Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **521,** L59–L63 (2023) https://doi.org/10.1093/mnrasl/slad015

The mass of our observable Universe

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Accepted 2023 February 6. Received 2023 January 31; in original form 2023 January 13

ABSTRACT

The standard cosmological model Lambda Cold Dark Matter (LCDM) assumes a global expanding space–time of infinite extent around us. But such idea is inconsistent with the observed cosmic acceleration unless we advocate for the existence of a mysterious dark energy (DE) or a cosmological constant (Λ). Here, we argue instead that our Universe has a very large but finite regular mass M, without the need to invoke DE or Λ. A system with a finite mass M has a finite gravitational radius $r_S = 2GM$. When M is contained within r_S, this is a black hole (BH). Nothing from inside can escape outside r_S, which becomes a boundary for the inside dynamics. In the limit where there is nothing else outside, the inside corresponds then to a local isolated universe. Such boundary condition is equivalent to a Λ term: $\Lambda = 3/r_S^2$. We can therefore interpret cosmic acceleration as a measurement of the gravitational radius of our Universe, r_S, with a mass $M \simeq 6 \times 10^{22}$ M$_\odot$. Such BH Universe is observationally very similar to the LCDM, except for the lack of the largest scale perturbations, which are bounded by r_S.

Key words: dark energy – black hole physics.

1 INTRODUCTION

The standard cosmological model (Dodelson 2003; Weinberg 2008), also called LCDM, assumes that our Universe corresponds to a global space–time that began in a hot big bang (BB) expansion at the very beginning of time. Such initial condition seems to violate the classical concept of energy conservation and is very unlikely (Tolman 1931; Dyson, Kleban & Susskind 2002; Penrose 2006; Brandenberger 2017). According to the singular start BB model, the full observable Universe came out of (macroscopic) nothing, possibly resulting from some quantum gravity vacuum fluctuations that we can only speculate about. We will never be able to test experimentally these ideas because of the enormous energies involved (10^{19} GeV) and there is no direct evidence that this ever occurred. The BB model also requires three more exotic patches: cosmic inflation, dark matter, and dark energy (DE), for which we have no direct evidence or understanding at any fundamental level.

Despite these shortfalls, the LCDM model seems very successful in explaining most observations by fitting just a handful of free cosmological parameters and a model for the formation and evolution of cosmic structures, like galaxies. Here, we discuss the black hole universe (BHU) as an alternative paradigm to the LCDM and elaborate that the main difference between these two models resides in whether the total mass (or extent) of our Universe is finite or not.

The fact that the universe might be generated from the inside of a black hole (BH) has been studied extensively in the literature. Pathria (1972) and Good (1972) proposed that the Friedmann–Lemaître–Robertson–Walke (FLRW) metric could be the interior of a BH. But these early proposals were not proper General Relativity (GR) solutions, but just incomplete analogies (see Knutsen 2009). Stuckey (1994) presented a rigorous demonstration within classical GR that the FLRW metric could be inside a BH, something that was also clear from the works of Oppenheimer & Snyder (1939) and Misner & Sharp (1964). More recent models (Smolin 1992; Daghigh, Kapusta & Hosotani 2000; Easson & Brandenberger 2001; Firouzjahi 2016; Popławski 2016; Oshita & Yokoyama 2018; Dymnikova 2019) involve modifications to classical GR and are therefore more speculative. There are also some simple scalar field $\varphi(x)$ models (e.g. Daghigh et al. 2000) within the scope of a classical GR and classical field theory with a false vacuum interior. Of particular interest are Bubble or Baby Universe solutions where the BH interior is de Sitter metric (Gonzalez-Diaz 1981; Blau, Guendelman & Guth 1987; Frolov, Markov & Mukhanov 1989; Grøn & Soleng 1989; Aguirre & Johnson 2005; Mazur & Mottola 2015; Garriga, Vilenkin & Zhang 2016; Kusenko et al. 2020). These solutions are always discontinuous and require some additional matter–energy content in the surface (the Bubble) to correct the discontinuity.

