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Don't Panic! Photon-Electron-Dust Interaction Replaces Dark Energy and Acceleration for Supernovae Dimming

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Abstract

This paper provides concrete evidence that the expanding and accelerating Universe mathematically expressed by dark energy is a purely mathematical abstraction. The energy loss of photons interacting with crystallized electrons in the intergalactic medium combined with the effect of cosmic dust on the travelling radiation predict supernovae dimming with a perfect fit to observational data. Accordingly, there is no need for any adjustment parameters and corrections. The outcome of this research plots the quantitative distance modulus predictions against redshift and compares them to the results obtained by the Pantheon+ inquiry. In this work frame, the SN-Ia distance modulus is rigorously provided by the sum of four main contributions: the distance in a non-expanding Universe, the energy loss of the travelling photons to the recoil of the crystallized electrons, the conversion value of the distances and, last but not least, the dust extinction due to interactions between photon and dust particles in the intergalactic medium.

Keywords

Supernovae Ia Dimming, Dark Energy, Photon-Electron-Dust Interaction, Non-Expanding Space, Distance Modulus

1. Introduction

This paper presents both an alternative point of view and a physical framework to the discussion on the acceleration of space expansion. That is, we will argue why discoveries and observations lead us to approach another scientific mindset without ending up in an accelerating Universe driven by dark energy. The observation of supernovae Ia (SN-Ia) is an important study in cosmology as we can infer the behaviour of the Universe. The dimming of these astronomical objects provides information about the physical mechanism occurring in space, allowing us to discuss the physics and mathematics of the radiation as it travels through the intergalactic medium (IGM). The first and most important inquiries were conducted analyzing a small set of SN-Ia [1] [2] and extended to several others in further inquiries [3]-[6] which interpret the measurements in terms of expanding space and, what counts in this cosmological framework, an accelerating one. The latter has a strong impact, not only on the current physics of the SN-Ia but also on the mindset in academic research to the extent that cosmologists discard other potential alternative explanations to the SN-Ia dimming. Accordingly, an accelerating Universe is indispensable from dark energy [7]-[10] and its previously-introduced cosmological constant [11]-[13]. As we will see, it is possible to predict the distance modulus-redshift curve simply by analyzing all the physical components in space including the effect of dust on the line of sight as well as the multiple interactions between photons and electrons in the IGM. The study of the radiation from SN-Ia involves important parameters and procedural analysis such as a dimming calibration [14] [15], light curves, and the application of proper cosmological filters [16]-[18] along with the correlation between absolute magnitude and colour [19]. Starting from this decisive analysis and corrections, it is possible to derive equations that will lead eventually to the distance modulus formula for SN-Ia.

The origin of the cosmological constant Λ starts with Albert Einstein's General Theory of Relativity (GR) [11]. In this theory, gravitational forces are explained in terms of curvature of space. GR was proven right, for instance, by the precession of the orbit of Mercury, as well as by the light "bending" around the Sun from Eddington's experiment [20] and so the time came to apply GR to the Universe as a whole. The theory said that the Universe was allowed to expand or contract but could not be static. Einstein's problem was that all the data from observations using the Doppler effect to measure the velocities of stars that could be seen and measured were going very slowly and in all sorts of random directions. There was no observational data to show an expansion or contraction: it looked static. So, for no other reason than to make the theory "fit" the observations, he included a cosmological constant, Λ, which was a repulsive constant to balance the gravitational effects of collapse and make the Universe static if only for a short time. Furthermore, Vesto Slipher [21] measured the redshifts and hence the recession "velocities" of certain nebula and found these to have huge redshifts. He noticed that "the dimmer the nebulae the greater the redshift". Previously, Henrietta Leavitt [22] calibrated Cepheid variables so that they could be used to determine distances. Thereafter, Edwin P. Hubble, working with the greatest telescope in the world at the time, measured the distance to the nebulae and showed that they were outside the Milky Way. He measured their redshift to calculate their recessional velocities, or what he called "apparent velocities", and found that the recessional velocities of distant galaxies are directly proportional to their distance from us [23]. That is, observational evidence implied that the universe was expanding as per GR. From then on cosmology focused on finding an accurate value for the Hubble constant H_0 in this physical and mathematical framework [24] [25]. Allan Sandage [26] put forward a method to determine the eventual outcome of the universe by observing the amount of deceleration as a result of the effects of gravity. This was to construct a Hubble diagram of velocity (or redshift) against distance and hence determine the rate of expansion now, H_0, and compare it to what it was in the past, *i.e.* determine the gradient. Several attempts were made using galaxies found by Cepheid variables but these distances were too short to show any deviation in the gradient from a straight line. But then, a confirmation came that a special type of SN, the SN-Ia, could be used as standard candles, and these were bright enough to be seen far into the distance and hence far into the past. Presently, the Big Bang theory (BB) parametrized in the ΛCDM (Lambda Cold Dark Matter) model with its expanding Universe is a theory on how the Universe began, and as such, the Hubble constant leads us to the age of the Universe. The Hubble constant is a measure of the rate at which the Universe is expanding and so in principle, we can reverse the expansion to find the point in time when "it all began". The Supernova Cosmology Project [27] and the High-z Supernova Search Team [28] used high-z SN to explore the expansion rate. In effect, they were drawing a Hubble diagram for galaxies nearby and comparing it with that for galaxies in the distance and hence back in time. What they found was a surprise to everyone: SN-Ia are observed much dimmer than expected meaning that when a Hubble diagram is drawn for distant SN-Ia, the gradient, H, is less than one drawn for local galaxies meaning that the Universe is expanding at a greater rate now than it did in the past. According to a current researcher in the field of Cosmology, no single theory explains the difference between the high redshift diagram and that from nearby [29]. This is how the ΛCDM stood and an accelerating Universe driven by dark energy was proposed. However, there is no evidence for acceleration or dark energy other than it makes the theory fit the observed data. Since evidence in support of the ΛCDM predictions is not so strong, an important question arises concerning the reliability of the concordance model and its expanding space. The New Tired Light theory (NTL) predicts the observed SN-Ia values from first principles relying on the physical properties of the electrons and the photons that are interacting in the IGM. We will see in detail each term of the distance modulus when we introduce the calculation methodology of SN-Ia dimming due to this process. To do that, we have first to introduce the most current development of the New Tired Light (NTL) theory.

2. Interaction between Photons and Electrons

Standard cosmology is based on the assumption of space expansion, or rather that photons are stretched out during their journey through the vast cosmological distances they travel, leading toward *ad hoc* cosmological solutions in the EFE (Einstein Field Equations). If we change both our perspective and the assumptions at the beginning of the calculation, we obtain a different result. It turns out that space might be not expanding and that another process can be applied to photons in space. Based on this reasoning, if we not only assume a different process ongoing in space responsible for the cosmological redshift but also provide scientific evidence for the most reliable physics, then the circle closes. The New Tired Light theory (NTL), is a development of the Tired Light (TL) theory of the last century and is based on existing physics. The NTL theory has two basic pillars:

1) Photons are absorbed and re-emitted by the electrons in the IGM which recoil at each event, transferring some of the photon energy to the recoiling electron;

2) Rejection of the old idea of the IGM consisting of a "hot" neutral plasma which is known to be wrong, and replacing it with a neutral plasma where the excess protons are held firm on dust particles whilst the excess electrons can fill the vast spaces in between, arranging themselves on a Wigner crystal lattice. This allows the energy of the incoming photon to be stored as vibrational energy of the electron during the delay between absorption and re-emission whilst allowing recoil to take along the line of sight and thus not blurring the image.

Added to this is an alternative dimming process of the radiation from SN-Ia strictly related to the redshift mechanism and dust interactions and thus making a predicted Distance modulus-redshift relationship that fully agrees with observational data.

NTL is the theory that is the most reliable antagonist of the ΛCDM model and explains the SN-Ia dimming without resorting to an accelerating expansion of space. NTL is a theory with a known mechanism and produces predictions that can be tested. They have good agreement with observations [30]-[33]. NTL is a photon-electron interaction whereby the photon transfers energy to the electrons in the IGM. The energy of the photon is reduced, the frequency is reduced, and the wavelength increased. It has been redshifted. The photons are repeatedly absorbed and re-emitted by the electrons in the IGM which recoil on absorption and re-emission. Some of the energy is transferred to the recoiling electron and it is this that accounts for the redshift.

