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"A Brief Assessment and Comparative Analysis of Major Gravity Models "

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Abstract

Due to the fact that a plethora of gravity concepts have been introduced over the years, as far back as Aristotle, the content of this essay has been limited to what I consider the most dominant ones. These concepts have been attempts to establish an understanding of gravity, yet to be achieved fully. Philosophers as far back as Plato and Aristotle have contributed their own thoughts on the subject. For example, Aristotle claimed that all objects fall to their own natural place under the influences of earth, air, fire, and water. He went on to state that the rate at which an object falls is proportional to its mass. Many centuries later, Galileo disputed this last statement with observations and associated empirical evidence. Still later, Newton showed, through his laws of motion, that Galileo's claim is correct. Since a theory is considered to be a widely accepted hypothesis, based upon much empirical evidence, not all "theories" of gravity are not, in fact, theories. So, the reader must be mindful that I am making an informal usage of the term, "theory". Hopefully this paper will be helpful in clarifying some key theoretical issues and tie the various concepts into a cohesive understanding of gravity as we know it today.

Introduction

There are several ways to sort out the various gravity theories. This process is simplified here by restricting the discussion to the main ones. Various features can be exploited in this organization. For example, heuristics versus mechanistic (i.e., mathematical versus causal, respectively) descriptions can be used for classification. We can also measure a theory based upon empirical versus philosophical. Still another strategy would be that of the types of physics (classical, relativistic, quantum). All the above features contribute to an epistemological understanding of gravity and will be included in the discussion for each type I have included. These gravity theory types are Newtonian (classical), Einsteinian (relativistic), modified Newtonian, Fatio/Le Sage, Van Flandern, Majorana, Fleming (ether influence), and quantum mechanical/GR approaches.

Newtonian Gravity

As history is recorded, Sir Isaac Newton (1642 – 1727) was undeniably the most dominant contributor to our understanding of gravity. In his time there was no physics community as we know today. In fact, the terms "physics" and "physicist" were not coined until 1750, twenty-three years after his death. However, he is still highly regarded as the father of physics. Heavily incorporating philosophy in their work, Newton's contemporaries (e.g., Des Cartes, Leibnitz), as himself, were called natural philosophers. Newton's generalized induction approach to developing scientific theories led him to establish equations in many areas of physics such as optics but, for this article, we will remain focused on gravity. An important part of his gravity work was that of integral and differential calculus, allowing him to mathematically model planetary motion in terms of acceleration, velocity, and position. Newton's three laws of motion, though similar to those of Des Cartes, were discussed in his famous *Prinicipia* [1]. They are briefly stated here:

First Law of Motion:

The state of a body, either at rest or moving at a constant speed in a straight line, will remain at that state unless acted upon by an external force. This law was first set forth as the Law of Inertia by Galileo Galilei and was also developed by Des Cartes as one of his laws of inertia. The distinction is that these prior laws were generalized into inertia whereas Newton specialized in the application to objects of inherent mass.

Second Law of Motion:

If an external force, *F*, is applied to an object that is free to move with mass, *m*, it will experience an instantaneous acceleration, *a*. The equation for this is typically written as:

$$F = ma \tag{1}$$

This is probably the most important equation found in freshman physics textbooks. If we divide both sides of the equation by *m* we get:

$$a = \frac{F}{m} \tag{2}$$

Equation (2) shows that the acceleration produced by the applied force is directly proportional to the force and inversely proportional to the mass. Such relationships become helpful in our understanding of how gravity works.

Third Law of Motion:

This law can be stated in the following manner: If an object exerts a force on another object, this second object must exert an equal force upon the first object but in the opposite direction. A widely used illustration of this is that of stepping from a boat onto a dock. The person doing this experiences a force in the forward direction while the boat experiences that same force rearward.

Universal Law of Gravity:

The laws of motion just described were all rigorously tested by Newton, yielding compelling results with corroborating data. They were so well proven and documented in *Principia* that they were eventually accepted as laws and not merely theories. Newton greatly used them, along with planetary motion observations, to establish the Universal Law of Gravity, which states that two objects of mass m_1 and m_2 experience a force of attraction, F, that is directly proportional to their product and inversely proportional to the square of the distance, R, between them.

$$F = \frac{Gm_1m_2}{R^2} \tag{3}$$

$$F = \frac{GMm}{R^2} \tag{4}$$

$$a = \frac{GM}{R^2} \approx 9.8\ \frac{m}{sec^2} \tag{5}$$

Using stakes and observing lengths of shadows at various locations, Eratosthenes (~200 BC) measured the radius of the earth within 2 percent error. In the late 1700's, using a highly sensitive torsion balance, Henry Cavendish determined the value for G to be 6.74×10^{-11} m^3 kg^{-1} sec^{-2}. This value is only 1% off the currently accepted value. Knowing these values, we are able to compute the mass of the earth simply by timing the drop of an object in a laboratory, using the freshman physics equation:

$$s = \frac{1}{2}at^2 \tag{6}$$

where s is the distance through which the object falls, and t is the elapsed time. Backing out a, and substituting it into (5), along with values for R and G, leaves only the mass of the earth, M, so is readily solved. The symbol used for this acceleration is g near the earth's surface and is measured to be ~ 9.8 m/s^2.

