Gravitation, the ‘Dark Matter’ Effect and the Fine Structure Constant

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Abstract

Gravitational anomalies such as the mine/borehole g anomaly, the near-flatness of the spiral galaxy rotation-velocity curves, currently interpreted as the ‘dark matter’ effect, the absence of that effect in ordinary elliptical galaxies, and the ongoing problems in accurately determining Newton’s gravitational constant G_N are explained by a generalisation of the Newtonian theory of gravity to a fluid-flow formalism with one new dimensionless constant. By analysing the borehole data this new constant is shown to be the fine structure constant $\alpha \approx 1/137$. The spiral galaxy rotation curve effect and the globular cluster central ‘black hole’ masses for M15 and G1 are then correctly predicted.

Keywords: Gravity, in-flow, fine structure constant, dark matter, spiral galaxies, globular clusters, G measurements

Contents

1 Introduction

Gravity has played a key role in the history of physics, with first the successes of the Newtonian theory and later the putative successes of the Einsteinian theory, General Relativity. However there are numerous gravitational phenomena which are inexplicable within both the Newtonian and Einsteinian theories of gravity, including the mine/borehole g anomaly [1, 2, 3], the almost flat rotation-velocity curves of spiral galaxies [4], the absence of that effect in ordinary elliptical galaxies [5], and an ongoing lack of convergence in measurements of the Newtonian Gravitational constant G_N over the last 60 years [6], and other anomalies not discussed here. The spiral galaxy effect has been interpreted as being caused by an unknown form of 'dark matter' [7].

It would at first appear highly unlikely that a new theory of gravity could supersede General Relativity by passing the same tests and yet explaining also the various anomalies. However this is the situation that is now unfolding. The decisive tests of General Relativity were in situations where the external Schwarzschild metric was applicable, namely external to a spherically symmetric matter distribution. A critical insight is that the gravitational anomalies involve either a non-spherical matter distribution, as in spiral galaxies, or are internal to a spherical matter distribution, as for the borehole anomaly. It turns out that the Newtonian theory can be exactly re-written in the language of a 'fluid in-flow' system. Historically the Newtonian theory was based on observations within the solar system, in which small test 'objects', planets, are in orbit about a large central mass - the sun. This led to Newton's famous inverse square law, where the gravitational force is inversely proportional to the square of the distance. In the new theory of gravity this law turns out to be only valid under special conditions. In other cases the gravitational force is different to that from Newtonian gravity. The evidence is that there exists a non-Newtonian aspect to gravity even in the non-relativistic limit.

The new generalised 'fluid in-flow' formalism involves one new dimensionless constant, so that now gravity involves two constants, this new constant and the familiar G. The surprising discovery reported herein is that this new constant is none other than the fine structure constant $\alpha = e^2/\hbar c = 1/137.036$. This discovery suggests that space has a quantum structure, even though the flow equation is itself a classical equation, i.e., the quantum effects are apparent at the classical level. The occurrence of α does not necessarily imply that it is Quantum Electrodynamics (QED) that is playing a role. In QED α plays the role of the probability of charged particles to emit/absorb a photon, and it is probably this role which is being now revealed as a generic role for α, namely that it is a generic measure of randomness at a very fundamental level. If this interpretation is valid then it suggests that the gravitational anomalies were then really quantum gravity effects. In gravity theories involving only G it was expected that quantum gravity effects would only show up at the scale of the Planck length, $l_P = \sqrt{\hbar G/c^3} \approx 10^{-35}$m, and time, $t_P = \sqrt{\hbar G/c^5} \approx 10^{-44}$s , but this may now turn out to have been an incorrect conjecture. Quantum gravity effects may in fact be relatively large and easily observed, just as they are in atomic systems. Indeed as discussed herein the Cavendish-type laboratory experiments have revealed systematic discrepancies of the order of $\alpha/4$, and so now a new analysis of data from such experiments is capable of giving the value of α via purely laboratory gravity experiments.

One new implication of the theory is that it successfully predicts the masses of the 'black holes' that have recently been reported at the centres of globular clusters, and this phenomenon also involves the value of α. So it turns out that both the Newtonian and Einsteinian theories of gravity are only valid in very special cases, and it was from these cases that these theories were incorrectly judged to offer an explanation of gravitational phenomena.

Here we derive the 'in-flow' theory of gravity, which involves a classical velocity field and the theory exhibits the 'dark matter' effect, with strength set by the fine structure constant. This flow theory is apparently the classical description of a quantum foam substructure to space , and the 'flow' describes the relative motion of this quantum foam with, as we now show, gravity arising from inhomogeneities and time variations in that flow. These gravitational effects can be caused by an in-flow into matter, or even produced purely by the self-interaction of space itself, as happens for instance for the new 'black holes', which do not contain in-fallen matter.

2 Gravity and the 'Dark Matter' Effect

The apparently most successful theory of gravity is the Einstein General Relativity (GR) which supposes a 4-dimensional differential manifold with a metric tensor $g_{\mu\nu}(x)$ which specifies the proper time interval according to

$$d\tau^2 = g_{\mu\nu}(x)dx^\mu dx^\nu. \tag{1}$$

Trajectories of test objects are determined by extremising the proper time $\delta\tau/\delta x_\mu = 0$, giving the geodesic equation in terms of the usual affine connection, constructed from $g_{\mu\nu}(x)$,

$$\Gamma^\lambda_{\mu\nu}\frac{dx^\mu}{d\tau}\frac{dx^\nu}{d\tau} + \frac{d^2x^\lambda}{d\tau^2} = 0. \tag{2}$$

However all direct tests or observations of the GR formalism have used only the external Schwarzschild metric, for which (1) takes the well-known form

$$d\tau^2 = (1-\frac{2GM}{c^2r})dt^2 - \frac{1}{c^2}r^2(d\theta^2+\sin^2(\theta)d\phi^2) - \frac{dr^2}{c^2(1-\frac{2GM}{c^2r})}. \tag{3}$$

external to a spherical mass M. However by way of the change of variables $t \to t'$ and $\mathbf{r} \to \mathbf{r}' = \mathbf{r}$ with

$$t' = t + \frac{2}{c}\sqrt{\frac{2GMr}{c^2}} - \frac{4GM}{c^2}\tanh^{-1}\sqrt{\frac{2GM}{c^2r}}, \tag{4}$$

