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A ZPF-MEDIATED COSMOLOGICAL ORIGIN OF ELECTRON INERTIA

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Abstract

Support is found for a fundamental role for the electromagnetic zero-point-field (ZPF) in the origin of inertia. Simply by requiring that that a universal noise field be self-consistent in the presence of the lightest charge, it is shown that this field must be the ZPF, and that the mass of that charge must be close to 10^{-30} kg. The ZPF functions as homeostatic regulator, with the electron mass decided by cosmological quantities. The calculation validates Dirac's second Large Number hypothesis.

1. Introduction

Several speakers at this conference have been pioneers championing the cause of an electromagnetic zero-point-field (EM ZPF) origin for inertia. Notable amongst these have been Haisch, Rueda and Puthoff [1-11]. Currently the implementations are classical, with a 'classicized' ZPF as conceived within the program of Stochastic Electrodynamics (SED), (see Kalitsin [12], Braffort [13] and Marshall [14] for the original works, and Boyer [15] for a review of this field). Epistemologically, a common theme of their work is that the ZPF is the cause of resistance to acceleration. In mathematical practice though, the end result is an inertial mass-energy that attributable to the ZPF. Broadly, the ZPF is seen as an external, energizing influence for a local degree of freedom, which, classically, is the co-ordinate of the particle whose mass we wish to explain. Thus the program has – in part – some of the flavor of Mach, because the ZPF provides a 'background' against which the acceleration can be measured. The particle, once energized, is conceived as having attributable energy, and therefore inertia. Although Haisch *et al* [11] in particular have made a distinction between the inertial and energetic aspects of matter, this distinction appears to be largely epistemological; since any 'localized' packet of energy is found to resist acceleration, it is sufficient to explain, within the context of this program, how EM ZPF energy can become localized.

Even so, within this program, there are two quite different possible implementations distinguished by different degrees of non-locality for the origin of mass. To date, despite the active role of the ZPF, current implementations result in a value for the inertial mass that is intrinsic to the particle in question. In contrast, the purpose of this paper is to argue for an alternative implementation, wherein the value of the inertial mass is determined entirely by external – cosmological – factors. For this reason the approach described here is much closer to the original conception of Mach (ca. 1883) than previous ZPF-as-background approach. In the following is given contrasting descriptions of the intrinsic and extrinsic approaches to ZPF-originated inertia. These are followed by a calculation supporting the latter, wherein one of Dirac's large number hypotheses [16,17] is derived and interpreted as evidence of a cosmological ZPF-origin of the inertial mass of the electron.

2. Role of the ZPF in a model of locally determined inertial mass

In a locally determined, ZPF-originated, model of inertia, there exists a local dynamical degree of freedom, such as an oscillator amplitude [1], or a resonator excitation level. This co-ordinate is conceived initially as quiescent, and having no intrinsic energy. Subsequently, if the ZPF is switched on, then the oscillator or resonator is energized, and the ZPF-originated energy that is now associated with the oscillator or resonator can be regarded as the 'rest' mass. In some work, the local properties ultimately deciding the mass of the charged particle enter as a Fourier form factor governing the spectral response to the ZPF [3,4,5]. This has the advantage of leaving open whether the response is due to the energetic resonance of an oscillator or geometric structure. But in either case it is taken to be a local property. The end result is the same in that not only is there resistance to acceleration, but there is also a localized energy density that can be associated with the particle in question. Clearly, in this approach, the object has zero true rest mass, whilst the ZPF-energized mass may nonetheless be *statistically* at rest due to the homogeneity and isotropy of the ZPF. Also, thanks to the peculiar **k**-space distribution of the ZPF - the ZPF retains the same homogeneous energy density in every inertial frame – it follows that with suitably chosen dynamics it should be possible to make the rest mass a fully invariant scalar.

These original ideas have stimulated new thinking about the origin of inertia and brought forth some encouraging responses [18,19,20]. However, it is premature to claim that the origin of inertia has been found in the ZPF, because there are some unresolved and unsatisfactory aspects of the current approach:

1. The particle oscillator or resonator must contain electrical charges capable of interaction with the ZPF, so the model cannot describe a neutral elementary particle such as a massive neutrino, for example.

2. The electron also poses a problem unless it is admitted that it has some – as yet unobserved – structure.

3. The values of the intrinsic mass (of the electron, muon, and tau say), are not predicted, but must be inserted by hand. The final mass – the energy stored in the oscillator or resonator – is decided by intrinsic qualities i.e.: locally, wherein combinations of charge–field coupling, geometric form factor, and spectral form factor, must be chosen to give the desired final mass. (The existence of these energy-storing 'degrees of freedom' rests upon the presumed existence of a structure for the particle in

question – points 1 and 2 - and neither this structure nor these coupling and form factors are explained.)

