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A Diamond Universe

Bernard GUY

Researcher Retired from Mines Saint-Etienne, Institut Mines Télécom, 158 Cours Fauriel, 42023 Saint-Etienne Cedex 2, France

bernard.guy15@wanadoo.fr

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ABSTRACT

Cosmology is currently facing some major challenges. In addition to dark matter and dark energy, the issue of 'impossible' galaxies has been brought to the fore by the James Webb Telescope. Something simple eludes us, and the various problems mentioned are interrelated. Our proposition is that, on the cosmological scale, it is appropriate to take a value of the speed of light c_c lower than its standard value c_0 in vacuum. This defines an optical index $n_c = c_0 / c_c$. We account for this 'refringence' by a Shapiro effect extended to the scale of the universe (use of Schwarzschild metric), described by its average density ρ_u and its equivalent gravitational radius R_u. Remarkably, universes with indices greater than two are entirely conceivable, and their characteristics are close to those we determine for our own. The velocities v of celestial objects are estimated from redshifts in ratios of the type v/c, where the speed c of light is usually taken to be equal to c_0. With an equal v/c ratio (all things considered, only the v/c ratio has any meaning), dividing c_0 by a certain factor α lowers the velocities v without postulating the existence of dark matter nor dark energy. Taking into account the problems cited earlier suggests a value of α close to 2.4. We are led to a lengthening of the age of the universe: it could reach 33 billion years. This would allow it to host in its relatively young phases objects that are already old and structured.

Keywords: Cosmology, dark matter, dark energy, Shapiro effect, Schwarzschild metric

INTRODUCTION

Cosmology is currently facing some major challenges. Since the James Webb Space Telescope (JWST) came into service, the question of 'impossible' galaxies (is the universe too young?) has been added to those of dark matter and dark energy (what are they made of, given that they make up some 95% of the Universe's matter and energy content?).
Among a vast literature, see, on the second subject, Zwicky (1933) and Rubin and Ford Jr (1970), on the third, Perlmutter, Turner, and White (1999), and on the first, Boyett et al. (2024), as well as Gupta (2023) where numerous references can be found.
In the present work, we would like to put the following conjecture to the test: there is no need for new detectors nor new equations (Another way of saying: let us make do with the data at our disposal, and keep as far as possible the tried-and-tested theories on which we have built our representation of the world.), something simple eludes us, and the various problems mentioned are interrelated.

The proposition we are putting on the table is that, on the cosmological scale, we need to take a value for the speed of light c that is lower than its standard value c_0 in a vacuum. For this, we will write $c = c_c$ (subscript c for 'cosmological'). This defines an optical index $n_c = c_0 / c_c$. We account for this refringence by a Shapiro effect extended to the scale of the universe, described by its average density ρ_u and its equivalent gravitational radius R_u. The light velocity slowdown results from the cumulative influence of length and time variations in a non-Euclidean metric.

As it happens, the velocities v of celestial objects are estimated from redshifts in ratios of the type v/c, where the speed of light c is taken to be equal to c_0. With an equal v/c ratio (only the ratio has any meaning), by dividing c_0 by a certain factor α, we lower the velocities v without postulating the existence of dark matter nor dark energy.

If we accept this approach, we are also led to a lengthening of the age of the universe. Taking the above problems into account suggests a value of α close to 2.4. Preliminary use of the Schwarzschild metric (also used for the Shapiro effect) shows that we can hold an index n_c equal to the factor α for values of mean density and radius of the universe consistent with the ranges of values accepted today (ρ_u in the interval $10^{-28} - 10^{-26}$ kg/m^3, R_u to be counted in tens of billions of light-years).

Our plan is as follows. In section 2, we will take a look at the reduction in the speed of light on a cosmological scale, by calculating the equivalent refractive index n_c (extended Shapiro effect), and giving a first indication of the values of the densities and sizes of the universe: we will see that it is indeed possible to lower c on this scale. We will discuss the different ways of talking about the speed of light within the framework of general relativity.

In the third and fourth sections, we will look at the problems of dark matter and dark energy: what factor α makes it possible to bring the excessive speeds that make them postulate down to a level consistent with our usual physical laws, dividing the speed of light c that brings us the information? Dark matter section will review several situations where it is postulated: galaxies and galaxy clusters, gravitational lensing, cosmic microwave background.

We will then compare (section 5) the results of sections 3 and 4 with those of section 2: fortunately, the two approaches can be brought together, by identifying the α factor with an optical index n_c, calculable and of value 2.4 for plausible choices of density and universe size that we can identify.

We will examine the consequences of our approach on the age of the universe, with its possible upward revision, and the view to be drawn from it on the case of impossible galaxies.

We end (section 6) with a few concluding words: our hypothesis stands up to initial tests. On it we are building what is at this stage only a first iteration and a framework for re-examining models; due to the coupling between theoretical approaches, observations and measurements (object distances, redshifts, Hubble constant, size and age of the universe, densities, etc.) a readjustment of the whole representation of our universe is required. At this preliminary stage, we have not reviewed all the tensions that are appearing in cosmology today (see some effort in Guy (2022). Furthermore, and in this context, the values of physical quantities announced here should not be given a precision they do not have.

2. A REFRACTIVE UNIVERSE

Shapiro effect on the scale of Universe. Calculation of the equivalent index

The Shapiro effect (1964) is manifested by an increase in the travel time of light, due to the effect of a mass intervening along its path. This is due as much to the lengthening of the path in a space curved locally by matter, as to the consequences for clocks of a non-Euclidean metric. The result can be seen in comparison with a travel assumed to take place in a vacuum in the absence of matter; or in comparison with a Euclidean distance projected towards distant objects, which is the case with the use of standard candles, or angular distances (In the remainder of the text, the distances r used will be such distances.) using our local standards based on $c = c_0$.

This effect, that must be calculated taking into account all the masses in the universe that influence the path from a distant object, leads us to understand that the equivalent 'speed' of light on the cosmological scale is, in any case, strictly less than c_0. The lengthening is conveniently expressed by an equivalent optical index of refraction, greater than one. On the scale of the universe, the path of a photon, reaching us from distances to be counted in light-years up to billions of light-years, is slowed down by all the masses encountered. These masses are of different sizes, and we can replace them, at this scale, by an equivalent density of matter.

A calculation is possible using a non-Euclidean metric within the framework of general relativity. As a preliminary approach, we choose the Schwarzschild (1916) metric. The simplest, it is used by the authors to determine an optical index equivalent to a matter distribution, in particular for the effect of a single mass. It has the advantage that both its temporal and spatial coefficients are modified, whereas for the other metrics, only the spatial term is affected (by the scaling factor $a(t)$). This makes things more balanced, as both time and space are involved in the estimates of the various quantities we handle. The optical analogy is not new; it has been proposed, at least to first order, by many authors: Möller (1952), Feynman (1963), Landau and Lifschitz (1970), Evans, Nandi, and Islam (1996), Straumann (2000), Nandi and Islam (2009), Sarazin, Couchot, Djannati-Ataï, and Urban (2018). Szondy (2003) discusses Janossy's book (1971) where an ether-based gravitation theory (with optical properties) is shown to be equivalent to general relativity. Page and Tupper (1968) propose scalar gravitational theories with variable velocity of light.

The Schwarzschild metric implements directly accessible parameters such as masses and their distances, and its writing requires no special assumptions about the evolution of the universe. By contrast, in other metrics, the parameters are engaged in circularities involving choices about the expansion of the universe. In the FLRW (Friedmann Lemaître Robertson Walker) metric information on masses and distances are not provided, but density parameters Ω_i (curvature, ordinary and dark matter, vacuum energy, radiation), which are themselves subject to different assumptions.

This metric is based on a scaling parameter $a(t)$: in this case, we manipulate comoving distances, the physical meaning of which to link to a global optical index is more problematic.

De Sitter's metrics, on the other hand, involve the cosmological constant (linked to dark energy), which is precisely what we want to dispense with. In a second step, we will have to take the expansion of the universe into account. For a problem with spherical symmetry, the Schwarzschild metric can be read, in spherical coordinates:

$$ds^2 = ac^2dt^2 - b(dr^2 + r^2\, d\theta^2 + r^2 sin^2\theta d\varphi^2) \tag{1}$$

with

$$a = (1 - \frac{2GM}{rc^2}) \tag{2}$$

and

$$b = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \tag{3}$$

The coefficients of the metric involve the influential mass M seen at distance r. The value c is the usual standard value c_0 (in the absence of a subscript in the following, $c = c_0$). Within the framework of the cosmological hypothesis of isotropy and homogeneity of the universe, we will not need to take into account possible variations in angles θ and φ, i.e. $d\theta = 0$, $d\varphi = 0$. Writing that the propagation of light is defined by, and respects, $ds^2 = 0$ (a mathematical property expressing the second postulate of special relativity, extended to general relativity in non-Euclidean space), we derive from the preceding relations

$$\frac{dr^2}{dt^2} = \frac{c^2}{n^2} \tag{4}$$

Where we define the optical index n equivalent to the gravitational effect of the mass M at a distance r from the observer. We have

$$n^2 = \frac{b}{a} = \left(1 - \frac{2GM}{rc^2}\right)^{-2} \tag{5}$$

From which we derive:

$$n = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \tag{6}$$

The previous value applies to the effect of a single mass M; but we are looking for a property of the universe as a whole, and we have to take into account all the masses m_i that populate it, at distances r_i. These include interstellar dust and gas as well as stars, galaxies, galaxy clusters and so on. Summing up all these masses, we get

$$n = \left(1 - \frac{2G}{c^2}\sum_i \frac{m_i}{r_i}\right)^{-1} \tag{7}$$

Where i subscript runs through all the particles of matter, from the smallest to the largest. This can be written so because it is a summation of scalars, not vectors. But we obviously lack complete knowledge of the distribution of matter in the universe.