In the BHU solution (Gaztañaga 2022a, b, c, d, e), no Bubble is needed and the inside is not filled with a false vacuum, but with regular matter and radiation. The gravitational radius r_S, corresponding to the regular energy and mass contents inside, represents a boundary term which plays the role of a Bubble. The model by Zhang (2018) has the same name and similar features as the BHU, but it does not result from a physical solution to a GR problem but it is presented as a new fundamental postulate to GR.

As we will show, the difference between the BHU and the classical solutions of Oppenheimer & Snyder (1939) and Misner & Sharp (1964) is that the latter considered only collapsing (and not expanding) solutions and they did not account for the role of the gravitational radius r_S (or effective Λ term) as a boundary condition for an expanding solution (Gaztañaga 2022c).

In Section 2, we review GR solutions to the problem of a uniform spherical ball with fixed total relativistic mass M_T. In Section 3, we

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interpret what we mean by M_T and then show in Section 4 that the observed cosmic expansion is consistent with the BHU model. We end with conclusions and a discussion of how the BHU could form.

2 A UNIFORM SPHERICAL BALL

A metric $g_{\mu\nu}$ with spherical symmetry in spherical coordinates and proper time $dx^\mu = (d\tau, d\chi, d\theta, d\phi)$ can be expressed as (Tolman 1934; Oppenheimer & Snyder 1939; Misner & Sharp 1964)

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu = -d\tau^2 + e^{\lambda(\tau,\chi)}d\chi^2 + r^2(\tau,\chi)d\Omega^2, \quad (1)$$

where we use units of speed of light $c = 1$ and the radial coordinate χ will be taken here to be comoving with the matter content. This metric is sometimes called the Lemaitre–Tolman (Lemaître 1927; Tolman 1934) or the Lemaitre–Tolman–Bondi metric. This metric is localized around a reference central point in space, which we have set to be the origin ($\boldsymbol{r} = 0$) for simplicity.

For an observer moving with a perfect fluid, the energy–momentum tensor is diagonal: $T^\nu_\mu = \mathrm{diag}[-\rho, p, p, p]$, where $\rho = \rho(\tau, \chi)$ is the energy density and $p = p(\tau, \chi)$ is the pressure. The off-diagonal terms of the field equation are zero, e.g. $8\pi G T^1_0 = G^1_0 = 0$, which translates into

$$(\partial_\tau\lambda)(\partial_\chi r) = 2\partial_\tau(\partial_\chi r). \quad (2)$$

This equation can be solved as $e^\lambda = C(\partial_\chi r)^2$, where $\partial_\tau C = 0$. The case $C = 1$ corresponds to a flat geometry:

$$ds^2 = -d\tau^2 + [\partial_\chi r]^2 d\chi^2 + r^2 d\Omega^2, \quad (3)$$

so that there is only one function we need to solve: $r = r(\tau, \chi)$, which corresponds to the radial proper distance. The field equations for r (with $\Lambda = 0$) are

$$H^2 \equiv r_H^{-2} \equiv \left(\frac{\dot r}{r}\right)^2 = \frac{2GM}{r^3}, \quad (4)$$

$$M \equiv \int_0^\chi \rho\, 4\pi r^2(\partial_\chi r)d\chi = M(\tau, \chi), \quad (5)$$

where the dot here is $\dot r \equiv \partial_\tau r$. When $\rho = \rho(\tau)$ is uniform, we have $M = \frac{4\pi}{3}r^3\rho$ and $r = a(\tau)\chi$, so that equation (3) reproduces the flat (global) FLRW metric, $ds^2 = -d\tau^2 + a^2(d\chi^2 + \chi^2 d\Omega^2)$, and equation (4) is the corresponding solution, $3H^2(\tau) = 8\pi G\rho(\tau)$, which is a global solution (any point can be chosen to be the centre $\boldsymbol{r} = 0$). The non-flat case, or more sophisticated global topologies, could also be reproduced if we consider the more general case, but there is no observational or theoretical evidence that such complications are in fact needed. For a matter-dominated universe with $\rho = \rho_0 a^{-3}$, we have a constant mass inside χ: $M = \frac{4\pi}{3}\chi^3\rho_0$. More generally, M could be a function of time. But at any given time, the total mass M_T is always infinite: $M_T \equiv M(\chi < \infty) = \infty$ in the global FLRW solution.

