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Do The Many Problems of Contemporary Cosmology Have a Single Cause? A Research Program

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ABSTRACT

A number of key predictions of the standard cosmological model are in tension with observations, including the apparent need for dark matter and dark energy, the Hubble tension, the S_8 tension, and the existence of seemingly "impossible" early galaxies. Together, these issues imply that only about 5% of the Universe's matter–energy content is understood, yet they are typically examined in isolation. In this work, we explore a single unifying hypothesis: these diverse discrepancies may arise from a systematic misestimation of the speed of light on cosmological scales. We propose that the effective cosmological light speed is reduced by a factor of approximately 2.4 relative to its local vacuum value. This framework introduces no new forms of matter, fields, or laws; instead, it is grounded in general relativity through an extension of the Shapiro effect. From this assumption, we derive a set of quantitative predictions and compare them with observations across roughly a dozen major cosmological problems. The agreement obtained is consistently favorable, and the coherence of the approach strengthens its plausibility. While it may be premature to dismiss the standard model outright, our results suggest that its interpretation par-ticularly its assumption that the speed of light is universally equal to its local value requires reconsideration. We advocate pursuing this hypothesis in parallel with the ΛCDM model, as it offers a simple, unified alternative to the numerous ad hoc components currently invoked.

Keywords: cosmological tensions; effective speed of light; cosmological refractive index; Shapiro effect; general relativity; ΛCDM model; dark matter; dark energy

INTRODUCTION

When reviewing contemporary cosmological literature, it is clear that researchers are concerned about a number of issues. These are described in various ways as problems, tensions, questions, and in some cases even as symptoms of a crisis. Several difficulties appear to be significant and persistent, threatening the standard model, while others, encountered more sporadically, seem secondary and are expected to be resolved by improved data.

We may cite, in a non-exhaustive and unordered way, the problem of dark matter, the problem of dark energy, the possible variation of the cosmological constant over time, the Hubble tension, the S8 tension, "impossible" galaxies, the

puzzles of inflation, the problem of the cosmological constant and vacuum energy, the relative absence of dark matter in the Milky Way, the interpretation of the multiverse, and so on.
Altogether, we are told that we understand only about 5% of the matter and energy content of the Universe.
These topics are usually treated separately: most authors do not consider that they might be different manifestations of a single underlying difficulty.
In this article, by contrast, we ask whether there could be a unique cause for all these troubles. The thesis we seek to explore is the following: on cosmological scales, the speed of light is not equal to its vacuum value c_0(for example, as measured in the solar system), but to a smaller value c_c(index $c$for "cosmological"), explainable as a general-relativistic effect (an extended Shapiro effect).
The corresponding reduction factor $n_c = c_0/c_c$ could be of order 2.4; this is the value that allows us, on average, to accommodate the apparent existence of dark matter and dark energy, as well as to address the other difficulties mentioned above.
Our plan is as follows. In the first part, we discuss the calculation of an effective refractive index $n_c$on a cosmological scale. In the second part, we review the various problems just listed and examine how our hypothesis can alleviate them. In the third part, we discuss the regimes in which our proposal does not work satisfactorily. While it seems to function well on average, it does not account for every specific case; we therefore ask what avenues should be explored in such situations. We also offer an epistemological discussion of the place of our proposal relative to the standard model.
This is necessary, as we are faced with what appears to be an enormous gap between our approach and the standard model, which has served us so well. What experimental evidence can be claimed in favor of our proposal? In contrast, what should we make of all the evidence accumulated in support of the ΛCDM model (notwithstanding its 95% of unknown components)?
These questions lead us to reflect on the proper functioning of science and on how a satisfactory correspondence between observations and theories is established. Concepts such as prediction, refutation, paradigm change, and theoretical pluralism naturally arise; these will be briefly discussed in our third part. We conclude with a few final remarks.
The present paper offers a general overview of our research. To be fully convincing, each issue raised here would require a dedicated, in-depth treatment. Our angle of attack is different: given the multitude of diverse "tensions," the prospect of a single solution has a particular appeal. This perspective can only be maintained if we keep some distance from the details of each problem, without dwelling too long on individual cases (at the risk of an apparent lack of rigor). The work presented here should therefore be understood as a research program, calling for many subsequent detailed studies. In this spirit, the bibliography will remain succinct: the corresponding issues regularly appear in the public scientific arena, in research articles as well as in popular-science publications.
Numerous references can be found in Guy (2022, 2024a), to which we add a few complementary ones. Some passages from our earlier unpublished work are reused here with minor modifications.

