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Making Stargates: The Physics of Traversable Absurdly Benign Wormholes

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Abstract

Extremely short throat "absurdly benign" wormholes enabling near instantaneous travel to arbitrarily remote locations in both space and time – stargates – have long been a staple of science fiction. The physical requirements for the production of such devices were worked out by Morris and Thorne in 1988. They approached the issue of rapid spacetime transport by asking the question: what constraints do the laws of physics as we know them place on an "arbitrarily advanced culture" (AAC)? Their answer – a Jupiter mass of negative restmass matter in a structure a few tens of meters in size – seems to have rendered such things beyond the realm of the believably achievable. This might be taken as justification for abandoning further serious exploration of the physics of stargates. If such an investigation is pursued, however, one way to do so is to invert Morris and Thorne's question and ask: if "arbitrarily advanced aliens" (AAAs) have actually made stargates, what must be true of the laws of physics for them to have done so? Elementary arithmetic reveals that stargates would have an "exotic" density of on the order of 1022 gm/cm3, that is, orders of magnitude higher than nuclear density. Not only does one have to achieve this stupendous density of negative mass matter, it must be done, presumably, only with the application of "low" energy electromagnetic fields. We examine this problem, finding that a plausible solution does not depend on the laws of quantum gravity, as some have proposed. Rather, the solution depends on understanding the nature of electrons in terms of a semi-classical extension of the exact, general relativistic electron model of Arnowitt, Deser, and Misner (ADM), and Mach's Principle.

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1. Introduction

Getting around spacetime quickly has been a dream of some for more than a century. Until 1988, those dreamers were members of two distinct groups: aficionados interstellar spaceflight and fans of time travel. The technologies envisaged by these groups were distinct, for though space and time had been forged into spacetime by Einstein in his theories of relativity, space and time are sufficiently dissimilar that traveling in space was thought fundamentally different from traveling through time. Morris and Thorne's [1] work in 1988 changed that by showing that shortcuts in space and time require the same technology: traversable wormholes, macroscopic spacetime distortions connecting distant events (understood in the relativistic sense of a location in space *and* time) via very short structures in hyperspace. They found that a wide range of wormholes satisfy reasonable criteria for traversability. But most of them produce distortions that would seriously disrupt the surrounding spacetime over large distances. Morris and Thorne designated the class of wormholes that do not do this to their surrounding spacetime as "absurdly benign". The details of such wormholes are to be found in an Appendix to their paper on page 410.

From the practical point of view, the problem with absurdly benign wormholes of traversable dimensions is that they require "exotic" *restmass* matter – that is, real stuff *you can stop* in a laboratory that has negative mass. And you need a Jupiter mass – 2 X 10^{27} kg – concentrated in a region of small dimensions. A simple calculation assuming a throat diameter of, say, 10 meters and a wall thickness of a meter or so, leads to an exotic density of ~ 10^{22} gm/cm^3, that is, on the order of seven orders of magnitude greater than nuclear density. Similar densities, as a matter of idle interest, are required to make the "warp drives" proposed several years later by Alcubierre [2]

Construction of devices that demand exotic matter of such densities seems, on its face, insuperable. The laws of physics as they are widely understood do not prohibit the existence of negative restmass matter as once thought. But its density and the amount required are breathtaking. And those laws seem not to even hint at where such stuff might be found and how it could be assembled into a stargate. Thorne has suggested that we must first master the so far vainly sought theory of quantum gravity before we have even the slimmest hope of figuring out how to make stargates. Nonetheless, if AAAs have actually built stagnates, presumably they have already done this. Should we want to build stargates, it seems that perhaps we should ask: What plausible physics must be true if absurdly benign wormholes are to be technically feasible? It may be there is no plausible physics, or that quantum gravity is required to answer this question. But we do not assume this before we investigate answers to the question since, improbable as it may seem, plausible physics may exist and quantum gravity may be irrelevant to the answer.

2. The Vacuum

The vacuum – the quantum vacuum in particular – has been associated with traversable wormholes from the publication of Morris and Thorne's paper [1]. Before that time, it was widely assumed that the "positive energy theorem" was true. That is, everyone assumed that negative mass matter was physically impossible. Thorne showed that this assumption was wrong by appealing to the fact that the energy density between the plates of a Casimir cavity is less than zero – that is, the energy density is negative. Nowadays, pretty much everyone allows that Thorne was right. The association between wormholes and the Casimir effect has been perpetuated because it is very difficult to think of other ways to create negative energy that might be used to stabilize wormhole throats. Indeed, even a cursory search of the web for wormholes leads one to several sources that claim that "zero point energy" or "zero point fields" – the quantum fluctuations thought by most to fill the vacuum – that allegedly produce the Casimir effect are the path to making real wormholes. As a noted, recently retired employee of NASA's Jet Propulsion Laboratory has remarked, the problem of advanced propulsion is figuring out how to expand the distance between a pair of Casimir plates to macroscopic dimensions while maintaining the negative energy density of microscopic dimensions. Since the dependence of the Casimir effect on plate separation is well-known to go as the inverse fourth power of the distance, such conjectures are, of course, silly, though the motivating sentiment may not be.

There is an even more fundamental problem with the vacuum. As Milonni [3] (and refs. therein) and others showed about forty years ago, quantum electodynamics does not – on the basis of the Casimir effect at least – demand that the quantum vacuum be filled with anything at all. That is, quantum electrodynamics can be consistently interpreted as without any zero point vacuum fluctuations of the electromagnetic field at all. (The argument, however, does not include vacuum fluctuations of the *electron* field, that is, the creation and annihilation *ex nihilo* of virtual electron-positron pairs in the vacuum.) In this view, the Casimir force is a result of direct interactions between the particles in the plates, so one can still claim that there is an effective negative energy density in the space separating the plates. But there are no vacuum fluctuations *with independent degrees of freedom* between the plates. Aficionados of zero point energy and fields are not enamored of this fact. The cautionary message of all this is that one should be very careful when asserting that nothing is really something, and that the something nothing is the solution to all of our technical problems.

3. A Jupiter Mass Of Exotic Matter

Aside from issues involving the vacuum, two problems arise in making a stargate. The first is figuring out where you are going to get your hands on some exotic matter – indeed, where you are going to get your hands on a Jupiter mass of exotic matter. The second is figuring out how you are going to get all of that matter into a structure that will produce a density of ~ 10^{22} gm/cm^3. In the early days of traversable wormhole physics, some speculated that it might be possible to motor around in ones spacecraft and harvest such exotic matter as one might find lying around here and there. This approach presumes that there is exotic matter out there waiting to be harvested. This is an extremely dubious proposition. Were there naturally occurring exotic matter, and were it fairly common, one might reasonably expect that there should be some here on Earth. None has ever been reported. You might think that exotic matter with negative mass, since it is repelled by the positive mass matter that makes up the Earth and its environs, if ever present locally, would have been driven away, explaining why we don't see the stuff around us all the time. This is a common mistake made even by prominent physicists. Negative mass matter, notwithstanding that it is repelled by positive mass matter, nonetheless moves *toward* the Earth because its inertial mass is negative too (as demanded by the Equivalence Principle). So its mechanical response to a force is in the opposite direction of that of normal matter. Speaking Newtonianly, when negative mass matter is pushed away from the Earth by the force of its gravity, it responds by moving toward the Earth. (See [4], on the behavior of negative mass matter.) Moreover, this approach is bedeviled by another problem. Even if you could harvest a Jupiter mass of exotic matter, you would have to find a way to compact it all into a structure of very modest dimensions. This would be a daunting engineering feat, if at all doable.

In light of the problems of the harvesting scenario, it seems as though the only realistic methods of making stargates are going to depend on finding a way to transform some pre-existing stuff into a Jupiter mass of exotic matter *in situ* so that the compaction problem is averted as the exotic matter is "created" already compacted. This means that the exotic matter we seek to make our stargate must, in some sense, be already present in latent form in the world as we find it. And we must find a way to expose the already present exotic mass. We (and our AAAs) set aside the proposition of creation of exotic matter *ex nihilo* as that is an egregious violation of the principle of local momenergy conservation.

Section summary: The only plausible source of a compact Jupiter mass of exotic matter must be something latent in the world as we find it that can be exposed in some way.

4. Spacetime Foam

Not longafter Thorne and his graduate students proposed traversable wormholes, a legion of critics arose claiming that, for one reason or another, their work was flawed and traversable wormholes were physically impossible. The luminary in their number was none other than Stephen Hawking, Thorne's very good friend. Hawking [5] published his Chronology Protection Conjecture (CPC) in 1992, remarking that the CPC "made the Universe safe for historians" (MUSH). The CPC was based on a supposed defect in the method Thorne had proposed for making a time machine, or, in our parlance, stargate. At the time, it was widely believed that tearing spacetime – that is, changing the topology of spacetime – was forbidden, since doing so would induce a singularity. If the induced singularity was like that of a black hole, topology change would be catastrophic, and certainly not a way to make a stargate.

