

# Dark Energy, Exponential Expansion, CMB, Wave/Particle Duality – All Result from Lorentz-Covariance of Boltzmann’s Transport Equation

Arne Bergstrom\*

B&E Scientific Ltd, Seaford BN25 4PA, UK

\*Corresponding author: [arne.bergstrom@physics.org](mailto:arne.bergstrom@physics.org)

Received June 17, 2014; Revised August 10, 2014; Accepted August 13, 2014

**Abstract** The Boltzmann transport equation is the rigorous continuity equation for the angular flux  $f(\mathbf{r}, t, \mathbf{v})$  of photons at positions  $\mathbf{r}$ , time  $t$ , moving in direction  $\mathbf{v}$ , and interacting with a surrounding medium by localized collisions. This equation is not necessarily Lorentz-covariant, but can be specialized to a Lorentz-covariant equation describing the propagation of a photon distribution through space. However, this requirement of Lorentz-covariance of the Boltzmann transport equation then leads to a wave-particle duality, in which an ensemble of photons behave as waves, but in which each individual photon interferes only with itself. Applied on cosmological scales, this requirement of Lorentz-covariance of the Boltzmann transport equation also leads to an apparent quantum multiplication, which could explain the existence of the huge amounts of the mysterious “dark energy” that appears to permeate the universe. In addition, it also requires the universe to appear subjected to an exponential expansion as observed, similar to a perspective distortion in time, and then also as a consequence to appear surrounded by a cosmic microwave background radiation (CMB) with an exact Planck spectrum, as observed.

**Keywords:** *boltzmann’s transport equation, cosmological expansion, dark energy/dark matter, wave/particle duality*

**Cite This Article:** Arne Bergstrom, “Dark Energy, Exponential Expansion, CMB, Wave/Particle Duality – All Result from Lorentz-Covariance of Boltzmann’s Transport Equation.” *International Journal of Physics*, vol. 2, no. 4 (2014): 112-117. doi: 10.12691/ijp-2-4-4.

## 1. Introduction

When studying the Coma cluster of galaxies in 1933, Fritz Zwicky used the virial theorem to infer the existence of some unknown “dark matter” as a dominating part of the total mass of galaxies [1]. However, Zwicky’s important discovery of this dark matter surrounding galaxies – and thus actually pointing to a new cosmology – was largely ignored.

Fortunately, Vera Rubin picked up the trail [2] again in the 1980s, and the possible existence of large amounts of some unknown dark matter around galaxies was finally beginning to be taken seriously.

Then, just before the start of the new millennium, the breakthrough came in the form of the astonishing observations by Perlmutter, *et al.* [3], and Riess, *et al.* [4], that the universe is in a state of accelerated expansion, as if caused by some “dark energy” that completely dominates over the force of gravity on cosmological scales.

As a result of these and subsequent observations, we now have the interesting situation that the mass of our universe seems to consist mostly of something we do not know at all what it is. The universe is now considered [5] to be made up of 68.3 % of dark energy, essentially uniformly distributed, and of 26.8 % of dark matter,

mainly localised around galaxies, and with ordinary matter accounting for only 4.9 % of the total mass of the universe. But it is still a complete mystery what this dark energy and this dark matter really are. The present article attempts to address at least the problem of the origin of dark energy.

The starting point is an analysis of the properties of the fundamental continuity equation governing the time-dependent quantum propagation in space, and which all (neutral) quanta must be assumed to be forced to obey.

The Boltzmann transport equation [6] is this fundamental continuity equation describing how neutral particles propagate in a medium with which they interact by localized collisions. The Boltzmann transport equation has been used for over fifty years to calculate how, *e.g.*, gamma rays or neutrons propagate in nuclear reactors, nuclear weapons and radiation shields. The Boltzmann equation is an exact equation for such transport of neutral particles through a medium of arbitrary geometrical complexity, and is exactly valid as long as only the problem is linear, *i.e.* that the interactions between the propagating particles themselves can be neglected.

However, although exactly describing the propagation of the particles, the Boltzmann transport equation is not necessarily Lorentz-covariant in the form it is normally written. As long as it is used for its normal applications, this is no problem. However, if we want to use it to describe, say, photons travelling through intergalactic

space from sources maybe billions of light-years away, then this lack of Lorentz-covariance might cause problems. In fact, such problems actually arise also in more mundane applications in the form of the wave-particle duality, which thus enters as an unavoidable ingredient [7] in the approach that will be described in the following.

