Thank for invitation.

STATUS OF

ELECTROMAGNETIC

ACCELERATING UNIVERSE

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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 this talk, 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 talk may be regarded as a follow up to a 2018 paper 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 is that electromagnetism dominates over gravitation in the explanation of the accelerating cosmological expansion. This idea takes us beyond the first paper (Einstein) which applied general relativity to theoretical cosmology. This is not surprising, since in 1917 that author was obviously unaware of the fact 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 may be classified into those which arise from the gravitational collapse of stars and others which do not. By primordial, we shall 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 proposed by Novikov and Zeldovich and independently seven years later in the West by Carr and Hawking The idea that the dark matter constituents are PBHs was first suggested by Chapline.

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

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

Shortly thereafter, the Reissner-Nordstrom metric for a static Black Hole with electric charge was found. It then took a surprising forty-five years until Kerr cleverly found a solution 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 which use Kerr's generalisation, spin is an inessential complication in all of our subsequent considerations.

2.1 Primordial Intermediate Mass Black Holes as Galactic Dark Matter

Global fits to cosmological parameters have led to a consensus that about one quarter of the energy of the universe is in the form of electrically-neutral dark matter. It seemed natural to propose that the dark matter constituents are primordial black holes with masses many times the mass of the Sun. In a galaxy like the Milky Way, the proposal was 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 naturally known as Intermediate Mass Black Hole (IMBHs) since they lie intermediate between the masses of stellar-mass black holes and the masses of the supermassive black holes at galactic centres.

The existence of stellar mass black holes in Nature was established sixty years ago in 1964 by the discovery in Cygnus X-1 of such a black hole with mass about $15M_{\odot}$. Such X-Ray binaries were studied in which black holes appear in the mass range between $5M_{\odot}$ and $100M_{\odot}$,

The existence of dark matter was first discovered by Zwicky in 1933 in the Coma Cluster. Its presence in individual galaxies was demonstrated convincingly by Rubin in the 1970s from measurement of the rotation curves which demanded the existence of additional matter to what was luminous.

The PBH mass function is all important, Possible PBH masses extend upwards to many solar masses and without any obvious upper limit, far beyond what was was thought possible in the twentieth century when ignorance about PBHs with many solar masses probably prevented the MACHO and EROS Collaborations from discovering a larger fraction of the dark matter.

Black holes formed by gravitational collapse cannot satisfy $M_{BH} \ll M_{\odot}$ because stars powered by nuclear fusion cannot be far below $M = M_{\odot}$. This was contradicted by the studies in primordiality which suggested that much lighter black holes can be produced in the earliest stages of the Big Bang.

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 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 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 which are possible.

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

$$M_{Planck} \sim 10^{-8} kg \sim 10^{-38} M_\odot. \tag{5}$$

Let us define a Planck density ρ_{Planck} by

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

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

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

which means that for a solar-mass black hole

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

while for a billion solar mass black hole

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

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 Solar Mass units we find

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

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

$$M_{PBH} < 10^{-7} M_{\odot} \qquad (11)$$

Such an upper bound as Eq.(11) explains why the MACHO searches at the turn of the twenty-first century, inspired by the clever suggestion of Paczynski, lacked motivation to pursue searching above $100 M_{\odot}$ because it was thought incorrectly at that time that PBHs were far too light. It was known correctly that the results of gravitational collapse of normal stars, or even large early stars, were below $100 M_{\odot}$. Supermassive black holes with $M > 10^6 M_{\odot}$ 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 Section 2.2.

Using the mechanism for Hawking radiation provides the lifetime for a black hole evaporating *in vacuo* given by

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

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:

$$10^{-18} M_\odot < M_{PBH} < 10^{-7} M_\odot \qquad (13)$$

The lowest mass possible for s surviving PBH in Eq.(13) has the density $\rho \sim 10^{58} \rho_{H_2O}$. It is an 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 given by

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

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 $\sim 6 \times 10^{10} K$, the inverse square law renders the intensity of Hawking radiation too small, by many orders of magnitude, to allow detection by any foreseeable terrestrial apparatus.

The originally suggested 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 quite different mechanism. As already discussed, PBH formation requires very large inhomogeneities. Here we shall illustrate how mathematically to produce inhomogeneities which are exponentially large.

In the simplest single-stage inflation, no exceptionally large density perturbation is expected. Therefore it is necessary to consider at least a two-stage hybrid inflation with respective fields called inflaton and waterfall. The idea then involves parametric resonance in that, after the first of the two stages of inflation, mutual couplings of the inflaton and waterfall fields cause both to oscillate arbitraily wildly and produce perturbations which can grow exponentially.