The solution in equations (4) and (5) can also be used to solve non-homogeneous cases. The simplest is the case of an expanding (or collapsing) uniform spherical ball inside a comoving coordinate χ_*:

$$\rho(\tau, \chi) = \begin{cases} \rho(\tau) & \text{for } \chi \le \chi_* \\ 0 & \text{for } \chi > \chi_* \end{cases}, \quad (6)$$

which reproduces the exact same FLRW metric and solution $r = a\chi$ with the same mass inside $\chi < \chi_*$ as in the infinite FLRW case. The Hubble–Lemaitre expansion law, $\dot r = H(\tau)r$, of equation (4) with $3H^2(\tau) = 8\pi G\rho(\tau)$ is also the same inside χ_*. The only difference is that this is now a local FLRW solution with empty space outside χ_*, so that the total mass is finite:

$$M_T \equiv M(\chi < \infty) = M(\chi < \chi_*) = \frac{4}{3}\pi R^3\rho(\tau) < \infty, \quad (7)$$

where $R \equiv a\chi_*$. This is a consequence of *Birkhoff's theorem* (see Johansen & Ravndal 2006; Faraoni & Atieh 2020), since a sphere cut out of an infinite uniform distribution has the same spherical symmetry. Thus, the FLRW metric is both a solution to a global homogeneous (i.e. infinite M_T) uniform background and also to the inside of a local (finite-mass) uniform sphere centred around one particular point. The local solution is called the FLRW cloud (Gaztañaga 2022c).

3 RELATIVISTIC MASS

Misner & Sharp (1964) mass energy $M_{\rm MS}$ inside a spatial hypersurface Σ of equation (1), given by $r < R$ (or $\chi < \chi_*$), is

$$M_{\rm MS} = \int_0^R \rho 4\pi r^2 dr = \int_0^{\chi_*} \rho \left(1 + \frac{\dot r^2}{c^2} - \frac{2GM_{\rm MS}}{c^2 r}\right)^{1/2} dV_3, \quad (8)$$

where $dV_3 = d^3y\sqrt{-h} = 4\pi r^2 e^{\lambda/2}d\chi$ is the 3D spatial volume element of the metric in Σ (we recover here units if $c \neq 1$ to check the non-relativistic limit). The first term is the material or passive mass (which we call here M):

$$M = \int_\Sigma \rho\, dV_3 = \int_0^{\chi_*} \rho\, 4\pi r^2(\partial_\chi r)d\chi, \quad (9)$$

and corresponds to equation (5). We can then interpret the next two terms in equation (8) as the contribution to mass energy from the kinetic and potential energy (see also Hayward 1996 for a more general description). In the non-relativistic limit ($c = \infty$), these two terms are negligible and $M_{\rm MS} = M$. But in general, as indicated by equation (8), $M_{\rm MS}$ cannot be expressed as a sum of individual energies as $M_{\rm MS}$ also appears inside the integral, reflecting the non-linear nature of gravity. But in the case of equation (4), the kinetic and potential energy terms cancel for $M = M_{\rm MS}$ and we can interpret M as the total relativistic mass energy of the system.

For the case in equations (4) and (5), the mass inside χ is constant for matter-dominated fluid when $\rho \sim a^{-3}$. But in the early stages of the expansion, when the energy density is dominated by radiation or a fluid with a different equation of state, the mass inside χ is a function of τ. If we want M_T in equation (7) to be constant throughout the evolution, we need the junction χ_* in equation (6) to be a function of time τ:

$$R^3(\tau) \equiv a^3(\tau)\chi_*^3(\tau) = \frac{3M_T}{4\pi\rho(\tau)}. \quad (10)$$

Note that both R and χ_* here are just radial coordinates and not proper distances between events. A different, but equivalent, approach to the problem of having a finite fixed mass M_T is the use of junction conditions to match the FLRW solution inside R to a Schwarzschild solution outside, see Gaztañaga (2022c, e).

