International Journal of Astronomy and Astrophysics, 2025, 15(2), 80-89
https://www.scirp.org/journal/ijaa
ISSN Online: 2161-4725
ISSN Print: 2161-4717

The Energy Depletion Model of Light and Cosmology

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How to cite this paper: Houz, M. (2025) The Energy Depletion Model of Light and Cosmology. *International Journal of Astronomy and Astrophysics*, **15**, 80-89.
https://doi.org/10.4236/ijaa.2025.152006

Received: March 9, 2025
Accepted: June 14, 2025
Published: June 17, 2025

Abstract

We model the energy depletion of light from a distant object with two components: loss in photon rates (number of photons) and loss per photon particle. We model the rate loss based on intergalactic extinction, which, unlike extinctions within our local group of Milky Way, LMC and SMC, has not been previously accounted for. Ignoring intergalactic extinction results in the overestimation of cosmic distances with standard distance moduli. Such extinction effect is more profound on large scales (Gpc) that we have only started to observe today. We then apply the tired light model for energy loss (redshift) per photon. These two model components are mathematically very simple, leading to a new equation between luminosity distance and redshift. The model performed equally well as ΛCDM with Pantheon + SN data while outperforming it with the deep-field galaxy angular size test. The main implications of the intergalactic extinction model are two-fold: it identifies a major bias in distance measurements based on standard candles; it is also a key missing piece for static universe models to offer as viable alternatives to ΛCDM. Thus, the model has further implications on the interpretation of cosmic redshift, Hubble's law, the Hubble constant, Hubble tension, and universe history.

Keywords

Intergalactic Extinction, ΛCDM, Static Model, Hubble Tension

1. Introduction

ΛCDM is currently the standard model of cosmology. Its success, however, has been challenged recently by HST and JWST observations in the model's early universe billions of light years away. Multiple mature galaxies were reported [1]-[3], which are not predicted by the standard model. The Hubble tension further highlights the difficulty facing ΛCDM if data measurement issues are not the culprit.

These have prompted some to call for new physics, e.g. [4]. This paper presents a simple model to account for extinctions in vast intergalactic space. We discuss the proposed intergalactic extinction model in combination with the tired light model, which together had performed equally well as ΛCDM with Pantheon+ SN data and outperformed it with galaxy angular size data, in support of a static universe model over ΛCDM making the Hubble tension irrelevant and deep space mature structures explainable. In section 2, we propose a simple model of light energy depletion through intergalactic extinction and energy redshift. The two components together are necessary to describe energy behaviors throughout the light's travel path. Section 3 discusses previous estimation results and the fitness of the proposed model vs. ΛCDM to the data. The conclusion is in section 4.

2. The Proposed Models

2.1 The Energy Depletion Model of Light

Without loss of generality, we decompose and write the flux received on earth from a beam of light with wavelength λ as

$$E = NE_{\lambda} \tag{1}$$

$$\text{where} \quad N = N_0 / 4\pi d^2 \tag{2}$$

is the number of photons per square area per time unit, d is the true distance (or the proper distance in an expanding universe) from the emitter, N_0 is the number of photons emitted by the emitter per time unit; and

$$E_{\lambda} = hc/\lambda \tag{3}$$

is the energy per photon, and h is the Planck constant. Also $E_{\lambda 0} = hc/\lambda_0$ where λ_0 and $E_{\lambda 0}$ are the wave length and energy per photon at source.

2.2. The Intergalactic Extinction Model

Interstellar and host (or internal, extragalactic) extinctions have been studied extensively close to Earth on the Milky Way (MW) Galaxy, Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC), and on host galaxies respectively. It has been essential to apply corrections to distance moduli to account for such extinctions when estimating distances or the intrinsic brightness of the source. Brout and Riess [5] give a comprehensive review of these extinctions[1]. However, similar types of extinctions due to intergalactic media in between the host galaxy and MW/LMC/SMC along the vast distances of light travel have not been accounted for, which should increase with distance and thus become increasingly critical as our modern telescopes look into deeper space on the Gpc scale, resulting in overestimation of distances.

