A Single Big Bang and Innumerable Similar Finite Observable Universes

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Gravity dominated Universe until it was 3.214 Gyr old and, after that, dark energy dominates leading to an eternal expansion, no matter if the Universe is closed, flat or open. That is the prediction of the expansion factor recently proposed by Silva [2]. It is also shown that there is an upper limit for the size of the Observable Universe *relative radial comoving coordinate*, beyond which nothing is observed by our fundamental observer, on Earth. Our Observable Universe may be only a tiny portion of a much bigger Universe most of it unobservable to us. This leads to the idea that an endless number of other fundamental observers may live on equal number of Observable Universes similar to ours. An unique Big Bang originated an unique Universe, only part of it observable to us.

1 Introduction

Since 1929, with Hubble [1], we learned that our Observable Universe has been continuously expanding. Nearly all galaxies are moving away from us, the further they are, the faster they move away. If the galaxies are moving apart today, they certainly were closer together when the Universe was younger. This led to the idea of the Big Bang theory, which is the most accepted theory for the explanation on how the Universe began. According to it, all started from a physical singularity where all Universe matter-energy-space were extremely concentrated with temperature well above 10^{32} K, when a cataclismic expansion ocurred and the size of it went from a Planck's length to some Gigayears (Gyrs) in an extremely tiny fraction of a second.

According to the theory, as the Universe cooled, the first building blocks of matter, quarks and electrons, were formed, followed by the production of protons and neutrons. In minutes protons and neutrons aggregated to produce nuclei.

Around 380,000 years after the Big Bang, there was the so called recombination era in which matter cooled enough to allow formation of atoms transforming the Universe into a transparent eletrically neutral gas. The first photons that managed to be traveling freely through the Universe constitute the so called Cosmic Microwave Background (CMB) which are detected today. This "afterglow light" study is very important because they show how was the the Primeval Universe. Next step is the formation of the structure which gave rise to the astronomical objects [4–10].

Today the Universe keeps expanding, but since 1998 we learned that it has a positive acceleration rate. This indicates that there is something overcoming the gravity and that has been called dark energy. A completely characterization of the dark energy is not done yet. Most researchers think it comes from the vacuum.

In previous papers [2, 3], we have succeeded in obtaining an expression for the Universe scale factor or the Universe expansion factor as you may well call it too:

$$a(t) = \exp\left(\frac{H_0 T_0}{\beta}\left(\left(\frac{t}{T_0}\right)^{\beta} - 1\right)\right), \qquad (1)$$
$$\beta = 1 + H_0 T_0\left(-\frac{1}{2}\Omega_m(T_0) + \Omega_\Lambda(T_0) - 1\right)$$

and H_0 is the so called Hubble constant, the value of the Hubble parameter $H(t)$ at $t = T_0$, the current age of the Universe. Expression (1) is supposed to be describing the expansion of the Universe from the beginning of the so called *matter era* ($t \approx 10^{-4}$ Gyr, after the Big Bang). Right before that the Universe went through the so called *radiation era*. Only the role of the matter (baryonic and non-baryonic) and the dark energy, both treated as perfect fluids are considered. In our work the dark energy was associated to an *a priori* time dependent $\Lambda(t)$ (cosmological "constant").

Figure 1 shows the expansion factor $a(t)$ as function of the Universe age. In Figure 2 the behaviour of the expansion factor acceleration, $\ddot{a}(t)$, is reproduced. Before $t = T_\star = 3.214$ Gyr, acceleration was negative, and after that, acceleration is positive. To perform the numerical calculations we

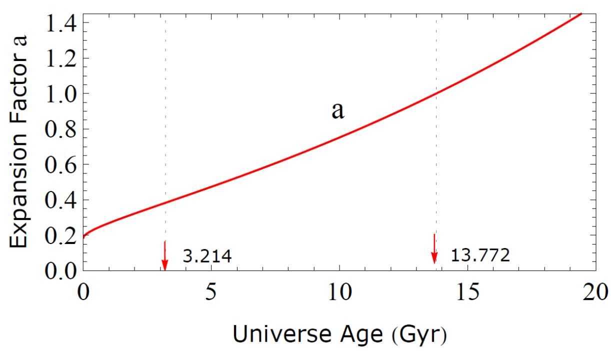

Fig. 1: $a(t) = \exp\left(\frac{H_0 T_0}{\beta}\left(\left(\frac{t}{T_0}\right)^{\beta} - 1\right)\right)$.