We can attempt a calculation (which will be accurate on an ensemble scale) using two parameters thought to give an adequate account of the universe's properties: - the average density of the universe ρ_u, and – its 'equivalent' gravitational radius R_u, responsible for the gravitational potential at the point where the observer is located. The pair (ρ_u, R_u) determines the total influential mass of the universe at a certain average distance. In a first approach, we assume that this makes sense, despite the expansion of the universe; the average density of the universe is commonly referred to (see Copi, Schramm, and Turner (1995)), even though universe is expanding, and the same for its Hubble radius.

Let us sum the previous expression over the spherical volume of the universe of radius R_u around the observer. We then have:

$$\sum_i \left(\frac{m_i}{r_i}\right) \approx \int_0^{R_u} \left(\frac{\rho_u dV}{r}\right) \tag{8}$$

and

$$n = \left(1 - \frac{2G}{c^2}\int_0^{R_u} \frac{\rho_u dV}{r}\right)^{-1} \tag{9}$$

Equation (9) expresses the change of scale we propose by referring to a continuous rather than a discrete summation (cosmological scale and cosmological principle). Local effects (such as the deviation of light by a single star like the sun, used as a test for the Schwarzschild metric) are incorporated. Using polar coordinates, the integration volume around the observer is written as $dV = (4\pi r^2)dr$ (corona of thickness dr located at distance r). By transferring to the previous relationship, the r in the numerator is simplified and the part to be integrated remains:

$$\int_0^{R_u} \left(\frac{\rho_u}{r}\right) dV = \int_0^{R_u} (4\pi\rho_u r)dr \tag{10}$$

Whose value is

$$2\pi\rho_u R_u^2 \tag{11}$$

It then comes

$$n_c = \left(1 - \frac{4\pi\rho_u G R_u^2}{c^2}\right)^{-1} \tag{12}$$

Where we call n_c the index on the cosmological scale. Equation (12) can be applied to any point in the universe; it includes the influence of stars close to the point of calculation, corresponding to higher densities and on a very small scale compared to that of the universe where n_c is evaluated. What is important is homogeneity and isotropy on different scales, despite differences in densities (or distances between objects). Isotropy and homogeneity are already guaranteed on the scale of stars in a galaxy (light-years) (Actually, strictly speaking, the homogeneity of the universe is not guaranteed until we reach the scale of several Mpc (at lower scale, there are large voids between galaxy superclusters). We do not discuss the questions of gauge invariance that may arise when using the Scharzschild metric in our calculation of the cosmological index. The observables appear to us to be distances and densities, estimated by the usual methods. Gauge transformations may concern the metric's coefficients, as a result, for example, of coordinate axes rotations or the choice of length scales.). Note that, in the Schwarzschild metric as used, we do not need to take into account the wavelength shifts caused by the 'Einstein effect' (gravitational redshift for light arriving from a zone of higher gravitational potential). Because we do not have a gravitational potential gradient, we are at a scale where n is the same everywhere.

FIRST EXPLORATION

Our aim in this work is not to say: 'This is the density; this is the radius of our universe'. It is more simply to ask the question: 'Is a universe with a cosmological index of the order of 2.4 conceivable for amplitudes $\Delta\rho$ and ΔR that frame the values of the universe that hosts us?' As a result of the circularities between models (choice of laws, choice of parameters, which, as we propose, will have to evolve), observations and measurements, our universe itself cannot already be characterized by defined parameter values, but by intervals. Equation (12) provides a basis for discussion of the relationships between the value of the index n_c and those of the density and size parameters of the universe. It can also be written as:

$$\rho_u R_u^2 = \left(\frac{n_c-1}{n_c}\right)\left(\frac{c^2}{4\pi G}\right) \quad (13)$$

Let us use this last relation (It is interesting to note that A. Einstein (Lorentz, Einstein, & Minkowski, 1922; O'Raifeartaigh, O'Keeffe, Nahm, & Mitton, 2017), in his paper on a static universe of radius R and matter density ρ, found the relationship $\rho R^2 = c^2/4\pi G$, identical to ours to within a factor $(n_c-1)/n_c$. It corresponds to a universe where, according to our analysis, the index n_c is infinite and light cannot propagate on this scale (see below). This is actually what Einstein did analyze: 'light can never leave the system'.) to represent the conceivable refractive universes in an a priori general way, and let us position the values of n_c in a space (R_u, ρ_u). We will adopt a logarithmic representation (base 10) where the n_c iso-index curves are straight lines of equation:

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

They have a slope equal to -2. For the universes we will be dealing with, it is appropriate to express distances in billions of light-years, i.e. 9.46×10^{24} m (1 light-year = 9.46×10^{15}m). If R'_u is the value of R_u in billions of light-years, we have $R_u = R'_u\times9.46\times10^{24}$. Carrying this expression for R_u into (14), we get

$$log\rho_u + 2logR'_u = \left(log\frac{n_c-1}{n_c}\right) + \left(log\frac{c^2}{4\pi G}\right) - 2\log(9.46) - 2\times24 \quad (15)$$

We carry out the various calculations with $c = n_0 = 3\times10^8$ m/s (inherited from the Schwarzschild metric in its original expression, referring to 'local' standards) and $G = 6.67\times10^{-11}$ (in SI unit). We are primarily interested in orders of magnitude, and the significant digits used in the calculations have a simple intermediate and relative value. We have $log\,(c^2/4\pi G) = 26.03$ and the constant part of the second member of equation (15) is equal to $26.03 - 1.95 - 48 = -23.92$. This gives:

$$log\rho_u + 2logR'_u = \left(log\frac{n_c-1}{n_c}\right) - 23{,}92 \quad (16)$$

In the following, we will write R_u or R'_u indifferently, knowing that the radii are expressed in billions of light-years. Which domain of space (R_u, ρ_u) should we explore? Let us study a field of a priori plausible values for universes encompassing the one we inhabit.

The range of orders of magnitude of the density of matter ρ_m can be assessed by inspection of the quantity of gas, dust, stars, galaxies, etc., observed directly or indirectly, and its distribution as a function of the assumed size of the domains examined. Today, it takes account of possible dark matter, highlighted by estimates of the velocities of observed objects and their comparison with a priori models of behavior.

'Direct' inspection taking dark matter into account leads to values of ρ_m of the order of 5×10^{-27} kg/m^3 (Gasparini, 2020). This value needs to be lowered to exclude dark matter (estimated to be 6 times more abundant than ordinary baryonic matter), which is precisely what we want to avoid. Dividing the previous figure by 7, we obtain a ρ_m of the order of 7×10^{-28} kg /m^3. This value is in line with that found by various authors such as Chardin (2018) , Copi et al. (1995), Gasparini (2020).

The value of the critical density ρ_c, a function of the Hubble constant $H(\rho_c = 3H^2/8\pi G)$ gives another indication. For $H = 71$ km/s/Mpc, ρ_c is of the order of 10^{-26} kg/m^3 for a universe age of 13.8 billion years (This value 13,8 Gy for the age of the universe represents a kind of average, taking into account the variability of H and the different models and their density parameters Ω_i.).

The so-called Hubble tension shows an interval for H of between 67 and 73 km/s/Mpc, which is reflected in the Hubble radius (to which we return later) and the age of the universe, between 13.4 and 14.6 billion years. The detour via the critical density is consistent with the total density ρ_m (baryonic matter + dark matter) via the densities Ω_i of the different energies in the expansion models. With $\Omega_m = \rho_m/\rho_c = 30\%$ (according to the standard ΛCDM model), we find the order of magnitude $\rho_m = 3\times10^{-27}$ kg/m^3 close to that given just now (5×10^{-27} kg/m^3). If we restrict ourselves to ordinary matter, we arrive at a value just under 5.10^{-28} kg /m^3, close to the 7×10^{-28} kg /m^3 given just now.

All in all, we are led to an interval of between 10^{-26} and 10^{-28} kg/m^3, as a first approximation without taking into account the expansion of the universe, which causes it to vary slowly. In our present understanding, the density value of our universe is probably close to the lower values of this interval (of the order of 5×10^{-28} kg/m^3; this is for ordinary baryonic matter).

As for the size R_u of a gravitationally-influenced universe equivalent to our own (this determines the gravitational potential at our Earth observation point, given that gravitational influences travel at the same speed as electromagnetic light waves), an order of magnitude is given by the Hubble radius R_H (derived from the value of H).

This represents the distance light has travelled to us from the earliest objects in the Big Bang, taking into account the age of the universe (this distance refers to the date of emission of the light reaching us).

The estimated age of the universe today is 13.8 billion years, giving a Hubble radius of 13.8 billion light-years. A different view of the same distant points concerns their position today (time at reception), given the distance they have receded as light was reaching us. In terms of distances, we speak of the cosmological horizon R_z limiting the observable universe, which, depending on the model, is equal to several times the Hubble radius (e.g. $R_z = 45$ billion light-years). From points beyond these distances, no signal can be received, due to the finite speed of light and the expansion of the universe (recession velocities then exceed that of light). As a first approximation, these different orders of magnitude of R-radiuses are considered independently of the expansion of the universe.

They are related to our local Euclidean standards, knowing that the detours made by light to transport images of distant celestial objects to us are accommodated by the index n_c.

Thus, we can frame likely ρ_u in the range 10^{-26}-10^{-28} kg/m^3 and radii R_u of the order of magnitude equal to tens of billions of light-years. As a first step, in a ‘broad’ way, we will take densities and sizes of universes largely encompassing the previous values: sizes spanning four orders of magnitude, from 10^0 to 10^3 billion light-years, densities covering five orders of magnitude from 10^{-29} to 10^{-24} kg/m^3.