Intergalactic extinctions (IEs) may occur after the emitted light of a star leaves its host galaxy and before it enters the LMC/SMC/MW range. IE increases with

[1]Throughout this paper, we assume that interstellar and host extinctions are already taken into consideration with distance data. Our intergalactic extinction model here offers a new and additional factor.

distance, and may come from three sources:

1) the light may encounter one or more galaxies in our line-of-sight;

2) it may encounter edges of galaxies or circumgalactic medium (CGM);

3) it may encounter Warm-Hot intergalactic medium (WHIM) or Intracluster medium (ICM), and a great majority of baryonic matters in the universe too dimmed to be seen yet by existing telescopes (Massimo and Salucci [6]).

To gauge the significance of intergalactic extinction source 1 above, Let's do a rough estimation by answering the question: how likely would one expect to have a galaxy or galaxies in the line-of-sight between the light source and an earth observer? It's a battle of two sheer numbers: the very large number of galaxies in the very large volume of the universe. Detailed in **Appendix A**, the answer is: 6% probability per Gpc if the source is a galaxy, and 25% probability per Gpc if the source is a star (Cepheid, Supernova etc). These conservatively estimated probabilities are significant and must not be ignored.

Unlike interstellar and host extinctions, intergalactic extinction cannot be estimated with extinction curves since there is no photometric or spectroscopic data available for unidentified extinction media. However, we can still model and estimate its effect statistically. We now apply the exponential decay function $\mathrm{e}^{-2d/D}$ to the photon rate in Equation (2): $N = \left(N_0/4\pi d^2\right) * \mathrm{e}^{-2d/D} = N_0/4\pi\left(d\mathrm{e}^{d/D}\right)^2$ with the decay coefficient written as $2/D$ (instead of $1/D$) for subsequent convenience. Equation (1) then becomes: flux $E = N_0 E_\lambda/4\pi\left(d\mathrm{e}^{d/D}\right)^2$. Since the term within the bracket is the luminosity distance by definition, the intergalactic extinction (IE) model can be written simply as

$$d_L(d) = d\mathrm{e}^{d/D} \tag{4}$$

where d_L is the indirectly measurable luminosity distance and D is a constant. $D/2$ is the distance by which 36.8% (1/e) photons remain alive from extinction, or the mean life-distance (analogue to mean lifetime for decays over time) of photons. (D was estimated to be 21.0 Gly with the Pantheon+ SN data as discussed in section 3 below.)

Figure 1 shows the behavior of d_L versus d for D = 21 Gly (a calibrated value discussed in Section 3), and $d_L = d$ as $D \to \infty$. The luminosity distance d_L approximates the true distance d well for small distance ($d \ll D$) but deviates upwards exponentially.

It is important to note that only d_L can be calculated with the distance modulus $m - M = 5\log d_L - 5$. The true distance d in a static universe (or the proper distance in an expanding universe) can only be calculated after the parameter D is estimated. These properties of d_L and d are independent of cosmological models, expanding or not. In the case of expanding universe models such as ΛCDM, the distance modulus overestimates the proper distance d with d_L, unless corrections are made to the modulus formula; and further, Hubble's law is the ratio of recession velocity to the measured luminosity distance, and not to the proper distance. Since $v = H_0 d_L$, we can place velocity v on the vertical axis in Figure 1 which implies that the universe is decelerating instead of accelerating as the v-d curve is above the straight $v = H_0 d$ (or $d_L = d$). One may conclude an accelerating universe by using d_L but that is delusional as d_L is an overestimation.