As will be discussed in the following, the main consequence of the requirement on the Boltzmann equation to be Lorentz-covariant is, apart from the wave-particle duality, that it requires [8] the universe to appear exponentially expanding on large scales, as observed.

As will also be discussed in the following, the special requirements on the parameters in the Boltzmann equation in order to make it Lorentz-covariant also forces photon transport over cosmological distances to appear to involve a photon multiplication process, which is most likely the origin [8] of the unexpected, dominating amounts of dark energy observed to exist in the universe.

It will furthermore in the following be described how this effect of requiring stars to be subjected to an apparent, exponential expansion also, somewhat surprisingly, leads [9] to a cosmic microwave background radiation with an exact blackbody spectrum, as observed. This is a property specific for exponential expansion – other types of expansion do not give blackbody spectra, as will be discussed below. CMB may thus not necessarily be the afterglow of a primordial big bang, but may thus possibly be just an observational effect due to our requirements of Lorentz-covariant observations.

## 2. Boltzmann's Transport Equation

The time-dependent propagation of neutral quanta (such as, *e g*, in gamma radiation) moving with the velocity of light  $c$  through a medium with which they interact by localized collisions, is rigorously described by the Boltzmann transport equation [8] given as follows,

$$\begin{aligned} \frac{\partial f(r,t,\mathbf{\Omega})}{c\partial t} &= -\mathbf{\Omega}\cdot\nabla f(r,t,\mathbf{\Omega}) \\ &+ \int \Sigma(r,t,\mathbf{\Omega}') K(r,t,\mathbf{\Omega}' \rightarrow \mathbf{\Omega}) f(r,t,\mathbf{\Omega}') d\mathbf{\Omega}' \\ &- \Sigma(r,t,\mathbf{\Omega}) f(r,t,\mathbf{\Omega}) + S(r,t,\mathbf{\Omega}), \end{aligned} \quad (1)$$

where  $S(r,t,\mathbf{\Omega})$  is a source term, and  $f(r,t,\mathbf{\Omega})$  is the angular flux in direction  $\mathbf{\Omega} = (\Omega_x, \Omega_y, \Omega_z)$  at point  $r = (x, y, z)$  and time  $t$ . Possible interactions with the medium through which the quanta propagate are described by the interaction cross section  $\Sigma(r,t,\mathbf{\Omega})$ , and where the kernel

$K(r,t,\mathbf{\Omega}' \rightarrow \mathbf{\Omega})$  then describes how quanta may become scattered from direction  $\mathbf{\Omega}'$  to direction  $\mathbf{\Omega}$ , and/or partially absorbed or multiplied (like neutrons in fission) in the process. It should again be emphasized that the Boltzmann transport equation is a rigorous continuity equation for the angular flux, and is exact as long as the angular flux is sufficiently low so that the effects of particle-particle interactions between the propagating quanta themselves can be neglected.

## 3. Wave-Particle Duality

The total flux  $\Phi(r,t)$  is defined from the angular flux  $f(r,t,\mathbf{\Omega})$  as

$$\Phi(r,t) = \int f(r,t,\mathbf{\Omega}) d\mathbf{\Omega}. \quad (2)$$

For quanta undergoing isotropic scattering in a homogeneous medium, the quantum propagation as described by the flux  $\Phi(r,t)$  in (2) can be derived [7] rigorously from the Boltzmann transport equation (1) to take the form of the “telegrapher’s equation” [10, 11],

$$\begin{aligned} \Delta\Phi - \frac{\partial^2\Phi}{c^2\partial t^2} - \left(\frac{1}{3D} + \Sigma_a\right) \frac{\partial\Phi}{c\partial t} \\ - \left(\frac{\Sigma_a}{3D} + \frac{\partial\Sigma_a}{c\partial t}\right) \Phi + \left(\frac{1}{3D} + \frac{\partial}{c\partial t}\right) S = 0. \end{aligned} \quad (3)$$

where

$$D = \frac{1}{3\Sigma}, \quad (4)$$

$$\Sigma_a = (1-\nu)\Sigma, \quad (5)$$

with

$$\nu = \int K(r,t,\mathbf{\Omega}' \rightarrow \mathbf{\Omega}) d\mathbf{\Omega}', \quad (6)$$

and where, *e g*, the value  $\nu = 0$  corresponds to pure absorption,  $\nu = 1$  to pure scattering, and  $\nu > 1$  to a multiplying medium. The condition of isotropic scattering in a homogeneous medium implies  $\Sigma(r,t,\mathbf{\Omega}) = \Sigma(t)$ , so that  $\Sigma_a = \Sigma_a(t)$ .