For optical indices, let us choose three degrees within the range of possible values from 1 to infinity: $n_c = \infty$, $n_c = 2.4$ and $n_c = 1.2$. As for the lowest values, $n_c = 1$ is not obtained, except, asymptotically, for densities tending towards zero (as soon as we have matter, the index is greater than 1, as the formulas of the Shapiro effect tell us again) and/or for universes of size also tending towards zero. For an infinite value of the index, the term $log((n_c - 1)/n_c)$ in equation (16) cancels out, leaving equation

$$log\rho_u + 2logR'_u = -23.92 \qquad (17)$$

For values of n_c equal to 1.2 and 2.4, the terms $log((n_c - 1)/n_c)$ are respectively equal to - 0.778 and - 0.234, and we have the two equations:

$$log\rho_u + 2logR'_u = -24.70 \qquad (18)$$

And

$$log\rho_u + 2logR'_u = -24.15 \qquad (19)$$

Fig. 1 shows the equal value lines for $n_c = 1.2$, $n_c = 2.4$ and n_c infinite, in the plane (R_u, ρ_u). They form an oblique scarf, highlighted in color on the figure; the band is bounded on the upper right by n_c infinite. Beyond this, light does not propagate on a cosmological scale; for the lower zone, the index slowly decreases towards 1 at infinity in the bottom left.

Let us now restrict the values of universe sizes and densities to get even closer to our own: dimensions in the tens of billions of light-years (let us take the interval $10 - 100 \times 10^9$ light-year) and densities in the interval 10^{-26}, 10^{-28} kg/m^3. This time, we are in a tighter neighborhood around the Hubble radius (13.8 billion light-years), with densities closer to the critical density (10^{-26} kg/m^3) and average density (5×10^{-28} kg/m^3), as reviewed above. These choices make it possible to draw two colored bands on the figure, for sizes and densities respectively.

Let us take a look at how the three bands of indices, sizes and densities selected just now are positioned in relation to each other. A priori, we might expect a random distribution, the most likely being one in which the three bands' intersections define a triangle of any kind. In other words, the zone of ‘strong’ indices (around 2) of interest to us has no reason to correspond to any of the universes we have selected; either these universes are too small or too large, or they are too dense or too sparse.

As it happens, no. Remarkably, the zone of strong indices lies in the middle of the zone of plausible universes. Or, conversely, the zone of selected universes contains the zone of strong indices. We observe an ‘improbable’ fit, in a single region, of the three overlapping sectors: strong indices, ‘expected’ universe densities and sizes.

Let us leave it at that for now, and remember that, interestingly enough, universes with indices greater than two are not unreasonable. We will come back to this after Section 4.

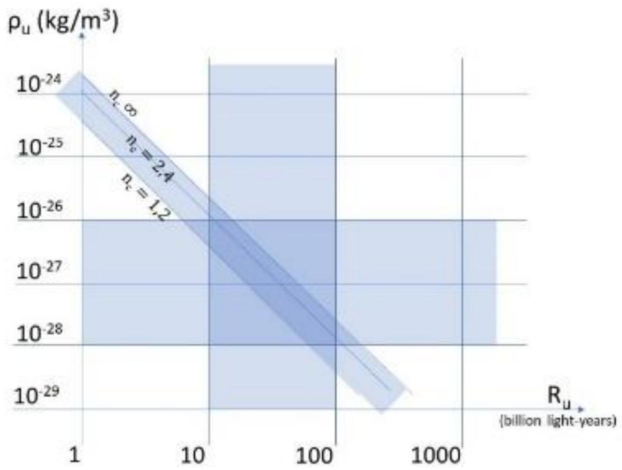

Figure 1. Representation of universes in the plane (R_u, ρ_u). Representation of universes characterized by their average density ρ_u (in the range 10^{-24}, 10^{-29} kg/m^3) and their equivalent gravitational radius R_u (in the range 1 to 10^3 billion light-years). Logarithmic scales. A reduced window closer to our universe: (10^{-26}, 10^{-28} kg/m^3) and (10 to 10^2 billion light-years) has been highlighted by coloring. The iso-index curves are straight lines, of which we have shown three: n_c infinite, $n_c = 2.4$ and $n_c = 1.2$, also defining a colored band. Remarkably (see text), the three zones overlap, demonstrating the possibility that indices greater than two are relevant to our universe on its own scale.

Two ways of talking about the speed of light

Is the postulate that '$c = c_0$ in vacuum is a universal constant' called into question by talking of a reduced speed of light in the cosmological vacuum? In response, let us point out that two non-contradictory points of view on the speed of light, corresponding to two scales of observation, are adopted.

First of all, there is the local world of terrestrial observers. The word local extends to the space around us, up to the sun and the solar system (150 million km and beyond). On this scale, we relate to a speed of light 'fixed' by convention at the value c_0. This is the value used in special relativity and its Euclidean space, where we describe increments of space and time by the small amplitudes dx, dy, dz and dt, linked as to their measurements by the relation $dx^2 + dy^2 + dz^2 = c_0^2 dt^2$. For objects distant from the observer, it is the right thing to do relating everything to his space and time standards based on the reference c_0.

Angular distances, or luminosity distances in cosmology, correspond, as we have said, to a projected distance in a supposedly Euclidean universe like our own, but, because of the effect of the non-Euclidean metric, they do not refer to the actual path of the light that reaches us. Following the logic of the 1983 definition of the metre (corresponding to a certain travel time of light at its decreed speed c_0 in a vacuum), it would seem natural, for the journey of light from objects of evaluated distances d, to imagine durations given by $t = d/c_0$. This is what we commonly do when we talk quantitatively about the 'past' we contemplate when looking at the sky. But, because of the 'refringence' calculated above, we have to break this quantitative correspondence with c_0. For distant objects on the scale of the universe, we no longer use the local speed of light c_0 but c_c and the durations are lengthened according to d/c_c. We then need to define the translation coefficients between the two scales (local / cosmological), and the second way of talking about the speed of light comes into play as follows.

The cosmological point of view corresponds to a scale where the representative elementary volume has a side equal to the light year, larger by a factor of 10^5 than the previous local scale (the distance to the sun). It is as if we could look at the universe from the outside, with the appearance of a homogeneous fluid. On this scale, relating it to the c_0 of our base, light travels at a speed c_0/n_c. This is the same as in a refractive medium, where the 'macroscopic' speed is different from the local speed. In water, for example, the speed of the photon remains c_0 between atom-to-atom interactions on the nanometric scale, but it would be a mistake to assign this value to light arriving from millimeter to hectometer distances, as it is slowed down by interactions with the electrons of the atoms encountered (absorption/excitation-de-excitation/re-emission delay).

Similarly, the light we receive from celestial objects is always c_0 in its elementary paths, but c_c on the scale of the overall path, due to interactions - this time gravitational (taken into account by a non-Euclidean metric)-with all the matter it encounters.

Note that in the case of the universe, there is no interface with an outside world; we are inside. But that does not mean that we cannot consider two scales and two speeds. In short, mathematical formalism enables us to distinguish between:

1) the local scale, in the tangent plane to the overall curved space; here we define the increments of distances and durations dx, dy, dz, dt measured by the standard of motion at speed c_0.

2) space in its cosmological dimension, where lengths are measured by weighting dx, dy, dz, dt by the coefficients g_{ij} of a metric. Their effect is responsible, via the writing of $ds^2 = 0$, for a megascopic speed of light of less than c_0.

Captive light

The two previous levels of scaling can be seen in what is said about the speed of light in black holes. We continue to speak of c_0 locally, but if we step back, we can say that, when trying to cross outward the event horizon, it is as if the speed of light could be cancelled out (seen from the outside, it is not equal to c_0).

If we return to the optical comparison, we can calculate an optical index for the Schwarzschild black hole. For this metric, the index is:

$$n = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \qquad (6)$$

For the value of the horizon radius $r = 2GM/c^2$, we have an asymptote with n tending towards infinity; the speed of light tends towards zero. For the universe as a whole, we find the situation seen above, for straight lines in the plane (R_u, ρ_u) along which n_c is infinite (Fig. 1).

The universe then prevents the progression of light on its megascopic scale (whereas locally it is always equal to c_0). With

$$n_c = \left(1 - \frac{4\pi\rho_u G R_u^2}{c^2}\right)^{-1} \qquad (16)$$

n_c is infinite for $\rho_u R_u^2 = c^2/4\pi G$. We are led to a 'horizon' discussion, to be distinguished from other horizons relating to the expansion of the universe.

The difference between the two points of view ('local' and cosmological) can be seen in the way the aforementioned authors use the equivalent optical index obtained from the Schwarzschild metric, following a first-order approximation. Taking equation (6), we have

$$n(r) = \left(1 - \frac{2GM}{rc^2}\right)^{-1} \approx \left(1 + \frac{2GM}{rc^2}\right) \qquad (20)$$

in a development limited to first order. For 'local' use, the $2GM/rc^2$ term is negligible in front of 1 and we use the approximate formula

$$n(r) = \left(1 + \frac{2GM}{rc^2}\right) \qquad (21)$$

The latter expression is frequently used in the literature, seeming to have forgotten that it is an approximation. It is the one that has successfully passed tests on the 'local' scale of the solar system. On the contrary, when summed to the scale of the universe, the GM/rc^2 term is not negligible in front of 1, and is even of order zero!

The considerations in this first section (about the speed of light on a cosmological scale), may be extended to what is said about the speed of propagation of gravitational interactions (whether gravitons or gravitational waves). It can be said that the latter also propagate at the speed $c_c = c_0 / n_c$, which corresponds to what has been observed: for various events detected in recent years by gravitational wave detectors, the arrivals are simultaneous with those of light waves detected by conventional means. Some authors have even pointed out that the Shapiro effect is just as effective for some as for others. This makes the overall approach coherent and supports the one we propose.

3. DOES THE UNIVERSE HAVE A DARK SIDE? A. DARK MATTER

Leaving aside general relativity and calculations of the equivalent speed of light on a cosmological scale, let us return to the problems raised in the introduction.

