Status of Electromagnetic Accelerating Universe *

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Abstract

To describe the dark side of the Universe, we adopt a novel approach where dark energy is explained as an electrically charged majority of dark matter. Dark energy, as such, does not exist. The Friedmann equation at the present time coincides with that in a conventional approach, although the cosmological "constant" in the Electromagnetic Accelerating Universe (EAU) Model shares a time dependence with the matter component. Its equation of state is $\omega \equiv P/\rho \equiv -1$ within observational accuracy.

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1 Introduction to the EAU Model

Theoretical cosmology is at an exciting stage because about 95% of the energy in the Visible Universe remains incompletely understood. The 25% which is Dark Matter has constituents whose mass is unknown by over one hundred orders of magnitude. The 70% which is Dark Energy is, if anything, more mysterious: although it can be parametrised by a Cosmological Constant with equation of state $\omega = -1$ which provides an excellent phenomenological description, that is only a parametrisation and not a complete understanding.

in the present paper, we address the issues of Dark Matter and Dark Energy using a novel approach. We use only the classical theories of electrodynamics and general relativity. We shall not employ any knowledge of quantum mechanics or of theories describing the short range strong and weak interactions.

This paper may be regarded as a follow up to our 2018 paper [1] entitled On the Origin and Nature of Dark Matter and could have simply added and Energy to that title. We have, however, chosen Status of Electromagnetic Accelerating Universe because it more accurately characterises our present emphasis on the EAU model whose main idea that electromagnetism dominates over gravitation in the explanation of the accelerating cosmological expansion. This idea takes us beyond the first paper [2] which applied general relativity to theoretical cosmology. This is not surprising, since in 1917 that author was obviously unaware of the fact [3,4] discovered only in 1998 that the rate of cosmological expansion is accelerating.

The make up of this paper is that Primordial Black Holes are discussed in Section 2, then Primordial Naked Singularities in Section 3. Section 4 contains a possible supporting evidence for the EAU model based on the recently reported Amaterasu cosmic ray. Finally in Section 5 there is a Discussion.

2 Primordial Black Holes (PBHs)

Black holes in the universe fall into two classes, those which arise from the gravitational collapse of stars and others which do not. By primordial, we refer to all of the others. In general, PBHs with masses up to $10^5 M_{\odot}$ are expected to be formed during the first second after the Big Bang and arise from inhomogeneities and fluctuations of spacetime. The existence of PBHs was first posited in Russia [5] by Novikov and Zeldovich and independently seven years later in the West by Carr and Hawking [6]. The idea that the dark matter constituents are PBHs was first suggested by Chapline [7].

Shortly after the original presentation of general relativity [8] a metric describing a static black hole of mass M with zero charge and zero spin was discovered by Schwarzschild [9] in the form

$$ds^{2} = -\left(1 - \frac{r_{S}}{r}\right)dt^{2} + \left(1 - \frac{r_{S}}{r}\right)^{-1}dr^{2} + r^{2}d\Omega^{2}$$
(1)

Shortly thereafter, the Reissner-Nordstrom metric [10] for a static Black Hole with electric charge was found. It then took a surprising forty-five years until Kerr cleverly found a solution [11] of general relativity corresponding to a such a solution with spin. We shall not discuss the case of non-zero spin in the present paper because, although we expect that all the objects we discuss do spin in Nature, according to the calculations in [12] which use Kerr's generalisation, spin is an inessential complication in all of our subsequent considerations.

2.1 Primordial Intermediate Mass Black Holes (PIMBHs) as Galactic Dark Matter

According to global analyses of the cosmological parameters about one quarter of the energy of the universe is in the form of electrically-neutral dark matter. It has been proposed [13] that the dark matter constituents are black holes with masses many times the mass of the Sun. In a galaxy like the Milky Way, the proposal is that residing in the galaxy are between ten million and ten billion black holes with masses between one hundred and one hundred thousand solar masses.

Black holes in this range of masses are commonly known as Intermediate Mass Black Hole (IMBHs) since they lie above the masses of stellar-mass black holes and below the masses of the supermassive black holes at galactic centres. It has long been mysterious why there is a mass gap between stellarmass and supermassive black holes. If the proposed solution of the galactic dark matter problem is correct, it will answer this old question.

There is irrefutable evidence for stellar-mass black holes from observations of X-ray binaries. Such systems were first emphasized in [14] then further studied in [15]. All the known stellar-mass black holes are members of X-ray binaries. The first was discovered sixty years ago in 1964 in Cygnus X-1 and many stellar-mass black holes have since been discovered from studies of X-ray binaries, with masses in a range between $5M_{\odot}$ and $100M_{\odot}$, where the first-discovered Cygnus X-1 is at about $15M_{\odot}$.

