A simple explanation for the redshift of cosmological objects

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Abstract

We discuss the notion of perception, and describe a simple mechanism by which distortion of observed distances occurs in a static universe, that is compatible with many cosmological observations.
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1 Introduction

The intuition of a static universe has led Albert Einstein in 1917 to consider the only static solution to its equations of general relativity to be the universe we live in. He described a spatially closed universe of spherical curvature [1]. This required 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 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 was the discovery of the redshift of galaxies by Hubble in 1929 [4] that convinced Einstein, at the beginning reluctant, to finally change his mind and accept the global consensus on models based on expansion of space [5],[6]. Such models [7], [12] explain very well observations, but 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 [13] 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. Its analysis povides important informations on the state of the primordial universe. In 1998, an 'acceleration of the expansion of universe' was detected. It has surprised cosmologists [9] and led to the introduction 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 result of it is the standard model of cosmology, so called ΛCDM. Alternative theories have been developed to explain the redshift of cosmological objects, such as tired light theory [8], but errors have been discovered and the theory has never been commonly accepted and seem to be now completely abandoned [10]. In the framework of general relativity alone, 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.

The aim of the present work is to show how a careful examination of our perception of the world, the way we collect information and perform measurements, can provide a simple heuristic explanation for these observations. We will assume a simple spherical geometry and will show that for an observer in an inertial reference frame, a *static*, isotropic and homogenous spatial universe can make up a cosmological horizon. We will then see that such a static model of our universe is compatible with many phenomena observed in the far away universe.

2 On perception

In order to guarantee the consistency of observations, we must suppose that our frame of reference is inertial, and that the observed speed of light remains constant equal to c in any region of the universe. For example, we want to be able to relate wavelength and frequency of a photon, and not see objects travelling faster than light. If we want to eximinate the relation between distance and redshift, one must specify what he means by distance. In general relativity, notions of distances and time intervals are defined locally, and one cannot talk about space and time independently. Now, in the way we perceive the world (which can be described as Newtonian), we experience space and time differently. Denying this fact is denying the very idea of non-local movement, and so of perception, and thought. The supposition that we make here is that they can be tackled independently when it comes to perception. We introduce the following separation principle :

For any observed event s, one can associate a perception distance $d(s)$, defined independently of time.

Of course, the perception distance of an object changes with time if the object is moving, but essentially, if one consider that the object is not moving, one can define this distance without any reference to time. In particular, for a manifold of constant curvature, d can be defined as a function of the angular diameter distance $d_A = \frac{x}{\theta}$, where x is the supposed diameter of the object (in local coordinates) and θ the angle at which we are observing it. This is a good candidate, because, though it is hard to estimate (because it requires some knowledge about the object), it is derived directly from observations. We want the perception distance to be the most natural quantity to work with. Intuitively, we want to be able to do basic geometry, and we want it to stick with our familiar notion of distance, that is a metric quantity associated to a straight line connecting two points in a manifold. It can be thought as the length of the spatial trajectory of the light from the source to the observer. For a manifold of constant curvature K, we define it as follows :

$$\begin{cases} -\text{if } K = 0,\ d = d_A. \\ \\ -\text{if } K > 0 : \\ d_A = Rsin(\frac{d}{R}),\ \text{where } R = K^{-\frac{1}{2}},\ \text{so that :} \\ d = \begin{cases} Rarcsin(\frac{d_A}{R}) & \text{if} \quad d < \frac{\pi R}{2}. \\ \pi R - Rarcsin(\frac{d_A}{R}) & \text{if} \quad \frac{\pi R}{2} < d < \pi R. \end{cases} \\ \\ -\text{if } K < 0,\ d = \frac{asinh(\sqrt{|K|}d_A)}{\sqrt{|K|}}. \end{cases} \tag{1}$$

Now that we have defined, in the particular case of manifolds of constant curvature, a natural distance, and with the assumption that the speed of light remains a constant c in any observed region, we also define a perception time $t(s) = \frac{d(s)}{c}$. Let us now see what happens when we are looking at distant objects.