Overestimated speeds

As we have already said, the problems we are facing, before they concern matter and energy, are first and foremost linked to the way we estimate the velocities v of distant celestial objects, which are excessive in relation to our well-established laws of physics. How are these velocities established? In answer, they are not established by determining ratios between distances travelled Δl and time intervals Δt, in the form $v = \Delta l/\Delta t$: they are established through ratios to the speed of light v/c, informed by its redshifts (the Doppler effect in the broadest sense) (Strictly speaking, this is not true for velocities evaluated by parallax variations, as we will allude to later; but the relational aspect discussed just below is present, albeit more hidden.).
This is a general characteristic of physics based on ratios of magnitudes (including what concerns light), as analyzed in our various works (cf. (Guy, 2011, 2019, 2022). We are dealing with ratios $\tau = v/c$ and only these ratios are 'true'; c is the speed of light. If the 'measured' speed v_m of a distant object (via a c_0 corresponding to our local standards) is too great and does not correspond to the value v_e that we 'expect' from it, we need to ask ourselves the question of a smaller speed of light c_c (on the cosmological scale) which carries us the information. We have the fundamental relation:

$$\tau = \frac{v_m}{c_0} = \frac{v_e}{c_c} \qquad (22)$$

or

$$v_e = \frac{1}{\alpha} v_m \qquad (23)$$

With

$$\alpha = \frac{c_0}{c_c} \qquad (24)$$

If dark matter is 'demonstrated' by excessively high velocities, the question is whether we can determine the same α ratio in the various cases, which would bring us back to velocities in line with the physical laws we know, experience and measure (in our laboratories and the experiments within our reach, extended to our solar system)? We will then have to confront this α factor with an n_c index calculable according to the method set out in the second section for a universe of characteristics to be discussed.

The considerations set out in the second section of this article would be enough to make us accept the idea of a speed of light below its standard value in a vacuum. But, in the course of our research, other, more fundamental considerations had steered us towards the path just outlined. They are rooted in a historical review and in epistemological reflections. On the first point, it is worth pointing out that none of the measurements of the speed of light (Römer, Bradley, Fizeau, Foucault, etc.) reveal this speed as a simple ratio between an interval of space and an interval of time, space and time assumed to be already defined and equipped with independent gauges. But another motion is always involved (earth's motion, the motion of a cogwheel, etc.) and the speed of light appears in a ratio of the type $\tau = c/v$ or v/c (Lehoucq & Uzan, 2005). If we estimate that we know v, we deduce c. The 1983 decree sets $c = c_0 = 299{,}792{,}458$ meters per second. Since then, it has been as if we were only thinking in terms of c, forgetting the fundamental relational aspect expressed in speed ratios. Where have all the other v's gone? What is m/s, the speed of one metre per second, which is not linked to any other phenomenon? The preceding decree is not without question! We have to accept being reduced to circular comparisons of v/c ratios (particularly in cosmology); we fix a numerator or denominator by inevitable convention, but only the ratios have any meaning.
As for the second point (epistemological considerations), the duality of points of view (c_0, c_c) is very much in keeping with a 'relational' rationality based on comparisons between physical quantities. Henri Poincaré (1902,1905) would remind us that we cannot say anything about space on its own (is it Euclidean or not?): we base its properties on matter, the trajectories that pass through it, compared with one another: we speak of a curve in relation to what we call (what we decide to call) a straight line, and vice versa. The same applies to velocities: the ratios v/c relate gravitation (for v) to electromagnetism (for c). This 'solidarity' of the two phenomena (gravitation / electromagnetism) cannot be avoided in the two terms of the ratio c_0/c_c (nor is c_0 alone there). The two ways of talking about the speed of light (referring to two different phenomena) are not contradictory, but complementary, and indispensable to each other in a comparison (See also from this point of view our work on the relationship between quantum mechanics and general relativity, Guy (2018).

Dark matter in spiral galaxies

If we want to summarize the emergence of this problem, two authors, (Zwicky, 1933) and Rubin (Rubin & Ford Jr, 1970), played a pioneering role. The first looked at galaxy velocities in galaxy clusters, while the second looked at star velocities in spiral galaxies. In both cases, values are estimated using Doppler shifts. Different corrections are required, depending on the assumed angles between star velocities and observer radii. If the galaxy is seen from the surface, no relative star motion is detected. If we view it from the edge, the movements of stars at different distances from the center are superimposed, causing confusion, especially in the denser inner parts. The speed of recession of galaxies as a whole, due to the expansion of the universe, must also be taken into account.

Finally, there may be signal disturbances of various kinds on the way to the observer. Based on this data acquisition work, Zwicky and Rubin both concluded that the observed velocities were too high in relation to what was expected, i.e. in relation to the estimated mass of the objects involved (which presupposes a transition between mass and velocity, using Newton's laws), given their luminosity and a standard link between luminosity and mass.

But the question is precisely how to estimate the expected masses to be involved in understanding the observed movements. At the start of this research, the supposed missing mass was very large (Zwicky speaks of a factor of 100 compared with the visible mass), but we later came to understand the large quantity of gas and dust present and yet unseen. It is now thought that luminous baryonic matter (stars) accounts for only one-fifteenth of the total baryonic mass; gas and diffuse gas, in equal proportions, account for the remaining 14/15. This is established by measurements of non-visible light wavelengths, in particular the 21 cm radio line for neutral hydrogen HI, in dominant quantity in gases (in addition to information in the near infrared at 3.6 μm). The terms 'missing mass' or 'dark matter' are now used only for non-baryonic matter (whereas in early texts, they included non-luminous baryonic mass).

Today, it is generally agreed that the ratio between baryonic and dark matter is on the order of 1 to 6, i.e. 17% baryonic matter to total matter (baryonic + dark).

Let us take a close look at the movements of stars and gas in spiral galaxies. They provide a fine example, allowing us to get to the heart of our proposal. In Fig. 2, we have selected two curves from the work of Stacy S McGaugh (2014) (We have not chosen galaxies where the two curves of the two velocity profiles (measurements / models) show the strong difference, for distances away from the center, between the stable plateau of the 'measurements', and the decay of the models. It is this type of curves that are usually presented to prove and discuss the presence of dark matter.

But these curves do not meet the average ratio between dark matter and baryonic matter, but rather show an excessive value, greater than the ratio of 6 to 1, or, for velocity ratio, greater than 2.4. And, precisely, these are not the only possible behaviors.).

They show the variation in velocities of stars, or gas, as a function of the distance R from the galaxy center. For each galaxy, we represent the observed/measured velocities v_m (using our notation; the dotted curves result from adjustments to the data points), and the calculated expected velocities v_e (solid curves). This assumes that we have sufficiently good knowledge of the existence, quantity and mass distribution of gas, stars and dust, acting gravitationally.

We have chosen two galaxies where the distinction between the two curves (measured/expected velocities) is clear for small R, as this is generally not the case: near the galaxy center, velocity variations are large (slopes close to the vertical; within a mass distribution of constant density, the spatial derivative of velocity is in $R^{-1/2}$ and becomes infinite at the origin). The two curves tend to merge, and small inaccuracies in R translate into large inaccuracies in v.

Furthermore, information on small R is of inferior quality: - superimpositions of signals from stars at different distances from the center; - blurring of information depending on the orientation of the galaxy; - difficulties in calculating v_e, which is very sensitive to the spatial distribution of baryons (gas and stars) in the central zones; - poorer mass/luminosity relationship at the center (Stacy S McGaugh, Lelli, & Schombert, 2016).

All in all, the data are not of the best quality.

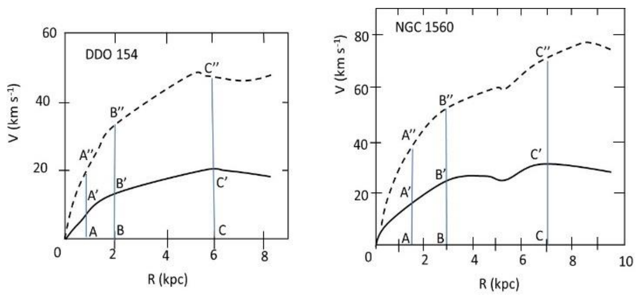

Figure 2. Star speeds in spiral galaxies. Two spiral galaxies were chosen from Stacy S McGaugh (2014): the DDO 154 galaxy on the left, the NGC 1560 galaxy on the right. The rotational velocities of the stars are plotted on the ordinate (km/s), their distance from the galaxy center is noted R, on the abscissa (kpc). Two curves are shown for each galaxy: the dotted line represents the 'measured' values (original points in the article cited); the solid line represents the values estimated on the basis of assumptions made about the amount of baryonic matter and its distribution in the galaxy. As a function of increasing R, velocities rise sharply, stabilize at a plateau and then fall back slightly. The velocities in the rising parts of both curves show a constant ratio (the slopes are not strictly rectilinear, but the ratio between velocity values remains roughly constant). This ratio is the same on the plateaus, where it is particularly noticeable. That is, we have $AA''/AA' \approx BB''/BB' \approx CC''/CC'$ for each of the two galaxies. For DDO 154, the ratios are respectively equal to 2.3; 2.5 and 2.4; for NGC 1560, the ratios are respectively equal to 2.4; 2.3 and 2.3 (rough estimates). These are therefore also the same ratios found in the two different galaxies.

The two examples chosen (Fig. 2) correspond to a certain variability in velocity ranges (10 to 80 km/s), and spatial amplitudes; other galaxies in the Stacy S McGaugh et al. (2016) data deviate even further from these value fields (velocities from 10 up to 300 km/s; distances to center in tenths of kpc up to several tens of kpc). Two sets of remarks can be made about the curves.

1) In the part corresponding to small distances from the center of the galaxy, we observe a rise in velocities according to more or less regular inclinations (monotonicity of the curve rises in $R^{-1/2}$). For a given galaxy and for each abscissa R, the ratio α of the velocities read on the two curves (measurements / estimates, i.e. v_m / v_e) remains within a narrow range (roughly constant ratio), whatever the values of the slopes and velocities. For the two galaxies in Fig. 2, this ratio is equal to 2.4 (galaxy DDO 154) and 2.36 (NGC 1560), roughly estimated by the ratios of the AA''/AA' and BB''/BB' segments (averaged over two values).