A REFRACTION OF THE UNIVERSE ON A COSMOLOGICAL SCALE

Calculation of an equivalent refractive index

We have suggested that the speed of light on cosmological scales may be lower than its local vacuum value. Let us now examine how such a reduction could arise. A useful starting point is the Shapiro effect, well known in general relativity: in the gravitational field of an isolated mass, light experiences a time delay. This delay can be interpreted as a reduced effective speed, insofar as the distances involved are typically evaluated as Euclidean projections toward distant objects (using standard candles, angular-size measurements, and similar methods), while the actual trajectory of light forced to follow the curvature of spacetime is longer than the "straight" Euclidean path. The Shapiro effect therefore already tells us that, strictly speaking, $c$is not equal to $c_0$when considered over curved, non-Euclidean regions of spacetime. This naturally raises the question: can the Shapiro effect be extended to the entire mass content of the universe?
Our universe is expanding, and within general relativity the appropriate large-scale description is the FLRW (Friedmann–Lemaître–Robertson–Walker) metric. Nevertheless, as a first approximation, we adopt a static representation of the universe. This is the framework commonly used when discussing average cosmological density even though this density evolves with cosmic time or when characterizing an effective radius or size of the universe that reflects its gravitational potential. For this purpose, we rely on the Schwarzschild metric, extending it beyond its usual domain of application.
Owing to its spherical symmetry and its simplicity, the Schwarzschild metric allows one to define an optical-equivalent index associated with a mass distribution, in particular for an isolated mass. It has the advantage that both its temporal and spatial components (the coefficients of $t$and r) differ from their Euclidean counterparts. In contrast, the FLRW metric modifies only the spatial part through the scale factor $a(t)$.
In this respect, the Schwarzschild framework provides a more balanced treatment of space and time in the estimation of the physical quantities of interest.
The Shapiro effect itself manifests as an increase in the travel time of light, which effectively mimics a reduced propagation speed when compared with the Euclidean path. This arises both from the geometric lengthening of the trajectory in curved spacetime and from the influence of the non-Euclidean metric on local clock rates.
The Schwarzschild metric thus enables a direct modification of the mass and distance parameters relevant to our problem, without requiring assumptions about cosmic expansion. In contrast, the FLRW density parameters $\Omega_i$enter into mutual circularities and depend on auxiliary assumptions.
With this in mind, we consider a universe filled with masses spanning a wide range of scales from dust and gas to galaxies and clusters. Since the detailed mass distribution is unknown,

we replace it with an average cosmic density ρ_u, integrated over a universe of equivalent gravitational radius R_u under the assumption of spherical symmetry. This approach is similar to that used by other authors who frequently invoke an average density and an effective gravitational radius, even in an expanding universe. For light propagation we impose $ds^2 = 0$, as prescribed by general relativity. From this condition one obtains dr^2/dt^2, which in turn allows us to derive an equivalent refractive index. Completing the corresponding summation leads to the expression (Guy, 2024a).

$$n_c = \left(1 - \frac{4\pi\rho_u G R_u^2}{c^2}\right)^{-1} \quad (1)$$

This expression refers to the equivalent refractive index n_c on a cosmological scale, where G is the gravitational constant, c denotes the local vacuum speed of light c_0, ρ_u is the average density of the Universe, and R_u is its corresponding effective gravitational radius. To our knowledge, calculations of this type do not appear in the literature; instead, one typically finds only first-order expansions of n_c describing the local influence of isolated point masses. The next question is whether a value of $n_c \approx 2.4$ is physically plausible.

In Figure 1, we have therefore plotted, in logarithmic coordinates, straight lines corresponding to iso-values of the index as a function of the Universe's characteristic size (horizontal axis) and its average density (vertical axis).

This diagram represents the following relation, obtained by rearranging the expression for the index in Eq. (1)

$$log\rho_u + 2logR_u = log\left(\frac{n_c - 1}{n_c}\right) + log\left(\frac{c^2}{4\pi G}\right) \quad (2)$$

In Figure 1, the highlighted regions correspond to plausible values of the Universe's radius, ranging from 10 to 100 billion light-years, together with density ranges consistent with current estimates, between 10^{-26} and 10^{-28} kg m^{-3}.

We also display a band of index values extending from 1.2 to infinity, within which the line corresponding to an index of 2.4 is explicitly indicated.

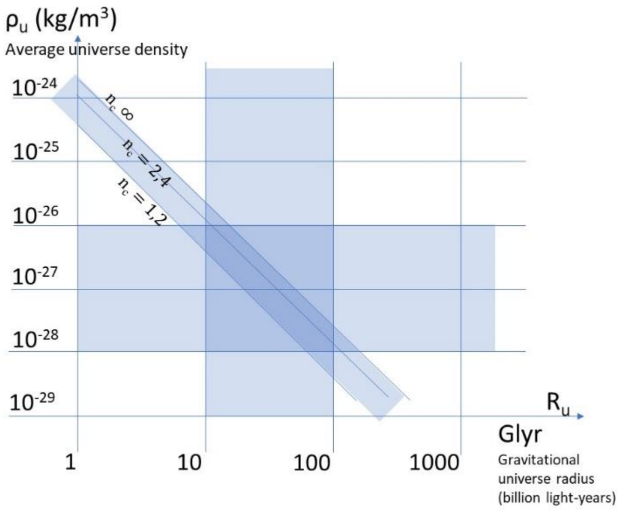

Figure 1. Representation of universes.

Average density $\rho_u(10^{-24}$–10^{-29} kg m$^{-3})$ is plotted against the equivalent gravitational radius $R_u(1$–10^3 billion light-years), both on logarithmic scales.

The colored inset highlights the currently favored region $\rho_u = 10^{-26}$–10^{-28} kg m^{-3} and $R_u = 10$–10^2 billion light-years. Iso-index straight lines are shown for $n_c = \infty$, 2.4, and 1.2, with the corresponding-colored band indicated. The overlap of these three domains (as discussed in the text) suggests that index values greater than 2 may indeed be relevant for our Universe. Modified from Guy (2024a).

One might have expected these three bands to be mutually independent. Remarkably, however, the line corresponding to $n_c = 2.4$ falls precisely within the intersection region of the density and size intervals considered reasonable on empirical grounds.

Thus, this first approach indicates that it is entirely plausible to consider a cosmological-scale speed of light c_c reduced by a factor of about 2.4 relative to the local vacuum speed. Although such a reduction may at first appear substantial, we should recall the magnitude of the problem we are attempting to address namely, that approximately 95% of the Universe's matter and energy content remains unexplained. A solution of comparable scale is therefore expected, and our proposal does not rely on forcing any parameters beyond what is naturally suggested by the analysis.

How can we understand the speeds of celestial bodies?