We note historically that dark matter was first discovered by Zwicky [16,17] in 1933 in the Coma Cluster, and its presence in galaxies was demonstrated convincingly by Rubin in the 1960s and 1970s from the rotation curves of many galaxies [18].

Regarding the PBH mass range, the possible PBH masses extend upwards to many solar masses and above, far beyond what was was thought possible twenty years ago when ignorance about PBHs with many solar masses probably prevented the MACHO [19] and EROS [20] Collaborations from discovering more of the dark matter.

If all black holes were formed by gravitational collapse then black holes with $M_{BH} \ll M_{\odot}$ would be impossible because stars powered by nuclear fusion cannot be far below $M = M_{\odot}$. It was first suggested in [5,6] that black holes can be produced in the early stages of the cosmological expansion.

Such PBHs are of special interest for several reasons. Firstly, they are the only type of black hole which can be so light, down to $10^{12}kg \sim 10^{-18}M_{\odot}$, that Hawking radiation might conceivably be detected. Secondly, PBHs in the intermediate-mass region $100M_{\odot} \leq M_{IMBH} \leq 10^5 M_{\odot}$ can provide the galactic dark matter.

The mechanism of PBH formation involves large fluctuations or inhomogeneities. Carr and Hawking [6] argued that we know there are fluctuations in the universe in order to seed structure formation and there must similarly be fluctuations in the early universe. Provided the radiation is compressed to a high enough density, meaning to a radius as small as its Schwarzschild radius, a PBH will form. Because the density in the early universe is extremely high, it is very likely that PBHs will be created. The two necessities are high density which is guaranteed and large inhomogeneities. During radiation domination

$$a(t) \propto t^{1/2} \tag{2}$$

and

$$\rho_{\gamma} \propto a(t)^{-4} \propto t^{-2} \tag{3}$$

Ignoring factors O(1) and bearing in mind that the radius of a black hole is

$$r_{BH} \sim \left(\frac{M_{BH}}{M_{Planck}^2}\right) \tag{4}$$

with

$$M_{Planck} \sim 10^{19} GeV \sim 10^{-8} kg \sim 10^{-38} M_{\odot}$$
 (5)

and using the Planck density ρ_{Planck}

$$\rho_{Planck} \equiv (M_{Planck})^4 \sim (10^{-5}g)(10^{-33}cm)^{-3} = 10^{94}\rho_{H_2O} \tag{6}$$

the density of a general black hole $\rho_{BH}(M_{BH})$ is

$$\rho_{BH}(M_{BH}) \sim \left(\frac{M_{BH}}{r_{BH}^3}\right) = \rho_{Planck} \left(\frac{M_{Planck}}{M_{BH}}\right)^2 \sim 10^{94} \rho_{H_2O} \left(\frac{10^{-38} M_{\odot}}{M_{BH}}\right)^2 \tag{7}$$

which means that for a solar-mass black hole

$$\rho_{BH}(M_{\odot}) \sim 10^{18} \rho_{H_2O}$$
(8)

while for a billion solar mass black hole

$$\rho_{BH}(10^9 M_{\odot}) \sim \rho_{H_2O}.$$
(9)

and above this mass the density falls as M_{BH}^{-2} .

The mass of the PBH is derived by combining Eqs. (3) and (7). We see from these two equations that M_{PBH} grows linearly with time and using Planckian units or Solar units we find respectively

$$M_{PBH} \sim \left(\frac{t}{10^{-43}sec}\right) M_{Planck} \sim \left(\frac{t}{1sec}\right) 10^5 M_{\odot}$$
 (10)

which implies, if we insisted on PBH formation before the electroweak phase transition, $t < 10^{-12}s$, that

$$M_{PBH} < 10^{-7} M_{\odot} \tag{11}$$

The upper bound in Eq.(11) explains historically why the MACHO searches around 2000 [19,20], inspired by the 1986 suggestion of Paczynski [21], lacked motivation to pursue searching beyond $100M_{\odot}$ because it was thought incorrectly at that time that PBHs were too light. It was known correctly that the results of gravitational collapse of normal stars, or even large early stars, were below $100M_{\odot}$. Supermassive black holes with $M > 10^6M_{\odot}$ such as $SagA^*$ in the Milky Way were beginning to be discovered in galactic centers but their origin was unclear and will be discussed further in the following Section 2.2.