Thorne's [6] way to avoid topology change was to assert that the way to make a time machine was to extract a pre-existing wormhole from the hypothetical Planck-scale quantum spacetime "foam" where spacetime consists of a frothing sea of microscopic wormholes that flit into and out of existence in conformity with Heisenberg's energy-time Uncertainty relationship. The transient energy conservation violation enabled by the Uncertainty relationship at the Planck scale turns out to be surprisingly large – about 10^{-5} gm – the Planck mass and that of Lloyd Motz's fundamental gravitational charge, the "uniton". By unspecified means, a microscopic wormhole is "amplified" to macroscopic dimensions. One of the two mouths of the wormhole is then taken on a "twins paradox" trip at high speed relative to the other mouth. Alternatively, one of the mouths can be placed near the event horizon of a black hole, where time slows markedly, for some reasonable duration. This produces a time shift between the mouths as the traveling or horizon proximate mouth ages more slowly than the non-traveling or normal space mouth. Hawking noted that to make a time machine, the time-slowed mouth must sooner or later be brought into the vicinity of the normal ageing mouth. When this is done, the time-slowed mouth must cross the future light cone of the normally aged mouth. At the instant of light cone traversal a "closed timelike curve" (CTC) forms. And quantum fields (actually, non-quantum fields too) can circulate along the CTC – again and again and again and . . . . *ad nauseam*. This, Hawking claimed, would lead to an infinite buildup of energy that would destroy the wormhole. Thorne's investigation showed that this might not be true. But in the absence of a quantum theory of gravity, the issue could not be conclusively settled one way or the other.

Much ink has been spilt over wormholes and the CPC in the now nearly 20 years since Hawking first proposed it. Hawking retreated a bit from the certainty of his initial claim in 1995. In a recent performance, however, he makes clear that he still believes that the CPC is correct. He also mentions that if he had a time machine, he would go back to see Marilyn Monroe in her prime and Galileo looking through his telescope. Others have noted that the singularities of topology change need not be of the catastrophic black hole variety, and if topology change is possible, then avoidance of inconvenient future light cones is trivial and stargates can be built without fear of Hawking's CPC.

At the most profound level, Thorne's proposal suffers from a fundamental problem: there is no generally accepted background independent quantum theory of gravity and there is no evidence whatsoever that spacetime at the Planck scale consists of a foam of transient microscopic wormholes. (Experiments, however, intended to detect predicted effects of spacetime foam are presently being contemplated.) Absent a quantum theory of gravity and evidence for spacetime foam, there is no reason to believe that this proposal has any chance of working. Likely, this is the reason for Thorne's deeply pessimistic view of the prospects of making time machines. Nonetheless, the belief that a quantum theory of gravity will eventually be created, and that it will justify belief in the existence of spacetime foam, is widespread. So we ask, if spacetime foam does exist and consist of microscopic transient wormholes, is there any prospect of amplifying one into a stargate? And if so, how might this be done?

The customary way of making things larger is to blow them up. This is usually done by adding energy, sometimes explosively, to the object to be enlarged. It is worth noting that this process works for blowing things up *in* spacetime. Whether it will work for blowing up spacetime itself is another matter.

The size of the wormholes of the putative quantum spacetime foam presumably are about the Planck length large – that is, about 10^{-33} cm across. This is about 20 orders of magnitude smaller than the classical electron radius and 18 orders of magnitude smaller than the diameter of nuclei. How do you blow up something so fantastically small? By smoking everything in its environs along with it. The two tools at our disposal to attempt this are the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). Taking these devices (optimistically) to put about 10 TeV per interaction event at our disposal, we find in equivalent mass that gives us about 10^{-20} gm. This is roughly 15 orders of magnitude less that the mass of our transient wormholes to be ablated – hardly enough to perturb a wormhole, much less blow it up. Moreover, the transient wormholes only exist for 10^{-43} seconds, making the temporal interaction cross-section hopelessly small. So given present and foreseeable technology, this scheme is arguably impossible. It seems most doubtful that AAAs would have pursued this avenue to stargates.

If amplifying quantum spacetime foam is an impossible scheme, at least in the absence of a quantum theory of gravity, are all possible microscopic wormhole schemes irrefragably flawed? Not necessarily. Recall, Wheeler's motivation for introducing the concept of microscopic wormholes was not to create the concept of spacetime foam. It was to make the structure of electrons and other electrically charged elementary particles wormholes threaded by self-repulsive electric fields to stabilize them so that electric charge could be eliminated as a fundamental physical entity. Where foam wormholes only exist fleetingly, electrons and quarks exist forever. So it would seem that instead of wasting our time on some scheme to amplify the vacuum that we assume to have some structure that has never been detected, we should focus our attention on electrons instead. They, at least, have been detected. From the energetic point of view, this course of action seems much more promising as the mass of the electron is 10^{-27} gm, some seven orders of magnitude *smaller* than the interaction energy available at RHIC and the LHC. Of course, amplification by ablation of electrons or other elementary particles into mesoscopic wormholes has never been observed at either the RHIC or the LHC, or any other accelerator for that matter, so evidently if electrons are to be used to make wormholes, some more subtle process than simply blowing them up by slamming other stuff into them will be required.

Section summary: "Amplification" of transient wormholes in the putative quantum spacetime foam is not a plausible way to make stargates. Electrons (and other elementary particles), however, may play a role in stargate construction either as wormholes themselves, or as the repositories of latent exoticity.

5. The Structure Of Elementary Particles

Ablating transient wormholes out of the hypothetical quantum spacetime foam is not viable. But electrons, should they be wormholes as suggested by Wheeler, are more promising as they last forever and are much lower energy objects. While mesoscopic wormholes have not been observed in deep inelastic lepton-lepton scattering experiments, looking at electrons (and the other constituents of everyday matter) for their potential in making stargates makes sense as vacuum schemes like that just considered are not tenable. The currently accepted model for the electron is that of the Standard Model: a point infinite charge dressed down to its observed value by a suitable polarization charge induced in its immediate environs. The obvious remark here is that there is no wormhole in this model. Note, however, that something relevant and important is present. As Milonni [3] pointed out to me many years ago [in a private conversation], the bare mass of the Standard Model electron, like the bare charge, is infinite – and it is also *negative*. The negative bare mass is dressed to a small positive value by the virtual photons that give the electron its electromagnetic self-energy. No wormhole. But if you could figure out how to "undress" electrons, presumably you would expose an enormous amount of negative rest-mass. Alas, no remotely plausible scheme for stripping bare particles of their virtual dressings has ever been proposed; and none seems likely to be proposed. Especially since Standard Modelers, faced with infinite negative bare masses, a proposition on its face preposterous if you take the positive energy theorem seriously, found ways to make it appear that the bare masses tend to zero. [In this connection see: [7], esp. p. 118.]

The electron of the Standard Model, in addition to not being undressable, has another problem: it does not involve gravity. Clearly, whether we are interested in electrons as wormholes or large repositories of negative mass, we need an electron model that explicitly includes gravity. As it turns out, such a model has been sitting around for fifty years. A bit more than twenty years ago Ashtekar [7] (at a 1989 Texas Symposium for Relativistic Astrophysics) invoked the model in his introductory remarks motivating his work on non-perturbative quantum gravity. He noted that as electrons are very simple, their masses could be characterized by a bare mass, m_o, and two self-energy terms, the electrical due to their electric charge and the gravitational due to their bare mass. Separately, the self-energy terms go to infinity as the radius of the charge distribution goes to zero. But if these terms are "fine tuned", since they are of opposite sign, they can be made to cancel. The situation, when general relativity is taken into consideration, is different. In general relativity, since everything couples to gravity, including gravity itself, the mass in the gravitational self-energy term becomes the total mass, rather than the bare mass, so:

$$m(\varepsilon) = m_o + \frac{e^2}{\varepsilon} - \frac{Gm^2}{\varepsilon},$$

which is quadratic in $m(\varepsilon)$ [where ε is the radius of a sphere of electrically charged dust of total charge e]. This equation has two roots, the positive one being:

$$m(\varepsilon) = -\frac{\varepsilon}{2G} + \frac{1}{G}\sqrt{\left(\frac{\varepsilon^2}{4} + Gm_o\varepsilon + Ge^2\right)}.$$

In the limit as ε goes to zero we have,

$$m(\varepsilon = 0) = \frac{e}{\sqrt{G}},$$

a finite result obtained without any fine tuning at all. Ashtekar [8] remarked that had one done a perturbation expansion in powers of Newton's constant, each of the terms in the series would have diverged, notwithstanding that the non-perturbative solution is finite. Moreover, this turns out to be the case for all gravity theories that are background independent. Ashtekar pointed out that the above calculation was shown to be an exact solution of Einstein's gravity field equations by Arnowitt, Deser, and Misner [9 – 11] in the 1960s; but the solution does not return a realistic mass for electrons, presumably because it is too simple. For example, it ignores quantum mechanical effects like spin.

