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An observer-based referential that is consistent with cosmological observations

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Abstract

We propose an alternative explanation for the redshift of cosmological objects. In this approach, the wavelength of a photon is affected by the spatial curvature integrated along its trajectory from the source to the observer. We explain this effect by postulating that all measurements are performed in an observer-based representation referential that has the geometrical properties of flat space, resulting in a distortion of lengths associated to distant objects. Applying these considerations in the Einstein's static universe, we obtain a redshift/distance relationship that is consistent with observations. We are also able to explain the existence and characteristics of the Cosmic Microwave Background.

1 Introduction

The intuition of a static universe led Albert Einstein in 1917 to consider a finite static solution of the equations of general relativity to be the universe we live in. He described a spatially closed universe of spherical curvature [1], requiring the introduction of a controversial cosmological constant that kept the universe from collapsing due to gravitational effects. Shortly after, this vision of the universe faced two major challenges. In 1930, Eddington was the first to consider the question of stability of the Einstein world [2] and showed that it is unstable under certain types of small perturbations. This issue is still subject to investigations and is thought to be an important point to understand the early universe [3]. It is the discovery of the linear relation between the redshift of galaxies and their distance in the late twenties [4] that convinced Einstein, at the beginning reluctant, to finally change his mind and accept the growing consensus on models based on expansion of space [5, 7, 8]. Such models suited quite well the small amount of observational data yet available, although the existence of an initial spacetime singularity it requires raises important physical and philosophical questions. The discovery of a cosmic microwave background (CMB) made by Penzias and Wilson in 1964 [9] became a strong support for this theory, since its characteristics are compatible with a dense primordial plasma that emitted light shortly after the big bang, whose analysis is thought to provide important information on the state of the primordial universe. In 1998, an 'acceleration of the expansion of the universe' was detected and surprised cosmologists [10]. This led to the introduction in the models of a dark energy

that acts as a repulsive gravitational force, whose origin remains very speculative. Efforts have been made to combine all these considerations and the most accomplished result is the standard model of cosmology, so called Λ CDM. Alternative theories have been developed to explain the redshift of cosmological objects, such as tired light theory [11], but errors have been pointed out. The theory has never been commonly accepted and seems to be now completely abandoned [12]. In the current understanding of general relativity, if we neglect hypothetical physical processes that pump energy from light, the only possible explanation for this redshift is a mechanism that acts on the metric of spacetime. As for now, there is growing evidence that this standard cosmological model has fundamental flaws: thanks to enhanced precision of measurements, some tensions have become increasingly apparent [13, 14].

We will here propose an alternative explanation for the redshift of galaxies, by postulating that the wavelength of photons (as well as their frequency) is affected by the radial curvature of space. When placing ourselves in the Einstein's static universe, this produces a redshift of incoming photons that grows with the distance of the light source, in a way that is consistent with observations. The effect originates from the observer's perception of its environment as being flat. The latter performs measurements in a usual Galilean referential, resulting in a distortion of observed lengths that affects the nature of incoming light. We start by motivating this idea and we then show its consistency with observations, in particular with Hubble diagrams and CMB characteristics.

2 An observer-based referential

In his book *Wholeness and the implicate order* [15], David Bohm points out a fundamental duality of the physical reality: a world, hardly accessible to our senses, home to unfamiliar processes that he calls the *implicate order*, reveals itself in an unfolded, *explicate order*, in which measurements can be performed, and which corresponds to our everyday experience of the physical environment. Originally thought to account for the puzzling properties of quantum mechanics, these views also find an echo in general relativity. In the latter, the fundamental object is a curved 4-dimensional pseudo-Riemannian manifold in which space and time are entangled in a profound interlace. Yet in our way of representing this environment, space and time are fundamentally distinct objects, for otherwise no measurement would be possible. We will refer to this fact as the *separation principle*.

In this explicate world of observation, the environment is also perceived as being flat, as we are living in a locally flat portion of the universe and our brain is equipped to make linear representations of our surroundings. To this extent, Albert Einstein writes in his famous 1905 paper [16]:

“If a material point is at rest relatively to a system of co-ordinates, its position can be defined relatively thereto by the employment of rigid standards of measurement and the methods of Euclidean geometry, and can be expressed in Cartesian co-ordinates.”