Hawking radiation implies that the lifetime for a black hole evaporating *in vacuo* is given by the cubic formula

$$\tau_{BH} \sim \left(\frac{M_{BH}}{M_{\odot}}\right)^3 \times 10^{64} years$$
(12)

so that to survive for the age 10^{10} years of the universe, there is a lower bound on M_{PBH} to augment the upper bound in Eq.(11), giving as the full range of Carr-Hawking PBHs:

$$10^{-18} M_{\odot} < M_{PBH} < 10^{-7} M_{\odot} \tag{13}$$

The lowest mass surviving PBH in Eq.(13) has the density $\rho \sim 10^{58} \rho_{H_2O}$. It is an awesome object which has the physical size of a proton and the mass of Mount Everest.

The Hawking temperature $T_H(M_{BH})$ of a black hole is

$$T_H(M_{BH}) = 6 \times 10^{-8} K\left(\frac{M_{\odot}}{M_{BH}}\right)$$
(14)

which would be above the CMB temperature, and hence there would be outgoing radiation for all of the cases with $M_{BH} < 2 \times 10^{-8} M_{\odot}$. Hypothetically, if the dark matter halo were made entirely of the brightest possible (in terms of Hawking radiation) $10^{-18} M_{\odot}$ PBHs, the expected distance to the nearest PBH would be about 10^7 km. Although the PBH temperature, according to Eq. (14) is ~ 6 × $10^{10} K$, the inverse square law renders the intensity of Hawking radiation too small, by many orders of magnitude, to allow its detection by any foreseeable apparatus on Earth.

The original mechanism produces PBHs with masses in the range up to $10^{-7}M_{\odot}$. We shall now discuss formation of far more massive PBHs by a different mechanism. As discussed, PBH formation requires very large inhomogeneities. Here we shall briefly illustrate how mathematically to produce inhomogeneities which are exponentially large.

In a single inflation, no exceptionally large density perturbation is expected. Therefore we use two-stage hybrid inflation with respective fields called [22], inflaton and waterfall. The idea of parametric resonance is that after the first inflation mutual couplings of the inflaton and waterfall fields cause both to oscillate wildly and produce perturbations which grow exponentially. The secondary (waterfall) inflation then stretches further these inhomogeneities, enabling production of PBHs with arbitrarily high mass. The specific model provides an existence theorem to confirm that arbitrary mass PBHs can be produced. The resulting mass function is spiked, but it is possible that other PBH production mechanisms can produce a smoother mass function, as deserves further study. The details of the model are in [23] where the inflaton and waterfall fields are denoted by σ and ψ respectively.

Between the two stages of inflation, the σ and ψ fields oscillate, decaying into their quanta via their self and mutual couplings. Specific modes of σ and ψ are amplified by parametric resonance. The resulting equation which couples the two fields is of Mathieu type with the required exponentiallygrowing solutions. Numerical solution shows that the peak wave number k_{peak} is approximately linear in m_{σ} . The resultant PBH mass, the horizon mass when the fluctuations re-enter the horizon, is approximately

$$M_{PBH} \sim 1.4 \times 10^{13} M_{\odot} \left(\frac{k_{peak}}{Mpc^{-1}}\right)^{-2}$$
 (15)

Explicit plots were exhibited in [23] for the cases $M_{PBH} = 10^{-8} M_{\odot}$, $10^{-7} M_{\odot}$ and $10^5 M_{\odot}$ but it was checked at that time in 2010 that the parameters can be chosen to produce arbitrarily high PBH mass.

In this production mechanism based on hybrid inflation with parametric resonance, the mass function is sharply spiked at a specific mass region. Whether such a mass function is a general feature of PBH formation, or is only a property of this specific mechanism, merits further study. The mechanism demonstrates the possibility of primordial formation of black holes with many solar masses. For completeness, it should be pointed out that PBHs with masses up to $10^{-15} M_{\odot}$ were discussed already in the 1970s, for example by Carr [24] and by Novikov, Polnarev, Starobinskii and Zeldovich [25].

For dark matter in galaxies, PIMBHs are important, where the upper end may be truncated at $10^5 M_{\odot}$ to stay well away from galactic disk instability [26].

The dark matter in the Milky Way fills out an approximately spherical halo somewhat larger in radius than the disk occupied by the luminous stars. Numerical simulations of structure formation suggest a profile of the dark matter of the NFW types [27]. The NFW profile is independent of the mass of the dark matter constituent.