(3) may be written in the form

$$d\tau^2 = dt'^2 - \frac{1}{c^2}(dr' + \sqrt{\frac{2GM}{r'}}dt')^2 - \frac{1}{c^2}r'^2(d\theta'^2+\sin^2(\theta')d\phi'^2), \tag{5}$$

with r' is the radial distance, and which involves the radial in-flow velocity field

$$\mathbf{v}(\mathbf{r}) = -\sqrt{\frac{2GM}{r}}\hat{\mathbf{r}}. \tag{6}$$

So in all cases the explicit tests of GR actually involved a velocity field. Cases where the metric is not equivalent to (3) or (5) have not been experimentally tested. This and other experimental evidence, see below, suggest that gravity may be in fact a consequence of a flow field, and that the metric formalism may have been misleading. A form for the proper time for a general velocity field $\mathbf{v}(\mathbf{r}(t),t)$, that generalises (5), is

$$d\tau^2 = g_{\mu\nu}dx^\mu dx^\nu = dt^2 - \frac{1}{c^2}(d\mathbf{r}(t) - \mathbf{v}(\mathbf{r}(t),t)dt)^2. \tag{7}$$

Then the geodesic equation (2) is explicitly computed to give the acceleration of the test object

$$\frac{d\mathbf{v}_0}{dt} = \left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v}\right) + (\nabla \times \mathbf{v}) \times \mathbf{v}_R - \frac{\mathbf{v}_R}{1 - \dfrac{\mathbf{v}_R^2}{c^2}} \frac{1}{2} \frac{d}{dt}\left(\frac{\mathbf{v}_R^2}{c^2}\right), \tag{8}$$

where $\mathbf{v}_0$ is the velocity of the test object, and $\mathbf{v}_R(\mathbf{r}(t), t) = \mathbf{v}_0 - \mathbf{v}(\mathbf{r}(t), t)$ is the velocity of the test object relative to the local 'substratum' that actually is flowing, according to the frame to which positions and speeds are referenced. To be explicit the frame defined by the Cosmic Background Radiation (CBR) could be used, though this does not imply any special local privilege to the frame. Eqn.(8) is exact for metrics of the form in (7), which are known as Panlevé-Gullstrand metrics. Of course (8) is independent of the mass of the test object, which is the equivalence principle. Eqn.(8) is particularly revealing. The first term is the well-known Euler 'total derivative' fluid acceleration, and involves the explicit time-dependence as well as the convective fluid acceleration component, the 2nd term is the Helmholtz fluid acceleration component caused by vorticity in the flow, while the last term is the relativistic effect, which causes precession of elliptical orbits, event horizons, etc. This form then suggests that the phenomenon of gravity is caused by time variations and inhomogeneities of some flow, and that the curved spacetime manifold mathematics was essentially concealing that observation. This of course suggests a critical reassessment even of the Newtonian gravity formalism.

The Newtonian theory was formulated in terms of a force field, the gravitational acceleration $\mathbf{g}(\mathbf{r}, t)$, and was based on Kepler's laws for the observed motion of the planets within the solar system. Newton had essentially suggested that $\mathbf{g}(\mathbf{r}, t)$ is determined by the matter density $\rho(\mathbf{r}, t)$ according to

$$\nabla.\mathbf{g}(\mathbf{r}, t) = -4\pi G\rho(\mathbf{r}, t). \tag{9}$$

However the acceleration in (8) implies that a velocity field formalism is more fundamental, as clearly the acceleration cannot be re-constructed from the velocity field. Only the terms in (8) independent of the test object velocity can be dynamically associated with the flow dynamics itself, and so the Euler fluid acceleration should be used in (9) in place of $\mathbf{g}(\mathbf{r}, t)$, giving

$$\nabla.\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v}\right) = -4\pi G\rho, \tag{10}$$

with $\mathbf{g}$ now a derived quantity given by the Euler fluid acceleration

$$\mathbf{g}(\mathbf{r}, t) = \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v} \equiv \frac{d\mathbf{v}}{dt}, \tag{11}$$

the last expression defines the total Euler fluid derivative. External to a spherically symmetric mass M the solution to (10), is (6), and then from (11) we get the usual inverse square law

$$\mathbf{g}(\mathbf{r}) = -\frac{GM}{r^2}\hat{\mathbf{r}}, \quad r > R. \tag{12}$$

It must be emphasised that the velocity field formalism in (10)-(11) is *mathematically* equivalent to the acceleration field formalism (9); they both always give the same acceleration field. However there are two reasons for believing that the velocity field is *physically* more fundamental: (i) (10)-(11) permit a generalisation that leads to an explanation of the so-called 'dark matter' effect, and to numerous other effects, discussed in later sections, whereas (9) does not permit that generalisation, and (ii) the velocity field has been directly observed. The experimental evidence for the velocity field has been extensively reported in [8, 9], where the velocity field is apparently associated with galactic gravitational effects, but most significantly a smaller component of the velocity field flowing past the earth towards the sun has been recently extracted from the Miller data from 1925/26, and has a value consistent with (6) where M is the mass of the sun.

However there is one immediate insight into gravity that arises from (10), and that is that the inverse square law for gravity is now seen to be a consequence of the inhomogeneity part of the Euler fluid acceleration, namely $(\mathbf{v}.\nabla)\mathbf{v}$, which for zero vorticity has the form $\nabla(\mathbf{v}^2)/2$. In turn the form of this inhomogeneity is determined by the requirement that the acceleration in (11) be Galilean covariant.