2) After the rise in velocity from the center, we observe a more or less flat or slightly descending plateau (depending on the spatial amplitude observed, bearing in mind that we can now detect rotational gas motions significantly outside the visible

galaxy). This plateau is connected to the top of the ascending parts described in 1). The ratio between v_m and v_e remains roughly constant, although the absolute values may differ. Measurements taken on the figure give values of 2.35 (DD0 154), 2.3 (NGC 1560), again roughly estimated by the ratios of the CC''/CC' segments. The velocity comparison is easier to read on the plateaus for large R distances to galaxy centers. In contrast to the data for central stars, the peripheral gas is very reliable, with better velocity behavior.
Let us insist: it is the same behavior, i.e. the same v_m/v_e, for both ascents and plateaus. The ratio can be read on the plateau, but it is already there. Without concern for mathematical and statistical rigor, we can average the velocities read on the plateaus by including the various galaxies discussed by Stacy S McGaugh (2014) and Stacy S McGaugh et al. (2016): these are NGC 7331 (1.7 read at 38 kpc), DDO 154 (2.4 at 6 kpc), UGC 128 (2.4 at 55), NGC 6946 (1.7 at 18), NGC 1560 (2.5 at 10), NGC 7814 (2.7 at 25), NGC 6503 (2.6 at 20) and NGC 3741 (4.5 at 7). The velocity shift is not only apparent in areas of low gravitational potential (corrected by the MOND law), but also in areas close to the center and of higher potential.
On these few examples (real statistical studies on larger samples would certainly be needed) we have an average α ratio of between 2.4 and 2.5 (The α value close to 2.4 is in line with the velocity issue discussed here, but room must be left for other mechanisms invoked by the authors that may explain why, in some cases, it may not have that 2.4 value.). This corresponds to the dark matter/baryonic matter ratio of 6 to 1. In fact, we relate velocities to masses by the relation

$$\left(\frac{m_m}{m_e}\right) = \left(\frac{v_m}{v_e}\right)^2 \qquad (25)$$

which is justified by Newton's laws of speed, mass and distance: the velocity of a body (e.g. a planet) around a star of mass M and distance r is such that

$$\left(\frac{v^2}{r}\right) = \left(\frac{GM}{r^2}\right) \qquad (26)$$

For the same r, the ratio of masses is equal to that of speeds, squared. And $\alpha^2 = (2.4)^2 \approx 6$, proportion of mass seemingly missing.

Gravitational mirages

A gravitational mirage (also known as a gravitational lensing effect) shows the displacement of the image of a distant object in a direction that is not its 'true' direction; it can also lead to its distortion, and sometimes its multiplication. It results from interaction with a massive object (a star, a galaxy, a cluster of galaxies) interposed between the distant object and the observer. The theory of this effect is well established, based on general relativity. Its amplitude is considered by many to be proof of the existence of dark matter.
A variety of observations, measurements and theories can be found, depending on the size and shape of the interposed object, and the geometry of the overall system (we distinguish in particular between micro-, weak and strong lensing effects). For the purposes of our discussion, we will retain that the angle manifesting the effect of gravitational mirage verifies the following generic formula (e.g. Gasparini (2020); Claeskens (2003):

$$\theta = \left(\frac{4GM}{dc^2}\right) \qquad (27)$$

where M is the deviating mass, d is the distance to the mass M of the light beam carrying the image of the observed object, G is the gravitational constant and c is the speed of light in a vacuum (i.e. our c_0; classical Newtonian reasoning gives the same relationship with a factor of 2 instead of 4).
According to the authors, the deflection angles θ do not correspond to the observed masses M: they are too large. They highlight mass excesses, blamed on invisible dark matter, in average proportions similar to those postulated in other situations in relation to baryonic matter (around 6 times more). Taking up the formula just given, we can propose another interpretation.
Indeed, if we decrease the value of c by the proportion indicated above (a factor α of the order of 2.4), we see that, all other things being equal, the mass M respecting the same value of angle θ will be divided by α^2, i.e. by a factor close to 6. We do this if, in relation to our local standards, the assignment of such a value to M seems aberrant to us. In this way, the need for dark matter disappears. This is a situation in which there is no object moving at a speed v that needs to be determined. The magnitude under discussion here is an angle: our approach thus seems supported by the resolution of two distinct problems (a velocity on one side, an angle on the other (It may come as a surprise that angular deflection yields roughly the same percentage of dark matter as galaxy rotation curves?
The explanatory theoretical frameworks are different: the speed of celestial objects refers to Newtonian theory, gravitational mirages to general relativity, which certainly encompasses the former.), with the adoption of the same α factor (same value of c, i.e. c_c).
We are not comparing v/c ratios here; but general thinking on velocities encourages us to modify c on its own in the equations (which amounts to changing c in relation to c_0, and indirectly in relation to another v's). We are led to do this in situations where we must not forget that c refers to propagation, and is not just a structural constant. This makes it possible to bring the equations into play in conditions where the speed of light (which guides other phenomena, not only for measurement but also for physical mechanisms) may be different from c_0 and, for example, lower. We are thinking of situations where the equations of general relativity are brought into play in the cosmological medium.

The cosmic microwave background and dark matter

Work on cosmic microwave background radiation (CMB) has also led the authors to postulate dark matter. The CMB is the relic of the radiation emitted by the hot, dense horizon, at the moment when photons can break free and the universe becomes transparent. The horizon is the opaque wall we come up against as we go back in time, reaching a state of the universe that did not allow light to pass through (estimated to be 380,000 years after the Big Bang).
At its origin, radiation had a temperature of around 3,000 K, but the expansion of the universe has brought it down to an estimated 3 K today. The study of the CMB involves acoustic

velocities, combined with temperatures and high densities, through specific interactions between matter and radiation, inside a plasma where electrons and protons are dissociated. This is the so-called pre-recombination period. The characteristics of this early state come into play when we question the homogeneity properties of the universe as observed today. The fluctuations observed in the CMB allow us to predict the different structures of galaxies, clusters, superclusters, filaments and so on.
CMB radiation is that of a black body, i.e. the spectrum of wavelengths emitted is a function solely of temperature. There are very small temperature fluctuations (determined by the wavelengths of light in the context of blackbody radiation) of the relative order of 10^{-5}.
The Planck satellite has made it possible to map these fluctuations. These fluctuations are related to density fluctuations, via the propagation of acoustic waves in the dense plasma of the horizon. The relationship between temperature and density fluctuations is demonstrated (Aubert, 2019).

$$\frac{\delta T}{T} = -\frac{1}{6}\left(\frac{\delta\rho}{\rho}\right) \quad (28)$$

where T is the temperature and ρ the density of matter (a priori including dark matter and baryonic matter).
According to the authors, a proper quantitative understanding of this physics (acoustic waves, coupling with thermal equilibrium, links between temperature and density) requires the intervention of dark matter. Do we have a say? The CMB horizon from which the $3K$ radiation originates is receding away from the observer due to the expansion of the universe. To plot the temperature map, we need to take into account the escape velocity, deduced from the Doppler effect (for a z of the order of 1100).
If our reasoning is correct, we can imagine that the escape velocity has been exaggerated; however, this velocity shifts everything towards the red, i.e. lowers the temperatures T of black bodies. On the other hand, the δT remain the same (these are differences, the two limits of the interval are equally shifted by the expansion).
So, for the same red, by decreasing the escape velocity, which would have been exaggerated, we increase the thermal red, i.e. we decrease the temperature.
We increase the ratio $\delta T/T$; the previous relationship shows us that we then increase the absolute value of the density fluctuation without the need for additional dark matter.
The previous question reflects only one of the many aspects relating to CMB. There is the question of the chronology of dark matter's intervention in relation to baryonic matter. Dark matter is insensitive to electromagnetic interaction, and does not interact with charges in plasma (ionized matter): it is unaffected by acoustic waves.
It can form lumps that will then attract baryonic matter: the seeds of galactic structures. The authors estimate that these structures would not have had time to form (given the age assigned to them) if dark matter had not initiated their birth. Insofar as the authors believe that, for these various questions, the proportion of dark matter is still a factor of 6 higher than baryonic matter, we are comforted as to a velocity gap of a factor $(6)^{1/2}$ influencing the interplay of temperatures, the guiding parameter for phenomena taking place in the CMB.

Discussion of dark matter

There is a wealth of literature on where dark matter is postulated to exist. It covers a wide variety of galaxy types (elliptical, spiral, diffuse, ultra-diffuse, young or old, large or small, massive or not) and groupings (clusters, superclusters, filaments, colliding galaxies, etc.), each with its own star/galaxy behavior, depending on position and mass distribution. For each case, the discussion focuses not only on the existence of dark matter, but also on its distribution: larger or smaller/fragmented halos, encompassing galaxies or nestled within them, variations according to distance from the center of the galaxy or cluster, and so on.
The refractive universe hypothesis gives a megascopic approach (a kind of filter applied to the whole universe) and accounts for the average abundances of dark matter (and dark energy, see below). But in the detail of individual galaxies, etc., there is some variability in the amount of postulated dark matter and its distribution that questions the refringence model. So, we have to look for other 'local' causes (to be added to the refringence effect). Insofar as dark matter manifests itself as a discrepancy between data and models, its quantity and distribution are a function of these two factors (data/models).
At the level of data acquisition, there may be some variability due to various biases, errors (choice of target objects, stars, neutral or ionized gas, and observed wavelengths...) and various corrections (galaxy inclination; statistical approaches...) that would be responsible for the discrepancy with the prediction of the refringent model.
In terms of models, there can be local variability depending on whether or not we take into account the influences of the motions of stars closer or further away in the same galaxy, or in neighboring galaxies within a galaxy cluster. The way in which the expansion of the universe is taken into account can also play a part.
Perhaps other mechanisms also need to be brought into play: could gravito-magnetic effects, predicted by general relativity (gravitational attraction depending on the velocities of the masses in motion) be added to the usual Newtonian attraction? We may still think of birefringence effects (and not 'simple' refringence) due to the fact that galaxies are not isotropic (the possible polarization of light can also play a role, both in the transmission and reception of signals (Effects similar to pleochroism of birefringent minerals.).
Some authors propose modifying the laws of gravitation (MOND model, Milgrom (2002); Bekenstein (2009); Sus (2014); Borka, Capozziello, Jovanović, and Jovanović (2016). G Paturel and Teerikorpi (2006) and Georges Paturel, Teerikorpi, and Baryshev (2017) highlight the various biases affecting the evaluation of the Hubble constant.
For Buchert (2012) curvature and the existence of higher density zones in the universe would be responsible for the effects attributed to dark matter, while (Maeder, 2017a, 2017b) proposes a scale invariance hypothesis.
Ván, Abe, and Applications (2022) and Pszota and Ván (2023) propose a modified law of gravity coming from thermodynamics. And we must not rule out still other explanations, of which the Dirac Milne universe is one (Chardin, 2018).

