Cosmological Redshift Mechanism

by R. F. Vaughan

It has been shown in the paper, 'Edwin Hubble's Discovery' (available on this site) that redshift is a distance related phenomenon. It is an inherently unitless parameter that has been given units of velocity by cosmologists to satisfy their urge to explain it as a recessional Doppler phenomenon because that was the only mechanism known to produce such an effect on spectra. But defining units of v/c doesn't change anything. Observations do not demonstrate a velocity interpretation; what is demonstrated is the distance association – the fainter the spectrum of an object, the greater its redshift. That's all we have. In the paper 'The Proximate Cause of Cosmological Redshift' (also available on this site) I have shown that a fixed increase in wavelength, as a photon propagates in a non-vacuous medium through each successive distance equal to its *extinction interval*, ultimately effectuates the observed cosmological distance-redshift relation. The extinction interval is the distance required for the speed of light to adjust appropriate to the electron density of a medium. In this paper we demonstrate the details of the mechanism that produces that effect.

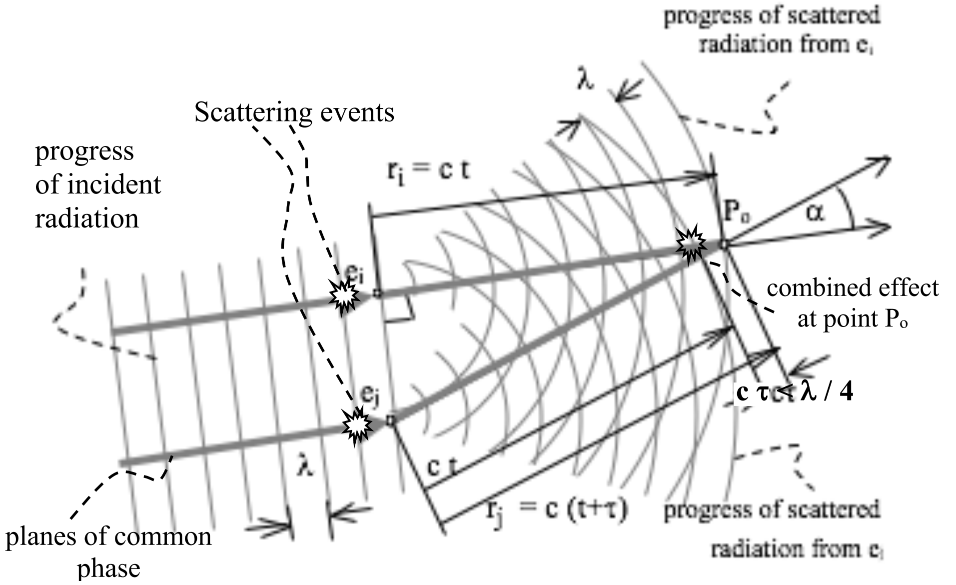
It may be passe to say that nature abhors a vacuum, because in fact, everyone knows that it does. But the term 'vacuum' like any other scientific term must be quantified. As with everything else, there are degrees to which a situation adheres to a definition. Quantification in this case is measurable density – a null value defines a vacuum. With regard to radiation passing through a region of space, it is its electron density that determines propagation characterization. It is the negatively charged electrons for which electric field variations in radiation cause them to alter their locations in resonance with the electrodynamic wave function oscillations of the radiation. They are thousands of times less massive than associated positive ions that cannot respond in resonance.

Although there is a universal constant that represents the speed of light in a vacuum, it is never completely realized except for unmitigated direct interactions between submicroscopic particles. The speed of light is altered in propagating through a medium as one aspect of a process known as forward scattering. Kirckoff rigorously refined Huygen's wave propagation process as electrons along the general direction of a photon's path contributing to photon replacement by out of phase secondary radiation produced by resonating electrons. Earlier Born and Wolf performed a thorough analysis of this process which led them to the conclusion that there would be no change in the wavelength of radiation as photons were repeatedly replaced by out of phase counterparts. Significantly however, relativistic effects were not considered in their analyses. A change in wavelength would correspond directly to a change in energy, so their conclusion was that there was no exchange of energy in this process. But physical processes involve energy exchanges by their very nature – no tickie, no washie. It's that simple. One must reject the notion that forward scattering does not alter the wavelength of replaced photons. Exchanges of energy may be small, but they must exist. Always. That is the lesson of entropy. There is no free lunch. Processes that seem to be reversible are only thought to be so because the irreversible (frictional) associations are too small to measure.

