Article

Before the Big Bang: the Apollonian Universe

Enrique Gaztanaga [1,2]

[1] Institute of Space Sciences (ICE, CSIC), 08193 Barcelona, Spain; gaztanaga@darkcosmos.com
[2] Institut d Estudis Espacials de Catalunya (IEEC), 08034 Barcelona, Spain

Abstract: We propose that the Big Bang does not have a singular start, but that it originates from gravitational collapse of a low density cloud to form a Black Hole (BH) of mass $M \simeq 6 \times 10^{22} M_\odot$ about 25 Gyrs ago. After 11Gyrs of collapse, it results in a high density cloud that bounces into expansion because of neutron degeneracy pressure. Observationally, this model is very similar to the standard Big Bang cosmology but there is no need for Inflation or Dark Energy (DE). The observed cosmological constant Λ is not a new form of DE, but results from the dynamics of the Big Bang expansion inside the BH event horizon $r_S = 2GM = \sqrt{3/\Lambda}$. Why our Universe has such a large mass M (or small Λ value)? If $\tau_O \simeq 10$Gyr is the astronomical time needed for observers like us to exist, we find a simple anthropic prediction, based only on gravitational collapse from Gaussian fluctuations, that the maximum probability for M is $M_O < M < 3M_O$ where $M_O = \tau_O/3G$. This agrees well with the measured values for τ_O and M in our Universe.

Keywords: cosmology; dark energy; general relativity; black holes

1. Introduction

A cosmological model predicts the background evolution, composition and structure of the observed Universe given some initial conditions. The standard cosmological model [1,2], also called ΛCDM, assumes that our Universe began in a hot Big Bang expansion at the very beginning of space-time. Such initial conditions seem to violate energy conservation and are very unlikely [3–5]. The model also requires three more exotic ingredients: Inflation, Dark Matter and Dark Energy (DE), for which we have no direct evidence or understanding at any fundamental level. Despite these shortfalls, the ΛCDM model seems very successful in explaining most observations by fitting just a handful of free cosmological parameters, such as H_0 and Ω_m. We propose a new cosmological model, the Black Hole Universe (BHU) [6–8], based on well established physical concepts that can explain the same observations without the need of introducing such exotic ingredients. Recent observations show discrepancies or tensions with ΛCDM prediction in the measurements of cosmological parameters from different time-scales (see [9] for an extended review). Such tensions, if confirmed, could be supportive of the BHU model [10–12].

1.1. The local spherical metric

The most general form of a flat metric with spherical symmetry in physical or Schwarzschild (SW) coordinates (t, r, θ, ϕ) in units of $c \equiv 1$, can be written as follows:

$$ds^2 = -[1 + 2\Psi(t,r)]dt^2 + \frac{dr^2}{1 + 2\Phi(t,r)} + r^2 d\Omega^2. \quad (1)$$

The simplest approximation for a static BH is the SW metric: $2\Phi = 2\Psi = -2GM/r \equiv -r_S/r$ which corresponds to a singular point of mass M [13]. Regardless of its metric, a

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physical BH can be defined as an object of total mass-energy M with a radial size R that is smaller or equal to its SW radius r_S:

$$r_S = \frac{2GM}{c^2} \simeq 2.9\text{Km} \frac{M}{M_\odot}. \tag{2}$$

This corresponds to a radial escape velocity $\dot{r}_S = c \equiv 1$. As events cannot travel faster than c, nothing can escape from inside r_S. The energy density of a BH inside r_S is always:

$$\rho_{BH} = \frac{M}{V} = \frac{3M}{4\pi r_S^3} = \frac{3r_S^{-2}}{8\pi G} \simeq 9.8 \times 10^{-3} \left[\frac{M_\odot}{M}\right]^2 \frac{M_\odot}{\text{Km}^3}. \tag{3}$$

This value should be compared with the atomic nuclear saturation density:

$$\rho_{NS} \simeq 2 \times 10^{-4} \frac{M_\odot}{\text{Km}^3} \tag{4}$$

which corresponds to the density of heavy nuclei and results from the Pauli Exclusion Principle applied to neutrons and protons. For a Neutron Star (NS) with $M \simeq 7M_\odot$, both densities are the same: $\rho_{BH} = \rho_{NS}$. This similarity explains why NS are never larger than $M \simeq 7M_\odot$, as a collapsing cloud with such mass reaches BH density ρ_{BH} before it reaches ρ_{NS}. The maximum observed M for NS is closer to $M \simeq 3M_\odot$ [14], which agrees with more detailed considerations that include the equation of state estimates. Cold nuclear matter at neutron density is a major unsolved problem in modern physics. As we will show, it could be key to understand cosmic expansion.