Interestingly, for our Milky Way, the postulated amount of dark matter is much lower (by a factor of 5) than in other galaxies of the same type (Jiao et al., 2023).

We would like to link this to the fact that, in the case of our galaxy, star velocities are largely measured by parallax effects. We had anticipated, in the form of a question (Guy, 2022), that then dark matter would not need to be hypothesized.

Some are convinced of the existence of dark matter and are looking for the particles that might correspond to it (physics work aims at a modification of the Standard Model and the detection of new particles, in a so-called supersymmetry framework, Bertone (2014).

The problematic nature of dark matter and the situations in which it can be found are highlighted by many: - it manifests itself through gravitational effects, but does not interact with baryonic matter, nor with itself; - it is correlated with ordinary matter in a large number of galaxies Stacy S McGaugh et al. (2016); -it seems capricious, sometimes overabundant, sometimes virtually absent; - it can be correlated with the age of objects; - surprising effects are observed in its appearance or disappearance, in the loss of symmetries observed during certain transformations; -its behavior over time and as a function of relative distances in galaxy clusters is difficult to explain, given what is otherwise assumed for it (Aubert, 2019); - the question of its production and annihilation arises in the course of the universe's history; -the question of its distribution in space is made tricky by the very interplay of gravitational forces: long-distance forces: dark matter is positioned where it does not play; integrative character: an infinite number of spatial distributions are possible for the same gravitational effect (additional assumptions must be made to choose the most reasonable one).

Some authors make no secret of their embarrassment and question the very existence of dark matter.

As a conclusion to these steps on dark matter, without having inspected in detail all the situations where it is postulated with variable quantity (Examining every situation is a research program in itself.), we will underline, as a key of more general value, the beautiful homotheticity between star velocity curves, measured on the one hand, expected on the other, in many galaxies.

The α ratio is not just an average of scattered data, it holds together along particular curves, observed on stars and outer gas, and has the same value for very many galaxies. This fit is a little strong for dark matter, which is reputed not to interact with ordinary matter! There is something constant, not the effect of chance, behind this variety of observations.

On this basis, it seems to us that we are dealing with an artefact, and not with the problem of a missing mass to search for. This hypothesis is extended and strengthened by the fact that it works well in the case of gravitational mirages and by a preliminary analysis of other situations (such as those of the CMB).

This is in line with work highlighting the correlations between dark matter and baryonic matter. This leads us to say: if this effect of poorly estimated velocities does indeed come into play in such situations, it will inevitably manifest itself in all others where motions are at stake (expansion of the universe, dark energy, Hubble tension, etc.).

4. DOES THE UNIVERSE HAVE A DARK SIDE? B. DARK ENERGY

Dark energy is evidenced by the fact that the speed of expansion of the universe exceeds that predicted by modelling: this is known as acceleration. It has been postulated by three teams of astrophysicists, led respectively by Saul Perlmutter, Brian Schmidt and Adam Riess (see, for example, (Perlmutter et al., 1999)). The excess of the expansion velocity is manifested for recent periods, since 5 billion years, i.e. from an age of the universe equal to some 8 billion years. Gasparini (2020) recalls the results of the Supernovae cosmology project: the luminosity distance of Supernovae Ia is plotted as a function of redshift, and observations are compared with models of decelerated universes, without dark energy. The least bright supernovae, and therefore the most distant, are less luminous than predicted for a normally decelerated universe. The distance at which they occur is greater than expected, indicating an accelerating universe. To accommodate this, some theorists introduce into the evolution equations a density Ω_v (the subscript v stands for 'vacuum'; also referred to as Ω_Λ where Λ is the cosmological constant) manifesting a repulsive energy (dark energy).

Let us look at the proportions accepted today for Ω_v (Ω_Λ) and Ω_m. The term Ω_Λ corresponds to a 'missing' quantity of around 68-70% of the universe's energy, calculated according to the respective weights of Ω_i in the evolution equations (compared with 32-30% for ordinary and dark matter taken together with 4-5% for the former and 25-26% for the latter).

According to Asgari et al. (2020), the relative weight of Ω_Λ could reach a larger value of 82%, bringing the sum of ordinary and dark matter down to 18% (The difference between the values of the density parameters predicted by Asgari *et al.* (based on gravitational, or so-called weak lensing, shear effects by nearby galaxies, $z = 1.5$) and those usually predicted (based on data acquired by the Planck satellite on the cosmic microwave background) is what we call the S_8 tension, named after the parameter concerned, depending on Ω_m.).

Given that ordinary matter accounts for roughly one-sixth of the latter fraction, we can estimate that its weight vis-à-vis dark energy, if we dispense with dark matter, is of the order of 3%, opposed to 97%.

One avenue already shows the potential contribution of our approach. It takes advantage of the authors' work on the cosmological constant in Einstein's equation, which they claim accommodates the question of dark energy. Einstein's equation is, in fact, the source of models for the expansion of the universe. In its initial version, with no cosmological constant, it is written:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \left(\frac{8\pi G}{c^4}\right)T_{\mu\nu} \quad (29)$$

The geometric parameters of metric $g_{\mu\nu}$, Ricci Tensor $R_{\mu\nu}$ and scalar curvature R (to the left of the equal sign) are linked to the energy content (stress-energy tensor $T_{\mu\nu}$, to the right, expressed in mass, i.e. kg). By adding a term to the left-hand member, involving the cosmological constant Λ, we show that a repulsive force is manifested that accommodates the accelerated expansion:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} \quad (30)$$

We can propose another solution, noting that the factor c is explicitly involved in the denominator of the factor on the right. If we think that, on the cosmic scale where the problems arise, we must divide c by a factor α, we see that we are committing an error of a factor $(\alpha^4 - 1)$ according to:

$$\left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} = \alpha^4 \left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} - (\alpha^4 - 1)\left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} \quad (31)$$

In fact, according to our analysis, we should take only the first term of the second member of the above equation, which can also be written as:

$$\alpha^4 \left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} = \left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} + (\alpha^4 - 1)\left(\frac{8\pi G}{c^4}\right) T_{\mu\nu} \quad (32)$$

This shows that, wanting to take only the term in α^4, we have to correct the usual term by adding the factor $(\alpha^4 - 1)\left(\frac{8\pi G}{c^4}\right) T_{\mu\nu}$. Let us write two exponents to differentiate, in the stress-energy tensor, the standard term referring to the usual matter m, and the corrective term designated by Λ; we can write

$$T_{\mu\nu}^{(\Lambda)} = (\alpha^4 - 1) T_{\mu\nu}^{(\mathrm{m})} \quad (33)$$

The stress-energy tensor we have to add is larger than the usual stress-energy tensor by a factor $(\alpha^4 - 1)$. This manifests itself in mass energies, or mass densities, in the same ratio. If we take α to be close to 2.4, the factor $(\alpha^4 - 1)$ is close to 35. We thus expect

$$\rho_\Lambda = (\alpha^4 - 1)\rho_m \quad (34)$$

or approximately $\rho_\Lambda \approx 35\rho_m$. As it happens, the ratio of 1 to 35, out of a total of 36 corresponds to the ratio of 3 to 97 (baryonic matter, without dark matter/dark energy) that we discussed just now from the work of Asgari et al. (the correspondence is a little better than for the proportion of 4 to 5% versus 95 to 96% in the other works). What is important is the notable difference between the ordinary matter/dark matter proportion and the ordinary matter/dark energy proportion, which could be accommodated by the ratio α^4/α^2 equal to α^2 i.e. of the order of 6.

If we take for ρ_m a value in the range discussed in Section 2, in particular the low value of the order of 5.10^{-28} kg/m^3, we are led to propose $\rho_\Lambda \approx 35 \times 5 \times 10^{-28}$ kg/cm^3 $= 1.75 \times 10^{-26}$ kg/m^3. From this we deduce, via the relationship between ρ_Λ and Λ, i.e. $\rho_\Lambda = c^2\Lambda/8\pi G$, a cosmological constant Λ of the order of 10^{-52} m^{-2}.

This is in line with what we read in the literature, both for ρ_Λ and for Λ. Taking the high end of the density range, of the order of 5×10^{-27} kg/m^3 multiplies the previous values of ρ_Λ and Λ by ten. In any case, ρ_Λ is a fictitious density designed to correct an error in the initial understanding. The consistency of our approach in this respect is a way of giving the cosmological constant its full value in solving the problem of dark energy, as various authors have called for.

A great deal of research is being carried out to understand what lies behind dark energy of density Ω_v. As we said, some authors identify it with the cosmological constant Λ. The latter, which opposes the attractive force of gravitation, was introduced by A. Einstein in his equations to guarantee a stationary universe. Others see it as the expression of vacuum energy (in the sense of quantum mechanics): however, according to particle physics and quantum field theory, there is a big difference in orders of magnitude between the two energies.