3 Searching a spatial limit horizon

A cosmological horizon is a distance for which observations end to make any sense. Observations of the far away universe suggest that light coming from distant objects becomes extremely redshifted and it seems that space vanishes in a singularity for a certain distance d_{max}. A static, isotropic and homogenous spatial universe have necessarily a constant curvature K. Let us examine three possible values for K :

3.1 $K = 0$

In a static flat universe, an object situated at a distance d from us is contained in the sphere of area $S_0(d) = 4\pi d^2$ of all the objects at distance d from us. And as d increase, so does the area of the sphere, the surface of observation never degenerate and we never reach a cosmological horizon. The following figure sums up what has just been said :

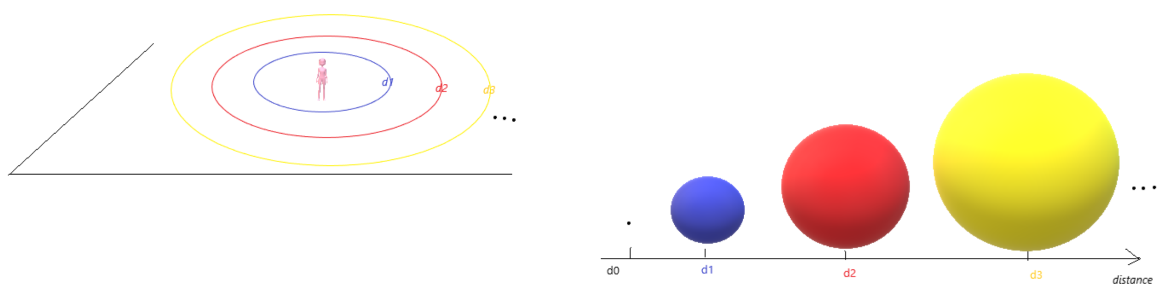

Figure 1: Behaviour of the containing spheres in 2D (left) and 3D (right)

3.2 $K < 0$

In a negative curvature universe, the area S_- of these containing spheres increases at an even faster rate than in the case $K = 0$:

$$S_-(d) = 4\pi \frac{sinh^2(\mid K \mid^{\frac{1}{2}} d)}{\mid K \mid}.$$

We have that S_- is strictly increasing, and $\lim_{d\to\infty} S_-(d) = \infty$. We never reach a cosmological horizon.

3.3 $K > 0$

The spatial universe is in this case a 3-sphere of radius $R = K^{-\frac{1}{2}}$. The area of these containing-spheres grows in the first place, reaches a maximum value for objects situated on the equator and then starts decreasing and reaches the limit value 0 when the object observed is situated at our antipode.

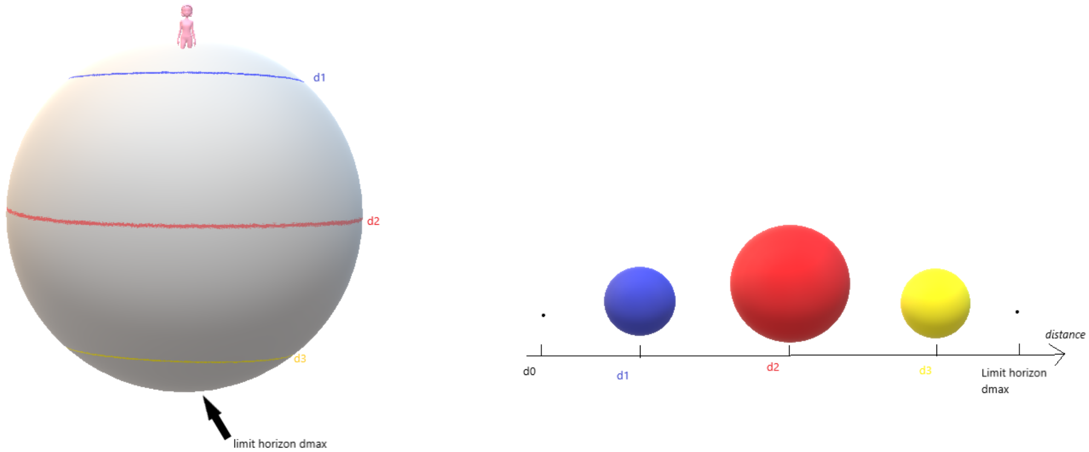

Figure 2: Behaviour of the containing spheres in 2D (left) and 3D (right)

In fact, we can compute the area of these spheres. The light of objects on these spheres arriving to us in a straight line trajectory, the geometrical objects of length d we consider in this curved geometry are sections of great circles of the 3-sphere.