1.2. The global FLRW metric

The Friedmann–Lemaitre–Robertson–Walker (FLRW) metric can describe a flat infinite homogeneous and isotropic space. In co-moving coordinates $\xi^\alpha = (\tau, \chi, \theta, \phi)$:

$$ds^2 = -d\tau^2 + a(\tau)^2 \left[d\chi^2 + \chi^2 d\Omega\right]. \tag{5}$$

This metric is also spherically symmetric, so it is a particular case of Eq.1. Comparing the solid angle term $d\Omega$ to Eq.1, note that the SW or physical coordinates are $r = a\chi$, which imply Hubble's law: $\dot{r} \equiv dr/d\tau = \frac{\dot{a}}{a} r \equiv Hr$. The scale factor, $a(\tau)$, gives the expansion/contraction as a function of co-moving or cosmic time τ (proper time for a co-moving observer). For a perfect fluid with density ρ and pressure p, the solution to GR field equations is well-known:

$$H^2 = \frac{8\pi G}{3} \rho = H_0^2 \left[\Omega_m a^{-3} + \Omega_R a^{-4} + \Omega_\Lambda\right], \tag{6}$$

where $\rho_c \equiv \frac{3H_0^2}{8\pi G}$ and $\Omega_X \equiv \frac{\rho_X}{\rho_c}$, where Ω_m represents the current ($a = 1$) matter density and Ω_R is the radiation. The effective cosmological constant term Ω_Λ results from: $\rho_\Lambda \equiv \rho_{\text{vac}} + \frac{\Lambda}{8\pi G}$ where ρ_{vac} represents the vacuum or the ground state of a scalar field: $\rho_{\text{vac}} = -p_{\text{vac}} = V(\varphi)$ with negligible kinetic energy. At any time, the expansion rate H^2 is given by ρ. Energy–mass conservation requires that $\rho \propto a^{-3(1+\omega)}$, where $\omega = p/\rho$ is the equation of state of the different components: $\omega = 0$ for matter, $\omega = 1/3$ for radiation, and $\omega = -1$ for ρ_Λ. Given $a_* = a(\tau_*)$ at time τ_* the solution dominated by a component with ω is:

$$a(\tau) = a_* \left[\frac{3(1+\omega)}{2} \tau H_*\right]^{\frac{2}{3(1+\omega)}} \Rightarrow r_H = \frac{3(1+\omega)}{2} \tau \tag{7}$$

The Hubble Horizon is defined as $r_H \equiv H^{-1}$. Structures that are larger than r_H cannot evolve because the time that a perturbation takes to travel that distance is larger than the expansion time. How can these structures form if they were never in causal contact? This

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question poses the horizon problem. In the Big Bang model, this problem is solved by Cosmic Inflation [15–18], a period of exponential expansion that must have happened right at the beginning of time ($\tau = 10^{-30}$sec). After expanding by a factor e^{60}, Inflation leaves the universe empty and we need a mechanism to stop Inflation and to create the matter and radiation that we observe today. This is called re-heating. These components require fine-tuning and free parameters that we do not understand at a fundamental level and occur at energies ($> 10^{15}$GeV) that are out of reach from direct validation [1].

1.3. Cosmic Acceleration

Cosmic acceleration is defined as $q \equiv (\ddot{a}/a)H^{-2}$. Taking a derivative of Eq.7, we find $q = -\frac{1}{2}(1+3\omega)$. For regular matter, we have $\omega > 0$ so we expect the expansion to decelerate ($q < 0$). However, the latest concordant measurements from a Type Ia supernova (SN), galaxy clustering, and the Cosmic Microwave Background (CMB) all agree with DE with $\omega = -1.03 \pm 0.03$ [19], which means that the expansion ends up dominated by $q \simeq 1$. However, there is no fundamental understanding of what DE is or why $\omega \simeq -1$. This is very similar to Inflation above but at 10^{-12} GeV energy. A candidate for DE is ρ_Λ [20–23]. The value $q \simeq 1$ is also important to obtain a longer age estimate of 14 Gyr, which is needed to account for the oldest stars and to give more time for structures to grow from the CMB seeds $\delta_T \simeq 10^{-5}$ to the amplitude (and shape) we observe today [24–26].