The breakthrough into the cause of cosmological redshift is the realization that however sparse electron density in intergalactic plasma, forward scattering of photons does occur. The tremendous distances to redshifted galaxies accommodate an extremely large number of scattering events in the propagation of a photon from such distant regions of the cosmos to observation here on earth, notwithstanding the fact that individual photon replacement intervals involve astronomical distances. Energy exchanges occur for all physical processes and are observable over sufficient periods of time – billions of years in this case. So what did Born and Wolf miss? It had to be in their having ignored relativistic effects.

What is involved in the forward scattering process is that photons are 'cloned' by a replication process – one formerly thought to be reversible. Any net change in the dynamic state of an ensemble of electrons involved in replication must involve a transfer of energy and momentum from the photon to the electrons. The most famous advocate for this *not* happening was Yakov Zel'dovich who averred that the electrons whose motions are altered in the process must return immediately to their former state after the replication has taken place. In short, that there can be no net transfer of energy or momentum from the photon to the electrons; thus, no red shifting of radiation associated with the scattering process. This opinion became a final nail in the coffin of all so-called 'tired light' theories of cosmological redshift, a possibility had initially been favored by Edwin Hubble and others. As proof, Zel'dovich claimed that if he was wrong, the direction of photons would be altered, ultimately blurring, and totally obscuring images of distant galaxies after the innumerable replications. He was less resistant to accepting previously unknown and definitively invisible dark matter to produce observed effects. It turns out that there is a mechanism whereby energy and momentum *are* transferred to scattering electrons that does not alter the direction of the photon despite the requisite decrease in momentum and energy of the photon. The mechanism involves coherent constructive interference of scattered radiation that is the essential aspect of forward scattering but now including the effects of relativistic motions of the scattering electrons.

A photon of radiation is a wavefunction involving on the order of several million oscillations of virtually identical wavelength. Thus, a photon of visible light is less than a foot long, its *coherence length*. To coherently interfere, the photons must overlap in time and space. Two photons of identical wavelength propagating in the same direction within the coherence length of each other will result in a wave function of the same wavelength but with an amplitude somewhere between zero and twice the amplitude of the original photons. When directions are not identical as in the case of the secondary radiation given off by two electrons in the figure below, they can still positively interfere at the point P_o if the angle between the directions accommodates their emanations being less than a quarter wavelength out of phase.



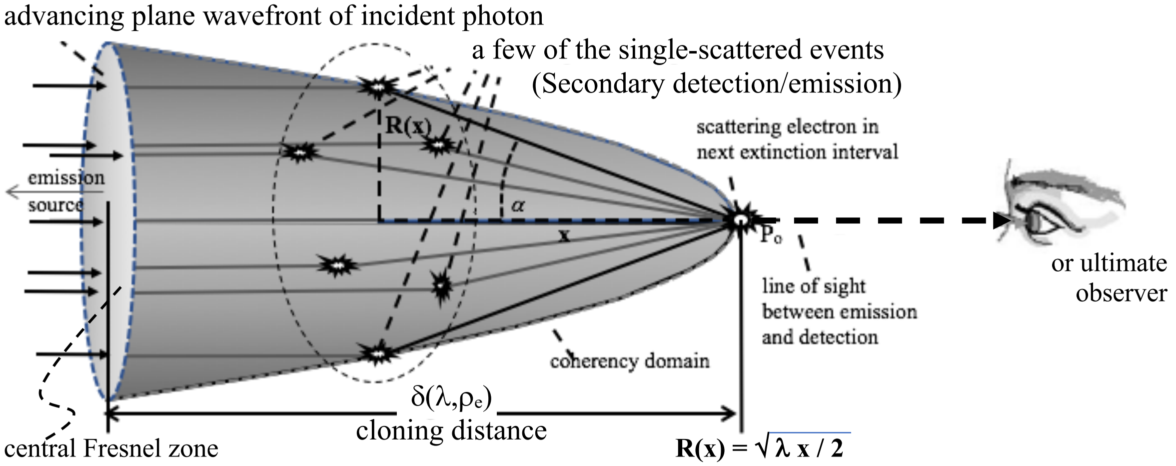
Conditions for in-phase coherent forward scattering

This constraint of in-phase coherent reinforcement defines a domain along the direction of propagation throughout which electron scattering contributes to a process of reinforcing secondary radiation. Ultimately this out of phase secondary radiation will overwhelm (extinguish by doubling the amplitude of) the incident radiation and replace it. This *coherency domain* is defined as a central Fresnel zone. Outside of this zone, reinforcement alternates between destructive and constructive so that the net effect is small from outside this central region. A line to/from any point in the central Fresnel zone is no more than a quarter wavelength greater in length than along the centerline to the point P_o. See the next figure.