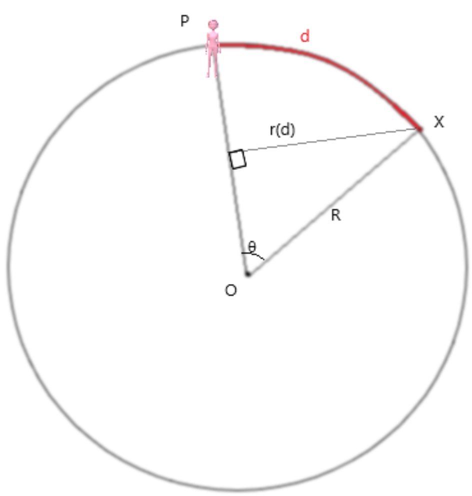

Figure 3: For the computation of the area of the containing spheres

We have the following relation :

$$\begin{cases} sin(\theta) = \frac{r(d)}{R} \\ d = R\theta \end{cases} , \quad (2)$$

where $r(d)$ is somehow the radius associated to the containing sphere, θ is the angle formed between our position P, the centre O of the 3-sphere that makes up our universe, and the observed object X. Combining these two expressions, we have that

$$r(d) = Rsin(\frac{d}{R}).$$

And so we can compute the area S_+ :

$$S_+(d) = 4\pi R^2 sin^2(\frac{d}{R}). \tag{3}$$

When d tends to $d_{max} = R\pi$, $S_+(d)$ tends to 0, and that makes up a singularity, or rather a cosmological horizon. Space seems, from our point of view, to vanish at this point.

3.4 Multi-connected universe

The previous statements still hold for non simply-connected spatial universe. In fact, the key point here is the curvature of space. Multi-connected topologies like the 3-torus may make these spheres cross each other and we would see the same object looking at different directions, but that wouldn't make up a limit horizon. We have found that the only possibility that a static, isotropic, homogenous spatial universe makes up a cosmological horizon, is that it is a 3-sphere, or a multi-connected relative. The question that raises naturally is how would these considerations get a physical meaning and affect our measurements?

4 Reinterpretation of the scaling factor

When we observe objects at a distance d from us, they appear, because we live localized in this curved space and we don't see the extrinsic geometry of the universe, to be contained in a sphere of area $S_0(d) = 4\pi d^2$, like it should be in a flat universe. Now, we have seen that the geometry of a 3-sphere is such that when we look at objects at a distance d from us, the area of the observation surface is actually

$$S_+(d) = 4\pi R^2 sin^2(\frac{d}{R}).$$

giving rise to an area scaling factor for object situated in this surface :

$$s(d) = \frac{S_+(d)}{S_0(d)} = \frac{R^2 sin^2(\frac{d}{R})}{d^2}.$$

And so distances are distorted by a scaling factor

$$a(d) = \sqrt{s(d)} = \frac{Rsin(\frac{d}{R})}{d}. \tag{4}$$

When $d \to 0, a(d) \sim 1$, implying no distortion of distances for our close surrounding universe, and observations are quite faithful. As we expected, when $d \to d_{max}, a(d) \to 0$, the distances get extremely distorted and that makes up a singularity.