Note how $q = 1$ means $\dot{H} = 0$, so that H becomes constant and all structures become super-horizon and freeze, such as in Inflation. In the physical (SW) frame of Eq.1, this corresponds to a static hypersphere (deSitter) metric with:

$$2\Phi = 2\Psi = -\Lambda r^2/3 \equiv -\frac{r^2}{r_\Lambda^2} \equiv -r^2 H_\Lambda^2. \tag{8}$$

We often say that the expansion accelerates but it is more physical to say that the expansion becomes asymptotically static, as proposed by Einstein [20] when he introduced Λ. A constant H is equivalent to $H = 0$ for a physical observer.

2. Inside a Black Hole

The density of our Universe (in Eq.6) inside its Hubble Horizon $r_H = 1/H$ corresponds to that of a BH in Eq.3. This can be easily understood, because the escape velocity (or Hubble flow) at $r = r_H$ is the speed of light: $\dot{r}_H = Hr_H = 1$. The mass inside r_H follows $r_H = 2GM$ and H^2 tends toward a constant $H_\Lambda^2 = \frac{8\pi G}{3}\rho_\Lambda = H_0^2\Omega_\Lambda$. The Universe becomes asymptotically static (in the SW frame) with a fixed radius ($r_\Lambda = H_\Lambda^{-1}$). In that limit we have an static BH with $r_S = r_\Lambda$. Consider an outgoing radial null geodesic to ∞ (i.e., the Event Horizon, [27]) starting at proper time τ from anywhere inside the FLRW metric:

$$r_* = a\int_\tau^\infty \frac{d\tau}{a(\tau)} = a\int_a^\infty \frac{d\ln a}{aH(a)} < \frac{1}{H_\Lambda} \equiv r_\Lambda \tag{9}$$

As the Hubble rate becomes constant, r_* freezes to a constant value $r_* = r_H = r_\Lambda$. So the FLRW Event Horizon corresponds to the interior of a BH. What is outside r_Λ? In the limit of empty space outside, Birkhoff's Theorem (see [28,29]) tell us that the metric outside should be SW metric [30]. This solution can also be verified using Israel's junction conditions (see below). So, no signal from inside r_Λ can reach outside and we have SW metric outside with a mass inside given by $r_\Lambda = 2GM$. This is pretty much the definition of a BH. The FLRW metric with Λ is a BH as seeing from outside. This also provides a fundamental interpretation for Λ, which is just given by the SW mass inside [7]. For $\Omega_\Lambda \simeq 0.7$ and $H_0 \simeq 70$ Km/s/Mpc we have:

$$r_S \simeq 1.6 \times 10^{23} km \;\; ; \;\; M = \frac{r_S}{2G} \simeq 6 \times 10^{22} M_\odot \tag{10}$$

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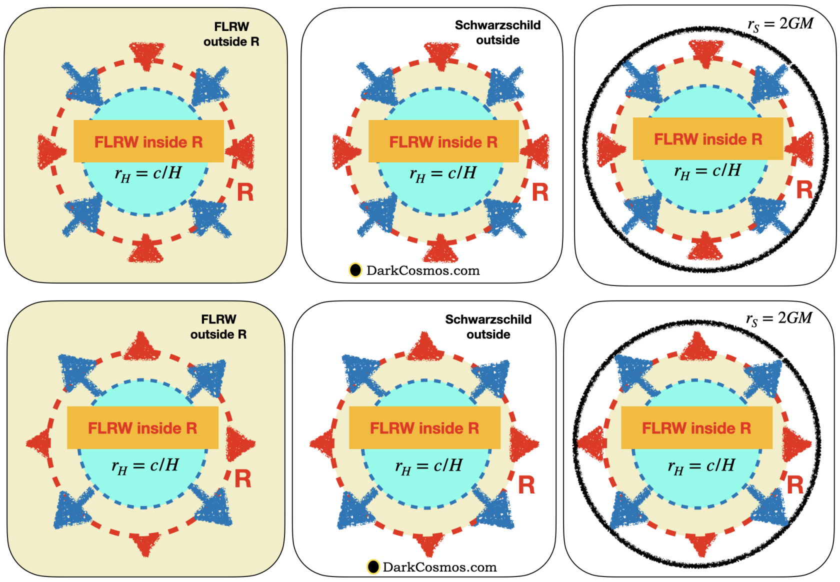