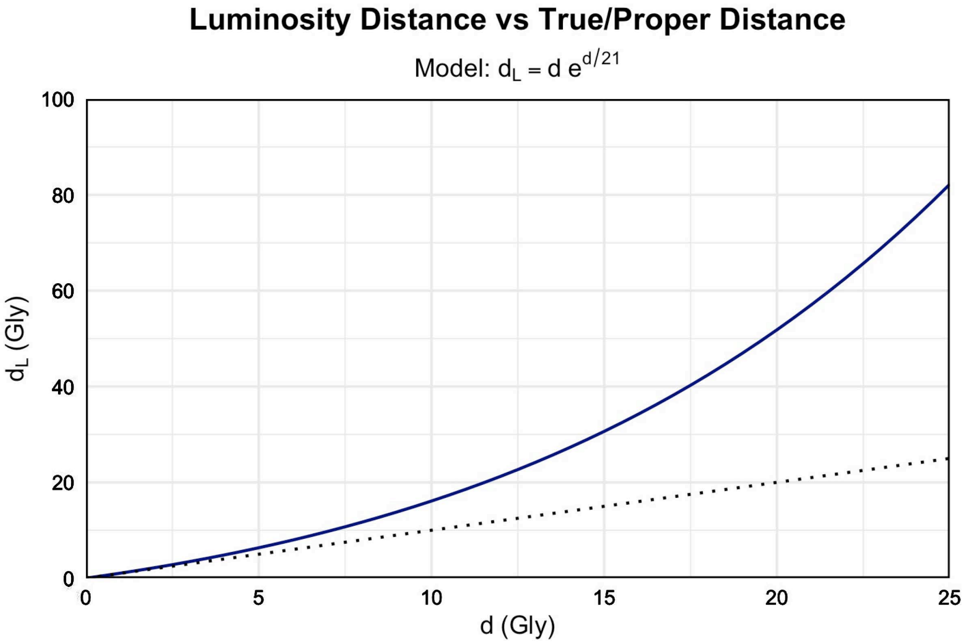

Figure 1. The IE model $d_L = de^{d/D}$ for $D = 21$. The dotted straight line is $d_L = d$, above/below which the universe is decelerating/accelerating under ΛCDM as seen by placing $v = H_0 d_L$ on the vertical axis and noting that the dotted line becomes $v = H_0 d$.

2.3. The Redshift Model

Similar to the IE model, to model the light energy depletion due to redshift of each photon in the light, we apply the exponential decay function $e^{-d/\Delta}$ to Equation (3): $E_\lambda = E_{\lambda 0} * e^{-d/\Delta}$, or $\lambda = \lambda_0 e^{d/\Delta}$. Since $\lambda = \lambda_0 (1+z)$,

$$z(d) = e^{d/\Delta} - 1 \quad (5)$$

$$\text{or} \quad d = \Delta \ln(1+z) \quad (5')$$

where Δ is a constant. This is the classical specification of the tired light theories. While the tired light models as originally put forward by Zwicky [7] in 1929 have seen its status reduced to fringe, we want to reevaluate it here by incorporating the IE model as a new element. We will discuss the historical challenges of the tired light theories and results of this paper together in Section 4.

For $d \ll \Delta$ and $d \ll D$, with Taylor expansions, Equations (4) and (5) reduce to $d_L = d$ and $z = d/\Delta$. Thus, we have Hubble's law $z = d_L/\Delta$ in which $\Delta = c/H_0$ and H_0 is the Hubble constant, and $\Delta \approx 13.8$ Gly is in fact the familiar Hubble distance. Given an observed value of z, the true distance to the light source can also be calculated simply with Equation (5'). The observed d_L is very useful for estimation purposes but is not the true distance and is biased and thus delusional as it does not take intergalactic extinction into account.

Under this model, for each Hubble distance Δ traveled, the photon's wave length is redshifted by e-1 (~1.72) or the associated photon energy remaining is

1/e (~36.8%). Δ is also the expected value of distance weighted by the energy level as probability density during a photon's entire trip from distance zero to infinity. While Δ = Hubble distance, it does not have the same interpretation here as under the expanding universe hypothesis as there is no expanding space and recession velocity in a static universe.

2.4. The Combined Empirical Model

Substituting Equation (5') into Equation (4), we obtain the empirical d_L-z relationship:

$$d_L = \Delta(1+z)^{\Delta/D}\ln(1+z). \tag{6}$$

In terms of the distance modulus $m - M = 5\log(d_L) - 5$,

$$m - M = 5(\log\Delta - 1) + 5\left(\log(\ln(1+z)) + \log(1+z)^{\Delta/D}\right). \tag{7}$$

Equations (6) and (7) are equivalent (called the IETL model hereafter for Intergalactic Extinction and Tired Light model) and have two parameters: Δ (or $H_0 = c/\Delta$) and D (or Δ/D), which can be empirically estimated. (The total flux can also be written as $E(d) = E_0 e^{-d(1/\Delta + 2/D)}$ where E_0 is energy at source.)