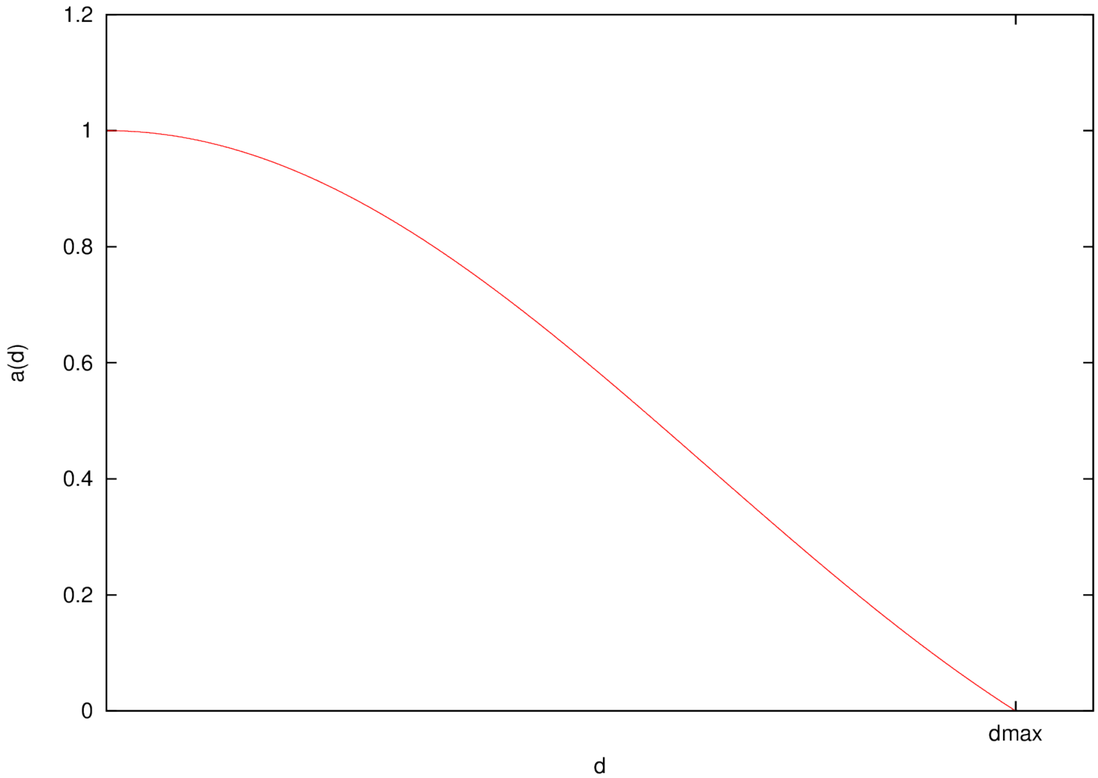

Figure 4: scaling factor vs distance

5 Curvature of time

We saw that for a region of space at distance of perception d from us, a scaling factor $a(d)$ is applied to distances. If we want that the observed speed of light remains unchanged equal to c, we must suppose that there is also a scaling factor for time $a(t(s)) = a(d(s)) = a(s)$, so that light travelling in the region of the observed event s has perception velocity $v = \frac{a(s)\delta l}{a(s)\delta t'} = \frac{\delta l}{\delta t'} = c$, where δl is the distance travelled by the photon and $\delta t'$ is the interval of time it took, in local coordinates.
In other words, time is curved along with space, and by the same mechanism that we described for distances, it is also subject to a distortion of perception. The earlier an observed phenomenon occured, the longer it appears to last. Time dilation has been deduced from observation of the explosion of distant Type1A Supernovae [11], and a broader dataset could confirm the predicted scaling.

6 Computation of the redshift

The redshift of a cosmological object can be computed by comparing the spectrum of the light arriving to us with its theoretical emission spectrum. For an object at distance d, it is defined as follow :

$$z(d) = \frac{\lambda_{ob}(d) - \lambda_{em}(d)}{\lambda_{em}(d)},$$

where $\lambda_{ob}(d)$ is the observed wavelength and $\lambda_{em}(d)$ is the actual theoretical wavelength of the emitted photon.

We have the following relation due to distortion of distances :

$$a(d) = \frac{\lambda_{em}(d)}{\lambda_{ob}(d)}.$$

And so, redshift z and scaling factor are related in the following way :

$$z(d) = \frac{1}{a(d)} - 1,$$

which gives us the formula :