After all Newton's success, he was not completely satisfied. The equations he derived, as he admitted were only heuristic tools for determining motions, positions, and events of objects but did not provide an understanding of the unseen physical mechanisms that cause the observed behavior. How could there be instant action at a distance? What actually contributes to the inverse square gravitational force? He made the statement, *"I will feign no hypothesis*". This frustrated his contemporaries even more. They were more of the mechanistic persuasion, promoting an unmeasurable (at that time) medium.

Einsteinian Gravity

Although Newton's explanation of gravity in terms of mathematics, inductive reasoning, and empirical philosophy, what came to be called Newtonian mechanics, was accepted by most during his lifetime, much of it would later be replaced as physics advanced into areas such as relativistic and quantum mechanics. As Newton himself admitted, he could not establish a causal, physical mechanism with which to confirm action at a distance. Maxwell raised several issues he had with Newton's laws of motion and universal gravity[2]. Mach [2] was highly critical of Newton's reliance on absolute motion, as represented by the famous "spinning bucket of water" exercise. He advanced his idea that the mass and inertial motion of a body is caused by the influence of all surrounding matter (including that which is beyond our solar system). This concept served as a driving motivation for the development of the GR theory of gravity.

Lorentz [3] introduced the realization that Newtonian mechanics breaks down with motion at speeds near the speed of light. To resolve this, he introduced what are known as Lorentzian transformations, these are mathematical tools for adjusting length and time observations between reference frames in motion with respect to each other. His work, along with Poincare's [2] four-dimensional spacetime coordinate system, and Minkowski's [4] related mathematics, were crucial to Einstein's formulation of GR theory and to address, among other phenomena, a new way of thinking about gravity. The key equation that resulted from this work is the Einstein Field Equation (EFE) [5]:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu} \tag{7}$$

where $R_{\mu\nu}$ is the Ricci curvature tensor, R is the scalar curvature, $g_{\mu\nu}$ is the metric tensor, Λ is the cosmological constant, and $T_{\mu\nu}$ is the stress-energy tensor. The constant, k, is the Einstein gravitational constant and it is defined as :

$$\kappa = 8\pi G \tag{8}$$

The key thing to understand here is that gravity is treated as a quantity of acceleration in a spacetime geometric of curvilinear space in which curvature, R, of the trajectory of an object is driven by the local gravity (acceleration).

In GR, gravity is not treated as a force so there is no longer a need to resolve Newton's action at a distance conundrum. It serves as a mathematical interpretation of a physical phenomenon not yet well understood. GR equations have been useful for predicting behavior of light, such as in gravitational bending, or slowing of clocks near an object of great mass. GR has also been used to help us understand the precession of the Mercury obit. Einstein's special relativity (SR) has been used in predicting "relativistic" mass increases in electrons accelerated near the speed of light, or changes in clock rates. Such experiments have widely contributed to a broad acceptance of relativity within the mainstream physics establishment, so much so that the standard cosmology is based upon the EFE (in which the cosmological constant was given a value that was compatible with the accepted rate of expansion). Yet one must also realize that observations that are said to substantiate GR are also consistent with other theories that are discussed later in this paper. I plan to expand upon these topics in future papers.

Einstein’s relativity equations that unfold from expansion of the EFE were extremely complex. Because of this, physicists and mathematicians endeavored to develop a formalism with which to implement them in an organized manner [6]. The most known of these were Richard Arnowitt, Stanley Deser and Charles W. Misner and their combined efforts resulted in what we call the ADM formulism.

There are some problems and limitations with both SR and GR. For now, I will focus on GR since it embodies Einsteinian gravity. Note that the list I am including here is not exhaustive. First of all, GR leads to predictions of “black holes” with singularities (curvature is infinite) at their centers. This should be of concern since it can only be true in mathematics but cannot be real. Another problem, one that Einstein tried to solve in his unified field theory work, is the incompatibility between GR and quantum mechanics. Many have tried to resolve this, but none have yet succeeded, at least not in mainstream physics. Then there is the issue of the rejection of a physical medium that is required for the propagation of electromagnetic waves, which is what light is. In GR everything is purely mathematical in nature, consisting of a set of tensor equations that form imaginary surfaces (i.e., spacetime grid) with nodes that stretch in scale at speeds greater than the speed of light without affecting the size of stars and galaxies residing on this grid.

Quantum Gravity

The complexity of GR becomes much greater when attempting to find a mathematical transition to a quantum mechanics (QM) level. With the development of quantum field theory (QFT), there exists a set of fields in which atomic particles (photons, electrons, quarks, protons, etc.) move around and interact. For photons, there is the electromagnetic field. For electrons there is the Dirac field. The proton field is a product of the three quark fields. Presently, there appears to be no representative field for gravity, other than, perhaps a derivation of the GR spacetime continuum. Here is where the extreme difficulty begins. If it is possible to quantize the spacetime, we are, in essence, creating a QFT field for gravity and thus, providing a transition between GR and QM.