The vacuum energy estimated by quantum mechanics would be some 10^{40} times greater, making the supposed link between the two problematics. For some authors, this is one of physics' greatest enigmas. For us, there is no problem with the cosmological constant, insofar as it does not refer to an actual force of nature but expresses a correction to an initial erroneous understanding.

Rather, many are seeking to dispense with dark energy, and point to the difficulties or paradoxes associated with it (e.g. Huterer and Turner (1999): - we do not know which physical field to link it to; - its density does not decrease with expansion (this observation would not be embarrassing for us, since it is a question of misjudged velocities, not of energy and density); - its intervention is intermittent in the history of the universe (cf. the accelerated expansion of inflation at the very beginning of the Big Bang). Not to mention the superimposed problems of dark matter and dark energy playing antagonistic roles in the equations, leading to a kind of outbidding: the authors speak of degeneracies that are difficult to resolve.

Buchert (2000, 2008) points to the non-homogeneity of the universe and the existence of voids on large scales (negative curvature). Chardin (2018) proposes a role for anti-matter. Without fundamentally challenging the idea of accelerated expansion, Fleury, Dupuy, and Uzan (2013) attempt to calculate the Hubble diagram in the case of a non-homogeneous universe.

5. DISCUSSION: A NON-DARK UNIVERSE, AN OLDER UNIVERSE?

Orders of magnitude

At this point in our work, we are looking at two pieces of a puzzle, each with its own consistency and solidity. One shows us that it is possible to envisage a refractive universe characterized by an index n_c that can reach and exceed the value 2 (2nd section).

The other shows that the same α factor, of the order of 2.4, dividing the speed of light as it travels through the universe, seems an interesting way to account for the problems of the dark side of physics (3rd and 4th sections). Can we put these two pieces together? By a pleasant surprise, our answer is: yes! They fit almost perfectly! In fact, their synergy reinforces both theoretical predictions and observational data! So, we will take a gamble and say: by getting rid of its dark side, the α factor can be explained by the refringence of the universe.

This is characterized by a density ρ_u and an equivalent radius R_u linked together by the value $n_c = 2.4$ in relations (13) or (19). Let us look at where we started from: "only about 5% of the matter and energy in the universe is known; 25% of unknown dark matter (6 times more abundant than ordinary matter) and 70% of mysterious dark energy are missing from the inventory." We therefore propose a simple solution to these challenges by considering the universe on a cosmological scale as a refractive medium. The numbers given here are orders of magnitude subject to a certain variability. It is to these proportions, considered on average, that our proposals apply. On average, the value α ≈ 2.4 accounts for the velocity differences observed for celestial objects; its square $\alpha^2 \approx 6$ gives the ratio of dark matter to baryonic (or ordinary) matter, its power 4, i.e. $\alpha^4 \approx 36$, the ratio of dark energy to ordinary matter. These powers are derived from physical reasoning using Newton's laws and Einstein's equations. Dark matter and dark energy are the names of corrections to compensate for the error made in keeping for the speed of light at cosmological scales its 'usual' value in a vacuum. Can we go further and discuss more precisely for our universe the value of the coordinates of the point (R_u, ρ_u) on the line connecting them (Fig. 1)? Before we do so, it is appropriate to make two sets of remarks, firstly (section 5) on the use of the value c_c in the equations derived from relativity (in response to objections that might arise), and secondly (section 5) on the age of the universe.

Back to gravitational mirages and Einstein's equations

The distinction between scales (section 2): local scale and its velocity c_0 vs cosmological scale and its velocity c_c, allows us to clarify a question we could, or should, have asked ourselves. This concerns the replacement of $c = c_0$ by c_c, in the gravitational mirage equations (section 3) on the one hand, and in Einstein's equations (section 4) on the other. Why do it? Isn't refractivity (bringing velocity c_c) already accommodated by the metric's g_{ij} coefficients, as seen in section 2 with the Schwarzschild metric? In response, however, it seems to us that we have done the right thing.
For gravitational deflection first of all, the curved path from the objects observed by astronomers must be considered on a cosmological scale. But the calculation is made in general relativity as if the deflecting mass were alone, bypassed by a photon at speed c_0, and not bathed in the real universe populated by matter. In this latter case, as we have shown, we need to consider a global velocity equal to c_c. Without repeating all the calculations, we can see that a good approximation of what is happening is provided by replacing $c = c_0$ by c_c in equation (27). The situation is similar for the Einstein equation. This equation has its first value in local space in the sense we have given it (which can extend as far as the solar system).
The speed of light is c_0. However, in the case of the (accelerated) expansion of the universe, it must be transposed to the cosmological scale (the stress-energy tensor will be that of a fluid or gas of galaxies and not of a star). We restore the situation by taking a value of c_c for the speed of light in this equation, replacing $c = c_0$.

The age of the universe and 'impossible' galaxies

An important consequence of the above developments relates to the age of the universe, i.e. the time elapsed since the Big Bang. This age is determined from the Hubble constant, itself estimated from the escape velocities of galaxies as a function of their Euclidean distances 'projected' from our spot as observers on Earth. If we say that we now need to reduce the escape velocities of galaxies, the entire Hubble diagram must be tilted by a factor of n_c. We end up with a new constant $H' = H/c_c$, i.e. an age of the universe multiplied by n_c; starting from a standard age of 13.8 billion years, the modified age would then be 33 billion years?
The reason for this increase lies in the chronology based on Hubble's law, with a constant revised downwards (These considerations must also come into play in the discussion of the Hubble tension, cf. Guy (2022)), in correspondence with the slower evolutionary dynamics of certain phenomena due to smaller masses than previously thought.
At first glance, this should not compromise the various stages in the history of the universe, bearing in mind that there are always circularities between models and observations; can we think of them working better with c_c than with c_0? To make progress in this direction, we need to re-examine the scenarios, measurements and assumptions that regulate the variation of the scale factor $a(t)$ as a function of time.
However, a few simple considerations already provide some approximate results. With these, we can tackle the question of impossible galaxies. In recent years, we have been observing objects (massive black holes, quasars, stars, galaxies) inhabiting the very young universe, and have found that the existence of such objects, which require long periods of time to structure, does not match the supposed youth of the universe that hosts them. For example, galaxy formation and structuring times are in the region of one to several billions of years, whereas galaxies are now observed to be a few hundred million years old.
See Boyett et al. (2024) on galaxies, in a very abundant literature dealing with the data obtained by the JWST; the problem also arises for black holes (Maiolino et al., 2024). Gupta (2023) provides numerous references.
According to our proposal, if all the times allocated to the observed objects are multiplied by the same factor of 2.4, the young galaxies observed will correspond to universe ages that can exceed one billion years (i.e. the hundreds of millions of years allocated by the JWST multiplied by 2.4). This gives them greater temporal latitude to form and structure, and provides an avenue to alleviate their 'impossibility' character. But if all the durations are lengthened in the same proportion, including those needed to structure the objects (stars, galaxies) in question, the problem of their registration in a longer duration will still arise.
Let us propose a first answer to this problem: star formation times are estimated on the basis of the kinetic constants of various reactions, particularly nuclear (but also thermal and matter diffusion), measured in the laboratory with our 'local' standards (especially $c = c_0$), and there is no need to modify them. For the same formation time, the problem of matching the age of the universe estimated from 'distant' data could then be solved by extending the age of the universe.
If the increase in the age of the universe and its modalities do not leave enough time for the evolutionary durations of galaxies at the beginning of the Big-Bang history (we are talking several billion years, not just one, for the increase in galaxy mass and their structuring), we will have to revise our copy. We must take into account: - the part of the duration amplitudes of stars and galaxies that are calibrated by the

overall cosmological data (and not only the 'laboratory' ones); - the expansion of the universe and – the possible greater cosmological index n_c at early stages (it slows down light velocity and physical processes at these remote epochs); - the non-linear function between age (or expansion scale factor $a(t)$) and redshift z values (for the most distant objects; the relation between observed quantities and redshift z does not change, because z does not change, but the link with $a(t)$ changes as a function of the model inputs (according to the presence or absence of dark matter, dark energy…).

As a second answer to the 'impossible' galaxies issue, we may explore further the non-linearity hypothesis. Based on a model combining the standard model of cosmology and the theory of tired light, Gupta (2023) proposes an age of the universe of 26.7 billion years, alleviating in his own way the problem of impossible galaxies. What is interesting is that the age extension compared with the ΛCDM model is not homogeneous, but mainly concerns the early universe defined in terms of z (the cosmic time is stretched by some 5.8 to 3.5 billion years for $z = 10$ to 20). This leaves time for early galaxies (and their stars) to form (several billion years), and leaves recent evolutions virtually unaffected.

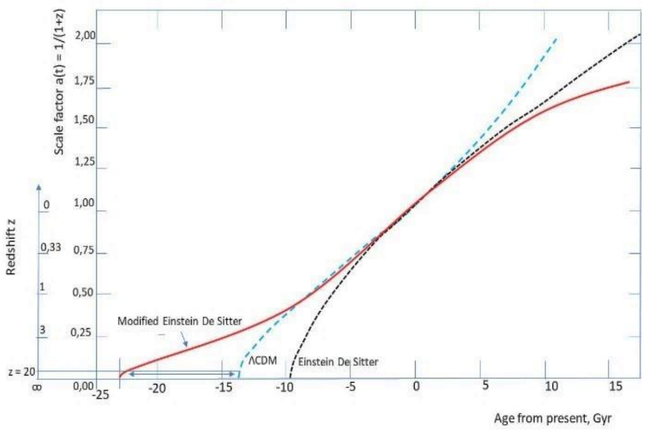

Figure 3. Scale factor $a(t)$ as a function of time for several universe models. Horizontal axis: age from present in Gyr's. Vertical axis: scale factor $a(t)$. The correspondence with the redshift z is also shown for $z > 0$. Redrawn from (Aubert, 2019). Three models are being considered: the standard ΛCDM model ($\Omega_m = 0.315$, $\Omega_\Lambda = 0.685$), blue dashed curve; the standard Einstein De Sitter model ($\Omega_m = 1$, $\Omega_\Lambda = 0$), black dashed curve; our proposition (Einstein De Sitter model with a reduced Hubble constant, $H_0/2.4$), continuous red curve. As Aubert, we have taken H_0 = 67 km/s/Mpc. The equation for the Einstein De Sitter model is $a(t) = (3H_0t/2)^{2/3} + 1$. Interestingly, the continuous curve and the blue spaced dotted curve are very close together for our local universe ($0 < z < 1$), whereas, in a more distant past, a large duration, reaching some 10 Gyr's (for high z, reaching $z = 20$) appears. This may give a comfortable latitude for galaxies to form and evolve in the earlier stages of a prolonged universe, and respect the standard evolution of stars in the later stages.