The difficulties outlined in the introduction are, first and foremost, problems of velocities that appear excessively high, rather than problems of mass or energy. The velocities of distant celestial objects are inferred from measured ratios v/c (via the Doppler effect). If the true cosmological-scale speed of light c_c is smaller than the local vacuum value c_0, then for a fixed measured ratio v/c which must remain unchanged, since the measurement itself concerns only this ratio the inferred velocity v naturally becomes smaller. Consequently, the need to artificially increase velocities to justify dark matter is removed.

More generally, all velocities are defined through such ratios, consistent with the relational epistemology we have emphasized (Guy, 2024b), and light is no exception. Any speed measured at our scale implicitly incorporates the local reference value c_0 in the definitions of both length and time. This relational viewpoint motivated us to consider a variation of c on cosmological scales. However, even from a strictly formal standpoint, this philosophical detour is not essential for the argument that follows.

Within our own galaxy, a significant portion of stellar velocities is obtained using geometric methods, particularly parallax.

In these cases, the standard value c_0 is used (and not c_c), and therefore no correction is required consistent with the comparatively small inferred amount of dark matter in the Milky Way relative to other galaxies, as discussed later.

To clarify the link between velocities and masses, which is crucial for estimating dark matter content, we recall that these quantities are related through the virial theorem. For gravitational systems in a quasi-stationary state, the virial theorem equates kinetic and potential energies.

Thus, for two systems 1 and 2, all else being equal, one expects a proportionality between the ratio of their total masses and the ratio of their squared velocities, namely

$$\frac{m_1}{m_2} = \left(\frac{v_1}{v_2}\right)^2 \quad (3)$$

We denote by v'_m, or "measured" velocity, the speed inferred using standard observational procedures. In computing this quantity, the value $c_0$of the speed of light in a vacuum is implicitly placed in the denominator of the measured ratio v/c, without being questioned.

However, this measured velocity v'_mturns out to be systematically larger than the velocity v_e(subscript $e$for "estimated") inferred from known masses. If, instead, we replace $c_0$by a smaller cosmological value $c_c$in the denominator of the ratio v/c, the inferred velocity $v$naturally decreases, allowing it to match $v_e$without invoking any additional unseen mass. We may define the ratio

$$\alpha = \frac{v'_m}{v_e} = \frac{c_0}{c_c},$$

which plays the role of an effective refractive index, analogous to the previously introduced n_c. Relation (3) shows that if the inferred velocities differ by a factor of approximately 2.4, then the associated mass ratio will be on the order of 6, since $(2.4)^2 \approx 6$.

EXAMINATION OF PROBLEMS

Dark matter

Let's see what these considerations tell us about dark matter. It is interesting to note that the ratio announced by the authors between baryonic matter (i.e., ordinary matter) and dark matter is roughly constant and close to 6 for a wide variety of situations. This ratio results from a velocity ratio equal to the square root of 6, or close to 2.4, which is what we started with. Let's try to find it in different examples.

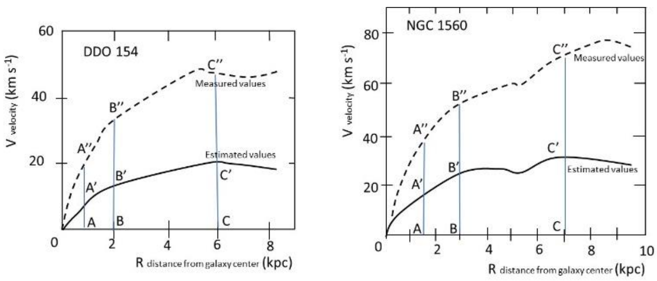

Figure 2. Rotational velocities of spiral galaxies

Two spiral galaxies (McGaugh, 2014) are shown: DDO 154 (left) and NGC 1560 (right).

The vertical axis gives the rotational velocity (km s⁻¹), and the horizontal axis shows the galactocentric radius R(kpc).

Each galaxy displays two curves: the dotted line corresponds to the measured velocities (original observational data), while the solid line represents the values estimated from baryonic mass models and assumed mass distributions.

The general velocity profile exhibits an initial rise, followed by a plateau, and finally a mild decline. In both the rising and plateau regions, the ratio of measured to estimated velocities remains approximately constant, as illustrated by the segments $AA'/AA'' \approx BB'/BB'' \approx CC'/CC''$. For DDO 154, the ratios are approximately 2.3, 2.5, and 2.4; for NGC 1560, they are 2.4, 2.3, and 2.3.

These similar values across both galaxies indicate a repeating pattern. Modified from Guy (2024a).

Among the many contexts in which dark matter is invoked, the rotation curves of spiral galaxies are perhaps the most iconic. Figure 2 reproduces several such curves (cf. McGaugh, 2014; see also McGaugh et al., 2016), with rotational velocity plotted on the y-axis and radial distance from the galactic center on the x-axis. Where available, dotted lines show the measured velocities, while solid lines give the baryon-only estimates. Much attention has historically focused on the "flat" outer plateau of measured velocities at large radii.

However, the full curves reveal that the discrepancy between measured and estimated velocities is not restricted to the plateau: it is present across the entire profile, including the inner regions where velocities are rising. For several galaxies, this ratio is consistently close to 2.4. This factor naturally yields a baryonic-to-dark-matter mass ratio of roughly 1:6, exactly as commonly inferred.

We are not claiming that all galactic rotation curves follow this pattern; the situation is undeniably more complex. However, this repeated ratio is, for us, an essential starting point and one that appears not to have been emphasized in prior literature. The observation challenges the MOND framework, which applies only in regimes of low acceleration, whereas here the discrepancy already appears in the high-acceleration central regions. It also raises questions about the conventional hypothesis of dark-matter halos introduced primarily to explain the outer plateaus, without considering what occurs near the galactic center.