A second (waterfall) inflation then stretches further the inhomogeneities, thus enabling production of PBHs with arbitrarily high mass. This specific model may not describe Nature but provides an existence theorem to confirm that arbitrarily large mass PBHs can be produced mathematically. The resulting mass function is spiked, but it is possible that other PBH production mechanisms can produce a smoother mass function.

Full details of the model are presented in 2010 (F.K.T.Y) 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 coupled equations for the two fields are of Mathieu type with the exponentially-growing 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

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

Explicit plots were exhibited in FKTY 2010 for the cases $M_{PBH} = 10^{-8} M_\odot, 10^{-7} M_\odot$ and $10^5 M_\odot$. At that time (2010) , although not included in the paper, it was confirmed that parameters can always be chosen such that arbitrarily high mass PBHs, at or even beyond the mass of the universe, may be produced. This is an important result to be borne in mind.

In the PBH production mechanism based on hybrid inflation with parametric resonance, the mass function is generally sharply spiked at a specific mass region. Such a peculiar mass function is not expected to be a general feature of PBH formation, only a property of this specific mechanism. But this specific mechanism readily 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 and by Novikov, Polnarev, Starobinskii and Zeldovich.

For dark matter in galaxies, PIMBHs are important, where the upper end must be truncated at $10^5 M_\odot$ to stay well away from galactic disk instability first discussed by Ostriker *et al.* They showed convincingly that an object with mass one million solar masses out in the spiral arms of the Milky Way destabilizes the galactic disk to such an extent that the entire galaxy collapses.

Observations of rotation curves reveal that the dark matter in galaxies including 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 type.

Note that he NFW profile is independent of the mass of the dark matter constituent. and the numerical calculations are restricted by the available computer size, for a system as large as a typical galaxy, to constituents which have many solar masses.

In our discussion of 2015, we focused on galaxies like the Milky Way and restricted the mass range for the dark matter constituents to lie within the three orders of magnitude

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

We shall not repeat lengthy entropy arguments here, just to say that the constituents were proposed to be Primordial Intermediate Mass Black Holes, PIMBHs.

Assuming a total dark halo mass of $10^{12}M_\odot$, Eq.(16) implies that the number N of PIMBHs is between ten million (10^7) and ten billion (10^{10}) Assuming further that the dark halo has a radius R of a hundred thousand (10^5) light years the mean separation $\bar{L}$ of PIMBHs can then estimated by

$$\bar{L} \sim \left(\frac{R}{N^{1/3}}\right) \tag{17}$$

which translates approximately to

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

which provides also a reasonable estimate of the distance to the nearest PIMBH from the Earth which is very far outside the Solar System where the orbital radius of the outermost planet Neptune is ~ 0.001 ly.

To an outsider, It may be surprising that millions of intermediate-mass black holes in the Milky Way can have remained undetected. Ironically, hey could have been detected more than two decades ago had the MACHO Collaboration persisted in its microlensing experiment at Mount Stromlo Observatory in Australia.

Dark matter was first discovered almost a century ago by Zwicky in the Coma cluster, a large cluster at 99 Mpc containing over a thousand galaxies and with total mass estimated at $6 \times 10^{14} M_{\odot}$. A convincing proof of the existence of cluster dark matter was provided by the Bullet cluster collision where the distinct behaviours of the X-ray emitting gas which collides, and the dark matter which does not, was observable.

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 than possible for the PIMBHs within galaxies

The possible 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 promising. Microlensing experiments were carried out by the MACHO and EROS Collaborations decades 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 $100 M_{\odot}$.

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

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

which assumes a transit velocity $200km/s$. Subsituting 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. It is to be hoped that MACHO searches will soon resume at the Vera Rubin Observatory and focus on highest longevity microlensing events. Is it possible that convincing observations showing only a fraction of a light curve 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.