Our discussion [13] focused on galaxies like the Milky Way and restricted the mass range for the appropriate dark matter to only three orders of magnitude

$$10^2 M_{\odot} < M < 10^5 M_{\odot} \tag{16}$$

We shall not repeat the arguments here, just to say that the constituents are Primordial Intermediate Mass Black Holes, PIMBHs. Given a total dark halo mass of $10^{12} M_{\odot}$, the number N of PIMBHs is between ten million (10⁷) and ten billion (10¹⁰) Assuming the dark halo has radius R of a hundred thousand (10⁵) light years the mean separation \bar{L} of PIMBHs can be estimated by

$$\bar{L} \sim \left(\frac{R}{N}\right) \tag{17}$$

which translates to

$$100ly < \bar{L} < 1000ly \tag{18}$$

which is also an estimate of the distance of the nearest PIMBH to the Earth.

It may be surprising that as many as $10^7 \leq N \leq 10^{10}$ intermediate-mass black holes in the Milky Way have remained undetected. They could have been detected more than two decades ago had the MACHO Collaboration [19] persisted in its microlensing experiment at Mount Stromlo Observatory in Australia.

The first discovery of dark matter by Zwicky [16,17] was in the Coma cluster which is a large cluster at 99 Mpc containing over a thousand galaxies and with total mass estimated at $6 \times 10^{14} M_{\odot}$ [28]. A nearer cluster at 16.5 Mpc is the Virgo cluster with over two thousand galaxies and whose mass $\sim 10^{15} M_{\odot}$ is also dominated by dark matter, as well as a small amount of X-ray emitting gas [29,30]. A proof of the existence (if more were needed) of cluster dark matter was provided by the Bullet cluster collision where the distinct behaviors of the X-ray emitting gas which collides, and the dark matter which does not collide, was clearly observable [31].

Since there is not the same disk stability limit as for galaxies, the constituents of the cluster dark matter can involve also PSMBHs up to much higher masses.

Such a solution of the galactic dark matter problem cries out for experimental verification. Three methods have been discussed: wide binaries, distortion

of the CMB, and microlensing. Of these, microlensing seems the most direct and the most promising.

Microlensing experiments were carried out by the MACHO [19] and EROS [20] Collaborations many years ago. At that time, it was believed that PBH masses were below $10^{-7}M_{\odot}$ by virtue of the Carr-Hawking mechanism. Heavier black holes could, it was then believed, arise only from gravitational collapse of normal stars, or heavier early stars, and would have mass below $100M_{\odot}$.

For this reason, there was no motivation to suspect that there might be MACHOs which led to higher-longevity microlensing events. The longevity, \hat{t} , of an event is

$$\hat{t} = 0.2yrs \left(\frac{M_{PBH}}{M_{\odot}}\right)^{\frac{1}{2}}$$
(19)

which assumes a transit velocity 200 km/s. Substituting our extended PBH masses, one finds approximately $\hat{t} \sim 6, 20, 60$ years for $M_{PBH} \sim 10^3, 10^4, 10^5 M_{\odot}$ respectively, and searching for light curves with these higher values of \hat{t} could be very rewarding.

Our understanding is that the original telescope used by the MACHO Collaboration [19] at the Mount Stromlo Observatory in Australia was accidentally destroyed by fire, and that some other appropriate telescopes are presently being used to search for extasolar planets, of which over six thousand are already known. It is seriously hoped that MACHO searches will resume and focus on greater longevity microlensing events. Some encouragement can be derived from this, by a member of the original MACHO Collaboration *There is no known problem with searching for events of greater longevity than those discovered in 2000; only the longevity of the people!* It is possible that convincing observations showing only a fraction of the light curves could suffice? If so, only a fraction of the *e.g.* six years, corresponding to PIMBHs with one thousand solar masses, could be enough to confirm the theory.

2.2 Primordial Supermassive Black Holes (PSMBHs) at Galactic Centers

There is observational evidence for supermassive black holes from the observations of fast-moving stars around them and such stars being swallowed or torn apart by the strong gravitational field. The first discovered SMBH was naturally the one, Sag A^* , at the core of the Milky Way which was discovered

in 1974 and has mass $M_{SagA*} \sim 4.1 \times 10^6 M_{\odot}$. SMBHs discovered at galactic cores include those for galaxies named M31, NGC4889, among many others. The SMBH at the core of the nearby Andromeda galaxy (M31) has mass $M = 2 \times 10^8 M_{\odot}$, fifty times M_{SagA*} . The most massive core SMBH so far observed is for NGC4889 with $M \sim 2.1 \times 10^9 M_{\odot}$. Some galaxies contain two SMBHs in a binary, believed to be the result of a galaxy merger. Quasars contain black holes with even higher masses up to at least $4 \times 10^{10} M_{\odot}$.