Without getting too deep in mathematical detail, I will attempt here to touch on the highlights related to the development of quantum gravity. As mentioned earlier, ADM formulism was developed to begin the process of quantizing the spacetime manifold advanced by Einstein. In addition to the EFE, we have the Einstein-Hilbert action (EHA). With EHA we have the following [7]:

$$g = \int_X R(g)dvol(g) \tag{9}$$

where:

X is a given compact, smooth spacetime manifold (hyperspace structure),
g is the Riemannian metric on X,
R(g) is the scalar curvature function of g,
dvol(g) is the volume defined by the metric, and

$\int_X^{\square} \square$ is the integration of differential forms over *X*.

After applying much tensor and geometrical calculus on mathematical hypersurfaces called manifolds, incorporating Hamiltonian constraints, splitting the manifold into "slices", we arrive at the ADM formulism [6]:

$$16\pi G_N S_{ADM} = \int_{\mathcal{M}}^{\square} dt d^3x \left(p^{\dot{a}b} h_{ab} - N\mathcal{H}_1^g - N^a \mathcal{H}_a^g\right) \tag{10}$$

where:

N's describe how to move from slice to slice,
G_N is the covariant form of the DeWitt metric,
p's are momentum tensors,
$\mathcal{H}$'s are Hamiltonian constraints:

$$\mathcal{H}_1^g = 16\pi G_N G_{abcd} p^{ab} p^{cd} - \frac{\sqrt{\hbar}}{16\pi G_N}(R - 2\Lambda) \tag{11}$$

$$\mathcal{H}_a^g = -2 D_b p_a^b \tag{12}$$

where:

D_b is the covariant derivative on a given slice of the manifold.

This formulism becomes useful when quantizing the GR spacetime manifold. But now we address the issue of time. Since GR is back-ground independent, time is treated only as a dynamic variable within a set of equations. In quantum mechanics, time is treated as an absolute parameter and is therefore considered to be background dependent. This is one of the complex challenges in bridging the gap between GR and QM. So, how do we handle this key equation, derived from the Wheeler-Dewitt Equation [6]:

$$\hat{\mathcal{H}}_1 \Psi[h_{ab}(x)] := \left(-16\pi G_N \hbar^2 G_{abcd} \frac{\delta^2}{\delta h_{ab}\delta h_{cd}} - \frac{\sqrt{\hbar}}{16\pi G_N}\left({}^{(3)}_{\square}R - 2\Lambda\right)\right)\Psi[h_{ab}(x)] = 0 \tag{13}$$

where the product of the Hamiltonian and the wave function is set to zero. Here is the fork in the road to proceed further into the development of quantum gravity. We either dismiss time altogether or we treat it as infinitesimally small both prior and after quantization. Either way, time, and therefore spacetime, are dropped from the equations, leaving only the spatial coordinates. Such a move is highly controversial, and understandably so, drawing much criticism. The final result of performing the above approach is that we end up with a configuration of many gravity fields taking the place of one gravity field. This leads to other multiple approaches such as the ones addressed below.

Loop Quantum Gravity (LQG)

Development of LQG has mainly focused on those fundamental quantum gravity issues that continue to exist since early works by Dirac [8], Bergmann[9], Wheeler[10], and others. The key issue is the challenge related to the constrained Hamiltonian system when there are no available background fields (i.e., background-independent), or perturbative techniques, such as those used in quantum electrodynamics (QED). Ashtekar [11] contributed to the advancement of LQG by the introduction of variables, such as quantized angular momentum (i.e., spin) that later were used by Dupuis, Freidel, Livine, Speziale and Tambornino in the paradigm of a spin network, composed of quantized entities called spinors. Others such as Smolin and Rovelli, developed LQG further by solving the Wheeler-Dewit equation with the concept of quantized loops, using the mathematics of parallel transport vectors, or connectors.

Due to the extreme complexity related to LQG, details of related mathematics are not included here but a good summary is provided in [11]. LQG has not yet been verified empirically nor does it appear that it ever will be due to the extreme weakness of the quantized gravitational force. Furthermore, as is true for all relativistic and quantum mechanical approaches, even if it could be tested physically and verified, in the end it would serve only as a heuristic prediction tool such as GR and would not adequately provide a description of the physical mechanism behind gravity.

String Theory and Related Graviton

String theory has its origin in particle physics research in the 1960s. A series of tests were being performed in pursuit of understanding the strong nuclear force (prior to most of the acceptance of the notion of quarks and their gluon binding) with the application of string theory. Particular attention was focused on quantum chromodynamics (QCD), the study of protons, neutrons, and mesons, quarks, and gluons. Even though string theory was not the ultimate answer to the question of strong baryonic nuclear force and interest within the physics community became more directed on quarks and gluons for the answer to the strong nuclear force, the string theory research still proved to be advantageous. It uncovered a string oscillation mode that would be a very good fit for a particle related to gravity. This new “particle” or “string”, for now referred to as the graviton (in theory only) is analogous with a gluon as it relates to quarks, and also analogous to a photon as it relates to electrons and positrons. One of these “strings” exhibited (0,2) (i.e., zero mass and spin 2) attributes, just what one would expect for a graviton. As much more research poured into the development of string theory for this purpose, the complexities and observational difficulties began to abound. The main issue is that this “string” requires 10 dimensions. Currently, this appears to be an insurmountable problem, rendering the string theory graviton unfalsifiable. A good reference for the history and mathematics of string theory is [12].