Note especially here Ashtekar's [8] observation that all gravity field theories that are background independent – that is, all theories where the metric of spacetime *is the reality* of the structure of spacetime rather than a field in a flat (or other) background space – have the property that perturbative expansions are divergent. This means that we *must* use a model like that of Arnowitt, Deser, and Misner (ADM, [9 – 11]) to explore the behavior of matter in the presence of gravity if we want to get finite, reasonable results. The question is: can the ADM model be modified to get a realistic mass for electrons?

The ADM model was indeed first published in 1960. It is the exact general relativistic solution (in isotropic coordinates) for a sphere of electrically charged dust with total charge e and bare mass m_o. The model leads, as Ashtekar shows above, to the ADM mass for the electron when the radius of the charge goes to zero. The ADM mass, which differs from the Planck mass by a factor of the square root of the fine structure constant [$\alpha = e^2/\hbar c$], is far too large, by some 21 orders of magnitude in cgs units, to be a realistic representation of electrons. Nonetheless, the ADM model involves no renormalization with its attendant clouds of virtual particles, and it explicitly assumes general relativity as the correct theory of gravity, assuring us of the background independence demanded of any theory of matter where real wormholes are to be made. The question is: Can we adapt the ADM model in a reasonable way to explore the question whether it is possible to expose the latent exotic matter supposedly present in the bare masses of elementary particles?

We start by writing the ADM solution in slightly different notation and units [*i.e.*, we do not set c = 1] than those used by Ashtekar [and here above]:

$$m = m_o + \frac{e^2}{Rc^2} - \frac{Gm^2}{Rc^2} \ , \tag{1}$$

where R is the radius of the cloud of dust with charge e and bare [dispersed and non-interacting] mass m_o. The solution for zero radius is:

$$m = \pm\sqrt{\frac{e^2}{G}} \ . \tag{2}$$

In order to turn this solution into a realistic model of the electron, the first thing we must do, suggested by the Standard Model, is assume that the bare mass of the electron is *negative*, not positive. Moreover, we must also assume that the radius of the charge distribution is *not* zero, for zero radius, irrespective of the bare mass, returns Equation (2). The question then is: What do we use for the bare mass of the electron? Well, the charged leptons are simple. They only interact via the electromagnetic interaction.[†] So, it would seem a reasonable assumption that they consist only of dispersed dust particles of electric charge. Since only electrical and gravitational energies contribute to the ADM solution of Equation (2), it appears that the constituent dust should obey:

$$dm_o = \pm\, de / G^{1/2} \, , \tag{3}$$

and summing over the dust to get the bare mass gives:

$$m_o = \pm\sqrt{\frac{e^2}{G}} \tag{4}$$

The negativity of the bare mass dictates that the negative root be chosen in Equation (4) when substitutions for m_o are made in other equations.

Substitution of the negative root of the radical in Equation (4) for m_o does not exhaust the modifications needed to accommodate a negative bare mass in the ADM model. The Equivalence Principle dictates that when any of the inertial or gravitational masses are assumed negative, all of the masses must be taken as negative. The negativity of the inertial mass of the dust that accompanies assuming that it is gravitationally negative reverses the normal roles of gravity and electricity in the dust. The repulsive electrical force effectively becomes attractive, and the attractive gravitational force effectively becomes repulsive. That means that the signs of the self-energy terms in Equation (1) must be reversed. That is, Equation (1) must be replaced by:

$$m = m_0 - \frac{e^2}{Rc^2} + \frac{Gm^2}{Rc^2} \, , \tag{5}$$

so,

[†] Note, however, that the essentially exclusive decay mode of the muon is a pair of neutrinos mediated by a W boson.

$$m^2 - \frac{Rc^2}{G}m + \frac{Rc^2}{G}m_0 - \frac{e^2}{G} = 0\,, \tag{6}$$

and,

$$m = \frac{Rc^2}{2G} \pm \sqrt{\left(\frac{Rc^2}{2G}\right)^2 - \left(\frac{Rc^2}{G}m_0 - \frac{e^2}{G}\right)}. \tag{7}$$

As before the sign reversal to account for the Equivalence Principle, when R goes to zero, Equation (2) is recovered. So, using Equation (4) for the dust bare mass is unaffected. This substitution produces:

$$m = \frac{Rc^2}{2G} \pm \sqrt{\left(\frac{Rc^2}{2G}\right)^2 \pm 2\frac{Rc^2}{2G}\sqrt{\frac{e^2}{G}} + \frac{e^2}{G}}\,. \tag{8}$$

The main radical can be factored to give:

$$m = \frac{Rc^2}{2G} \pm \left(\frac{Rc^2}{2G} \pm \sqrt{\frac{e^2}{G}}\right). \tag{9}$$

Reading from the left, we take the first root positive and get two terms on the RHS of Equation (9). Since the charged dust bare mass is negative, we take the second root negative, and we thus get for m:

$$m = \frac{Rc^2}{G} - \sqrt{\frac{e^2}{G}}\,. \tag{10}$$

If the first term on the RHS of equation (10) is very slightly larger than the second term – which will be the case when the dust lies about at its gravitational radius [defined by $2Gm_0/Rc^2 \approx 1$ in this case] – a very small positive mass for the electron results. Moreover, a structure of this sort is stable as small perturbations from the quiescent non-zero radius produce forces on the dust that tend to restore the equilibrium configuration. But latent in the negative bare mass ADM electron is the second term on the RHS of equation (10) – an ADM mass of exotic matter. From the point of view of making stargates, the obvious question is: Is there any way to expose the latent exotic masses of electrons? To answer this question, we need to explore a contentious topic: Mach's Principle.

Section summary: The standard model of elementary particles and their interactions suggests that the bare masses of such particles are negative and very large. However, the model suggests that exposing the negative bare masses of elementary particles is impossible. An alternative model to the standard model is the Arnowitt-Deser-Misner (ADM) model. When the bare mass of the ADM model is taken to be negative and equal in amount to the ADM mass for zero radius, a finite radius electron solution is possible where the real electron mass can be recovered if the radius of the dust is assumed to lie close to its gravitational radius. Whether the negative bare masses of ADM electrons can be exposed depends on understanding Mach's Principle.

6. Mach's Principle

Wheeler, who gave us "black hole" and "wormhole", also encapsulated the current view of GRT in "spacetime tells matter how to move, and matter tells spacetime how to curve". That is, for example, planetary orbital motion is NOT the result of the Newtonian force of gravity acting on planets. Planets simply follow an inertial path (a geodesic) through spacetime that happens to be curved due to the presence of the Sun. There is no Newtonian-like gravitational force in GRT. This has led to the belief that there are no gravitational forces in GRT. Although this characterization of planetary motion in GRT is correct, the perception that there are no forces in GRT is not. In fact, all inertial reaction forces experienced by objects acted on by other forces that cause them to deviate from inertial (geodesic) motion are gravitational forces in our universe. The failure to realize that inertial forces are gravitational in GRT has led to considerable confusion about the proposition called "Mach's Principle" – the proposition that all inertial reaction forces are of gravitational origin – by Einstein. Two chief views of this Principle have emerged over the years: the "relationalist" and the "physical". The relationalist view asserts that all dynamics must be stated in terms that refer to the positions of other objects – and no more. The physical view asserts that the material contents of the universe cause inertial reaction forces by the action of a field produced by "matter" [through gravity in the case of GRT]. What counts as matter can be debated. But generally, things that go on the sources side of Einstein's field equations (the RHS) are taken to be "matter". In a particularly instructive exchange, Rindler [12] argued the relationalist position, and claimed (correctly) that it led to false conclusions. Bondi and Samuel [13] three years later, after listing about a dozen different statements of Mach's Principle, pointed out that though Rindler's argument against the relationalist view was correct, it did not apply to the physical view represented by GRT and a vector approximation thereto advanced by Sciama [14] in 1953.

