produces gravitational effects is unambiguous.

[xviii] [TBD] Wikipedia reference General relativity I believe.

[xix] Photovoltaic conversion of electromagnetic radiation from the sun into electrical energy (e.g., solar cells) is an everyday example of this aspect of physics.

[xx] Dispersing this recoil effect into a crystal lattice to minimize the effect is demonstrated in the Mössbauer effect whereby the recoil energy is treated as being applied to the entire lattice mass $M >> m$, that greatly reduces the effects of the recoil.

[xxi] *"As to the behavior of the test rays, we shall find that a ray of light moving parallel to the pencil and in the same direction would have unit velocity, the same as that in the pencil itself; but in the case of rays moving in other directions we shall find that they would suffer a gravitational disturbance when in the field of the pencil."* Richard, C., Paul Tolman, And Norman Bridge, *On The Gravitational Field Produced By Light.,* https://authors.library.caltech.edu/1544/1/TOLpr31a.pdf

[xxii] Schneiter, Fabienne, Dennis Rätzel, and Daniel Braun, *The gravitational field of a laser beam beyond the short wavelength approximation*, Classical and Quantum Gravity 35.19 (2018): 195007, https://iopscience.iop.org/article/10.1088/1361-6382/aadc81/pdf

[xxiii] The gravitational attraction of photons within a laser pulse, although not detectable at the moment, continues to attract attention.
[xxiv] Vesto M. Slipher, Wikipedia, https://en.wikipedia.org/wiki/Vesto_M._Slipher
[xxv] Cepheid variable, Wikipedia, https://en.wikipedia.org/wiki/Cepheid_variable
[xxvi] The distance ladder and its calibration, Jones, M. H., & Lambourne, R. J. (Eds.). (2015 Second Edition). Galaxies and cosmology. Open University, p. 77
[xxvii] Hubble's Law and the expanding universe, Neta A. Bahcall, Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, https://www.pnas.org/doi/abs/10.1073/pnas.1424299112
[xxviii] Scale factor (cosmology), Wikipedia, https://en.wikipedia.org/wiki/Scale_factor_(cosmology)
[xxix] Relativistic values calculated for Ho = 69.6, OmegaM = 0.286, Omegavac = 0.714, Edward L. Wright. (2006, PASP, 118, 1711). Last modified on 07/23/2018 17:22:14, https://www.astro.ucla.edu/~wright/CosmoCalc.html
[xxx] Continuing out further, the effect of H_{0w} would be to continually redshift distant galaxies to longer wavelengths so that the visible light from them would be redshifted into wavelengths invisible to human eyes, thus providing a satisfactory explanation of Olber's Paradox of a dark night sky.
[xxxi] LIGO, Wikipedia, https://en.wikipedia.org/wiki/LIGO
[xxxii] LIGO: Observatories and Collaborations https://www.ligo.caltech.edu/page/observatories-collaborations
[xxxiii] "LIGO and Virgo make first detection of gravitational waves produced by colliding neutron stars, Discovery marks first cosmic event observed in both gravitational waves and light," GW170817 Press Release, https://www.ligo.caltech.edu/page/press-release-gw170817
[xxxiv] P 125 of 187, https://courses.edx.org/assets/courseware/v1/3b02eb81d147b6e53d390ad62ac2a8c7/asset-v1:ANUx+ANU-ASTRO1x+2T2020+type@asset+block/A1_Combined_Transcripts.pdf
[xxxv] Energy radiated: 3.0 ± 0.5 solar masses, from "A primer on LIGO and Virgo gravitational wave detection," Jo van den Brand, Nikhef and VU University Amsterdam, Maastricht University, CERN Academic Lectures, Geneva, October 9-11, 2019, https://indico.cern.ch/event/806260/attachments/1923785/3186015/CERN_Academic_Lecture_2_Jo_van_den_Brand.pdf
[xxxvi] A mechanical spring analogy would show that if a stiff truck spring was energized by a one newton impact force it would deform, quickly rebound and then settle to a stable state, while a 'slinky' would have a much longer deformation and a slower restoration period.
[xxxvii] An integration of the waveform was not done to support the assertion that the sum of the captured differential summed to zero. While error bars for the measurements were not provided, the traces suggest a summation to zero.
[xxxviii]
https://commons.wikimedia.org/wiki/File:First_gravitational_waveform_ever_seen,_PhysRevLett.116.061102.pdf
[xxxix] "Gravitational Waves and How They Distort Space," https://www.universetoday.com/127255/gravitational-waves-101/
[xl] https://sci.esa.int/web/lisa/-/31417-gravitational-waves and https://web.archive.org/web/20050307235616/http://esapub.esrin.esa.it/br/br164/LISA.pdf
[xli] Our expanding universe: Age, history & other facts, Charles Q. Choi, Ailsa Harvey, March 15, 2022, space.com. https://www.space.com/52-the-expanding-universe-from-the-big-bang-to-today.html
[xlii] Wavelengths that originated with a black body centered at 3,000 K would that is not observed at 2.7 K implies a redshift of z = 3000/2.7 ~=1,100.
[xliii] Interferometry, European Southern Observatory, https://www.eso.org/public/teles-instr/technology/interferometry/
[xliv] Very Large Telescope, Wikipedia, https://en.wikipedia.org/wiki/Very_Large_Telescope
[xlv] *"Throughout the history of science, theoretical arguments and mathematical reasoning have settled relatively few debates. Much more often, it's new observations and data that end arguments and change minds."* Hooper, D. (2019). At the Edge of Time: Exploring the Mysteries of our Universe's First Seconds (Vol. 31). Princeton University Press, p. 36.