4 BLACK HOLE SOLUTION

For the local top-hat distribution of equation (6), if all the mass M_T is contained within $R < r_S = 2GM_T$, the solution corresponds to a BH (see Firouzjaee & Mansouri 2010). In the limit where the exterior is empty, the gravitational radius r_S should be interpreted as a boundary that separates the interior ($r < r_S$) from the exterior manifold. This creates an isolated Universe inside with a boundary condition at r_S.

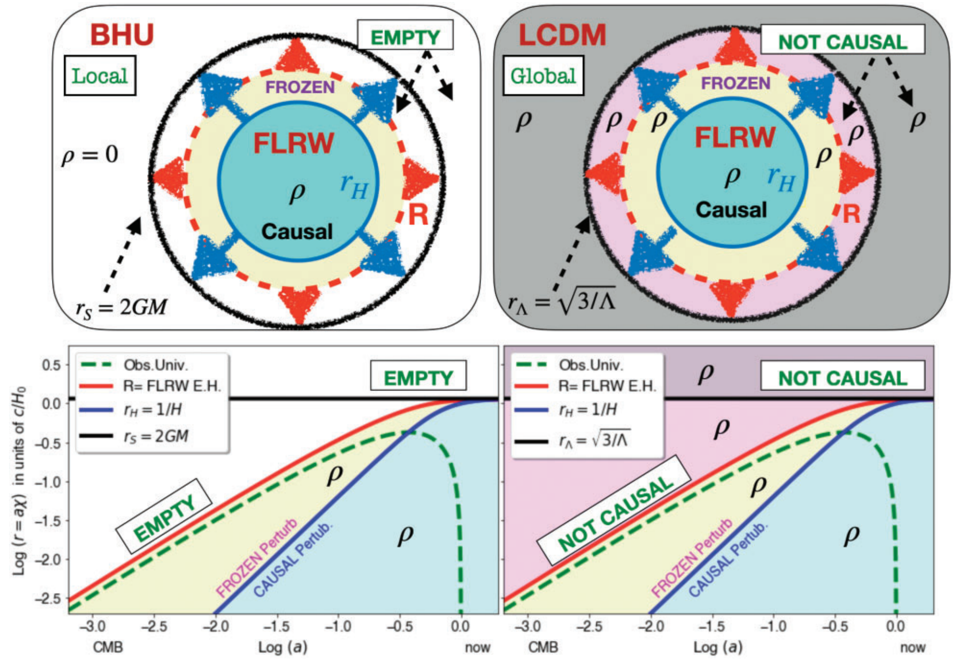

Figure 1. Top panels: Comparison of the proper radius $r = a\chi$ of the BHU (left) and the LCDM (right) models at a fixed time. The inner blue circle represents a sphere of radius $r_H = 1/H$. The dashed red one corresponds to the future event horizon R of the FLRW metric in equation (22). Both r_H and R expand towards the fixed black sphere: the gravitational radius r_S in the BHU and $r_\Lambda = \sqrt{\Lambda/3}$ in LCDM. Scales $r > R$ are not causally connected; despite this, the LCDM has the same density everywhere. Bottom panels: Evolution of the different radius as a function of time (given by the scale factor a) for $\Omega_\Lambda = 0.7$. The dashed green line is the past light cone or observable Universe: $a\int_a^1 \frac{da}{Ha^2}$. We can only see photons emitted in the past along this green line radial trajectory (in all directions). So, we cannot measure background anisotropies (from outside R) even if the observer is off-centred within the local BHU solution.

Having a boundary condition or surface term changes the Einstein–Hilbert action $S = S_{\rm EH}$ and therefore the field equations. Without surface terms,

$$S_{\rm EH} = \int_{V_4} {\rm d}V_4 \left[\frac{R}{16\pi G} + \mathcal{L}\right], \tag{11}$$

where ${\rm d}V_4 = \sqrt{-g}{\rm d}^4x$ is the invariant volume element, V_4 is the volume of the 4D space–time manifold, $R = R^\mu_\mu = g^{\mu\nu}R_{\mu\nu}$ is the Ricci scalar curvature, and $\mathcal{L}$ is the Lagrangian of the energy–matter content. Including also a Λ term, which we call here $\Lambda_{\rm raw}$ to refer to a priori or fundamental contribution, the total action is $S = S_{\rm EH} + S_\Lambda$, where

$$S_\Lambda \equiv \int_{V_4} {\rm d}V_4 \left[\frac{-2\Lambda_{\rm raw}}{16\pi G}\right]. \tag{12}$$