4. There is no clear path of development for the theory by which it can unite the inertial and gravitational aspects of mass. There *is* the hope that it also has something to do with the EM ZPF, as first suggested by Sakharov [21,22]. But to date there have been no successful implementations of a ZPF origin for gravity.

Perhaps the most attractive feature of the current thinking along these lines is that the proposed energetic source by which means both gravity and inertia may perhaps be united - the ZPF - is a 'ready-made', omnipresent, influence. In the next section is investigated a different implementation which retains this foundational feature, but which overcomes some of the above enumerated difficulties.

3. A model for non-locally determined inertial mass

By non-local model is here meant that inertia is conceived not as an intrinsic, unitary property, but as arising out of a non-local *mutual* interaction. Just as the mutual interaction energy of charges, current elements, and (gravitating) masses cannot be assigned to either partner in the interaction, so - it is suggested - inertial mass-energy cannot be ascribed to a single particular particle, but results from the multiple mutual (pair-wise) interactions with distant partners. Like the foregoing examples, the Casimir and van-der-Waals energies are also mutual, yet these are different in that they exist only by virtue of the ZPF. Though an apparently intrinsic Casimir energy *does* exist for a conducting curved surface embedded in the ZPF [23], one may regard this energy as arising out of the mutual interaction of *local* elements of the curved structure, just as in a Casimir cavity. To date, no one has identified a mutual yet *distant* interaction energy of electromagnetic origin that can explain inertia. And this is the reason why the ZPF-inertia advocates have concentrated on local, 'unitary' qualities that might cooperate to localize ZPF energy. A detailed description of the distant interaction believed to be responsible will be given in a future document. Briefly, a consequence of that work is that, like the local models, the positional / motional particle degree of freedom may be regarded as 'energized' by the ZPF. But unlike the local models, the energy of interaction turns out to be mutual, involving all distant particles. A good metaphor is provided by the van-der-Waals binding energy, except for the fact that the rate of radial fall-off precludes it from candidature. For now, the following calculation is presented as evidence to support the claim that inertial mass is a non-local energy - with the ZPF as its *means*.

4. Derivation of the electron mass

In the following calculation it will be assumed that associated in some way with a charged particle is a resistance to acceleration equal to a final renormalized (not bare) inertial mass m_e. It will be assumed that underlying this mass is a particle in micro-motion (commonly, but not very accurately termed zitterbewegung). We also need to assume that an EM noise field and the micro motion of the charge are consonant in that the 'in' fields impacting the source and the 'out' fields leaving the source have the same statistics. In other words, it will be assumed that the EM noise field has attained a self-consistent state in the presence of the particle micro-motion. (A causal flow is not implied here: the particle's motion does not *cause* the field nor does the field *cause* the particle's motion. Rather, the field and motion are to be viewed as mutually consistent.)

So far this sounds rather like the SED program that results in a ZPF-energized, but nonetheless intrinsic-valued, inertia. However, the particle employed here is deemed to have no intrinsic structure, and therefore cannot have an intrinsic-valued inertia - with or without the ZPF. Very broadly, this can be concluded simply from the absence of any length scale that could conceivably be associated with a mass. More specifically, it can be shown that a massless classical point charge dropped into the ZPF leaves the electromagnetic spectrum and energy density unchanged from that of the charge and ZPF considered apart from each other - *unless* the charge is permitted to interact with other charges.

It must be admitted at the outset that the particle that will be singled out by this calculation is the electron. This is because it is the *lightest* charged particle. As a consequence it gives the largest acceleration per unit field, and therefore the largest out field per unit in field. It follows that, provided the in and out fields are universally self-consistent, the fields must be maintained predominantly by the electron. Therefore, in the following calculation, it will be assumed that $N \sim 10^{80}$ electrons, sprinkled approximately uniformly throughout the visible universe, cooperate in the maintenance of an EM noise field. Further, it can reasonably be assumed that the micro-motion will have a coherence length somewhere between the classical electron radius and the Compton wavelength. From this it follows that, although widely varying, the local environment of electrons is to a good approximation of no consequence to the presumed micro-motion, since the coherence length of the latter is relatively so short.