2.1. Redshift Due to Photon Energy Loss

The Hubble Law becomes, "photons from a galaxy twice as far away, interact with twice as many electrons in the IGM, transfer twice the energy to the electrons in the IGM, their frequency is reduced by twice as much and the wavelength increased by twice as much". Hence the redshift z is doubled, where:

$$z = \frac{\Delta\lambda}{\lambda_L} = \frac{\lambda_0 - \lambda_L}{\lambda_L} = e^{\frac{H_{NTL} d_{NTL}}{c}} - 1, \tag{1}$$

in which $\Delta\lambda$ is the increase of wavelength, given by the difference between observed wavelength λ_0 and the reference wavelength in the laboratory λ_L associated to a specific absorption/emission line of an atom, d_{NTL} is the distance between emitter and observer in a non-expanding space and H_{NTL} is the Hubble constant which assumes now an innovative and unique physical meaning. It is no longer the rate of expansion of the Universe as in the standard cosmological model, but rather it is the constant rate for which the photons lose energy during the multiple interactions with crystallized electrons in the IGM. The Hubble constant is now only a function of the electron properties such as the classical electron radius r_e, the electron number density in the IGM $n_e = 0.5\ \text{el}/\text{m}^3$ [30] [33], the electron mass m_e and the Planck constant *h*. Indeed

$$H_{NTL} = \frac{2hr_e n_e}{m_e} = 2.05\times10^{-18}\frac{1}{\text{sec}} = 63.26\frac{\text{km}}{\text{sec}\cdot\text{Mpc}}, \tag{2}$$

which is included in the range that the Hubble constant assumes in the so-called Hubble tension. Different to many TL approaches in the scientific literature, this time we are able to derive both formulae of Equation (1) and Equation (2) in a very exact way. The equations have concrete physical meaning. Therefore, it is strictly necessary to recall the scientific reasoning behind these results leading toward a NTL process before proceeding with the analysis of the SN-Ia. If we consider a single photon encountering an electron in the crystallized IGM, the photon transfers a tiny part of its energy to the recoiling electron on retention and on release. Due to this, the emitted photon has less energy or rather it has been redshifted and its wavelength is now longer. The energy transferred from the incoming photon with wavelength λ and energy E_λ to the electron [33] can be expressed by

$$\frac{E_\lambda}{m_e c^2} = \frac{h^2c^2}{\lambda^2c^2m_e^2} = \frac{h^2}{\lambda^2m_e^2}. \tag{3}$$

Since it has to be equal to the difference between the incoming energy of the photon E_λ with the energy of the emitted photon $E_{\lambda'}$ with wavelength λ' where clearly $E_\lambda - E_{\lambda'} > 0$ as well as the wavelength increase $\lambda = \lambda' - \lambda > 0$, then we can write that

$$\frac{hc}{\lambda} - \frac{hc}{\lambda'} = \frac{h^2}{\lambda^2m_e^2}. \tag{4}$$

After several algebraic steps, Equation (3) reduces to a specific value

$$\delta\lambda = \frac{h}{m_e c} = 2.43\times10^{-12}\ \text{m}, \tag{5}$$

in which we imposed during the derivation that $h \ll \lambda m_e c$ is valid for all incoming wavelengths of the photons $\lambda \gg 10^{-11}\ \text{m}$ in the classical approach. This leads to the Hubble law but we must also address the fact that redshift is independent of wavelength. In NTL this is explained by the collision cross-section. Using published collision cross-sections [34]-[36] from the interaction of low energy X-rays with matter we see that the collision cross-section for a photon-electron interaction is

$$\sigma = 2r_e\lambda. \tag{6}$$

Consequently, a photon having twice the wavelength has twice the collision cross-section, undergoes twice the number of photon-electron interactions in travelling the same distance and suffers twice the increase in wavelength $\Delta\lambda$. Twice the increase in wavelength with twice the wavelength means the redshift of Equation (1) is the same for all wavelengths. If we consider now the absorption and re-emission of a photon as it passes through the IGM after a procession of multiple interactions from the emitter to the observer, we can mathematically express the universal distance travelled by the photon as the sum, or rather an integral for several multiple interactions N, of all free mean paths:

$$d = \frac{1}{2r_e n_e \left\{ \int_0^{N-1} \left[\lambda + x\left(\frac{h}{m_e c}\right) \right] \mathrm{d}x \right\}}, \tag{7}$$

which, recalling the definition of redshift of the left-hand side of Equation (1) and introducing the total increase in wavelength as

$$\Delta\lambda = N\delta\lambda, \tag{8}$$

leads after several steps [33] [37] exactly to the right-hand side of Equation (1) with the Hubble constant expressed by Equation (2). This kind of approach (as well as the same mathematical and physical reasoning) can be applied to different astrophysical analysis, not only the cosmological redshift, such as the center-to-limb problem of the Sun in which photons are redshifted more toward the limb than the center [38]. Moreover, NTL binds with GR once we assume that the cosmic time is not equal to the proper time in FLRW (Friedmann-Lemaitre-Robertson-Walker) metric and in turn on the EFE (Einstein Field Equations) [39]. It turns out that the NTL redshift calculation is the dominant redshift all over the Cosmos and can be labelled as the only responsible mechanism of the cosmological redshift. Moreover, for small z, the right-hand side of Equation (1) reduces to the known linear Hubble law

$$z \cong \frac{H_{NTL} d_{NTL}}{c}, \tag{9}$$

where, once again, the physical meaning encloses the loss of energy of the photons by encountering crystallized electron in the IGM and not the expansion of space. In both cosmological models the recessional velocities are apparent and not real. Indeed, in our framework, for small z, we can write from Equation (9) that

$$v = H_{NTL} d_{NTL} = cz. \tag{10}$$

2.2. Comparison to Other Scattering Processes

In the past, tired light theories have been rejected on the basis that the image would be blurred since, using Compton effect, the photons would be scattered and not travel in a straight line. With the NTL theory, recoil takes place along the line of sight and so there is no scattering or blurring of the image as shown in **Figure 1**. In Compton scatter there is no method by which the free electron can store the energy of the photon and so absorption and re-emission must be instantaneous hence the scatter.

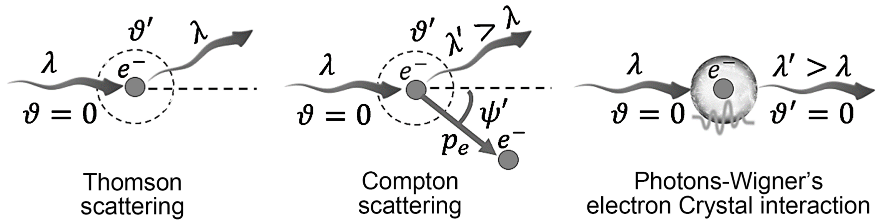

Figure 1. Difference between classic interaction between photons and electrons (Thomson and Compton scattering) in high-temperature environments against the interaction between photons and Wigner crystallized elctrons.

We can exclude the Thomson scattering since it is an elastic process for which the photon changes trajectory without losing energy. It is valid for an incoming photon energy smaller than the rest mass of the electron or rather $\frac{hc}{\lambda} \ll m_e c^2$. The Compton effect cannot also describe the interaction between photons and electrons at cosmological distances as we would see blurring of the images of all astronomical sources and this is not seen. Moreover, in the Compton process, the photons would be deviated from their original trajectory so that, overall, we might be not able to identify the exact origin of the source. This process is valid when the incoming energy of the photon is greater than the rest mass energy of the electron $\frac{hc}{\lambda} \geq m_e c^2$. This causes the electron to gain momentum and to be moved from its original rest position potentially altering, in turn, the next interaction photon-electron which would be regularly different from the previous one. The probability for the photons to interact with electrons is expressed by the Klein-Nishina cross section which is in turn related to the Thomson cross-section. The latter is the lower limit in a Compton approach when the photon energy does not overcome the electron rest mass energy.

2.3. Redshift Mechanism

To explain fully how NTL works we need to look at models of the IGM. Little was known about the IGM until a background of high-energy X-rays was discovered coming from far away and in every direction. To explain this, it was proposed that the IGM consisted of a fully ionized plasma at a temperature of 50,000 K. Later the source of these X-rays was found to be AGN's in the background and so there was now no need for this early model of the IGM [40]. However, people still to this day raise objections to tired light theories based on this now defunct model (since there is no way an electron can interact with a free electron in a plasma). What is proposed is an IGM with dust particles. Several studies have been done on these dust particles in the IGM since they will be charged positively by high energy photons in the UV and above by the photo-electric effect. Indeed, the expected electrical potential of the dust particles is expected to reach an equilibrium potential of approximately 25 V for graphite [41] where the rate at which electrons are ejected is equal to the rate at which they return. What these studies have not considered is what happens to the ejected electron. They must move off into the

IGM giving us the model whereby the IGM is overall neutral but like a “dirty plasma”. Excess protons are “fixed” on the dust particles whilst the electrons occupy the voids of the IGM.

In an environment where we can identify a specific electron density in a medium or in a material, Eugen Wigner [42] [43] predicted that under certain conditions electrons will arrange themselves on a crystal lattice leaving his studies in the realm of speculation for a long time. However, this phenomenon has recently been observed for the first time in two different scientific inquiries [44] [45] conducted in the laboratory. These confirmed Wigner’s predictions and introduced the description of a new quantum state into the scientific community. The main condition is that the Coulomb interactions between electrons is stronger than their own kinetic energy. The latter is related to the temperature of the system. One of the authors [31] introduced a Wigner crystal-like configuration for the electrons in the IGM before the discovery of the Wigner electron in the laboratory as an integral part of the redshift mechanism: photons are absorbed and re-emitted in procession by crystallized electrons during their cosmological journey. In a traditional Wigner crystal, the “free” electrons form a plasma within a neutralizing background and as to whether they position themselves on a crystal lattice requires the electrical potential energy E_{Coul} of the electrons to be greater than their kinetic energy $E_{kin.}$. The conditions needed in order that the electrons crystallize is normally given in terms of the plasma coupling parameter Γ, and this is basically just a measure of the ratio of the inter-particle coulomb potential energy to the electrons kinetic energy [46]

$$\Gamma \sim \frac{E_{Coul}}{E_{kin}}. \tag{11}$$

The condition necessary for the electrons to crystallize is [47] [48]:

$$\Gamma \geq 175. \tag{12}$$

That is, as long as the inter-particle coulomb potential energy is greater than (or equal to) one hundred and seventy-five times the particles kinetic energy, the electrons will crystallize on a BCC (Body-centered cubic) crystal lattice. The coulomb potential energy depends upon the electron number density and the kinetic energy depends upon the temperature and consequently, it is not the actual electron number density or temperature that matters but the ratio between them. This is why we have electrons arranged on a Wigner crystal in the center of white dwarf stars [49] where the temperatures and electron number density are both huge and, in the traditional Wigner crystal with neutralizing background, very low cryogenic temperatures where the electron number density is very small. Under normal circumstances, with the small electron number density of 0.5 m^{-3} in the IGM [33], this would require cryogenic temperatures but things are different in the IGM. As stated earlier, here the electrons have been released from dust particles by the photo-electric effect and reach an equilibrium electrical potential of ≈25 V and, depending upon particle size, this means each dust particle releases between 20 - 20,000 electrons for grain sizes between 10^{-9} m to 10^{-6} m radius [31] [41]. Whilst the IGM is overall neutral (a requirement since a plasma made up entirely of negative charges would "explode") the same number of protons would be clumped on a single dust particle but in the regions in between, the large numbers of individual electrons would always arrange themselves on a Wigner crystal lattice. In the crystallization process, electrons are held in place on their crystal lattice by their mutual repulsion. In the IGM, this lattice vibrates under the passage of the photons creating a vibrational transparent and invisible structure to both human eyes and telescopes responsible for the detection of cosmological redshift as shown in **Figure 2**. Once electrons crystallize it is irrelevant as to whether they are bound in an atom or they are free electrons. Not by chance, graphene has been one of the first material under examination for the study. Cosmic dust is made up mostly of graphene and dust is also one of the main reasons for the distance modulus for the SN-Ia as we will see in the next paragraphs. Going into detail, whenever a cloud of electrons gathers without protons, the electrons arrange themselves on BCC Wigner-Seitz crystal lattice, with the electrons held in place by their mutual repulsion [42] [43]. On this lattice the electrical potential energy exceeds the kinetic energy and so the electrons oscillate with SHM (Simple Harmonic Motion). This is how light is transmitted through a transparent medium, "*The transmission and reflection of light is nothing more than an electron picking up a photon, scratching its head so to speak and then emitting a 'new' photon.*" [50]. Consequently, as the photons of light travel through the IGM they are continually absorbed and re-emitted by the electrons arranged on their crystal lattice. Electrons arranged on a Wigner-Seitz crystal are also known as an "electron glass", and this is why the photons interact with the electrons in the IGM and are transmitted without scatter or "blurring" of the image. A photon comes along and is absorbed by the electron which oscillates with SHM about its position on the lattice. The energy of the photon has been transferred to vibrational energy of the electron. The electron then emits a new photon. The electron recoils in order that momentum be conserved and some of the original photons' energy is transferred to kinetic energy of the recoiling electron. The electron recoils both on absorption and re-emission and so not all of the energy of the incoming photon is available to the "new" photon re-emitted. The energy is less, the frequency less and the wavelength longer. It has been redshifted.

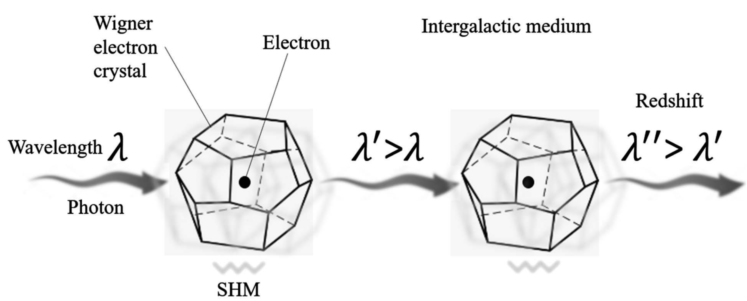

Figure 2. Schematization of the NTL redshift process occurring in the IGM. Free electrons crystallize and recoil at the transit of photons. Due to this, no scattering process takes place but photons lose energy at each crystal transit.

3. Distance Modulus of Supernovae-Ia

The distance modulus is a parameter that expresses the distance of any emitting source as measured from Earth, and also in the SN-Ia context, refers to the apparent magnitude determined according to a logarithmic logic based on an approach still in force nowadays. In this sense, the core of this inquiry is to compare the NTL approach with the ΛCDM one for determining the distance modulus μ. SN-Ia are thermonuclear explosions and have almost a constant absolute magnitude $M = -19.3$ mag as all the white dwarfs, from which they originate, explode when they gain mass from a neighboring star and overcome the Chandrasekhar limit $M > 1.4M_{Sun}$. SN-Ia show no H and He signature in the spectra but only a strong ionized Si line which leads to a thermonuclear reaction. SN-Ia are extremely bright objects and allow cosmologists to extend the Hubble diagram to far greater distances than those determined by Cepheids. What was found was that the rate of expansion in the past was less than it is now *i.e.* the expansion was accelerating and Dark Energy was proposed as the mechanism behind it. However, as we will see in this paper, the same measurements can be explained by another approach in astrophysics and cosmology leading to a totally different interpretation of the Hubble constant with important implications on the belief of an expanding Universe. In support of this statement, it is possible to point out the measurements of the JWST (James Webb Space Telescope) where unexpected galaxies at a higher evolutionary stage have been found at a redshift associated to an epoch where we should see a primordial stage of galaxies [51]. We can also follow the calculation of the angular size which deviates from the ΛCDM expectations [52].

3.1. Expanding Universe Framework

The Pantheon+ (P+) database and its methodology [53] are an extension of the previous Pantheon inquiry [4]. Both analyses interpret the data in the assumption of an expanding Universe. The new analysis, the Pantheon+, includes more SN-Ia and it is tied up directly with the SH0ES (Supernovae and H0 for the Equation of State of dark energy) analysis involving the ladder distance method for the determination of the Hubble constant as well as the cosmological parameters of the ΛCDM model. The absolute magnitude M of the SN-Ia is strictly related to the distance modulus of the Cepheids μ_{ceph} in the host galaxy and to the apparent magnitude in the B-Band as follows

$$M = m_B - \mu_{ceph}. \tag{13}$$

The known Cepheids are used as a distance calibrator for the SN-Ia study. The constancy in the absolute magnitude for all SN-Ia makes them standard candles in astronomy for the calibration of the distances by means of the distance modulus. However, SN-Ia are standard candles once the light curve has been standardized for the absolute magnitude. Indeed, there is a scatter process of the SN-Ia magnitude when plotted against the redshift which is considered in the Philipp & Tripp formula for the correction of the absolute magnitude in the distance modulus formula

$$\mu|_{P+,\Lambda CDM} = m - M_{corr}. \tag{14}$$

The corrected absolute magnitude is given by

$$M_{corr} = M - \alpha \cdot x_1 + \beta \cdot c + \delta_{\mu\_bias} - \delta_{\mu\_host}. \tag{15}$$

It is a linear relation which adjusts the absolute magnitude with the width of the SN-Ia and is in turn related to the fall down of the magnitude after a specific number of days. Moreover, this relation considers the color corrections due to the absorption of optical photons from dust: this causes the color to be bluer than it actually is and it is proportional to the absolute magnitude. It is a tool to standardize all SN-Ia light curves into one single SN-Ia light curve. Based on Equation (14), we can write that

$$\mu|_{P+,\Lambda CDM} = m - M + \alpha \cdot x_1 - \beta \cdot c - \delta_{\mu\_bias} + \delta_{\mu\_host}. \tag{16}$$

We can define the last terms of Equation (16) as the correction factor

$$K_v = \alpha \cdot x_1 - \beta \cdot c - \delta_{\mu\_bias} + \delta_{\mu\_host}, \tag{17}$$

where x_1 is the curve structure parameter, c the color parameter (not to be confused with the speed of light in this context). x_1 and c vary for each SN-Ia and it is included in the update of P+ compared to the previous Pantheon analysis in which only one c parameter has been considered. The SN-Ia magnitude scatter versus redshift is color-dependent. α and β are the nuisance parameters: alpha is the coefficient for the "broader-brighter" width luminosity relation and Beta is the coefficient for the "redder-dimmer" colour-luminosity relation. The latter have the following values

$$\alpha = 0.148, \tag{18}$$

and

$$\beta = 3.112. \tag{19}$$

The presence of these parameter allows us to consider a different dust law for each host galaxy in turn associated to a specific SN-Ia. Dust explains mostly the scatter of the SN-Ia in the distance modulus vs redshift plot in a dominant way. Dust is the most important parameter in any astrophysical process as it causes the dimming of the luminosity. Due to diffraction processes, the dust particles absorb photons in the short wavelengths but not the long ones causing the light curve to be redder than expected. Due to this point, cosmologists need a correction to the light curve to take into account this effect. δ_{μ_bias} varies depending on SN-Ia and it is a useful factor to further standardize the SN-Ia. It is an observed correlation between the residual brightness and the properties of the host galaxies. There is therefore a color-dependence to the property of the host galaxies: the bigger the galaxies the bigger is the impact of the dust to the SN-Ia light curve due to the presence of more dust through which the light has to travel. δ_{μ_host} represents the correction between the standardized magnitude of the SN-Ia and the mass of the host galaxy. This parameter is negligible and therefore does not provide any relevant contribution to the measurements. For this reason,

$$K_\nu = \alpha \cdot x_1 - \beta \cdot c - \delta_{\mu\_bias}. \tag{20}$$

Accordingly, Equation (16) becomes

$$\mu|_{P+,\Lambda CDM} = m - M + K_\nu, \tag{21}$$

where m is the apparent magnitude, M is the absolute magnitude of the SN-Ia and the coefficient K_ν is the correction to the overall extinction effects due to the presence of dust in the IGM and in the host galaxy. This parameter affects the apparent magnitude of the SN-Ia making them dimmer than they are. For this reason, generally $K_\nu < 0$ in the formula as it corresponds to a "brighter" factor added to m in order to compensate for the above effects. This is the procedure undertaken by P+. In terms of flux, we can write from Equation (21) that