We can obtain Einstein's field equations for the metric field $g_{\mu\nu}$ by requiring S to be stationary $\delta S = 0$ under arbitrary variations of the metric $\delta g^{\mu\nu}$. The solution is (e.g. Padmanabhan 2010)

$$G_{\mu\nu} + \Lambda_{\rm raw} g_{\mu\nu} = 8\pi G T_{\mu\nu} \equiv -\frac{16\pi G}{\sqrt{-g}}\frac{\delta(\sqrt{-g}\mathcal{L})}{\delta g^{\mu\nu}}, \tag{13}$$

where $G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$. Equation (13) requires that boundary terms vanish. Otherwise, we need to add a Gibbons–Hawking–York (GHY) boundary term (York 1972; Gibbons & Hawking 1977; Hawking & Horowitz 1996) to the total action $S = S_{\rm EH} + S_\Lambda + S_{\rm GHY}$ where

$$S_{\rm GHY} \equiv \frac{1}{8\pi G}\oint_{\partial V_4} {\rm d}^3y\sqrt{-h}\,K, \tag{14}$$

where K is the trace of the extrinsic curvature at the boundary ∂V_4 and h is the induced metric. Gaztañaga (2022c) showed how when the FLRW evolution happens inside r_S, we have $K = -2/r_S$ (independently of $\Lambda_{\rm raw}$). Such GHY boundary generates an effective Λ term, $\Lambda_{\rm e} = 3/r_S^2$ (when $\Lambda_{\rm raw} = 0$), so that

$$S_{\rm GHY} = \frac{1}{8\pi G}\int {\rm d}\tau\, 4\pi r_S^2\, K = -\frac{r_S^3\Lambda_{\rm e}}{3G}\tau = \int_{V_4} {\rm d}V_4\left[\frac{-2\Lambda_{\rm e}}{16\pi G}\right]. \tag{15}$$

So, we have that the new action, including the surface term, is the same as the original action but it has, in principle, two degenerate contributions to the observed Λ value – a raw value $\Lambda_{\rm raw}$ (that we could add a priori by hand) and the surface term $\Lambda_{\rm e} = 3/r_S^2$:

$$\Lambda = \Lambda_{\rm raw} + \Lambda_{\rm e} = \Lambda_{\rm raw} + \frac{3}{r_S^2}. \tag{16}$$

The fact that a GHY surface term from r_S mimics a Λ term was originally proposed in Gaztañaga (2021) and also developed in Gaztañaga (2022b, c, e). As is well known, a Λ term changes the field equation in equation (4) into

$$H^2 = \frac{2GM}{r^3} + \frac{\Lambda}{3} = \frac{8\pi G}{3}\sum_i \rho_i^0 a^{-3(1+\omega_i)} + \frac{\Lambda}{3}, \tag{17}$$

where in the last step we have used $r = a\chi$ and $\rho = \sum_i \rho_i^0 a^{-3(1+\omega_i)}$, with $\omega_i \equiv p_i/\rho_i$ is the equation of state of each fluid component. Note that equation (5) does not change when we modify the field equations with a Λ term because it results from energy conservation: $\nabla_\mu T^\mu_\nu = 0$ (while equation 4 comes from the G^0_0 component of Einstein's field equations in equation 13). Also note that we still have $M = M_{\rm MS}$, because the Λ term adds another contribution to $M_{\rm MS}$ in equation (13):

$$M_{\rm MS} = \int_\Sigma \rho\left(1 + \frac{\dot{r}^2}{c^2} - \frac{2GM_{\rm MS}}{c^2 r} - \frac{\Lambda}{3}r^2\right)^{1/2} {\rm d}V_3, \tag{18}$$

which cancels out with the new Hubble law in equation (17). In terms of $\Omega_i = \rho_i/\rho_c$, where $\rho_c = 3H_0^2/(8\pi G)$

$$H^2 = H_0^2 \left[\sum_i \Omega_i a^{-3(1+\omega_i)}\right] + \frac{\Lambda}{3}, \quad (19)$$