One consequence of the velocity field formalism (10)-(11) is that it can be generalised to include a new unique term

$$\frac{\partial}{\partial t}(\nabla.\mathbf{v}) + \nabla.((\mathbf{v}.\nabla)\mathbf{v}) + C(\mathbf{v}) = -4\pi G\rho, \tag{13}$$

where

$$C(\mathbf{v}) = \frac{\alpha}{8}((trD)^2 - tr(D^2)), \tag{14}$$

and

$$D_{ij} = \frac{1}{2}\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}\right). \tag{15}$$

Eqn.(13) has the same solution (6) external to a spherically symmetric mass, because $C(\mathbf{v}) = 0$ for that flow, and so the presence of the $C(\mathbf{v})$ would not have manifested in the special case of planets in orbit about the massive central sun. So (13)-(11) are consistent with Kepler's laws for planetary motion in the solar system, and including the relativistic term in (8) we obtain as well the precession of elliptical orbits. Here α is a dimensionless constant - a new gravitational constant, in addition to the Newtonian gravitational constant G. From (11) we can write (13)) as

$$\nabla.\mathbf{g} = -4\pi G\rho - 4\pi G\rho_{DM}, \tag{16}$$

where

$$\rho_{DM}(\mathbf{r}) = \frac{\alpha}{32\pi G}((trD)^2 - tr(D^2)), \tag{17}$$

which introduces an effective 'matter density' onto the RHS of the Newtonian formalism in (9), phenomenologically representing the flow self-interaction dynamics associated with the $C(\mathbf{v})$ term. However the dynamical effect represented by this new term cannot be included, in a closed form, in the gravitational acceleration dynamics formalism of (9) because it cannot be expressed in terms of the gravitational field $\mathbf{g}$. This dynamical effect is shown here to be the 'dark matter' effect. The main theme of this paper is the determination of the value of α from experimental data, and then the computation of various observed effects that then follow.

We apply the new gravity theory to an earth based experiment to determine the value of α. However we know that earth in-flow is a small component compared to the total flow, as given by the experimental data discussed in [8, 9]. For completeness we would then need to demonstrate that the results for this experimental situation are unaffected by the larger 'background' flow. This has been done, but requires a much more detailed analysis then given herein. Then for a zero-vorticity stationary flow, and ignoring any background flow, (13) may be written in the form of a non-linear integral equation

$$\mathbf{v}^2(\mathbf{r}) = 2G\int d^3s\frac{\rho(\mathbf{s})}{|\mathbf{r}-\mathbf{s}|} + 2G\int d^3s\frac{\rho_{DM}(\mathbf{v}(\mathbf{s}))}{|\mathbf{r}-\mathbf{s}|}, \tag{18}$$

as $\nabla^2\frac{1}{|\mathbf{r}-\mathbf{s}|} = -4\pi\delta^4(\mathbf{r}-\mathbf{s})$. In particular when the matter density and the flow are both spherically symmetric and stationary in time (13) becomes, with $v' \equiv dv/dr$, the non-linear differential equation

$$2\frac{vv'}{r} + (v')^2 + vv'' = -4\pi G\rho(r) - 4\pi G\rho_{DM}(v(r)), \tag{19}$$

with now

$$\rho_{DM}(v(r)) = \frac{\alpha}{8\pi G}\left(\frac{v^2}{2r^2} + \frac{vv'}{r}\right). \tag{20}$$

Then (18) gives a non-linear radial integral form for (19), on doing the angle integrations,

$$\begin{aligned} v^2(r) \;&=\; \frac{8\pi G}{r}\int_0^r s^2\left[\rho(s) + \rho_{DM}(v(s))\right]ds \\ &\quad +8\pi G\int_r^\infty s\left[\rho(s) + \rho_{DM}(v(s))\right]ds, \end{aligned} \tag{21}$$

It needs to be emphasised that with $\alpha = 0$ (19) is completely equivalent to Newtonian gravity.

First consider solutions to (20) and (21) in the perturbative regime. Iterating once we find,

$$\rho_{DM}(r) = \frac{\alpha}{2r^2}\int_r^\infty s\rho(s)ds + O(\alpha^2), \tag{22}$$

so that in spherical systems the 'dark matter' effect is concentrated near the centre, and we find the total 'dark matter'

$$\begin{aligned} M_{DM} &\equiv 4\pi\int_0^\infty r^2\rho_{DM}(r)dr = \frac{4\pi\alpha}{2}\int_0^\infty r^2\rho(r)dr + O(\alpha^2) \\ &= \frac{\alpha}{2}M + O(\alpha^2), \end{aligned} \tag{23}$$

where M is the total amount of (actual) matter. Hence to $O(\alpha)$ $M_{DM}/M = \alpha/2$ independently of the matter density profile. This turns out be be directly applicable to the case of globular clusters, as shown later, and also implies that the theory of stellar structures needs to be reconsidered, as this central 'dark matter' effect changes the central $g(r)$ considerably. This may have some bearing on the solar neutrino problem.

3 Borehole g Anomaly

When the matter density $\rho(r) = 0$ for $r \geq R$, as for the earth, then we also obtain, to $O(\alpha)$, from (20) and (21), and then (11),

$$g(r) = \begin{cases} -\dfrac{(1+\frac{\alpha}{2})GM}{r^2}, \quad r > R, \\ -\dfrac{4\pi G}{r^2}\displaystyle\int_0^r s^2\rho(s)ds - \dfrac{2\pi\alpha G}{r^2}\displaystyle\int_0^r \left(\int_s^R s'\rho(s')ds'\right) ds, \\ \qquad\qquad r < R, \end{cases} \tag{24}$$

which gives Newton's 'inverse square law' for $r > R$, but in which we see that the effective Newtonian gravitational constant is $G_N = (1 + \frac{\alpha}{2})G$, which is different to the fundamental gravitational constant G in (10). The result in (24), which is different from that of the Newtonian theory ($\alpha = 0$) has actually been observed in mine/borehole measurements [1, 2, 3] of $g(r)$, though of course there had been no explanation for the effect, and indeed the reality of the effect was eventually doubted. The gravity residual [1, 2, 3] is defined as

$$\Delta g(r) \equiv g(r)_{Newton} - g(r)_{observed} \tag{25}$$

$$= g(r)_{Newton} - g(r). \tag{26}$$

The 'Newtonian theory' assumed in the determination of the gravity residuals is, in the present context,

$$g(r)_{Newton} = \begin{cases} -\dfrac{G_N M}{r^2}, \quad r > R, \\ -\dfrac{4\pi G_N}{r^2}\displaystyle\int_0^r s^2\rho(s)ds, \quad r < R, \end{cases} \tag{27}$$