Quantum Field Gravitons

In quantum field theory, a graviton is described as an excitation in a theoretical graviton field. As I touched on before, the main roadblock to this development is the lack of ability to apply renormalization, a mathematical process used in QCD and QED to validate a theory of particles to infinitesimally small lengths. Such a procedure is necessary to suppress divergence. However, due to the quantum gravity constraint of background-independence to comply with GR, this tool cannot be applied. This is partially explained by the fact that gravity cannot be modeled by the Schrodinger wave function as can the particles that currently make up the standard model of particle physics. It appears after many years of research through quantum field theory that the theoretical graviton cannot even be modeled mathematically with this approach. It is difficult to find any new results of work in this area over the last twenty-five years.

Push Gravity

Up to this point in the paper, I have discussed gravity theories that only address mathematical tools for modeling gravity and predicting experimental outcomes. Some of these tools have proven to be accurate. However, neither of them, whether they be Newtonian, Einsteinian, or quantum related, provide an understanding of the actual physical mechanism that causes the effect we call gravity. As mentioned earlier, Newton stated that he would not attempt to hypothesize any rationale behind the physical cause (although he reconsidered this later), only stating an unwavering belief that there is somehow action at a distance between objects of mass. Einstein, through his GR theory development, attempted to solve this problem by representing gravity, not as a force of attraction, but as curvature in a complex spacetime continuum, a highly mathematical approach that could not transition to the quantum scale. Even if it could, it would still be purely mathematical and not satisfy the need for understanding the physical mechanism behind gravity. Fortunately, there is an alternative approach that does focus on the cause and not just the mathematical prediction of gravitational behavior and this approach is called “push” or “shadow” gravity. The following paragraphs address key contributions to this gravity theory approach from the 17th century to the present.

Nicolas Fatio de Duillier

A contemporary of Newton, Fatio was one of the earliest developers of the push gravity theory in the late 1600’s [13]. He based it on the notion originally proposed by Rene Descartes in which space is saturated by minute particles in rapid motion . It was recognized that in a system of two or more bodies of matter, separated in space, interaction of the particles between the bodies is less than that of the particles on the exterior of the system of bodies. This is known as the shadow effect. It was later demonstrated that these particles exist and do cause attractive force in the 1900’s as the Casimir effect [14] (although the Casimir effect is one over the 4th power of the distance between them when brought to a very close distance -- nanometers). Since more particles are pushing from outside of the bodies than between them the net result appears to be an attractive force between them. Fatio never seemed to come to a full decision regarding whether the collisions of the particles with ordinary matter were purely inelastic or not. He considered the possibilities that post-impact results could include a combination of vibrational, rotational, and translational energy. In Fatio's work, he addressed the structure of matter as consisting of what we now call atoms. Before his time, he was convinced that matter was mostly empty space through which most of the particles would pass. He wrote several manuscripts contributing to his major work, *De la Cause de la Pesanteur* but none of his writings were published until after his death.

Le Sage

In the mid-1700's Georges-Louis Le Sage [15] revived Fatio's concept and basically served to keep it alive. He called these mysterious particles "ultra-mundanes". Le Sage did much analysis into the nature of the interactions of the ultra-mundanes with matter, adding more mathematical structure to the ideas of matter and how the surface collision angles relate to the force on bodies. He assumed the ultra-mundanes to be very small (much smaller than what he assumed to be structure balls, what we now call atoms), travel in straight lines, and interact with matter in purely inelastic collisions. If they were purely elastic, no force would be transferred to an object. However, being inelastic implies that some energy would be absorbed by the object that is struck by the ultra-mundane, creating a thermal problem. Le Sage countered this with the notion (and a true one at that) that matter consists mostly of empty space so most ultra-mundanes would simply pass through the object without colliding with any of its structure. Unfortunately, this limits the amount of force applied to the object. Preston contributed to the theory with the realization that the mean-free path for interaction of the ultra-mundanes with each other would need to be at least equal to the distance between planets. At the end of Le Sage's life, it was clear that his (and Fatio's) push theory was not accepted in the physics community except by a few. Regardless, it appears that both Fatio and Le Sage paved the way to a better understanding of the structure of matter. Furthermore, the Fatio/Le Sage theory is considered to be the first and only gravity model that provides the physical mechanism behind it. Such was agreed upon, and still is, by most physicists.

Kelvin

Le Sage's idea of ultra-mundane inelastic collisions with matter gained a renewed interest in the late 1800's due to a paper published by Lord Kelvin in 1873. He proposed that the kinetic energy loss in the ultra-mundanes, themselves, could be absorbed and converted to vibrational or rotational internal energy modes such as what occurs in gas molecules [6].

Maxwell

Maxwell was not content with Newton's assumed mysterious action at a distance with the lack of mechanical explanation for the physical cause of attraction between two neutral bodies of matter.