However, the derivation of the telegrapher’s equation (3) above – with wave-front velocity  $c$  – from the Boltzmann transport equation (1) requires [7] the flux  $\Phi(r,t)$  to propagate with velocity  $c$  in a specific direction, not by the average velocity of the flux averaged over all angles. Thus, even though (3) is a wave-type equation, its derivation requires that each particle in the underlying transport defines its own flux  $\Phi(r,t)$  as in an ensemble of potential, repeated experiments, and independently of the other particles, otherwise the propagation velocity of the wave would be lower than  $c$  (in fact normally equal to  $c/\sqrt{3}$  [12], *cf* also Figure 6 and Figure 7 in [8]). The flux  $\Phi(r,t)$  is thus required to behave as in the famous double-slit experiment [13]: “Each photon interferes only with itself. Interference between two different photons never occurs” (Dirac [14]).

## 4. Dark Energy

Due to the third and fourth terms on the left-hand side of the telegrapher’s equation (3) above, this equation will not be Lorentz-covariant and it will also display dispersion – two properties that would make it incompatible with a wave equation derived from, *e g*, electromagnetism. However, we note that the telegrapher’s equation above is compatible with a Lorentz-covariant and dispersion-free quantum propagation as described by a wave equation in the special case when the third and fourth terms in (3) vanish, *i e*

$$\frac{1}{3D} + \Sigma_a = 0, \tag{7}$$

$$\frac{\Sigma_a}{3D} + \frac{\partial \Sigma_a}{c \partial t} = 0, \tag{8}$$

which thus combine to

$$\frac{\partial \Sigma_a}{c \partial t} - \Sigma_a^2 = 0. \tag{9}$$

The differential equation (9) has the following solution ( $R$  is an integration constant)

$$\Sigma_a = \frac{-1}{R + ct}. \tag{10}$$

We note in passing that the second-order time derivative in the basic wave equation (3) [after setting (7) and (8)] may lead to a wavelength with an arbitrarily much shorter characteristic length than the parameter  $R$  in (10). This wavelength corresponding to the time derivative may easily be in, *e g*, the optical region, despite the fact that the parameter  $R$  defining the collision rate may possibly be up to the order of the extension of the observable universe.

From (4) and (7) we see that  $\Sigma_a = -\Sigma$ , and from (10) and (5), respectively, we thus get

$$\Sigma = \frac{1}{R + ct}, \tag{11}$$

$$\nu = 2. \tag{12}$$

The requirement that quantum transport through intergalactic space should be Lorentz-covariant thus forces the medium through which the particles propagate to appear to double the flux as shown in (12) for each time a particle collides with the medium. This is thus a seemingly mysterious multiplying effect caused by the requirement of Lorentz-covariance, and which thus after sufficiently many collisions will create a monstrous flux of what might be interpreted as “dark energy”. This dark energy has been suggested to be what causes distant galaxies to accelerate away from us [3,4] as will be discussed in Sect. 5 below.

However, according to what is discussed in this communication, both effects – dark energy and exponential expansion – will in the approach discussed here be *separate* consequences of the requirement of Lorentz-invariance: the accelerated expansion is *not* dynamically driven by any pressure from dark energy. This thus removes a disturbing problem [15] concerning their respective magnitudes, which is serious obstacle in the conventional picture.

### 5. Exponentially Accelerated Expansion

The somewhat peculiar quantum transport process described above with time-varying cross-sections and quantum creation will now be further illustrated by an alternative approach, and comparing it to a much simpler transport process.