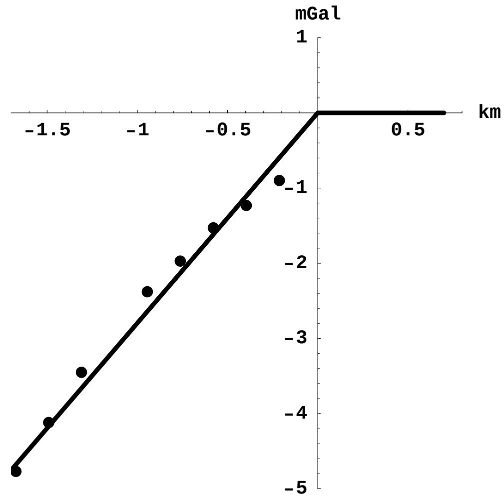

Figure 1: The data shows the gravity residuals for the Greenland Ice Cap [3] Airy measurements of the $g(r)$ profile, defined as $\Delta g(r) = g_{Newton} - g_{observed}$, and measured in mGal (1mGal $= 10^{-3}$ cm/s^2), plotted against depth in km. Using (28) we obtain $\alpha^{-1} = 139 \pm 5$ from fitting the slope of the data, as shown.

with $G_N = (1 + \frac{\alpha}{2})G$. Then $\Delta g(r)$ is found to be, to 1st order in α and in $R - r$, i.e. near the surface,

$$\Delta g(r) = \begin{cases} 0, \quad r > R, \\ -2\pi\alpha G_N \rho(R)(R - r), \quad r < R, \end{cases} \tag{28}$$

which is the form actually observed [1, 2, 3]. So outside of the spherical earth the Newtonian theory and the in-flow theory are indistinguishable, as indicated by the horizontal line, for $r > R$, in Fig.1. However inside the earth the two theories give a different dependence on r, due to the 'dark matter' effect within the earth. Even though the 'dark matter' effect is concentrated near the centre in this case, there is still a small effect just beneath the surface.

Gravity residuals from a borehole into the Greenland Ice Cap were determined down to a depth of 1.5km [3]. The ice had a measured density of $\rho = 930$ kg/m^3, and from (28), using $G_N = 6.6742 \times 10^{-11}$ m^{3}s^{-2}kg^{-1}, we obtain from a linear fit to the slope of the data points in Fig.1 that $\alpha^{-1} = 139 \pm 5$, which equals the value of the fine structure constant $\alpha^{-1} = 137.036$ to within the errors, and for this reason we identify the constant α in (14) as being the fine structure constant.

To confirm that this is not a coincidence we now predict the spiral galaxy 'dark matter' effect and the globular cluster 'black hole' masses using this value for α, and also indicate the likely origin of the unexplained systematic discrepancies apparent in the ongoing attempts to measure G with increased accuracy.

4 Spiral Galaxies

Consider the non-perturbative solution of (13), say for a galaxy with a non-spherical matter distribution. Then numerical techniques are necessary, but beyond a sufficiently large distance the in-flow will have spherical symmetry, and in that region we may use (19) and (20) with $\rho(r) = 0$. Remarkably then the pair (19) and (20) has an exact non-perturbative two-parameter analytic solution,

$$v(r) = K\left(\frac{1}{r} + \frac{1}{R_S}\left(\frac{R_S}{r}\right)^{\frac{\alpha}{2}}\right)^{1/2}, \tag{29}$$

where K and R_S are arbitrary constants in the $\rho = 0$ region, but whose values are determined by matching to the solution in the matter region. Here R_S characterises the length scale of the non-perturbative part of this expression, and K depends on α and G and details of the matter distribution. The galactic circular orbital velocities of stars etc may be used to observe this in-flow process in a spiral galaxy and from (11) and (29) we obtain a replacement for the Newtonian 'inverse square law' ,

$$g(r) = \frac{K^2}{2}\left(\frac{1}{r^2} + \frac{\alpha}{2rR_S}\left(\frac{R_S}{r}\right)^{\frac{\alpha}{2}}\right), \tag{30}$$

in the asymptotic limit. From (30) the centripetal acceleration relation for circular orbits $v_O(r) = \sqrt{rg(r)}$ gives a 'universal rotation-speed curve'

$$v_O(r) = \frac{K}{2}\left(\frac{1}{r} + \frac{\alpha}{2R_S}\left(\frac{R_S}{r}\right)^{\frac{\alpha}{2}}\right)^{1/2}. \tag{31}$$

Because of the α dependent part this rotation-velocity curve falls off extremely slowly with r, as is indeed observed for spiral galaxies. Of course it was the inability of the Newtonian and Einsteinian gravity theories to explain these observations that led to the notion of 'dark matter'. It is possible to illustrate the form in (31) by comparing it with rotation curves of spiral galaxies. Persic, Salucci and Stel [4] analysed some 1100 optical and radio rotation curves, and demonstrated that they are describable by the empirical universal rotation curve (URC)

$$\begin{aligned} v_O(x) \;\; = \;\; v(R_{opt})\Bigg[&\left(0.72 + 0.44\mathrm{Log}\frac{L}{L_*}\right)\frac{1.97x^{1.22}}{(x^2+0.78^2)^{1.43}} \\ &+ 1.6\mathrm{e}^{-0.4(L/L_*)}\frac{x^2}{x^2+1.5^2(\frac{L}{L_*})^{0.4}}\Bigg]^{1/2} \end{aligned} \tag{32}$$