He sought the answer in a "mechanical fluid" (ether), approach but in the end, could not commit to it. At that time there was no established development of the quantum field that includes such a medium. Such lack of knowledge about what we know to exist today made Maxwell skeptical of such a gravitational concept. Further skepticism was brought on by his belief that the mechanical fluid theory could not be justified on the grounds of thermodynamics. If objects of matter were being pushed by the ultra-mundane particles inelastically, he believed there would be energy absorbed in the matter in the form of heat that would quickly vaporize the object. However, through the history of Casimir plate experiments [14], there does not appear to be a thermodynamic issue.

Majorana

Quirino Majorana was a well respected, extremely skillful Italian scientist who performed many laboratory experiments from the end of the 19th century through the first half of the 20th century. One of his strong interests in physics was that of gravitational absorption [16]. Motivated by the Fatio/Le Sage gravity hypothesis, he set about performing many experiments to determine what he called the gravitational absorption coefficient. By arranging a massive shielding mechanism overhead in a laboratory and immersing various metallic balls inside a tank of liquid mercury, he was able to measure the minutest weight change in the balls. After several experiments he confirmed with confidence that there was a weight change on the order of 10^{-8} N's weight change (~ 1 microgram) in the test items. This result, along with succeeding experiments, supports the Fatio/Le Sage gravity hypothesis.

Quirino Majorana's reputation for experimental skill and accuracy was highly rated among his peers. Michelson showed interest even to the effect that he and a colleague would perhaps pursue research in gravitational absorption. However, Majorana also had his critics such as the astronomer H. N. Russel who published a paper in 1921 [17], calling into question Majorana's gravitational absorption coefficient value, claiming that it is not consistent with observed planetary motion. He was also criticized by Eddington. This well known early supporter of GR argued that a body in free fall does not experience any gravitational effect and, therefore, does not absorb anything. In the end, however, Majorana revealed the possibility that there is a physical cause and that we could measure it.

Van Flandern

Thomas Van Flandern was an astrophysicist who did most of his work in the late 20th century. Employed by the United States Naval Observatory for some twenty years, his career there as one of the chief scientists ended due to his strong interest in non-mainstream physics interests. One of these interests was push gravity[18]. He highly regarded the Fatio/Le Sage hypothesis as the best explanation for gravity[19]. One of the ideas that always puzzled Van Flandern from the time he began to study physics in college was that of the required speed for the force between bodies to cause an immediate gravitational attraction. The mainstream-established assumption to this day has always been that the speed of gravity is the same as the speed of light. However, if that were true, gravitational aberration would exist as it does for electromagnetic radiation. In other words, if there was such a thing as gravitational aberration, there would be a time lag in communication of the force. Such a delay would then lead to orbital decay of moons and planets, which obviously does not occur.

Interests such as the one just mentioned led Van Flandern to develop his own push gravity model. He concluded that there must be dense "sea", similar to the Dirac sea, of particles he also named gravitons. For instant action at a distance, these gravitons would need to travel at very high superluminal speeds, a violation of the well accepted mainstream SR law of the light speed limit. Van Flandern adhered to Lorentzian relativity (LR) and has made several compelling arguments against the validity of SR. He also computed that the mean path length before collision with another graviton would need to be approximately 3,000 light years. Here again another violation of a mainstream physics law, Newton's universal gravity law. Newton assumed that gravitational attraction is the same throughout the universe as it is near Earth. It is interesting to note that, if Van Flandern was right, it could possibly shed some light on the understanding of the observed non-Newtonian behavior of objects far (beyond the 3,000 light years) from the center of a large galaxy, traveling at speeds equivalent to objects near the center.

Fleming

Ray Fleming, a retired particle physicist with expertise in quantum field theory[20], proposes a very interesting concept for gravity that is in line with push gravity but also makes the adaptation to a modified GR theory. This modification is mainly a change in the stress-tensor metric in which gravitation is modeled as interactions between virtual particle pairs (e.g., electrons-positrons, protons-antiprotons). With this change, he is able to unify electromagnetism with gravity. Fleming states that his working hypothesis is based on the mutual repulsion between electron-positron quantum dipole pairs and proton-antiproton quantum dipole pairs. Such repulsion is manifested as a Van der Waals-like pressure. This was demonstrated through Casimir effect experiments. Treating the dipoles in this manner satisfies the inverse square law (at distances greater than a few nanometers) of gravity and, furthermore, supports the Fatio/Le Sage model of gravity with more pressure applied on the unshielded side of an object than what is applied on the shielded side. Fleming is not concerned about thermodynamic heat absorption mainly due to the fact that we have experimental evidence both of the existence of quantum "ether" and its failure to vaporize the plates in the Casimir effect experiments as was predicted by Maxwell.

MOND

As previously discussed, an "anomalous" phenomenon has long been observed regarding spiral galaxies. When the velocities of outer stars are measured, they are in conflict with predictions of both Newton's universal gravity law and GR. What is expected from application of these theories is that the velocity of an orbiting object decreases with increased distance from the center of rotation. This has been a major motivation to the "invention" of cold dark matter, consisting of non-baryonic, directly unobservable substance that seems to only interact gravitationally (not electromagnetically). However, dark matter has not yet been proven to be a reality. Therefore, it can only be approached through computer simulation. Dozens of universities have received grants to simulate and analyze this phenomenon. The particle physics community has made some effort to find the particle or particles that would form dark matter but yet to no avail.