A few years later, the development of general relativity challenged this view and introduced more sophisticated geometrical tools to describe the physical world. We now follow the point of view of the observer to investigate the existence of a consistent referential in which Einstein's considerations apply. Let us consider the following situation: in a universe whose geometry is described by Einstein's field equations (possibly with a cosmological constant), lives an observer, whose fundamental nature is to create a consistent representation of its physical environment, in which he is able to measure quantities such as lengths and durations associated to events around him, using a ruler and a chronometer for example. In Minkowskian spacetime and for objects in uniform linear motion with respect to the observer, direct comparison is not possible and a procedure was proposed by Einstein to determine the length of such an object, based on the constancy of the speed of light c . This procedure turns out to give a value in the direction of motion that is different from the length one would measure directly by comparing the object with a ruler. This is the core of special relativity. A similar procedure allows to determine the distance between the observer and an object at rest: he can send a light ray in the direction of the object at time t_0 , and wait for the light ray to be reflected back to him at time t_1 . The distance d from the event s is then defined in the following way:

$$d(s) = c \frac{t_1 - t_0}{2}. \quad (1)$$

This definition of distance extends to more general spacetime geometries and is called *proper* distance in the context of a static universe. It can be thought of as the length of the shortest geodesic connecting the observer to the object.

Now that he is able to measure lengths and durations associated to events in its direct environment using his local coordinates and to determine the distance of an object, the observer may ask the following question: is there a procedure to assign lengths and durations to events situated at large distance d , and how to do so? In a flat spacetime, and if the object is at rest, the answer is trivial: it can be done by using of the tools of Euclidean geometry, as stated by Einstein. To provide an answer to this question in the more general set up of curved spacetime geometry, we will make a strong hypothesis.

Let R_0 be the referential in which a geodesic connecting the observer to an observed object in the physical space is mapped, by a transformation T , into a straight line leaving the observer with the same direction as the geodesic, with respect to its local referential. We take T such that it preserves the distances between the observer and the objects, in the sense that the proper distance in the physical world and the Euclidean distance in R_0 are equal. In R_0 , a photon travelling from an object to the observer will follow straight lines and travel at a constant speed c . T is not a mere change of the coordinates describing the spatial geometry, since we now impose a linear geometrical structure in R_0 , given by the Euclidean metric. In this referential, physical objects are represented stretched, deformed, eventually split and present in different locations of the referential. That corresponds exactly to the usual way we observe them with our telescopes and perceive our environment, and there would be no way for the observer to distinguish between a flat space and

a curved space without a priori knowledge of the constitution of its physical environment. For this reason, we will postulate that all the measures performed by the observer are performed in the representation referential R_0 , and are therefore consistent with the rules of Euclidean geometry. In particular, radiations behave as in a flat space and the photons, once emitted, keep a constant wavelength.

Of course, in curved spatial geometries, the lengths measured in R_0 differ from the ones measured in the object's natural referential, and the hypothesis that we made may appear surprising to the reader, but we will see that it is consistent with observations. To quantify the distortion of lengths of the observed objects, we introduce for each point x in R_0 a quantity $a(x)$, that we shall call the *scaling factor*. We may determine it in the following way: a bundle of light rays with infinitesimal solid angle $\delta\Omega$ is sent in the direction of x , and we compute

$$a(x) = \sqrt{\frac{\delta S}{\delta S_0}},$$

where δS is the area intersected by the bundle in the neighborhood of x in the natural referential around x and δS_0 is the area that intersects the bundle in R_0 ($\delta S_0 = d^2\delta\Omega^2$). This scaling field is a priori not continuous, can contain singularities and domains where it is not defined (in a black hole region for example). In order to compute it in a general set up and for a point x at proper distance d , one needs to study the local properties of the metric of the surface defined by all the points at geodesic distance d from the observer. To the author's knowledge, no such object has yet been studied in a systematic fashion in the mathematical literature.

With the assumption that the speed of light is constant equal to c everywhere in R_0 (as expected in a flat geometry), the time component that has been discarded until now thanks to the separation principle can be restored by introducing a scaling factor that applies to infinitesimal durations associated to events happening at the point x . This scaling factor must be taken equal to the one for the spatial component $a(x)$, so that a photon travelling in the region of the observed event has velocity

$$\frac{a(x)\delta l}{a(x)\delta\tau} = \frac{\delta l}{\delta\tau} = c, \quad (2)$$

where δl is the distance travelled by the photon and $\delta\tau$ is the interval of time it took, in local coordinates. This time dilation for distant events has been observed for Supernovae [17].