Figure 1. The FLRW metric can be used to model an infinite universe (left), collapsing (top) or expanding (bottom), and a cloud of finite mass M and size $R(\tau)$ (red circle) in empty space (middle) or inside its SW radius $r_S = 2GM$ (right). In the BHU, cosmic expansion originated with the freefall of a FLRW cloud (top middle) that collapsed into a BH (top right) and later bounced into expansion (bottom right), trapped inside r_S, which results in cosmic acceleration. The Hubble Horizon $r_H = H^{-1}$ (blue circle) moves faster than R, so that perturbations become super-horizon during collapse and re-enter during expansion, solving the horizon problem without Inflation.

This interpretation breaks homogeneity (on scales larger than r_Λ), but this is needed if we want causality. Homogeneity is inconsistent with a causal origin [30,31], the same way that a Big Bang out of nothing is inconsistent with Energy conservation.

2.1. The FLRW cloud

We can arrive at the same conclusion from a different perspective. The FLRW solution and metric can also be used to describe a local spherical homogeneous cloud of variable radius R and fix mass M, which collapses or expands in freefall. Based on Gauss law (or the corollary to Birkhoff's theorem [28]) each sphere $r < R$ evolves with independence of what is outside $r > R$. As a consequence, the local FLRW solution is also a valid solution in GR [32]. Using Israel junction conditions [33], one can show [6,8] that the physical radius coordinate R of the FLRW cloud follows:

$$R = [r_H^2 r_S]^{1/3} \tag{11}$$

For a regular star $R > r_S$ so the expansion is subluminar $R < r_H$. The static solution requires the famous $R > 9/8 r_S$ Buchdahl bound [34]. But it is clear that our Universe has $R > r_H$ (we observe super-horizon scales in the CMB) which requires $R < r_S$ in Eq.11: i.e. we are inside our own BH!

In the SW frame of Eq.1, this local FLRW solution corresponds to $2\Phi = -H^2 r^2$ for $r < R$ (and $2\Phi = -r_S/r$ for $r > R$), which for the static case is a well known solution for a BH interior [35]. This frame duality can be understood as a Lorentz contraction $\gamma = 1/\sqrt{1-\dot{r}^2}$ where the velocity $\dot{r}$ is given by the Hubble law: $\dot{r} = Hr$, which results from the change of variables: $r = a\chi$. An observer in the SW frame, not moving with the fluid, sees the moving fluid element $ad\chi$ contracted by the Lorentz factor γ: $ad\chi \Rightarrow \gamma dr$, which explains how you can get $2\Phi = -H^2 r^2$ in Eq.1 from Eq.5 [6]. For $\omega = p = 0$, R in Eq.11 follows a time-like geodesic in freefall with constant $\chi = R/a = r_S/a_{BH}$. For $\omega \neq 0$, $R = r_*$ follows the null geodesic in Eq.9. Compared with Eq.7, R grows slower than r_H

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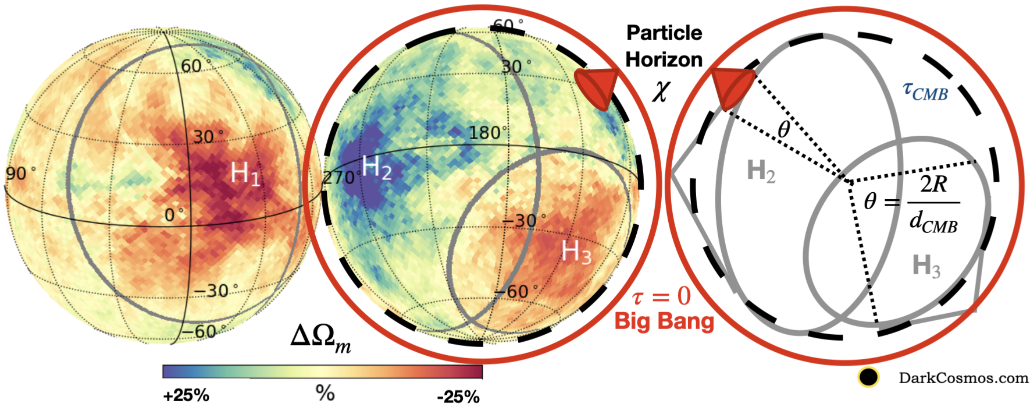