There is another option with which to explain the galactic spiral rotational velocity phenomenon. It is called the modified Newtonian dynamics (MOND) theory. An explanation is provided in this section in regard to why this can be called a theory over a hypothesis. Mordehai Milgrom, in 1983, was the first one known to propose MOND as the solution to spiral galaxy non-Newtonian observations[21]. The key premise behind MOND is that of a threshold acceleration, a_0, below which the velocity of the rotating object drops off as the inverse of the distance to the center as opposed to the inverse square of the distance, as Newton would predict. The following simple equations [22] show the derivation and conclusion, yielding what the MOND acceleration would predict. In McGaugh's MOND research [23], he determined the value of a_0 to be $1.2\text{x}10^{-8}$ cm/sec^2. We start with:

$$a_N = a\mu\left(\frac{a}{a_0}\right) \tag{14}$$

where a_N is the Newtonian acceleration, a is the actual acceleration and μ is the interpolation function of the ratio, a/a_0. When $a >> a_0$, $\mu = 1$ but when $a << a_0$, $\mu = \frac{a}{a_0}$. Substituting this, along with the expression for Newtonian acceleration for a_N, into (14) yields:

$$a = \sqrt{a_N a_0} = \frac{\sqrt{GMa_0}}{r} \tag{15}$$

Observe the 1/r dependence rather than $1/\text{r}^2$. Milgrom's expression for $\mu\left(\frac{a}{a_0}\right)$ is as follows:

$$\mu\left(\frac{a}{a_0}\right) = \frac{\frac{a}{a_0}}{\sqrt{1+\left(\frac{a}{a_0}\right)^2}} \tag{16}$$

This leads to the MOND gravitational acceleration equation:

$$a = a_N\left(\frac{1}{2}+\frac{1}{2}\sqrt{1+\left(\frac{2a_0}{a_N}\right)^2}\right)^{1/2} \tag{17}$$

A former strong dark matter proponent, Stacy McGaugh, explored the MOND approach and performed independent tests on hundreds of spiral galaxies, using measured rotational velocities and generating plots showing the Tully-Fisher relation for each [23]. He was so impressed with the consistent accuracy of the MOND predictions, he came to favor the MOND theory over the dark matter hypothesis. Dark matter advocates, however, hold to the claim that there remains a need for dark matter to account for such phenomena as gravitational lensing and GR predictions of inhomogeneous matter that are not accounted for solely based on baryonic (directly observable) matter alone. Critics have also raised the question of applicability to GR formulation. This issue was resolved by one of Milgrom's colleagues, Bekenstein [24] in his development of the Tensor-Vector-Scalar model (TeVeS) which was used to successfully produce gravitational lensing effects.

Comparative Analysis

To summarize the information that has been presented so far in this paper, I have compiled key points for each major gravity concept into a table (see Appendix). Serious attempts were made to minimize bias and maximize objectivity. I qualitatively assessed each gravity concept in terms of mathematical complexity, empirical support, provision of physical causal mechanism, acceptance in mainstream physics, weaknesses, and strengths. It was difficult to conceive of a weakness for MOND. Dark matter advocates claim that even though it appears that MOND resolves the rotation rate issue for spiral galaxies, the suggested exclusion of dark matter raises interpreted inconsistency issues with the observed CMB power spectrum. It was also a challenge to concede an item for strength to quantum gravity due to extremely complex mathematics and major problems with observing such things as six extra dimensions in string theory.

It should be noted that observations are interpreted through biased lenses, figuratively speaking. Gravitational lensing is an example (no pun intended). Although the application of GR is consistent with bending of light near massive objects, it is probably not the only model that is. Radial distribution of quantum vacuum energy density surrounding massive objects explains the same phenomenon. Regarding CMB, temperature maps have been highly massaged by Big Bang advocates.

Interesting Gravitational Effects

For the remainder of this paper, I would like to focus on interesting effects related to gravity rather than gravity theories or hypotheses, i.e., only applications. For brevity's sake, only two were selected: one from within mainstream physics and the other from without.

Gravitational Waves

Probably no paper that focusses on gravity as the main subject would be complete without a discussion of gravitational waves [25]. However, it was intentionally not included with the above models because it is really a subset of GR and not a stand-alone model of gravity. Since the GR spacetime continuum is itself, a mathematical model of gravity, transient excitations (e.g., merging of binary stars) form propagating ripples, or waves, that warp the grid similarly to the way circular ripples are formed when a pebble drops into a pond. Einstein postulated gravitational waves as part of GR in 1916 but later reconsidered the idea. Some observational data exists that support the existence of gravitational waves.

Not long after the discovery of pulsars by Hulse and Taylor in 1974, they began observing orbital parameters of a pulsar with an assumed neutron star orbiting each other around a common center of mass. Over time, they discovered that this orbit was decaying at a rate well consistent with what was predicted by GR theory. Observations were consistent with predictions based on the hypothesis of gravitational wave generation by massive bodies in motion.