Dark matter is also invoked in other settings, historically most notably in galaxy clusters. We do not enter into a detailed discussion of cluster-scale evidence here; we simply recall that a missing mass of roughly six times the visible mass is again typically inferred.

Gravitational lenses

The previous recipe also works for gravitational lenses: this is remarkable, given that the formalism used to detect dark matter is different. Let us return to the generic formula giving the angle of deviation of the light ray θ caused by the influence of an intervening mass M, passing at a distance d from this mass. It is written as:

$$\theta = \frac{4GM}{dc^2} \quad (4)$$

where G is the gravitational constant and $c$is the speed of light. The deflection angle depends on the ratio M/c^2.

If we replace $c$by $c/2.4$ while keeping the measured angle hence the ratio unchanged, the inferred mass Mmust be divided by approximately 6. In this case, no additional dark matter needs to be introduced. While many authors interpret gravitational-lensing deviations as strong evidence for dark matter, they can equally well be viewed as supporting our hypothesis, albeit through a different physical mechanism.

Dark matter and the cosmic microwave background

The cosmic microwave background (CMB) is the relic radiation emitted by the hot, dense surface of last scattering in the early Universe. It corresponds to the epoch when photons first decoupled from matter and the cosmos became transparent. This "horizon" represents the opaque boundary we encounter when looking back in time to an era roughly 380,000 years after the Big Bang when the Universe could no longer allow light to propagate freely.

The radiation initially possessed a temperature of around 3,000 K, but cosmic expansion has redshifted it to the present-day value of about 3 K.

CMB radiation has the spectrum of a black body, meaning that its distribution of wavelengths depends solely on temperature. Across the sky, we observe extremely small temperature fluctuations, on the order of 10^{-5}, as revealed with remarkable precision by the Planck satellite. These fluctuations reflect variations in the density of the primordial plasma, transmitted through the propagation of acoustic waves prior to photon decoupling. The relationship between temperature fluctuations and density fluctuations has been established (Aubert, 2019):

$$\frac{\delta T}{T} = -\frac{1}{6}\frac{\delta\rho}{\rho} \tag{5}$$

The ratio $\delta T/T$is the fundamental starting point for many developments in CMB analysis. Observationally, this ratio leads us toward density fluctuations larger than those expected from ordinary (baryonic) matter alone hence the standard introduction of dark matter to account for the discrepancy.

The CMB surface of last scattering, from which the present 3 K radiation originates, is receding from us due to cosmic expansion. When reconstructing the temperature map, one must consider the corresponding recession velocity, inferred from the Doppler effect at a redshift $z \approx 1100$.

If our line of reasoning is correct, this inferred escape velocity may have been overestimated. An inflated recession velocity would shift all black-body spectra further toward the red, effectively lowering the observed temperatures T.

Meanwhile, the temperature differences δTremain unchanged, since they represent contrasts both extremes of the interval are shifted together by the expansion.

Thus, for a fixed redshift, reducing an overestimated recession velocity enhances the thermal redshift and therefore decreases the inferred temperature T. The ratio $\delta T/T$consequently increases. According to relation (5), this corresponds to a larger absolute density fluctuation, achieved without introducing any additional matter. In this first approximation, therefore, supplementary dark matter would not be required to account for the CMB fluctuations either.

Dark energy

Continuing along these lines, let us now examine the case of dark energy. The observational evidence for dark energy comes from the apparent acceleration of the Universe's expansion. In this regard, we rely on the standard interpretation adopted by astrophysicists: introducing a cosmological constant Λinto Einstein's field equations accounts for this accelerated expansion. Writing Einstein's equations with this constant included gives:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu} + \Lambda g_{\mu\nu} = \left(\frac{8\pi G}{c^4}\right)T_{\mu\nu} \tag{6}$$

where $g_{\mu\nu}$is the metric tensor, $R_{\mu\nu}$the curvature tensor, and $T_{\mu\nu}$the energy–momentum tensor, with $\mu$and νdenoting space–time indices. We note that the speed of light appears in these equations raised to the fourth power.

If the correct cosmological-scale value of the speed of light is $c/2.4$, and if the Λ-term is in fact unnecessary, then a correction must be applied to the energy–momentum tensor corresponding to a factor of $c^4 - 1$. Numerically, this factor is approximately 35.

In terms of mass–energy, or equivalently mass density, this yields a ratio between dark energy and the energy associated with known matter that matches the values reported by astrophysicists (thereby allowing us to dispense with dark energy; see the calculations in Guy, 2024a). Variations may arise depending on how the density parameters Ω_i are weighted, but what matters in this initial approach is the striking contrast between the ratios involved: baryonic mass relative to dark mass (a few percent) and baryonic mass relative to dark energy (a few tens of percent). The expected orders of magnitude are roughly $6/35$, consistent with our reasoning. From this, we may propose a value for the cosmological constant of order 10^{-52} m^{-2}(Guy, 2024a), which agrees well with published estimates.

In short, what we call dark matter and dark energy correspond to the corrections introduced to compensate for assuming $c = c_0$on cosmological scales. The fact that these various results remain mutually consistent highlights the impressive internal coherence of the ΛCDM framework. The model itself continues to provide a robust foundation what must be reconsidered is not the model's structure, but its interpretation.

Impossible galaxies and models of the universe

Let us now consider the history of the Universe's expansion. To do so, we begin by "tilting" Hubble's diagram i.e., adjusting the relationship between recession velocities and distances by adopting a value of the Hubble constant H_0reduced by a factor of 2.4. In this preliminary approach, we do not enter into the detailed equations governing cosmological models, which describe how the scale factor $a(t)$evolves with cosmic time and incorporate both the density parameters Ω_i associated with the various energy components and the value of H_0. Instead, we turn to an Einstein–de Sitter model (featuring neither dark matter nor dark energy), modified only by this adjusted Hubble constant, to obtain an initial indication of the consequences of our hypothesis. This modified model was presented in Guy (2024a) and is reproduced in Figure 3. For comparison, the standard ΛCDM model and the unmodified Einstein–de Sitter model are also shown.