3 Cosmological considerations

3.1 Einstein universe

Let us from now on place ourselves in the Einstein's static universe of radius of curvature R . It has closed spatial geometry and is a solution of its field equations with a positive cosmological constant, assuming a fined-tuned homogenous distribution of matter [1]. The spatial component of the metric is the one induced by the

ambient Euclidean coordinates x_i on the manifold

$$\sum_{i=1}^4 x_i^2 = R^2.$$

The time component of the metric is set to 1 and allows the possibility of a cyclic time. In this eternal return scenario, contemplated by many cosmogonies, the age of astronomical objects would be bounded, as seems to be the case, at least for nearby stars.

The procedure described in the preceding section gives for a point at distance d from the observer the following scaling factor:

$$a = \sqrt{\frac{\delta S}{\delta S_0}} = \frac{R \sin(\frac{d}{R})}{d}. \quad (3)$$

In figure 3.1, we give a representation of the effect in dimension 2.

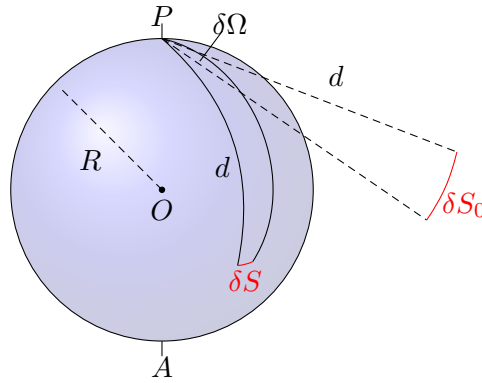


Figure 1: The observer is at position P . The scaling factor decreases with the distance d until degeneration when the antipode A is reached. Space seems to vanish at this point. An infinitesimally small object located at the exact antipode would appear stretched over the whole celestial vault, impacting the measured wavelength of its radiation in this model.

3.2 On the relation between redshift and distance

As postulated, the photon, which acts as a messenger between the emitting source and the observer, keeps track of the orthogonal dilation of the metric quantities, so that light coming from an object located at distance d has a redshift z that can be computed by comparing the measured wavelength λ_{ob} of an incoming photon with its wavelength at emission λ_{em} . We have by definition:

$$z = \frac{\lambda_{ob} - \lambda_{em}}{\lambda_{em}}. \quad (4)$$

Considering that

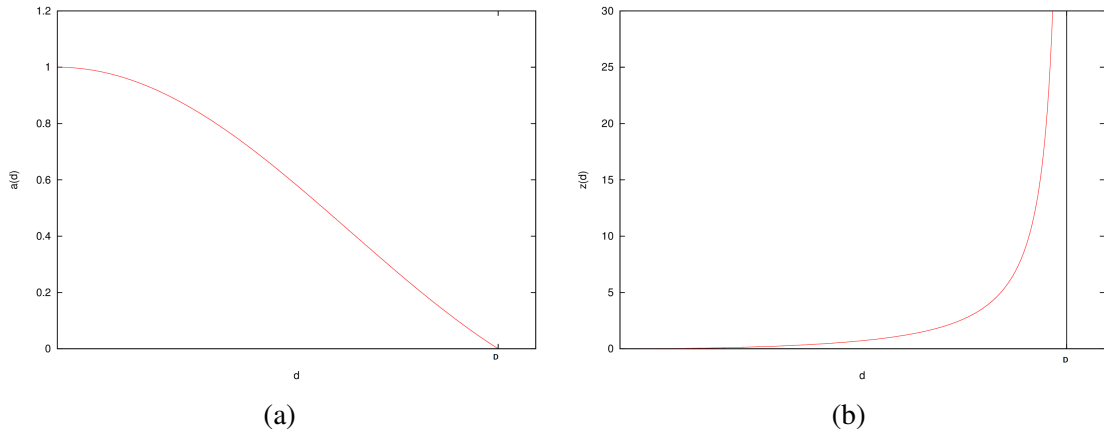


Figure 2: Evolution with proper distance of the scaling factor (left) and the redshift (right) in the Einstein universe

$$a = \frac{\lambda_{em}}{\lambda_{ob}}, \quad (5)$$

we get that the redshift for a source at distance d is:

$$z = \frac{d}{R \sin(\frac{d}{R})} - 1. \quad (6)$$

A graphical representation of equation 6 is depicted in figure 2b.