Sciama's argument, since it is a vector approximation to the tensor formalism of GRT, is so simple it can be stated with but a few lines of math. In *analogy* with Maxwell's electrodynamics, Sciama noted that the "gravitoelectric" field **E** that acts on an object is given by:

$$\mathbf{E} = -\nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}\,, \tag{11}$$

where is c the vacuum speed of light, and ϕ and **A** are the scalar and three-vector parts of the four-potential of the gravitational field respectively. **A**, by analogy with electrodynamics, is just the integral over all causally connected space (out to the particle horizon) of the *matter* current density, that is, $\mathbf{v}\rho$, in each volume element divided by the distance r from the test particle to the volume element dV:

$$\mathbf{A} = -\frac{G}{c}\int_V \frac{\mathbf{v}\rho}{r}\,dV\,. \tag{12}$$

Sciama, for the case of a test particle being accelerated by an external force, argued that since the entire universe appears to be accelerating rigidly in the opposite direction from the point of view of the test particle, **v** can be removed from the integration; and the remaining integral just yields the total scalar gravitational potential ϕ at the location of the accelerating test particle. As a result one finds that:

$$\mathbf{E} = -\nabla\phi - \frac{\phi}{c^2}\frac{\partial \mathbf{v}}{\partial t}\,. \tag{13}$$

Since the mean cosmic matter density ρ was not known with much accuracy in the 1950s, his calculation returned only a very rough estimate of ϕ. Equation (13) is the equation for the gravitoelectric field in a non-inertial frame of reference accelerating with acceleration $\partial\mathbf{v}/\partial t$ with respect to some specified inertial frame of reference. Note that even when there is no gravitational field as customarily understood (*i.e.,* $\nabla\phi \neq 0$ for the presence of a gravitational field in Newtonian physics), the second term, absent in Newton's theory, does not necessarily vanish. And if $\phi/c^2 = 1$, then the second term on the RHS produces the inertial reaction force experienced by an object with acceleration $\partial\mathbf{v}/\partial t$. Note that this tells us something else important. Since $\phi = c^2$ when inertial reaction forces are caused by gravity – as Mach's Principle demands – we find that because $E = mc^2$, it follows by simple substitution that $E = m\phi$. That is, the masses and energy contents of material things are caused by the action of gravity.

Much discussion and disputation about Mach's Principle has taken place since the 1950s. For example, Hoyle and Narlikar [15], implementing the ideas of Wheeler and Feynman [16, 17], made it the centerpiece of their *Action at a Distance in Physics and Cosmology*. More importantly, much has been learned about cosmology – facts, not theory, though theory has made great strides too – that was not known before the '90s that bears directly on whether inertial reaction forces are gravitational in origin. The first and most important question is: Is it factually true that $\phi \approx c^2$? The answer is yes. This is the condition of so-called "critical cosmic matter density" and when that condition is satisfied – critical cosmic matter density obtains – the cosmos is spatially flat at the cosmic scale. Since 2003 when the results of the WMAP survey of the cosmic microwave background radiation were reported, it has been known that cosmic spatial flatness obtains to better than 1% accuracy. Accordingly, at least here and now, it is a *fact* that inertial reaction forces arise exclusively from the gravitational interaction, via the vector potential, with chiefly the most distant gravitating stuff in the cosmos as their source. That is, it is a matter of *fact* that Mach's Principle, at least in the here and now, is true. Inertial reaction forces are gravitational in origin if GRT is correct.

That's fine for the here and now. What about other places and other times? Naively, $\phi = GM/R$, and R at least is a function of time. Evidently, the only way that inertial reaction forces can equal the forces that excite them, independent of place and time, is if $\phi \approx c^2$ is always true. Since c is a locally measured invariant [but *not* a "constant" as its value may differ from 3 X 10^{10} cm/s in the presence of local mass concentrations when measured by distant observers], so too must ϕ be a locally measured invariant. This means that no matter where or when you are, you will *always* measure c to be 3 X 10^{10} cm/s and ϕ to be the square of c. It is worth remarking that this curious feature of GRT, first explained by Brans [18] in 1962, needed to get inertial reaction forces right, is built into the foundations of the theory in the form of the "Einstein Equivalence Principle" (EEP) which forbids the localization of gravitational potential energy. Locally, ϕ is always measured to have the same value: ~ c^2. It is the EEP that makes GRT background independent, and makes Newton's third law universally applicable. Should any of these features of GRT be wrong, they and GRT are all wrong. Should that be the case, there is no consistent mechanics and there will be no stargates.

Section summary: Mach's Principle, the assertion that inertial reaction forces are caused by the gravitational action of chiefly distant "matter" [everything that gravitates] in the universe, is correct in the present. Because the Einstein Equivalence Principle is true, gravitational potential energy cannot be localized, so ϕ is a locally measured invariant like c, and $\phi \approx c^2$ everywhere and everywhen, so Mach's Principle is also true for all epochs and places.

7. ADM Electrons And The Universe

In the previous section we have seen that the Machian nature of GRT and its foundational EEP require that at every point in spacetime there is a gravitational potential present that is a locally measured invariant equal to the square of the vacuum speed of light. The ADM electron, and, for that matter, all other local solutions of the GRT field equations which assume asymptotically flat spacetime are constructed in the spacetime where c and ϕ are locally measured invariants and $\phi \approx c^2$. Gravitational potential energy, as required by the EEP, may not be localizable in GRT, but that does *not* mean that gravitational potential energy can be ignored. Indeed, we find that the total gravitational potential energy, E_{grav}, of a body with mass m is just:

$$E_{grav} = m\phi = mc^2 . \qquad (14)$$

The obvious generalization of this observation is that the masses of material objects in the universe arise because of their gravitational potential energy whose source is the rest of the matter in the universe. Thus we see that Mach's principle not only identifies the source of inertial reaction forces as the gravitational action of chiefly distant matter, it also identifies the origin of mass-energy itself as gravitational potential energy.

We now turn to the issue of how the universe couples to the ADM negative bare mass electron. The only quantity in Equation (10) that isn't either a constant or locally measured invariant is R. It seems that we must express R in terms of gravitational potential(s) in order to achieve our objective. We proceed by first writing down energy E_e of the electron as determined by distant observers:

$$E_e = mc^2 = m\phi_u , \tag{15}$$

where we have put a subscript u on ϕ to identify the potential as arising from chiefly cosmic matter. Next we consider the gravitational energy of the charge distribution from the perspective of an observer located near to the distribution, but not in the distribution (as the gravitational potential seen by an observer in the distribution, owing to the locally measured invariance of the potential, is just c^2). Our nearby observer will see the bare mass m_o and the potential in the dust ϕ_i which has two contributions, the potential due to distant matter and the potential due to the bare dust itself. E_e for the nearby observer will be $m_o\phi_i$, and that, by energy conservation, is equal to $m\,c^2$, so:

$$m_o = m\frac{c^2}{\phi_i}. \tag{16}$$

Now the gravitational radius of m_o by definition is $R = 2Gm_o / c^2 = 2Gm/\phi_i$, so substituting for R in Equation (10) and with a little algebraic manipulation we get:

$$m = -\frac{\sqrt{\dfrac{e^2}{G}}}{\left[1-\dfrac{2c^2}{\phi_i}\right]} = -\frac{\sqrt{\dfrac{e^2}{G}}}{\left[1-\dfrac{2c^2}{\phi_u+\phi_b}\right]}. \tag{17}$$

When ϕ_u and ϕ_b are almost exactly equal and opposite with a difference of order unity, as they are in this case since ϕ_b is negative owing to the negative bare mass of the charged dust, the denominator of the RHS of Equation (17), up to a factor of order unity, becomes $\sim -c^2$ and the actual mass of the electron is recovered. The presence of ϕ_i in Equation (17) insures that the dimensions of the electron mass are correct. We now remark that could we find a way to screen our electron from the gravitational potential due to the rest of the universe, the denominator would become of order unity and the ***exotic*** bare mass of the electron – 21 orders of magnitude larger than its normal mass and negative – would be exposed. Do this to a modest amount of normal stuff and you would have your Jupiter mass of exotic matter to make a traversable stargate – *if the negative bare mass ADM model of elementary particles is a plausible representation of reality.*

Section summary: Mach's Principle and the Einstein Equivalence Principle require that the locally measured value of the scalar gravitational potential, ϕ , be equal to c^2 and invariant. This means that the masses of gravitating entities arise as a result of their gravitational potential energy, or $E = mc^2 = m\phi$, so $m = E / c^2 = E / \phi$. From the point of view of an observer nearby to an electron, s/he sees the bare mass of the electron, m_0 , acted upon by both the gravitational potential of the universe, $\phi_u = c^2$, and the gravitational potential of the bare dust, $\phi_b \cong -c^2$ if the dust lies very near to its gravitational radius. The sum of these potentials is that seen by the nearby observer in the dust, and it is their almost exact cancellation that leads to the very small observed mass of the electron. If a way can be found to suppress the gravitational action of the universe on electrons (and other elementary particles), their ADM exotic masses can be exposed, enabling the construction of real, traversable stargates.

8. The Plausibility of ADM Electrons

The negative bare mass ADM electron model we have considered so far, attractive though it may be for making stargates, is not a plausible model of reality as it stands. It is a Planck scale object that lacks important properties of real electrons. [This can be ascertained by solving Equation (10) for R.] Namely, it lacks the properties that arise from spin: angular momentum and a magnetic moment. Classical electron modelers might not be concerned that quantum mechanics is not involved. But almost everyone else would say that as a classical entity, the ADM model can't be realistic, for reality is quantum mechanical (except for gravity so far at least of course). Can the negative bare mass ADM model be made realistic? Perhaps.