The simplest, nontrivial transport is linear transport in an infinite, homogeneous and isotropic medium with pure isotropic scattering described by a scattering cross-section

$\Sigma_0$ , constant in space and time, and a multiplication factor  $\nu_0 = 1$  (*i e* with kernel  $K = 1/4\pi$  above). Using (1), the quantum transport will then be exactly described by the following Boltzmann equation for the angular flux  $\varphi(\rho, \tau, \omega)$  in space coordinates  $\rho$ , time  $\tau$ , and direction  $\omega$ ,

$$\frac{\partial \varphi(\rho, \tau, \omega)}{c \partial \tau} = -\omega \cdot \nabla \varphi(\rho, \tau, \omega) + \int \frac{\Sigma_0}{4\pi} \varphi(\rho, \tau, \omega) d\omega - \Sigma_0 \varphi(\rho, \tau, \omega) + S(\rho, \tau, \omega), \tag{13}$$

which as discussed above will not lead to a Lorentz-covariant and dispersion-free wave equation in the  $\rho\tau$  system.

However, we may transform the above Boltzmann equation (13) into one which does represent a Lorentz-covariant and dispersion-free transport by making the following variable transformations (*cf* also Sect. 6 below),

$$d\rho = \alpha dr, \tag{14}$$

$$d\tau = \alpha dt, \tag{15}$$

$$\varphi(\rho, \tau, \omega) = \alpha f(r, t, \Omega), \tag{16}$$

where

$$\alpha = \frac{2}{\Sigma_0} (R + ct)^{-1}. \tag{17}$$

Making these transformations in the simple, non-Lorentz-covariant transport equation (13) above, we get

$$\begin{aligned} & \frac{\partial f(r, t, \Omega)}{c \partial t} + f(r, t, \Omega) \frac{\partial \alpha}{c \alpha \partial t} \\ &= -\Omega \cdot \nabla f(r, t, \Omega) + \int \frac{1}{R + ct} \frac{2}{4\pi} f(r, t, \Omega) d\Omega \\ & \quad - \frac{2}{R + ct} f(r, t, \Omega), \end{aligned} \tag{18}$$

which since  $\partial \alpha / \partial t = -c\alpha / (R + ct)$  simplifies to

$$\begin{aligned} & \frac{\partial f(r, t, \Omega)}{c \partial t} \\ &= -\Omega \cdot \nabla f(r, t, \Omega) + \int \frac{1}{R + ct} \frac{2}{4\pi} f(r, t, \Omega) d\Omega \\ & \quad - \frac{1}{R + ct} f(r, t, \Omega), \end{aligned} \tag{19}$$

and which we can identify from (1) and (5) to have  $\Sigma = 1/(R + ct)$  and  $\nu = 2$ , and hence is a Boltzmann equation for a Lorentz-covariant and dispersion-free transport as discussed at (11) and (12) above.

We can verify from the two transformations  $d\rho = \alpha dr$  and  $d\tau = \alpha dt$  in (14) and (15) above that the velocity of light is equal to  $c$  in both the  $\rho\tau$  and  $rt$  systems.

By using (15) and (17), the relationship between  $\tau$  and  $t$  can be derived from the following equation

$$d\tau = \alpha dt = \frac{2dt}{\Sigma_0 (R + ct)}, \tag{20}$$

which integrates to (with  $\tau = 0$  for  $t = 0$ )

$$\tau = \frac{2}{c\Sigma_0} \ln\left(1 + \frac{ct}{R}\right), \quad (21)$$

or in units so that (after Taylor expansion) we can set  $2/(c\Sigma_0) = 1$  and  $c/R = 1$ ,

$$\tau = \ln(1+t), \quad (22)$$

i.e

$$t = e^\tau - 1. \quad (23)$$

Differentiating (23),

$$dt = e^\tau d\tau, \quad (24)$$

and comparing with the transformation  $d\tau = \alpha dt$  in (15), we thus get  $\alpha = e^{-\tau}$ , and hence  $d\rho = \alpha dr = e^{-\tau} dr$ , i.e