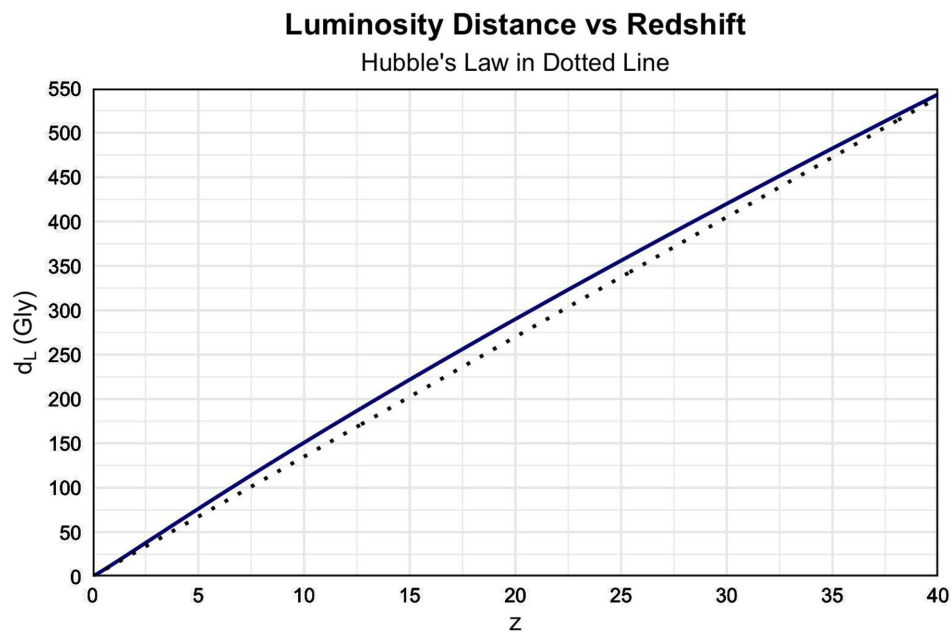

Figure 2. The IETL model of luminosity distance vs redshift. The dotted line is the Hubble's Law $d_L = \Delta z$ with $\Delta = c/H_0$. The two functions deviate less than 13.4% over $0 \le z \le 125$.

Figure 2 shows the graph of Equations (6). The d_L-z relationship is a s-curve[2],

[2] Let $\beta = \Delta/D$. From Equation (6), the second derivative $d_L'' = \Delta(1+z)^{\beta-2}\left[2\beta - 1 + \beta(\beta-1)\ln(1+z)\right]$. So, (a) $d_L'' > 0$ for $\beta \ge 1$; (b) $d_L'' < 0$ for $\beta \le 1/2$; and (c) $d_L'' \gtrless 0$ iff $z \lessgtr e^{(2\beta-1)/\beta(1-\beta)} - 1$ for $1/2 < \beta < 1$ which is a s-curve but the curve shape is inconsequential because it is very close to the straight line Δz.

closely approximating the straight $d_L = \Delta z$ or Hubble's law, with deviations ≤ 13.4% over $0 \le z \le 125$ (for Δ = 13.5 Gly and D = 21 Gly both taken from empirical estimation discussed in Section 3 below). In other words, the luminosity distance per unit (100%) of redshift is roughly 13.5 Gly.

Note also the symmetry between Equations (4) and (5) in terms of d_L/d and λ/λ_0 (= 1 + z). We may call $r_\lambda \equiv \lambda/\lambda_0$ the redshift ratio, and $r_d \equiv d_L/d$ the dimshift ratio (as the light is shifted dimer by extinction). We take first derivatives with respect to d in Equations (4) and (5) and get

$$D r'_d / r_d = \Delta r'_\lambda / r_\lambda \quad \text{and} \quad r_\lambda r'_d / r_d r'_\lambda = \Delta / D \tag{8}$$

Thus, Δ/D (≈0.64 per Pantheon+ SN sample) can be interpreted as the percentage change in the dimshift ratio as one percentage change in the redshift ratio or in wavelength λ.