Classical and semi-classical (with some elements of quantum mechanics included) electron modeling has been a cottage industry for more than a century and especially since Goudsmit and Uhlenbeck [19] proposed electron spin. The fundamental problem all such proposals have faced has been known from the time of Goudsmit and Uhlenbeck's proposal. If the electron is viewed as sphere of charge with a "classical" radius [a radius that makes the electron's mass due entirely to its electrostatic self-energy, about 10^{-13} cm], then its equatorial surface velocity must be about 100c to account for its magnetic moment. If the surface velocity is to be kept at c or less, the radius must be of the order of the Compton wavelength of the electron, that is, about 10^{-11} cm. Classical models that make the radius of the charge distribution smaller than the Compton wavelength face another criticism. They at least appear to violate the constraints of the Uncertainty Principle (UP). Using the position-momentum UP, and noting that $E \approx pc$, it is easy to show that the confinement region of an electron Δx dictated by the UP is:

$$\Delta x \approx \hbar / mc, \tag{18}$$

where $\hbar$ is Planck's constant divided by 2π. Not surprisingly, when the electronic mass is substituted into Equation (18), the minimum confinement distance turns out to be about 10^{-11} cm. – the Compton wavelength of the electron. So, both relativity and quantum mechanics seem to require that electrons not be smaller than the Compton wavelength.

References to the literature of classical and semi-classical electron modeling before the mid-1990s can be found in Woodward [20] and Wesson [21]. Recent examples of this sort of work are those of Burinskii [22 – 24] and Puthoff [25]. Burinskii has long advocated the Kerr-Newman solution of Einstein's field equations [for an electrically charged, rotating source] as a plausible representation of an extended electron. Part of the appeal of the Kerr-Newman solution is that it automatically returns a gyromagnetic ratio [or Lande factor] of 2, rather than 1. The problem with the model is the size of the ring singularity: the Compton wavelength of the electron, orders of magnitude larger than the known dimensions of the electron [less than 10^{-17} cm].

The negative bare mass ADM electron has problems too of course. A Planck-scale extended electron with the electron's mass is incompatible with Equation (18). And if we assume that the minimum energy condition should be applied to Equation (10), we get zero for the electron mass as the charged dust will settle to a radius that makes $m = 0$ identically. This solution, by the way, is stable. Reversal of the action of the gravitational and electromagnetic forces in negative bare mass electrons makes gravity repulsive and electrostatic forces between like charges effectively attractive. Since gravity is non-linear, if a perturbation causes the charged sphere to collapse, the repulsive gravitational force will tend to restore the initial configuration as gravity will be stronger than the electrical force. If the perturbation causes the sphere of charge to expand, the attractive electrical force will be larger than the repulsive gravitational force, and again the initial configuration will tend to be restored.

Were we intent on suggesting a replacement for the Standard Model of elementary particles and their interactions, we might be interested in exploring Kerr-Newman analogs of the negative bare mass ADM solution of Einstein's field equations. Such an undertaking, however, is not required since we are only interested in seeing if the ADM solution can be adjusted to include spin in a plausible way. Should this be possible, it is arguably reasonable to suppose that electrons might be exceedingly small spinning structures with negative bare masses that can be exposed if a way can be found to gravitationally decouple them from the action of the bulk of the matter in the universe.

The only obvious generalization of the ADM solution of Einstein's field equations, Equation (1) with the self-energy terms signs reversed to allow for the negative bare mass, that leaves it a simple quadratic equation that can be solved for m in the usual way is:

$$m = m_o - \frac{Ae^2}{Rc^2} + \frac{Gm^2}{Rc^2} \ , \tag{19}$$

where A is a constant to be determined. Following the procedures spelled out above, and taking account of the fact that angular momentum conservation requires that we associate angular momentum with the dispersed bare mass of our electrons [that is, a factor of A will appear in the counterparts of Equations (2), (3), and (4)], we get in place of Equation (10):

$$m = \frac{Rc^2}{G} - \sqrt{\frac{Ae^2}{G}} \ . \tag{20}$$

As long as we can find a way to express the angular momentum and its associated energy of rotation and magnetic self-energy in terms of e^2/R, then all we need do is choose A appropriately to incorporate these quantities into our solution.

If we are willing to make a simple approximation, including quantized angular momentum and magnetic-self energy turns out to be much simpler than one might expect. The approximation is that the electronic charge, rather than being a sphere, is a ring of radius R circulating with velocity v. We start with the mechanical energy of rotation, E_{rot}. This is just $\frac{1}{2}I\omega^2$, I being the moment of inertia of the ring and ω its angular velocity. For the simple case of a circular ring spinning around its axis of symmetry, E_{rot} is just $\frac{1}{2}mv^2$. To put this in terms of e^2/R we first invoke the Bohr quantization condition on angular momentum: $mvR = \frac{1}{2}\hbar$. The Bohr condition gives $m = \frac{1}{2}\hbar/vR$, so:

$$E_{rot} = \hbar v / 4R \, , \tag{21}$$

And we can use the fine structure constant [$\alpha = e^2/\hbar c$] to show the explicit dependence on e^2:

$$E_{rot} = \frac{v}{4\alpha c}\frac{e^2}{R} \, . \tag{22}$$

If v were $\approx c$, and the coefficient of e^2/R would be especially simple. We know, however, that cannot be the case, for were it true, the predicted angular momentum of the electron would be many orders of magnitude too small. To recover reality, v must be very much larger than c. Despite the seeming defect of violation of relativity because of a highly superluminal v, at least quantization is implicit in Equation (22) via the presence of the fine structure constant which depends on Planck's constant. We defer comment on the ***apparent*** violation of relativity until after discussion of magnetic self-energy.

Turning now to the magnetic self-energy associated with the loop of current created by the spinning electric charge, we note that it is a commonplace of both classical and quantum physics that the angular momentum and magnetic moment of a current are intimately related, their ratio being a constant called the "gyromagnetic", or "magnetogyric" (depending on how prissy the physicist speaking happens to be) ratio. This is a consequence of the fact that the charge to mass ratio of elementary particles is fixed, and the magnetic moment of a current loop is defined as $\mu = evR/2c$. This being the case, it stands to reason that if the mechanical angular energy can be expressed as a function of e^2/R, it should be possible to do the same for the magnetic self-energy. An approximate calculation of the magnetic self-energy that shows this is:

$$E_{mag} \approx \frac{1}{8\pi}\int_R^\infty H^2\, dV\ , \tag{23}$$

where H is the magnetic field intensity and dV is a volume element which is integrated from $r = R$ (exceedingly small) to infinity. Equation (23) is recovered from the general definition of the energy density of the electromagnetic field, for the special circumstances of a simple ring current. Now H for a simple dipole source is $\approx \mu/r^3$ and $dV = 4\pi r^2 dr$. Note that μ here is the dipole moment of the current ring, not the permeability of the vacuum. Carrying out the integration of Equation (23) gives:

$$E_{mag} \approx \frac{1}{6}\frac{\mu^2}{R^3} = \frac{1}{24}\left(\frac{v}{c}\right)^2 \frac{e^2}{R} = A_{mag}\frac{e^2}{R}\ . \tag{24}$$

As in the case of mechanical energy of rotation, the magnetic self-energy can also be expressed in terms of e^2/R. But where the mechanical energy depends on v/c, the magnetic self-energy depends on the square of that quantity. And if v is larger than c, then the magnetic self-energy dominates the contributions to A. That is, $A \cong A_{mag}$.

In fact, we know that v must be very much larger than c, notwithstanding that this is an apparent violation of the principle of relativity. The exceedingly small size of the ADM electron, even with spin included, requires that this be the case to recover the observed values of the angular momentum and magnetic moment. How can that be? Well, recall that the ADM solution is done in "isotropic" coordinates. In these coordinates the speed of light is the same in all directions point-by-point (hence "isotropic") and the coordinates give space the appearance of flatness. But in fact, for a compact or point source the radial coordinate may be highly distorted by the source at and near the origin of coordinates (see: [26], p. 93). For example, the relationship between the usual r of the Schwarzschild solution and r_i of the isotropic coordinates for the same solution is:

$$r = \left(1 + \frac{GM}{2c^2 r_i}\right)^2 r_i\,, \tag{25}$$

where M is the mass of the source. More importantly, the speed of light in isotropic coordinates differs from its locally measured invariant value. For distant observers it becomes:

$$c_{obs} = \frac{\left(1 - \frac{GM}{2r_i c^2}\right)^2}{\left(1 + \frac{GM}{2r_i c^2}\right)^3}\, c\ . \tag{26}$$

If M is positive, as, for example, it is for a black hole, then as one observes light propagating near the event horizon (the gravitational radius) from a distance, the speed appears to drop, going to zero at the horizon. If M is negative, as is the bare mass of our ADM electron, Equation (26) returns a different result: *the speed of light, for distant observers, appears to increase as the gravitational radius is approached, going to infinity at the gravitational radius* (as the denominator of the coefficient of c on the RHS in Equation (26) goes to zero). If our ring of electronic charge circulates very near to its gravitational radius – as it must for the small observed mass of the electron to be recovered – then while measured locally v is always less than c, distant observers will measure v to be orders of magnitude larger than c. The negative bare mass of our ADM electrons thus provides a natural explanation for the feature of classical and semi-classical electron models that has confounded these models from the outset. $\boldsymbol{v \gg c}$ as measured by us distant observers is *not* a violation of the principle of relativity when the bare mass of the electron is negative. It is to be expected.