where typically we have $i = \{1, 2\}$ with $\omega_1 = 0$ for matter and $\omega_2 = 1/3$ for radiation. This is exactly what we measure in cosmological surveys. It shows how we can interpret the observed cosmic expansion as being a local BH solution, the BHU with $\Lambda = \Lambda_e = 1/r_S^2$ and $\Lambda_{raw} = 0$. If there is also DE and/or Λ_{raw}, we have to add all three contributions: a DE term with $\omega_{DE} = p_{DE}/\rho_{DE}$ in the i sum of equation (19) and the two terms of Λ in equation (16). Given that the three terms are approximately constant (for $\omega_{DE} = -1$), there is no way to distinguish them using measurements of the Hubble–Lemaitre law. Current observations tell us that indeed $\omega_{DE} \simeq -1$ (DES Collaboration 2019) and the sum of the three terms is the observed Λ term such that $\Omega_\Lambda \equiv \frac{\Lambda}{3H_0^2} \simeq 0.7$ or, in other words,

$$\Lambda \equiv 3/r_\Lambda^2 \equiv 3\Omega_\Lambda H_0^2 \equiv 8\pi G\rho_{DE} + \Lambda_{raw} + 3/r_S^2 \simeq 2.1H_0^2. \quad (20)$$

If $\rho_{DE} = \Lambda_{raw} = 0$, we have that $r_S = r_\Lambda$ and the mass of our Universe is

$$M_T = \frac{c^2}{2G}\sqrt{3/\Lambda} = \frac{c^2}{2G}\Omega_\Lambda^{-1/2} H_0^{-1} \simeq 6 \times 10^{22}\,\mathrm{M}_\odot, \quad (21)$$

where we have returned to units of $c \neq 1$ here to be more explicit. This corresponds to the BHU. In the other limit, if $r_S = \infty$, we recover the infinite LCDM model with $M_T = \infty$ and $\Omega_\Lambda = \Omega_{DE} \simeq 0.7$. Both possible solutions have the same future event horizon, R as

$$R(a) = a\int_a^\infty \frac{da}{Ha^2} < r_\Lambda, \quad (22)$$

which is bounded by $R < r_\Lambda$ (Gaztañaga 2022c): anything that is at $r > R(a)$ is outside causal reach. Here, $R(a)$ is the maximum proper distance that a photon can travel. Fig. 1 shows a comparison of the two possible interpretations.

We could also have an intermediate situation, but it would be quite unnatural that r_S (from M_T) and r_Λ (from DE or Λ_{raw}) are fine-tuned to both contribute significantly to the observed cosmic acceleration. We therefore have to choose one of the two interpretations. Given that $M_T = \infty$ is a non-physical (and not causally possible) solution and that we do not know what DE or Λ_{raw} is, it seems more plausible and simpler to interpret cosmic acceleration as a measurement for the mass M_T of our Universe. In this case, $\rho_{DE} \simeq \Lambda_{raw} \simeq 0$ and our Universe is inside a local BHU.

5 CONCLUSION

We have interpreted the observed Λ to be an effective term that corresponds to the gravitational radius $r_S = \sqrt{3/\Lambda_e} = 2GM_T$ of our local Universe. This has several implications:

(i) The mass of our Universe can be estimated to be $M_T \simeq 6 \times 10^{22}$ $\mathrm{M}_\odot$ (see equation 21), which agrees well with what we have observed in the largest Galaxy surveys, such as DES Collaboration (2019).

(ii) The corresponding dynamical time is $\tau \sim GM_T \sim 14$ Gyr, which is close to the measured age of the oldest galaxies and stars that we observe.

(iii) Our Universe is a local solution inside its gravitational radius r_S. It is therefore a BHU rather than a white hole solution (e.g. see Gaztañaga 2022e). The mean density that we have measured for our Universe today is extremely low (few atoms per cubic metric) but still larger than the BH density corresponding to the mass M_T that we have measured from the observed cosmic acceleration. This fact indicates that our Universe is inside its gravitational radius (as otherwise the observed density should be smaller). We also know that we are inside a BH from the fact that we observed Baryon Acoustic Oscillations (BAOs) which corresponds to perturbations that enter the Hubble horizon (see Fig.1).