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Appendix – Comments – Not Yet Incorporated

One of the comments communicated to the author has noted the similarity of the hypothesis to the concept of "tired light" as first put forth by Fritz Zwicky in 1929. While similarities exist, Zwicky (or others) never put forth a mechanism for tired light. A proposed mechanism underlying the concept of "tired light" is a central concept presented in this paper; it is explained as an exchange of kinetic energy for an equal amount of gravitational energy between passing photons.

Below are a few interesting quotes that will be considered in a future expansion of this appendix.

"Finally, it might be interesting to study the gravitational drag exerted by light upon light."
On The Redshift of Spectral Lines Through Interstellar Space, F. Zwicky, October 15, 1929,
https://doi.org/10.1073/pnas.15.10.773

Nevertheless, the possibility that the red-shift may be due to some other cause, connected with the long time or distance involved in the passage of light from nebula to observer, should not be prematurely neglected; and several investigators have indeed suggested such other causes, although without as yet giving an entirely satisfactory detailed account of their mechanism.

Until further evidence is available, both the present writers wish to express an open mind with respect to the ultimately most satisfactory explanation of the nebular red-shift and, in the presentation of purely observational findings, to continue to use the phrase “apparent” velocity of recession. They both incline to the opinion, however, that if the red-shift is not due to recessional motion, its explanation will probably involve some quite new physical principles.

Two Methods of Investigating The Nature of The Nebular Red-Shift, Edwin Hubble and Richard C. Tolman, 1935,
https://articles.adsabs.harvard.edu/pdf/1935ApJ....82..302H

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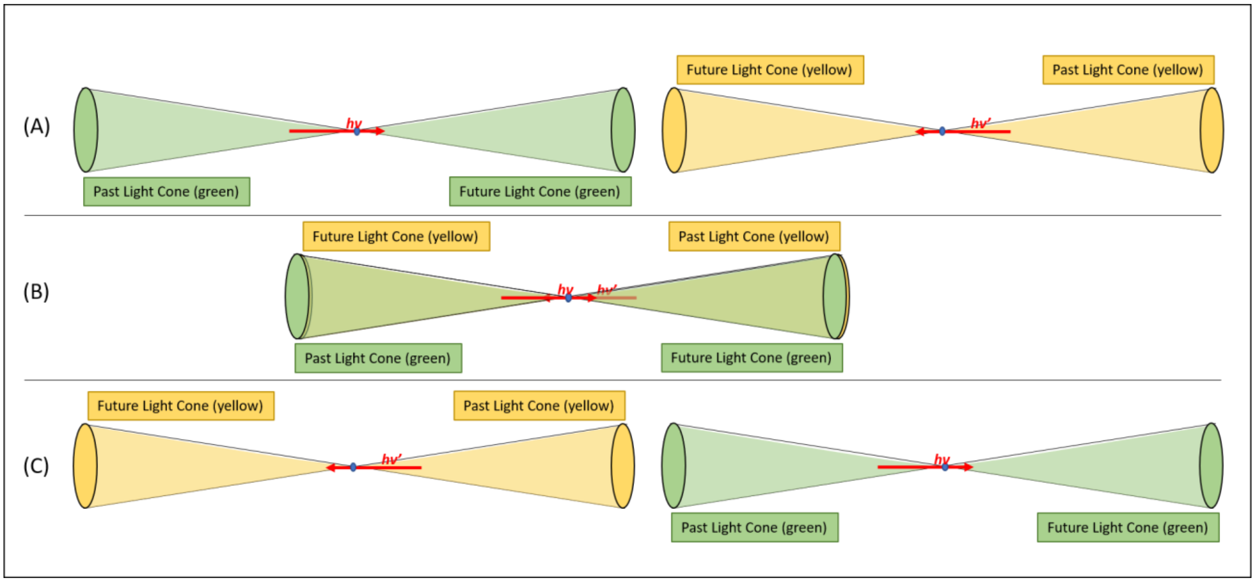
" Ultimately ... the number of competing interpretations will be reduced to a minimum."

Thus is red-shifts do measure the expansion of the universe, we may be able to gather reliable information over a quarter of its history since expansion began, and some information over nearly a half of the history."

The Law of Red-shifts: George Darwin Lecture, delivered by Dr Edwin Hubble on 1953 May 8, Monthly Notices of the Royal Astronomical Society, Volume 113, Issue 6, December 1953, Pages 658–666,
https://doi.org/10.1093/mnras/113.6.658, https://academic.oup.com/mnras/article/113/6/658/2602016



I am not sure I understand your focus on the aspect of a "dimensionless point." To me issue is that before the photons pass each other, they cannot be aware of each other's energy (e.g, issue). Once they pass each other, their energy will be behind them (e.g, issue) and that energy will add to the aggregate mass/energy behind them -- thus an increase the curvature of space behind it. This will then impart some additional gravitational energy into the system which must come form somewhere. I see this as coming from the photon that becomes redshifted.

To answer your question, this is a continuous process with each passing photon adding a little more energy to the past light cone. If the electromagnetic (and gravity) wave flux is constant the effect would be linear. One of the complaints about the Compton scattering explanation of Tired Light was that voids -- with their few electrons to scatter photons -- had no effect. However, voids are just as full of electromagnetic (and gravity) wave flux as any other denser area -- so the hypothesized effect isn't affected by voids.

I added a Figure 17 to the paper in the Appendix A2 to illustrate the question you seem to be interested in -- but I used Earth, a baseball and an asteroid as the active elements.