$$\mu|_{P+,\Lambda CDM} = -2.5\log_{10}\left(\frac{F}{F_{10\,pc}}\right) + K_\nu, \tag{22}$$

where F is the incoming flux of the SN and $F_{10\,pc}$ is the reference flux at distance of 10 parsecs. Based on the definition of the flux being inversely proportional to the luminosity distance squared for a generic astronomical source x,

$$F_x = \frac{L_x}{4\pi d_{L,x}^2}, \tag{23}$$

and by knowing that

$$d_{L,10\,pc} = 10\text{ pc}, \tag{24}$$

after some mathematical steps contained in **Appendix A**, it yields

$$\mu|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{L,\Lambda CDM}\right) + K_\nu - 5. \tag{25}$$

which is exactly the derived Equation (A7). The latter expresses the relation between the distance modulus and the luminosity distance taking into account the overall extinction coefficient due to dust in the IGM as the contribution at 10 pc distance. In the next steps, our target is now to explicit the luminosity distance in terms of transverse comoving distance in the ΛCDM framework. In generic terms for a generic astronomical source x, according to the inverse square law, the luminosity reduces as

$$F_{o,x} = \frac{L_{o,x}}{4\pi r_{0,x}^2}, \tag{26}$$

where we recognize the observed flux $F_{o,x}$, the observed luminosity $L_{o,x}$ and the generic distance $r_{0,x}$ emitter-observer in a specific cosmology. Obviously, we are dealing now with SN-Ia in standard cosmology in this section or namely $x \equiv SNIa$. Therefore, r_0 is the radial distance determined depending on the curvature of the space-time in place. For a flat space-time with curvature, based on the most current observational data, the radial distance coincides with the transverse comoving distance determined by a distance ladder method such as cepheids as follows

$$r_0 \equiv d_{\Lambda CDM}. \tag{27}$$

By applying the definition of observed L_o and emitted luminosity L_e as well as the redshift formula z according to standard cosmology, we can determine the expression of the observed luminosity from Equation (B9) in **Appendix B** so that we end up with the following expression for the observed flux

$$F_o = \frac{1}{4\pi d_{\Lambda CDM}^2} \frac{L_e}{(1+z)^2}, \tag{28}$$

as function of the emitted luminosity and the transverse comoving distance. It is important to stress that, in this reasoning, the result of Equation (28) is possible only because the ΛCDM model admits a time dilation which translates into a difference photon rate at emission and reception. Approaching in this phase the definition of bolometric flux and considering the luminosity distance for a generic astronomical source

$$F_{bol,x} = \frac{L_{bol,x}}{4\pi d_{L,x}^2}, \tag{29}$$

we can apply this formula to our specific calculation case, and ultimately, from **Appendix C** in Equation (C4), we can obtain the important relation between the luminosity distance and the transverse comoving distance in the ΛCDM cosmology as

$$d_{L,\Lambda CDM} = d_{\Lambda \mathrm{CDM}} (1+z). \tag{30}$$

Due to this result, we can now substitute Equation (30) in Equation (25) and proceed with the calculation in **Appendix D** until we reach an important milestone formula in standard cosmology corresponding to Equation (D10) or namely:

$$\mu\big|_{P+,\Lambda CDM} = 5\log_{10}(d_{\Lambda CDM}) + 5\log_{10}(1+z) + 25 + K_\nu. \tag{31}$$

In Equation (31) we changed our distance framework from parsecs to megaparsecs in order to leave the galactic scale and step into a cosmological one. Finally, we can now focus on the transverse comoving distance and the cosmological parameters conceived in an expanding space. Indeed, $d_{\Lambda CDM}$ is the transverse comoving distance in the FLRW metric expressed as

$$d_{\Lambda CDM} = \frac{c}{H_0} \frac{1}{\sqrt{\Omega_{k,0}}} \cdot \sinh\left[\sqrt{\Omega_{k,0}} \int_0^z \frac{\mathrm{d}z}{\sqrt{\Omega_{m,0}(1+z)^3 - \Omega_{k,0}(1+z)^2 + \Omega_{\Lambda,0}}}\right], \tag{32}$$

where H_0 is the Hubble constant in our current epoch. The following relation is valid

$$\Omega_{m,0} + \Omega_{k,0} + \Omega_{\Lambda,0} \cong 1, \tag{33}$$

where $\Omega_{m,0}$ is the omega density parameter for matter, $\Omega_{k,0}$ the omega density parameter for the space curvature and $\Omega_{\Lambda,0}$ the omega lambda parameter associated with the dark energy, and in turn to the expanding space. All parameters refer to our visible Universe in "our current epoch" and are based on observational data from the most modern telescope technology. An overview of the most important parameter is contained in the following set

$$\begin{cases} \Omega_{r,0} \cong 0 \\ \Omega_{k,0} = 0.0007 \\ \Omega_{m,0} \cong 0.3 \\ \Omega_{\Lambda,0} \cong 0.7 \\ H_0 = 73.5 \dfrac{\text{km}}{\text{sec} \cdot \text{Mpc}} \end{cases} \tag{34}$$

Thus, the transverse comoving distance is a well-known parameter at any redshift in standard cosmology. Equation (32) is normally solved by numerical methods such as the Gaussian quadrature available in several online calculators. At this point, based on Equation (31), the raw data for the distance modulus, including dust extinction effects, can accordingly only be provided by the following expression

$$\mu_{raw}\big|_{P+,\Lambda CDM} = \mu\big|_{P+,\Lambda CDM} - K_\nu. \tag{35}$$

We rely on this formula to compare the effect of the current analysis to the NTL approach. Since generally $K_\nu < 0$ for each SN-Ia, we are basically adding a dimming (positive in sign) contribution to the distance modulus of each SN-Ia in order to account for the extinction effects. Based on previous Equation (31) and considering the mathematical expression of Equation (20) which cancels out, the raw distance modulus according to the ΛCDM approach is given by

$$\mu_{raw}\big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\right) + 5\log_{10}\left(1+z\right) + 25. \tag{36}$$

3.2. Non-Expanding Universe Framework

Our task is to compare the raw data, which includes the dust extinction, between the P+ ΛCDM approach and the NTL one schematized in **Figure 3**. In this way, we are comparing comparable and homogeneous data without differences as we remove the extinction effect from dust. Similarly to Equation (22) but in a different contest and without corrections for dust, we can write for definition in a different cosmology that the raw distance modulus is given by

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left(\frac{F}{F_{10pc}}\right). \tag{37}$$

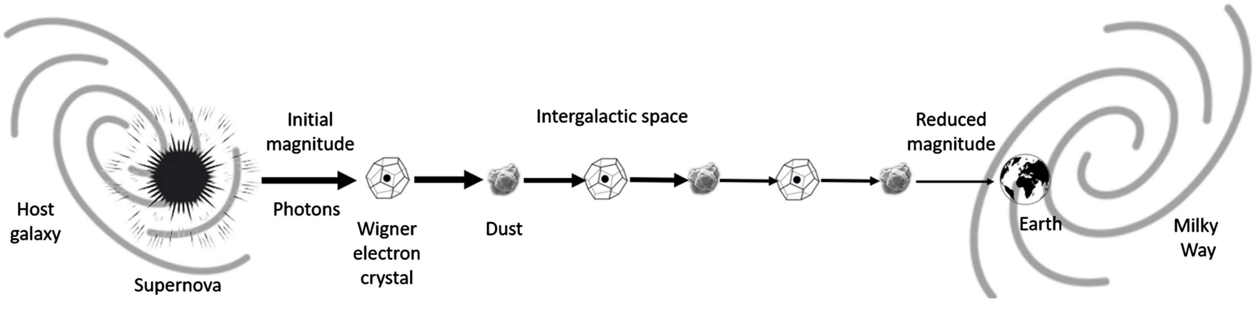

Figure 3. Schematization of a Supernova dimming process according to a NTL mindset.

The luminosity distance in the formula of the observed flux of Equation (23) is now $d_{L,NTL}$. We want to express the luminosity in terms of intensity of radiation since the luminosity is a synonym of power. The observed flux is the luminosity observed by the source which reduces according to the inverse square law as in Equation (26) where now r_0 is the straight distance as determined in a non-expanding Universe based on the NTL theory or rather

$$r_0 \equiv d_{NTL}. \tag{38}$$

This distance does not coincide with a measured distance in a flat space-time with a zero-space curvature, as it is a function of cosmological parameters here not admitted. Therefore, starting from the definition of emitted intensity as power per unit area A and introducing the radiative transfer equation which allows us to describe the absorption of the light along its travel due to dust, we end up with Equation (E15) in **Appendix E** written as

$$F_o = \frac{AI_e}{4\pi d_{L,NTL}^2} \frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}} (1+z)}. \tag{39}$$