$$dr = e^\tau d\rho. \quad (25)$$

Integrating (25) (with suitable origins) we thus get

$$r = e^\tau \rho. \quad (26)$$

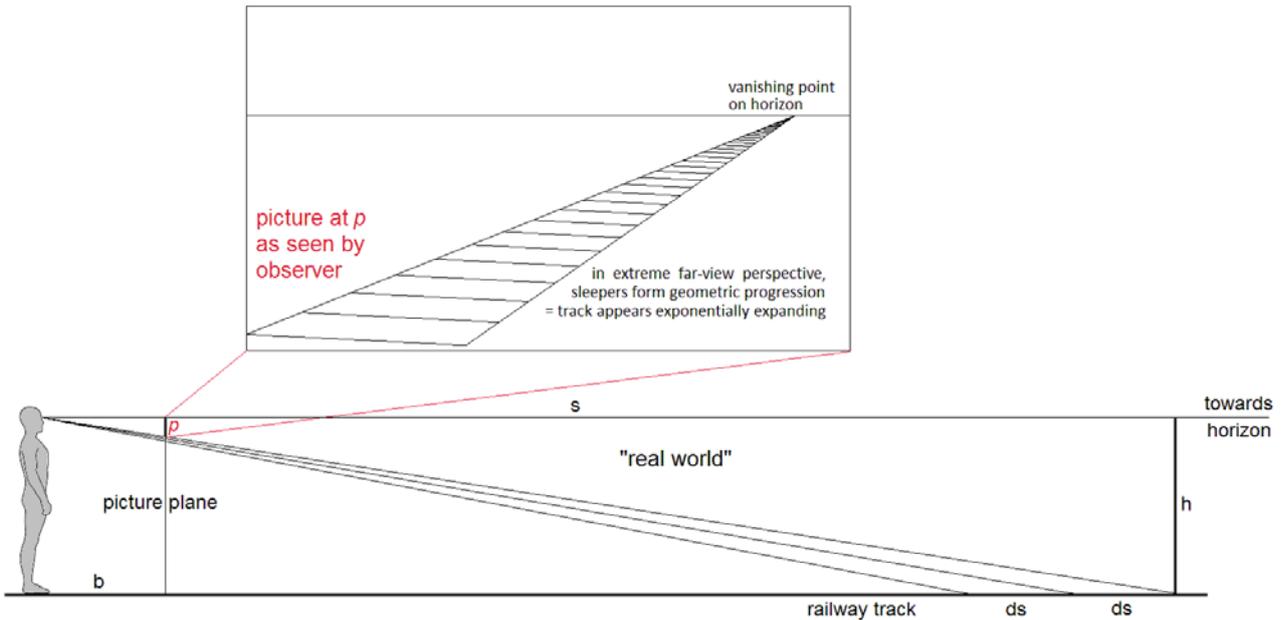
As defined above, the  $\rho\tau$  system is a system with "classical" spacetime. Compared to the simple, classical

transport in the  $\rho\tau$  system, the Lorentz-covariant system  $rt$ , with which the  $\rho\tau$  system coincides for  $t = \tau = 0$ , is thus subjected to an exponentially accelerated expansion as given by (25) and (26), showing how a line element  $dr$  in the Lorentz-covariant  $rt$  system increases exponentially with time  $\tau$  [and correspondingly for a time element  $dt$  as shown in (24)].

The requirement that photon transport over cosmological distances should be Lorentz-covariant thus requires the universe to appear exponentially expanding as shown by (26), and as is also observed [3,4].

## 6. Exponential Expansion as Perspective in Time

Historically, it took a very long time for artists to understand how to correctly represent a three-dimensional world onto a two-dimensional canvas. The first groundbreaking, geometrical construct for rendering a correct such perspective of three-dimensional objects onto a two-dimensional surface is credited [16] to the renaissance artist and architect Filippo Brunelleschi in Florence around 1413.



**Figure 1.** Schematic picture of spatial perspective distortion, showing that in the special case of extreme far-view perspective, evenly spaced sleepers on a railway track form a geometric progression on the picture, with the distances between the sleepers being proportional to their respective distances to the vanishing point on the horizon. Thus the track in that case appears exponentially expanding from the vanishing point towards the observer. As discussed in the text, the exponential cosmological expansion of the universe can be regarded as a similar perspective expansion, but in the time dimension instead

The depth scale in perspective can be described as follows. Suppose we take a photograph of a very long, straight railway track with evenly spaced sleepers (ties) as in Figure 1. The camera will picture this straight track in perspective, and show it shrinking towards a vanishing point on the horizon, and with the distances between the sleepers in the picture getting successively smaller the further away they are from the camera.