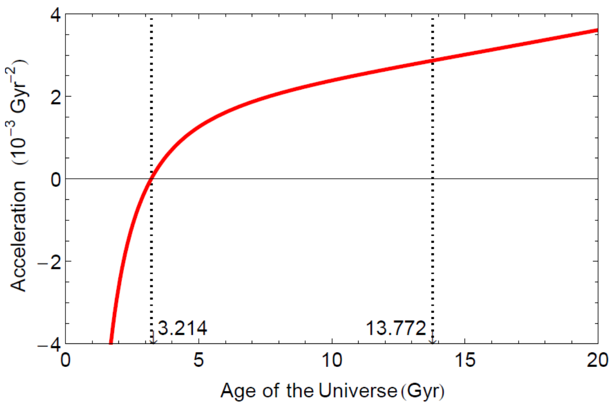

Fig. 2: $\ddot{a}(t) = a(t)\left(H_0\left(\frac{t}{T_0}\right)^\beta - (1-\beta)\frac{1}{t}\right)H_0\left(\frac{t}{T_0}\right)^{\beta-1}$.

have used the following values [11]:

$$\begin{aligned} H_0 &= 69.32\ \text{kms}^{-1}\text{Mpc}^{-1} \\ &= 0.0709\ \text{Gyr}^{-1}, \\ T_0 &= 13.772\ \text{Gyr}, \\ \Omega_m(T_0) &= 0.2865, \\ \Omega_\Lambda(T_0) &= 0.7135. \end{aligned} \tag{2}$$

In reference [2], some properties such as Gaussian curvature $K(t)$, Ricci scalar curvature $R(t)$, matter and dark energy density parameters $(\Omega_m, \Omega_\lambda)$, matter and dark energy densities (ρ_m, ρ_λ), were calculated and plotted against the age of the Universe, for $k = +1, 0, -1$. It was found that the current curvature radius $\Re(T_0)$ has to be larger than 100 Gly, for $k = \pm 1$. Obviously, for $k = 0$, $\Re = \infty$. So, arbitrarily [2], we have chosen $\Re(T_0) = 102$ Gly. None of the results were sufficient to decide which value of k is more appropriate for the Universe. The bigger the radius of curvature, the less we can distinguish which should be the right k among the three possible values. Considering that, we pick the most intuitive geometry, at least in our view, we work here with the closed Universe version.

2 Closed Universe

The closed Universe Friedmann - Lemaitre - Robertson - Walker (FLRW) spacetime metric is given by [4–10]:

$$\begin{aligned} ds^2 &= \Re^2(t)\left(d\psi^2 + \sin^2\psi\left(d\theta^2 + \sin^2\theta d\phi^2\right)\right) - c^2dt^2 \\ &= \Re^2(T_0)\,a^2(t)\left(d\psi^2 + \sin^2\psi\left(d\theta^2 + \sin^2\theta d\phi^2\right)\right) \\ &\quad - c^2dt^2, \end{aligned} \tag{3}$$

where ψ, θ and ϕ are comoving space coordinates ($0 \leq \psi \leq \pi$, $0 \leq \theta \leq \pi$ and, $0 \leq \phi \leq 2\pi$), t is the time shown by any observer clock in the comoving system. $\Re(t)$ is the scale factor in units of distance; actually it is *radius of curvature* of the Universe as already said in previous section. The time t is also known as the cosmic time. The function $a(t)$ is the usual expansion factor

$$a(t) = \frac{\Re(t)}{\Re(T_0)}, \tag{4}$$

here assumed to be that of Equation 1.

The FLRW metric embodies the so called Cosmological Principle which says that the Universe is spatially homogeneous and isotropic in suficient large scales.