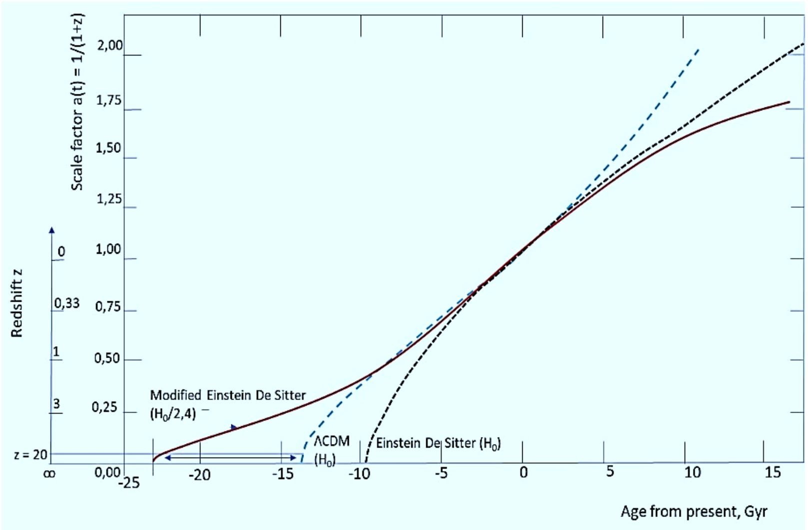

Figure 3. Scale factor a(t) as a function of time for several universe models

Axes: Horizontal axis: cosmic age (Gyr relative to the present); vertical axis: scale factor $a(t)$. The corresponding redshift $z$is indicated on the left for $z > 0$. Models shown in the following table:

Model	Cosmological Parameters	Representation in Figure	Notes
ΛCDM	$\Omega_m = 0.315$ $\Omega_\Lambda = 0.685$	Blue dashed line	Redrawn from Aubert (2019)
Einstein–de Sitter	$\Omega_m = 1$ $\Omega_\Lambda = 0$	Black dotted line	Standard EdS universe
Modified Einstein–de Sitter (proposed)	H_0 replaced With $H_0/2.4$	Solid red line	Proposed model in this article

The constants and relations are as: Hubble constant adopted:$H_0 = 67$ km s^{-1}Mpc^{-1} , Einstein–de Sitter scale factor:$a(t) = \left(\frac{3H_0t}{2}\right)^{2/3} + 1$

The red and blue curves almost coincide for the nearby Universe ($0 < z < 1$). At higher redshifts (up to $z \approx 20$), the modified model (solid red) yields a significantly longer early cosmic duration (≈ 10 Gyr), providing more time for the formation of early galaxies and the subsequent evolution of their stellar populations. Modified from Guy (2024a).

The age of the Universe increases significantly in this framework: the modified Einstein–de Sitter model yields an age of roughly 25 billion years, while taking the inverse of the reduced Hubble constant gives an age of about 33 billion years. Notably, the differences between the standard model and the modified Einstein–de Sitter model become substantial both in the earliest phases after the Big Bang and in the most recent epochs.

The two models overlap closely in the intermediate period, but diverge markedly at the beginning and at the end of cosmic history.

Regarding the earliest times, we may refer to the so-called “impossible galaxies.” These are high-redshift galaxies observed in the infrared by the James Webb Space Telescope that appear only a few hundred million years after the Big Bang yet already display the structure and maturity of well-formed galaxies. Standard galaxy-formation models predict that such systems should be more than a billion years old; the detection of massive black holes at these epochs is equally surprising. Under the modified Einstein–de Sitter model, however, galaxies observed at high redshift would have had ample time to form, without invoking physical mechanisms different from those calibrated for galaxies in the nearby Universe.

A similar divergence appears in recent epochs. Results recently reported by the DSI collaboration provide a promising opportunity to examine discrepancies between observations of the Universe’s late-time evolution and the predictions of the standard model. These results may support the idea consistent with our proposal that new hypotheses need not be introduced to explain certain features of the Universe’s more recent history.

The variation of the cosmological constant over time

In our interpretation, the cosmological constant Λeffectively reflects the use of Einstein's equations with a speed of light that is reduced on cosmological scales by a factor $n_c$relative to its usual vacuum value c_0. This factor $n_c$depends on the average density of the Universe and on its equivalent gravitational radius. As the Universe expands, we impose the natural constraint that the total amount of matter remains constant while the average density decreases and the equivalent gravitational radius increases, according to

$$\rho \frac{4\pi}{3} R^3 = M \tag{7}$$

Where M is the mass of the universe. In formula (1) giving n_c, ρ and R appear in the factor ρR^2. We derive from (7) that

$$\rho R^2 = \frac{3M}{4\pi R} \tag{8}$$

Which we can insert into the equation for n_c:

$$n_c = \left(1 - \frac{4\pi\rho_u G R_u^2}{c^2}\right)^{-1} = \left(1 - \left(\frac{4\pi G}{c^2}\right)\left(\frac{3M}{4\pi R}\right)\right)^{-1}$$

$$n_c = \left(1 - \frac{3GM}{Rc^2}\right)^{-1} \tag{9}$$

Now, looking back in time, we see that as the radius of the universe decreases, the index n_c increases. In the context of the equivalence between the cosmological constant approach and the apparent refractive index n_c approach, the following relation holds (cf. Guy, 2024a):

$$\rho_\Lambda = (n_c^4 - 1)\rho_{\mathrm{m}} = \left(\frac{c^2\Lambda}{8\pi G}\right) \tag{10}$$