Moreover, by considerations on the emitted luminosity, we can also reach the formula of Equation (F6) contained in **Appendix F** as

$$F_o = \frac{1}{4\pi d_{NTL}^2} \frac{L_e}{1+z}, \tag{40}$$

in which we expressed the observed flux, in a non-expanding Universe, directly as function of the emitted luminosity L_e, and the luminosity distance $d_{L,NTL}$. Differently from an expanding space, the result of Equation (40) is also possible because a non-expanding cosmology such as the NTL model, does not admit a time dilation, it translates into an unchanged photon rate between emission and observation. However, in the definition of bolometric flux of Equation (29), after several steps contained in **Appendix G**, we obtain the important derived formula of Equation (G5) in a non-expanding Universe

$$d_{L,NTL} \equiv d_{NTL} \sqrt{1+z}, \tag{41}$$

which relates the luminosity distance and the straight distance to the source according to a non-expanding model. The square root of the $1+z$ term of Equation (41) is expected in any TL process. The difference between a NTL process and a generic TL process consists in the photon energy loss. In the NTL theory, the latter is expressed by the Hubble constant, function in terms of the properties of the electrons as seen in Equation (2). Combining the results of Equations (39)-(41) and collecting the mathematics in **Appendix H**, we obtain the relation of Equation (H2)

$$F_o = \frac{L_e}{4\pi d_{NTL}^2 (1+z)^2} \frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}}}, \tag{42}$$

which is the first term at the numerator in the parenthesis of Equation (37). In order to fulfill all the terms of the distance modulus equation in Equation (37), it remains to define in a similar way the observed flux at 10 parsecs determined from Equation (I5) in **Appendix I** as

$$F_{10pc} = \frac{L_e}{4\pi 10^2}. \tag{43}$$

In order to complete the circle of equations, we have to calculate the remaining parameters that will lead us toward the final expression for the distance modulus in a non-expanding space. In this regard, the speed of light has the known value

$$c = 299792458 \frac{\text{m}}{\text{sec}}, \tag{44}$$

and according to the NTL theory explained in the previous chapter, the Hubble constant is now exclusively a function of the electron properties. The observed number electron density in the IGM is equal to [32] [33]

$$n_e = 0.5 \frac{\text{el}}{\text{m}^3}. \tag{45}$$

The ratio of speed of light to NTL Hubble constant in the IGM is according to Equation (2) and Equation (44) is the following

$$\frac{c}{H_{NTL}} = 1.463 \times 10^{26} \text{ m}. \tag{46}$$

At this stage, according to the previous calculations and physical and mathematical reasonings, we can substitute Equations (42) and (43) into Equation (37) and after several mathematical steps in **Appendix J**, we obtain an important result contained in Equation (J16)

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25 + 1.588 \times 10^{26} \alpha_\nu. \tag{47}$$

Notice how the last term of Equation (47) is equivalent to a "dust factor" incorporated in the NTL theory and mathematics as

$$\eta_{NTL} = 1.588 \times 10^{26} \alpha_\nu. \tag{48}$$

Therefore, Equation (47) can be written as

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25 + \eta_{NTL}, \tag{49}$$

or rather, the raw distance modulus is the sum of a nominal contribution plus the "dust factor"

$$\mu_{raw}\big|_{NTL} = \mu\big|_{NTL} + \eta_{NTL}, \tag{50}$$

where

$$\mu\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25. \tag{51}$$

The peculiarity of this inquiry is that, in other terms and based on derived Equation (49), we calculated that the NTL raw distance modulus is given by the sum of four different contributions

$$\mu_{raw} = \mu_{dist} + \mu_{phot} + \mu_{unit} + \mu_{dim} \tag{52}$$

where:

- $\mu_{dist} = 5\log_{10}(d_{NTL})$ is the contribution due to distances in a static Universe (which is an exponential function) according to a NTL approach instead of distances in an expanding Universe (as function of the omega density parameters including the dark energy term) for the ΛCDM.
- $\mu_{phot} = 5\log_{10}(1+z)$ is the contribution due to energy loss as the photons transfer energy to the recoiling electrons according to the NTL theory whereas, according to the ΛCDM, it is the contribution due to energy loss as the photons lose energy due to the alleged stretching of space;
- $\mu_{unit} = 25$ is the contribution related to the unity of measurement due to the conversion of the distances from parsecs to megaparsecs valid both for NTL and ΛCDM;
- $\mu_{dim} = 1.588\times10^{26}\alpha_{\nu} \equiv \eta_{NTL}$ is the contribution caused by dust extinction "dimming" of the supernovae-Ia calculated straightforward in the NTL approach whereas, based on the ΛCDM theory in the Pantheon+ approach, this term is basically obtained by subtracting the correction parameter, as we will see in the next paragraphs, used to adjust the curve.

We refer to a "raw" distance modulus as there are no correction factors in the calculation methodology. It is a required action in order to compare the NTL predictions with the raw data from the Pantheon+ inquiry, as we will see in the next paragraphs. Moreover, in contrast to the ΛCDM physics, a TL process does not conceive a time dilation as the photon rate is the same at emission and reception. On the contrary, the ΛCDM model conceives intrinsically a time dilation in the equations.

Proceeding with our calculation methodology, the nominal distance modulus according to the NTL process is summed up with a positive dimming contribution given by the dust extinction, where η_{NTL} is the dust extinction contribution in the IGM and depends on the dust absorption coefficient α_{ν}. Through the NTL distance formula extracted from Equation (1), namely Equation (E14) in **Appendix E**, the raw distance modulus of Equation (50) can be for the first time expressed as

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.379 + 1.588\times10^{26}\alpha_{\nu}. \quad (53)$$

The derivation is contained in **Appendix K** in which the NTL distance formula is converted into megaparsecs in order to homogenize the unit of measurement for the cosmological distances. The very last step consists in the calculation of the dust absorption coefficient based on known physics and mathematics. For this reason, we refer to the dust absorption coefficient for known baryonic matter $\alpha_{\nu,b}$. Due to this, we impose $\alpha_{\nu} \equiv \alpha_{\nu,b}$. Thus, we end up with the following value contained in Equation (L16)

$$\alpha_{\nu,b} = \frac{\pi}{4}\frac{\bar{\rho}_{m,b}}{\bar{\rho}_{dust}}\frac{1}{\bar{D}_{dust}} = 2.062\times10^{-28}\,\frac{1}{\text{m}}. \quad (54)$$

Indeed, the reasoning behind this value as well as its long mathematical steps are enclosed in **Appendix L**. $\bar{\rho}_{dust}$ is the average dust grain density whereas $\bar{\rho}_{m,b}$ is the average baryonic mass density of matter in the Universe and $\bar{D}_{dust}$ is the average dust grain diameter according to existing scientific inquiries. Eventually, we can substitute the value obtained in Equation (54) into Equation (53) which leads to the final Equation (M5) of the inquiry enclosed in **Appendix M** or namely

$$\mu_{raw}\big|_{NTL,b} \cong 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.4. \quad (55)$$

3.3. Outcome

This inquiry reaches the target to compare the distance modulus of SN-Ia in an expanding and non-expanding space according to the most current knowledge and observational data available. In order to sum up the results and to plot the comparison graph, we need to recall the most important equations. Scientists observe the flux of SN-Ia with their instruments and accordingly they calculate the distance modulus only according to one cosmological framework: the ΛCDM model characterized by photons losing energy throughout space due to the expanding space guided by the dark energy. The most known and valuable database is the Pantheon+ inquiry which detects the flux of the SN-Ia and removes the dust contribution through the correction factor K_ν of Equation (20). From a NTL perspective, in order to compare similar physical quantities, we require a raw distance modulus in which we consider the dust effect on the observed radiation. This mindset is enclosed in Equation (35) and, in turn, Equation (36), and it represents the raw SN-Ia distance modulus for an expanding Universe. Cosmologists remove the dust effect. We do include it. As it is based on observational data, the curve of the SN-Ia dimming is not smooth and it is shown in black in **Figure 4**. The deviations from the mean refer to the dust corrections removed for each SN-Ia which has different parameters. It translates into wells and peaks in the black curve, however with a well-defined trend. On the other side, we can undertake a non-expanding approach in which photons lose energy after multiple interactions with crystallized electrons as well as dust grains scattered in the IGM. The NTL mathematics is as known as the standard cosmology. In this framework, we calculate the distance modulus for SN-Ia including the dust effect on the radiation similarly to the calculations for the ΛCDM model. We derive Equation (55) as function of the redshift z and it is represented by the orange curve in the distance modulus plot of **Figure 4**. The latter consists of a comparison between the distance modulus of SN-Ia based on two cosmological models and mindsets: Equation (36) for the ΛCDM model, expanding Universe, and Equation (55) for the NTL model, non-expanding Universe. Both models do include now the dust effect. **Figure 4** provides an undeniable conclusion: the two cosmologies explain exactly the same measurements for the distance modulus of SN-Ia and accordingly for the observational data. The main calculations are contained in one single spreadsheet from which the two curves have been plotted.