The derivative of the scaling factor, that in big bang theories is interpreted as its rate of expansion, is given by

$$a'(d) = \frac{\cos(\frac{d}{R})}{d} - \frac{R}{d^2} \sin(\frac{d}{R}). \quad (7)$$

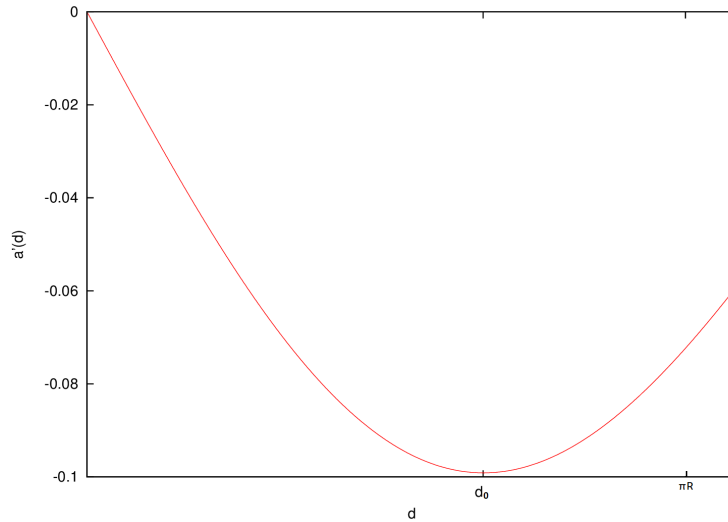


Figure 3: Evolution of the derivative of the scaling factor with proper distance

We observe a change of monotony for a' at a certain distance d_0 (see figure 3). Observations of type Ia Supernovae have pointed out this fact [6], and actual cosmological models interpret it as an acceleration of the expansion of the universe that started a few billion years ago. In the present context, we do not have to refer to any kind of dark energy.

3.3 Test

We now test our model by examining the relation between redshift and distance. Estimating the distance of cosmological objects is a long standing issue [18], but two redshift-independent methods are commonly used. Both require some knowledge about the observed object. The luminosity distance is computed by comparing the flux of incoming light with the luminosity of the source that is supposed to be known. The estimation of the angular diameter distance for its part requires some knowledge about the diameter of the observed object. Let us now determine the relation between the proper distance d and the luminosity distance d_L in our model, which is defined implicitly in the relation:

$$F_{obs} = \frac{L}{4\pi d_L^2}. \quad (8)$$

Here, F_{obs} is the flux measured by the observer and L is the luminosity of the object in its local referential.

Let us consider an object situated at proper distance d from the observer, that emits n photons of energy $h\nu$ per unit of surface per unit of time, where all these quantities are expressed in the natural referential of the object. With the hypothesis that we made, in the observer's referential R_0 , the situation is equivalent to the following: in a flat universe, an object at proper distance d is emitting n photons of energy $h\nu/(z+1)$ per $(z+1)^2$ units of surface per $(z+1)$ units of time. Therefore, the luminosity of the object in the observer's referential is

$$L_{obs} = L/(z+1)^4.$$

In the flat space R_0 , the measured flux follows the inverse square law, so that

$$F_{obs} = \frac{L_{obs}}{4\pi d^2} = \frac{L}{4\pi d^2(z+1)^4}. \quad (9)$$

Combining 8 and 9, we get that

$$d_L = d(z+1)^2. \quad (10)$$

In a space of spherical geometry, the angular diameter distance d_A is for its part given by

$$d_A = R \sin\left(\frac{d}{R}\right) = \frac{d}{z+1}. \quad (11)$$

Note that the Etherington-Ellis reciprocity theorem does not hold in this situation, since

$$d_L = d_A(z+1)^3.$$

In figure (4a), we performed a fit of the Supernovae 1A data provided by the Union 2 catalog [19]. The same general trend is observed between the theoretical curve and the observational data, although the fit for small values of z is not satisfying. This may be due to systematic bias in the supernovae data [20]. For this reason, we discarded the closest galaxies and performed a χ^2 fit only for the 257 most distant galaxies of the catalog. The best fit is obtained for a value of R of around $R = 2.67$ Gly. The antipodal region, that constitutes an apparent cosmological horizon, is therefore at distance $D = R\pi = 8.4$ Gly, which is of the same order of magnitude as estimates of the horizon in the current standard model of cosmology [6]. In the right hand side of figure 4, we also plotted different fits for the angular diameter distance/redshift relationship, where the data are taken from the hydrostatic equilibrium model in [21]. Estimates of R are consistent for both approaches, although a more precise analysis of this relation, using model independent data needs to be performed. We stress that in both cases, the fits involve only one parameter: the radius of curvature R of the universe.