It relates the density associated with dark energy, that associated with ordinary mass, the cosmological constant, and the index. From this we derive a value for the cosmological constant

$$\Lambda = \left(\frac{8\pi G}{c^2}\right)(n_c^4 - 1)\rho_{\mathrm{m}} = \left(\frac{6MG}{R^3c^2}\right)\left[\left(1 - \frac{3GM}{Rc^2}\right)^{-4} - 1\right] \tag{11}$$

where we have used relation (7). We can thus see the dependence of Λ on the radius of the universe R, for a universe with a total mass equal to M. The cosmological constant, another name for a correction calibrated by the speed of light on a cosmological scale, can therefore vary over time, and we can expect it to be greater in the past when the universe was smaller and denser. Can this be reconciled with the results of the DSI collaboration?

The cosmological constant and vacuum energy

Much effort has been devoted to understanding the nature of dark energy, whose density is typically denoted Ω_v or Ω_Λ. As discussed above, many authors associate dark energy with the cosmological constant Λ.

Historically, Λ was introduced by A. Einstein into his field equations to permit a stationary universe by counteracting gravitational attraction. Another common interpretation identifies Λwith the energy of the quantum vacuum. However, within particle physics and quantum field theory, the vacuum energy is predicted to be enormously larger by roughly forty orders of magnitude than the energy density associated with the cosmological constant. This enormous discrepancy renders the proposed equivalence highly problematic and is often cited as one of the deepest puzzles in modern physics.

In our view, the cosmological constant does not pose such difficulties, since it does not represent a real physical force of nature. Rather, it expresses the correction of an initial conceptual misunderstanding. Within this perspective, the vast mismatch between the quantum-mechanical vacuum energy and the effective cosmological constant does not arise as a problem.

Hubble tension

The Hubble tension refers to the discrepancy between the two principal estimates of the Hubble constant H_0:

– one obtained from observations of the **local Universe**, where distances are measured using standard candles (notably Cepheids and Type Ia supernovae), and

– another inferred from analyses of the **cosmic microwave background** (CMB).

The first method yields a value of approximately 73 *km* $\mathrm{s}^{-1}\,\mathrm{Mpc}^{-1}$, whereas the second gives a value of 67.7 *km* $\mathrm{s}^{-1}\,\mathrm{Mpc}^{-1}$. Since their respective uncertainty ranges do not overlap, the term "tension" is used. What can be said in the context of our approach? First, dividing both values by 2.4, as proposed previously, naturally brings them closer together this occurs without altering the uncertainty intervals, which depend on observational and methodological conditions. The confidence intervals therefore converge.

Furthermore, the two determinations differ in nature. The local measurement is, in a sense, direct. The CMB-based measurement, however, is **model-dependent**. It relies on evaluating how the angular sizes of CMB fluctuations are stretched by the expansion history predicted by the standard model. The inferred value of $H_0$is thus the one that best reproduces the observed angular scales. Because the standard model incorporates dark matter and dark energy components, we aim to dispense with modifying these parameters will necessarily change the value of H_0inferred from the CMB, even if the **CMB** measurements themselves remain unchanged.

The literature shows that simply reducing the matter density parameter Ω_m(removing dark matter) increases the value of H_0inferred from the CMB.

This provides a second mechanism, within our framework, for mitigating the Hubble tension. A more detailed reformulation of the standard model would, of course, clarify this point further.

The S_8 tension

The S_8 tension concerns the parameter S_8, often discussed alongside the related quantity σ_8, which characterizes the amplitude of matter-density fluctuations in the Universe. The parameter σ_8 is defined as the root-mean-square fluctuation of matter density smoothed over a comoving radius of $8\,h^{-1}$ Mpc, where $h = H_0/100$. The derived parameter S_8, given by

$$S_8 = \sigma_8 \sqrt{\frac{\Omega_m}{0.3}} \tag{12}$$

is the combination most directly constrained by weak-lensing observations. The tension arises because observational determinations of S_8 are lower than those predicted by standard ΛCDM models calibrated on the CMB.

Tension arises because standard cosmological models particularly those calibrated on CMB measurements predict a higher amplitude of matter inhomogeneity than is actually observed. Our approach naturally reduces this discrepancy. Indeed, dividing H_0 by 2.4 lowers the value of $h = H_0/100$, thereby increasing the smoothing scale $8\,h^{-1}$ Mpc used to define S_8.

A larger smoothing radius yields a more homogeneous distribution and therefore a smaller predicted fluctuation amplitude. This shift brings theoretical predictions and observational determinations of S_8 into closer agreement. Importantly, this reasoning does not require modifying the observational inputs themselves, which remain interpreted within the spatial model projected from our local frame.

The relative poverty of our galaxy in dark matter

It is noteworthy that, for the Milky Way, the inferred amount of dark matter is significantly lower than in other galaxies of comparable type: instead of being six times greater than the baryonic mass, it is estimated to be only about twice as great (Jiao et al., 2023) that is, roughly one-third of the usual ratio. We see here a connection with the fact that, in our own galaxy, stellar velocities are largely determined through parallax measurements. We had previously anticipated, in the form of a question (Guy, 2022), that in such circumstances the need to postulate dark matter would be diminished.

To clarify this point, consider the relative proportions of velocities measured by parallax and by the Doppler effect. Jiao et al. (2023) report that the velocities of the 1.8 billion stars surveyed by the Gaia satellite include both parallax-derived velocities and Doppler-derived radial velocities. Broadly speaking, about one-third of the velocity components in the Milky Way are measured through the Doppler effect, while for distant galaxies the velocity field is determined exclusively by Doppler measurements.