Figure 2. The CMB sky represented as the surface of a sphere (two view angles) whose radius is the distance traveled by the CMB light to reach us (at the center of the sphere). The red circle represents the Big Bang surface ($\tau = 0$). The CMB particle horizon $\chi \simeq r_H$ (small red cones) is the distance travel by light between $\tau = 0$ and τ_{CMB} and subtends a small angle ($\simeq$ 1deg.) in the CMB sky. Large grey circles on the CMB surface are super-horizon boundaries (labeled H_1, H_2 and H_3) in the relative variations of cosmological parameters (color scale) at different locations of the CMB sky [10] (see also [36]). They show that there is a cutoff in super-horizon perturbations (of size $\theta \simeq 2R/d_{CMB} \simeq$ 60deg.) out of the $\tau = 0$ surface. Here we show Ω_m but maps are very similar for other parameters, such as H_0 (see [10] for details).

so perturbations become super-horizon during collapse and re-enter during expansion, solving the horizon problem without the need of Inflation, as explain in Fig.1.

3. The Black Hole Universe (BHU)

How did we end up inside a BH? Our local FLRW cloud must have collapsed and formed a BH. Before it collapse, the density of such a large cloud was so small that radiation escaped the cloud, so that $p = 0$ ($\omega = 0$). Radial co-moving shells of matter are in free-fall collapse and continuously passes $R = r_S$ inside its own BH horizon. If we take τ_* in Eq.7 as the time τ_{BH} (a_{BH}) when $r_H = -r_S$, we find that the BH forms at time:

$$\tau_{BH} = \tau_* = -\frac{2}{3(1+\omega)} r_S \simeq -11\text{Gyrs}, \tag{12}$$

i.e. before $\tau = 0$ (the Big Bang) or 25Gyr ago. The collapse continuous inside until it reaches nuclear saturation (GeV) in Eq.4 and the situation is similar to the interior of a collapsing star. We conjecture that this leads to a Big Bounce because of the Pauli Exclusion Principle. The collapse is halted by neutron degeneracy pressure, causing the implosion to rebound [37]. Neutron stars or small primordial BHs could result in compact remnants that can make up all or part of Dark Matter Ω_m [38]. Diffuse remnants then correspond to regular (baryonic) matter Ω_B. The observed ratio $\Omega_m/\Omega_B \simeq 4$ indicates that most remnants were compact.

Gravitational instability [39–41] allows perturbations in ρ to grow causally during the collapse but they exit r_H as we approach $\tau = 0$. Such causally disconnected regions will therefore have slightly different Ω_m and H_0 at the time close to the Big Bounce (10^{-4}s). These regions correspond to super-horizon perturbations in the CMB (see Fig.2) that re-enter r_H during the expansion given rise to the structures that we see today in Cosmic Maps. Because R is always finite, we expect a cut-off in the spectrum of perturbations which is at odds with the simplest prediction of Inflation. As illustrated in Fig.2, recent anomalies in measurements of cosmological parameters over very large super-horizon scales [9] agree well with the BHU predictions [10,11].

A comoving observer sees the Hubble law of Eq.6 from anywhere inside but the background is not isotropic for $R > r_S$ in Eq.11 unless you are at the center. Once the

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FLRW cloud collapses to become a BH, nothing can escape out of the event horizon r_S, so the condition $p = 0$ at the horizon $r = r_* = R$ is automatically fulfill, even when in the last stages of the collapse part of the energy could transformed into heat ($p \neq 0$). The GR field equations change for an expanding FLRW cloud inside a BH because r_S becomes a boundary in the Hilbert action [7]: r_S behaves like a Λ term ($\Lambda = 3/r_S^2$), despite having $\Lambda = 0$ to start with. A co-moving observer anywhere inside such a local FLRW cloud has no way to distinguish it from an infinite FLRW universe. We can understand this curious behavior in the dual frame by considering radial null events ($ds^2 = 0$) connecting $(0, r_0)$ with (t, r) in deSitter metric Eq.8, which follow:

$$r = r_\Lambda \frac{r_\Lambda + r_0 - (r_\Lambda - r_0)e^{-2t/r_\Lambda}}{r_\Lambda + r_0 + (r_\Lambda - r_0)e^{-2t/r_\Lambda}}.$$