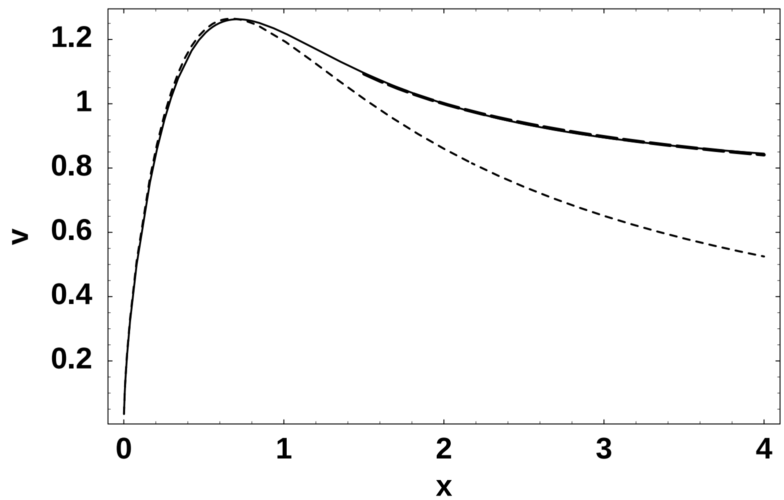

Figure 2: Spiral galaxy rotation speed curve plots, with $x = r/R_{opt}$. Solid line is the Universal Rotation Curve (URC) for luminosity $L/L_* = 3$, using the URC in (32), Ref.[4]. Short-dashes line is URC with only the matter exponential-disk contribution, and re-fitted to the full URC at low x. Long-dashes line, essentially overlaying the upper solid line for $x > 1.5$, is the form in (31), for $\alpha = 1/137$ and $R_S = 0.01R_{opt}$.

where $x = r/R_{opt}$, and where R_{opt} is the optical radius, or 85% matter limit. The first term is the Newtonian contribution from an exponential matter disk, and the 2nd term is the 'dark matter' contribution. This two-term form also arises from the in-flow theory, as seen in (18). The form in (31) with $\alpha = 1/137$ fits, for example, the high luminosity URC, for a suitable value of R_S, which depends on the luminosity, as shown by one example in Fig.2. For low luminosity data the observations do not appear to extend far enough to reveal the asymptotic form of the rotation curve, predicted by (31). The non-Keplerian rotation curve effect from the new theory of gravity is shown for the spiral galaxy NGC3198 in Fig.3.

But the general form in (29) leads to a key question. Why is it that R_S is essentially very large for the earth, as shown by the borehole data, and also for elliptical galaxies as shown by the recent discovery [5] that planetary nebulae in ordinary elliptical galaxies, serving as observable 'test objects', have Keplerian or Newtonian rotation-speed curves, whereas spiral galaxies have small values of R_S compared to their R_{opt} values, and that furthermore their R_S values are related to their luminosity. The answer to this question is that the in-flow equation actually has a one-parameter class of matter-free non-perturbative exact solutions of the form

$$v(r) = \frac{\beta}{r^{\alpha/4}}, \tag{33}$$

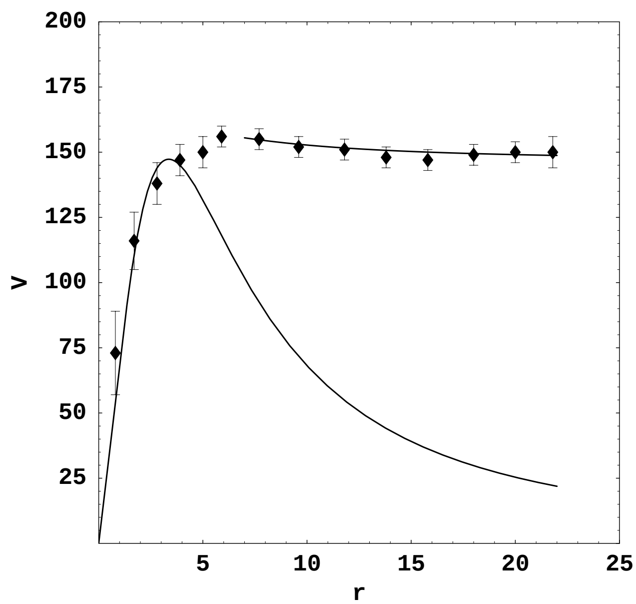

Figure 3: Data shows the non-Keplerian rotation-speed curve v_O for the spiral galaxy NGC3198 in km/s plotted against radius in kpc/h. Lower curve is the rotation curve from the Newtonian theory or from General Relativity for an exponential disk, which decreases asymptotically like $1/\sqrt{r}$. The upper curve shows the asymptotic form from (31), with the decrease determined by the small value of α. This asymptotic form is caused by the primordial black holes at the centres of spiral galaxies, and which play a critical role in their formation. The spiral structure is caused by the rapid in-fall towards these primordial black holes.

where the $1/r$ term in (29) is inadmissible because it does not satisfy the matter-free in-flow equation at $r = 0$. These solutions correspond to a novel feature of the new theory of gravity, namely the occurrence of these gravitational attractors. These attractors presumably were produced during the big-bang, and since they can coalesce to form larger attractors, it is most likely that it is such an attractor that leads to the formation of spiral galaxies. Attractors appear to form a cellular network, with the attractor form in (33) only valid for a single attractor. Attractors with large β values, and so large regions of influence, will attract greater quantities of the original post-big-bang gas. As well because these have large in-flow velocities the matter will end up with high angular momentum, resulting in a spiral galaxy. Then the magnitude of β is related to the total amount of matter in the galaxy, which manifests eventually as its luminosity. Smaller attractors will form galaxies with lower in-flow speeds and so are less likely to have large amounts of angular momentum. These new 'gravitational attractors' are the 'black holes' of the new theory of gravity, and their properties are determined by α, and not by G.