$$z(d) = \frac{d}{Rsin(\frac{d}{R})} - 1. \tag{5}$$

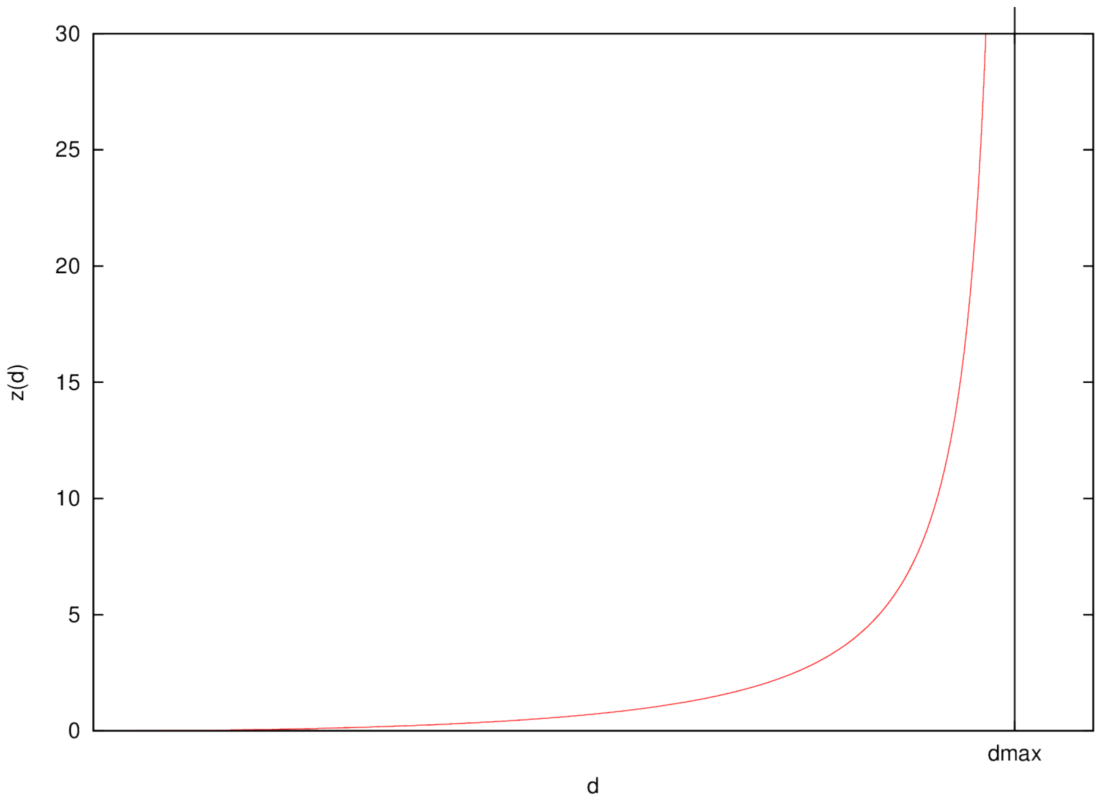

Figure 5: Redshift vs distance

7 On the derivative of the scaling factor

It is of interest to look at the behaviour of the derivative of the scaling factor, that in the case of an expanding universe is interpreted as its rate of expansion. The derivative of a is given by the formula :

$$a'(d) = \frac{cos(\frac{d}{R})}{d} - \frac{R}{d^2} sin(\frac{d}{R}) \tag{6}$$

Figure 6: a' vs distance

Study of the derivative of a shows a change of monotony at a certain distance d_0 and a' decreases with distance before that. Observations [12] have pointed out this fact, and the reason invoked is an acceleration of the expansion of the universe, that started $t_0 = \frac{d_0}{c}$ years ago, that could be driven by some dark energy that derives the galaxies away.

8 Test

We want now to test our model, by examining the relation between redshift and distance. Estimating the distance of cosmological objects is a long standing issue [15]. Two redshift-independent methods are commonly used, but both require some knowledge about the observed object. The luminosity distance is computed by comparing the luminosity of the light arriving to us with the intrinsic luminosity of the object. Estimation of the angular diameter distance, that we defined in section 2, requires some knowledge about the diameter of the observed object. The uncertainty of these estimations together with imprecision of measurements lead to imprecise data, however necessary to test a cosmological model. We will use data from [14]

Let us express the redshift as a function of the angular diameter distance. Combining eq. [1] and [5] we have that :

$$z(d_A) = \begin{cases} \frac{Rarcsin(\frac{d_A}{R})}{d_A} - 1 & \text{if} \quad z < \frac{\pi}{2} - 1 \\ \frac{R(\pi - arcsin(\frac{d_A}{R}))}{d_A} - 1 & \text{if} \quad z > \frac{\pi}{2} - 1 \end{cases} . \tag{7}$$