Figure 1 shows such sleepers at horizontal distances  $s, s-ds, s-2ds, etc.$ , along the track in the real world, and how they are projected towards the observer's eye, where they are seen in the picture plane at distances  $p_0, p_1, p_2, etc.$ ,

down from the horizon in the picture. From self-similar triangles, we have  $p_0/b = h/s, p_1/b = h/(s-ds), p_2/b = h/(s-2ds), \dots, p_n/b = h/(s-nds), etc.$

We thus get the following expression for the apparent distance between two sleepers in the picture relative to their distance to the vanishing point,

$$\frac{p_n - p_{n-1}}{p_{n-1}} = \frac{\frac{bh}{s-nds} - \frac{bh}{s-(n-1)ds}}{\frac{bh}{s-(n-1)ds}}, \quad (27)$$

*i e*

$$\frac{p_n - p_{n-1}}{p_{n-1}} = \frac{ds}{s - n ds}. \quad (28)$$

The relative distance in (28) between sleepers will obviously in general depend on their position along the track, *i e* depend on  $n$ . However, astronomical observations through telescopes correspond to cases of extreme far-view perspective, in which the sleepers in the railway-track analogy above could correspond to wavelengths  $ds$  in a beam of light originating maybe from distances of thousands or even billions of light-years away. Even with a large number  $n$  of such sleepers/waves in the picture, the term  $-n ds$  in the denominator in (28) would be negligible compared to  $s$ , and the quotient on the right-hand side of (28) then reduces to a constant factor, *i e*,

$$\frac{p_n - p_{n-1}}{p_{n-1}} = \frac{ds}{s}. \quad (29)$$

The apparent positions of the sleepers along the track in such extreme far-view perspective (as in a big telescope) thus form a geometric progression. An observer could then describe this by saying that the railway track looks exponentially expanding from the horizon towards him.

The space dimensions of our world, as we actually see them in perspective, thus appear exponentially expanding from large distances, and do not look as the rectangular grid we know that they “really are”. The surprising thing is that also the time dimension of our world, as derived in Sect. 5 above, appears subjected to a similar exponential distortion – like a “perspective in time” [7]. If we look sufficiently far away in time, this perspective effect then appears as an exponential expansion – in this case as the cosmological expansion of the universe we discussed earlier. This exponential expansion of the universe could thus be viewed as just a perspective effect of this kind in the time dimension of spacetime, just like ordinary perspective is in the space dimensions of spacetime.

## 7. Cosmic Microwave Background

Intimately related to the concept of spatial perspective, discussed in the preceding section, is the concept of a horizon as we also discussed there – an artificial, perceived limit of the world as seen by the observer. However, such a perceived limit of our world may not necessarily lie so far away as that light can still only barely reach us, but may possibly lie much closer, as will now be discussed next.

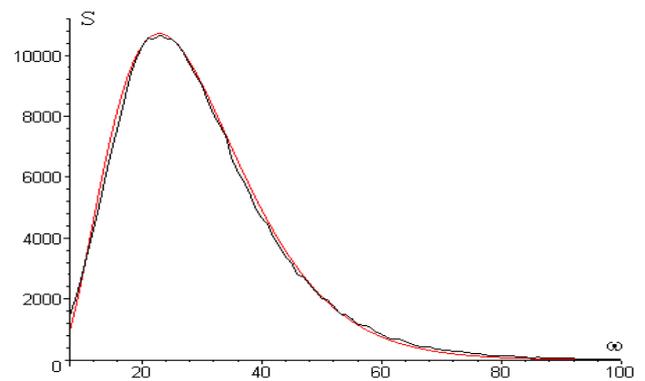
An infinite, roughly uniform distribution of extended, opaque objects of roughly the same size will be perceived from a point inside this distribution as being limited by an opaque wall at some finite distance away. This is for instance how the trees in a forest seemingly coalesce to an impenetrable wall around you at some distance away, or how you seem to be enclosed by a white sphere when flying in a cloud or being in a fog.

Similarly, this would also be how an assumed infinite, roughly uniform distribution of (primeval) stars would appear as seen from somewhere inside this distribution, thus possibly being the source of the apparent, roughly

homogeneous cosmic microwave background we observe around us [17].

In this picture, the cosmic microwave background could thus be caused by such an apparent wall of stars, rather than by a big bang. This explanation thus sidesteps the so-called “horizon problem” [18], *i e* why different regions of the universe have very similar temperature and other properties despite not having had time to be in causal contact with each other after the assumed big bang – a problem usually solved by somewhat artificially invoking an assumed period of inflation.