(iv) An observer placed anywhere within the local BHU measures the same background as one within the LCDM. This becomes obvious when we note that the future event horizon R in equation (22) is a null geodesic and therefore no signal can reach us from outside R, no matter how close the observer is to the boundary (see Fig. 1 and Gaztañaga 2022c for more details).

(v) The smoking gun of the BHU is a cut-off in the scale of the largest perturbations, which has already been measured in cosmic microwave background maps (Fosalba & Gaztañaga 2021; Gaztañaga & Camacho-Quevedo 2022).

(vi) Our BHU might not be unique: there could also exist other universes, like ours, elsewhere. The same way we found that there are other island universes (or galaxies), there could also be other BHUs, may be similar to ours, elsewhere outside our gravitational radius. This is part of the Copernican Revolution: our place is not special. There is more than one planet, one Sun, one galaxy, or one BHU?

Figure 2. Left: The expanding Crab Nebula supernova remnant, as observed in 1999 from the *Hubble Space Telescope*, 945 yr after the explosion. The observed pulsar remnant could be part of the dark matter, in the form of primordial neutron stars and primordial BHs. Right: The MICE simulation (Carretero et al. 2015) of large-scale structures in our expanding Universe.

How did such a BHU form? Here, we enter the more speculative grounds of the BB theories. The BHU could have formed in a similar way as the standard LCDM universe: out of one of the many existing models of cosmic inflation (Starobinskiǐ 1979; Guth 1981; Albrecht & Steinhardt 1982; Linde 1982; Liddle 1999) or from some of the quantum gravity alternatives (e.g. Easson & Brandenberger 2001; Novello & Bergliaffa 2008; Popławski 2016; Brandenberger 2017; Ijjas & Steinhardt 2018).

The BHU could have also formed in a much simpler way, just like the first stars: collapsing and exploding in a supernova following the known laws of physics (Gaztañaga 2022d). Left-hand panel of Fig. 2 shows the Crab Nebula, a remnant of a supernova, which can be thought as a small version of our Universe today. In such case, cosmic inflation or quantum gravity explanations are not needed to understand the origin of our cosmic expansion. Such simple beginning would provide us with an anthropic explanation for the observed value of r_S and the coincidence problem (only a mass M_T as large as measured here can host observers like us at a time when Λ becomes important). It also yields new candidates for dark matter in the form of compact remnants of the collapse and bouncing phases, such as primordial BHs and primordial neutron stars (Gaztañaga 2022d).

The BHU exists within a larger background that may or may not be totally empty outside. In the latter case, r_S could increase if there is accretion from outside. This case is more speculative and needs to be studied in more detail, but it could result in an effective Λ_e term that decreases with time ($\omega_{DE} > -1$). The alternative interpretation is that M_T (and therefore r_S) are infinite so that the measured Λ can only be attributed to DE. This is the standard (LCDM) interpretation. In our view, this alternative is less appealing because it involves non-physical infinite, non-causal structure (Gaztañaga 2020, 2021) and new components, DE or Λ_{raw}, which are not really needed.

ACKNOWLEDGEMENTS

We acknowledge grants from Spain Plan Nacional (PGC2018-102021-B-100) and Maria de Maeztu (CEX2020-001058-M).

DATA AVAILABILITY

No new data are presented in this letter.