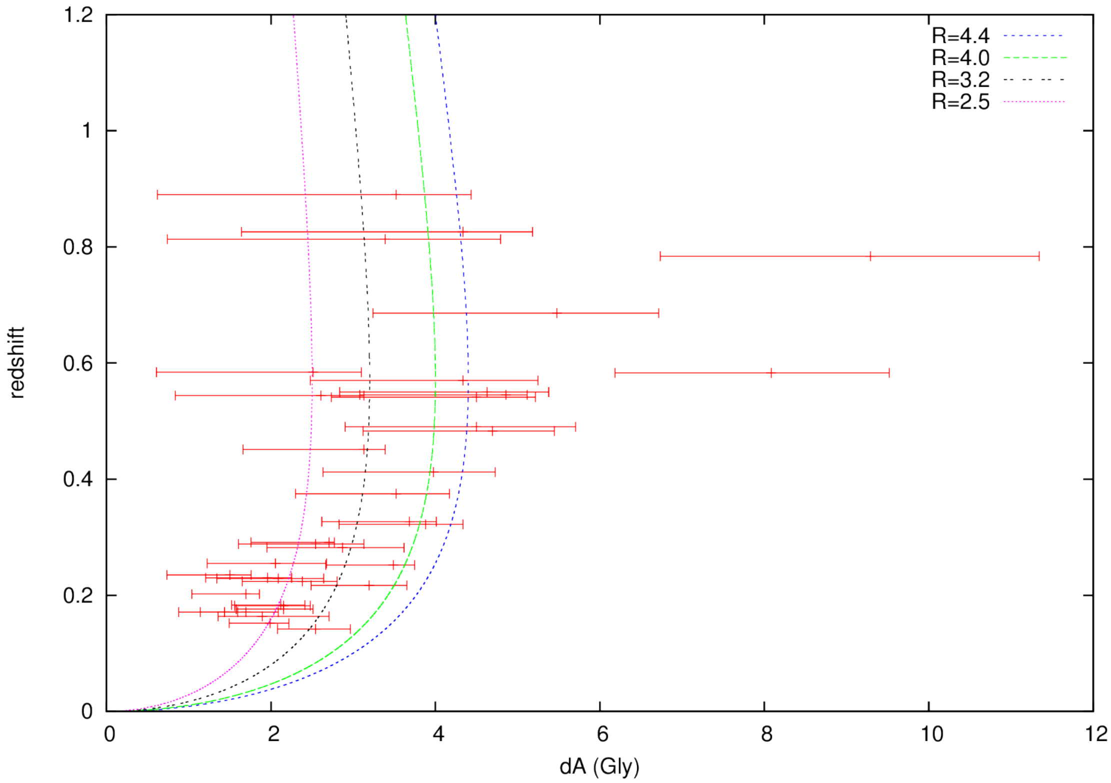

Figure 7: fit for different values of R

Empirical fitting gives reasonable value for R between 2.5 Gly and 4.4 Gly. That corresponds to $d_{max} = \pi R$ comprised between 7.85 Gly and 13.82 Gly, which corresponds to a time of emission from now of $t_{max} = \frac{d_{max}}{c}$, which is of the same order of magnitude as estimates made of 'the age of the universe' in the context of an expanding universe [16]. More precise data could help us confirm this theory and refine the value of R.

9 On the CMB

Until here, our study has been limited to distances smaller that d_{max}. Once the horizon reached, the area of the observation surface starts growing again and decreasing, and repeat this pattern forever. We can see events from over the horizon. We suppose that we can extend our definition of perception distance for these events, so that it corresponds intuitively to the length of the trajectory of the photon from the object to the observer. We find that the scaling factor associated to them is given by :

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

The absolute value is taken, because we don't consider orientation of distances that might be inverted. The redshift observed for these objects is the following :