Measuring pulsar electromagnetic emissions is not the only method used for detecting gravitational waves. Early in the 21st century, laboratories such as the Laser Interferometer Gravitational waves Observatory (LIGO) were built under National Science Foundation (NSF) funding for the purpose of gravitational wave detection. Incorporating two 2.5 mile long perpendicular arms, the Michelson laser interferometer approach is used to detect a pathlength shift the size of 1/1000th the diameter of a proton. They claim to use preprogrammed signal "templates" to sort out the signal from the noise. These facilities are operated by Caltech and MIT. Within 48 hours after completion of the first setup following detector upgrades of the apparatus in September 2015, it was reported that they (LIGO staff) detected a gravitational wave. LIGO scientists believe it was emitted by a binary system of black holes rapidly orbiting each other. There are two LIGO facilities: one in Livingston, Louisiana and the other in Hansford, Washington. Internationally, there are two more observatories: Virgo, in Italy, and KAGRA in Japan. Approximately 90 detections have been reported as of 2022.

There has been considerable criticism and lack of acceptance of the LIGO claims within the international and national physics community. One is that it should be fundamentally impossible to detect a gravitational wave with a Michelson interferometer since, based on GR alone, a gravitational wave changes the wavelength of light [26]. Furthermore, the speed of light is not constant in the presence of gravitational waves. According to GR theory, a gravitational wave would affect spatial distance and therefore, the wavelength of light[26]. Another strong criticism centers around the process LIGO used to extract the alleged gravitational wave signal from the noise even if it were fundamentally achievable[27].

With serious doubts about using the Michelson interferometer approach to measuring gravitational waves, many physicists are now focusing on measuring pulsar signals again. A consortium of astronomers with the name of NANOGrav (which stands for North American Nanohertz Observatory for Gravitational waves) has been established for the purpose of detecting gravitational waves with regular observations from pulsars [28]. They are working in collaboration with other astronomers in the Pulsar Timing Array (PTA) consortium [29]. With these groups combined there is a broad set of very large radio antennas spread throughout the globe. The principle behind their method of measurement is as follows. Consider a long "arm" in space two endpoints: one is the center of our solar system, and the other is a distant pulsar. Pulsars are known to transmit periodic radio signals. Because of this, they are used as reference clocks. Now consider one of these “clocks” at one end of the arm, transmitting regular signals which are being tracked on the Earth by the above mentioned array of antennas. When a gravitational wave passes the pulsar, according to GR theory, it should perturb the rotational oscillation frequency of the pulsar. One of the main challenges with this approach is that there are many cosmic events in space that combine to a “sea” of GR-predicted disturbances, compounded further by extreme attenuation.

Thought Experiment Applications of Push Gravity

When one considers the push model as the physical description of gravity, especially as described by Fleming, some interesting thought experiments emerge. From Newton’s second law of motion, equation (2), we know that gravitational acceleration on the surface of a massive object such as Earth is uniform. However, this raises the question of how a bird feather and a bowling ball, dropped from the same height in a vacuum, could impact the ground simultaneously? Key to this situation is that, although acceleration is constant for these two objects, neither the forces nor the masses are the same. A net downward force on each object is directly proportional to its mass. In other words, with push gravity, there is a differential force much like the Bernoulli effect which explains the lift force on an aircraft by differential fluidic air pressure between the top and bottom surfaces of a wing. Differences with respect to this analogy are the medium (quantum vacuum fluctuations in the place of air molecules) and the direction of net force (downward rather than upward).

To understand physically why the force is proportional to the mass, one needs to realize that mass is proportional to the number of baryons and electrons in the material. According to Fleming, vacuum quantum fluctuations impose Van der Walls-like pressure on an object, interacting with the electrons and baryons contained in its matter. Since there are less quantum fluctuations under the object than there are above, due to the shadow effect, the net force is downward.

Conclusion

In this essay on gravity, I have tried to portray a fair analysis and summary of the philosophy, math, and physics of key concepts. Rather than posing these models as confrontational or in competition with each other, I would rather like to interpret them as several pieces of a puzzle that, together provide us with the best understanding we could have of gravity. Some concepts, such as GR, have impressively predicted gravitational effects through complex mathematical models. Others may not be as complex mathematically yet provide us with a possible physical mechanism that actually causes gravitational attraction. It is my opinion that there should be more funding for push gravity research and less for dark matter. I believe that if Newton or Maxwell were alive today, from what we know about quantum fluctuations through experiments like the Casimir effect and the Lamb shift, they would reconsider their rejection of such a medium.

References

[1] I. Newton, *Philosophiae Naturalis Principia Mathematica* (“*Mathematical Principles of Natural Philosophy*”), London, 1687; Cambridge, 1713; London, 1726.

[2] N. Sfetcu, “Epistemology of Experimental Gravity -- Scientific Rationality”, Essays Collection, Multimedia Publishing, Nov. 2019.

[3] A. Kyriakos, “Lorentz-invariant Gravitation Theory”, AKVY Press, Toronto, Canada, 2016.