A black hole with the mass of $SagA^*$ would disrupt the disk dynamics [26] were it out in the spiral arms but at, or near to, the center of mass it is more stable. $SagA^*$ is far too massive to have been the result of a gravitational collapse, and if we take the view that all black holes either are the result of gravitational collapse or are primordial then the galaxies' core SMBHs must be primordial.

Nevertheless, it is probable that the PSMBHs are built up by merging and accretion from less massive PIMBH seeds.

3 Primordial Naked Singularities (PNSs)

Just as neutral black holes can be formed as PBHs in the early universe, we expect that objects can be formed based on the Reissner-Nordstrom metric [10]

$$ds^{2} = f(r)dt^{2} - f(r)^{-1}dr^{2} - r^{2}d\theta^{2} - r^{2}\sin^{2}\theta d\phi^{2}$$
(20)

where

$$f(r) \equiv \left(1 - \frac{r_S}{r} + \frac{r_Q^2}{r^2}\right). \tag{21}$$

with

$$r_S = 2GM \qquad r_Q = Q^2G \tag{22}$$

The horizon(s) of the RN metric occur when

$$f(r) = 0 \tag{23}$$

which gives

$$r_{\pm} = \frac{1}{2} \left(r_S \pm \sqrt{r_S^2 - 4r_Q^2} \right) \tag{24}$$

For $2r_Q < r_S$, $Q^2 < M$, there are two horizons. When $2r_Q = r_S$, $Q^2 = M$ the RN black hole is extremal and there is only one horizon. If $2r_Q > r_S$, $Q^2 > M$, the RN metric is super-extremal, there is no horizon at all and the r = 0 singularity is observable to a distant observer. This is known as a naked singularity and with this last inequality it is no longer a black hole which, by definition, requires an horizon.

Consider two identical objects with mass M and charge Q. Then the electromagnetic repulsive force $F_{em} \propto k_e Q^2$ and the gravitational attraction $F_{grav} \propto GM^2$. Thus, for the electromagnetic repulsion to exceed the gravitational attraction we need $Q^2 > GM^2/k_e$ and hence perhaps super-extremal Reissner-Nordstrom or Naked Singularities(NSs)³ We cannot claim to understand the formation of PNSs. One idea hinted at in [32] is that extremely massive ones, charger PEMNSs might begin life as electrically neutral PBHs which selectively accrete electrons over protons. However this formation process evolves, it must be completed before the onset of accelerated expansion some 4 billion years ago at cosmic time $t \sim 9.8$ Gy.

³To anticipate NSs we shall replace BH by NS for charged dark matter. If charges satisfy $Q^2 < M$ this replacement is unnecessary.

3.1 Like-Sign-Charged Primordial Extremely Massive Naked Singularities (PEMNSs) and Accelerated Expansion: the EAU Model

A novel EAU model was suggested in [33,34] where dark energy is replaced by charged dark matter in the form of PEMNSs or charged Primordial Extremely Massive Naked Singularities⁴. That discussion involved the new idea that at the largest cosmological distances, *e.g.* greater than 1 Gpc, the dominant force is electromagnetism rather than gravitation.

The production mechanism for PBHs in general is not well understood, and for the PEMNSs we shall make the assumption that they are formed before the accelerated expansion begins at $t = t_{DE} \sim 9.8$ Gy, For the expansion before t_{DE} we shall assume that the ΛCDM model is approximately accurate.

The subsequent expansion in the charged dark matter cPEMBH model will in the future depart markedly from the ΛCDM case. We can regard this as advantageous because the future fate of the universe in the conventional picture does have certain distasteful features in terms of the extroverse, as we briefly review.

In the ΛCDM model the introverse, or what is also called the visible universe, coincides with the extroverse at $t = t_{DE} \sim 9.8$ Gy with the common radius

$$R_{EV}(t_{DE}) = R_{IV}(t_{DE}) = 39Gly.$$
(25)

The introverse expansion is limited by the speed of light and its radius increases from Eq. (25) to 44 Gly at the present time $t = t_0$ and asymptotes to

$$R_{IV}(t \to \infty) \to 58Gly$$
 (26)

The extroverse expansion is exponential and superluminal. Its radius increases from its value 39 Gly in Eq. (25) to 52 Gly at the present time $t = t_0$ and grows without limit so that after a trillion years it attains the extremely large value

$$R_{EV}(t = 1Ty) = 9.7 \times 10^{32} Gly.$$
(27)

This future for the ΛCDM scenario seems distasteful because the introverse becomes of ever decreasing, and eventually vanishing, significance, relative to the extroverse.