In this paper the self-consistency calculation will be simplified by assuming that the micro-motion is non-relativistic. For this to be true for all electrons from the perspective of our own earthly reference frame, we must necessarily consider only a static universe – i.e. without expansion. This is because the electrons near the Hubble radius will turn out to dominate the self-consistent field calculation. (A more complicated calculation admitting expansion gives a very similar result, as discussed below.) With this restriction the electromagnetic noise-induced acceleration is approximately ($c = 4\pi\varepsilon_0 = 1$)

$$\mathbf{a} = \mathbf{E}_{\text{in}} \left(e/m_e \right) \tag{1}$$

for which the outgoing radiation, in the far-field, has electric field

$$\mathbf{E}_{\text{out}} \left(\mathbf{r}, t \right) = \hat{\mathbf{r}} \times \left(\hat{\mathbf{r}} \times \mathbf{a} \right) \left(e/r \right). \tag{2}$$

The corresponding 3D orientation averaged energy density from both the magnetic and electric fields, as viewed in the frame in which the particle's expected position is always at the origin, is

$$\left\langle \varepsilon_{1,out}\left(\mathbf{r},t\right)\right\rangle = \frac{1}{4\pi}\left\langle \left|\mathbf{E}_{\text{out}}\left(\mathbf{r},t\right)\right|^2\right\rangle = \frac{e^2a^2\left\langle \sin^2\left(\theta_{\mathbf{r},\mathbf{a}}\right)\right\rangle}{4\pi r^2} = \frac{e^2a^2}{6\pi r^2}. \tag{3}$$

In the presumed static cosmology there are N sources approximately uniformly distributed throughout the universe of static radius R, i.e., $\rho\left(\mathbf{r}\right)d^3r = \left(3N/4\pi R^3\right)d^3r$. The expected energy density from all the sources is therefore

$$\left\langle \varepsilon_{N,out}\right\rangle = \int d^3r\rho\left(\mathbf{r}\right)\left\langle \varepsilon_1\left(\mathbf{r},t\right)\right\rangle = \frac{3N}{4\pi R^3}\frac{e^2a^2}{6\pi}\oiint d\Omega\int_0^R drr^2\frac{1}{r^2} = \frac{Ne^2a^2}{2\pi R^2}. \tag{4}$$

By contrast, the energy density of the in field at the particle in question can be expressed in terms of the acceleration using Eq. (1):

$$\left\langle \varepsilon_{\text{in}}\right\rangle = \frac{1}{4\pi}\left\langle \left|\mathbf{E}_{\text{in}}\left(\mathbf{r},t\right)\right|^2\right\rangle = \frac{1}{4\pi}\frac{m_e^2a^2}{e^2}. \tag{5}$$

For self-consistency the energy density of the in field must, at all locations, equal the energy density due to all the out fields:

$$\left\langle \varepsilon_{\text{in}}\right\rangle = \left\langle \varepsilon_{N,out}\right\rangle \Rightarrow \frac{1}{4\pi}\frac{m_e^2a^2}{e^2} = \frac{Ne^2a^2}{2\pi R^2}. \tag{6}$$

Consequently, one obtains the Dirac large number hypothesis [16]

$$m_e = \sqrt{2N}e^2/R. \tag{7}$$

With $N = 10^{80}$, and R set to the Hubble radius of 10^{28} cm, this computes to 0.36 x 10^{-30} kg, i.e. 40% of the observed value of the electron mass – well within the tolerance set by the uncertainty in $N^{1/2}$ (which expressed as a factor is between about 0.5 and 2).

5. Discussion

The above calculation establishes a linear relationship between the in and out fields. It follows directly that it does not matter how strong or weak is the noise field; the electron mass given by Eq. (7) would have the same value whatever. Another consequence of the linearity is that the computed electron mass is also insensitive to the energy spectrum of the ZPF. (A consequence of the fact that the charge-field scattering is elastic.)

A relativistically correct version of this calculation performed in a flat expanding universe turns out to give, apart from a numerical coefficient of order unity, the same Dirac relation, and therefore the same electron mass as a function of cosmological constants, with the former remaining independent of time. Specifically, taking into account the special role played by the ZPF in maintaining homeostasis, the second Dirac hypothesis [16] - that $N^{1/2}e^2/R$ is constant - can be validated. Dirac's suggestions seem to have been rejected mostly on the basis of his first relation, which predicts a time-dependent gravitational constant, and is considered to be incompatible with observation; see [24] and [25] for reviews. Although not directly impacting the validity of the second relation under investigation here, it is nonetheless interesting that similar ZPF-mediated arguments have led Puthoff [26,27] to claim a time-independence for the first relation. It is hoped to reproduce elsewhere the detailed calculations and qualifying cosmologies discovered to maintain constancy of the second relation. In those calculations it turns out that appeal must be made to velocity-invariant statistics of the EM noise field. That is, the self-consistent field must be, at least at the level of expectations of quadratic field operators, the electromagnetic zero-point field as furnished by second-quantized Maxwell (henceforth the ZPF).