Our approach allows us to discuss the non-linearity aspect: a first simple indication for lengthening, especially at the beginning of Big Bang evolution, can be given by considering the Einstein de Sitter universe (Ω_m= 1 and Ω_v= 0) and compare it with the standard ΛCDM model. For the Einstein de Sitter model, we know the law of the scale factor: $a(t) = (3H_0t/2)^{2/3} + 1$.

The age of the Big-Bang is 9 billion years, with $H_0 = 67$ km/s/Mpc (Aubert, 2019). If we divide the Hubble constant H by 2.4, the age of such a universe is $9 \times 2.4 = 23$ billion years. By plotting the new curve, $a(t)$ with $H/2.4$ (taking up the figure in Aubert, op. cit.) the deviation from the ΛCDM model occurs mainly at the beginning of the Big-Bang (Fig. 3). This does not affect our knowledge on nearby stars and galaxies, which have been well studied.

The model does not put into question any of the standard theoretical ingredients. It stretches cosmic time and Big-Bang age by nearly 10 billion years for $z = 20$, three times more than Gupta's model. Stars and galaxies have the time to appear, evolve and disappear in generations prior to those that we have closer to us (and for which no change is to be expected). Recall that stars remain on the Main Sequence for around 5 billion years (depending on its mass, a star can last from a few hundred million years to almost 1000 billion years). On their side, galaxies evolve by collisions and mutual ingestions, in addition to the evolution of their own stars.

The various figures announced for ages are orders of magnitude, the use of the Hubble constant gives an approximate indication of the age of the Big Bang (for the ΛCDM model, the age of the Big-Bang is not necessarily 1/H; close to the beginning, both cosmological index and Hubble parameter were greater (For an expanding universe with constant mass, cosmological index n_c is greater for low radius values: in the $(log\ \rho, log\ R)$ plane the slope of constant mass trend is – 3 and cuts the n_c trend in such a way that n_c increases when R decreases; as for the Hubble parameter, its derivation from the Friedman equations with $H = 1/a\ (da/dt)$ shows its increase for low a.

For both reasons, there could be a still larger stretching of time at the early epochs for a completely reworked model encompassing refringence.)

Choose an average density and equivalent radius of the universe?

As we have said, our main objective is not to focus on the precise characteristics of our universe, but to understand as plausible its refractive quality on its own scale, with an index of the order of 2.4. However, as a more or less artificially chosen reference point, can we position a universe with coordinates ρ_u and R_u on the index line $n_c = 2.4$ in the diagram in Fig. 1? The Hubble radius (statically equivalent, in terms of its gravitational influence, to the radius of an expanding universe) is estimated from the age of the universe, itself evaluated by Hubble's law. If we trust this method, in our case we will have to start from a higher age (that we have just talked about impossible galaxies), and take a Hubble radius increased by the same proportion 2.4. Given today's accepted age of 13.8 billion years, the new radius R_u is $13.8 \times 2.4 = 33.12$ light-years (we took 33).

The corresponding density value is obtained from equation (19), i.e. $log\ \rho_u = -26.96$, or $\rho_u = 1.1 \times 10^{-27}$ kg/m³. Let us call this point U_0 (Fig. 4).

It summarizes our proposal, increasing the value of R_u , it corresponds to a lower value of ρ_u compared to what is accepted today (see section 2). Universe is indeed devoid of dark matter (which contributes to lowering ρ_u).

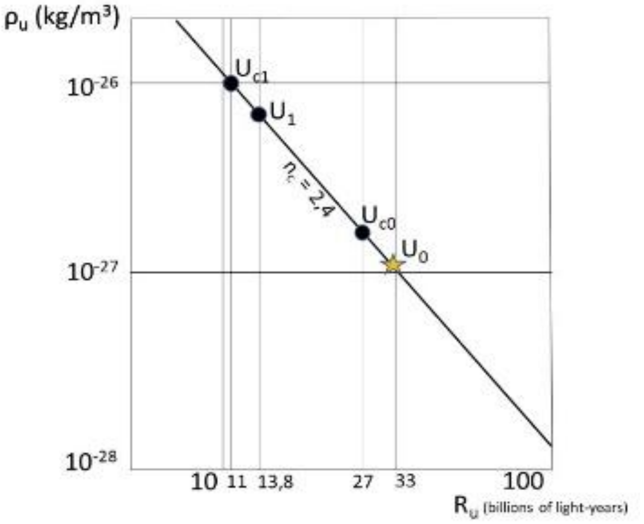

Figure 4. Universe positionings along the straight line $n_c = 2.4$ in the plane (R_u, ρ_u). These are simple milestones in a revision process that is yet to be iterated. Each is characterized by its pair of coordinates R_u and ρ_u. The points U_0, U_1, U_{c0} and U_{c1} are defined in the text; they correspond respectively to our proposal (U_0), to the "standard" universe accepted today (U_1), to universes of critical density for two Hubble constants, the downwardly revised U_{c0} and that of the universe in its standard knowledge (U_{c1}).

What other values should be shown on the diagram?
As an indication, we can position other points in Fig. 4. The point U_1 corresponds to the universe as we know it today (before our proposal), with $R_u = 13.8$ billion light-years. We then have log $\rho_u = -26.19$, or $\rho_u = 6.5 \times 10^{-27}$ kg/m^3. In relation to the previous point, we can say that, for the same total mass, if we decrease the radius (and therefore the volume), we need to increase the density.
We can also position critical density universes, both for the standard universe and for our proposed one. This density corresponds to a flat universe without curvature; it is calculated from the Hubble constant by the formula

$$\rho_c = \left(\frac{3H^2}{8\pi G}\right) \quad (35)$$

For the standard universe, accepted values for the Hubble constant range from 67 to 73 km/s/Mpc. For an intermediate value (see section 2.1), we find log $\rho_u = -26.00$. For this value, the radius is still given by equation (19) and has the value $R_u = 11.09$ billion light-years, or $10^{1{,}045}$. Let us call the corresponding point on Fig. 4 U_{c1}.
The value of the critical density calculated for the modified universe, i.e. with a value of constant H revised downwards by a factor of 2.4, is equal to the standard critical density divided by $(2.4)^2 = 6$. From the relations $\rho R^2 = cte$ derived from equation (13) defining the index, and (35) for the critical density as a function of the constant H, we deduce that $\rho/H^2 = cte$. A division of H by 2.4 will induce a lowering of ρ by 6. This gives log $\rho_u = -26.78$ or $\rho_u = 1.7 \times 10^{-27}$ kg/m^3. The corresponding radius is then given (equation 19) by $log R_u =$ 1.435 i.e., $R_u = 10^{1.435} = 27.22$ billion light-years. We call the corresponding point in Fig. 4 U_{c0}. The points U_0, U_1 U_{c0} and U_{c1}, simple milestone, are all four positioned on the straight line $n_c = 2.4$ in Fig. 4. The vertical offset between points U_{c0} and U_{c1} is the same as between points U_0 and U_1, equal to log 6 or 0.78. The horizontal offset also remains unchanged.

6. CONCLUSIONS

In conclusion, in the face of contemporary astrophysical problems, wouldn't it be encouraging to consider, on a cosmological scale, a speed of light a factor of around 2.4 slower than in our 'local' physics? Gravitation could be responsible for this reduction, with a 'cosmological' index that we have calculated to be equal to

$$n_c = \left(1 - \frac{4\pi G \rho_u R_u^2}{c^2}\right)^{-1} \quad (36)$$

for a universe with matter density ρ_u and equivalent gravitational radius R_u. The values of ρ_u and R_u where such an index is conceivable are consistent with the range of values accepted today for our universe; bearing in mind that we need to shift the characteristics of our 'standard' universe by making use of the parameter $\alpha = n_c$ and its powers. The factor $\alpha = n_c$ for reducing the velocity values of distant objects avoids the need for dark matter, dark energy and, by increasing the age of the universe, may spare us the difficulty of 'impossible' galaxies.
We have not gone through all the situations that raise questions, particularly those concerning dark matter: in such and such cases where we are led to postulate it, our scenario (dividing the speed of light by a ratio n_c) may seem flawed (even though proponents of modified laws of gravitation or of other effects, such as those related to the non-homogeneity of the universe, would not see dark matter either.). We then need to go back to the drawing board, taking a close look at how the data were obtained and the various biases that may have come into play (absence of observations or observations tainted by uncertainties, types of data processing, including statistical processing, data based on a model, or models, that are debatable in a circularity that needs to be properly framed, etc.).
This examination can be cross-referenced with the work of authors who, proposing other explanations, highlight the problems of dark matter and dark energy. It is possible for several explanations to play out concurrently, in cases where, for various reasons, the optical model exhibits unexplained local variability. In the meantime, we would like to emphasize the great economy of means of our preliminary approach, proposing a single explanation to solve a variety of a priori disjoint problems (dark matter, dark energy, CMB issues, gravitational lensing, impossible galaxies, cosmological tensions).
Our economy extends to the compliance with existing laws (we do not propose any new laws, such as that of the MOND model, whose limitations dark matter proponents point out). The refractive universe hypothesis is another way of using, or saying, general relativity. It is simply more convenient than transporting Einstein's equations, but it is still general relativity.

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