It takes $t = \infty$ to reach $r = r_\Lambda$ from any point inside, no matter where r_0 is. This agrees with Eq.9. The homogeneous solution seems to have larger symmetry (more killing vectors) than the FLRW cloud, but this is not the case when we have Λ or when we are inside a BH (which is equivalent). This is apparent in deSitter metric, which can be expressed as a homogeneous expanding FLRW metric of Eq.5 with $H = H_\Lambda$ or as a static hypersphere of Eq.8 (see also [42]).

4. The Apollonian Universe

What was there before our BHU collapsed? We will assume here that there are other BHUs and regular matter within a larger space-time that we call the Apollonian Universe. This has to be a much larger space-time, may be unbounded, but we assume that otherwise similar to ours: a uniform background with energy density $\bar{\rho}$ with an initially Gaussian distribution of small fluctuations δ, so that $\rho = \bar{\rho}(1 + \delta)$. We don't know the initial particle composition of the Apollonian Universe, but we can assume that it is similar to the one in our BHU. For weakly interacting, collisionless dark matter (CDM), the hierarchical gravitational collapse leads to dense dark matter halos and not to collapsing BHs. This is the case even if the CDM that we observed today does not correspond to a new exotic particle but is made of compact objects with regular matter (like stellar BHs and Neutron stars). BHs could still form inside CDM halos. So compact objects could correspond to halos with smaller BHs or just regular BHs.

By its definition, gravity dominates for masses above the Jeans mass $M > M_J$. For such large masses, we can then use the Press-Schechter formalism [43] to predict the number of collapsed objects $n(M)$ of a given mass M. For scale-free power spectrum (also close to the one in our BHU):

$$n(M)dM = \sqrt{\frac{1}{\pi}} \left(\frac{M}{M_*}\right)^{1/2} \exp\left(-\frac{M}{M_*}\right) \frac{\bar{\rho}\, dM}{M^2} \tag{13}$$

where M_* is corresponds to the gravitational collapse non-linear transition scale. The important point to notice is that large collapsed objects are exponentially suppressed for $M > M_*$. The typical value of M_* increases with time. The value today corresponds to a cluster mass: $M_* \simeq 10^{14} M_\odot$ but was lower in the past.

We assume that the probability of having observers like us increases linearly with time for $\tau > \tau_O$ and is zero for $\tau < \tau_O$. So τ_O is the astronomical time needed for observers like us to exist. Its value must be close to $\tau_O \simeq 13$Gyrs, corresponding to the age of our galaxy [44], which is only about 3 times the age of our planet: 4.5Gyr [45]. The BH collapse time in Eq.12 is proportional to M, so that a large mass $M \simeq 6 \times 10^{22} M_\odot$ in Eq.10 has a typical collapse time of $\tau \simeq 11$Gyr in Eq.12. The expansion time is longer because of the acceleration caused by the BH event horizon, but during deSitter phase the Hubble horizon shrinks and structure formation halts. So in practice, the relevant timescale is the one given by matter domination ($\omega \simeq 0$) in Eq.12: $\tau = 3GM$.