A simulation of the energy spectrum from such a distribution of stars is shown in Figure 2, assuming only (i) that a closer star completely obstructs the light from more distant ones in the same direction, and (ii) that the spectra of distant such stars appear redshifted as if subjected to an exponentially accelerated expansion as derived above [8], and as is also observed.

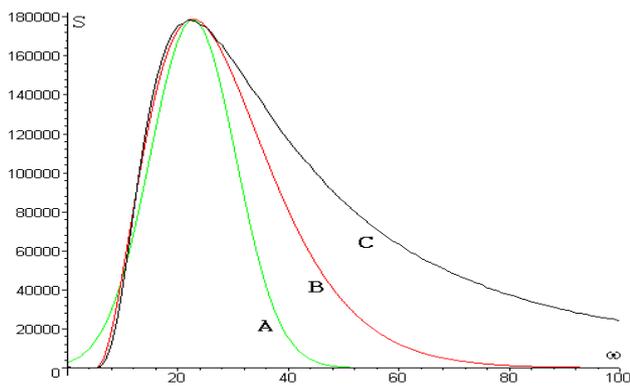


**Figure 2.** Simulated received radiation  $S(\omega)$  from different directions in a small region of the sky assuming an exponentially expanding universe, and with closer sources assumed to be completely opaque to the radiation from more distant ones in the same direction. The sampled spectrum (black) is virtually indistinguishable from the Planck spectrum (red) also shown

As a consequence of the deep-space emission considered here, the width (and thus spectral form) of the individual spectra of the distant stars considered can be neglected in comparison with their corresponding, much larger redshifts. It should also be remarked that what is considered here are deep-space distributions of stars, such that the possibility of large contributions from individual, much closer stars or galaxies can be neglected.

Figure 2 shows that under the above conditions the energy spectrum from an infinite, roughly uniform distribution of such stars will be observed as an exact blackbody spectrum in agreement with astronomical observations [19]. The cosmic microwave background radiation might thus possibly be just an observational effect of this type [8], and may hence not necessarily have any cosmological significance.

The spectrum shown in Figure 2 was calculated using a Monte Carlo simulation of the radiation from surrounding stars, assuming closer stars to completely obstruct the emission from more distant ones in the same direction. It should be remarked that this assumed obstruction by closer stars of the emission from more distant ones in the same direction is crucial for the formation of the blackbody spectrum discussed here and given by spectrum B i Figure 3.



**Figure 3.** Sampled ( $10^8$  histories) energy spectra  $S(\omega)$  as in Figure 2 for (A) a Gaussian distribution (stars transparent), (B) a Planck distribution (stars opaque, exponentially accelerated expansion), and (C) a Planck-type distribution with distorted tail (stars opaque, but no accelerated expansion)

If closer stars were instead (unphysically) considered completely transparent to the emission from more distant ones, then the spectrum would instead be a Gaussian distribution (as expected and as shown in spectrum A in Figure 3), not a blackbody spectrum. It is important to notice that other forms of expansions than an exponentially accelerating expansion will not give blackbody spectra but severely distorted such spectra [8], as exemplified by spectrum C in Figure 3 for a purely linear Hubble expansion.

## 8. Concluding Remarks

Gravity plays an important role (together with “dark matter”) in the dynamics of galaxies, but on cosmological scales “dark energy” completely dominates. It is in this article shown that dark energy, the exponential expansion of the universe, the cosmic microwave background, and the wave/particle duality, can all be understood as results of Lorentz-covariance of Boltzmann’s transport equation.

In an article [20] in *NewScientist*, Michael Brooks makes the following comment on the enigma of dark matter/energy: “Maybe we can’t work out what dark matter is because it doesn’t actually exist.” Vera Rubin, mentioned above [2], has expressed a similar view [20]: “If I could have my pick, I would like to learn that Newton’s laws must be modified in order to correctly describe gravitational interactions at large distances. That’s more appealing than a universe filled with a new kind of sub-nuclear particle.”