The reader may be alert to the fact that a proper relativistic treatment necessitates the use of the Lorentz-Dirac equation with non-linear radiation reaction terms, or – in the quantum domain - the corresponding Heisenberg equation of motion [26]. This, and related issues concerning the bandwidth of the self-consistent field and the origin of time asymmetry, require a much more detailed treatment, and will also be addressed elsewhere.

A concern expressed by some is that the cosmological distribution of matter is such that any alleged derivation of particle constants from cosmology will suffer from an unacceptable level of frame dependent, or perhaps time dependent, variability. A rough estimate of the variability in the predicted value of mass is to entertain fluctuations in N, which are likely to be of order $N^{1/2}$. This gives rise to corresponding fluctuations in $N^{1/2}$ of order unity, i.e. one part in 10^{40}. Therefore, at least by this mechanism, cosmological variability does not lead to a detectable variability in the mass.

It must be emphasized that nowhere in the above was inertial mass 'explained'. Rather, this calculation tells us only that if the fields are to be self-consistent, the electron mass could not have any value other than the one it is observed to have, given the cosmological numbers. The calculation does not explain the *mechanism* of the mass.

Despite these caveats, the success of the calculation provides support for the novel emphasis placed on the ZPF by Haisch and others in their work on inertial mass. This work continues that effort, but with a different role for the ZPF. Here, the ZPF is the means by which homeostasis is maintained; it is the means by which the electrons throughout the universe come into electromagnetic equilibrium with each other, whereby the electron mass attains universal consistency.

6. Cosmological origin of length-scale

In natural units where $e = 1$, mass has units of $(\text{length})^{-1}$; the classical length corresponding to the electron mass (the classical electron radius) is, in S.I. units, $e^2/(4\pi\varepsilon_0 m_e c^2)$, which is about 3×10^{-15} m. In the previous calculation based upon cosmological self-consistency this length is found from Eq. (7) to be $R/(2N)^{1/2}$, where both R and N are cosmological constants. Despite all the talk of electromagnetism and ZPF-induced micro-motion, the final result constructs a very small length out of cosmological constants. If the cosmic somehow *determines* this length, as implied in this work, then there should be a direct cosmological interpretation for this very small length, without any reference to electrons. This is the focus of the following discussion.

Notice that the integral in Eq. (4) may be regarded as computing the expectation of r^{-2} over the Hubble volume. For a homogeneous distribution, $<r^n>\sim R^n$ for any n, so nearly the whole contribution to the integral comes from matter *at* the Hubble radius. In other words, for the purposes of computing a self-consistent field, and to a very good approximation, all the matter in the universe appears to be at the Hubble radius. It is as if all matter is projected onto the Hubble sphere, creating the appearance of a surface density at the Hubble radius of $N/(4\pi R^2)$, whereupon $2R/N^{1/2}$ is approximately the mean nearest neighbor distance between the points. That is, $2R/N^{1/2}$ is the mean nearest neighbor distance on the Hubble sphere between the points that are the radial projections of all the electrons in the universe. To within a factor of order unity this is the previously computed mass-length of the electron, and therefore this distance must be the corresponding cosmological entity, and, allegedly, the origin of that length.

It is clear from the above that a sufficiently large telescope could, in principle, be used to resolve the individual electrons in the universe if its probing radiation had a wavelength shorter than the mass-length. This means that the universe of electrons must be at least partly transparent to ZPF 'radiation' at this and shorter wavelengths. Ignoring for now the possibility of future collapse, it follows that the electrons cannot maintain a universally self-consistent noise field beyond the mass-frequency. (In a more realistic cosmology it is to be hoped that this quantity will look like a frame independent cut-off.) In other words, the mass-length is also the critical wavelength at which the universe of electrons starts to become transparent. Therefore, based upon the considerations of this and the previous section combined, one may conclude that the locally observed mass-length is authored cosmically (as $R/N^{1/2}$) and broadcast by the ZPF (as a cutoff at that wavelength).

No attempt has been made to investigate, from this cosmological perspective, the relationship between the Compton wavelength and the mass length. Since their ratio is the fine structure constant, a search for a cosmic relation is therefore equivalent to a search, in this context, for a *geometric* interpretation of α. It is interesting that Wyler [29] (see [30] for a review in English) found an expression for α involving the ratio of projections of volume elements – especially since the mass-length calculation above also involves a projection. Obviously, the dimensionality here is wrong because we have ignored universal expansion; if the two paths *do* converge there remains much more work to be done.

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