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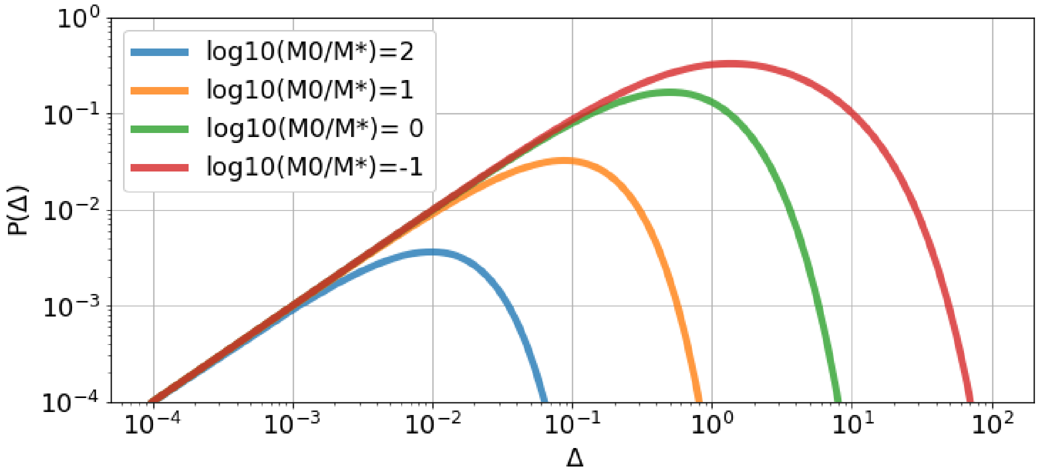

Figure 3. Anthropic probability $P(\Delta)$ in Eq.14 for different values of M_O/M_*. This corresponds to the probability for an observer like us to be in a BH of mass $M = M_O(1+\Delta)$. M_O corresponds to the minimum time $\tau_O \simeq 10$Gyr needed for a galaxy and planet like ours to form. M_* is the non-linear mass scale. Regardless of M_*, the maximum in $P(\Delta)$ is always within $0 < \Delta < 2$ or $M_O < M < 3M_O$.

We express M in terms of Δ: $M = M_O(1+\Delta)$, where $M_O = \tau_O/3G$ is the BH mass corresponding to τ_O in Eq.12. The anthropic probability $P(\Delta)$ that an observer lives inside a BH of such mass is them:

$$P(\Delta) \propto \frac{n(M)}{n(M_O)}\Delta = (1+\Delta)^{-3/2}\,\Delta\,\exp\left(-\frac{M_0}{M_*}\Delta\right) \tag{14}$$

We have divided $n(M)$ in Eq.13 by $n(M_0)$ because we are interested in the relative number of BHs above the ones with the minimal mass M_O. Fig.3 shows Eq.14 for some values of M_O/M_*. For $M_O \gg M_*$ the probability is dominated by the exponential suppression and $P(\Delta)$ peaks around $\Delta = 0$. This means that most observers will live in a BH with mass M_O. So an accurate estimation of τ_O provides a prediction for M_O and therefore a prediction for $r_S = 2GM_O$ and $\Lambda = 3/r_S^2$, in agreement with the values measured in our BHU. For $M_O \simeq M_*$ the probability $P(\Delta)$ peaks around $\Delta = 1$, which predicts that most observers live in BHs which are two times M_O. For $M_O \ll M_*$ the result is independent of M_* and the peak is at $\Delta = 2$. Thus, regardless of M_*, the maximum probability corresponds to observers in a BH with mass $M_O < M < 3M_O$ or collapse times $\tau_O < \tau < 3\tau_O$, which is very consistent with the measurements in our Universe for τ_O and M in Eq.10. In terms of Λ this corresponds to $\Lambda_O/9 < \Lambda < \Lambda_O$, where Λ_O is the value corresponding to M_O or τ_O.

5. Discussion and Conclusion

We propose that cosmic expansion originated from the collapse of a cloud in an existing background. We assume that such background is flat with $k = 0$ and $\Lambda = 0$, as in empty space. The field equations of GR are local and they do not change k or Λ because these are global topological quantities which are not altered by the presence of matter. We should therefore adopt the most simple topology, that of empty space, unless we find some evidence or good reason to the contrary. The so call flatness problem, that is solved by Inflation, is only a problem if the Big Bang singularity creates curvature. In the BHU model the singularity is avoided at GeV, well before Quantum Gravity effects (10^{19} GeV), so we do not expect a global curvature or Λ in this model's background.

In nature, we never observe cold matter with densities larger than that of an atomic nuclei in Eq.4. This is due to Pauli Exclusion Principle in Quantum Mechanics, which prevents fermions from occupying the same quantum state. We propose here that, when the collapse reaches nuclear saturation density, it bounces back, as it happens in a supernova core collapse. The bounce happens at times and energy densities that are many orders of

Table 1. Model comparison. Observations that require explanation.