3. Results and Discussions

The two simple equations (4) and (5) are all we need to describe a static universe consistent with Hubble's Law without the complicated ΛCDM model assuming expansion of space accelerated by dark energy. The two equations combine to produce the IETL model, which can be empirically applied to z directly measured and d_L indirectly via the distance modulus. The true distance, d, is not measurable outside the model and is a confounding exogeneous variable that affects both d_L and z through Equations (4) and (5) respectively. In this static universe, there is no space expansion and acceleration, no dark energy to search for (which one will never find if it doesn't exist outside the hypothetical world of the standard model), not even the age of the universe, beginning of time, nor the big bang. We will not be surprised to see JWST and other future telescopes continue to find more mature galaxies and structures in unbound distances.

Gupta [8] discussed the ΛCDM model and several alternative models including a TL+ model where an unknown flux loss term 5log $(1 + z)^\beta$ was added to the distance modulus formula. This TL+ model is indeed the exact same model mathematically as the IETL model here (Equation (7)) in that the TL+ parameter $\beta = \Delta/D$. So, thanks to Gupta, the IETL/TL+ model was already tested with the Pantheon+ SN data. Therefore, we will not repeat the tests but will summarize them with respect to ΛCDM, TL+, and TL models. The Pantheon+ SN test's summary statistics are (from Table 1 in Gupta [8]): H_0 is 72.99 ± 0.34 for ΛCDM, 72.46 ± 0.34 for TL+, and 64.42 ± 0.36 for TL; β is 0.64 ± 0.02 for TL+; χ^2 is 745.4 for ΛCDM, 749.9 for TL+, and 2580 for TL; and sample size is 1701. These results showed that while the TL (tired light) model alone performed poorly as expected, the IETL/TL+ model fit the data equally well as ΛCDM, with estimated parameters H_0 = 72.46 Km s^{-1} Mpc^{-1} and β = 0.6418, and thus $\Delta = c/H_0$ = 13.5 Gly and D = Δ/β = 21.0 Gly which were used in **Figure 1** and **Figure 2**.

Gupta [8] further tested the models with galaxy angular size data and found that the IETL/TL+ model's fit was acceptable for high redshift whereas ΛCDM was not, which may be a smoking gun in favor of the IETL/TL+ model over

ΛCDM. In other words, although Gupta included the TL+ model for discussion purposes only, it in fact turned out to explain the data equally well as or better than ΛCDM. For detailed results of the IETL/TL+ model fitted with the data, please refer to the TL+ model in Gupta [8]. Zhang [9] also put forward the same model as IETL/TL+ but the β parameter there was preassigned a given value of 1.2 (as opposed to calibrated $\beta = 0.6418$ by Gupta) before fitting the SCP Union SNIa data. Both papers [8] and [9] added the β-term somewhat arbitrarily to the tired light model or otherwise the model was inadequate as demonstrated by Gupta and above. The missing piece to previous tired light models is in fact the IE model proposed here. No arbitrary term is needed. Again in cosmology, the dust tricked us.

From Equation (4), the relative bias of d_L as a measure of d is given by $d_L/d - 1 = e^{d/D} - 1$. For $d \ll D$, this bias is approximately d/D, and thus is linear and small. For example, at $d = 1\%D \approx 210$ Mly, the bias is 1%; at $d = 10\%D \approx 2.1$ Gly, the bias is a significant 10.5%. When d approaches D, however, the bias grows exponentially and dominates such that at $d = D \approx 21$ Gly, the bias is a whopping 172%! Thus, any claim on achieving a small measurement uncertainty as in the case of estimating the Hubble constant using the distance ladder method for Hubble tension discussions, is irrelevant if one ignores the biggest bias of all – intergalactic extinction. It is surreal to claim that the total measurement errors can be so small when measuring vast distance of space still full of many unknowns and measuring it indirectly through source brightness.