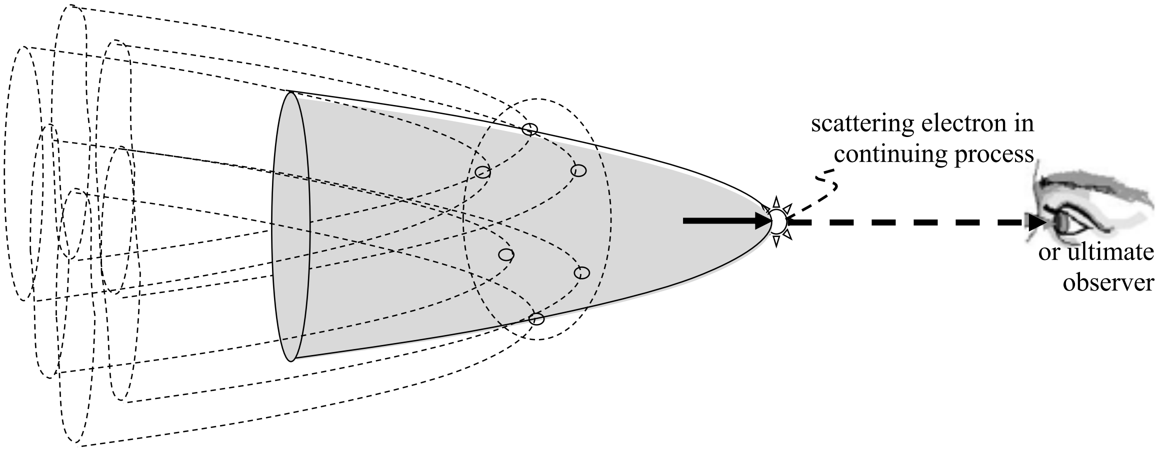
The length of this domain as applied to forward scattering is inversely proportional to electron density and wavelength of the radiation. The length of this domain is this extinction interval of how far light must travel through a medium before the incident radiation is extinguished and the speed of light and other characteristics are altered by the density of scattering electrons in the new medium rather than that of a medium it may have just left. The accepted functionality and value of this extinction interval distance is:

$$\delta(\lambda,\rho_e) \approx m_e\, c^2 / (\rho_e\, e^2\, \lambda) \cong 3.55 \times 10^{12} / \lambda\, \rho_e \text{ cm.}$$

Here m_e is the mass of an electron, c the speed of light in a vacuum, ρ_e is the electron density, and λ is the wavelength of the radiation. These domains are actually much more needle-like than as shown.



Parabolic coherency domain in a scattering medium



Collaborative coherency domain contributions

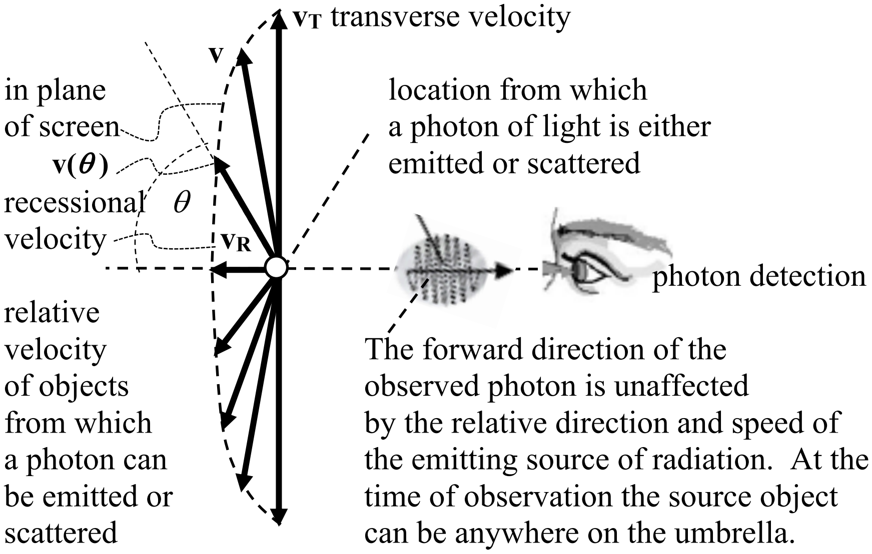
Forward scattering is a continuous process, not discrete, involving all electron in the path of the incident radiation. For visible light, the number of electrons involved in a single cloning process despite their sparsity in intergalactic plasma is on the order of 10^{36}. The coherency domains may be as much as several thousand light years in length and thousands of square miles at their base.