If we suppose, statistically, that each velocity component contributes approximately one-third of the inferred dark-matter effect, we obtain exactly the observed proportion. This offers a plausible explanation, compatible with our proposal, for the relative paucity of dark matter inferred in our own galaxy.

The mysteries of inflation

When examining the earliest stages of cosmic evolution, several difficulties arise, particularly concerning the homogeneity of the Universe (how can causally disconnected regions exhibit such similar properties?) and its flatness. Inflation was introduced to resolve these issues: a phase of exponential expansion by a factor of 10^{50} occurring over a timescale of order 10^{-32} s. How can such an extreme process be understood?

This extraordinary expansion and its minute duration compel us to revisit our understanding of space and time. In our relational epistemology (see, e.g., Guy 2011, 2019, 2024b, 2025), neither space nor time exists independently; we are confronted only with motions to be compared with one another. Space emerges from the negligible relative motions (compared to those that define time), and from these comparisons we derive the operational concepts of space and time concepts that depend on specific choices and limitations. An optical index is one way of comparing different effective speeds of light; these speeds are tied to the particular reference motion chosen to define our standards of space and time. At the beginning of the Universe, matter was extremely dense, and the effective speed of light c_c was far smaller than c_0. This reduced velocity governed the unfolding of physical processes and thereby defined standards of space and time fundamentally different from those based on c_0. When we reinterpret these early processes using our present-day standards (based on c_0), it is akin to "playing the film" at the speed c_0: time intervals become vanishingly small, and spatial intervals become excessively large (see also Guy, 2022).

Captive light (black holes and the Universe)

This perspective can be extended to our description of light propagation near black holes. Although we continue to refer to the local value c_0, taking a broader view suggests that, when attempting to cross the event horizon outward, it is as if the speed of light were effectively reduced to zero (as seen from an external observer). Returning to the optical analogy, we may compute an equivalent refractive index for the Schwarzschild black hole. For this metric, the corresponding index is:

$$n = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \tag{13}$$

For the value of the Schwarzschild horizon radius $r = 2GM/c^2$, the refractive index n diverges, tending to infinity; correspondingly, the apparent speed of light approaches zero. At the scale of the Universe as a whole, we encounter an analogous situation: in the (R_u, ρ_u) plane, the straight lines along which n_c becomes infinite (see Fig. 1) likewise represent conditions under which the propagation of light is effectively halted.

In this regime, the Universe prevents light from progressing on megascopic scales although locally, of course, the speed of light remains equal to c_0. With

$$n_c = \left(1 - \frac{4\pi\rho_u G R_u^2}{c^2}\right)^{-1} \quad (14)$$

becomes infinite when

$$\rho_u R_u^2 = \frac{c^2}{4\pi G} \quad (15)$$

This naturally leads to a discussion of an associated "horizon," which must be distinguished from the usual horizons arising in the context of cosmic expansion. The contrast between the "local'' and "cosmological'' viewpoints become apparent when we examine how various authors use the equivalent optical index derived from the Schwarzschild metric under a first-order approximation. Using equation (12), we obtain

$$n(r) = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \approx 1 + \left(\frac{2GM}{rc^2}\right) \quad (16)$$

in a first-order expansion. For *local* applications, the factor $2GM/(rc^2)$is extremely small compared with 1, and the approximation

$$n(r) = 1 + \left(\frac{2GM}{rc^2}\right) \quad (17)$$

is used. This latter expression is widely employed in the literature, although it is often forgotten that it is only an approximation. It is indeed the form that successfully reproduces "local'' tests in the solar system. By contrast, when the same expression is summed over the scale of the Universe, the term $GM/(rc^2)$ is not negligible compared with 1; it is, in fact, of order unity.

These considerations regarding the speed of light at cosmological scales can be extended to discussions of the propagation speed of gravitational interactions (whether in terms of gravitons or gravitational waves). One may likewise argue that gravitational waves propagate at the cosmological value $c_c = c_0/n_c$, consistent with the observed simultaneity of arrival times for gravitational-wave events and their electromagnetic counterparts. Several authors have noted that the Shapiro effect applies equally to both, reinforcing the coherence of the overall approach and supporting the hypothesis proposed here.

Do we have anything to say about the multiverse?

Our research highlights the relational aspects underlying the functioning of physics (thus giving primary importance to the ratio (v/c) rather than to the isolated quantities $v$and c).

This perspective is general: physical laws can be viewed as the outcome of comparisons between processes. Their formulation is not dictated uniquely by reality; to a certain extent, it is shaped by choices and conventions.

In this context, we need not assume that the laws of our Universe are fixed in a way that could differ fundamentally from those in hypothetical other universes. The possibility of differing physical laws is one of the central arguments in favor of the multiverse (Leconte-Chevillard, 2024), but such an assumption does not appear compelling from our standpoint.

DISCUSSION

What avenues remain for unexplained cases?

Our approach currently works at an *average* level for example, in recovering the well-known factor of six between dark matter and ordinary matter but it is not yet capable of explaining every specific situation in which dark matter is invoked. Some cases remain challenging (e.g., the Bullet Cluster). What avenues might be explored?

A first step, in doubtful situations, is to revisit the reliability of the data: are there unrecognized biases or underestimated sources of error? Next, we may investigate the optical analogy more deeply by computing **local variations in the index** n_c. Higher values of $n_c$are expected in regions large enough for the approximation to remain meaningful galaxies, clusters where the density notably exceeds the cosmic mean. One may even consider **birefringence-like effects**, not merely refringence, within the optical analogy.