4. Conclusions

The proposed IE model is independent of cosmology models and may coexist with ΛCDM. However, the IE model also implies that the Hubble tension is an artifact in that the luminosity distance d_L in Hubble's law used for estimation is subject to intergalactic extinction, and is not the true or proper distance d. It thus identifies a major bias for distance and H_0 local measurements using standard candles and other luminosity-based methods. It implies both H_0 measurement errors and (not so) new physics in the context of Hubble tension discussions. Additionally, given ΛCDM together with the IE model, the universe is not accelerating and is decelerating instead.

The IE model also provides the missing piece of the puzzle to tired light theories and explains the deep space data equally well as or better than ΛCDM. Why marginalize a simple static model in favor of a complex expanding-universe model, particularly in light of increasing observations in deep space favoring the former over the latter as well as the addition of the proposed IE model here?

It is not a sound argument to refute tired light models on the ground that there is no knowledge in physics for photons to redshift over distance. The evidence of such knowledge is unobtainable independently in a lab or in nature as it would require distances in millions of light years to conduct such an experiment, which is the exact observations that the proposed model here and others do predict. This can be seen easily from Hubble's law $z = d_L/13.8$ Gly: a distance of 138 Mly (or 138 million years in scientists' life to observe) is required to detect $z = 0.01$, 13.8 Mly to detect $z = 0.001$, etc. The "decay" rate of energy redshift, *i.e.*, the Hubble distance Δ, is just too large.

Over the past decades the tired light theories have been just about universally abandoned in favor of ΛCDM, due to their difficulties especially with the Cosmic Microwave Background, Tolman surface brightness test, the (controversial) supernova time dilation, the blurring distant objects argument, and the supernova distance-redshift relationship. However, in this paper, we demonstrated that when the intergalactic extinction is accounted for using the proposed IE model, the tired light model explained the distance-redshift data at least as well as ΛCDM and better. Now that ΛCDM is facing more and more of its own share of difficulties in explaining new observations and tensions, an open mind to other alternatives is warranted. Future work may revisit and further develop the tired light model in regard to its other challenges from the perspective of the IE model. Note also that López-Corredoira and Marmet [10] had a comprehensive review of alternative cosmology theories including tired light theories, plasma cosmology etc., but none has the same mechanism and mathematical formulation as the IE model. The IE model is very simple, yet it captures a missing piece in cosmology, namely, identifying and quantifying a major systematic bias in large distance measurement. Another direction for future research is to study intergalactic extinctions or the IE model at different frequency spectrums as they are expected to be dependent.

The proposed models here and the data results by Gupta suggest the need to consider or reconsider other alternatives to the FLRW metrics and the ΛCDM cosmology. The current standard model has encountered and will likely continue to encounter more contradictory evidence in deeper space, and bandages to patch it are not attractive solutions.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Curtis-Lake, E., Carniani, S., Cameron, A., Charlot, S., Jakobsen, P., Maiolino, R., *et al.* (2023) Spectroscopic Confirmation of Four Metal-Poor Galaxies at Z = 10.3-13.2. *Nature Astronomy*, **7**, 622-632. https://doi.org/10.1038/s41550-023-01918-w

[2] Labbé, I., van Dokkum, P., Nelson, E., Bezanson, R., Suess, K.A., Leja, J., *et al.* (2023) A Population of Red Candidate Massive Galaxies ~600 Myr after the Big Bang. *Nature*, **616**, 266-269. https://doi.org/10.1038/s41586-023-05786-2

[3] Robertson, B.E., Tacchella, S., Johnson, B.D., Hainline, K., Whitler, L., Eisenstein, D.J., *et al.* (2023) Identification and Properties of Intense Star-Forming Galaxies at Redshifts Z > 10. *Nature Astronomy*, **7**, 611-621. https://doi.org/10.1038/s41550-023-01921-1

[4] Steinhardt, C.L., Sneppen, A., Clausen, T., Katz, H., Rey, M.P. and Stahlschmidt, J.