The inclusion of spin in the ADM electron as sketched here changes things so that the solution obtained using Mach's Principle and energy conservation in the previous section does not return the electron mass in terms of interest. To calculate the electron mass, as before, we proceed by substituting for R in the first term on the RHS of Equation (20). But instead of using energy conservation and the energies measured by near and distant observers of the dust cloud, we use the Bohr quantization condition to express R in terms of the other quantities in that relationship. That is, we use $R = ½\hbar / mv$. Substitution and a little algebra yields:

$$\sqrt{\frac{G}{Ae^2}}\,m^2 + m - \sqrt{\frac{G}{Ae^2}}\,\frac{\hbar c^2}{2Gv} = 0\,. \tag{27}$$

Equation (27) has the solution:

$$m \cong \frac{1}{2}\sqrt{\frac{Ae^2}{G}}\left[-1 \pm \left(1 + \frac{1}{2}\,\frac{\hbar c^2}{2Ae^2 v}\right)\right], \tag{28}$$

and choosing the root that leads to the cancellation of the ADM bare mass by the first two terms on the RHS,

$$m \cong \frac{1}{8}\sqrt{\frac{Ae^2}{G}}\,\frac{\hbar c^2}{Ae^2 v}\,. \tag{29}$$

Since we know that $v \gg c$ (as measured by us distant observers), it follows that A will be dominated by the magnetic self-energy term, so from equation (24) we can take:

$$A \cong \frac{1}{24}\left(\frac{v}{c}\right)^2. \tag{30}$$

Substitution for A in equation (29) and more algebra yields:

$$m \cong 3\,\frac{c^3}{v^2}\,\frac{\hbar}{e^2}\sqrt{\frac{e^2}{24G}}\,. \tag{31}$$

Using the definition of the fine structure constant, this somewhat clunky expression can be stated in terms of the ADM mass as:

$$m \cong \sqrt{\frac{9}{24}}\left(\frac{c}{v}\right)^2 \alpha^{-1}\sqrt{\frac{e^2}{G}}\,. \tag{32}$$

The fine structure constant is present in Equation (32) because we used the Bohr quantization condition to express R in equation (20), so equation (32) is arguably at least semi-classical. We have implicitly set n, the principal quantum number in the Bohr angular momentum quantization condition, to one.

Should we want to know the (mass)-energy spectrum that follows from the choice of *n* equal to values other than one, I note that the calculation involved was carried out by Asim O. Barut many years ago [27, 28]. Barut started by remarking on the well-known, but unexplained, relationship between the electron and muon:

$$m_\mu = \left(1 + \frac{3}{2\alpha}\right) m_e \,, \tag{33}$$

claiming it could be derived on the basis of the magnetic self-interaction of the electron. In a footnote he did a simple calculation to show that the magnetic self-energy should depend on a principal quantum number as n^4. Considering an electric charge moving in a circular orbit in the field of a magnetic dipole he noted the equation of motion is $F = ma = mv^2 / R = e\mu v / R^3$ and the Bohr quantization condition is $mvR = n\hbar$. He solved the quantization condition for *R* and substituted into the equation of motion, getting $v = n^2 \hbar^2 / e\mu m$. Squaring this equation gives: $v^2 = n^4 \hbar^4 / e^2 \mu^2 m^2$, so the kinetic energy of the charge in orbit is: $mv^2/2 = n^4 \hbar^4 / 2e^2 \mu^2 m$ and energy quantization goes as n^4. A charge in circular orbit around a dipole is equivalent to the magnetic self-interaction of a ring current, so the energy quantization dependence of a ring electron on *n* should be the same as that calculated by Barut. Taking *n* = 1 to be implicit in equation (33), Barut conjectured that the mass of the τ should be:

$$m_\tau = m_\mu + \frac{3}{2\alpha} n^4 m_e, \quad n = 2\,. \tag{34}$$

or, more generally expressed,

$$m_{lep} = m_e \left(1 + \frac{3}{2\alpha} \sum_{n=0}^{n_{lep}} n^4 \right), \tag{35}$$

where *n* = 0 for the electron, *n* = 1 for the muon, and *n* = 2 for the tau lepton. The charged lepton masses computed with Barut's formula are surprisingly accurate. Barut did not know of the negative bare mass ADM electron model modified to include spin. Presumably, he assumed that something like it must exist, for it was obvious to him that the magnetic self-energy of the electron must dominate the electromagnetic self-energy. That being the case, he thought it natural to view the muon and tau as excited states of the electron. However, quoting Glashow, Barut remarked, "We have no plausible precedent for, nor any theoretical understanding of this kind of superfluous replication of fundamental entities [the charged leptons]. Nor is any vision in sight wherein the various fermions may be regarded as composites of more elementary stuff. . . ." The spin modified negative bare mass ADM model provides a physical model that arguably underpins Barut's conjecture. Note, however, that the principal quantum number 1 is implicitly assigned to the electron in Equations (27) to (32), whereas it is assigned to the muon in Barut's calculation. Evidently, the *n*s of the two calculations, both principal quantum numbers, are not the same. Since the electron, muon, and tau are all spin one half particles, the *n* implicit in equations (27) to (32) must be one, and the same value for all the charged leptons as they all have the same angular momenta: $\frac{1}{2}\hbar$. Notwithstanding that Barut invoked the Bohr quantization condition in his argument, his *n* must assume a range of values to account for the different mass-energies of the charged leptons. While it is tempting to pursue old quantum theory and invoke Wilson-Sommerfeld quantization conditions to explain the charged leptons as splitting of a ground state due to structural differences in the ring current, such speculations exceed the scope of this essay.

What about Heisenberg's UP [Uncertainty Principle] argument about energy and confinement size? Well, if you believe that the UP is a statement about our ability to measure reality, rather than an assertion about the inherent nature of reality, you won't have a problem with the negative bare mass ADM electron. After all, how big something is is not the same thing as how accurately you can measure its position. If you think the UP is an assertion, with Bohr and his followers, about the inherent nature of reality, you will have a problem with all this. And you won't be likely to think it possible to build stargates, ever. You may be right.

What about quantum gravity? What does it have to do with all this? Well, in terms of the sort of approach Ashtekar motivated with the ADM electron model many years ago – loop quantum gravity as it is now known – nothing. The negative bare mass spin modified ADM model describes objects much larger than the Planck scale, and quantum gravity is supposed to be significant only at and near the Planck scale. This can be shown by solving Equation (32) for $(v/c)^2$, substituting the result into Equation (30) and taking the square root. This yields a factor of ~ 10^{11} for the square root of A, and the radius of the spin modified negative bare mass ADM electron is larger than the classical ADM electron by this amount. That is, this model gives the electron a radius on the order of 10^{-23} cm. Several orders of magnitude smaller than the present level of detectability. But a decade of orders of magnitude larger than the Planck length. Electrons, with their humongous exotic bare masses, are *not* firmly locked in the embrace of quantum gravity it would seem. So perhaps there is hope that they may be exposed to make stargates without first mastering quantum gravity.

Section summary: The negative bare mass ADM model of the electron can be modified to accommodate quantized spin by including a constant coefficient, A, in the electrostatic self-energy term because both the mechanical energy of rotation and the magnetic self-energy of a current ring can be expressed as an appropriate coefficient times e^2/R. The mechanical energy of rotation contains a factor of v/c, and the magnetic self-energy $(v/c)^2$, where v is the velocity of the ring current of charged dust in the model. v is orders of magnitude larger than c as measured by us distant observers. But the ADM model is constructed in isotropic coordinates; and in those coordinates, if the source mass is negative (as in this case), velocities arbitrarily larger than c are possible if the ring current lies near its gravitational radius. So, this model is completely consistent with relativity notwithstanding the apparently superluminal velocity of the spinning ring of charge. Elaboration of the model in analogy with old quantum theory suggests that the charged leptons may be viewable as excited states of the electron.