We have to set that our "fundamental" observer (on Earth) occupies the $\psi = 0$ position in the comoving reference system. To reach him(her) at cosmic time T, the CMB photons spend time T since their emission at time $t \approx 380,000$ yr, after the Big Bang, at a specific value of the comoving coordinate ψ. Let us call ψ_T this specific value of ψ. We are admitting that the emission of the CMB photons occured simultaneously for all possible values of ψ. Although that happened at $t \approx 380,000$ yr, for purposes of integrations ahead it is assumed to be $t \approx 0$ with no considerable loss.

Having said that, we can write, for the trajectory followed by a CMB photon ($ds^2 = 0, d\phi = d\theta = 0$), the following:

$$-\frac{cdt}{\Re(t)} = d\psi, \tag{5}$$

$$-\int_0^T \frac{c}{\Re(t)}dt = \int_{\psi_T}^0 d\psi, \tag{6}$$

$$\psi_T = \frac{c}{\Re(T_0)}\int_0^T \frac{1}{a(t)}dt, \tag{7}$$

The events ($\psi = 0$, $t = T$) and ($\psi = \psi_T$, $t = 0$) are connected by a null geodesics. The first event is relative to the fundamental Observer, while the second event refers to the emission of the CMB photons at $t \approx 0$ as explained above. ψ_T gets bigger as T increases which means that *the older the Universe gets, the further the referred Observer sees from the CMB*.

The comoving coordinate which corresponds to the current "edge" (horizon) of our Observable Universe is

$$\begin{aligned} \psi_{T_0} &= \frac{c}{\Re(T_0)}\int_0^{T_0} \frac{1}{a(t)}dt \\ &= \frac{c}{\Re(T_0)}\int_0^{T_0} \exp\left(\frac{H_0T_0}{\beta}\left(1-\left(\frac{t}{T_0}\right)^\beta\right)\right)dt \\ &= 0.275\ \text{Radians} = 15.7\ \text{Degrees}. \end{aligned} \tag{8}$$

where, again, $\Re(T_0)$ is assumed to be 102 Gly for the reason exposed in reference [2] ($\Re(T_0) > 100$ Gly). Very much probably $\Re(T_0)$ should be much greater than that. The value of the current curvature radius is crucial in the sense of determining the coordinate ψ_{T_0}.

So CMB photons emitted at ψ_{T_0} and $t = 0$ should arrive at $\psi = 0$ and $t = T_0$, the current age. Along their