Cosmic observation	Big Bang (ΛCDM) explanation	BHU explanation
Expansion law	FLRW metric	FLRW metric
Element abundance	Nucleosynthesis	Nucleosynthesis
Cosmic Microwave Background (CMB)	recombination	recombination
All sky CMB uniformity	Inflation	Uniform Big Bounce
Cosmic acceleration, BAO & ISW	Dark Energy	BH event horizon size
14Gyr age since $\tau = 0$	Dark Energy	BH event horizon size
Rotational curves & Cosmic flows	Dark Matter	compact remnants (BHs, NS) of Big Bounce
$\Omega_m > \Omega_B$ & gravitational lensing	Dark Matter	compact remnants (BHs, NS) of Big Bounce
CMB fluctuations $\delta T = 10^{-5}$	free parameter	Big Crunch perturbations
$\Omega_m/\Omega_B \simeq 4$	free parameter	fraction of compact to difuse renmants
$\Omega_\Lambda/\Omega_m \simeq 3$	free parameter	time to deSitter phase
Large scales anomalies in CMB	Cosmic Variance (bad luck)	super-horizon cutoff $\lambda < 2R$
anomalies in cosmological parameters	Systematic effects	super-horizon perturbations
flat universe $k = 0$	Inflation	topology of empty space
monopole problem	Inflation	low energy Big Bounce

magnitudes away from Inflation or Planck times. Thus, Quantum Gravity or Inflation are not needed to understand cosmic expansion or the monopole problem [16]. Further work is needed to understand the details of such a Big Bounce: to estimate the perturbations, composition, and fraction of compact and diffuse remnants that resulted. This could explained from first principles some of the free parameters in the ΛCDM model, as shown in Table 1.

The Big Bounce could provide a uniform start for the Big Bang, solving the horizon problem (see Fig.1): super-horizon perturbations during collapse (and bounce) seed structure (BAO and galaxies) as they re-enter r_H during expansion. The main differences with Inflation are the origin of those perturbations and the existence of a cutoff in the spectrum of fluctuations given by R in Eq.11. Such a cutoff has recently been measured in CMB maps [8,10–12] (see Fig.2). Galaxy maps are also able to measure this signal [46,47] which could also appear as a dipole [48]. The existence of such super-horizon perturbations could be related to the tension in measurements of the cosmological parameters from different cosmic scaletimes [9,49–52], which have similar variations in cosmological parameters to the measured CMB cutoff anomalies in Fig.2.

The fact that the universe might be generated from the inside of a BH has been studied extensively in the literature [53–58]. The BHU solution is similar to the Bubble Universe solutions [59–66]. However, some important differences exist. In the BHU, no surface terms (or Bubble) are needed and the matter and radiation inside are regular. Several authors have previously proposed that the FLRW metric could be the interior of a BH [67–72] but not quite as formulated here.

The BH collapse time in Eq.12 is proportional to M, so that a large mass $M \simeq 6 \times 10^{22} M_\odot$ in Eq.10 is just the right one to allow enough time for galaxies and planets to form before deSitter phase dominates. This provides an anthropic explanation [26,73] as to why we life inside such a large BH or why $\Lambda = 3/r_S$ is so small. According to Eq.14 (see also Fig.3) the maximum probability corresponds to observers to appear in BH with $\Lambda_O > \Lambda > \Lambda_O/9$, where Λ_O is the value corresponding $r_S \simeq 2/3\tau_O$ in Eq.12 for the minimum time τ_O needed for observers to exit. If we assume that this time τ agrees with the age of our galaxy we find good agreement between this prediction and the estimated Λ measurements. These arguments neglect global rotation of the FLRW cloud (or the BHU). Such rotation could slow down the expansion rate (see Appendix C in [8]) and play some role in the bounce and collapse time.

The BHU solution can also be used to model the interior of smaller BHs, but they will not form regular galaxies or stars. The bounce proposed here, based in Quantum

Mechanics, could avoid both the BH and the Big Bang singularities [74,75]. The BHU also eludes the entropy paradox [4] in a similar way as that proposed by Penrose [5]. The difference is that the BHU does not require new laws (infinite conformal re-scaling) or cyclic repetition. Our expansion will end up trapped and static inside a larger and older universe, possibly containing other BHUs.

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