9. Making Stargates And Mach Effects

The key to the solution of the problem of making stargates is to be found in Equation (17). Given some modest amount of everyday type matter, say a few hundred or thousand kilograms, all we have to do is enclose the matter within another presumably thin shell of matter wherein we can change its mass from positive to negative. It would have to become sufficiently negative to null the positive mass of the initial mass of the shell and the matter it encloses. But if we could do that, we would screen the gravitational influence of the matter in the rest of the universe on the matter within the thin shell. That would make ϕ_u in Equation (17) zero for all of the elementary particles making up the enclosed matter. That, in turn, for distant observers, would render their masses negative and about 21 orders of magnitude larger than their original positive masses. And that would give us the Jupiter mass of exotic matter we need to make an absurdly benign wormhole. *The really neat thing about this is that because both c and ϕ are locally measured invariants, the throat of the induced wormhole will look to you, the traversor, as though everything is completely normal, notwithstanding that someone outside the wormhole sees a major spacetime distortion present at the wormhole.*

How do we null ϕ_u? Is there any way to generate enough exotic matter to do the screening needed to expose the bare masses of enough normal matter to make the Jupiter mass needed for our wormhole? Yes. Mach's Principle does more than simply explain the origin of inertial reaction forces as the gravitational action of chiefly distant matter in the universe and the origin of mass as gravitational potential energy, arising from a potential that is a locally measured invariant. It also predicts that when objects that store internal energy are accelerated, transient changes in their masses take place. Such effects, if they exist at all, might be expected to be exceedingly small. So small indeed that they would be useless for making a Jupiter mass of exotic matter. But these are Newtonian order effects, and so much larger than otherwise would be expected. They are derived by assuming that inertial reaction forces are produced by a field – the gravitational field of the chiefly distant matter in the universe in fact – and then computing the local four-divergence of that field to find the local sources of the field. (For a detailed derivation of Mach effects see [20] and [29] Appendix A.) For a test object being accelerated by an "external" force, this produces the equation:

$$\nabla^2\phi - \frac{1}{\rho_0 c^2}\frac{\partial^2 E_0}{\partial t^2} + \left(\frac{1}{\rho_0 c^2}\right)^2\left(\frac{\partial E_0}{\partial t}\right)^2 = 4\pi G\rho_0 . \tag{36}$$

In this equation ϕ is the scalar potential of the gravitational field, ρ_0 the local proper matter density, E_0 the local proper energy density. The time-dependent terms in this equation arise from the fact that the derivative with respect to proper time of the four-momentum includes the time-derivative of *mc*, the time-like component thereof, and *m* can be a function of time. Equation (36) can be transformed into a customary classical wave equation for the field using Mach's Principle in the form that identifies the origin of mass-energy of an entity as its gravitational potential energy. Using this form of Mach's Principle, we can write:

$$E_0 = \rho_0\phi , \tag{37}$$

and this expression can be used in Equation (36) to affect the separation of variables. Keeping in mind that $\phi/c^2 = 1$, after some straight-forward algebra we find:

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} = 4\pi G\rho_0 + \frac{\phi}{\rho_0 c^4}\frac{\partial^2 E_0}{\partial t^2} - \left(\frac{\phi}{\rho_0 c^4}\right)^2\left(\frac{\partial E_0}{\partial t}\right)^2 - \frac{1}{c^4}\left(\frac{\partial\phi}{\partial t}\right)^2 . \tag{38}$$

This is a classical wave equation for the gravitational potential ϕ. Unlike Equation (36), the field terms that comprise the d'Alembertian of the potential are isolated on the left hand side of Equation (38).

The transient source terms on the RHS in Equation (38) are of interest to us. Note that they can be written:

$$\delta\rho_0(t) \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_0 c^2}\frac{\partial^2 E_o}{\partial t^2} - \left(\frac{1}{\rho_0 c^2}\right)^2\left(\frac{\partial E_0}{\partial t}\right)^2\right], \tag{39}$$

where the last term in Equation (38) has been dropped as it is always minuscule. It is in the transient proper matter density effects – the right hand side of Equation (39) – that we seek effects that will make absurdly benign wormholes that will take us to the stars (and perhaps the future and past as stargates at least in principle enable time travel). You may be thinking, "this can't possibly be right. What happened to general relativity? All we have used is special relativity to get the effects in equations (38) and (39)." Well, yes. But keep in mind that general relativity is constructed on the *assumption* that in sufficiently small regions of spacetime, special relativity obtains. Since we are only looking at local sources in a small region of spacetime, special relativity should be all that is needed. And we have used Mach's Principle – a feature of general relativity, but not special relativity – both as the origin of inertial reaction forces and as the origin of mass-energy, to obtain Equations (36) and (37). So general relativity is built into the predicted transient source effects even though the full formal machinery of the theory was not needed to get the effects of interest.

Note that we have not invoked any "new" physics to get these predicted effects. It's all "old" physics that has been around for decades or more. We've used it in novel ways. But it is still all "old" physics. And there isn't a single instance of "and then a miracle occurs". There is, however, one caveat that needs to be emphasized. *The predicted time-dependent effects only occur under two conditions: a local object is being accelerated* and *during the acceleration its state of internal energy changes. If either of these conditions is absent, no effects are expected.* Should we want to show explicitly the dependence of the effects on the acceleration of the local object in which they are produced, all we need note is that the work done by the accelerating force is $\mathbf{F}\bullet d\mathbf{s} = dE$, and the rate of change of work is the rate of change of energy, so:

$$\frac{\partial E_0}{\partial t} = \frac{\partial}{\partial t}\left(\mathbf{F}\bullet d\mathbf{s}\right) = \mathbf{F}\bullet\mathbf{v} = m\mathbf{a}\bullet\mathbf{v}. \tag{40}$$

It is important to note here that **v** is not the velocity normally encountered in elementary calculations of work and energy because we are talking about proper, that is, internal energy changes, rather than the kinetic energy acquired as the result of the acceleration of a rigid object. **v** here is the typical velocity of the parts of the object as it is compressed by the external force. If the object is incompressible (rigid), then **v** is zero and there are no internal energy changes. Concomitantly, there are no Mach effects. If **v** is not zero, it will likely be smaller than the bulk velocity acquired by the object (unless the object is externally constrained as it is compressed). The second time-derivative of E_o now is:

$$\frac{\partial^2 E_0}{\partial t^2} = \frac{\partial}{\partial t}\left(m\mathbf{a}\bullet\mathbf{v}\right) = m\mathbf{a}\bullet\frac{\partial\mathbf{v}}{\partial t} + \mathbf{v}\bullet\frac{\partial}{\partial t}\left(m\mathbf{a}\right) = m\,\mathbf{a}\bullet\frac{\partial\mathbf{v}}{\partial t} + \mathbf{v}\bullet\left(m\frac{\partial\mathbf{a}}{\partial t} + \mathbf{a}\frac{\partial m}{\partial t}\right). \tag{41}$$

Equations (40) and (41) can be used to explicitly display acceleration dependence of the effects via substitution in equation (39), but only when two considerations are taken account of. First, E_o in Equation (39) is the proper energy *density* because it follows from a field equation expressed in terms of densities, whereas E_o in Equations (40) and (41) is the proper energy of the entire object being accelerated, so Equation (39) must effectively be integrated over the whole accelerated object, making E_o the total proper energy, before the substitutions can be carried out. The second consideration that must be kept in mind is that the accelerating force can produce both changes in internal energy of the object accelerated and changes in its bulk velocity which do not contribute to internal energy changes. Only the part of the accelerating force that produces internal energy changes contributes to Mach effects. That is why $\partial\mathbf{v}/\partial t$ is written explicitly in equation (41) as it is only part of the total acceleration of the object. We can take account of the fact that **v** in equations (40) and (41) is only the part of the total **v** for the extended macroscopic object being accelerated by writing $\mathbf{v}_{\text{int}} = \eta\mathbf{v}$ and replacing **v** with $\mathbf{v}_{\text{int}}$ in the above equations. This leads to:

$$\frac{\partial^2 E_0}{\partial t^2} = \frac{\partial}{\partial t}\left(m\mathbf{a}\bullet\eta\mathbf{v}\right) = \eta m\mathbf{a}^2 + \eta\mathbf{v}\bullet\frac{\partial}{\partial t}\left(m\mathbf{a}\right) = \eta m\,\mathbf{a}^2 + \eta\mathbf{v}\bullet\left(m\frac{\partial\mathbf{a}}{\partial t} + \mathbf{a}\frac{\partial m}{\partial t}\right), \tag{42}$$

with $0 \le \eta \le 1$. As long as η can be taken to be a constant, the RHS of Equation (42) obtains and things are fairly simple. But in general, η will be a function of time, making matters more complicated and solutions more complex.