That is how forward scattering works, but we need to address ramifications of the relativistic effects of scattering electron motions. These effects result from the high temperatures that disassociate electrons from positive ions in the intergalactic medium, producing extreme thermal motions of the freed electrons. High velocity electrons as in a plasma such as this require a revised conclusion to Born and Wolf's otherwise completely valid results. Interpreting Hubble's discovery of increasing redshift with distance as a Doppler effect of recessional velocities of observed objects had been accepted by default since there had seemed to be no other viable mechanism to produce redshift. As observed redshifts become larger with increased distance, this required relativistic treatment, but that requirement pertained either to conjectured velocities of the original sources of the radiation or to a perceived expansion of space itself. The transverse aspect of relativistic treatment is different. There is another facet of Einstein's relativity.

Electromagnetic wave functions induced at high-speed scattering electrons exhibit longer wavelengths because of a transverse component addressed by Einstein's special relativity. Even without recessional velocities of distant sources of radiation, induced secondary emissions from high speed electrons along a propagation path are unilaterally redshifted with a cumulative effect indistinguishable from a recessional Doppler redshift of photons emitted directly from the observed object. That the effect is unilaterally to increase redshift is because the transverse component of relativistic Doppler is a second order effect in v/c and so, no matter the direction of the velocity, the result is always additive. With regard to the approaching and receding scattering electrons, these red and blue shifts do, in fact, cancel after many extinction intervals.

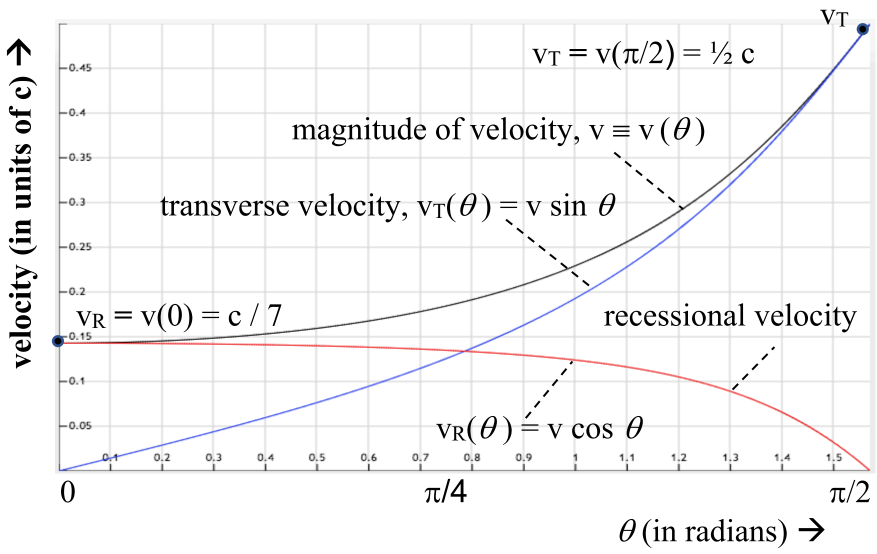
The following diagram illustrates the effect of the transverse velocity v_T of scattering electrons. The following plot shows the equivalence between recessional v_R and transverse Doppler redshift effects.

Redshift: $Ƶ(v(\theta)) + 1 = (1 + (v(\theta) / c) \cos \theta) / (1 - v(\theta)^2/c^2)^{1/2}$