 $^{{}^{4}}$ In [33, 34] the PEMNSs were called PEMBHs

A possible formation mechanism of PEMNSs was provided in [32] where their common sign of electric charge, negative, arises from preferential accretion of electrons relative to protons. This formation mechanism is not well understood ⁵ so to create a cosmological model we shall for simplicity assume that the PEMNSs are all formed before $t = t_{DE} \sim 9.8$ Gy and thereafter the Friedmann equation ignoring radiation, is

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{\Lambda(t)}{3} + \frac{8\pi G}{3}\rho_{matter}$$
(28)

where $\Lambda(t)$ is the cosmological constant generated by the Coulomb repulsion between the PEMNSs. From Eq.(28), with $a(t_0) = 1$ and constant $\Lambda(t) \equiv \Lambda_0$, we would predict that asymptotically in the future

$$a(t \to \infty) \sim exp\left(\sqrt{\frac{\Lambda_0}{3}}(t - t_0)\right)$$
 (29)

However, in the case of charged dark matter, with no dark energy, we must re-write Eq.(28) as

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho_{cPEMNSs} + \frac{8\pi G}{3}\rho_{matter}$$
(30)

in which

$$\rho_{matter}(t) = \frac{\rho_{matter}(t_0)}{a(t)^3} \tag{31}$$

where matter includes both normal matter and the uncharged dark matter. Of special interest in the present discussion is the expected future behaviour of the charged dark matter

$$\rho_{PEMNSs}(t) = \frac{\rho_{PEMNSs}(t_0)}{a(t)^3} \tag{32}$$

so that comparison of Eq.(28) and Eq.(30) suggests that the cosmological constant is predicted to decrease from its present value. More specifically, we find that asymptotically the scale factor will behave as if matter-dominated and the cosmological constant will decrease at large future times as a power

$$a(t \to \infty) \sim t^{\frac{2}{3}} \qquad \Lambda(t \to \infty) \sim t^{-2}.$$
 (33)

so that a trillion years in the future $\Lambda(t)$ will have decreased by some four orders of magnitude relative to $\Lambda(t_0)$. See Table 1.

 $^{^5 \}rm Electrically neutral PEMBHS were first considered, with a different acronym SLABs, in [35].$

time	$\Lambda(t)$
t_0	$(2.0meV)^4$
$t_0 + 10Gy$	$(1.0meV)^4$
$t_0 + 100Gy$	$(700 \mu eV)^4$
$t_0 + 1Ty$	$(230\mu eV)^4$
$t_0 + 1Py$	$(7.4\mu eV)^4$

Table 1: COSMOLOGICAL "CONSTANT".

According to the ΛCDM model, we live at a special time in cosmic history because of the density coincidence between dark matter and dark energy. In the present case where charged dark matter replaces dark energy, the present era is also special because the accelerated expansion, discovered in 1998, is a temporary phenomenon centred around the present time. Acceleration began about 4 Gy ago at $t_{DE} = 9.8Gy = t_0 - 4Gy$. This behaviour will disappear in a few more billion years. The value of the cosmological constant is predicted to fall like $a(t)^{-2}$ so that, when $t \sim \sqrt{2}t_0 \sim 19.5Gy \sim t_0 + 4.7Gy$, the value of $\Lambda(t)$ will be one half of its present value, $\Lambda(t_0)$. As discussed in [34], the equation of state associated with Λ is predicted to be extremely close to $\omega = -1$, so close that measuring the difference seems impracticable.

Let us discuss the future time evolution of the introverse and extroverse in the case of charged dark matter. For the introverse, nothing changes from the ΛCDM , and after a trillion years, the introverse radius will be at its asymptotic value $R_{IV} = 58Gly$, as stated in Eq.(26). By contrast, the future for the extroverse is very different for charged dark matter. With the growth $a(t) \propto t^{\frac{2}{3}}$ we find that the radius of the extroverse at t = 1 Ty is

$$R_{EV}(t = 1Ty) \sim 900Gly \tag{34}$$

to be compared with the corresponding huge value 9.7×10^{32} Gly predicted by the ΛCDM model, quoted in Eq.(27) above. Eq.(34) means that if there still exist humans in the Solar System, or at least in the Milky Way, their view of the distant universe will include many billions of galaxies.

In the ΛCDM case, a hypothetical observational cosmologist, one trillion years in the future, could observe only the Milky Way and objects which are gravitationally bound to it, so that cosmology could become an extinct science. In the case of charged dark matter, for comparison, the time dependence will allow about 180 billion out of a present trillion galaxies to remain observable at t = 1Ty so that the view of the universe at that distant future time will look quite similar to the view at the present.