5 Black Holes

At the center of matter distributions the new theory of gravity also has attractor phenomena, namely the occurrence of 'in-flow singularities' which, in this case, are induced by the matter, as seen in the borehole analysis. Such in-flow singularities, and the 'dark matter' effect in general, are mandated by the in-flow and are not contingent phenomena. These attractor in-flows singularities have an event horizon, where the in-flow speed reaches the speed of light. Hence they are a new form of 'black hole'. This phenomenon is different to that in general relativity where black holes arise from the past in-fall of matter.

Recently it has been reported that globular clusters [11, 12] have central 'black holes', which now appears to be merely an interpretation of the central 'dark matter' gravitational attractor effect. Again here the spatial structure of these 'black hole' in-flow effects is determined by α - they are presumably intrinsically quantum-space processes, and the effective 'mass' of this central attractor is computable within the new theory. Numerical solutions of (19) for typical cluster density profiles reveal that the central 'dark matter' mass is accurately given by the perturbative result in (23), $M_{DM}/M = \alpha/2 = 0.00365$. Then the M_{DM}/M mass ratio is independent of the density profile, as noted above. The clusters M15 and G1 then give an excellent opportunity to test again the new theory. For M15 the mass of the central 'black hole' was found to be [11] $M_{DM} = 1.7^{+2.7}_{-1.7} \times 10^3 \mathrm{M}_\odot$, and the total mass of M15 was determined [13] to be $4.9 \times 10^5 \mathrm{M}_\odot$. Then these results together give $M_{DM}/M = 0.0035^{+0.011}_{-0.0035}$ which is in excellent agreement with the above prediction. For G1 we have [12] $M_{DM} = 2.0^{+1.4}_{-0.8} \times 10^4 \mathrm{M}_\odot$, and $M = (7 - 17) \times 10^6 \mathrm{M}_\odot$. These values give $M_{MD}/M = 0.0006 - 0.0049$, which is also consistent with the above

$\alpha/2$ prediction. There is a singularity at $r = 0$ where the in-flow speed becomes unbounded, and an event horizon where $v = c$, the speed of light. The radius of this event horizon depends on α. This implies that the globular cluster central 'attractor' is a manifestation of the non-Newtonian in-flow, that is, an in-flow different to the form in (6). Hence the globular cluster observations again indicate the role of the fine structure constant in gravity.

6 Measuring G

Finally it is now possible to explain the cause of the longstanding variations [6] in the measurements of the value of G_N, shown in Fig.4. Note that the relative spread $\Delta G_N/G_N \approx O(\alpha/4)$, as we would now expect. Essentially the different Cavendish-type experiments used different matter geometries, and as we have seen, the geometry of the masses has a 'non-Newtonian' effect on the in-flow, and so on the measured force between the masses. In these experiments the asymptotic form in (29) is not relevant as the test masses are always close, and the data indicates non-Newtonian effects of relative size $\alpha/4$. These effects are caused by both a 'polarisation' of the central 'dark matter' effect, caused by the presence of the other test mass, and by a 'dark matter' region forming essentially between the two masses.

Only for the borehole-type experiments do we have a complete analytic analysis, and an ocean Airy measurement of g is in this class, and [10] gives $G_N = (6.677 \pm 0.013) \times 10^{-11}$ m^{3}s^{-2}kg^{-1}, shown by the upper horizontal line in Fig.4. From that value we may extract the value of the 'fundamental gravitational constant' G by removing the 'dark matter' effect: $G = (1-\frac{\alpha}{2})G_N+O(\alpha^2) = (6.6526\pm0.013)\times10^{-11}$ m^{3}s^{-2}kg^{-1}, compared to the current CODATA value of $G_N = (6.6742 \pm 0.001) \times 10^{-11}$ m^{3}s^{-2}kg^{-1}, which is contaminated with 'dark matter' effects. Then in the various experiments, without explicitly computing the 'dark matter' effect, one will find an 'effective' value of $G_N > G$ that depends on the geometry of the masses. A re-analysis of the data in Fig.4 using the in-flow theory is predicted to resolve these apparent discrepancies. The discrepancies in measuring G are then presumably quantum gravity effects and, if so, then quantum gravity may be easily studied in laboratory Cavendish experiments.

7 What Flows?

The evidence here is that the velocity field explanation for gravity is more encompassing of gravitational phenomena then either the 'acceleration field' theory of Newton, in the non-relativistic regime, or the 'curved spacetime formalism' of Einstein. Indeed in all cases where these two theories were successful they could be exactly recast into the velocity field formalism. But the velocity formalism permits a unique and natural generalisation, not possible in either of these theories, and