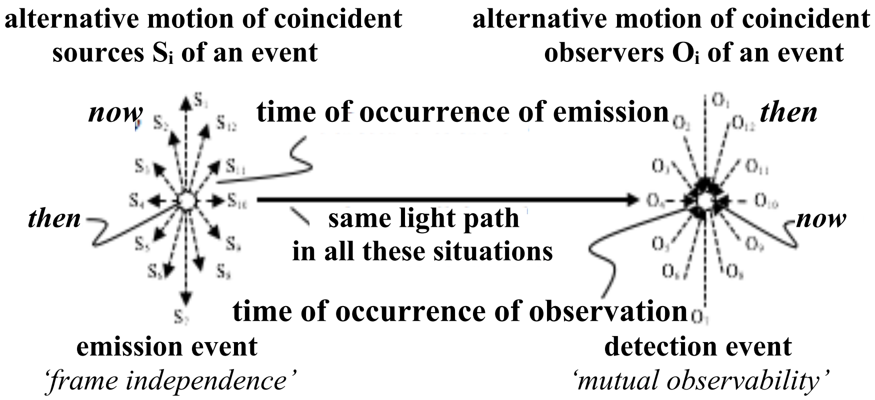
The forward direction of the observed photon is unaffected by the relative direction and speed of the emitting source of radiation. At the time of observation the source object can be anywhere on the umbrella.

Indistinguishability of Doppler redshift of an emitted photon caused by variously directed velocities of a source (whether primary or secondary)



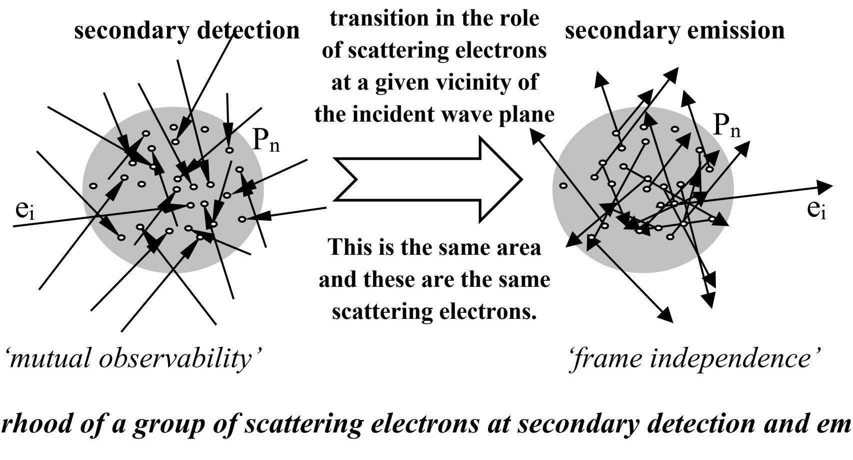
Range of electron velocity directions producing a redshift that is indistinguishable from a strictly recessional ($\theta = 0.0$) velocity v_R

Implicit in the Lorentz equations of Einstein's special theory is the concept of 'frame independence', which involves fixing an emission (of electromagnetic radiation) event relative in the observer's frame of reference independent of the velocity of the source of the radiation that is emitted. Radiation from sources that are in coincidence at the time of the emission event *will appear in the same direction* for an observer – any observer as shown in the following diagram. However, each observer with a unique relative velocity will observe the emission event in a unique direction dependent upon his relative velocity with respect to the event location.



'Frame independence' and 'mutual observability' in relativity

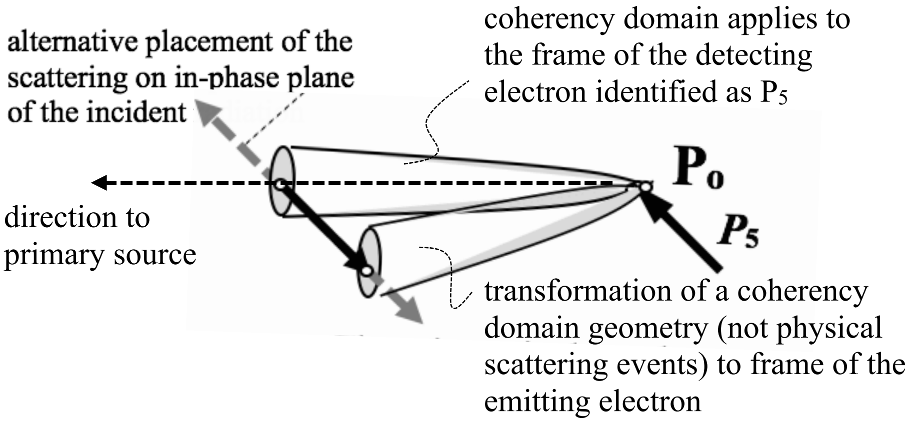
The scattering from electrons at or near the plane of common phase of the incident radiation (vertical cross sections of the coherency domains) involves a transition of electrons entering, to those leaving, an area of approximate coincidence where secondary emission takes place. The direction from which light is detected will depend upon the velocity of the detecting electron, but the secondary emissions from all electrons will be from the same coincident area at the next step in the propagation process. The direction from which light is detected will depend upon the velocity of the detecting electron, but the secondary emissions from all electrons will be observed from the same 'coincident' location when detected at a next step in the propagation process because of the frame independence of Einstein's relativity.