The distinct physics advantage of charged dark matter is that it avoids the idea of an unknown repulsive gravity inherent in "dark energy". Electromagnetism provides the only known long-range repulsion so it is more attractive to adopt it as the explanation for the accelerating universe. A second advantage of charged dark matter is that it provides a conducive environment for cosmology, a trillion years in the future.

4 Possible Support for the EAU Model from the Amaterasu Cosmic Ray

Particle theory deals with very tiny particles which are typically smaller than an atomic nucleus of size 10^{-15} m and therefore at least fifteen orders of magnitude below the scales familiar to us. It treats objects far smaller than anything we can see with the naked eye. Theoretical cosmology, by contrast, deals with very large objects which are typically larger than the Milky Way galaxy of size 10^{23} m and hence in excess of twenty-three orders of magnitude larger than familiar scales. It considers objects so huge that they stretch the powers of our human imagination.

An outsider could reasonable surmise that physicists who research particle theory form an entirely separate group from the physicists who research theoretical cosmology because the two groups study scales which differ by over thirty-eight orders of magnitude. However, it has been known for many decades that this surmise is mistaken because when we consider the early universe the temperature can be so high that subnuclear particles are inevitably produced. This fusion of the two research fields is sometimes displayed on an Ouroboros diagram, and the small-large connection has been very successfully exploited for over half a century.

In the present section, we hope to convince the reader of the claim that a small (proton)-large (Local Void) fusion can exist even at the present time. The claim is based on the recent observation of a super-GKZ cosmic ray, called Amaterasu, which provides us with a type of paradox whose resolution frequently results in a significant increase in human knowledge.

Historically, the most important theoretical result for ultra high energy cosmic rays is the GKZ bound [36,37] that, to traverse the CMB, the energy is bounded by

$$E < 50 EeV \tag{35}$$

Observationally, over the years since [36,37] the fortunes of the bound have ebbed and flowed but, at the present time, the cut off in Eq.(35) is very well established with only a few rare outliers exhibiting super-GKZ behaviour. The Amaterasu's energy is E = 240 EeV, the third largest ever recorded after previous super-GKZ cosmic rays with 320 EeV (1991) and E = 280EeV (2001).

What makes the Amaterasu particle [38] doubly interesting is that not only is it super-GKZ, but the direction tracks back to the Local Void which contains

no galaxies and therefore, it was thought, no source⁶.

The authors of [38], however, restricted their attention to the ΛCDM model, without considering the recently proposed EAU model [33, 34]. The latter forgoes the century old assumption that gravitation dominates electromagnetism at all length scales greater than that characterising molecules, as tacitly assumed in a paper [2] by the discoverer of relativity. We shall argue in the present section that the EAU model provides a natural resolution of the Amaterasu paradox.

In the EAU model, all the dark matter is composed of Primordial Black Holes (PBHs) with that in galaxies and clusters being Primordial Intermediate Mass Black Holes (PIMBHs), while at galactic centres there are Primordial Supermassive Black Holes (PSMBHs). All of these PBHs are electrically neutral like the stars and planets. Only Primordial Extremely Massive Naked Singularities (PEMNSs), with masses in excess of a trillion solar masses have negative⁷ electric charge with an overall charge asymmetry, relative to the totatly of the proton or electron charges, of about one in a billion billion.

Structure formation in galaxies and clusters, including the Local Void, is due only to gravitational forces. On the other hand, the structure formation regarding PEMNSs is due to electromagnetic forces, and the two results regarding voids are expected to be quite different. In particular, what is the Local Void in terms of galaxies expected to contain PEMNSs and their electric charge can underly the origin of the Amaterasu cosmic ray.

Consider a Primordial Extremely Massive Naked Singularity (PEMNS) with mass $M_{PEMNS} = 10^{12} M_{\odot}$ and negative electric charge $q_{PEMNS} = -10^{32}$ Coulombs at a distance 1Mpc from the Earth. Consider also a proton papproximately at rest, a candidate for the Amaterasu primary, at a distance x metres behind the Earth and precisely aligned with the PEMNS and the Earth. To be justified *a posteriori* we assume that x metres << 1 Mpc.

The Coulomb attraction between PEMNS and p is given by

$$F = \frac{k_e q_{PEMNS} q_{\bar{p}}}{r^2} \tag{36}$$

where the electric force constant is $k_e = 9 \times 10^9 N.m^2/C^2$. Using $1Mpc = 3 \times 10^{22}m$ and proton charge $+1.6 \times 10^{-19}$ Coulombs gives an attractive

⁶To allay all possible concerns that the primary direction used in [38] might be distorted by foreground effects, we found the excellent review by Anchoroqui [39] to be convincing.