2.1 Primordial Supermassive Black Holes (PSMBHs) at Galactic Centers

Evidence for supermassive black holes at galactic centres arises 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 the one, Sag A^*, at the core of the Milky Way which was discovered in 1974 and has mass $M_{SagA*} \sim 4.1 \times 10^6 M_\odot$. 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, expec5ed 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 were it out in the spiral arms but at, or near to, the center of mass of the Milky Way 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, it is natrual to assume that objects can be formed based on the Reissner-Nordstrom metric

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

where

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

with

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

The horizon(s) of the RN metric occur when

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

which gives

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

It follows that for $2r_Q < r_S$, $Q^2 < M$, there are two horizons. On the other hand, when $2r_Q = r_S$, $Q^2 = M$ the RN black hole is named extremal and there is only one horizon. If $2r_Q > r_S$, $Q^2 > M$, the RN metric may be called super-extremal. in this case there is no horizon at all and the $r = 0$ singularity becomes observable to a distant observer. This is called a naked singularity. 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)* We

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

cannot claim to understand the formation of PNSs. One idea hinted at in [**?**] is that extremely massive ones, charged PEMNSs might begin life as electrically neutral PBHs then, during the dark ages, 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.

3.1 Primordial Extremely Massive Naked Singularities – the EAU Model

A novel EAU model has been suggested in where dark energy is replaced by charged dark matter in the form of PEMNSs or charged Primordial Extremely Massive Naked Singularities[†]. That discussion involved the new idea that, at the very largest cosmological distances, the dominant force is electromagnetism rather than gravitation. This differs from the assumption tacitly made in the first application of general relativity to cosmology by Einstein.

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.

[†] In the original paper the PEMNSs were called PEMBHs

The subsequent expansion in the charged dark matter 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 unaesthetic features in terms of the extremely large size of the asymptotic extroverse.

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

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

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

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

The extroverse expansion is, by contrast, 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. After only a trillion years it attains the extremely large value

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

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

One attempt at a possible formation mechanism of PEMNSs was provided by Chileans, Araja *et al* where their common sign of electric charge, negative, arises from preferential accretion of electrons relative to protons.

This formation mechanism is not well understood [‡] 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

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

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

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

[‡] Electrically neutral PEMBHS were first considered, with a different acronym SLABs, by Carr *et al.*

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

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

in which

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

where matter includes normal matter and uncharged dark matter.

Of special interest to 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.

Table 1: COSMOLOGICAL “CONSTANT”.

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

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

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

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 *ut supra*.

In both the ΛCDM model and the EAU model, the present time is an unusual time in cosmic history. In the former case, there is the present similarity between the the densities of dark matter and energy. In the latter case with charged dark matter, the present accelerated expansion is maximal and will disappear within a few more billion years.

In the EAU model, 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, $\Lambda(t_0)$. On the other hand, the equation of state associated with Λ is predicted to be accurately $\omega = -1$, so close to that value that measuring the difference seems forever impracticable.

For charged dark matter, we now discuss the future time evolution of the introverse and extroverse. 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 than for the conventional ΛCDM case. WIth the growth $a(t) \propto t^{\frac{2}{3}}$ we find that the radius of the extroverse at $t = 1$ Ty is

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

This is in stark contrast to the extremely large value 9.7×10^{32} Gly predicted by the ΛCDM model, quoted in Eq.(27) above. Eq.(34) means that if there still exist scientific observers their view of the distant universe will be quite similar to the present one and will include many billions of galaxies.

In the ΛCDM case, such a hypothetical observational cosmologist, trillions of years in the future, could observe only the Milky Way and objects which are gravitationally bound to it, so that cosmology would become an extinct science.

The principal 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. The secondary advantage of charged dark matter, that it provides a conducive environment for observational cosmology trillions of years into the future, is not by itself a sufficient reason to select a theory.

4. Possible Support for 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 that, to traverse the CMB, the energy is bounded by

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

Observationally, over the years 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 (2023), the third largest ever recorded after previous super-GKZ cosmic rays with 320 EeV (1991) and $E = 280$ EeV (2001).

What makes the Amaterasu particle 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 source[§].

The Amaterasu authors, however, restricted their attention to the ΛCDM model, without considering the more recently proposed EAU model. The latter forgoes the century old assumption that gravitation dominates electromagnetism at all length scales greater than that characterising molecules. We shall argue in the present section that the EAU model provides a natural resolution of the Amaterasu paradox.

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

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 negative[¶] electric charge with an overall charge asymmetry, relative to the totatlty of the proton or electron charges, of about one in a billion billion.

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

Structure formation for galaxies and clusters, including the Local Void, is due only to gravitational forces. On the other hand, the structure formation regarding PEMNSs is due only 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, is 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 p approximately 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 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

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

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

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

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

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

with the initial acceleration $a_i = 10^5 m/s^2$ 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. .

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.

If our discussion is correct, this single cosmic ray has helped determine the correct choice of theoretical cosmological model.

5. Discussion

Although this paper is essentially speculative, 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 in 1998 shortly after the announcement of accelerated expansion. 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 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.

Thank you for your attention