Neighborhood of a group of scattering electrons at secondary detection and emission

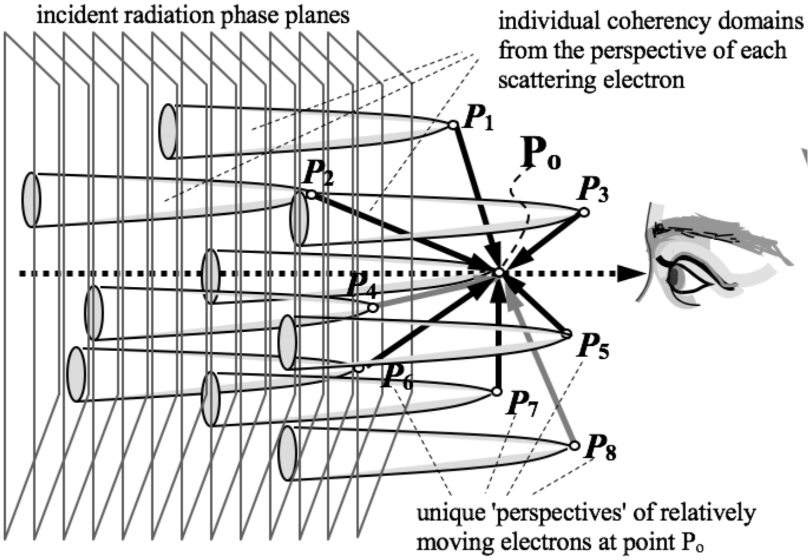
It may be somewhat confusing that each high-speed electrons is affected by (detects) light from a unique region on an incident wave plane. Each electron will emanations from electrons on the wave plane closest to the detecting electron at the instant that remote scattering took place in that region on the wave plane in the detecting electron's frame of reference. It is from the opposite direction of where relativistic aberration derives. Light detected by a coincident but relatively moving electron would have been emitted from a different location on the wave front. Secondary emissions from both region would occur simultaneously, but not in the frames of the two such relatively moving electrons. To be seen by the ‘other’ electron, the light would, in fact, be aberrated and not arrive until considerably later because of the non-simultaneity in their respective frames of reference.

Thus, relativistic phenomena significantly alter the coherency domains for the forward scattering process. The very concept of relative motion assures us that whether the velocity is considered that of an emitting or of a detecting electron is immaterial; they are one and the same. But the coherency domain is in the frame of the detecting electron (the *observer* in this case) so an electron moving parallel to a constant phase wave plane will detect scattered as well as incident light from the direction of the primary source. This is *not* the aberration effect; it is in the opposite direction and applies to uniquely separate rather than the same locations of coincident emission events.



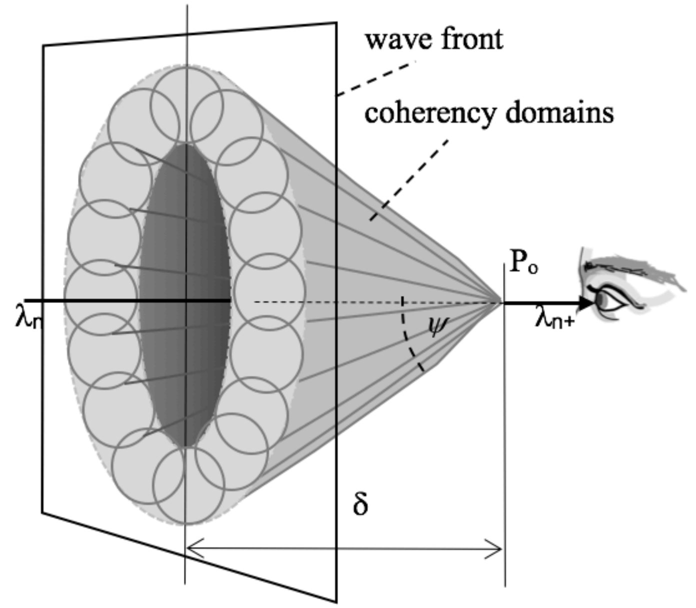
Different perspectives of a coherency domain for scattering electrons

The relativistic process is spread out into a collaboration of coordinated coherency domains, whose separations are proportional to the velocities of the scattering electrons. There is a convergence of these coherency domains where secondary scattered wave functions are finally detected by coincident scattering electrons. Thus, Zel’dovich was both correct and incorrect in his assessment of scattering in an intergalactic plasma medium. There is a momentum exchange and there is a bending of each light path, but because it is convergent rather than divergent – it always maintains the original radiation direction.