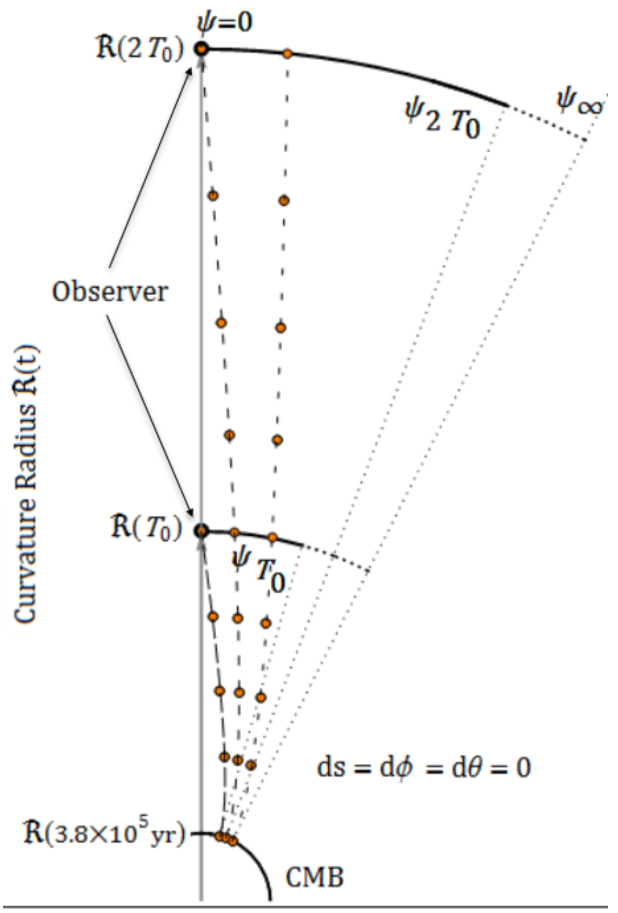

Fig. 3: The null geodesics connecting two events: (ψ_{T_0}, $t \approx 0$) and ($\psi = 0, t = T_0$); (ψ_{2T_0}, $t \approx 0$) and ($\psi = 0$, $t = 2T_0$). The null geodesic between ($\psi_\infty = 1.697\ \psi_{T_0}$, $t \approx 0$) and ($\psi = 0$, $t = \infty$) will never be accomplished. $\Re(T)$ is radius of curvature at age T.

whole trajectory, other photons emitted, at later times, by astronomical objects that lie on the way, join the troop before reaching the fundamental observer. So he(she) while looking outwards deep into the sky, may see all the information 'collected' along the trajectory of primordial *CMB* photons. Other photons emitted at the same time $t \approx 0$, at a comoving position $\psi > \psi_{T_0}$ will reach $\psi = 0$ at $t > T_0$, together with the other photons provenient from astronomical objects along the way. As the Universe gets older, its "edge" becomes more distant and its size gets bigger. See Figure 3.

The current value for ψ_{T_0} should actually be smaller than 0.275 Radians, because, as we said above, $\Re(T_0)$ should be greater than the assumed value (102 Gly).

To get rid of such dependence on $\Re(T_0)$, we find convenient to work with the ratio r

$$r \equiv \frac{\psi}{\psi_{T_0}}, \tag{9}$$

which we shall call the *relative radial comoving coordinate*.

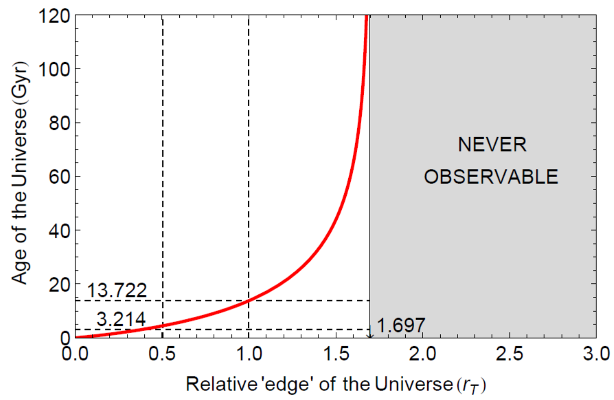

Fig. 4: $r_T = \int_0^T \frac{1}{a(t)} dt \Big/ \int_0^{T_0} \frac{1}{a(t)} dt$. The relative radial comoving coordinate r_T, from which *CMB* photons leave, at ($t \approx 0$), and reach relative comoving coordinate $r = 0$ at age $t = T$ gives the relative position of the "edge" of the Observable Universe ($r_{T\to\infty} \to 1.697$). (Axes were switched.)

Obviously, at age T, r_T is the *relative* measure of the "edge" position with respect to the fundamental observer ($\psi = 0$)

$$r_T = \int_0^T \frac{1}{a(t)} dt \Big/ \int_0^{T_0} \frac{1}{a(t)} dt, \tag{10}$$

and $r_{T_0} = 1$. For a plot of r_T see Figure 4.

3 Observable Universes

One question that should come out of the mind of the fundamental observer is: "Is there a maximum value for the relative comoving coordinate r?" What would be the value of r_∞?

By calculating r_∞, we get

$$r_\infty = \int_0^\infty \frac{1}{a(t)} dt \Big/ \int_0^{T_0} \frac{1}{a(t)} dt = 1.697. \tag{11}$$

To our fundamental observer (Earth), there is an upper limit for the relative comoving coordinate $r = r_\infty = 1.697$, beyond that no astronomical object can *ever* be seen by such fundamental observer.

This should raise a very interesting point under consideration.

Any other fundamental observer placed at a relative comoving coordinate $r > 2r_\infty$ ($\psi > 2\psi_\infty$), with respect to ours, will never be able to see what is meant to be our Observable Universe. He (she) will be in the middle of another visible portion of the same whole Universe; He (she) will be thinking that he (she) lives in an Observable Universe, just like ours. Everything we have been debating here should equally be applicable to such an 'other' Observable Universe.