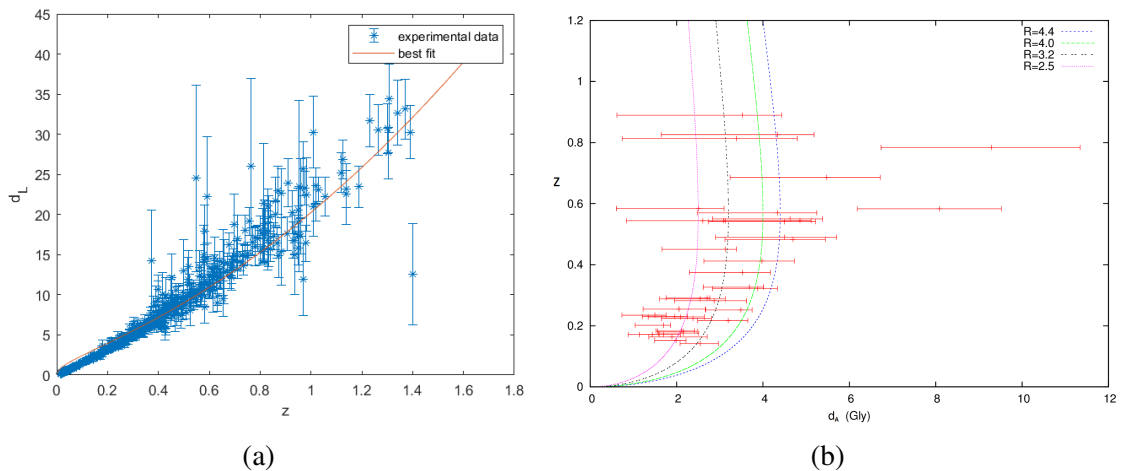


Figure 4: Left: Best fit of the model using the 257 most distant supernovae of the catalog. The best χ^2 fit is obtained for $R = 2.67$ Gly. Right: Comparison between theoretical curves and angular diameter distance data, for different values of R .

3.4 On the CMB

The Cosmic Microwave Background is a radiation detectable in all regions of the universe which has the property of being very regular in all directions in space, just showing some small anisotropies distributed with privileged angle scale [9]. The observed spectrum is one of a black body that has a maximum of emission at $\Lambda \approx 2$ mm. The existence and characteristics of the CMB is thought to be a strong evidence for a big bang scenario since it fits very well the predictions of Λ CDM [22], although several anomalies have been pointed out [23]. The aim of this section is to show that the model that we developed here may also be compatible with these observations.

3.4.1 Over the horizon

Until here, our study has been limited to distances smaller than the maximal geodesic distance $D = \pi R$. Although this distance could be called an apparent horizon, the observer can see (ghost) images from over this distance. In fact, we can extend the definition of proper distance d to objects over this horizon, so that it corresponds to the length of the trajectory of a photon from the object to the observer. Applying the arguments developed in the previous sections, we get that the scaling factor is then given by:

$$a(d) = \left| \frac{R \sin\left(\frac{d}{R}\right)}{d} \right|.$$

We take the absolute value, because we do not consider orientation of lengths that might be inverted. The redshift observed for these objects is then:

$$z(d) = \left| \frac{d}{R \sin\left(\frac{d}{R}\right)} \right| - 1.$$

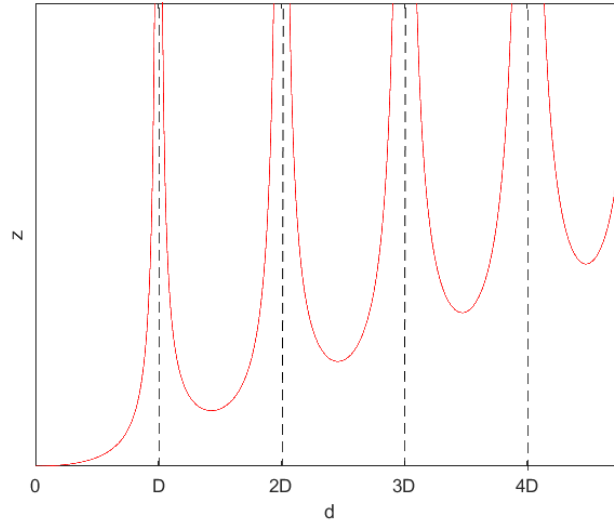


Figure 5: Evolution of the redshift with distance

In this static universe, we cannot explain the CMB by an extremely hot black body that emitted light in a primordial state of the universe. The radiation must be made out of light emitted by standard cosmological objects. Just by looking at the evolution of z , we can characterize two classes of sources that produce highly redshifted light, which could contribute to the CMB:

1. Very old objects whose radiation has travelled around the universe many times before arriving to us, at huge distance from us. This type of sources will be referred as class 1.

2. Objects that emitted the perceived light in the region of one pole of the 3-sphere (our current position or its antipode), whose distance is near a multiple of D . This type of objects will be referred as class 2.

We assume that the contribution of class 2 objects does not make up the essential of the microwave background, their proportion being negligible compared to type 1 objects. If we assume a homogenous universe, the global contribution in light of the infinity of highly redshifted class 1 objects would create a highly regular background radiation, with no privileged direction in the sky. This very ancient (and therefore highly redshifted) light has suffered scattering and absorption, so that it becomes difficult for the observer to trace back to its source. Overall, the resulting radiation should be completely randomized and resemble thermal radiation.

3.4.2 Anisotropies

We must now explain the different levels of primary anisotropies of the radiation. We stated in the previous section that the global light emission of class 1 object should make up a very regular background, leaving no place for irregularities. These small perturbations could be explained by the presence of type 2 object (mostly galaxies) in the pole regions. It is a well established fact that the distribution of the anisotropies in the CMB is consistent with the distribution of galactic structures in the universe. Their highly redshifted light adds to the regular background and leaves some trace. Each pole, at different times, contributes to one level of anisotropy and explains the peaks in the angular power spectrum of the CMB temperature anisotropy.

To formalize this, we will first assume that the emission spectrum of a galaxy is reduced to its strongest wavelength λ_0 which we assume to be the same for every galaxy. We will also assume that the power spectrum of the CMB is centered around its strongest wavelength Λ . These strong restrictions should still provide a decent estimate of the location of the peaks in the power spectrum. To add to the regular background of wavelength Λ , the received light must also have observed wavelength Λ , so the source must be at a distance d that satisfies the equation

$$\frac{\lambda_0}{a(d)} = \Lambda,$$

that is:

$$\frac{\lambda_0}{\Lambda} d = | R \sin\left(\frac{d}{R}\right) |. \quad (12)$$

The solutions of the above equations are typically close to a pole that we will call the pole k , at distance $k\pi R$ from us. For each k , there are two associated solutions d_k and d'_k , which correspond to distances to the pole k of $l_k = k\pi R - d_k$ and $l'_k = d'_k - k\pi R$. Replacing in equation 12, we have that:

$$\begin{cases} \frac{\lambda_0}{\Lambda}(k\pi R - l_k) = |R \sin(\frac{l_k}{R})| \\ \frac{\lambda_0}{\Lambda}(k\pi R + l'_k) = |R \sin(\frac{l'_k}{R})|. \end{cases} \quad (13)$$

As l_k and l'_k are typically small compared to R , we get

$$\begin{cases} \frac{\lambda_0}{\Lambda}(k\pi R - l_k) \approx l_k \\ \frac{\lambda_0}{\Lambda}(k\pi R + l'_k) \approx l'_k, \end{cases} \quad (14)$$

so that

$$\begin{cases} l_k = \frac{k\pi R}{\frac{\Lambda}{\lambda_0} + 1} \\ l'_k = \frac{k\pi R}{\frac{\Lambda}{\lambda_0} - 1}. \end{cases} \quad (15)$$

Since $\frac{\Lambda}{\lambda_0}$ has a big order of magnitude ($\approx 10^4$), l_k and l'_k correspond roughly to the same distance to the pole k , that we will call again l_k :

$$l_k = \frac{\lambda_0 k \pi R}{\Lambda} \quad (16)$$

Now that we have found the typical distance of these galaxies to the pole k , we can estimate the contribution of the pole k to the anisotropy power spectrum, by computing the number of galaxies near the pole k that will imprint their mark on the CMB. To constitute an anisotropy, their image must have an observed wavelength between $\Lambda - \varepsilon$ and $\Lambda + \varepsilon$, being ε of the order of the width of the CMB spectrum.