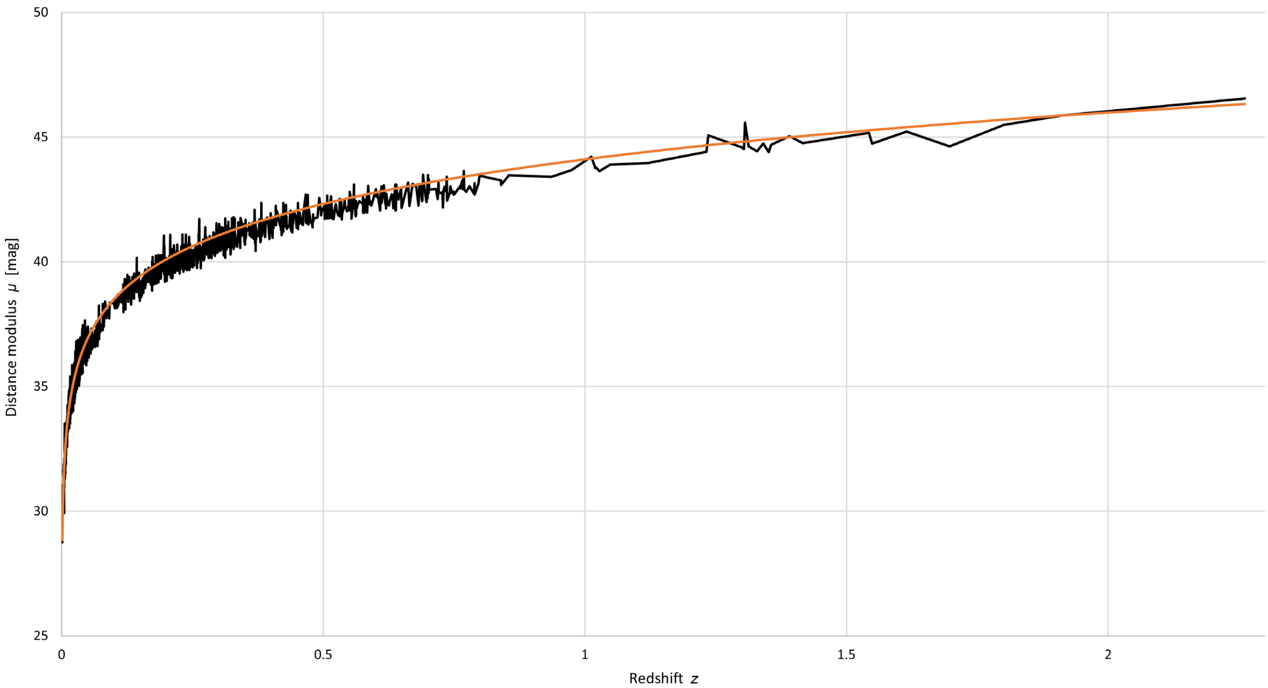

Figure 4. Distance modulus vs. redshift. Black curve: Pantheon+ with dust extinction; Orange curve: NTL trend with dust extinction.

4. Discussion and Conclusions

The perfect fit of the NTL predictions, in a non-expanding space, for the distance modulus of SN-Ia to observational data, is very remarkable and deserves the utmost attention in the scientific community. It is no more a matter of chance or speculation but the physics undergone in this inquiry leads toward a different process not only in the explanation of the dimming of the SN-Ia but also in the understanding of the redshift and its mechanism in the IGM beyond.

For the purpose of explaining the dimming of SN-Ia for increasing redshifts, we introduced the multiple interactions between photons and crystallized electrons in the IGM as well as the interaction between photons and dust grains which dim the incoming radiation interaction after interaction.

The main non-expanding mindset is based on existing physics and it does not contain any adjustable parameters. We demonstrate how by making a comparison between raw distance modulus measurements without dust corrections (from the Pantheon+ analysis) and a raw distance modulus analysis in a non-expanding space (through a NTL process) which includes the dust effect on the radiation, the two curves coincide.

The two approaches undertaken allow us to compare the cosmological models and to draw conclusions in an objective manner. If we did not remove the dust correction from the observational data, the comparison would be falsified. But it is not the case. This means that, in general, a tired light process, and specifically the NTL theory, can explain several main aspects of modern cosmology, from the dimming of SN-Ia to the cosmological redshift. The latter is strictly related to the SN-Ia dimming as shown in this article and all its appendices.

The number electron density in the IGM together with the presence of dust is a prerogative for obtaining the right distance modulus. It implies backwards that the interaction between photons and crystallized electrons in the IGM is very reliable and cosmology should focus on it for explaining the dimming of supernovae Ia. Laboratory tests should be planned for this new mindset and new physics departments should embark on an alternative theory in parallel to standard cosmology. Only in this way, the ΛCDM model can be confirmed or debunked. In absence of antagonist working projects in cosmology, science might commit irreversible mistakes.

The expanding Universe of the Big Bang Theory, currently parametrized in the ΛCDM model, has found the Hubble diagram extended up to large redshifts difficult, if not impossible to explain. There is not one relationship that will explain both near and far distance modulus-redshift relationships and so it has been necessary to resort to new physics such as space acceleration and the accompanying dark energy said to drive the space acceleration. However, no one has any clue as to what the dark energy consists of. It is an attempt to make the theory fit the data.

The ΛCDM model remains just a theory for which several points must be explained: the Hubble diagram associated to the apparent recession velocities of the galaxies, the Hubble Tension giving different Hubble constants depending on the adopted method and direction in the sky and, last but not least, the dark energy driving the space expansion.

The ΛCDM model relies on the prior assumption that the Universe is expanding in order to describe any cosmological phenomenon including the cosmological redshift and the SN-Ia dimming described by the analysis of distance modulus. On the contrary, New Tired Light is based on present day Physics and gives quantitative predictions on redshift and distance. Based on the distance to the supernovae-Ia and knowing the absolute magnitude of these standard candles it can predict a value for the distance modulus of each object.

In NTL, the photons lose energy as they travel, interacting with crystallized electrons in the IGM and so a correction must be added to the distance modulus for this. Since each photon has less energy on arrival than when it set off the apparent magnitude of the supernovae will be more and the supernovae appear farther away. Dust also has an effect on the distance modulus and a predicted adjustment is made. When the final quantitative value of the distance modulus is found by taking the distance modulus as predicted by NTL along with corrections for photon energy loss and dust, the predictions match the data perfectly with no adjustable parameters or any new required Physics. Moreover, in this new framework, the Hubble constant is no more related to an expanding and accelerating space, but rather it has just the meaning of photon energy loss, due to the interaction with Wigner electron crystals, as a function of the electron properties.

For the first time, for the first time overall, we derive exactly how the distance modulus in a NTL process is provided by the sum of four contributions as for Equation (49) and Equation (52): the contribution due to calculated distance in a non-expanding Universe, the contribution due to energy loss in the IGM as photons transfer energy to the recoiling electrons, the contribution related to the unity of measurement due to the conversion of the distances from parsecs to megaparsecs for accounting for the cosmological scales and, last but not least, the contribution caused by dust extinction dimming of the SN-Ia, the latter included in the dust parameter. The sum of these contributions provides exactly the same observational data trend determined by the ΛCDM cosmology by removing the dust corrections.

Data Availability Statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Author Contributions

The authors confirm being the sole contributor of this work and have approved it for publication.

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Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A

$$\mu\big|_{P+,\Lambda CDM} = -2.5\log_{10}\left(\frac{L_o}{4\pi d_{L,\Lambda CDM}^2}\frac{4\pi d_{L,10\,pc}^2}{L_o}\right) + K_\nu, \tag{A1}$$

$$\mu\big|_{P+,\Lambda CDM} = -2.5\log_{10}\left(\frac{d_{L,10\,pc}}{d_{L,\Lambda CDM}}\right)^2 + K_\nu, \tag{A2}$$

$$\mu\big|_{P+,\Lambda CDM} = -2\cdot 2.5\log_{10}\left(\frac{d_{L,10\,pc}}{d_{L,\Lambda CDM}}\right) + K_\nu, \tag{A3}$$

$$\mu\big|_{P+,\Lambda CDM} = -5\log_{10}\left(\frac{d_{L,10\,pc}}{d_{L,\Lambda CDM}}\right) + K_\nu, \tag{A4}$$

Moreover, due to Equation (24), we can write that

$$\mu\big|_{P+,\Lambda CDM} = -5\log_{10}\left(\frac{10}{d_{L,\Lambda CDM}}\right) + K_\nu, \tag{A5}$$

so that

$$\mu\big|_{P+,\Lambda CDM} = -5\log_{10}(10) - \left[-5\log_{10}\left(d_{L,\Lambda CDM}\right)\right] + K_\nu, \tag{A6}$$

$$\mu\big|_{P+,\Lambda CDM} = -5 + 5\log_{10}\left(d_{L,\Lambda CDM}\right) + K_\nu. \tag{A7}$$

Appendix B

The observe luminosity is

$$L_o = \frac{E_o}{T_0} = \frac{h\nu_o}{T_0} = \frac{hc}{T_0\lambda_o}. \tag{B1}$$

where E_o is the observed photon energy given by the scala product of the Planck constant h multiplied by the observed photon frequency ν_o. T_0 is the observed time, c is the speed of light and λ_o is the observed photon wavelength. From the definition of redshift

$$z = \frac{\lambda_o - \lambda_e}{\lambda_e} = \frac{\lambda_o}{\lambda_e} - 1, \tag{B2}$$

which implies

$$\frac{\lambda_o}{\lambda_e} = 1 + z = \frac{c\,\nu_o}{c\,\nu_e} = \frac{T_o}{T_e} = \frac{R_o}{R_e} = \frac{1}{R}, \tag{B3}$$

in which we can apply the scale factor in our "today epoch"

$$R_o = 1. \tag{B4}$$

It is important to stress how the ΛCDM cosmology in Equation (B3) conceives the existence of time dilation as the photon rate at emission and reception may be different. Indeed, in the same equation we are interested in the expression of the following parameter

$$T_o = \frac{T_e}{R}. \tag{B5}$$

Thus, substituting Equation (B5) into Equation (B1), we obtain

$$L_o = \frac{hc}{T_e}\frac{R}{\lambda_o}. \tag{B6}$$

Moreover, in terms of emitted physical quantities, it is possible to write

$$L_e = \frac{E_e}{T_e} = \frac{h\nu_e}{T_e} = \frac{hc}{T_e\lambda_e}, \tag{B7}$$

where E_e is the emitted photon energy given by the scala product of the Planck constant h multiplied by the emitted photon frequency ν_e. T_e is the emitted time and λ_e is the emitted photon wavelength. It implies that

$$\frac{hc}{T_e} = \lambda_e L_e. \tag{B8}$$

Considering the result of Equation (B8), Equation (B6) becomes

$$L_o = \lambda_e L_e \frac{R}{\lambda_o} = L_e R^2 = \frac{L_e}{(1+z)^2}. \tag{B9}$$