[4] H. Minkowski, “Space and Time”, Minkowski’s papers on relativity, translated by F. Lewertoff and V. Petkov, edited by V. Petkov, Minkowski Institute Press, 2012.

[5] A. Einstein, “The Collected Papers of Albert Einstein, Vol. 8 (CPAE, Vol.8):The Berlin Years: Correspondence, 1914-1918, Princeton University Press, 2002, Doc. 185.

[6] M. Hersch, “The Wheeler-Dewitt Equation”, WordPress.com, Feb. 2017.

[7] https://ncatlab.org/nlab/show/Einstein-Hilbert+action

[8] M. Bojowald, et. al., “Dirac Fields in Loop Quantum Gravity and Big Bang Nucleosynthesis”, Phys. Rev. D 77, 084003, published Apr. 2008.

[9] D. Salisbury, “Toward a Quantum Theory of Gravity—Syracuse 1949-1962”, arXiv:1909.05412v2, Dec 2020.

[10] J. M*ä*kel*ä*, “Wheeler’s It from Bit Proposal in Loop Quantum Gravity”, arXiv:1905.02611, May 2019.

[11] A. Ashtekar, et. al., ”A Short Review of Loop Quantum Gravity”, arXiv:2104.04394v1 [gr-qc] 9 Apr 2021.

[12] B. Chen, “The String Theory: Past and Present”, IOP Publishing, 3rd International Forum on Geoscience and Geodesy, 2002.

[13] F. von Lunteren, “Nicolas Fatio de Duillier on the Mechanical Cause of Universal Gravitation”, ResearchGate, Sep 2016.

[14] Z. Xu, et. al., “Observation and Control of Casimir Effects in a Sphere-Plate-Sphere System”, *Nature Communications*, Oct 2022.

[15] G. Le Sage, “The Le Sage Theory of Gravitation”, DigiCat 2022.

[16] G. Dragoni, “Q. Majorana’s Experiments on Gravitational Absorption: Further Documents and Manuscripts”, Fifth International Conference for History of Science in Science Education Keszthely, Hungary 2004: 13–34.

[17] H.N. Russell, ‘On Majorana’s theory of gravitation’, *Astrophys. J.* 54, 1921, 334-346.

[18] T. Van Flandern, “The Speed of Gravity--What the Experiments Say, by Tom Van Flandern, *Physics Letters A*, 250 ,1998, 1-11.

[19] Van Flandern's Fission-Explosion Model | Semantic Scholar

[20] R. Fleming, "General relativity as a quantum van der Waals torque effect", *ResearchGate,* Aug 2019.

[21] M. Milgrom, "The MOND Paradigm of Modified Dynamics", *Scholarpedia*, 9(6):31410, 2014.

[22] R. Scarpa, "Modified Newtonian Dynamics, an Introductory Review", arXiv:astro-ph/0601478, 2006.

[23] S. McGaugh, "MOND in the Early Universe", arXiv:astro-ph/9812328v1, 1998.

[24] J. D. Bekenstein, *Phys. Rev.* , 083509 (2004), eprint astro-ph/0403694.

[25] C. Will, "Theory and Experiment in Gravitational Physics", Second Edition, Cambridge University Press, Sep 2018.

[26] M. Huang, et.al., "LIGO Experiments Cannot Detect Gravitational Waves by Using Laser Michelson Interferometers…", *Journal of Modern Physics*, 7, 1749 – 1761.

[27] M. Brooks, "Exclusive: Grave doubts over LIGO's discovery of gravitational waves", *New Scientist*, Oct 2018.

[28] https://nanograv.org

[29] https://ipta4gw.org/

Appendix

This table summarizes, or highlights, my comparative analysis of the gravity concepts included in this paper.

Concept	***Mathematical Complexity***	***Empirically Supported***	***Provides Physical Causal Mechanism***	***Accepted by Mainstream***	***Weaknesses***	***Strengths***
Newtonian	Low	Yes[1]	No	Yes[2]	(1) Spiral galaxy rotation (2) Provides no causal mechanism	(1) Highly supported by empirical data[1]. (2) Simplicity.
Einsteinian	High	Yes[3]	No	Yes	(1) Provides no causal mechanism. (2) Incompatibility with quantum mechanics. (3) Singularity predictions.	(1) Highly supported by empirical data[4]. (2) Conceptually simple (albeit mathematically complex).
Quantum	Extremely High	No	No	No	(1) Extremely difficult to observe. (2) No causal mechanism.	(1) If successful, it would unify all fields.
Push	Low[5]	Yes	Yes	No	(1) Lacks backing. (2) Thermodynamics in question.	(1) Provides causal mechanism. (2) Good potential for unified field theory.
MOND	Low	Yes	No	No	(1) Resulting CMB power spectrum issues without dark matter present[6]. (2) Still does not provide a causal mechanism.	(1) Solves the rotational galaxies issue. (2) Simplicity. (3) Highly supported by empirical data.

Gravity Model Summary Table. Notes: [1]through many laboratory and planetary observations,. [2]within spatial limits, [3,4]gravitational lensing and Mercury orbital precession, [5]except for use of TeVes tensor, [6]assuming this is the correct interpretation of the CMB data.