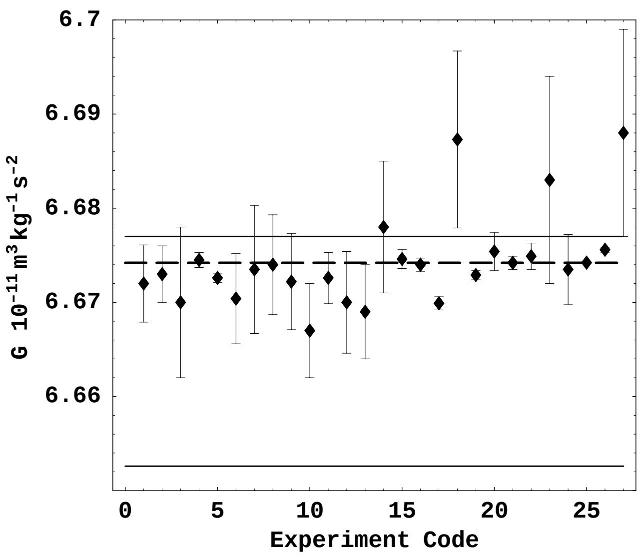

Figure 4: Results of precision measurements of G_N published in the last sixty years in which the Newtonian theory was used to analyse the data. These results show the presence of a systematic effect not in the Newtonian theory. **1:** Gaithersburg 1942, **2:** Magny-les-Hameaux 1971, **3:** Budapest 1974, **4:** Moscow 1979, **5:** Gaithersburg 1982, **6-9:** Fribourg Oct 84, Nov 84, Dec 84, Feb 85, **10:** Braunschweig 1987, **11:** Dye 3 Greenland 1995, **12:** Gigerwald Lake 1994, **13-14:** Gigerwald Lake 1995 112m, 88m, **15:** Lower Hutt 1995 MSL, **16:** Los Alamos 1997, **17:** Wuhan 1998, **18:** Boulder JILA 1998, **19:** Moscow 1998, **20:** Zurich 1998, **21:** Lower Hutt MSL 1999, **22:** Zurich 1999, **23:** Sevres 1999, **24:** Wuppertal 1999, **25:** Seattle 2000, **26:** Sevres 2001, **27:** Lake Brasimone 2001. The upper horizontal line shows the value from the 1991 ocean measurements [10], while the dashed line shows the current CODATA G_N value based on a statistical analysis of the indicated measurements. The lower line shows the value of G after removing the 'dark matter' effect within the earth on the Ref.[10] G_N value.

which then immediately explains numerous so-called gravitational 'anomalies', as shown herein for several examples.

Given that, the fundamental question is then: what is *flowing*? In [8, 9, 14] it is suggested that space has a quantum substratum, that space is a quantum system undergoing ongoing classicalisation. As well this quantum-foam system was argued to arise from an *information theoretic* model of reality. But what experimental evidence is there that what flows is not some material moving through some space, but some very exotic and new phenomenon? That evidence appeared when analysing the experiments of Michelson and Morley (1887), Miller (1925/26), and DeWitte (1991), as discussed in detail in [8, 9]. The first two experiments were gas-mode Michelson interferometer experiments which only in 2002 were finally understood [8]. Then using this first *post*-relativistic effects analysis it was shown that the non-null rotation-induced fringe shifts could be understood as arising from the combination of three effects: (i) the usual geometric path difference effect from motion through a substratum, that Michelson had used in the design of his interferometer, (ii) the physical Fitzgerald-Lorentz contraction of the arms of the interferometer, also from that motion, and (iii) the effects of the gas in the light paths which slightly slows the speed of light. In vacuum, that is with no gas present, (i) and (ii) exactly cancel, but in the presence of a gas this cancellation effect is only partial and a small residual effect occurs, which we now know explains why the gas-mode interferometer experiments, from 1887 onwards, have always shown small rotation-induced fringe shifts.

This explanation was confirmed by analysing data from three other interferometer experiments, by Illingworth (1927), Joos (1930) and by Jaseja *et al* (1964), that used He in the first two, and a He-Ne gas mixture in the last, allowing the effect of the gas, in terms of its refractive index, to be demonstrated by comparison with the air-mode data. To show that this analysis of the gas-mode interferometer was correct the results of the analysis were compared with the results from the 1st order in v/c RF travel-time coaxial cable experiments of Torr and Kolen (1981) and DeWitte (1991).

The key relevant aspect that arises from these interferometer experiments is that of the Fitzgerald-Lorentz contraction of the arms. Here that is a real physical effect, as originally proposed by Fitzgerald and Lorentz in the 19^{th} century. In contrast in the spacetime ontology interpretation by Minkowski and Einstein this contraction is merely a perspective effect, depending on the 'viewpoint' of an observer. But the above experimental data has being showing all along that the contraction was physical with its magnitude determined by the speed of motion of the arms through a physically existing 3-space, where as usual the contraction is in the direction of motion only. Such a uniform speed of itself has no connection with gravity. The observed speed is simply that of the apparatus through space, and in principle the experimentalists could choose that speed. So the contraction effect is caused by motion relative to a substratum, with apparently the contraction arising from the interaction between the atoms forming the arms being affected by that uniform motion.

So the argument is that a 3-space exists, and has structure, although we have as yet no measure of the size or nature of that structure, and that the amalgamation of the geometric models of time and 3-space into a four dimensional spacetime was not mandated by experiment. As well the velocity field formalism in (13) is Galilean covariant, which means that observers in relative motion may transform the velocity field using a Galilean transformation. This is not in contradiction with the Lorentz transformation; these two transformation rules relate the same data but in different forms. Hence the above suggests that the observed motion and the contraction effect are the consequence of a substructure to space itself, and not some flowing particulate matter. But then gravity turns out to be merely a consequence of the space itself being non-static and non-uniform, that is when its structure is in relative motion, This means that the structure in one region of space is moving relative to the structure in a different region of space, so the motion as such is only ever a differential motion, never a motion relative to some global background, whereas with a particulate interpretation of the flow, the motion would have to be relative to some background geometry, and we would be back to the original dualistic aether theories.

The relative motion of space itself is dramatically illustrated by the so-called Lense-Thirring effect. This is really the consequence of vorticity in the flow, that is, one region of space is rotating relative to a neighbouring region of space [16]. This is to be detected by the gyroscopes aboard the Gravity Probe B satellite experiment. There the spin direction of the gyroscopes is simply carried by the locally rotating space, with that rotation measured by comparison with distant space using light from a distant star. This vorticity or 'frame-dragging' effect, as it is called in General Relativity, does not require any dynamical calculation as would be the case if the vorticity was caused by some particulate matter moving through space. This vorticity is produced by the earth by means of its rotation, and as well its linear motion, upon the local space. The smaller component of the space-vorticity effect caused by the earth's rotation has been determined from the laser-ranged satellites LAGEOS(NASA) and LAGEOS 2(NASA-ASI) [17], and the data is agreement with the vorticity interpretation to within $\pm 10\%$. However that experiment cannot detect the larger component of the vorticity induced by the linear motion of the earth as that effect is not cumulative, while the rotation induced component is cumulative.

Miller didn't use the above theory for the interferometer, but used the changes in the observed velocity over a year to calibrate the instrument; that is, he detected the motion of the earth about the sun in a purely laboratory experiment. Of course in doing so he also detected the rotation of the earth about its own axis, but not relative to the sun, rather relative to the fixed stars; that is he saw a sidereal and not a solar day effect. A re-analysis of that data [8, 9] using the above interferometer theory has shown that the data reveals not only the orbital speed of the earth about the sun but an in-flow component towards the sun, in agreement with (6).