Appendix C

From Equation (29), we can write that

$$F_{bol} = \frac{L_{bol}}{4\pi d_{L.\Lambda CDM}^2}. \tag{C1}$$

This equation recalls Equation (28) and therefore, we can infer that the following parameters are equal, both

$$L_{bol} \equiv L_e, \tag{C2}$$

and

$$d_{L,\Lambda CDM}^2 \equiv d_{\Lambda CDM}^2 (1+z)^2. \tag{C3}$$

or rather

$$d_{L,\Lambda CDM} \equiv d_{\Lambda CDM} (1+z). \tag{C4}$$

Appendix D

$$\mu\big|_{P+,\Lambda CDM} = 5\log_{10}\left[d_{\Lambda CDM}(1+z)\right] - 5 + K_\nu, \tag{D1}$$

$$\mu\big|_{P+,\Lambda CDM} = 5\log_{10}(d_{\Lambda CDM}) + 5\log_{10}(1+z) - 5 + K_\nu. \tag{D2}$$

As the distance refers to the parsec scale. Equation (D2) can be better expressed as

$$\mu\big|_{P+,\Lambda CDM} = 5\log_{10}\left(\frac{d_{\Lambda CDM}}{\text{pc}}\right) + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D3}$$

and since we are dealing with large cosmological distances, cosmologists express them in megaparsecs instead of parsecs, therefore, we have to convert the overall distance scale as follows

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(\frac{d_{\Lambda CDM}}{\text{pc}}\frac{10^6\ \text{pc}}{\text{Mpc}}\right) + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D4}$$

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(\frac{d_{\Lambda CDM}\cdot 10^6}{\text{Mpc}}\right) + 5\log_{10}(1+z) - 5 + K_\nu. \tag{D5}$$

Going back to our previous terminology, removing the unit of measurements in the equations, we can write that

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\cdot 10^6\right) + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D6}$$

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\right) + 5\log_{10}\left(10^6\right) + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D7}$$

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\right) + 6\cdot 5\log_{10}(10) + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D8}$$

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\right) + 30 + 5\log_{10}(1+z) - 5 + K_\nu, \tag{D9}$$

$$\mu\Big|_{P+,\Lambda CDM} = 5\log_{10}\left(d_{\Lambda CDM}\right) + 5\log_{10}(1+z) + 25 + K_\nu. \tag{D10}$$

Appendix E

Based on generic Equation (23), we can write that

$$F_o = \frac{L_o}{4\pi d_{L,NTL}^2}, \tag{E1}$$

The definition of emitted intensity as power per unit area A allows us to write

$$I_o = \frac{L_o}{A}, \tag{E2}$$

from which

$$L_o = AI_o. \tag{E3}$$

Due to this, the observed flux of Equation (E1) becomes

$$F_o = \frac{AI_o}{4\pi d_{L,NTL}^2}. \tag{E4}$$

Our target is now to determine the expression for the observed intensity of radiation I_o as function of the emitted intensity as we want to consider the reduction of the intensity itself due to the presence of the dust in the IGM. The radiative transfer equation allows us to describe the absorption of the light along its travel as follows

$$\frac{\text{d}I}{\text{d}r} = -\alpha_\nu I, \tag{E5}$$

where r represents the distance parameter and α_ν the dust absorption coefficient. Reordering the factors, we can obtain that

$$\frac{\text{d}I}{I} = -\alpha_\nu \text{d}r, \tag{E6}$$

and integrating the variables between our earthly position and the generic distance of an emitting source x

$$\int_0^{d_x} \frac{\mathrm{d}I}{I} = \int_0^{d_x} -\alpha_\nu \mathrm{d}r, \tag{E7}$$

we obtain that

$$\ln\left[\frac{I(d_x)}{I(0)}\right] = -\alpha_\nu d_x, \tag{E8}$$

or namely

$$\frac{I(d_x)}{I(0)} = \mathrm{e}^{-\alpha_\nu d_x}. \tag{E9}$$

The intensity after the distance travelled d_x coincides with the observed intensity I_o so that $I(d_x) \equiv I_o$ and that the intensity emitted at the source coincides with the emitted intensity I_e expressed by $I(0) \equiv I_e$. Moreover, for coherence with the terminology, in this framework, we have to set

$$d_x \equiv d_{NTL}, \tag{E10}$$

where in our inquiry $x \equiv SNIa$ as we are dealing with supernovae Ia. Due to the previous considerations, Equation (E9) can be written as

$$I_o = \frac{I_e}{\mathrm{e}^{\alpha_\nu d_{NTL}}}. \tag{E11}$$

According to this, Equation (E4) becomes

$$F_o = \frac{A}{4\pi d_{L,NTL}^2} \frac{I_e}{\mathrm{e}^{\alpha_\nu d_{NTL}}} \tag{E12}$$

The distance of Equation (E11) in a non-expanding Universe can be obtained from NTL redshift distance shown in the right-hand side term of Equation (1) as follows

$$d_{NTL} = \frac{c}{H_{NTL}} \ln(1+z). \tag{E13}$$

Due to that, Equation (E12) evolves in

$$F_o = \frac{A}{4\pi d_{L,NTL}^2} \frac{I_e}{\mathrm{e}^{\alpha_\nu \frac{c}{H_{NTL}} \ln(1+z)}}. \tag{E14}$$

which can be also written as

$$F_o = \frac{A I_e}{4\pi d_{L,NTL}^2} \frac{1}{\mathrm{e}^{\alpha_\nu \frac{c}{H_{NTL}}}(1+z)}. \tag{E15}$$

Appendix F

In a non-expanding space, the observed luminosity is

$$L_o = \frac{E_o}{T_0} = \frac{h\nu_o}{T_0} = \frac{hc}{T\lambda_o}, \tag{F1}$$

and there is no time dilation as there is no change of photon rate between emission and reception. It is expressed by

$$T_e = T_0 = T. \tag{F2}$$

From the generic definition of redshift written in Equation (B2), it implies

$$\frac{\lambda_o}{\lambda_e} = 1 + z. \tag{F3}$$

Therefore, by defining and developing the expression of the emitted luminosity as for Equation (B7) but now including the previous considerations in a non-expanding space, we can write that

$$L_e = \frac{E_e}{T_e} = \frac{h\nu_e}{T_e} = \frac{hc}{T\lambda_e} = \frac{hc}{T}\frac{1+z}{\lambda_o} = L_o(1+z), \tag{F4}$$

from which the observed luminosity assumes now the mathematical expression

$$L_o = \frac{L_e}{1+z}. \tag{F5}$$

Therefore, going back to the observed flux of Equation (E1), we can write that

$$F_o = \frac{1}{4\pi d_{NTL}^2}\frac{L_e}{1+z} \tag{F6}$$

Appendix G

Due to Equation (29), it is possible to write

$$F_{bol} = \frac{L_{bol}}{4\pi d_{L,NTL}^2}. \tag{G1}$$

We can identify similarity in the form of the formulae between Equation (F1) and Equation (E15). Therefore, we can infer that

$$L_{bol} \equiv \frac{L_e}{e^{\alpha_\nu \frac{c}{H_{NTL}}}(1+z)}, \tag{G2}$$

where the emitted luminosity is

$$L_e = AI_e, \tag{G3}$$

as well as

$$d_L^2 \equiv d_{NTL}^2(1+z), \tag{G4}$$

from which we obtain the important formula in a non-expanding Universe

$$d_L \equiv d_{NTL}\sqrt{1+z}, \tag{G5}$$

Appendix H

Combining the results of **Appendix E, Appendix F, Appendix G**, respectively through Equations (E15), (F6), (G5), we can write that

$$F_o = \frac{L_e}{4\pi d_{NTL}^2(1+z)}\frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}}(1+z)}, \tag{H1}$$

in which, collecting the $1+z$ terms, it evolves into

$$F_o = \frac{L_e}{4\pi d_{NTL}^2 (1+z)^2} \frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}}}. \tag{H2}$$

Appendix I

From Equation (E15)

$$F_{10pc} = \frac{A}{4\pi \cdot 10^2} \frac{I_e}{e^{0 \cdot d_{NTL}}}, \tag{I1}$$

in which, as shown, our luminosity distance is now

$$d_{L,NTL} = 10 \text{ pc}, \tag{I2}$$

and moreover, we assume that in this short interstellar distance (not cosmological) the absorption coefficient is negligible (no absorption due to dust between Earth and this short distance) and therefore

$$\alpha_{10pc} \cong 0. \tag{I3}$$

Accordingly, Equation (I1) becomes

$$F_{10pc} = \frac{AI_e}{4\pi 10^2}. \tag{I4}$$

Due to previous Equation (G3), it yields

$$F_{10pc} = \frac{L_e}{4\pi 10^2}. \tag{I5}$$

Appendix J

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left[\frac{L_e}{4\pi d_{NTL}^2 (1+z)^2} \frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}}} \frac{4\pi 10^2}{L_e}\right], \tag{J1}$$

in which both the emitted luminosity and the solid angle 4π cancel out so that what remains is

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left[\frac{10^2}{d_{NTL}^2 (1+z)^2} \frac{1}{e^{\alpha_\nu \frac{c}{H_{NTL}}}}\right], \tag{J2}$$

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left[\frac{10^2}{d_{NTL}^2 (1+z)^2}\right] - \left[-2.5\log_{10}\left(e^{\alpha_\nu \frac{c}{H_{NTL}}}\right)\right], \tag{J3}$$