Composite of coherency domains for scattering electrons with various relative velocities to the line of sight to primary source

The ‘bending’ is relative to the perpendicular to the ‘locally stationary’ wave planes of constant phase of the incident radiation. These planes are fixed relative to the frame of the primary source of the radiation. This is equally true in the frame of the ultimate observer if the primary source is stationary with respect to the ultimate observer. The conservation laws to which Zel’dovich deferred are essentially those that pertain to the Compton scattering effect of energy and momentum being transferred to electrons. The electrons velocity (the variable in its kinetic energy and momentum) is the key parameter to the bending.



Convergence of secondary radiation at cloning event that constitutes Zel’dovich’s ‘bending’ of the light path without changing direction

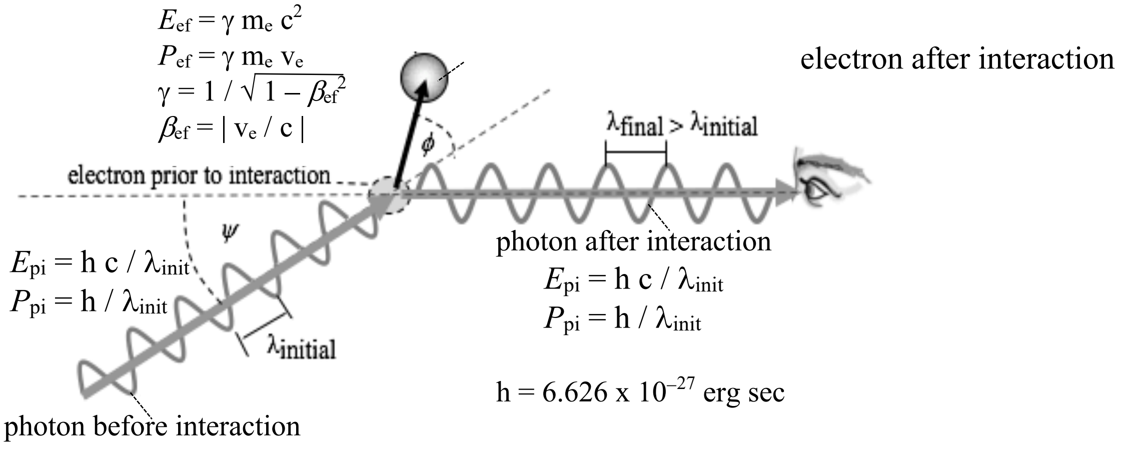


Illustration of similarity to Compton scattering conservation relations

The rationale for and values of the extreme electron velocities involves thermodynamic issues. The Maxwell/Boltzmann distribution of energies in a thermal plasma specifies the average root-mean-squared transverse velocity component $< v_e^2 >$ of electrons. The classical formula is:

$$\sqrt{< v_e^2 >} \approx \sqrt{3/2\ k\ T / m_e} = 4.77 \times 10^5 \sqrt{T} \quad \text{cm/sec}$$

The constant k is Boltzmann's constant and m_e is the mass of an electron. This solution is valid for temperatures T to about 10^8 K which is a value sometimes reached in intra-cluster plasma. The non-relativistic formula provides a fairly accurate approximation up to two or three percent of the speed of light.