So the evidence is that space has a differentially moving substructure, but that this motion has no absolute meaning, that is the motion of space is just that, and not the movement of some constituents located in a space. So it is space itself that *flows*. A simple analogy to help visualise this is to think of space as an abstract network of connected patterns, where the connections have an approximate embedding in a geometrical 3-space, but that embedding does not imply that the 3-space is a separate entity; rather it is an approximate coarse-grained description of the connectivity of the patterns. Then as these patterns evolve in time, as a real process, by older connections disappearing, and new connections forming, we can talk about the motion of one part of the pattern system moving relative to other parts, so long as there is sufficient continuity, over time, of the pattern connectivity. These patterns in turn may be explained as internal informational relations, as discussed in [14, 15].

8 Conclusion

Historically the phenomenon of gravity was first explained by Newton in terms of a gravitational acceleration field. Later Einstein proposed a geometric theory which explained gravity in terms of curvature of a four-dimensional manifold. However as shown herein, both these formalisms, in the cases where they have been explicitly tested, may be re-written in terms of a velocity field formalism, with the acceleration field given in terms of the Euler 'fluid' acceleration, though with vorticity and relativistic corrections. That by itself is remarkable, and shows that the nature of gravity may have been misunderstood all along. But even more significant is that a unique generalisation to that velocity field formalism introduces a dynamical effect that successfully explains a variety of known 'gravitational anomalies', the most dramatic being the so-called 'dark matter' effect seen in spiral galaxies. The strength of the new spatial self-interaction dynamics is found from experimental data to be determined by α, the fine structure constant, at least to within experimental errors.

The new theory of gravity is able to explain various gravitational anomalies. The theory describes gravity as an inhomogeneous in-flow, whether into matter or into a central 'attractor' which is a purely dynamical quantum-space effect, and essentially reveals space to be a quantum-foam process, with the strength of the self-interactions in this process set by the fine structure constant, while G specifies the strength of the effect of matter in producing the spatial in-flow. As reported in [8] there is experimental evidence that the in-flow velocity field is now evident in older experimental data, although not recognised as such by the experimentalists involved. Both the in-flow past the earth towards the sun, and also past the earth into the local galactic cluster are evident. As well the in-flow equations display turbulence, and this also is evident in older experimental data. This of course amounts to the discovery of a new form of gravitational wave, which is unlike that predicted by the Einstein theory. Hence there is in fact a great deal of experimental and observational evidence that demonstrates the success of the new theory of gravity.

Given that there is then considerable evidence that the velocity field formalism represents a significant development in our understanding of gravity, the question then arises as to what interpretation we might consider. This new theory of gravity has been shown to involve the fine structure constant, but this does not mean that the flow equations are themselves quantum-theoretic. Nevertheless that the fine structure constant arises in both the phenomenon of gravity and also in atomic, molecular and elementary particle systems, suggests that we are seeing, for the first time, suggestions of a grand unification of the, so far, disjointed phenomena that physicists have uncovered. As discussed in [14, 15] a new *information-theoretic* modelling of reality is under development, and there space and matter arise as self-organising informational patterns, where the 'information' here refers to internal information, and not to observer based information. There we see the first arguments that indicate the logical necessity for quantum behaviour, at both the spatial level and at the matter level. There space is, at one of the lowest levels, a quantum-foam system undergoing ongoing classicalisation. That model suggest that gravity is caused by matter changing the processing rate of the informational system that manifests as space, and as a consequence space effectively 'flows' towards matter. However this is not a 'flow' of some form of 'matter' through space, as previously considered in the aether models or in the 'random' particulate Le Sage kinetic theory of gravity, rather the flow is an ongoing rearrangement of the quantum-foam patterns that form space, and indeed only have a geometrical description at a coarse-grained level. Then the 'flow' in one region is relative only to the patterns in nearby regions, and not relative to some *a priori* background geometrical space. The classical description of that flow necessarily involves the Euler 'fluid' acceleration, as only that construction has the required covariance property, but then that requirement immediately requires Newton's inverse square law in the special case of small test objects external to a large central spherically symmetric mass, as was the case for the solar system. So not only does the new theory of gravity explain numerous anomalies, it also explains the origin of Newton's famous law for gravity. But also, significantly, it shows that this law, even in the non-relativistic limit, is not always valid. The assumption that the inverse square law was 'universally' valid in the non-relativistic regime, of course, led to the fruitless search for 'dark matter'. Even more significant is that the dark matter effect is not within General Relativity; this is most easily seen by noting that the GR formalism contains only one parameter, namely G, and certainly not the fine structure constant. This happened because GR was constructed to agree with Newtonian gravity in the non-relativistic limit, and that theory is now seen to be deficient even in that limit.

Theories must be tested by experiment, and a whole new field of experimentation is now possible in which laboratory Cavendish experiments can be used to extract the value of α, and as discussed herein there is ample evidence that this is possible, and indeed is the explanation for the long-standing problem in accurately measuring G. The new theory is then suggesting that these laboratory experiments are essentially quantum gravity experiments, and that they are revealing highly significant signatures of a deep unification of physics, namely the unification of gravitational theory with the quantum theory, and to do that we have to abandon not only Newtonian gravity, but also General Relativity and its curved spacetime formalism, the latter being a highly mathematical disguise for the classical description of an underlying processing quantum-foam system. This implies that quantum gravity effects do not set in at the extremely small scales of the Planck length and time, but manifest already in numerous laboratory experiments. As well, because α now occurs in both atomic and gravitational physics it is presumably necessary to consider that α is a fundamental dimensionless quantity, characterising in both cases a common deep random process, for that is the role that α plays in QED, and that there the electronic charge is given by $e = \sqrt{\alpha\hbar c}$.

Further results from the new theory of gravity are in [18].

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