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left[\frac{10^2}{d_{NTL}^2 (1+z)^2}\right] + 2.5\log_{10}\left(e^{\alpha_\nu \frac{c}{H_{NTL}}}\right), \tag{J4}$$

$$\mu_{raw}\big|_{NTL} = -2.5\log_{10}\left(10^2\right) - \left\{-2.5\log_{10}\left[d_{NTL}^2 (1+z)^2\right]\right\} + 2.5\alpha_\nu \frac{c}{H_{NTL}} \log_{10}(e), \tag{J5}$$

$$\mu_{raw}\big|_{NTL} = -2 \cdot 2.5\log_{10}(10) + 2.5\log_{10}\left[d_{NTL}^2 (1+z)^2\right] + 2.5\alpha_\nu \frac{c}{H_{NTL}} \log_{10}(e), \tag{J6}$$

$$\mu_{raw}\big|_{NTL} = -5\log_{10}(10) + 2.5\log_{10}\left(d_{NTL}^2\right) + 2.5\log_{10}(1+z)^2 + 2.5\alpha_\nu \frac{c}{H_{NTL}} \cdot 0.434, \tag{J7}$$

$$\mu_{raw}\big|_{NTL} = -5 + 2\cdot 2.5\log_{10}\left(d_{NTL}\right) + 2\cdot 2.5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}, \tag{J8}$$

$$\mu_{raw}\big|_{NTL} = -5 + 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}. \tag{J9}$$

Since we are dealing with high cosmological distances, we can express the distance in megaparsecs instead of parsecs, therefore, we have to convert the distance scale as

$$\mu_{raw}\big|_{NTL} = -5 + 5\log_{10}\left(\frac{d_{NTL}}{\text{pc}}\frac{10^6\ \text{pc}}{\text{Mpc}}\right) + 5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}, \tag{J10}$$

which leads to

$$\mu_{raw}\big|_{NTL} = -5 + 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(10^6\right) + 5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}, \tag{J11}$$

$$\mu_{raw}\big|_{NTL} = -5 + 5\log_{10}\left(d_{NTL}\right) + 6\cdot 5\log_{10}\left(10\right) + 5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}, \tag{J12}$$

$$\mu_{raw}\big|_{NTL} = -5 + 5\log_{10}\left(d_{NTL}\right) + 30 + 5\log_{10}\left(1+z\right) + 1.086\alpha_\nu \frac{c}{H_{NTL}}, \tag{J13}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25 + 1.086\alpha_\nu \frac{c}{H_{NTL}}. \tag{J14}$$

Due to Equation (46), it yields

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25 + 1.086\alpha_\nu \cdot 1.463\times 10^{26}, \tag{J15}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(d_{NTL}\right) + 5\log_{10}\left(1+z\right) + 25 + 1.588\times 10^{26}\alpha_\nu. \tag{J16}$$

Appendix K

Substituting Equation (E13) into Equation (47), we can write that

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left[\frac{\frac{c}{H_{NTL}}\ln\left(1+z\right)}{3.086\times 10^{22}}\right] + 5\log_{10}\left(1+z\right) + 25 + 1.588\times 10^{26}\alpha_\nu, \tag{K1}$$

where the factor 3.086E+22 is due to the conversion $1\,\text{m} = 3.086\times 10^{22}\,\text{Mpc}$. It leads to

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(\frac{\frac{c}{H_{NTL}}}{3.086\times 10^{22}}\right) + 5\log_{10}\left[\ln\left(1+z\right)\right] + 5\log_{10}\left(1+z\right) + 25 + 1.588\times 10^{26}\alpha_\nu, \tag{K2}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left(1.463\times 10^{26}\right) - 5\log_{10}\left(3.086\times 10^{22}\right) + 5\log_{10}\left[\ln\left(1+z\right)\right] + 5\log_{10}\left(1+z\right) + 25 + 1.588\times 10^{26}\alpha_\nu. \tag{K3}$$

Our target is now to express the formula just as a function of the redshift z as follows

$$\mu_{raw}\big|_{NTL} = 130.826 - 112.447 + 5\log_{10}\left[\ln(1+z)\right] + 5\log_{10}(1+z) + 25 + 1.588\times10^{26}\alpha_\nu, \tag{K4}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left[\ln(1+z)\right] + 5\log_{10}(1+z) + 43.379 + 1.588\times10^{26}\alpha_\nu, \tag{K5}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left[(1+z)\cdot\ln(1+z)\right] + 43.379 + 1.588\times10^{26}\alpha_\nu, \tag{K6}$$

$$\mu_{raw}\big|_{NTL} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.379 + 1.588\times10^{26}\alpha_\nu. \tag{K7}$$

Appendix L

We can determine the value of α_ν analytically as follows: the dust absorption coefficient can be expressed by the scalar product of the dust number density with the dust cross section

$$\alpha_\nu = n_{dust}\sigma_{dust}, \tag{L1}$$

$$\alpha_\nu = \frac{N_{dust}}{\bar{V}}\cdot\frac{A_{dust}}{N_{dust}} = \frac{A_{dust}}{\bar{V}} = \frac{\frac{\pi D_{dust}^2}{4}}{\bar{V}}, \tag{L2}$$

where we defined, respectively, the number density of dust per each cubic meter and the geometrical cross-section per dust grain. $\bar{V}$ is the average volume of space. Dimensional analysis

$$\left[\frac{1}{\text{m}}\right] = \left[\frac{\text{dust}}{\text{m}^3}\cdot\frac{\text{m}^2}{\text{dust}}\right].$$

From important scientific research [54], the diameter of the cosmic dust is

$$10 < D_{dust} < 1000\ \mu\text{m}. \tag{L3}$$

On earth, they have found in Antarctica the following dust grains

$$12 < D_{dust}^{Earth} < 700\ \mu\text{m}. \tag{L4}$$

Moreover, the estimated dust grain density from averaging all its single material components [55] is

$$\bar{\rho}_{dust} \cong 3200\frac{\text{kg}}{\text{m}^3}. \tag{L5}$$

The average volume of space $\bar{V}$ can be determined as follows in the next rows.

Let's consider a spherical volume, with diameter L, in which we place two half grains at the extremities as shown in **Figure L1**. The sum of the two masses in the volume has to be equal to the average mass in the estimated volume:

$$\bar{m}_V \cong \frac{1}{2}m_{dust} + \frac{1}{2}m_{dust}, \tag{L6}$$

$$\bar{m}_V \cong m_{dust}, \tag{L7}$$

$$\bar{\rho}_m V \cong \bar{\rho}_{dust}V_{dust}, \tag{L8}$$

$$\bar{\rho}_m\frac{4}{3}\pi L^3 \cong \bar{\rho}_{dust}\frac{4}{3}\pi D_{dust}^3, \tag{L9}$$

$$\bar{\rho}_m L^3 \cong \bar{\rho}_{dust}D_{dust}^3, \tag{L10}$$

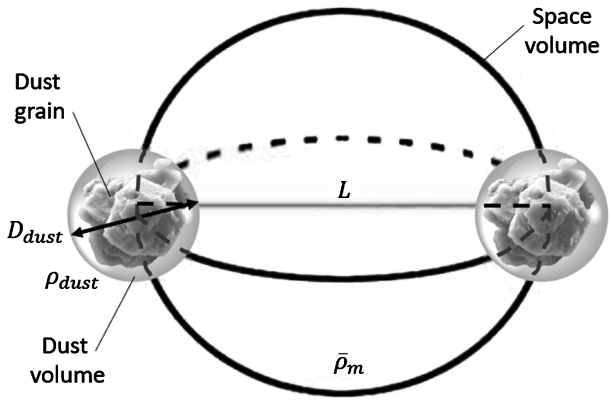

Figure L1. Schematization of the average dust density in the Universe.

$$L^3 = \bar{V} \cong \frac{\bar{\rho}_{dust}}{\bar{\rho}_m} D_{dust}^3. \quad \text{(L11)}$$

Therefore, due to Equation (L2)

$$\alpha_\nu = \frac{\pi D_{dust}^2}{4} \frac{\bar{\rho}_m}{\bar{\rho}_{dust}} \frac{1}{D_{dust}^3}, \quad \text{(L12)}$$

$$\alpha_\nu = \frac{\pi}{4} \frac{\bar{\rho}_m}{\bar{\rho}_{dust}} \frac{1}{D_{dust}}. \quad \text{(L13)}$$

The value of the average baryonic mass density of matter in the Universe is

$$\bar{\rho}_{m,b} = 4.201 \times 10^{-28} \frac{\text{kg}}{\text{m}^3}. \quad \text{(L14)}$$

Indeed, dust belongs only to baryonic matter. Therefore, we can calculate that for $\bar{\rho}_{m,b}$ and for an average dust grain diameter

$$\bar{D}_{dust} = 500\ \mu\text{m}, \quad \text{(L15)}$$

we obtain that

$$\alpha_{\nu,b} = \frac{\pi}{4} \frac{\bar{\rho}_{m,b}}{\bar{\rho}_{dust}} \frac{1}{\bar{D}_{dust}} = 2.062 \times 10^{-28} \frac{1}{\text{m}}. \quad \text{(L16)}$$

Appendix M

$$\mu_{raw}\big|_{NTL,b} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.379 + 1.588 \times 10^{26} \alpha_{\nu,b}, \quad \text{(M1)}$$

$$\mu_{raw}\big|_{NTL,b} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.379 + 1.588 \times 10^{26} \times 2.062 \times 10^{-28}, \quad \text{(M2)}$$

$$\mu_{raw}\big|_{NTL,b} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.379 + 0.033, \quad \text{(M3)}$$

$$\mu_{raw}\big|_{NTL,b} = 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.412, \quad \text{(M4)}$$

$$\mu_{raw}\big|_{NTL,b} \cong 5\log_{10}\left[\ln(1+z)^{(1+z)}\right] + 43.4. \quad \text{(M5)}$$