(2024) The Highest-Redshift Balmer Breaks as a Test of ΛCDM. *The Astrophysical Journal*, **967**, Article No. 172. https://doi.org/10.3847/1538-4357/ad3afb

[5] Brout, D. and Riess, A. (2024) The Impact of Dust on Cepheid and Type Ia Supernova Distances. In: Di Valentino, E. and Brout, D., Eds., *The Hubble Constant Tension*, Springer, 363-383. https://doi.org/10.1007/978-981-99-0177-7_19

[6] Persic, M. and Salucci, P. (1992) The Baryon Content of the Universe. *Monthly Notices of the Royal Astronomical Society*, **258**, 14P-18P. https://doi.org/10.1093/mnras/258.1.14p

[7] Zwicky, F. (1929) On the Redshift of Spectral Lines through Interstellar Space. *Proceedings of the National Academy of Sciences*, **15**, 773-779. https://doi.org/10.1073/pnas.15.10.773

[8] Gupta, R.P. (2023) *JWST* Early Universe Observations and ΛCDM Cosmology. *Monthly Notices of the Royal Astronomical Society*, **524**, 3385-3395. https://doi.org/10.1093/mnras/stad2032

[9] Zhang, T. (2018) Mach's Principle to Hubble's Law and Light Relativity. *Journal of Modern Physics*, **9**, 433-441. https://doi.org/10.4236/jmp.2018.93030

[10] López-Corredoira, M. and Marmet, L. (2022) Alternative Ideas in Cosmology. *International Journal of Modern Physics D*, **31**, Article ID: 2230014. https://doi.org/10.1142/s0218271822300142

Appendix A: Rough Estimation of Line-of-Sight Probabilities

Imagine a squared galaxy of dimension r at a distance d (both in Mpc) from earth emitting light. (Squared galaxy rather than spiral or elliptical is chosen for convenience as we care about only the estimated magnitude.) With earth at the center, the ratio of the number (N_d) of galaxies inside the sphere of radius d to the number (N_s) of galaxies of dimension r which fully covers the sphere will yield the average number (n_R) of galaxies in the line-of-sight: $n_R = N_d/N_s$. The dimensional diameters of galaxies are 10^{-3} to 10^{-1} Mpc. Let's use the average $r = 10^{-2}$ Mpc. Then $N_s = 4\pi d^2/r^2 \approx 10^5 d^2/\text{Mpc}^2$.

The most recent estimates for the number of galaxies inside the observable universe of radius 14 Gpc are 6 - 20 trillions. Let's take 10 trillion. Then $N_d = 10^{13} d^3/14{,}000^3 \approx 4d^3/\text{Mpc}^3$. Therefore $n_R \approx 4{*}10^{-5} d/\text{Mpc} = 0.04d/\text{Gpc}$, or $\text{Prob}_g = n_R/d = 4\%/\text{Gpc}$, a 4% probability that a galaxy will be entirely in the line-of-sight of a source galaxy per Gpc. We can further refine this probability since the galaxy line-of-sight is cone-shaped, so the blocking galaxy is more than entirely covering the host galaxy. On average, the blocking galaxy may even sit at the median distance $\sqrt[3]{0.5}$ in terms of volume, so a factor of $1\big/\left(\sqrt[3]{0.5}\right)^2 \approx 1.6$ can be applied to obtain final $\text{Prob}_g = 6.4\%/\text{Gpc}$.

Next, we calculate the probability, Prob_s, that the light from a single star (such as SNIa or Cepheid for typical distance measurements) inside the host galaxy being blocked by a galaxy along the travel path. Consider the squared host galaxy is 1 * 1 in area, then a small square of area = $(\text{Prob}_g)^{1/2} * (\text{Prob}_g)^{1/2}$ can be used to derive $\text{Prob}_s = 4\text{Prob}_g$ using a square of $2\,(\text{Prob}_g)^{1/2} * 2\,(\text{Prob}_g)^{1/2}$ centered at the star since this square is the area to ensure blocking the star. Therefore, $\underline{\text{Prob}_s \approx 25\%/\text{Gpc}}$. This means a very significant effect of intergalactic extinction but it is still an underestimation as it will go up when we further take into account CGM, WHIM, ICM, and other unseen or unknown baryonic matters in space.