From equation (16), these galaxies are at a distance from the pole k between

$$l_1^k = \frac{\lambda_0 k \pi R}{\Lambda + \varepsilon}$$

and

$$l_2^k = \frac{\lambda_0 k \pi R}{\Lambda - \varepsilon}.$$

Let ρ be the mean density of galaxies in the universe (we assume a homogenous repartition of galaxies). In S^3 , the volume of space between l_1^k and l_2^k is given by

$$\begin{aligned} V &= \pi R^2 (2l_2^k - 2l_1^k + R \sin(\frac{2l_2^k}{R}) - \sin(\frac{2l_1^k}{R})) \\ &\approx 4\pi R^2 (l_2^k - l_1^k), \end{aligned} \quad (17)$$

so that the number of galaxies at distances between l_1^k and l_2^k to the pole k is

$$\begin{aligned} N &= k\pi\rho 4\pi R^3 \lambda_0 \left(\frac{1}{\Lambda - \varepsilon} - \frac{1}{\Lambda + \varepsilon} \right) \\ &\approx \frac{8\pi^2 R^3 \rho k \lambda_0 \varepsilon}{\Lambda^2}. \end{aligned} \quad (18)$$

The number of galaxies associated to the pole k whose images are imprinted in the CMB is then $2N$, since the galaxies at distance d'_k also leave the same characteristic prints. If we assume equipartition of the galaxies and independence between the images of the galaxies at distances d_k and d'_k , these galaxies are equally spaced in the sky and their number corresponds to the multipole moment P_k for which we have a peak in the power spectrum:

$$P_k = \frac{16\pi^2 R^3 \rho \lambda_0 \varepsilon k}{\Lambda^2} = C_\varepsilon k. \quad (19)$$

Equation (19) shows a linear relation between P_k and k . We also predict that the strength of these peaks decreases with k , mostly due to extinction. Overall, these results seem compatible with the ones of the Planck collaboration [22], although I am presently not able to provide a more detailed analysis of the anisotropy spectrum. We have made some approximations in our computations and quite strong restrictions to arrive at this result: in reality, the spectra of both galaxies and CMB are composed of a large band of wavelengths. Moreover, the density of galaxies ρ may differ for the different pole regions, in particular due to the lacunary structure of the large-scale distribution of galaxies.

4 Conclusion and comments

We have performed an analysis of the notions of perception and measurement in general relativity, by introducing a referential in which the observer represents its physical environment and in which he can perform measurements. Such considerations turn out to be consistent with large-scale observations, such as redshift/distance relation and the existence and characteristics of the CMB. These effects should also affect gravitational waves, in a completely analogous way. In particular, the existence of a gravitational wave background is also predicted in this model. We are able to clear away questions raised by the existence of an initial spacetime singularity, and a dark energy that derives the galaxies dramatically away. More detailed theoretical works together with more complete data-based studies and a careful analysis of the CMB in the context of a static universe of spherical curvature could bring more support to this theory and refine estimations of the radius of the universe. Several complementary predictions could be verified experimentally on the short and longer run. The new generation of telescopes that will soon observe the distant universe could discover ghost images of galaxies and large-scale structures compatible with this model. More difficult to check at our temporal scale, the temperature of the CMB should not vary in time, and the different levels of anisotropies of the CMB should move with a characteristic speed, as the objects they represent had individual motions when they emitted the light.

The statement that lengths and durations are not absolute properties of observed events but depend on the referential in which they are measured is well established since the development of relativity. The relativity principle is here extended to distant objects in curved spacetime geometry. This approach introduces a fundamental duality between the physical world and its manifestation to the observer. Such a duality is reminiscent of quantum mechanics, in which the observer represents a world of non-locality, superposition and fuzziness as being composed of

actual objects that are localized, separated and which can be apprehended.

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