Although not invoking any such modification of Newton’s laws, the present article nevertheless seeks an explanation for dark energy in the same vein, namely in the properties of the fundamental continuity equation for quantum propagation. This approach thus shifts the emphasis away from what kind of quanta actually are involved and instead puts the emphasis on basic properties of relativistic space time itself. The present approach shows dark energy (and perhaps also dark matter?) to be due to the requirement of relativistic covariance of the quantum propagation itself.

Looking at the quanta themselves in this picture, with their rare collisions with their surroundings and their

required quantum doubling thereby to preserve Lorentz covariance, they may appear somewhat ghostlike. However, due to all these successive doublings over time, their total mass will after some hundreds of such doublings far exceed the total mass of all ordinary particles in the universe. This does make their effects seem anything but ghostlike...

## Acknowledgements

The author is indebted to the late Dr Staffan Söderberg for valuable mathematical assistance in the initial phase of this project. The author also wishes to thank Dr Hans-Olov Zetterström for many fruitful discussions and valuable suggestions with regard to this study.

## References

- [1] F. Zwicky, “Die Rotverschiebung von extragalaktischen Nebeln”, *Helvetica Physica Acta* 6, 110 (1933).  
F. Zwicky, “On the Masses of Nebulae and of Clusters of Nebulae”, *Astrophys. J.* 86, 217 (1937).
- [2] V. Rubin, D. Burstein, W. K. Ford, and N. Thonnard, “Rotation velocities of 16 SA galaxies and a comparison of Sa, Sb, and SC rotation properties”, *Astrophys. J.* 289, 81 (1985).
- [3] S. Perlmutter, G. Aldering, G. Goldhaber, R. A. Knop, P. Nugent, *et al.*, “Measurements of  $\Omega$  and  $\Lambda$  from 42 High-Redshift Supernovae”, *Astrophys. J.* 517, 565 (1999).
- [4] A. G. Riess, A. V. Filippenko, P. Challis, A. Clocchiatti, A. Diercks, *et al.*, “Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant”, *Astron. J.* 116, 1009 (1998).
- [5] [http://en.wikipedia.org/wiki/Planck\\_\(spacecraft\)](http://en.wikipedia.org/wiki/Planck_(spacecraft)) retrieved 2014-06-16.
- [6] A. M. Weinberg and E. P. Wigner, *The Physical Theory of Neutron Chain Reactors* (Univ. of Chicago Press, 1958), pp. 223, 232.
- [7] A. Bergstrom, “Relativistic invariance and the expansion of the universe”, *Nuovo Cimento* 27B, 145 (1975).
- [8] A. Bergstrom, “Lorentz-covariant quantum transport and the origin of dark energy”, *Phys. Scr.* 83, 055901 (2011).
- [9] A. Bergstrom, “Is CMB just an observational effect of a universe in accelerated expansion?”, *International Journal of Physics* 1, 133 (2013).
- [10] A. M. Weinberg and E. P. Wigner, *The Physical Theory of Neutron Chain Reactors* (Univ. of Chicago Press, 1958), p. 235.
- [11] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill, 1941), p. 550.
- [12] A. M. Weinberg and E. P. Wigner, *The Physical Theory of Neutron Chain Reactors* (Univ. of Chicago Press, 1958), p. 236.
- [13] R. Feynman, R. Leighton, and M. Sands, *The Feynman Lectures on Physics* (Addison-Wesley, 1965), Vol III, pp. 1.1-1.9.
- [14] P. A. M. Dirac, *The Principles of Quantum Mechanics* (Clarendon Press, 1991), p 9.
- [15] J. Frieman, M. Turner, and D. Huterer, “Dark Energy and the Accelerating Universe”, *Ann. Rev. Astron. Astrophys.* 46 385 (2008).
- [16] M. Kemp, *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat* (Yale University Press, 1990).
- [17] P. S. Wesson, “Olbers’s paradox and the spectral intensity of the extragalactic background light”, *Astrophys. J.* 367, 399 (1991).
- [18] G. D. Starkman and D. J. Schwarz, “Is the universe out of tune?”, *Sci. Am.* 293(2), 48 (2005).
- [19] D. J. Fixsen, E. S. Gheng, J. M. Gales, J. C. Mather, R. A. Shafer, and E. L. Wright, “The cosmic microwave background spectrum from the full COBE FIRAS data set”, *Astrophys. J.* 473, 576 (1996).
- [20] M. Brooks, “13 things that do not make sense”, *NewScientist*, 19 March 2005.