Variations in the inferred dark matter content as a function of galaxy type and age should be reassessed in light of modern simulations of galactic disks, which do not satisfy spherical symmetry and thus fall outside the scope of Gauss's theorem.

Beyond this, other non-dark alternatives exist in the literature. Some authors, while not providing a unified resolution to all problems we address, nevertheless propose "non-dark'' interpretations.

Thomas Buchert (2012) modifies Einstein's equations to include backreaction from inhomogeneities. Georges Paturel (2023) considers a variation in Newton's constant G(as does MOG). Earlier, de Vaucouleurs (1971) and Maeder (2017) highlighted scale invariance. In Guy (2024c), we derived an equation predicting the scale-invariant regression identified by de Vaucouleurs. Given the complexity of the issues, we may need to combine elements of several non-dark approaches. We also show that these different methods possess a degree of **equivalence**. From a philosophical standpoint rooted in the theoretical pluralism already defended by Henri Poincaré (1905) we have emphasized (Guy, 2024c) the relational necessity of equations of the type

$$r = \frac{G\rho R^2}{c^2} \quad (18)$$

which link the gravitational constant G, the speed of light c, and the mass distribution (through densities and inverse distances). Only these relations possess fundamental meaning, and different ways of satisfying them represent alternative but equivalent approaches to the "dark side'' of physics.

Is an epistemological reflection necessary?

Our proposal requires a significant reformulation of the standard model and a re-evaluation of many of its assumptions. The suggestion that the speed of light differs from c_0 on cosmological scales immediately generates resistance.

This reaction arises from the deeply ingrained conviction that the speed of light is a universal constant a conceptual taboo. Yet $c$clearly varies in refractive media; and even in vacuum, general relativity predicts Shapiro delays, effectively revealing a slower speed than the Euclidean, projected path. As noted earlier, several authors (Gupta 2023) have also entertained the idea of a reduced cosmological light speed. Given that we account for only ~5% of the Universe, a solution of commensurate magnitude is required.

The status of the speed of light must therefore be reconsidered. Historically, $c$has never been measured as a ratio between pre-existing spatial and temporal standards. Rather, it has always been determined *relationally* as the ratio between the speed of light and another physical process, typically one linked to gravitation. This relational epistemological foundation (Guy, 2022) must be emphasized: it is rarely recognized explicitly. This perspective reframes the question often raised:

How can we measure the speed of light on cosmological scales and verify that it is 2.4 times slower?

The answer is that we cannot determine such a speed using meters and seconds, just as we cannot determine $c_0$in that way. We can only determine it *relationally*, through a comparison with another speed either $c_0$or a gravitational motion. That is what we implicitly do whenever we compare light travel times along different paths in curved spacetime, or when we compare the speed of light to the rotational velocities of spiral galaxies to achieve a coherent physical picture.

Another question arises: *Is our proposal refutable?* All scientific theories must be falsifiable in this sense. The same question should be posed with equal rigor to the standard model particularly its assumption that $c = c_0$cosmologically. Many of the difficulties catalogued in previous sections constitute empirical tensions that the standard model fails to meet. The auxiliary hypotheses it invokes (dark matter, dark energy) can reasonably be seen as **ad hoc**. Their complexity makes them difficult to falsify rigorously, owing to interlocking layers of models, parameters, and circular dependencies. These circularities must be disentangled.

By contrast, our model contains no such contradictions and is not refuted by current observations. In Popper's terms, it may therefore be retained provisionally.

We are also asked whether our model yields new predictions. The answer is yes; they correspond precisely to the outcomes associated with the various cosmological tensions discussed earlier none of which contradict the observational data when interpreted within our framework.

The implicit concern behind this question is whether the enormous successes of the standard model (apart from its 95% dark sector) would be jeopardized by adopting $c = c_c$ on cosmological scales. Addressing this requires careful analysis beyond the scope of this article. Much of cosmology falls into two broad classes:

1. **Processes calibrated by laboratory physics**, based on local standards of time and space (nuclear burning, energy transport, diffusion). These processes need not be altered. If the age of the Universe is extended, early galaxy formation becomes compatible with standard stellar evolution timescales.
2. **Processes involving propagation of light or signals** across scales where general-relativistic effects matter. These durations *must* be rescaled. But if all such processes were rescaled uniformly, no advantage would follow. It is precisely the *distinction* between classes (1) and (2) that opens a pathway to resolving the "impossible galaxies" problem.

Finally, our model seems capable of suggesting genuinely new effects for instance, anisotropies in matter distribution (as in disk galaxies) interpreted via the optical analogy as a birefringence-like effect, with possible consequences for observed polarization. This offers a new direction for future research.

CONCLUSIONS

In summary, for a dozen major cosmological problems, our proposal offers a **single, unified explanation**. It does not require exotic new particles, fields, or equations. It respects the vast success of established physics while adhering to the principles of simplicity and parsimony. A *single* value for the cosmological-scale optical index $n_c$suffices to reproduce several otherwise disparate effects. These different arguments reinforce one another.

By contrast, the standard ΛCDM model depends on multiple invisible, ad hoc components dark matter, dark energy invoked piecemeal across independent problems. Many of its predictions fail to match observations without such adjustments. A paradigm shift appears increasingly necessary. Numerous authors have already called for this (e.g., Seifert et al., 2024; Lepeltier, 2014; Lepeltier & Bonnet-Bidaud, 2012). However, it would be premature to advocate abandoning the standard model outright. The epistemologies of the two frameworks differ: our approach emphasizes relational structures, whereas ΛCDM treats quantities more substantively. Following Leconte-Chevillard (2024), the scientific landscape is better viewed as a "permanent revolution," balancing normal science with the continual emergence of new hypotheses. This is, in essence, a form of theoretical pluralism.

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