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

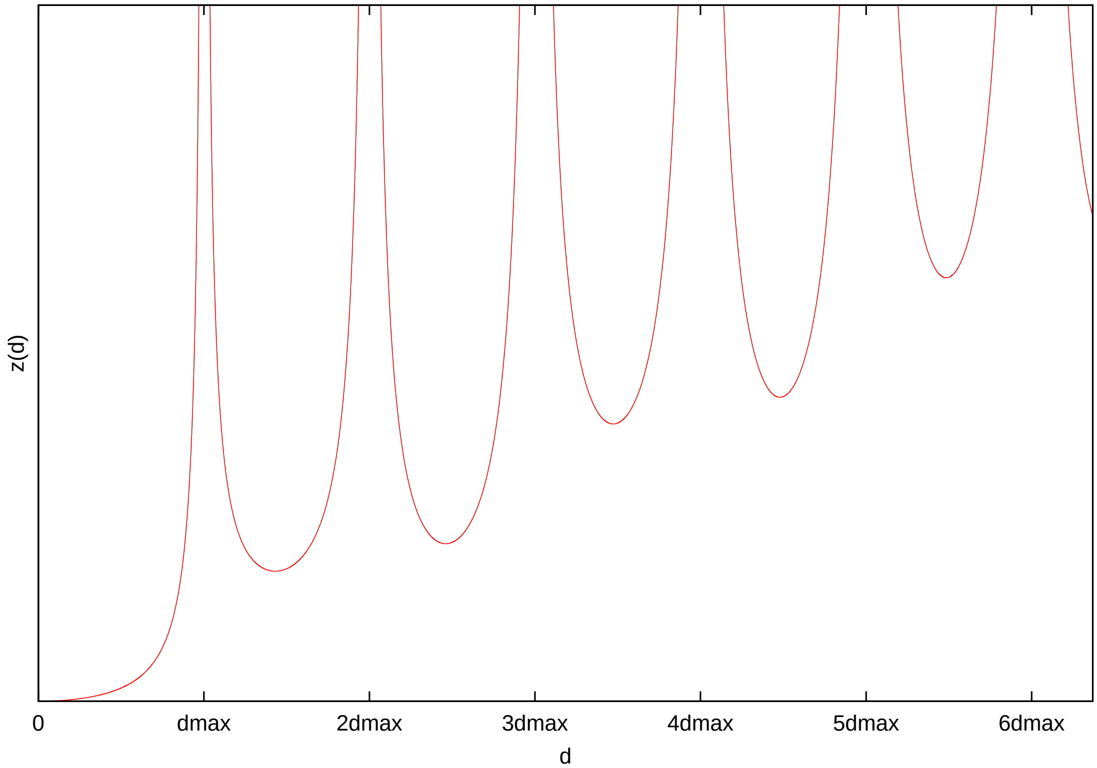

Figure 8: Evolution of the redshift with distance

Just by looking at the evolution of z, we can characterize two classes of events that produce high redshifted light, that could contribute to the CMB :

-Very old events whose light has travelled around the universe many times before arriving to us, whose perception distance is huge. This type of objects will be refered as class 1.

-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_{max}. This type of objects will be refered as class 2.

We assume that the contribution of type 2 objects doesn't contribute to the essential of the radiation spectrum, their proportion being negligeable compared to type 1 objects. The global contribution in light of the infinity of highly redshifted type 1 objects would create a highly regular background radiation, with no privileged direction in the sky, that provides an insight into the eternity of the universe.

The earlier the light is emitted, the lower is its luminosity when it arrives to us, explaining the decay of the CMB power spectrum for high wavelength micro-waves and radio waves. At the other side of the spectrum, the intensity of small wavelength photons would be small, because the number of objects with relatively small redshift is negligeable compared to the infinity of objects with relatively large redhisft. The competition between number of light sources and fading luminosity is such that the radiation should comport a wavelength of maximal intensity. The distribution shows all the caracteristics of a Planck distribution and an analogy with the emission spectrum of a black body can be made.

The primary anisotropies of the radiation could be explained by the presence of type 1 object in the pole regions. Their highly redshifted light adds to the highly regular background and leave some trace. Each pole, at different times, contributes to one level of anisotropy and explains the peaks in the power spectrum of the CMB temperature anisotropy. Each level of anisotropy constitutes a map of a pole region at a given time in the universe, frozen by the high dilation of time to which it is subject.

What has just been said still requires some mathematical formalization and will be subject to future work.

10 Conclusion and comments

We have described a theory that explains many of modern cosmological observations (redshift, behaviour of the scaling factor, relic radiation...) and is able to clear away questions raised by the existence of an initial spacetime singularity, and a dark energy that derives the galaxies dramatically away. Data-based studies and a careful analysis of the CMB in the context of a static universe of spherical curvature could bring support to this theory and refine estimations of the radius of the universe. It raises naturally some questions about the stability of such a static universe

It presupposes a fundamental distinction between perception and physical reality, principle that has some resonance in quantum physics, where a world of waves, superposition and non-locality is in apparent contradiction with the world of perception that separates, localizes and gives consistency to physical objects. In our world of perception, what is perceived as a particle has, by definition, reality only when it is observed, challenging physical realism. Consciousness of our own limitation, that involves inevitably separation (of space and time, of objects and their associated states...), is a crucial point to understand the counter-intuitive implications of modern physics.

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