⁷Note that if all the PEMNSs had, instead, a positive charge our discussion of accelerated expansion would go through.

electric force which is approximately constant if x is sufficiently small

$$F = 1.6 \times 10^{-22} N \tag{37}$$

in Newtons $N \equiv kg.m/s^2$. Inserting the proton mass $m(p) = m_0 = 1.6 \times 10^{-19}$ kg the initial acceleration is

$$a_i = a(\beta_i = 0) = \frac{F}{m_0} = 1.0 \times 10^5 m/s^2.$$
 (38)

The required BKZ final relativistic velocity $\beta_f = v_f/c$ is given by

$$\frac{E_f}{m_0} = \frac{1}{\sqrt{1 - \beta_f^2}} = \frac{2.4 \times 10^{20} eV}{938 \times 10^6 eV} = 2.56 \times 10^{11},\tag{39}$$

so that

$$\beta_f^2 = 1 - 1.52 \times 10^{-23}. \tag{40}$$

For the relativistic acceleration of $\beta = v/c$ from $\beta_i = 0$ to $\beta_f = \sqrt{1 - 1.52 \times 10^{-23}}$ we may use the integral

$$\int \frac{dx}{\sqrt{1-x^2}} = \sin^{-1}x.$$
 (41)

We now integrate the motion from rest at time $t = t_i$ to reaching energy 2.4×10^{20} eV at time $t = t_f$ using the acceleration

$$\frac{d^2s}{dt^2} = c\frac{d\beta}{dt} = \frac{F}{m(\beta)} = \frac{F}{m_0}\sqrt{1-\beta^2} = a_i\sqrt{1-\beta^2}$$
(42)

with the initial acceleration $a_i = 10^5 m/s^2$ (see Eq.(38)) and $c = 3 \times 10^8 m/s$.

Using the integral in Eq.(41) now gives the result

$$\beta_f = \sin\left[\frac{t_f - t_i}{3000s}\right]. \tag{43}$$

Since $\beta_f < 1$, we deduce from Eq.(43) that $(t_f - t_i) < 3000s$ which implies that the initial at-rest proton must be less than 10^9 km from the Earth which is well within the Solar System, actually within the orbit of Saturn.

We emphasise that this requires precise alignment of the Amaterasu primary with the PEMNS-to-Earth direction and this is expected only extremely rarely. Nevertheless, our work does suggest that the Amaterasu cosmic ray which hit the Earth's atmosphere on in May 2021 may remarkably shed light on the theory of the visible universe at the highest length scales.

Cosmic rays have historically had a major rôle in particle physics, such as the original discoveries of the positron, the pion and many other hadrons. The Amaterasu cosmic ray is only one event but it is an extraordinary one, as one of the three most energetic cosmic rays ever recorded and the only one of those three pointing back to the Local Void where, according to the ΛCDM model, there is no obvious source.

We have discussed a possible explanation for the Amaterasu particle where the source is a PEMNS residing in the Local Void which locally accelerates a proton primary. If our discussion is correct, this single cosmic ray has helped determine the correct choice of theoretical cosmological model.

5 Discussion

We may have engaged in idle speculation in this paper but we are unaware of any fatal flaw. We have replaced the conventional make up for the slices of the universe's energy pie (5% normal matter; 25% dark matter; 70% dark energy) with a similar but crucially changed version(5% normal matter; 25% dark matter; 70% charged dark matter).

The name dark energy was coined by Turner [40] in 1998 shortly after the announcement of accelerated expansion [3,4]. An outsider familiar with $E = Mc^2$ might guess that dark energy and matter are equivalent. If our model is correct, she would be correct although it has nothing to do with $E = mc^2$. Charged dark matter replaces dark energy, an ill-chosen name because it suggested that there exists an additional component in the Universe.

In the previous section, we argued that the unusual properties of the Amaterasu cosmic ray reported in November 2023 could provide support for the EAU model. More recently in April 2024, news [41] from the Dark Energy Spectroscopic Instrument (DESI) at Kitt Peak in Arizona, USA, gave a preliminary indication that the cosmological constant $\Lambda(t)$ is not constant but diminishing with time, as suggested by our Eq.(33), and by our Table 1, thus providing a second possible support for the EAU model.

Other supporting evidence could appear in the foreseeable future from the James Webb Space Telescope (JWST) which might shed light on the formation of PBHs in the early universe, also from the Vera C. Rubin Observatory in Chile which will study long duration microlensing light curves which could provide evidence for the existence of PIMBHs inside the Milky Way.

It will be interesting to learn how these and other observations may support the idea that the observed cosmic acceleration is caused by charged dark matter.

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