It is the bending of the light path that transfers energy and momentum from the radiation to the medium as Zel'dovich averred in deference to Compton's analyses. Applying the results of Compton's conservation analysis to coherency domains of forward scattering, one obtains the following net change in wavelength detected by the electron at the end of each coherency domain and thus per extinction interval:

$$\Delta\lambda_\delta \approx 3\, h\, k\, T / 4\, m_e^2\, c^3 \approx 3.07 \text{ x } 10^{-20}\ T \text{ cm}$$

The constant h is Planck's constant. Thus, wavelength is increased at every extinction interval independent of a propagation path, but that is not in itself a redshift. The accumulated change in wavelength divided by the wavelength from the primary source emission (the relation that defines redshift) can be determined by regression as follows:

$$\lambda(n) = \lambda_s + n\, \Delta\lambda_\delta > \cong \lambda_s\, (\, 1 + n\ 3.07 \text{ x } 10^{-20}\ T / \lambda_s\,)$$

$$\text{Ƶ}(n, \lambda_s) = (\, \lambda_n - \lambda_s\,) / \lambda_s \cong n\ 3.07 \text{ x } 10^{-20}\ T / \lambda_s$$

As seen in the plots, this does not provide a redshift-distance relationship per se. To demonstrate the relationship of distance to the change in wavelength the distance r(n) as a function of the number of cloning intervals n must be established. But because the length of these intervals depends upon the wavelength entering the interval, so r(n) becomes a summation of the lengths $\delta(\lambda)$ that are continuously changing rather than just the total number of intervals n times a uniform length. The length of a coherency domain is also dependent on the free electron density as defined earlier. Because of the inverse relationship to wavelength, the net result is dependence on wavelength that does in fact constitute a redshift.

As discussed elsewhere, galaxy clusters are the basic units of the universe. The thermodynamic characteristics of plasma gases in a representative galaxy cluster are plotted in figure 4. When averages are taken over all galaxy clusters, whose separations are on the order of tens of Mpc[1], the universal average electron density is nearly as low as 10^{-7} per cm^3, the average temperature less than 10^4 K, and yet the average of the product of these two parameters may be as large as 10^4 K per cm^3. It is the value of the average of this product that determines for the scattering model a redshift-distance relationship that matches observed cosmological redshift. This average is a million times greater than the product of the individual averages.

In this article we have derived and described the mechanism responsible for the observed phenomena associated with cosmological redshift. In the article 'The Proximate Cause of Cosmological Redshift' the implications of these effects are described and illustrated.

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[1] An Mpc is 'megaparsec', a unit of measure of distance. A megaparsec is one million parsecs, or about 3,260,000 light years or 3.0857×10^{18} cm.

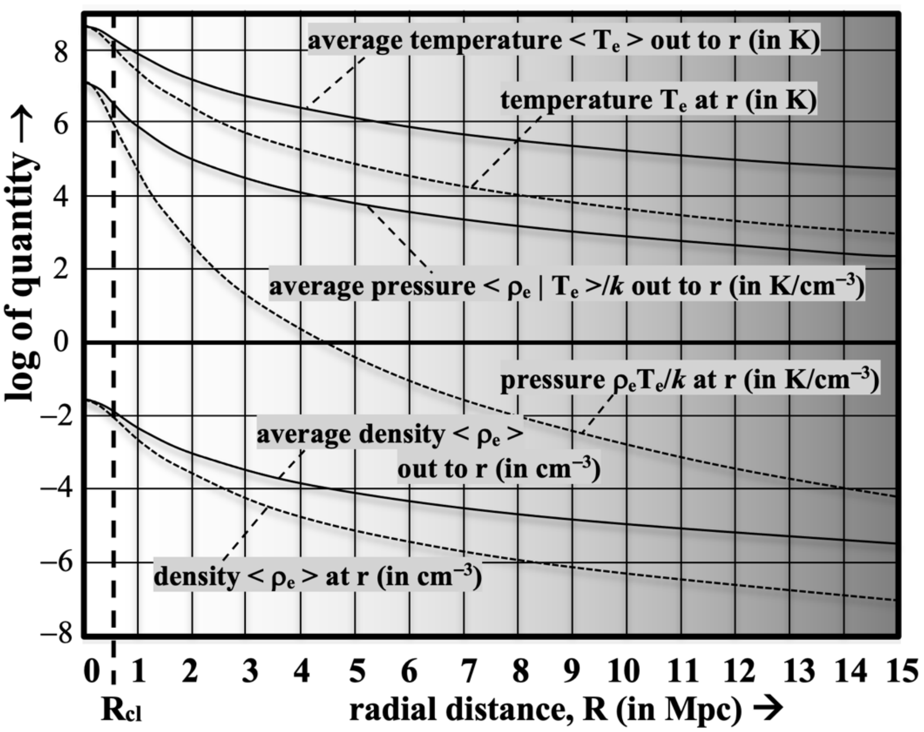

Figure 4: Representative temperature and density as functions of the distance from the center of galaxy clusters