The maximum possible value of ψ is π (Equation 3), then the maximum value of r should be at least 11.43. Just recall that $r = 1$ when $\psi = \psi_{T_0}$. This ψ_{T_0} was overevaluated as being 0.275 Radians = 15.7 Degrees, in equation (8)

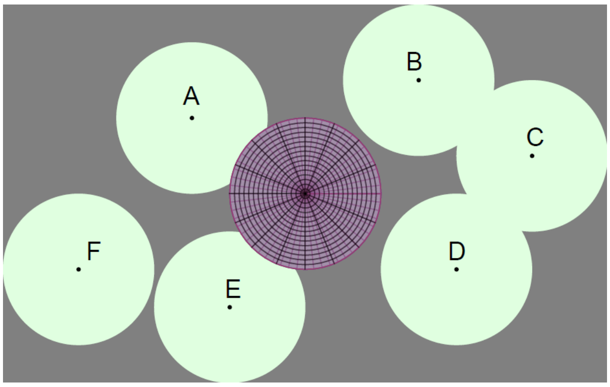

Fig. 5: This illustration tries to show schematically a hypersurface at time T with our Observable Universe surrounded by other similar Observable Universes, arbitrarily positioned, some of them overlapping.

when considering the current radius of curvature as $\Re(T_0)$ = 102 Gly. As found in reference [2] $\Re(T_0)$ should be bigger than that, not smaller. Consequently the real ψ_{T_0} should be smaller than 0.275 Radians = 15.7 Degrees, not bigger. One direct consequence of this is that there is room for the ocurrence of a large number of isolated similar *Observable Universes* just like ours.

We may say that the Big Bang gave birth to a large Universe, of which our current Observable Universe is part, perhaps a tiny part. The rest is unobservable to us and an endless number of portions just the size of our Observable Universe certainly exist, each one with their fundamental observer, very much probably discussing the same Physics as us.

Of course, we have to consider also the cases of overlapping Observable Universes.

One important thing is that we are talking about **one Universe**, originated from **one Big Bang**, which is not observable as a whole, and that may contain **many** other Observable Universes **similar** to ours. Would it be a *Multiverse*? See Figure 5.

4 Conclusion

The expansion factor $a(t) = exp\left(\frac{H_0 T_0}{\beta}\left(\left(\frac{t}{T_0}\right)^{\beta} - 1\right)\right)$, where $\beta = 1 + H_0 T_0\left(-\frac{1}{2}\Omega_m(T_0) + \Omega_\Lambda(T_0) - 1\right) = 0.5804$ [2], is applied to our Universe, here treated as being closed ($k = +1$). Some very interesting conclusions were drawn. One of them is that the radial relative comoving coordinate r, measured from the fundamental observer, $r = 0$ (on Earth), to the "edge" (horizon) of our Observable Universe has an upper limit. We found that $r \to 1.697$ when $T \to \infty$. Therefore all astronomical objects which lie beyond such limit would never be observed by our fundamental observer ($r = 0$). On the other hand any other fundamental observer that might exist at $r > 2 \times 1.697$ would be in the middle of another Observable Universe, just like ours; he (she) would never be able to observe our Universe. Perhaps he (she) might be thinking that his (her) Observable Universe is the only one to exist. An endless number of other fundamental observers and an equal number of Observable Universes similar to ours may clearly exist. Situations in which overlapping Universes should exist too. See Figure 5.

The fact is that the Big Bang originated a big Universe. A tiny portion of that is what we call our Observable Universe. The rest is unobservable to our fundamental observer (Earth). Equal portions of the rest may be called also Observable Universes by each of their fundamental observers if they exist. So we may speak about many Observable Universes - a Multiverse - or about only one Universe, a small part of it is observable to the fundamental observer.

By using the expansion factor here discussed we have also succeeded in finding a generalization of Hubble's Law, which may be found in reference [13].

The expansion factor, Equation 1, proposed in reference [2] has been shown to be a very good candidate to be describing the expansion of the Universe.

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