The obvious way to use the proper mass-energy density fluctuations predicted in Equation (39) is to subject capacitors to large, rapid voltage fluctuations. Since capacitors store energy in dielectric core lattice stresses as they are polarized, the condition that E_0 vary in time is met as the ions in the lattice are accelerated by the changing external electric field. If the amplitude of the proper energy density variation and its first and second time derivatives are large enough, and *if the capacitor is being accelerated at the same time*, a detectable mass fluctuation should ensue. That mass fluctuation, δm_0, is just the integral of $\delta\rho_0(t)$ given by Equation (39) over the volume of the capacitor, and the corresponding integral of the time derivatives of E_0, since $\partial E_0/\partial t$ is the power density, will be:

$$\delta m_0 = \frac{1}{4\pi G}\left[\frac{1}{\rho_0 c^2}\frac{\partial P}{\partial t} - \left(\frac{1}{\rho_0 c^2}\right)^2 \frac{P^2}{V}\right], \tag{43}$$

where P is the instantaneous power delivered to the capacitor and V the volume of the dielectric. An important caveat must be added here. Simply applying an alternating voltage to a capacitor will not, by itself, produce a mass fluctuation. The alternating voltage must be accompanied by a "bulk" acceleration of the capacitor with the same frequency as the applied voltage, as implied by Equation (42). And if the bulk acceleration is supplied separately from the internal energy fluctuation, its phase must be chosen with care. This follows from the fact that the derivation of these Mach effects is predicated on the acceleration of a test object which experiences a changing internal energy *during the acceleration*. In this case the bulk acceleration of the capacitors makes manifest the gravinertial reaction field that is responsible for the effects. The presence of one or the other of these conditions is *not* by itself sufficient to produce the effects. They must both be present simultaneously. *Note too that the assumption that all of the power delivered to the capacitors ends up as a* proper *energy density fluctuation is an optimistic, indeed, perhaps a wildly optimistic, assumption.*

Equation (43) has several important features when it comes to engineering stargates. The equation is non-linear and does not have analytical solutions. As a result, numerical integrations must be used for all specific cases considered. Nonetheless, important qualitative features of the equation can be identified from simple inspection. First, note the first term on the RHS can be either positive or negative, and it is normally orders of magnitude larger than the second term. It turns out that this term can be used to create accelerating forces on objects when its effects are combined with other mechanical actions (see for example, [29]). For this reason, we call the first term the "impulse" term in Equation (43). Next, note that the second term on the RHS is always negative since both the coefficient and P are squared, and V is positive definite. For this reason, we call this the "wormhole" term. However, because the coefficient contains a factor of c^{-4}, this term is almost always decades of orders of magnitude smaller than the leading term on the RHS. *Almost*, but not always. Both of the coefficients of the terms on the RHS also contain a factor of ρ_0^{-1}. And as the negative part of the cycles of the leading term produce sufficient negative mass to drive ρ_0 to zero, both coefficients asymptotically approach infinity. Since ρ_0 in the coefficient of the second term on the RHS is squared, the coefficient blows up more rapidly than the coefficient of the leading term, and the second term comes to dominate the equation. Simple numerical integrations show that this evolution can be made so pronounced that the value of the RHSs of Equations (39) and (43) remain negative after the state of negativity produced by the first cycle in which $\rho_0 = 0$ is achieved, notwithstanding that the leading term cycles to positive values ([30]; beware of serious flaws, introduced after copy editing was complete, in the published version of this paper).

You may be inclined to think that there must be something wrong with the sort of scenario being sketched out here. In particular, if you really could induce, say, a few hundred (or thousand) kilograms of exotic matter layered around a comparable mass of normal matter that you want to turn into a Jupiter mass of exotic matter to make a wormhole, you might think that the gargantuan gravitational fields that would be produced would explosively disrupt everything in sight. And even if you could maintain absurdly benign conditions outside the forming wormhole throat, anything in the throat region would be destroyed. However, some might say perversely, the property of the total gravitational potential identified in our discussion of Mach's Principle and the Einstein Equivalence Principle (EEP) – namely, the fact that the total gravitational potential is a *locally measured invariant* – means that the forming wormhole throat, observed by one in the throat, will look completely normal. I don't know about you, but I find this almost too good to be true. That the way to the stars, and the past and the future (as time machines are enabled by stargates), is already contained in the principle of relativity known to Galileo, and that Einstein got the EEP and the background independent geometrization of gravity right when he could have fallen in with conventional classical field theory, is *utterly amazing*. If AAAs took thousands or millions of years to get to wormholes and warp drives from where we were at the turn of the 20^{th} century, the delay must have been because they were not lucky enough to have had an Einstein [31] point the way and Thorne [6] willing to put his professional career on the line to spell out what needed to be done. I remark that *serious* courage is needed to take the sorts of risks taken by Einstein and Thorne.

How would you actually go about building a wormhole generator? Well, this paper is not intended to be a detailed engineering guide to the construction of such devices. [Engineering details of specific stargates are left as an exercise for the interested reader.] But a few general remarks are perhaps in order. First, in the tradition of the proverbial spherical chicken of physics lore, for simplicity we consider a spherical wormhole. We will need a layer of matter in which we can drive the impulse term effects in order to produce enough negative mass matter to decouple anything that lies within from the gravity of the rest of the universe. This we will want to dispose as a capacitor so that the dielectric material between the plates can be subjected to an alternating electric field. Since this alone, however, is not enough to drive a Mach effect impulse mass fluctuation, we will need to line our capacitive layer with a piezoelectric layer of material which can act as an actuator of the periodic (bulk) acceleration of the capacitor material we know to be necessary. In a practical device, additional circuitry will be required to activate both the capacitor and piezoelectric actuator. Power supplies and inductors to tune the circuits to resonant operation at some desired frequency will be needed along with power conditioning and impedance matching circuits. Whether the power supplies and inductors are situated within, or outside of the wormhole throat depends on whether you want to be able to move the wormhole around with ease. If yes, then they need to be in the throat. Sensors that provide feedback so that the circuits can be actively tuned will also be wanted, as you can expect the materials in the device to undergo changes during operation (due to heating and the like) that will change the state of tune. One other thing you will want: a foolproof fail-safe system to close the wormhole in case something goes wrong. (In this connection, never forget Murphy's Law.) You will want a very fast fail-safe system. If things go wrong with this sort of device, they are likely to do so very quickly.

Section summary: If some modest amount of normal matter can be gravitationally decoupled from the action of the rest of the universe, then the exotic bare mass of its constituent elementary particles can be exposed, making the construction of absurdly benign wormholes feasible. Mach effects hold out the promise of the generation of enough exotic matter to accomplish the task of gravitational decoupling. Mach effects are transient, Newtonian order effects that occur in objects as they are accelerated by external forces if, during the acceleration, their internal energies change. If the equation that captures the effects is written to display the explicit dependence of the effects on acceleration, care must be taken to include only the part of the dynamics that contributes to internal energy changes. Mach effects manifest themselves in two ways. The larger effect in most circumstances, for a periodically applied acceleration, produces a fluctuating change of the mass that is both positive and negative in the course of a full cycle. The smaller effect in most circumstances is always negative, notwithstanding that for periodic excitations it has a periodic component too. Owing to the non-linearity of the effects, the first effect can be used to create circumstances where the second effect becomes dominant. And this produces conditions where exceedingly large, stationary negative masses can be induced. This makes possible the gravitational decoupling of suitably disposed matter from the rest of the universe. And that in turn leads to the exposure of the exotic ADM bare masses of its constituent elementary particles. In sufficient quantity, such matter can induce the throat of an absurdly benign wormhole, making rapid spacetime transport a reality.

10. Conclusion

Plausibility, like truth and beauty, is often in the eye of the beholder – that is, you dear reader. So, the conclusion that you draw from the foregoing arguments will certainly depend on whether you think a reasonable case for the plausibility of Mach's Principle and the negative bare mass ADM electron with accommodation for spin has been made. The Standard Model of particle physics is a profound, thoroughly developed, elegant theory of the structure and interactions of elementary particles. The version of the ADM model presented here is but a crude sketch of such a theory. And you may choose to ignore it. The point, however, is that if our hypothetical AAAs really have figured out how to make absurdly benign wormholes, the physics on which they have based their accomplishment *cannot* be the Standard Model. Or anything like it based on renormalizable quantum field theory. Quantum gravity as commonly understood will not save the day, for, as Ashtekar remarked many years ago, background independent quantum gravity theories are not renormalizable. Our AAAs must have found a theory of matter that contains latent exotic mass that can be exposed in some simple, relatively low energy fashion like that laid out above. As Peter Woit [32] has remarked, "Finding . . . a new, deeper, and better way of thinking about fundamental physics is, however, an intellectually extremely demanding task. Unfortunately, it is not at all inconceivable that it is one that is beyond the capabilities of human beings if they are unaided by clues from experimentalists."

Faced with all this, we may ask: Is there any way forward? Yes. Experimental investigation of Mach effects – which turns out to be very much cheaper than building next generation accelerators – should illuminate whether stargates can in fact be built. Should that turn out to be possible, elaboration of the ADM model presented here might be worthy of some effort.

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