REFERENCES

Aguirre A., Johnson M. C., 2005, Phys. Rev. D, 72, 103525
Albrecht A., Steinhardt P. J., 1982, Phys. Rev. Lett., 48, 1220
Blau S. K., Guendelman E. I., Guth A. H., 1987, Phys. Rev. D, 35, 1747
Brandenberger R., 2017, Int. J. Mod. Phys. D, 26, 1740002
Carretero J., Castander F. J., Gaztañaga E., Crocce M., Fosalba P., 2015, MNRAS, 447, 646
Daghigh R. G., Kapusta J. I., Hosotani Y., 2000, preprint (arXiv:gr-qc/0008006)
DES Collaboration, 2019, Phys. Rev. Lett., 122, 171301
Dodelson S., 2003, Modern Cosmology, Academic Press, New York
Dymnikova I., 2019, Universe, 5, 111
Dyson L., Kleban M., Susskind L., 2002, J. High Energy Phys., 2002, 011
Easson D. A., Brandenberger R. H., 2001, J. High Energy Phys., 2001, 024
Faraoni V., Atieh F., 2020, Phys. Rev. D, 102, 044020
Firouzjaee J. T., Mansouri R., 2010, Gen. Relativ. Gravit., 42, 2431
Firouzjahi H., 2016, preprint (arXiv:1610.03767)
Fosalba P., Gaztañaga E., 2021, MNRAS, 504, 5840
Frolov V. P., Markov M. A., Mukhanov V. F., 1989, Phys. Lett. B, 216, 272
Garriga J., Vilenkin A., Zhang J., 2016, J. Cosmol. Astropart. Phys., 2016, 064
Gaztañaga E., 2020, MNRAS, 494, 2766
Gaztañaga E., 2021, MNRAS, 502, 436
Gaztañaga E., 2022a, Universe, 8, 257
Gaztañaga E., 2022b, Symmetry, 14, 300
Gaztañaga E., 2022c, Symmetry, 14, 1849
Gaztañaga E., 2022d, Symmetry, 14, 1984
Gaztañaga E., 2022e, preprint (202212.0447)
Gaztañaga E., Camacho-Quevedo B., 2022, Phys. Lett. B, 835, 137468
Gibbons G. W., Hawking S. W., 1977, Phys. Rev. D, 15, 2738
Gonzalez-Diaz P. F., 1981, Nuovo Cimento Lett., 32, 161
Good I. J., 1972, Phys. Today, 25, 15
Grøn Ø., Soleng H. H., 1989, Phys. Lett. A, 138, 89
Guth A. H., 1981, Phys. Rev. D, 23, 347
Hawking S. W., Horowitz G. T., 1996, Class. Quantum Gravity, 13, 1487
Hayward S. A., 1996, Phys. Rev. D, 53, 1938
Ijjas A., Steinhardt P. J., 2018, Class. Quantum Gravity, 35, 135004
Johansen N., Ravndal F., 2006, Gen. Relativ. Gravit., 38, 537
Knutsen H., 2009, Gravit. Cosmol., 15, 273
Kusenko A., Sasaki M., Sugiyama S., Takada M., Takhistov V., Vitagliano E., 2020, Phys. Rev. Lett., 125, 181304
Lemaître G., 1927, Ann. Soc. Sci. Brux., 47, 49
Liddle A. R., 1999, preprint (astro–ph/9910110)
Linde A. D., 1982, Phys. Lett. B, 108, 389
Mazur P. O., Mottola E., 2015, Class. Quantum Gravity, 32, 215024
Misner C. W., Sharp D. H., 1964, Phys. Rev., 136, B571
Novello M., Bergliaffa S. E. P., 2008, Phys. Rep., 463, 127
Oppenheimer J. R., Snyder H., 1939, Phys. Rev., 56, 455
Oshita N., Yokoyama J., 2018, Phys. Lett. B, 785, 197
Padmanabhan T., 2010, Gravitation. Cambridge Univ. Press, Cambridge
Pathria R. K., 1972, Nature, 240, 298
Penrose R., 2006, in Conf. Proc. C, Vol. 060626, Before the Big Bang: An Outrageous New Perspective and Its Implications for Particle Physics. p. 2759
Popławski N., 2016, ApJ, 832, 96
Smolin L., 1992, Class. Quantum Gravity, 9, 173
Starobinskiĭ A. A., 1979, Sov. J. Exp. Theor. Phys. Lett., 30, 682
Stuckey W. M., 1994, Am. J. Phys., 62, 788
Tolman R. C., 1931, Phys. Rev., 37, 1639
Tolman R. C., 1934, in Proceedings of the National Academy of Sciences of the United States of America, Vol. 20, Effect of Inhomogeneity on Cosmological Models. p. 169
Weinberg S., 2008, Cosmology, Oxford Univ. Press, Oxford
York J. W., 1972, Phys. Rev. Lett., 28, 1082
Zhang T. X., 2018, J. Mod. Phys., 9, 1838

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